RETURN TO SER AR INDEX

FIGURE 1

SDMS DocID 518619

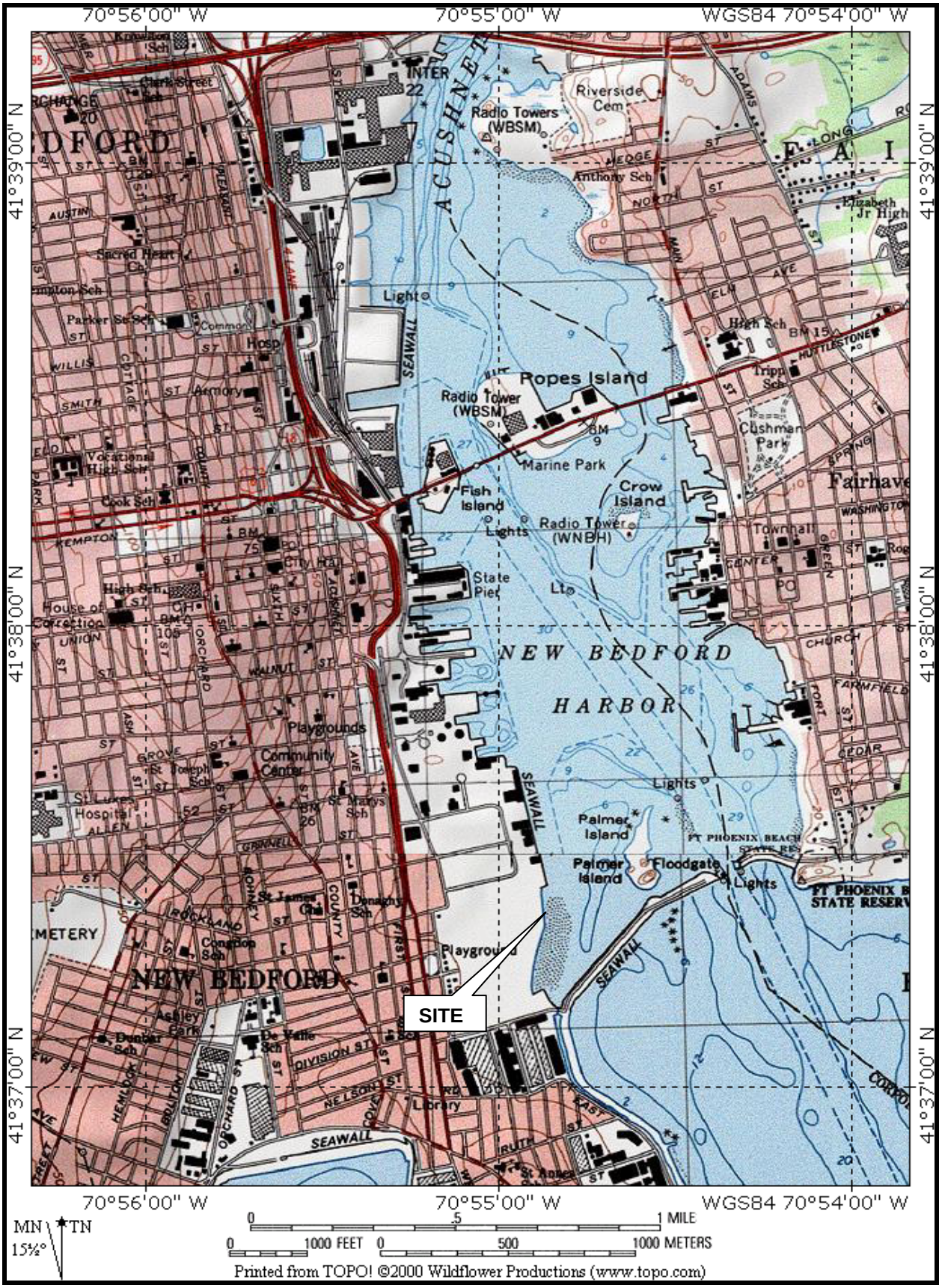

Figure 1: Site Location Map

South Terminal CDF Proposed Location

City of New Bedford, New Bedford, Massachusetts

FIGURE 2

Apex Companies, LLC.

1 WAMSUTTA STREET
SUITE 8
NEW BEDFORD, MA 02740
(508) 996-9828

184 HIGH STREET
SUITE 502
BOSTON MA 02110
(617) 728-0070

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PREPARED FOR:

THE NEW BEDFORD HARBOR DEVELOPMENT COMMISSION
NEW BEDFORD, MASSACHUSETTS

DRAWING TITLE:

SOUTH TERMINAL MARINE INFRASTRUCTURE PARK PROPOSED BULKHEAD

Scale: 1"=150'

0 75 150 300 450 FEET

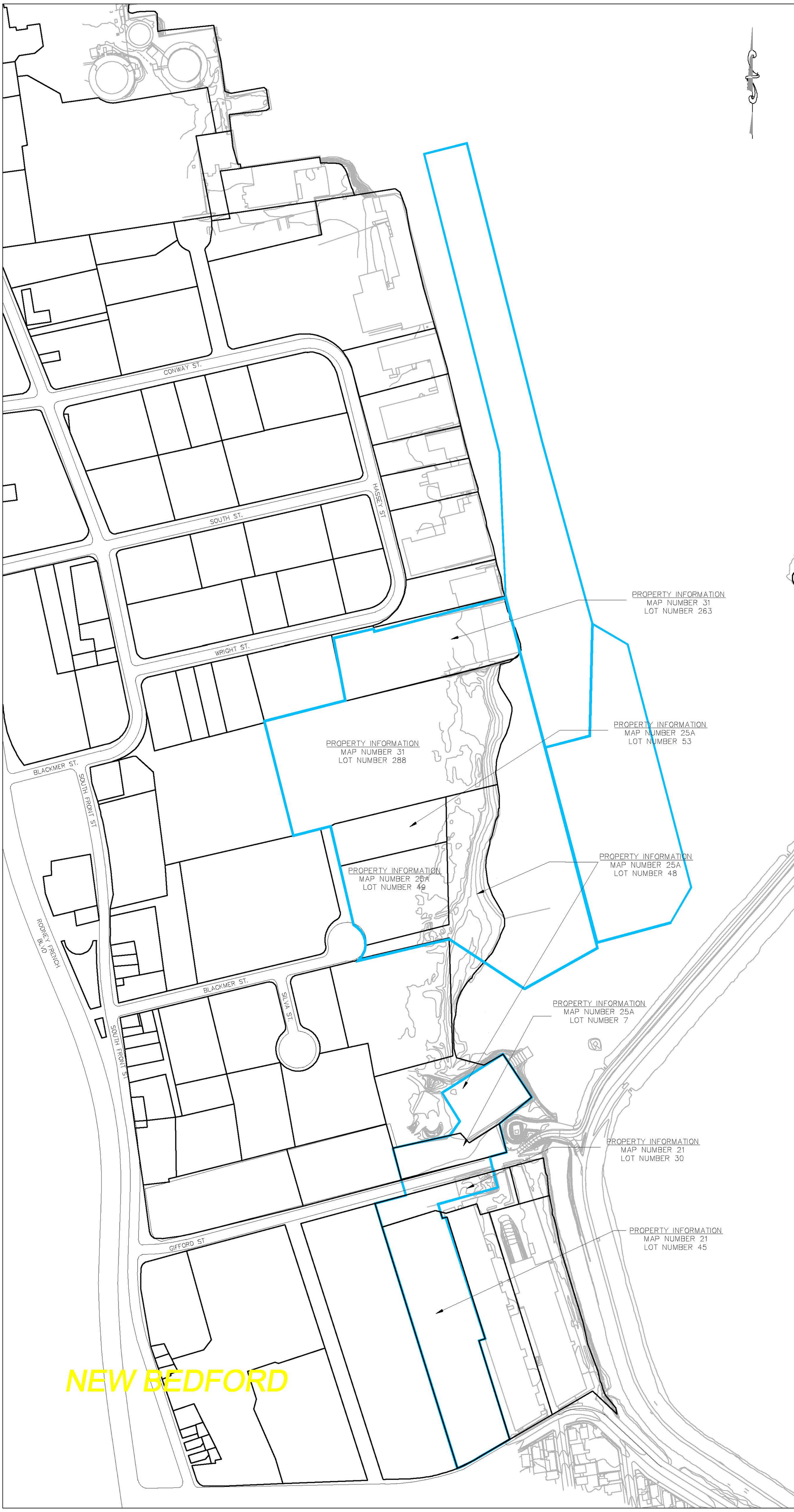
Date	3/24/10
Proj. Mgr.	JAB
Design	CWM
Check	CHM
Drawn	GCD
Job. No.	6690
Last Rev.	8/23/10

Drawing No.

P-4

P:\Jobs\6690 NBH_ Phase IV\PLANS\CAPEWIND\SOUTH_TERMINAL_EXPANSION_7-23-10_WORKING.dwg

FIGURE 3



Apex Companies, LLC.

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HARBOR DEVELOPMENT COMMISSION
41°38'N 70°56'W
NEW BEDFORD, MA

PREPARED FOR:

THE NEW BEDFORD
HARBOR DEVELOPMENT
COMMISSION
NEW BEDFORD,
MASSACHUSETTS

DRAWING TITLE:

SOUTH TERMINAL
MARINE
INFRASTRUCTURE PARK
PROPOSED BULKHEAD

Scale: 1"=150'

0 75 150 300 450 FEET

Date	3/24/10
Proj. Mgr.	JAB
Design	CWM
Check	CHM
Drawn	GCD
Job. No.	6690
Last Rev.	8/23/10

Drawing No.

P-4

P:\Jobs\6690 NBH_ Phase IV\PLANS\CAPEWIND\SOUTH_TERMINAL_EXPANSION_7-23-10_WORKING.dwg

FIGURE 4

Designated Port Area:

NEW BEDFORD - FAIRHAVEN

Dept. of Environmental Quality Engineering

Division of Wetlands and Waterways Regulation

Coastal Zone Management

Base map: NOAA Nautical Chart No. 13230, May 1985 Ed., USGS Quad. sheets and local maps.

FIGURE 5

Apex Companies, LLC.

184 HIGH STREET
SUITE 502
BOSTON MA 02110
(617) 728-0070

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1.	2/11/10	PRELIMINARY LAYOUT
2.	4/09/10	PRELIMINARY ASSESSMENT
3.	4/15/10	FIELD LOCATION
4.	7/07/10	ADD. FED. RESOURCE
5.	8/24/10	FINAL BULKHEAD ALIGNMENT

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NEW BEDFORD, MA

INTER-TIDAL

SUB-TIDAL

INTER-TIDAL SALT MARSH

APEX TEST PIT

PREPARED FOR:

THE NEW BEDFORD HARBOR DEVELOPMENT COMMISSION AND THE TOWN OF FAIRHAVEN, MASSACHUSETTS

DRAWING TITLE:

SOUTH TERMINAL MARINE INFRASTRUCTURE PARK 2010 FEDERAL RESOURCE AREA ASSESSMENT

Scale: 1"=150'

0 75 150 300 450 FEET

Date 3/24/10	Drawing No.
Proj. Mgr.	
Design	
Check CM	P-1
Drawn GCD	
Job. No. 6615	
Last Rev. 7/7/10	

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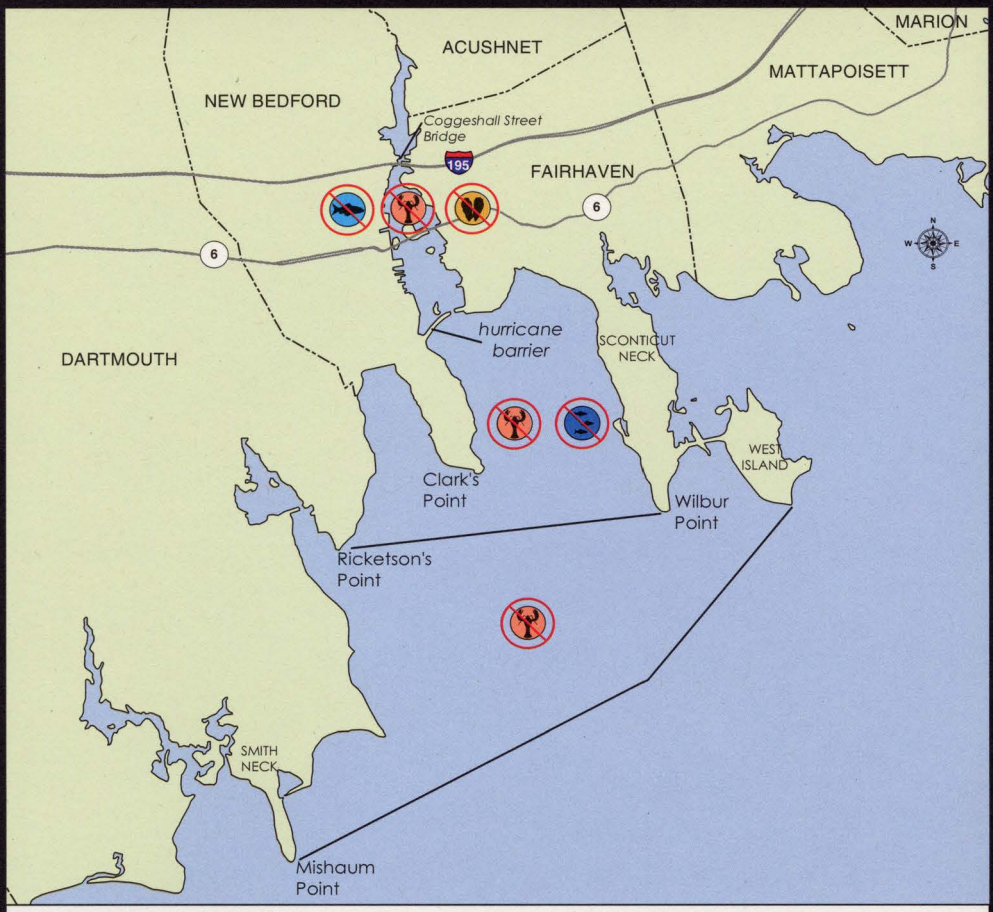
FIGURE 6

Fish Smart—Use this Chart



Fish Smart-Use this Chart
¡Pesque con cabeza! Utilice esta gráfica
Pesque esperto-Use este mapa

Don't eat any fish
No coma pescado
Não coma peixe

Don't eat any lobster
No coma langosta
Não coma lagosta

Don't eat any shellfish
No coma mariscos
Não coma mariscos

Don't eat any bottom fish:
No coma pescado de fondo:
Não coma peixe de fundo:

- flounder
- lenguado
- solha
- tautog
- tautoga
- bodião da ostra
- scup
- sargo
- sargo
- eel
- anguila
- anguila

Map Produced By The US EPA New England GIS Center
30 May 2003

FIGURE 7

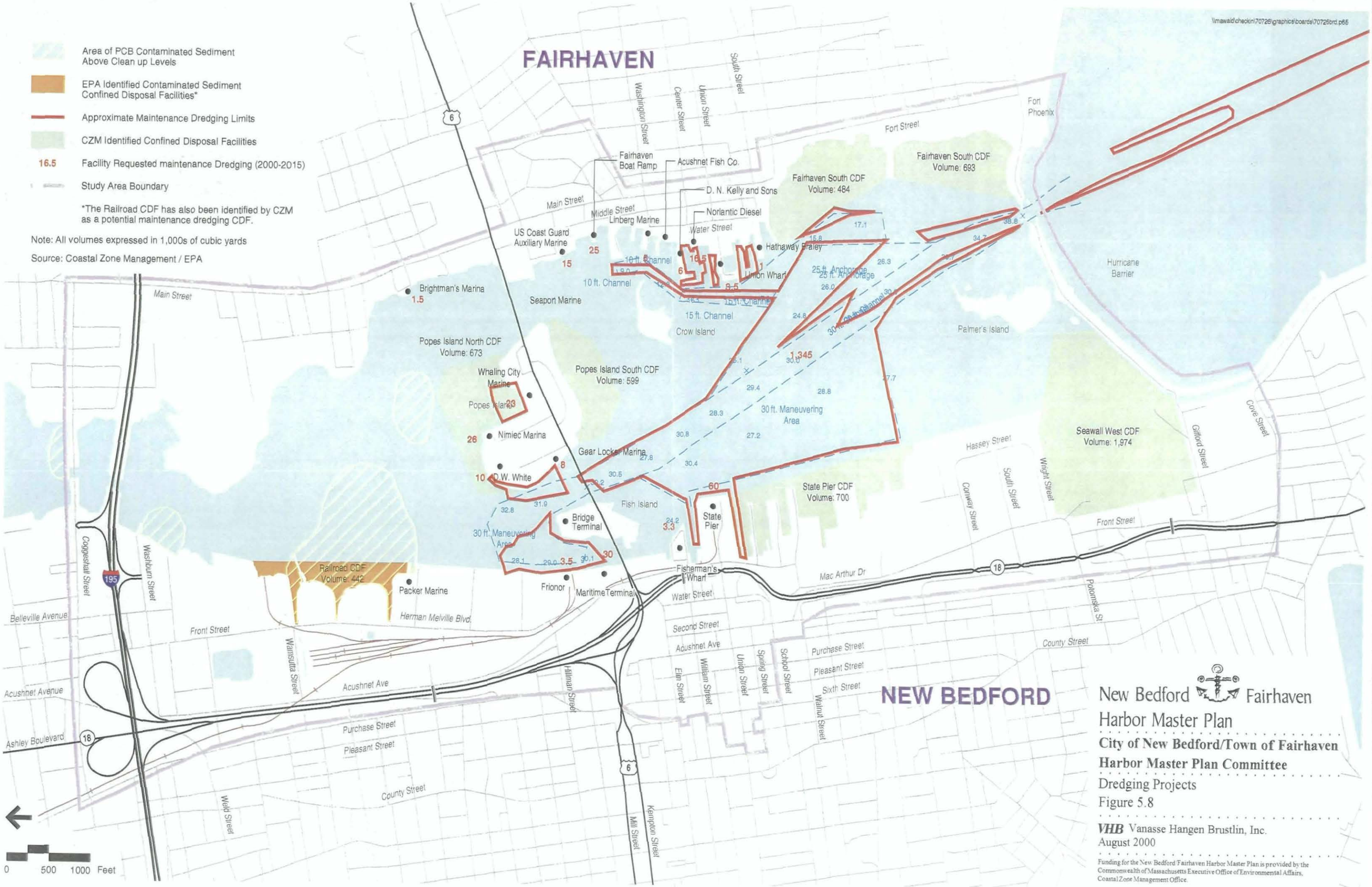

\\mawald\checkin\70726\graphics\boards\70726brd.p65
Area of PCB Contaminated Sediment Above Clean up Levels
EPA Identified Contaminated Sediment Confined Disposal Facilities*
Approximate Maintenance Dredging Limits
CZM Identified Confined Disposal Facilities
16.5 Facility Requested maintenance Dredging (2000-2015)
Study Area Boundary
*The Railroad CDF has also been identified by CZM as a potential maintenance dredging CDF.
Note: All volumes expressed in 1,000s of cubic yards
Source: Coastal Zone Management / EPA
FAIRHAVEN
NEW BEDFORD
Fairhaven Boat Ramp
Acushnet Fish Co.
D. N. Kelly and Sons
Norlantic Diesel
Linberg Marine
US Coast Guard Auxiliary Marine
Hathaway Braley
Union Wharf
Brightman's Marina
Seaport Marine
Popes Island North CDF Volume: 673
Whaling City Marine
Popes Island
Nimiec Marina
Gear Locker Marina
D.W. White
Popes Island South CDF Volume: 599
Fairhaven South CDF Volume: 484
Fairhaven South CDF Volume: 693
Fort Phoenix
Hurricane Barrier
Palmer's Island
Crow Island
Fish Island
30 ft. Maneuvering Area
State Pier CDF Volume: 700
State Pier
Bridge Terminal
Frionor
Maritime Terminal
Fisherman's Wharf
Railroad CDF Volume: 442
Packer Marine
Seawall West CDF Volume: 1,974
Main Street
Fort Street
Middle Street
Water Street
South Street
Washington Street
Center Street
Union Street
Hassey Street
Conway Street
Wright Street
Gifford Street
Cove Street
Front Street
Mac Arthur Dr
Potomska St
County Street
Second Street
Acushnet Ave
Purchase Street
Pleasant Street
Sixth Street
Walnut Street
School Street
Spring Street
Union Street
William Street
Elm Street
Hillman Street
Kempton Street
Mill Street
Herman Melville Blvd.
Belleville Avenue
Acushnet Avenue
Ashley Boulevard
Coggeshall Street
Washburn Street
Wamsutta Street
Weld Street
0 500 1000 Feet
New Bedford Fairhaven
Harbor Master Plan
City of New Bedford/Town of Fairhaven
Harbor Master Plan Committee
Dredging Projects
Figure 5.8
VHB Vanasse Hangen Brustlin, Inc.
August 2000
Funding for the New Bedford/Fairhaven Harbor Master Plan is provided by the Commonwealth of Massachusetts Executive Office of Environmental Affairs, Coastal Zone Management Office.

FIGURE 8

Apex Companies, LLC
1 WAMSUTTA STREET, SUITE 8
NEW BEDFORD, MA 02740
(617) 728-0070
184 HIGH STREET, SUITE 502
BOSTON MA 02110
(617) 728-0070

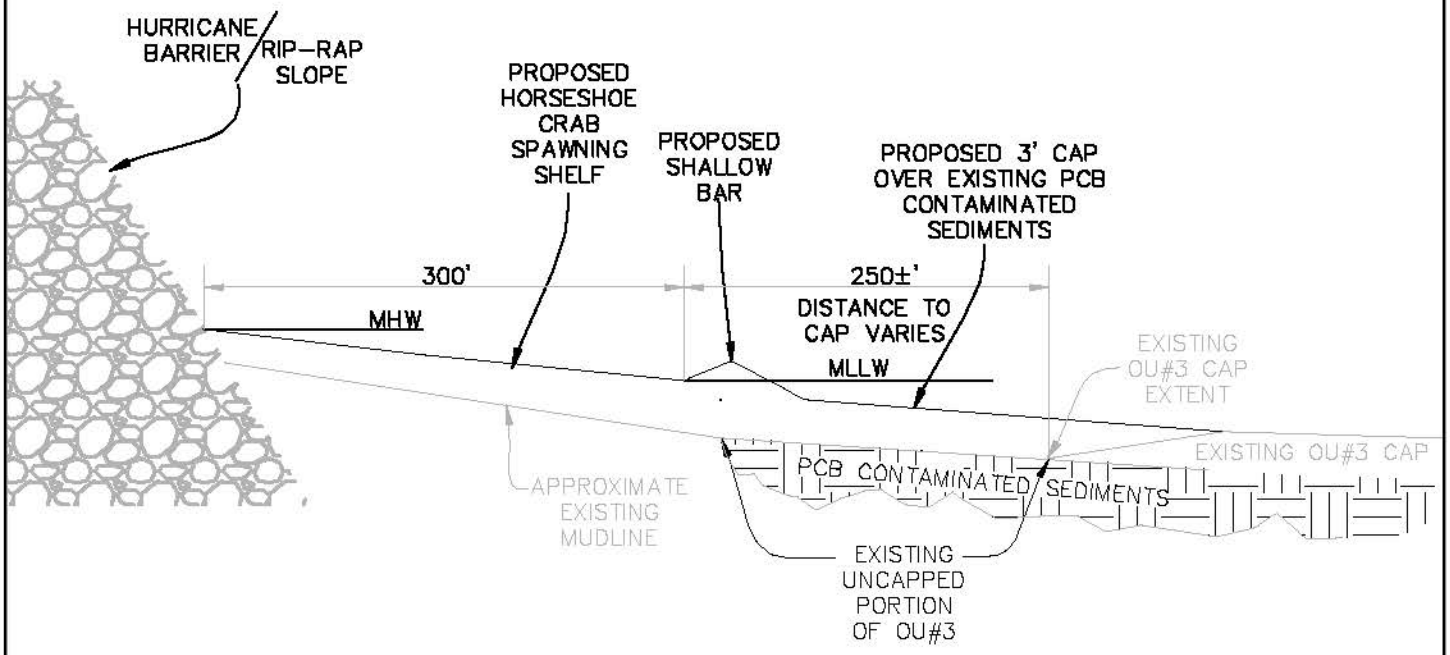
Mitigation Project Locus Map

SOUTH TERMINAL MARINE INFRASTRUCTURE PARK
NEW BEDFORD, MA

Scale: 1"=1500'

0 750 1500 2250

FIGURE 9



Scale: NOT TO SCALE

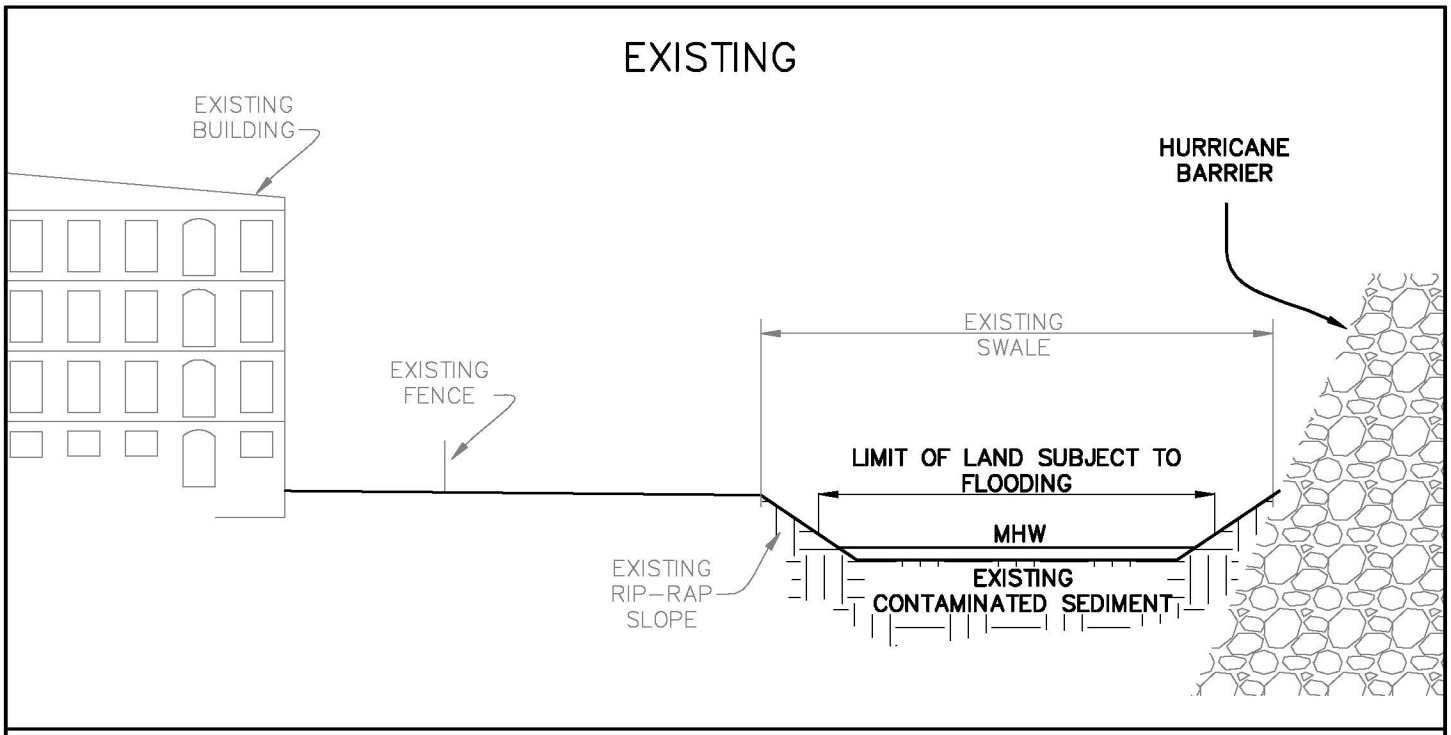
EXAMPLE COASTAL BEACH CREATION AREA OU#3 CAP LOCATION

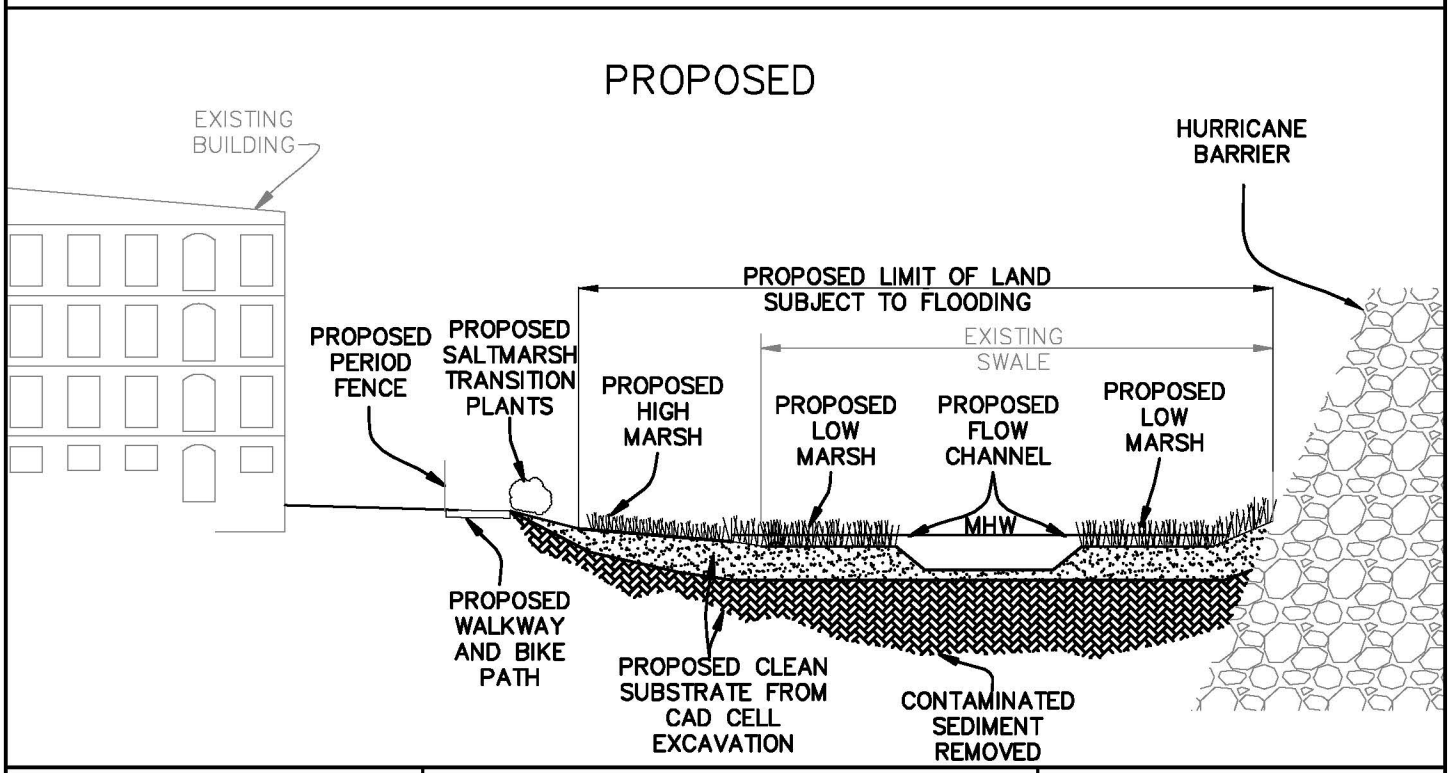
SOUTH TERMINAL CDF NEW BEDFORD, MA

Apex Companies, LLC
1 WAMSUTTA STREET, SUITE 8
NEW BEDFORD, MA 02740
(617) 728-0070
184 HIGH STREET, SUITE 502
BOSTON MA 02110
(617) 728-0070

NEW BEDFORD HARBOR DEVELOPMENT COMMISSION
106 CO-OP WHARF
NEW BEDFORD, MASSACHUSETTS 02740
(508) 961-3000

FIGURE 10





Scale: 1"=30'

0 15 30 60

HURRICANE BARRIER RESOURCE AREA ENHANCEMENT

SOUTH TERMINAL CDF NEW BEDFORD, MA

Apex Companies, LLC
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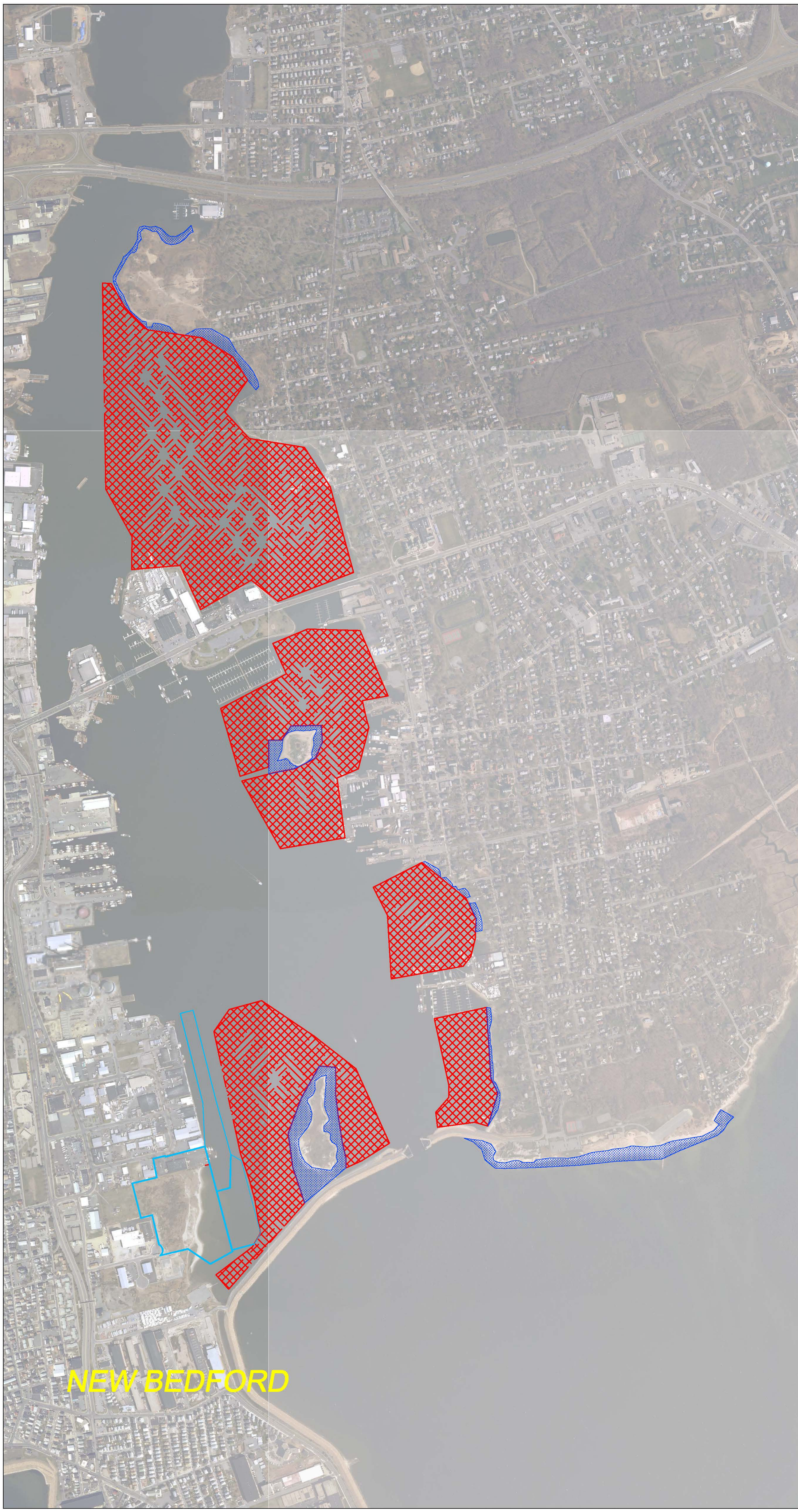
NEW BEDFORD, MA 02740
(617) 728-0070
184 HIGH STREET, SUITE 502
BOSTON MA 02110
(617) 728-0070

NEW BEDFORD HARBOR DEVELOPMENT COMMISSION
106 CO-OP WHARF
NEW BEDFORD, MASSACHUSETTS 02740
(508) 961-3000

FIGURE 11



Apex Companies, LLC.

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SUITE 502
BOSTON MA 02110
(617) 728-0070

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3.	4/15/10	FIELD LOCATION
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HARBOR DEVELOPMENT COMMISSION
41°38'N 70°56'W
NEW BEDFORD, MA

SUB-TIDAL
(0 TO -16 FT MLLW)

INTERTIDAL

PREPARED FOR:

THE NEW BEDFORD
HARBOR DEVELOPMENT
COMMISSION
NEW BEDFORD,
MASSACHUSETTS

DRAWING TITLE:

SOUTH TERMINAL
MARINE
INFRASTRUCTURE PARK
SIMILAR HABITATS
WITHIN NEW BEDFORD
HARBOR

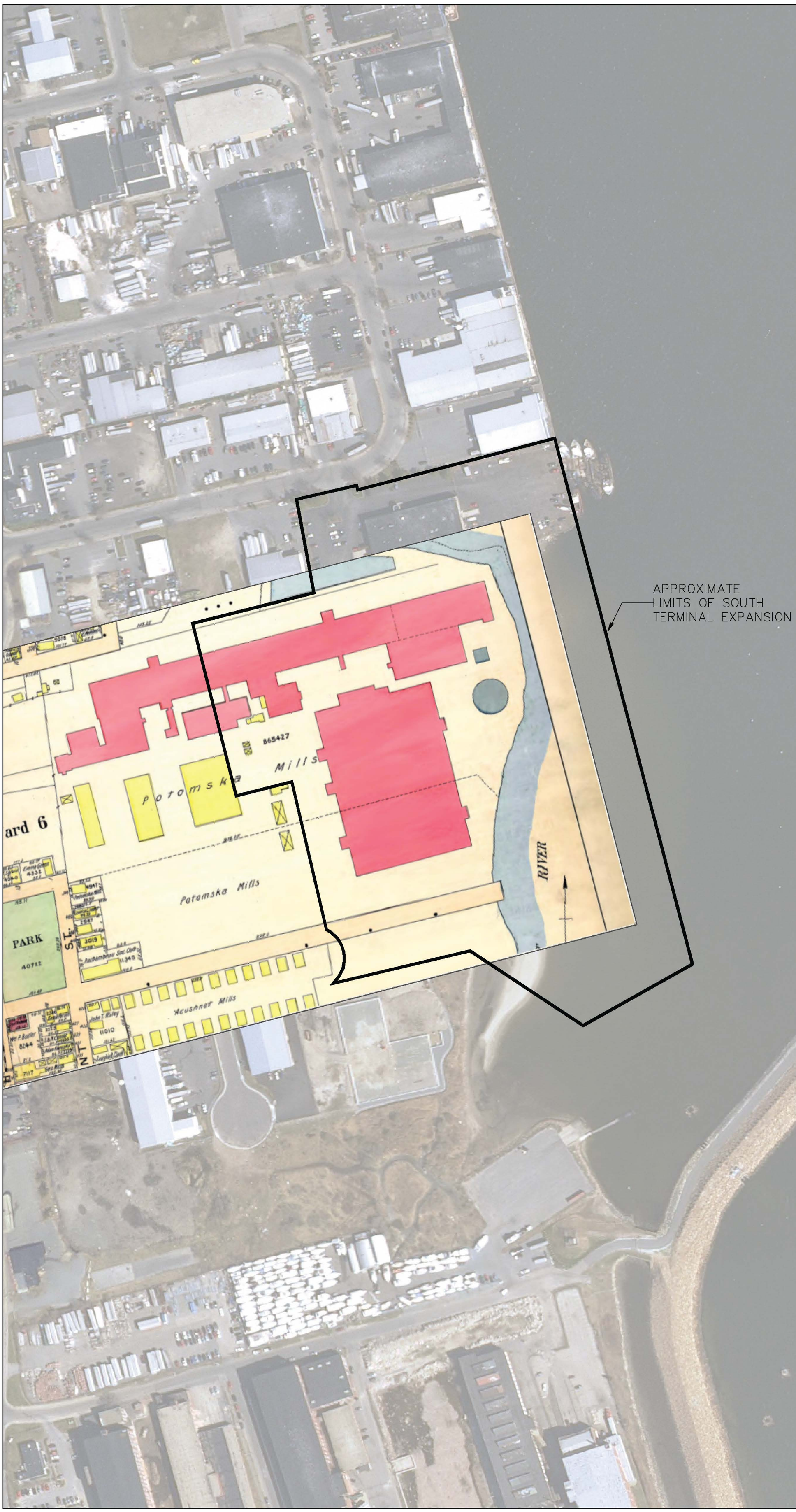
Scale: 1"=500'

0 250 500 1000 1500 FEET

Date 3/24/10	Drawing No.
Proj. Mgr.	
Design	
Check CM	P-1
Drawn GCD	
Job. No. 6615	
Last Rev. 7/7/10	

P:\Jobs\6600 NBH_ Phase IV\PLANS\SOUTHTERMINAL_RESOURCE_opt4.dwg

FIGURE 12



Apex Companies, LLC.

1 WAMSUTTA STREET
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NEW BEDFORD, MA 02740
(508) 996-9828

184 HIGH STREET
SUITE 502
BOSTON MA 02110
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HARBOR DEVELOPMENT COMMISSION
41°38'N 70°56'W
NEW BEDFORD, MA

PREPARED FOR:

THE NEW BEDFORD
HARBOR DEVELOPMENT
COMMISSION

DRAWING TITLE:

SOUTH TERMINAL
MARINE
INFRASTRUCTURE PARK
1911 POTOMSKA MILLS
OVERLAY

Scale: 1"=100'

0 50 100 200 300 FEET

Date	6/5/10
Proj. Mgr.	JAB
Design	GCD
Check	CM
Drawn	GCD
Job. No.	6690.002
Last Rev.	7/7/10

Drawing No.

A-1

P:\Jobs\6690 NBH_ Phase IV\PLANS\SOUTHTERMINAL_ARCHOVERLAY.dwg

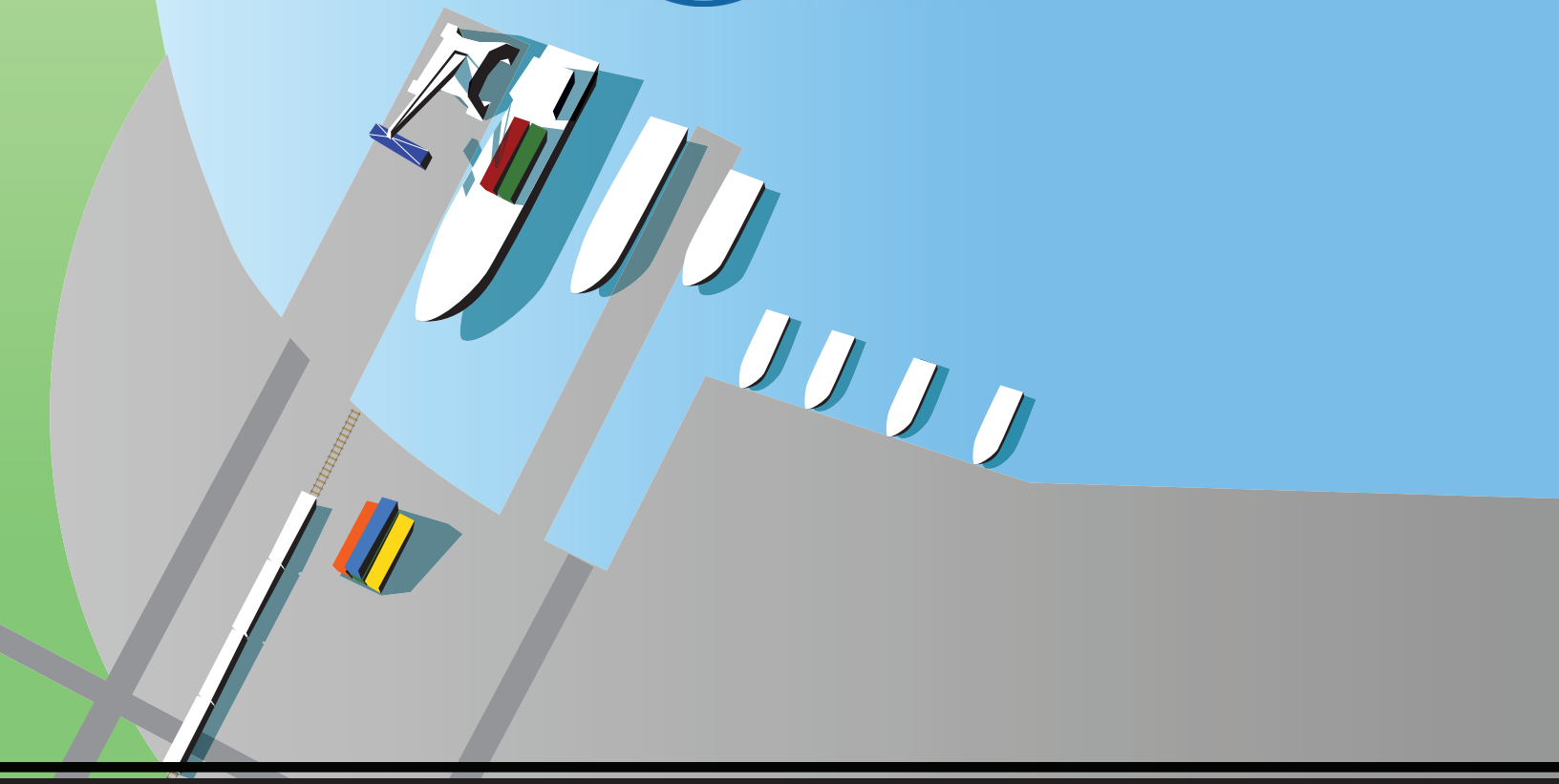
APPENDIX 1

FEBRUARY 2010

Port and Infrastructure Analysis for Offshore Wind Energy Development

PREPARED FOR

MASSACHUSETTS CLEAN ENERGY CENTER



TETRA TECH EC, INC.

133 Federal Street, Boston, Massachusetts 02110

Port and Infrastructure Analysis for Offshore Wind Energy Development

Prepared by:

TETRA TECH EC, INC.

and

Advanced Offshore Solutions

Childs Engineering Corporation

Durand & Anastas Environmental Strategies

FXM Associates

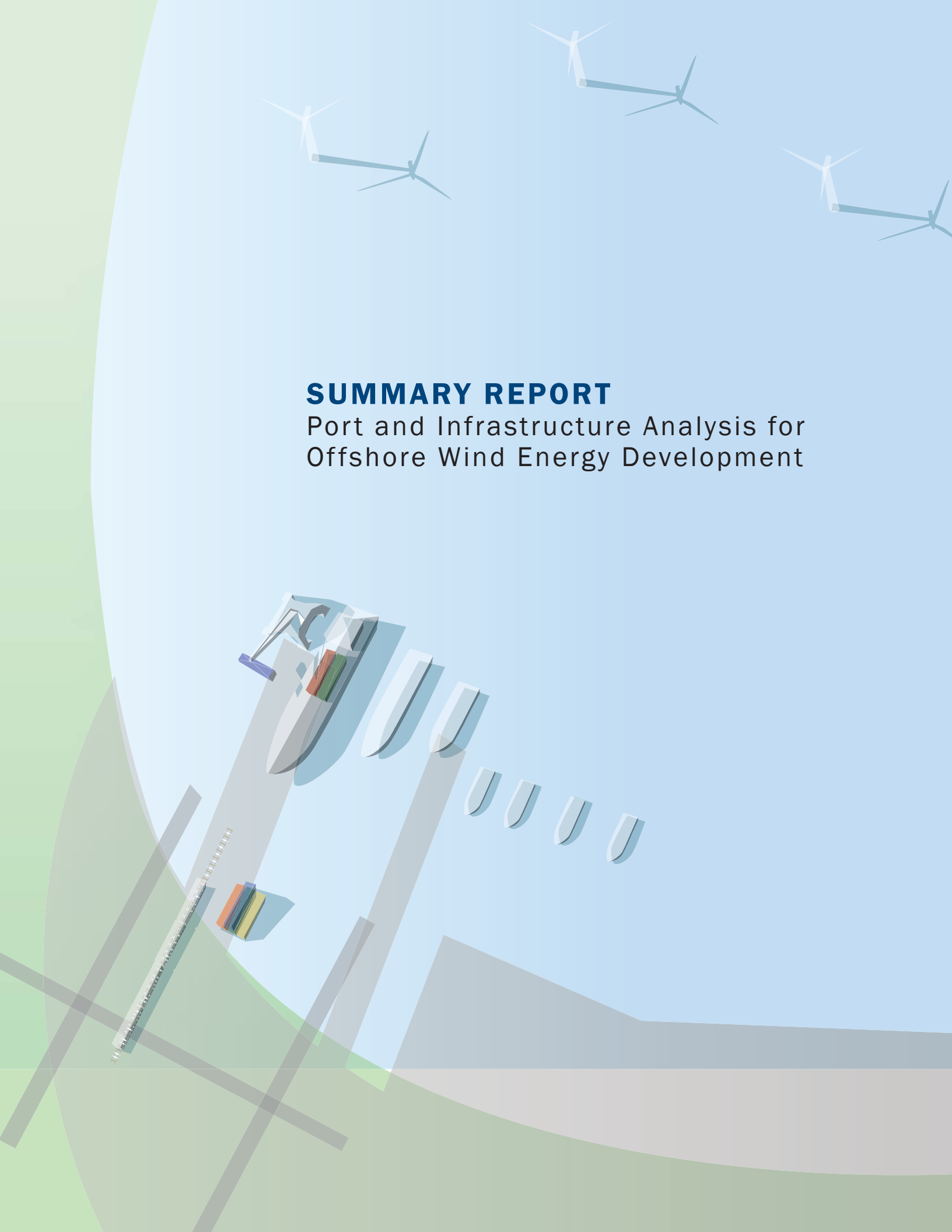
The Glosten Associates

MARPRO Associates International

February 2010

SUMMARY REPORT

Port and Infrastructure Analysis for Offshore Wind Energy Development



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ACRONYMS AND ABBREVIATIONS

DPAs	Designated Port Areas
EPA	Environmental Protection Agency
EWEA	European Wind Energy Association
FAA	Federal Aviation Administration
GDP	Gross Domestic Product
HDC	Harbor Development Commission
hp	horsepower
IBEW	International Brotherhood of Electrical Workers
LNG	liquid natural gas
MCEC	Massachusetts Clean Energy Center
MCZM	Massachusetts Coastal Zone Management
MDEP	Massachusetts Department of Environmental Protection
MDOT	Massachusetts Department of Transportation
MEPA	Massachusetts Environmental Policy Act
MIT	Massachusetts Institute of Technology
MREC	Marine Renewable Energy Center
mt	metric ton
MW	Megawatts
nm	nautical miles
NPDES	National Pollutant Discharge Elimination System
OCS	the Outer Continental Shelf
OMP	Ocean Management Plan
psf	per square foot
ROWEI	Representative Offshore Wind Energy Installation
USACE	U.S. Army Corps of Engineers
WHOI	Woods Hole Oceanographic Institute

1 Introduction

1.1 Background

In the context of a widespread interest in reversing the climate effects of fossil fuels and federal and state incentive programs that promote growth in the use of renewables for electricity generation, the overall goal of this report ("Summary Report" or "report") is to identify port facilities in Massachusetts that have the ability to support offshore renewable energy development. This report also seeks to explore the feasibility and economic development potential, as well as the economic impacts, of planned and potential port and landside facilities at short-listed Massachusetts ports. For this first-of-its-kind study of port infrastructure to support offshore wind, the Massachusetts Clean Energy Center (MCEC) contracted with Tetra Tech EC, Inc. and a team of specialized professionals (collectively "the Team") to conduct this study and issue a report on the findings.

As stated in the Request for Proposals solicitation for this study "Offshore wind energy is the most viable option available for developing utility-scale renewable energy electric generating facilities to the densely populated states along the Eastern seaboard in the near term." Marine-based wind energy generation has the advantage as a renewable energy source because it is closer to commercial deployment than other marine-based renewable energy generation approaches, such as tidal and wave technology. Furthermore, the large scale of equipment and components required for wind generation (i.e. the blades, foundations and towers) means that if a port can physically support offshore wind generation it most likely will meet the requirements for other marine based renewable energy technologies. Therefore, this study focused primarily on how Massachusetts ports can meet the requirements of commercial scale offshore wind energy generation projects.

This Summary Report has been distilled from the more detailed report ("Final Report"). The Final Report provides the approach, analysis, and recommendations that resulted in the identification of potentially appropriate port facilities in New Bedford and Boston, Massachusetts, which were subsequently evaluated in more depth. It also addresses the high level engineering requirements, associated costs, and economic impacts of the proposed port improvements at the two short-listed ports. The Final Report provides the key findings of our study and recommendations to the MCEC of the most effective investment in port facilities to support offshore wind energy generation construction, operation, and maintenance.

1.2 Context

The Northeast Atlantic coastal waters, particularly those off Massachusetts, provide a combination of relatively shallow waters, favorable wind conditions, and proximity to population centers that makes this area uniquely attractive for offshore wind energy development. Those Massachusetts ports possessing the facilities, land area, and navigational characteristics necessary for the assembly and transport of wind turbine components, and for long-term operation and maintenance needs of offshore wind farms, are well-positioned to serve the emerging demands of the offshore wind energy industry.

In April 2009 the U.S. Department of the Interior Minerals Management Service issued final regulations on "Renewable Energy and Alternative Uses of Existing Facilities on the Outer Continental Shelf (Final Rule)," establishing a process for leasing submerged lands for renewable energy projects on the Outer Continental Shelf (OCS). The Final Rule outlines the requirements for limited (short-term – for testing and characterizing) and commercial (long-term – for power generation) leases and the bidding and regulatory procedures a wind developer must follow to obtain rights to a wind farm development site on the OCS.

Additionally, the Massachusetts Ocean Management Plan (OMP) was released on January 4, 2010 by the Commonwealth's Executive Office of Energy and Environmental Affairs (EOEEA OMP 2010). The OMP establishes new protections for environmental resources, and sets parameters for the development of community-scale and commercial-scale offshore wind energy as well as other infrastructure in State waters. The OMP designates which areas are prohibited from use and which may be used for wind energy farms and other renewable energy facilities. This new regulatory framework indicates interest in and expectation for future offshore development. Two renewable energy areas were identified based on the presence of suitable wind resource, water depth, and the absence of conflict with other uses or sensitive resources. These areas are located approximately one mile offshore in the vicinity of the southern end of the Elizabeth Islands and southwest of Nomans Land Island. These areas could accommodate approximately 150 3.6 megawatts (MW) turbines at full build-out (OMP pp 4-1). The Team recognized the potential for these sites to be developed for offshore wind energy and the implications for port and infrastructure to support offshore wind farms. Massachusetts ports with the potential to satisfy the infrastructure requirements of the offshore wind energy industry are well-positioned to support construction, as well as operation and maintenance in these areas.

Developers have yet to construct any offshore wind generation facilities in U.S. waters (to date only meteorological towers to test wind characteristics). In turn, U.S. port facilities have yet to stage construction for any offshore wind farms. Other than the import of landside wind farm components, East Coast ports have no experience in handling, storing or assembling the offshore wind generation components. Therefore, the current experience of European ports servicing offshore wind facilities and U.S. Gulf of Mexico ports staging construction for the offshore petroleum industry have formed the basis of the Team's analysis of the port infrastructure needed to support the East Coast offshore wind industry. The combination of the trend toward production of much larger components (such as blades with lengths approaching 90 meters) and the expectation that stateside developers intend to skip pilot scale offshore facilities (which would present learning opportunities) in favor of full-scale production projects, complicates the Commonwealth's preparation for this new industry. Also, the physical constraints in and around Massachusetts ports suggest that its ability to cost effectively stage such offshore construction will take both physical improvements and creative problem solving.

The focus of this port infrastructure analysis is to specifically determine:

- The required characteristics of a port facility to be considered an appropriate staging point for construction of offshore wind generation facilities;
- The difference between traditional port facility features and those required for delivery, storage, handling and deployment of large offshore wind farm components;
- The harborside (navigational) and landside (port facility) needs of purpose-built installation and component delivery vessels (now and in the future);
- Port facilities in the Commonwealth of Massachusetts that could be upgraded or expanded to be considered appropriate staging points;
- The costs for required upgrades or expansions at short-listed ports; and
- The ability of facility improvements to attract wind farm developers and government investment and to ensure a return on investment to the Commonwealth.

Construction staging depends on a number of variables, including number of turbines in a given development scenario, size and weight of the component pieces, schedule of material needs and their point of origination. Other factors include the degree of assembly prior to transport to the development site and the specialty equipment needed for final installation.

The following section provides an overview of offshore wind turbine components as an introduction, since each component has handling and care characteristics that need to be considered. The subsequent analysis characterizes navigation and port infrastructure requirements and identifies Massachusetts ports for further evaluation of the costs and economic impacts and benefits to upgrade port facilities to required standards.

2 Assessment of Offshore Wind Energy Port Infrastructure Needs

This section provides a description of wind farm components and the issues affecting their delivery and deployment and explains how other marine industries offer insight into navigational and port requirements for offshore wind deployment.

2.1 Wind Farm Components

Offshore wind turbine components include the turbine, tower, transition piece, and foundation (see Figure 1). The turbine consists of the nacelle, rotor (with blades) and hub. Most current large-scale turbines use a three-bladed rotor connected through the drive train to the generator, which is housed in the nacelle. Offshore wind turbines are typically larger than 2 MW in generation capacity because of the higher return on the construction investment in terms of power and revenue generation. In this analysis, the Team considered 3 MW or 3.6 MW turbines, as these are the current generation of turbines being installed. For the purposes of this study, a minimum offshore wind turbine array was assumed to consist of ten turbines. Based upon discussions with current and future developers, larger wind farm arrays would include from 60 to 150 turbines.

Various foundation structures can be used, depending on seabed geology, wind/wave conditions and water depth at the site. Four standard types of offshore foundation structures exist and are described below (see Figure 2).

- Monopile
- Gravity-Based
- Multi-Leg or Jacket
- Floating

Monopile and gravity foundations are commonly used in shallow and transitional water depths up to 90 feet. Multi-leg configurations with broader bases such as tripods, jackets, and suction bucket support structures are used for water depths of 180 feet or greater. Floating turbines may also become feasible long-term options for deep water (beyond 180 ft depth). These structures would be secured to the ocean floor via catenary guy wires, mooring lines, or tension legs, which in turn would be fastened to anchors or gravity-based platforms, according to a publication released by the U.S. Offshore Wind Collaborative in 2009.

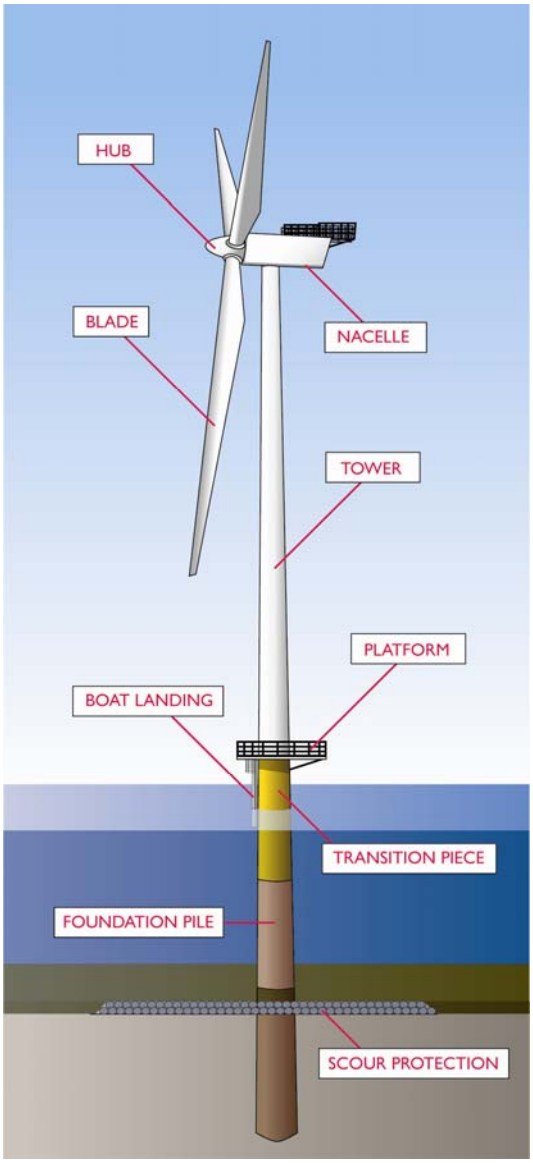

Figure 1 Primary Components of an Offshore Wind Turbine

Figure 2 shows five basic types of foundations. The illustration is not comprehensive as other pile type foundations exist. General depth ranges are shown in feet.

Dimensions of turbine components vary from make, model, and power rating. As stated above, most of the planned commercial-scale generation projects for the Northeast Atlantic coast expect to use turbines in the 3MW to 3.6MW range. Table 1 below provides an example of the magnitude of component dimensions.

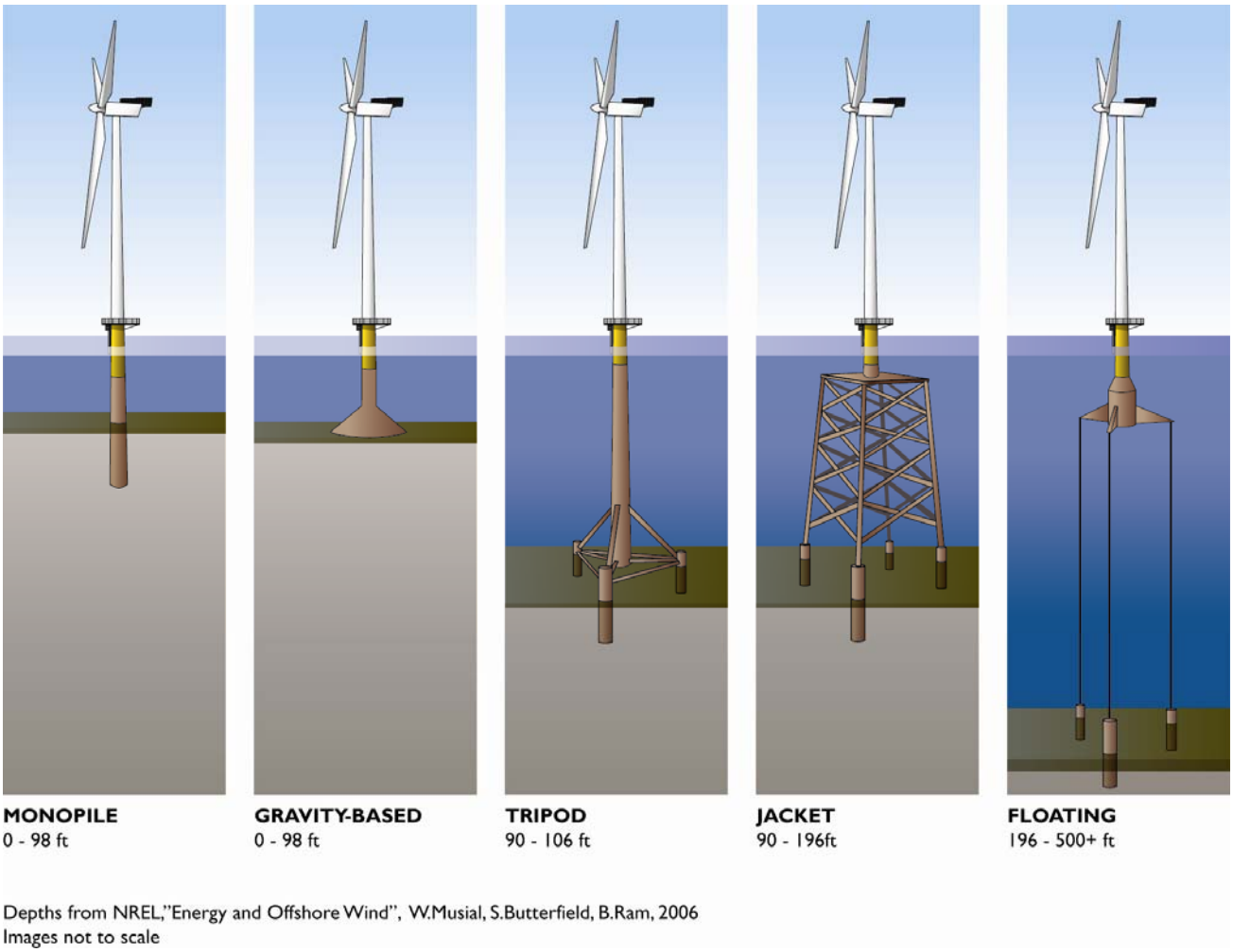

Figure 2 Types of Foundation for Offshore Wind Turbines

Table 1 Dimensions of Turbine Components (Technical data for Vestas V112-3.0 MW)

Dimensions				
Turbine Component	**Weight**	**Length**	**Height**	**Width/Diameter**
Monopile foundation	165 to 231 US ton (for 90 to 130 ft long monopile) 551 US tons (for 197 ft long monopile)	Varying 90 to 130 ft to up to 197 ft	N/A	D: 16.75 ft / 18 ft)
Transition piece	187 US tons	56 ft per unit	N/A	D: 13.8 ft
Nacelle (incl. hub)	138 to 165 US tons	46 ft	10.8 ft	w: 12.8 ft
One Blade	14 to < 20 US tons	179 ft	N/A	Max. w: 13.8 ft
Tower Section	Approximately 77 US tons	106.6 ft	197 ft assembled	d: 13 ft to 15 ft

(Source: Vestas 2008)

2.2 Wind Turbine Component Delivery and Deployment

Currently, very few offshore wind turbine components suitable for commercial-scale offshore wind farms are being manufactured in the U.S. that are of the size appropriate for a wind farm with 60 to 150 turbines. Manufacturers will have little incentive to set up large scale offshore wind component manufacturing operations in the United States until developers are ready to purchase components at a rate that makes the investment in a manufacturing facility financially attractive (based on Team discussions with manufacturers). Therefore the Team's analysis assumes that most, if not all turbine component pieces for the planned offshore wind farms would be manufactured and shipped from European facilities.

Foundations and transition pieces tend to be manufactured and delivered separately from the turbines, although there may be some manufacturing capacity overlap with towers. Currently, no operational rolled steel manufacturing facilities on the East Coast have been identified at a scale suitable for a large offshore wind farms. Like turbine manufacturers, foundation suppliers lack the incentive to set up an East Coast production facility, and therefore it is likely that foundation components would be shipped ready to be assembled on large barges from the Gulf of Mexico, Europe or Malaysia. Rail and truck delivery options are limited to aggregate for scour protection, or sectional pieces such as iron bars or flat sheets of steel for use in the foundations or transition pieces. Fully assembled foundations have dimensions which preclude shipping by rail or truck.

Developers do not necessarily have to stage foundations for offshore deployment out of the same port staging the turbine construction. The convenience of utilizing a common port facility generally would not outweigh the cost savings associated with improved logistics, less assembly, and minimizing storage space and handling needs. Barges also may be used for foundation storage in certain circumstances. Foundations can be delivered and stored on barges fully assembled and then tugged out to the installation site with less handling.

Turbine components may be transported from the staging port to the installation site in various stages of assembly (see Figures 3, 4, and 5 below). *Vessel Requirements for Offshore Wind Farm Construction and Maintenance* (The Glosten Associates 2009), which is Appendix A of the Final Report, provides more details on these transport options. The options range between offshore on-site assembly and installation at the wind farm site, and turbine assembly in the controlled environment of the staging port, with the fully assembled turbines transported to the installation site in an upright position. Assembly at the offshore installation site lessens the risk

associated with fully assembled turbine transport, but entails risks associated with turbine assembly in the marine environment.

Turbine manufacturers and contractors experienced in European wind farm construction prefer specialized purpose-built vessels for turbine installation. Purpose-built vessels are not currently available in the U.S. and are not expected to be available for use in the U.S. in time for the initial construction of commercial-scale wind generation facilities on the East Coast. Construction costs for these vessels range from $40 million ($40M) to $80M for tugged vessels and $150M to $250M for self-propelled vessels (The Glosten Associates 2009). Similar to potential investment in manufacturing facilities, the incentive to build a purpose-built installation vessel will depend on actual demand and potential return on such investment. Existing U.S. built jack-up vessels are less than optimal for offshore wind turbine installation, but probably can be used for the initial deployments for East Coast offshore wind construction. However, the use of these existing vessels involves more risk and would require more installation time than purpose-built vessels. Rental rates for installation vessels are high and developers will attempt to maximize the utilization of the vessels when they have them. This factor, along with the ever present possibility of weather and seasonal delays, indicates that the staging port must be available 24 hours per day and 7 days per week. Both the availability of wind turbine components and delivery and construction vessels are critical elements of the offshore wind energy supply chain.

Future Trends

Proposed offshore wind projects in Europe and North America for 2015 are forecasted to reach 40 GW, of which the United States is expected to undertake projects totaling more than 2 GW (Infocast, U.S. Offshore Wind Report 2009, p. 6). The European Wind Energy Association (EWEA) has set a target for 2020 of 40 GW of offshore wind capacity. European offshore demand for 2010 is forecasted to reach 10 GW. This implies a European need for 30 GW or more over a 5-year span, which cannot be supported by current manufacturing capacity (EWEA, Oceans of Opportunity 2009, p. 44). However, the offshore wind industry will need to deploy upwards of 10,000 structures by 2020 to meet the minimum forecasted European demand. The current offshore manufacturing industry cannot deliver this number of structures due to insufficient capacity (EWEA, Oceans of Opportunity 2009, p. 49). Significant additional manufacturing facilities and related industrial capacity are needed to meet the forecasted European and North American demand.

2.3 Similar Offshore Activities

Offshore wind generation as a new marine industry on the U.S. East Coast will be added to a region that has historically been heavily dependant on maritime industry and commerce. As a new industry, however, offshore wind will require specialized equipment, services and labor not currently operating out of any U.S. ports. Understanding what will be needed to support both short-term construction activities and long-term operational and maintenance activities involves both learning from recent construction of European offshore wind projects, as well as identifying how similar services and activities already associated with existing marine industries here in the U.S are currently performed. There are a number of marine industries, each with its own port requirements, currently operating in the waters offshore of the U. S., including, but not limited to, petroleum extraction, liquid natural gas (LNG) ports, commercial shipping, and commercial fishing. The Final Report describes these existing U.S. marine industries in more detail and discusses potential similarities with the offshore wind industry.

Each marine industry is specialized, requiring differing shore-side support as well as equipment for conducting offshore operations. However, understanding the needs of these industries can help to identify the port-related requirements for offshore wind development and the potential utilization of the available marine equipment and facilities along the U.S. East Coast. In many ways, wind turbine foundations (and approach to installation) are comparable to offshore petroleum structures. Commercial fishing operation requirements are very comparable to offshore wind construction and operational needs. However, offshore wind generation support needs are much smaller in scale than the warehousing and wharf frontage needed for commercial shipping. Port and support vessel requirements for maintenance of offshore wind farms are similar to those for commercial fishing, offshore LNG ports, and petroleum platforms. Offshore wind turbine foundation technology has been developed based on structural foundations already in use in petroleum extraction, primarily the use of piles and jackets. As with wind turbine foundations, the foundation types for petroleum platforms vary greatly with water depth. Deep water technologies such as semi-submersible and floating platform equipment are being explored for the offshore wind industry as well as deep water LNG ports. Anchor systems similar to those used for petroleum and LNG ports could be modified for use as wind turbine foundations, anchoring floating turbine structures in deep water locations.

Petroleum extraction platforms are currently assembled using specialized heavy lift vessels. Vessels currently in the fleet (including jack-up cranes, tow boats, and large barges) have the potential to be modified for use as construction platforms for wind turbines. While such modifications can be made to existing vessels, the specialized construction techniques and heavy lift needs of offshore wind turbine construction may make the modification option expensive and potentially risky. The option of applying modified existing equipment may also be limited to smaller construction projects in near-shore environments. Purpose-built construction vessels for offshore wind turbine construction most likely, in the long run, would be more cost effective, less risky, and flexible in terms of operational capabilities. An offshore wind farm, once constructed, will need operational support in the form of routine maintenance. Maintenance vessels used during wind farm operations would likely be similar in size to those currently in use to support offshore LNG ports and petroleum extraction operations. Berthing space for support vessels will be vital for port facilities, as well as yard and warehousing space for components and other maintenance supplies.

3 Industry Overview

3.1 Development of Port Criteria

To determine the port-facility/land-based requirements for both the installation and long-term servicing of planned offshore wind projects, the Team:

- Held discussions with offshore developers and compiled relevant data;
- Conducted research and compiled data on manufacturer requirements;
- Determined key harborside and landside port parameters;
- Developed a list of evaluation criteria for harbors and port facilities; and
- Identified the most highly desirable characteristics of port facilities.

The following sections of this Summary Report describe some of the specific areas of analysis listed above.

3.2 Discussions with Developers

The Team identified and contacted several prospective U.S. East Coast offshore wind farm developers with the goal of compiling a detailed understanding of the requirements necessary to successfully support the construction, operation and maintenance of a commercial-scale offshore wind farm. The Team intended to use this developer input to identify an objective set of weighted criteria with which to compare and evaluate Massachusetts port facilities. Many developers have yet to specify or disclose in detail the key parameters and characteristics that were sought for this purpose; however, developers did identify and explain many aspects of the most important parameters, which helped the Team establish the basic port criteria. The Team's discussions with developers did provide a better understanding of offshore wind farm components and the logistics of importing, storing, assembling, scheduling, and deploying wind turbines and foundations to installation sites.

Some developers have already initiated permitting or applied for lease blocks for several wind generation sites along the East Coast. From the available information on these projects, the Team determined that port infrastructure must support projects of varying scale ranging from 60 to 150 turbines. These proposed projects formed the starting point for the Team's analysis of port requirements. Table 2 below provides a quick view of these proposed projects based on available public information. Projects are listed by developer with particulars such as location, water depth, generating capacity, number of turbines, and distance from shore. Because these projects are in various stages of development, not all information on every project is publicly available.

As the developer's needs were analyzed, the Team found that Massachusetts ports had clear, distinguishable differences relative to the offshore wind development requirements.

Table 2 Planned Offshore Wind Projects

Developer/Project	Project Location	Water Depth at Proposed Location	Project Generating Capacity	Number of Turbines (Scale)	Foundation Type	Estimated Cost of Construction	Port Staging Area
Cape Wind Associates							
Cape Wind	4.5 NM (5.2 miles) from coast of Cape Cod, MA, 7.8 NM (9 miles) from Martha's Vineyard, 12 NM (13.8 miles) from coast of Nantucket Island	3.7 m (12 ft) MLLW (mean low low water) minimum depth	468 MW	130 (3.6 MW per turbine)	Monopile	$700 million	Quonset Davisville Port and Commerce Park, Quonset, Rhode Island
NRG Bluewater Wind							
Bluewater Delaware	11.3 to 19.1 NM (13 to 22 mi) east of Rehoboth Beach, DE (wind park); 14.3 NM (16.5 mi) due east Rehoboth Beach (met tower)	12.2m to 18.3m (40 to 60 feet)	200 to 450 MW	Up to 150	Monopile	$800 million	Port of Wilmington, Delaware; Delaware Bay Launch in Milford Delaware for crew boat and small cargo barge launch
Bluewater New Jersey	14 NM (16 mi) southeast of Atlantic City, NJ	21.3m to 30.5m (70 to 100 feet)	350 MW	116	Monopile	$1.4 billion	Port of Wilmington, Delaware; Delaware Bay Launch in Milford Delaware for crew boat and small cargo barge launch
Deepwater Wind							
Garden State Offshore Energy (Deepwater with PSEG Renewables)	13.6 NM (15.6 mi) from shore, 17.4 NM (20 mi) due east of Avalon, NJ	24.4m to 27.4m (80 to 90 feet)	350 MW	96	Jacket	$1 billion	Atlantic City, New Jersey
Deepwater Wind Rhode Island	2.6 NM (3 miles) off Block Island, RI for Phase 1; Phase 2 located 13 to 17.4 NM (15 to 20 mi) off RI coast (location TBD upon completion of RI Ocean Special Area Management Plan in 2010	'deeper' waters	20 MW (Phase I) 400 MW (Phase II)	Phase 1: 8 turbines Phase 2: 106 turbines	Jacket	$1 billion	Quonset, Rhode Island

Table 2 Planned Offshore Wind Projects

Developer/Project	Project Location	Water Depth at Proposed Location	Project Generating Capacity	Number of Turbines (Scale)	Foundation Type	Estimated Cost of Construction	Port Staging Area
Fisherman's Energy							
Fisherman's Energy of New Jersey Project	Phase 1: 2.6 NM (3 miles) off the coast of Atlantic City Phase 2: 6.1 NM (7 miles) off the coast	18.3m to 21.3m (60 to 70 feet)	Total: 350 MW Phase 1: 20MW Phase 2: 330 MW	Total: 74 Phase 1: 8 turbines Phase 2: 66 turbines	Monopile	$100 million for Phase 1 $1 to 1.5 billion for Phase II	Dorchester, Atlantic City, and or Cape May, New Jersey
Fisherman's Energy of Rhode Island Independence 1 Project	2.6 NM (3 miles) south off the southern coast of Block Island, RI	20 m to 30 m (65.6 to 98.4 feet)	400 MW	80	TBD	$1.25 to $1.5 billion	TBD

3.3 Key Parameters: Conditions at Ports and Wind Farm Locations

Wave height, water depth and wind speed impose limitations on at-sea construction operations. The Team studied sea states, wind conditions, and water depths at a number of proposed wind farm sites along the U.S. East Coast, as well as transit distances between proposed wind farm sites and potential staging ports.

The base line transit routes for cargo in the region track around the east end of Cape Cod and the primary alternative route is via the Cape Cod Canal (MARPRO Associates International 2009). Air draft (i.e., the free space above the water line below an overhead obstruction) in the Cape Cod Canal is limited to approximately 135 feet. Vessels or barges transporting 5 MW turbines in the "bunny ear" configuration (especially the "fore-aft" configuration – See Figures 3 and 4) most likely cannot transit the Cape Cod Canal. Alternative turbine load-out configurations (e.g., the "star" configuration – See Figure 5) and/or smaller turbines (e.g., 3.6 MW turbines) in the "bunny ear" configuration probably could utilize the Cape Cod Canal.

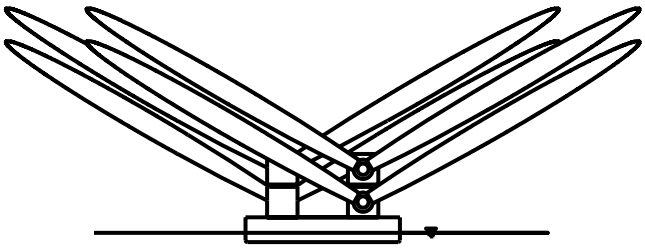

Figure 3 Bunny Ear Configuration (Lateral) – End view looking forward

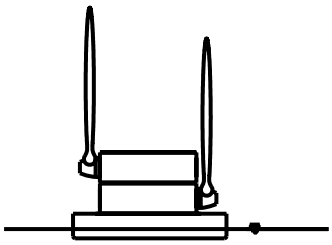

Figure 4 Bunny Ear Configuration (Fore-Aft) – End view looking forward

Figure 5 Star Configuration – End view looking forward
(Source of Figures 3-5: The Glosten Associates 2009)

3.4 Key Parameters: Vessel Constraints and Requirements

Characteristics of Available Vessels

The following sections discuss the basic characteristics, capabilities, limitations, and general availability of vessels that are currently available for use in the construction and maintenance of offshore wind farms. *Vessel Requirements for Offshore Wind Farm Construction and Maintenance* (The Glosten Associates 2009), which is Appendix A of the Final Report, provides further details.

Turbine Import/Delivery Vessels

The turbines used for the first round of U.S. offshore wind farms likely will be imported from Europe. Turbines are generally shipped in pieces (tower sections, nacelle, hub, individual blades) from the point of origin directly to the project site aboard open hatch cargo vessels.

Foundation Delivery and Installation Vessels

Foundations can be installed using either jack-up crane vessels or floating derrick barges. Jack-up crane vessels are described further below. Large floating derrick barges are in service on all three major U.S. coastlines and could be mobilized to serve the U.S. East Coast offshore wind energy market. Depending on the type of foundation being used (i.e., monopile, gravity-base, jacket, or tripod), a derrick barge could transport foundations between the staging port and the wind farm site on its own deck, or foundations could be transported using a separate barge.

Wind Turbine Installation Vessels

European offshore wind turbines have been installed using a variety of specialized equipment, which generally falls into one of three categories:

- Leg-Stabilized jack-up crane ships ("partial jack-ups");
- Jack-up crane barges; and
- Jack-up crane ships.

For all three vessel types, the limiting wind speed for at-sea crane operations is approximately 15 to 20 knots. For the leg-stabilized vessels, the limiting sea state for crane operations is approximately 1.7-foot seas, as the vessel's hull remains submerged and is subject to wave-induced motion. For the jack-up barges and ships, the process of jacking up and down is limited to approximately 5-foot seas. The crane can be operated in higher sea states once the vessel is jacked-up. Future wind turbine installation vessels are expected to focus on improving construction efficiency through faster transit speeds, larger payload capacity, and ability to erect turbines in higher wind speeds and larger sea states.

Maintenance Vessels

Regular, planned maintenance of offshore turbines requires personnel access to the wind farm facilities. Maintenance personnel are typically shuttled to the turbines by a crew boat or by helicopter. Major maintenance or repair of offshore wind turbines may require mobilization of a wind turbine installation vessel to reverse some or all of the installation process.

Vessel Requirements for Deployment and Maintenance

Understanding the marine vessel requirements for deploying and maintaining offshore wind farms along the U.S. East Coast is critical in the overall evaluation of ports' suitability as staging areas for offshore wind farm development. Vessel requirements are governed primarily by the following:

- Physical conditions in which vessels must operate at offshore wind farm sites;
- Size and weight of turbines being transported and installed; and
- Methodology for transporting and installing turbines.

The Team evaluated physical conditions, including wind speeds, wave regime, and water depth at proposed offshore wind farm installation sites along the U.S. East coast, as well as navigational constraints in and near existing Massachusetts port facilities. The Team reviewed demonstrated methodologies for transporting and installing offshore wind turbines.

Installation and Transport Vessel Requirements

For purposes of this study, it was assumed that the installation vessels discussed below would be subject to the Jones Act, which requires vessels engaged in the transport of passengers or cargo between U.S. places to be built and flagged in the United States, and owned and crewed by U.S. citizens.

The key dimensions of the turbine installation and turbine transport vessels are beam, length, draft, and vertical clearance (a.k.a. "air draft"). The beam of installation and transport vessels is largely dictated by vessel stability requirements during transit and, when applicable, the stability requirements and structural strength while elevated on legs (i.e., "jacked up"). The length of the vessel depends on functional and cargo requirements and structural considerations. The vessel's draft, or the required clearance between the waterline and sea bed, is dependant on the hull form and total weight, including cargo. Vertical clearance is dictated by three factors: length of legs (for a jackup barge or vessel), pre-assembly methodology, and crane height in the stowed position.

Figures 6 and 7 show a fully loaded 400-ft x 100-ft (length x beam) barge with jackup legs in transit and after installation configurations, respectively. Turbine tower sections are typically transported in the vertical orientation, with maximum height approximately even with the top of the blades in the bunny ear configuration.

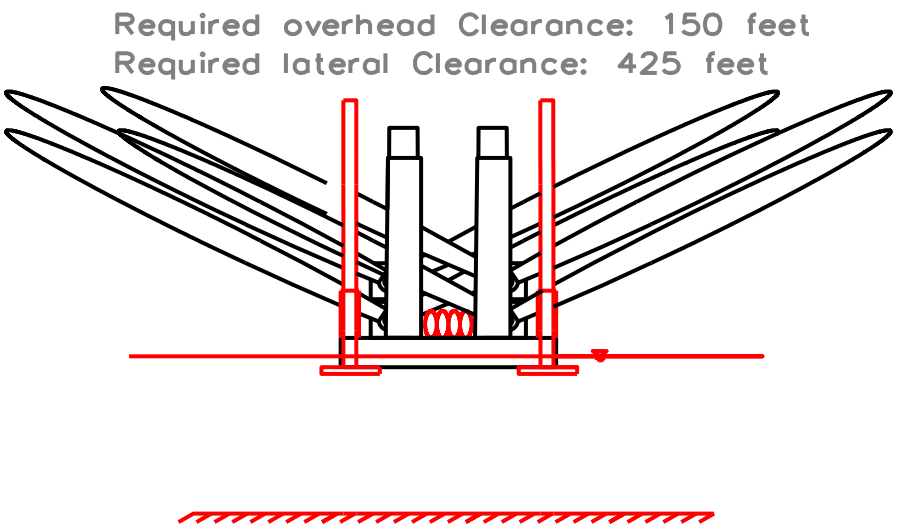

Figure 6 Loaded Barge in Transit

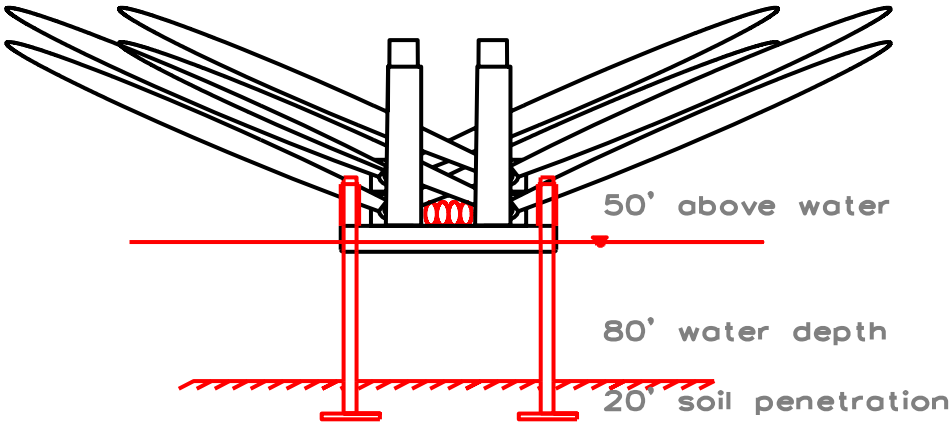

Figure 7 Barge on Site with Legs Down
(Source for Figures 6 and 7: The Glosten Associates 2009)

The required overhead clearance is approximately 150 ft. The star (Figure 5) and lateral bunny ear (Figure 3) configurations require a lateral clearance of approximately 425 ft. The lateral clearance for the fore-aft bunny ear (Figure 4) configuration is dictated by the barge or vessel beam, which is typically on the order of 100 to 125 ft. In the near future, it is expected that specialized installation vessels will transport multiple pre-assembled turbines on tower sections out to the installation sites, requiring overhead clearances in excess of 300 ft.

The principal dimensions and draft characteristics (navigational and air) of a typical installation or transport vessel are presented in Table 3.

Table 3 Principal Dimensions for Turbine Installation or Transport Vessels
(Source: The Glosten Associates 2009)

Length Overall	90 – 140 m (300' – 450')
Beam	30 – 40 m (100' to 130')
Navigation Draft	3.6 – 4.9 m (12' to 16')
Air Draft (legs in up position)	varies, approximately 46 m (150')
Air Draft (tower sections, bunny ears)	46 m (150')
Air Draft (crane in stowed position)	varies

Section 4.4.1 of the Final Report provides additional details of the principal dimensions of wind turbine installation vessels/barges and import vessels.

Tugboat and Auxiliary Vessels

Self-propelled wind turbine installation vessels likely will not require tug assistance, as they would be able to move and position themselves using their own propulsion and dynamic-positioning systems. Barges, on the other hand, would require at least one tug of approximately 4,000 to 5,000 horsepower (hp). In addition, a smaller tug of around 1,000 hp may be needed to help position the vessel for jacking operations. Additional necessary vessels include high-speed crew boats during wind farm construction and several auxiliary vessels to complete the marine fleet. These types of vessels are all readily available for hire throughout the Northeast U.S.

3.5 Key Parameters: Navigational Access and Transit Distances

The required navigational clearances for vessels involved in the construction and maintenance of offshore wind farms were presented. The key considerations for navigational access are:

- Vessel draft compared to navigable water depth;
- Vessel beam (including overhanging cargo) compared to channel width; and
- Vessel air draft compared to overhead clearance restrictions (bridges and aerial cables).

Table 4 summarizes the navigational restrictions associated with selected Massachusetts ports. Further details are given in *Vessel Requirements for Offshore Wind Farm Construction and Maintenance* (The Glosten Associates 2009), which is Appendix A of the Final Report.

Table 4 Summary of Navigational Constraints at Selected Massachusetts Ports

Staging Port	Potential Obstructions	Lateral Clearance	Overhead Clearance	Controlling Water Depth	Feasible Turbine Load-Out Configurations	Jack-Up Feasible?
New Bedford	Hurricane Barrier	45 m (150')	No Constraints	6.7-9.1 m (22'-30')	all	yes
Gloucester	water depth, channel width	61 m (200')	No Constraints	4.9-5.8 m (16'–19')	fore-aft bunny ear	Marginal (water depth)
Fall River	Mt. Hope Bridge	122 m (400')	41 m (135')	12.2 m (40')	star	Marginal (air draft)
Charlestown / East Boston (inner harbor)	Logan Airport	over 150 m (500')	Report air draft to airport traffic control	12.2 m (40')	all	yes

Table 4 Summary of Navigational Constraints at Selected Massachusetts Ports (continued)

Staging Port	Potential Obstructions	Lateral Clearance	Overhead Clearance	Controlling Water Depth	Feasible Turbine Load-Out Configurations	Jack-Up Feasible?
Mystic River	Tobin Memorial Bridge	over 150 m (500')	41 m (135')	7.6-10.7 m (25-35')	star	Marginal (air draft)
Chelsea River (West of Chelsea St. Bridge)	Andrew McArdle Bridge	53 m (175')	No Constraints	8.8-12.2 m (29-40')	fore-aft bunny ear	yes
Chelsea River (East of Chelsea St. Bridge)	Chelsea St. Bridge	28 m (93')	25 m (83')	8.8-12.2 m (29-40')	rotor disassembled	no

In selecting a support facility, distance to the wind farm must be considered in term of cost and effect on risk. Distance impacts fuel consumption, insurance and schedule costs. When turbine components are in transit from the staging port to the installation site, they are more vulnerable to risks associated with weather events and the ocean environment. The cost differential between a distant state-of-the-art facility and a closer facility with less than optimal component handling ability must be carefully evaluated. Table 5 provides transit distances to staging port locations from the Massachusetts OMP Wind Energy Areas located near the southern end of the Elizabeth Island and southwest of Nomans Land Island.

Table 5 Distances to Staging Port Locations from the OMP Wind Energy Areas

Staging Location	Primary Route Distance [nautical miles]	Alternate Route* Distance [nautical miles]
Boston, MA	260	100
Gloucester, MA	235	100
New Bedford, MA	35	n/a
Fall River, MA	50	n/a
Portland, ME	290	175
Quonset/Davisville, RI	40	n/a

* Alternative route is via the Cape Cod Canal

Staging Through-put Estimates

The Team examined the expected level of activity at a port serving as a staging area for offshore wind farm development and estimated the construction time for wind farm construction. Multiple wind farm construction scenarios were considered in order to develop upper and lower bounds of expected port activity. For this analysis the primary metric of port activity is the number of wind turbines deployed per month, which is referred to as "through-put."

The results of the desk top time line modeling of three different staging scenarios for New Bedford, MA were as follows:

- The time line modeling of the Baseline scenario for turbine staging and installation yielded an expected through-put of 15-18 turbines per month for 6-9 months.
- The time line modeling of the Optimistic scenario for turbine staging and installation yielded an expected through-put of 16-22 turbines per month for 12-15 months.

- The time line modeling of the Aggressive scenario for turbine staging and installation yielded an expected through-put of 15-20 turbines per month for 12-15 months and thereafter an expected through-put of 21-25 turbines per month for an additional 8-10 months.

Additional wind farm construction scenarios were evaluated to develop a better estimate of the potential ranges of through-put that may be required at regional staging ports. Each scenario was defined by a vessel type, a transit distance and a length of the construction season. The results of these multiple modeling runs are summarized in Table 6.

Table 6 Expected Through-Put at Staging Port, for Various Construction Scenarios

Transit Distance (staging port to wind farm site *)	Existing Vessels **		Future Vessels ***	
	Summer	Winter	Summer	Winter
50 nautical miles	20-22 turbines/month	16-18 turbines/month	30 turbines/month	30 turbines/month
150 nautical miles	18-20 turbines/month	15-17 turbines/month	21-25 turbines/month	21-25 turbines/month
250 nautical miles	15-17 turbines/month	12-15 turbines/month	16-20 turbines/month	16-20 turbines/month

Notes:
* The transit distance from New Bedford to the Cape Wind site is approximately 60 nautical miles (nm). The transit distance from Boston to Cape Wind is approximately 130 nm. The transit distance from New Bedford to the Deepwater sites near Delaware Bay is approximately 260 nm.
** Existing Vessels means jack-up vessels or barges with slewing cranes, typical of present European offshore wind farm construction practice.
*** Future Vessels means vessels or barges that transport and install fully assembled turbines.

(Source: The Glosten Associates 2009)

The through-put estimates are for turbine installation only. Foundation installation is typically completed in advance of turbine installation and can utilize a wider range of vessels and staging ports than turbine installation. For U.S. offshore wind farms, foundation installation can be completed using existing equipment, which is currently available.

Using a through-put of 18 to 22 turbines per month (based on the results of the time line modeling discussed above), the turbine manufacturer would want 20 nacelles stored at the staging port in advance of assembly and deployment. As workers assemble the turbines in preparation for loading onto the installation vessel, and bad weather hits the installation site, the assembled turbines would have to be stored at the port. Unassembled turbine components would continue to arrive from the manufacturer and require additional storage space for 20 more turbines. Throughput requirements translate into the laydown requirements discussed in Section 3.6 and may require multiple port facilities to support a given offshore wind development.

3.6 Key Parameters: Staging Port Facility Requirements

One developer we interviewed provided a description of the ideal port facility to support offshore wind; a port would have a 1000-ton crane on rolling tracks, which would carry components from a delivery vessel to a storage location; sufficient linear footage to efficiently load/unload one vessel at a time, with a preference for multiple deepwater berths to unload several vessels simultaneously; a secondary 80-ft berth; and about 200 acres for assembly and storage.

While no existing Massachusetts port facility has an assembly and staging area this large, the existing Commonwealth facilities could be repaired, upgraded, or expanded to provide sufficient area to meet the other requirements for staging offshore wind farm construction. If it is necessary to provide a larger area at these existing facilities, then a combination of properties at these marine parks, a combination of ports, or barge storage would have the ability to provide additional space.

Physical Considerations for Staging Turbines

There are a few minimum physical port characteristics that are necessary to stage offshore wind farm development. Based on a review of various European projects and available information from manufacturers, as well as discussions with potential U.S. offshore wind developers, the desirable (minimum) characteristics include:

1. Minimum 24-ft depth of water at low tide;
2. Minimum 450-ft berth;
3. Minimum horizontal channel clearance to harbor of 130 ft;
4. No restriction or air draft limitation on vertical clearance (in anticipation of a future need to transport fully assembled turbines to the installation site); and
5. Minimal distance in open water to project site (see Table 5 above).

Harborside

Water depth requirements relate directly to the vessel type, draft and function. The minimum water depth at mean low water applies to both the navigation channel and the berth. The deepest draft vessel used for transporting offshore wind components sets the navigation channel depth criteria. The vessel length of the largest expected vessel establishes the berth length. With visits from import vessels and transport/installation vessels overlapping, multiple berths or longer berths become more desirable.

Horizontal channel clearance not only depends on vessel beam, but also on component overhang during transport to the installation site. Unobstructed vertical clearance is highly recommended because of likely deployment methods in the future. Turbine manufacturers expect 197 foot-tall tower sections to be transported to the installation site in the upright position. If the turbines are fully assembled for transport, then the nacelle and blade would add significantly to this height. Furthermore, various installation tasks require jack up vessels (for stability at the site), the retracted legs of which would be in the 'up' position. There may be methods to work around vertical obstructions, such as placing a connector pin in the legs or utilizing a hydraulic leg that compresses within itself; however, these methods could add significant expense and complication. The salient point, however, is that vertical obstructions will limit assembly, transport, and vessel options. Further detail on vessel drafts and obstruction clearances can be found in Appendix A of the Final Report.

Landside

The port facility must have adequate laydown space for delivery, storage and assembly of turbine components. Among developers, manufacturers, and European staging facilities the estimated area varied widely, but a minimum of 10 acres was required with a 15- to 25-acre area desirable. If all components of a large development (110 turbines) were to be fully stored on land prior to installation, including both assembly and foundation

components, the area required would be about 200 acres. In general, the logistics of manufacturing, assembly, and installation would not require all elements to be on the ground at one time.

To maximize the use of construction equipment, vessels and crews, turbine suppliers require storage based on two factors: (1) having a supply of turbine components ready for assembly and deployment; and (2) having an additional area ready for instances where weather precludes deployment to the installation site while import vessels continue to deliver components to the staging port. While turbine assembly continues, the newly arrived unassembled turbine components need storage. Based on a manufacturer's recommendations, and assuming storage of 20 or more turbines at any one time, the minimum space needed in this scenario is about 8.5 acres.

An additional accommodation for interior storage and/or fabrication space is necessary at the port facility. Developers, contractors and manufacturers also have a strong preference for office space on site. Worker accommodations at the staging port or on a 'hotel' ship at the installation site did not emerge as a major factor in port selection decisions. Construction workers at the installation site would travel on fast crew transport vessels from the construction site to various landing points.

Based on the weight of many of the components, the lay down space may require very high load bearing ground or deck capacity. Using a simple "footprint" analysis, these loads can reach well over 2,000 pounds per square foot (psf). As with many of the facility needs, the deck/ground capacity issue can be accommodated by using certain types of equipment or by placing "load spreading" mats or slabs. Various cranes and other types of material handling equipment will be needed, but it is anticipated that the fabrication or erection contractor would provide these items. Table 7 summarizes the key crane requirements for two representative turbines (a Siemens 3.6 MW Offshore Turbine and a REPower 5 MW Offshore Turbine) and typical monopile components. Load capacity was not used as a criterion to short list the ports, but rather was an issue further analyzed in the engineering review of the shortlisted facilities.

Table 7 Crane Requirements for 3.6 MW and 5 MW Turbines and Associated Monopile Foundations
(Source: The Glosten Associates 2009)

	Siemens 3.6 MW	REPower 5 MW	Monopiles
Max Pick Weight*	Nacelle: 125 mt (138 tons)	Nacelle: 290 mt (320 tons)	180 – 455 mt (200 – 500 tons)
Max Pick Height**	80 m (260 ')	85 – 95 m (280'-310')	Less than 30 m (100')

* 1 ton = 2000 pounds = 0.908 metric ton (mt);
** height above calm sea surface

As noise levels at operating landside facilities must comply with applicable regulatory limits, this factor was not viewed as a discriminator for short-listing ports.

Physical Considerations for Staging Foundation Transport

Harborside criteria established for turbine transport do not apply to foundations, which can be transported flat on barges. Barge transport of foundations would not have the same height, draft or clearance requirements as that for turbine transport; however, the foundation installation vessel may have similar characteristics as the turbine installation vessel. If the foundation installation jack-up vessel is at the construction site and barges are used to transport foundations to the site, then there would be more options for the staging facility. Port facilities with insufficient navigation access for turbine staging potentially could stage foundation deployment.

The staging requirements for foundations depend upon the stage of assembly phase upon arrival and the size and type of foundation. The size of the foundation depends on the size of the assembled turbine and tower, transition piece and blades and the maximum wind load imposed on them, as well as the geotechnical conditions and water depth at the installation site. The staging facility will need landside areas for loading and unloading, storage, and potentially for assembly of foundations components. Fully assembled foundations require a storage area. This area needs to be larger if foundation assembly is required. Shipping unassembled steel bars maximizes cargo space, which would lower shipping costs by reducing the number of shipments. However, the shipping of unassembled foundations or foundation parts would involve the labor cost associated with bar welding. In this case, foundation staging becomes a financial decision.

Manufacturing and Assembly Requirements

Monopile foundation manufacturing utilizes a series of specialized machines not currently available on the East Coast of the U. S. The industry views this potential market as lucrative enough to consider opening facilities in anticipation of offshore wind energy development. However, the investment risk remains similar to that of turbine and purpose-built vessel construction. Until the demand is sufficient for a profitable return on investment, monopiles for East Coast offshore wind farms will have to be manufactured elsewhere. However, a phased approach can reduce the initial investment risk. Monopile pieces can be shipped to a staging port as ‘cans’, or basically smaller sections of rolled steel. At the staging port the ‘cans’ would be welded together to form the monopiles.

3.7 Key Parameters: Rail and Highway Access

The ability to move component parts via rail is determined by rail corridor track curvatures, component weights, and loaded height on the rail car. In general, the weight and length of the proposed units can be handled by the nationwide system. Components can be designed to be transported on the national rail system. They can be broken down to insure they do not exceed rail system limitations on weight or clearance.

Overweight and large roadway shipment units are limited by State permitting requirements. Infrastructure is also considered in permit approvals including limitations from overhead utilities, road lighting, road curvatures and intersections.

Highway and rail delivery modes appear unlikely options for turbine or foundation delivery to port facilities. However, highway and rail access is desirable for delivery of related products such as aggregate for scour protection and component pieces.

4 Evaluation Criteria

The information presented in Section 3 above was reviewed to identify a broad set of direct requirements and highly desirable characteristics of port facilities relative to supporting offshore wind farm construction and operation. These requirements and characteristics were distilled down into a smaller set of criteria to be used more efficiently in the comparative evaluation of the candidate ports. In the distillation process, the Team distinguished a "hard" physical requirement that must be met from a "soft" requirement that reflects preferences and advantages that are more subjective to the developer. Two sets of "hard" requirements were identified for comparing the ports: (1) those related to harbor access (referred to as the 1st Tier Criteria) and (2) those required to meet specific developer and turbine supplier needs (referred to as the 2nd Tier Criteria). Also, a set of "soft" criteria was developed that is somewhat more subjective, but nevertheless allows ports to be distinguished from one another.

4.1 1st Tier Hard Criteria

The 1st Tier Hard Criteria identified relative to harbor access were:

- Sheltered harbor;
- Unobstructed vertical (overhead) clearance (e.g. no bridges);
- Minimum horizontal clearance greater than approximately 130 feet;
- Minimum low tide navigational channel depth of 24 feet; and
- 24 hour/day and 7 days/week operational availability; and
- Exclusive use of the staging facility.

Physical parameters for marine vessels to access a harbor emerge as critical criteria, while rail and trucking access were believed to be present or easily attainable at the set of ports being compared. Staging ports need to accommodate vessels shipping and handling the large components used for commercial scale wind farms. The greatest vessel draft (depth) establishes the criteria for the shipping or navigation channel depth. The widest vessel beam (width) along with the method of component transport, which may involve overhang, establishes horizontal clearances. Along with vessel height, the options for method of transport also contribute to vertical clearance criteria. The potential for bad weather interruptions and the need to maximize labor and equipment availability makes a sheltered harbor an essential criterion.

Implications of the cost of contractor mobilization, vessel and equipment usage combined with weather and seasonal limitations on the construction window result in developers and turbine suppliers requiring a port facility that allows operations 24 hours a day, seven days a week. Given that optimal operations would entail moving large components around the clock, the staging port must also provide exclusive use of the staging facility.

4.2 2nd Tier Hard Criteria

The 2nd Tier Hard Criteria identified relative to the port facilities were:

- Minimum berth length of approximately 450 feet;
- Minimum berth water depth of 24 feet;
- Lay down storage and assembly area larger than 10 acres;
- Proximity to likely offshore wind farm site.

Water depth at the berth must be sufficient to accommodate industry vessel drafts or must be attainable through routine dredging. Additionally, vessel length and the number of vessels operating simultaneously establish the parameters needed for length of the berth. The size of the backland area landside of the bulkhead for storage and assembly of the turbine components and the ability to handle the loads of the components and construction equipment are significant criteria. Proximity of the port to the construction site can affect operational logistics, risks, and costs. The distance from a port facility to wind farm sites, therefore, has significance, but becomes secondary to the parameters discussed above.

4.3 Soft Criteria

Soft criteria parameters, as noted above, are other port area attributes that may attract developers to consider one port over another. The Soft Criteria identified were:

- Workforce availability;
- Education and training facilities;
- Political climate/community acceptance; and
- Regulatory considerations.

The location of education or training facilities and work force availability, including various skilled labor trades, as well as political climate and potential regulatory requirements, are factors that could influence port selection.

4.4 Screening and Short-Listing the Ports

The larger set of ports considered in this study were analyzed using these criteria. Those that did not meet minimum thresholds were eliminated from further consideration by the Team. Section 5 provides an overview of Massachusetts ports that could support staging and installation of offshore wind farms, as well as other regional ports that could meet the assembly, construction, and/or servicing needs of the offshore wind industry. Section 6 describes the process that resulted in the two short-listed ports, the South Terminal in the Port of New Bedford Renewable Energy Marine Park and Dry Dock #4 in the Port of Boston Marine Industrial Park.

5 Inventory of Massachusetts Ports

5.1 Overview of Massachusetts Port Facilities and Characteristics

Our initial inventory of port facilities in Massachusetts is based on: (1) an assessment of each of the state's 11 Designated Port Areas (DPAs) and (2) a review of other properties or areas in other states currently used for industrial maritime activities. DPAs in Massachusetts include Gloucester Inner Harbor, Beverly Harbor, Salem Harbor, Lynn, Mystic River, East Boston, Chelsea Creek, South Boston, Weymouth Fore River, New Bedford-Fairhaven, and Mount Hope Bay. *Comparison of Selected Northeast Ports for Potential Handling of Wind Power Offshore Energy Installations* (MARPRO Associates International 2009) and *Road and Rail Access Ports of Massachusetts* (MARPRO Associates International 2009), Appendices F and G in the Final Report, provide more detail on these ports and modes of transportation to and from the ports.

Massachusetts has a number of ports that, because of their existing or proposed marine terminals, geographic location and surrounding market area, already have substantive marine activity including a wide range of freight activity. In addition to the ports discussed below, the Team contacted the municipalities of Beverly, Chelsea, Lynn, Everett, Somerset, Weymouth, and Falmouth to obtain information about their port facilities; those ports were removed from further consideration based on navigational and/or landside constraints. All of the ports in Massachusetts have some rail access; however, waterfront access to particular facilities varies in each area. No ports in Massachusetts have access to second generation rail with vertical clearances over 19 feet. From north to south, brief summaries of these six remaining Massachusetts candidate ports and their potential to stage a Representative Offshore Wind Energy Installation (ROWEI) 130-turbine wind farm follow:

Gloucester has sufficient land area for a new marine facility, a readily available skilled work force, and rail access. However, water depth and lateral clearance are the most significant constraints for the inner harbor at the Port of Gloucester and the rail service is limited to commuter rail. Turbine installation vessels should be able to navigate the Port of Gloucester, but turbine import vessels most likely would not be able to call at this port.

Salem has limited potential for substantial expanded marine industrial activities, with limited access by road and rail. The port's only deepwater commercial terminal is situated at the head of the harbor; however, the terminal is primarily used to supply the needs of the Salem Power Plant. There is also very little area outside of Salem Terminal where large vessels could handle offshore wind turbine or foundation components. The immediate area in and around the waterfront is congested and has poor capacity for high volume roadway traffic flow.

Boston is the largest and most prominent freight port in the Commonwealth. It has the most diversified port mix and handles the largest volume of containers in New England and the second largest amount of petroleum cargo. However, direct rail connections to the waterfront need improvements. The Boston Redevelopment Authority has 'shovel ready' plans to expand the existing rail from the Boston Marine Industrial Park to the North Jetty and to Dry Dock #4. Roadways are congested and direct street connections between the terminal and highway connectors are a weak link in the landside transportation connection. There are areas within the Port that might be available to support offshore wind deployment, but issues of height due to FAA requirements associated with Logan Airport must be considered.

Fore River (Ship Yard) has served as the Central Receiving Point for new car delivery to local dealerships. The site, which features rail and roadway access, is currently undergoing an initial planning process to determine all

potential uses for the site including marine-related, residential, retail, office, and entertainment. The entrance to the Shipyard is restricted by the Fore River Bridge which has a 175 ft vertical clearance and a 175 ft horizontal clearance.

Fall River (Mount Hope Bay) is an active niche port serving several international markets. The port has the potential for industrial expansion at the State Pier, which has available storage and land area for operations but already is used for both industrial and tourism based activities. The State Pier can only handle small cargo ships and most of the critical infrastructure in the port is aging and in need of considerable repairs and improvements. Vertical clearance is the most significant navigational constraint for the Port of Fall River. The Braga Bridge and Mt. Hope Bridge each impose a height restriction of 135 feet. The port has good highway access and a rail corridor which requires additional infrastructure improvements.

New Bedford is an active freight seaport and a major logistical connection for agricultural products entering the New England market. Highway connections are good; the port would benefit from expanded and improved rail connections to meet freight needs. A request for TIGER Grant money was submitted to extend the rail line to the State Pier, but further rail extension to the proposed South Terminal expansion area is unrealistic. The port has sufficient deep water access for the size and type of vessel common to most break bulk and project cargo and has property available for expansion.

The Final Report contains more detailed data on each port, including location, facilities, harbor profile, advantages, disadvantages, and potential.

Other East Coast ports, including Portland Harbor (Maine), Portsmouth Harbor (New Hampshire), the Port of Providence (Rhode Island), the Port of Davisville (Rhode Island), New Haven Harbor (Connecticut), the Port of New York and New Jersey, the Port of Philadelphia (Pennsylvania), the Port of Baltimore (Maryland), the Port of Wilmington (Delaware), and the Port of Virginia, were evaluated to assess their suitability to support offshore wind projects. The Final Report describes these port facilities in more detail.

5.2 U.S. East and Gulf Coast Shipyard Construction and Repair Capacity

Declining domestic demand has reduced the number of available U.S. shipyards for new construction or repair of large vessels. In addition, existing shipyards' inability to comply with recent regulations, such as the "Jones Act," which requires vessels in domestic service or operating in domestic waters to be built and serviced in U.S. yards, has resulted in a decrease in yards available for new large vessel construction or repair. This is particularly evident in the Northeast U.S., including New England, where the ability to handle large tonnage vessels, such as deep water cargo ships, tankers, and specialty vessels for offshore delivery and support, has dramatically decreased in the past few decades. In other parts of the world, new shipyard capacity has replaced capacity lost in the U.S. However, in spite of the fact that the number of shipyards in the U.S. that handle large tonnage vessels has declined, the number of smaller yards has remained stable.

Specialty wind farm vessels have unique construction and servicing requirements. Smaller service vessels, including offshore supply vessels, tugs and barges, can be readily adapted to service offshore wind farm equipment. Installation and service vessels operating within the territorial waters of the U.S. most likely would be subject to the Jones Act, but import/delivery vessels could be foreign flagged if their operation is limited to equipment delivery at a single U.S. port. *US East and Gulf Coast Shipyard Construction and Repair Capacity and*

Availability Offshore Wind Turbine Delivery and Service Vessels (MARPRO Associates International 2009) provides detailed information on construction capacity and repair capacity at U.S. shipyards

Construction Demand and Capacity

In recent years, the U.S. small vessel construction industry has demonstrated growth. Stricter regulations and replacement requirements have increased demand for new small vessel construction, with the tug and barge industry emerging as the largest demand market. Tug and barge construction is of particular importance as the servicing and installation of offshore wind turbines may well be handled by tugs and barges in large part because of their lower operational costs.

Tank barge construction has had a major impact on shipyard capacity and delivery times. There are some new shipyards emerging to meet this demand for tank barges, and the major yards are ramping up production capabilities in anticipation of more tank barge orders. Increasing demand for tank barge construction is using up ship construction capacity in the yards where offshore specialty vessel construction could take place.

Shipyard Availability

The number of shipyards that have current capacity for large specialty vessel construction is limited within the U.S. Of the 350 active vessel construction companies in the U.S., only 52 have a history of significant vessel construction on the Atlantic and Gulf Coasts. A limited number are capable of handling large specialty vessels due to size limitations, but a number of them could handle smaller specialty vessels. The Final Report provides a list of the yards that can build offshore wind-related vessels on the Atlantic and Gulf Coasts.

Vessel Repair Capacity

In the Northeast, many of the yards have compressed operations due to increasing environmental concerns and gentrification of industrial areas. A number of yards confine activities to repair only and have refocused their efforts on small craft such as ferries, yachts and similar commercial watercraft. In the Gulf of Mexico, a number of the yards still have not fully restored operations to pre-Katrina levels primarily due to a shortage of qualified personnel and infrastructure that yards have chosen not to replace. Nevertheless, the Gulf of Mexico region still has the highest percentage of multi-purpose construction and repair yards in the country. Orders for vessels are averaging a 6 to 12 months delay to begin construction; however, there are several smaller yards in the Northeast and the Gulf that have no backlogs and can manage new vessel orders. Very few of these shipyards have multiple vessel capacity, and backlogs do not extend beyond 2011. Most of the shipyards on the Atlantic Coast that build vessels also have repair capacity; however, there is limited repair capacity in New England.

Shipyard Construction and Repair Capacity on the Atlantic Coast

Large vessel construction and small vessel construction most likely would be handled by different shipyards. Yard capacity varies from region to region. The industry can meet the demand for a phased-in cycle of new vessels on a limited basis up to approximately three units per year using multiple yards in various regions of the U.S. New England has new construction capability limited to smaller vessels, but has adequate repair capability for smaller vessels and some capacity for larger vessels. A developer should anticipate an 18-month lead time for design, contracting, construction and delivery of small vessels and up to 24 months for larger vessels. These projections along with the restrictions of the Jones Act will dictate time lines associated with the earliest offshore projects.

6 Short-Listing Ports for Further Evaluation

Based on the evaluation criteria developed for this report and further analysis, the Team concluded that the ports of New Bedford and Boston have the greatest potential to support the assembly and installation phases of planned and prospective offshore wind energy projects.

Of the Massachusetts ports described in Section 5 above, six ports (located in DPAs) were selected for further consideration. The Massachusetts Port Criteria Evaluation Matrix (see Table 8) clearly demonstrates how these six Massachusetts ports compare against each other with respect to the established "hard" criteria. Application of the identified "soft" criteria was reserved for only the short-listed ports.

Table 8 Massachusetts Port Criteria Analysis Matrix

PARAMETERS		PORTS					
Criteria	Recommended Values/Ranges	Boston	New Bedford	Fall River	Gloucester	Salem	Fore River
First Tier Harbor Navigational Access							
Protected Harbor	Sheltered from Weather Conditions	Yes	Yes	Yes	Yes	Yes	Yes
Shipping Vessel Channel Depth	Minimum 7.3 m (24')	12.2 – 13.7 m (40' - 45')	9.1 m (30')	10.7 m (40')	4.9 – 5.8 m (16' - 19')	9.4 m (31')	9.8 m (32')
Overhead Clearance	No Vertical Obstruction (NVO)	NVO, but FAA approval required	NVO	41 m (135')	NVO	NVO	53.3 m (175')
Horizontal Clearance	40 m (130') (beam plus overhang)	131 m (430')	45.7 m (150')	122 m (400')	61 m (200')	85.3 m (280')	53.3 m (175')
24/7 Operational Ability	24/7 operations	Yes	Yes	Yes	No	Yes	Yes
Exclusive Use of Port Facility	Ability to Offer Exclusive Use	Yes	Yes	No	No	No	Yes
Comments				Mt Hope Bridge height restriction	Navigational constraints	Salem DPA in full use by power plant	Fore River Bridge height restriction
Second Tier Port Facilities							
Berth Length	Minimum 138 m (450')	549 m (1,800')	488 m (1,600')	189 m (620')	427 m (1,400')	177 m (580')	244 m (800')
Shipping Vessel Water Depth	Minimum 7.3 m (24')	12.2 – 13.7 m (40' - 45')	9.1 m (30')	10.7 m (40')	4.9 – 5.8 m (16' - 19')	9.4 m (31')	9.8 m (32')
Total Wharf and Yard Upland Area	4.0 ha (10 ac)	5.7 – 6.9 ha (14-17 ac)	4.0+ ha (10+ ac)	2.8 ha (7.0 ac)	3.2 ha (7.8 ac)	NA	44.9 ha (111 ac)
Rail Access	Rail Access	Limited	Limited	Yes	Yes	No	Yes
Highway Access	Highway Access	Yes	Yes	Yes	Yes	No	No
Comments				State Pier can only accommodate small cargo vessels.	Limited adaptable area	Insufficient work area; additional focus on tourism	Multiple berths/ rough estimate; plans for mixed-use waterfront development

Legend NVO = No vertical obstruction
= Criteria not met
NA = Not available for ROWEI staging

6.1 Evaluation of Massachusetts Ports against Hard Criteria

Protected Harbor: All of the six Massachusetts ports are in protected harbors. The hurricane barrier in New Bedford adds an additional layer of protection for portside operations during inclement weather.

Shipping Channel Depth and Overhead Clearance: Navigational access to Fall River and Fore River is constrained by the overhead height restrictions of existing bridges, and the Port of Gloucester does not meet the minimum shipping channel depth of 24 feet (indicated by the shaded cells in Table 8). On the other hand, the shipping channels of New Bedford and Boston Harbors meet the minimum depth criterion. Both New Bedford and Boston Harbor have unobstructed overhead clearance. There are no vertical obstructions, such as bridges and/or power lines, which would prohibit offshore wind component delivery and installation vessels, including jack-up vessels, from accessing either harbor. However, FAA approval may be required in Boston Harbor because of the harbor's proximity to Logan International Airport.

Horizontal Clearance: None of the selected ports are restricted by horizontal (lateral) clearances less than 130 feet. The minimum horizontal clearance criterion eliminated facilities in New Bedford upstream of the New Bedford-Fairhaven Bridge (92 feet of lateral clearance). However, the South Terminal at New Bedford Harbor is downstream of the New Bedford-Fairhaven Bridge and upstream of the Hurricane Barrier.

24/7 Operational Ability and Exclusive Use of Port Facility: All ports being evaluated, with the exception of the Port of Gloucester, can operate round the clock and all year. The Ports of Gloucester and Salem also did not have the ability to offer exclusive use of their facilities.

Berth Length and Shipping Vessel Water Depth: The established berth length and channel and portside depth criteria reflect minimum requirements for accommodating berthing operations. The Port of Gloucester failed to meet the depth criterion. All other ports had sufficient length and depth.

Total Wharf and Yard Upland Area: Landside (upland) port facilities provide storage, staging and assembly work areas to facilitate offshore wind farm installation. The Team determined that given sufficient land area, storage, assembly, and load bearing issues could be addressed with improvements to the port. Neither Fall River, Gloucester, or Salem has sufficient adaptable space for the work area required to support offshore wind farm staging.

Rail Access: None of the Massachusetts ports evaluated for this study has second generation rail access. Existing rail lines could be used primarily for delivery of aggregate and related products rather than turbine or foundation components. Whereas Fall River, Gloucester, and Fore River have existing freight rail lines to the waterfront, Boston and New Bedford currently have limited rail access, and Salem has none. Boston and New Bedford submitted TIGER applications for rail extensions; however, the New Bedford rail line will connect the existing tracks to the State Pier, but not the South Terminal.

Highway Access: Road connections are important for transport of ancillary material and equipment, as well as personnel. Neither Salem Harbor nor the Fore River Shipyard has sufficient highway access due to roadway congestion. There is no highway access within the City of Salem; the nearest highway access to Route 128 is along Route 114 in neighboring Peabody. Fore River's access to the interstate highway network is via Route 3, a limited-access roadway that is about two miles away from the Shipyard.

Based on the hard criteria established in Section 4 and displayed in Table 8 above, the ports of Fall River, Gloucester, Salem, and Fore River fell short of the minimum requirements for navigational access and port infrastructure to support offshore wind development activities. The ports of New Bedford and Boston emerged as the two short-listed ports.

6.2 Engineering Cost Analysis of Port Upgrades for Short-Listed Ports

New Bedford Harbor

The project team identified two possible locations in New Bedford Harbor that could reasonably meet the established criteria, the South Terminal area and the State Pier facility. However, both facilities failed to meet all of the criteria and demonstrated deficiencies in their current physical condition. Cost estimates for facility improvements were provided by Childs Engineering Corporation.

South Terminal

The City of New Bedford has identified the expansion of the South Terminal as a major priority. The City applied for a TIGER grant to support its proposed plan to expand the berth by approximately 800 ft and dredge a 30-ft deep channel from the main channel to the new berth. The new facility would have significant backland load bearing capacity. There are between 14 and 20 acres of land adjacent to the berth. The cost of the new bulkhead and dredging is estimated to be approximately $20 million (see the cost analysis conducted for this study, which resulted in a comparable estimate), in the Final Report. Additional improvements, including paving, utilities and site equipment (such as a large crane), could add an additional $15 million and would provide a “future” life as a general cargo or container handling facility.

State Pier

The State Pier is constructed with a solid fill core surrounded by a marginal wharf. This construction is typical of many old New England ports. The wharf structure is in poor condition according to recent inspections and must be replaced or modified. The rebuild options include a repair/replace in kind, which would result in a reasonably low deck capacity. The preferred alternative would replace the wharf structure with solid fill behind a new bulkhead. A recent study suggested rebuild costs could be from about $12.1 million to more than $52 million. The immediate backland is about 7 to 8 acres, which does not meet the landside criterion. This lack of space would probably result in material rehandling costs, which would not occur on a larger site. The State Pier would best be described as a short-term, but an immediately available site. This solution also anticipates that no repairs would be performed and a larger land-based unloading crane would be employed inshore of the wharf structure.

The Team believes the preferred option for New Bedford is the South Terminal. The site is the most ideal in terms of meeting the port criteria established by the Team. The expansion cost is similar to the repair cost for the State Pier. However, the South Terminal has significantly more laydown area, which offsets any potential cost savings from the State Pier repair/rebuild.

Boston Harbor

The project Team identified three possible locations in Boston Harbor that reasonably meet the criteria. These include the North Jetty, Dry Dock #4 in the Boston Marine Industrial Park, and the former Coastal Oil site adjacent to Conley Terminal on the Reserved Channel. None of these facilities meet all of the defined criteria and each has

deficiencies in their current physical conditions. . Cost estimates for facility improvements were provided by Childs Engineering Corporation.

North Jetty

The North Jetty is constructed with a solid fill core supported by a steel sheet pile bulkhead fronted by a marginal wharf. The marginal wharf is comprised of steel h-piles supporting a reinforced concrete super structure. The wharf structure is in poor condition and must be replaced or rebuilt to be a viable staging port. The immediate backland is about 7 to 8 acres, with an additional 10 or more acres immediately adjacent. A 1996 design suggested rebuild costs (in 2010 dollars) would be about $15 million.

The City included the North Jetty rebuild in its application for a TIGER grant. Although the rebuild will correct current deficiencies, it will still leave the wharf with a deck capacity of 600 lb/ft^2, which is insufficient for unit loading under certain situations.

Dry Dock #4

The existing Dry Dock is in very poor condition but could be rebuilt to provide a two sided solid fill pier with almost 1800 feet of berthing. The Dry Dock would be filled with gravel and new steel sheet piling would be installed around the deteriorated bulkheads. The estimated cost to rebuild the site is approximately $20 million. This site would provide nominal laydown space, but the solid fill pier has very high ground capacity and the berth has “bonus” length. Although the site does not have covered space, there are such structures and warehouses in the Boston Marine Industrial Park.

Dry Dock #4 could accommodate the staging of offshore development with improvements at a reasonable cost. However, from a planning perspective, there are potential permitting issues associated with these improvements due to Dry Dock #4’s proximity to Logan Airport. Tall equipment, such as cranes, likely will require approvals from the FAA. Furthermore, the potential wind farm locations are much closer to New Bedford Harbor than Boston Harbor.

Coastal Oil Site

The Massachusetts Port Authority owns the former Coastal Oil terminal in South Boston. The site is approximately 35 acres and has a former oil tanker berth with a water depth in excess of 34 ft. The facility would require a new steel sheet pile bulkhead to be adequate for laydown. It also would need re-grading and paving to “cap” any environmental issues. The estimated cost for the repairs is approximately $20 million. The site does not have any covered space, and there is no covered space on the immediately adjacent parcel.

The Team believes the preferred option for Boston is Dry Dock #4, which meets most of the established criteria. The rebuild cost is similar to the cost of repairs for the North Jetty; however, Dry Dock #4 has significantly more berthing space, which offsets any potential repair/rebuild cost savings.

6.3 Soft Criteria

The Team examined education and training needs required to support the offshore wind energy industry in Massachusetts. We conducted interviews with various educational and training institutions to ascertain the status of programs designed specifically for the offshore wind industry.

More effective state support for renewable energy has encouraged investment in workforce training at many levels. The Massachusetts Maritime Academy is nationally known for its mariner training programs, and a regional Marine Renewable Energy Center (MREC) at the University of Massachusetts/ Dartmouth joins the resources of some of the region's leading academic institutions, community colleges, and trade unions to coordinate and plan appropriate training for this emerging industry. Several public and private academic institutions, including the Amherst and Dartmouth campuses of the University of Massachusetts system, Harvard, the Massachusetts Institute of Technology (MIT), the Massachusetts Maritime Academy, and the Woods Hole Oceanographic Institute (WHOI), have examined and will continue to explore numerous issues related to offshore renewable energy generation, including energy production, facility design, transmission issues, and maritime training.

Understanding that the ocean energy industry is evolving within the U.S. and specifically New England, MREC joined forces with Cape Wind, Resolute Marine Energy, Ocean Renewable Power Company, Local 56 Pile Drivers Union, the Massachusetts Maritime Academy, the New Bedford Department of Workforce Development, and the community college system to form the Ocean Energy Training Task Force. The Task Force meets regularly to identify issues and to discuss how best to meet the needs of offshore energy developers, and draws on the expertise of each of its members. Significant education and training programs related to offshore renewable energy are being developed, and some are currently being offered.

Massachusetts trade unions have been very active in identifying offshore energy construction needs and developing appropriate training courses. For example, Local 56 of the Massachusetts Pile Drivers is a statewide organization that has been at the forefront of training workers for offshore energy. Similarly, the International Brotherhood of Electrical Workers ("IBEW") Local 103 has demonstrated its leadership in support and training for the renewable energy industry through the erection of a publicly visible 100kW wind turbine and the installation of a 5.4kW solar roof at its headquarters and Apprentice Training Facility in Dorchester.

With the state aggressively supporting the development of offshore wind energy through policy initiatives, expertise, and financial support, and with academic institutions and trade unions actively developing and improving training opportunities, Massachusetts is well situated to respond to a wide variety of technologies used to harness renewable energy in offshore waters. Perhaps more relevant, Massachusetts is in a unique position to successfully meet the needs of the offshore wind energy industry because of its broad geographic coverage, extensive research facilities, in-depth industry expertise, and a trained, flexible work force.

Soft criteria also include regulatory considerations. Port facility upgrades may require Massachusetts environmental review if the project meets or exceeds certain thresholds established by the Massachusetts Environmental Policy Act (MEPA). A variety of federal, state and local permits also may be required, including, but not limited to:

- U.S. Army Corps of Engineers (USACE) Section 10 permit for structures in navigable waters,
- USACE Section 404 permit for discharge of dredged or fill materials into waters of the U.S.,
- Federal Aviation Administration (FAA) Determination of No Hazard,
- Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) permit,

- EPA Air Emission permit,
- Massachusetts Coastal Zone Management (MCZM) Consistency Determination,
- Massachusetts Department of Environmental Protection (MDEP) Water Quality Certificate,
- MDEP Chapter 91 License for work in, under, or over flowed or filled tidelands,
- Massachusetts Department of Transportation (MDOT) Oversize/overweight vehicle permit,
- Conservation Commission Order of Conditions for alteration of "any bank, fresh water wetland, coastal wetland, beach, dune, flat, marsh, meadow, or swamp bordering on the ocean or on any estuary (a broad mouth of a river into which the tide flows.), creek, river, stream, pond, or lake, or any land under said waters or any land subject to tidal action, coastal storm flowage, or flooding," and
- Local zoning, building or utility permits.

7 Economic and Tax Effects of Construction and Operating Expenditures

Based on the criteria and cost analysis presented above, the South Terminal in the Port of New Bedford Renewable Energy Marine Park (Figure 8) and Dry Dock #4 in the Port of Boston Marine Industrial Park (Figure 9) were selected for further evaluation and discussion. More detailed information about how the team arrived at this conclusion can be found in *Economic Effects of Offshore Wind Energy and Related Construction and Operating Expenditures* (FXM Associates 2009), which is Appendix J of the Final Report.

Figure 8 New Bedford Harbor

Figure 9 Boston Harbor

This section summarizes the economic and fiscal effects of construction and operation of these ports to support a ROWEI 130-turbine wind farm.

Construction and Operating Periods- Economic Effects

The measures of economic effects are:

- Output – which comprises business sales less the costs of materials and equipment produced outside Massachusetts;
- Employment – the full-time equivalent jobs expected to be held by Massachusetts residents;
- Income – the payroll and self-employment earnings of households; and
- GDP (Gross Domestic Product) – which measures the value added to the Massachusetts economy in terms of labor and proprietors' income, corporate profits, dividends, interest, rent and taxes.

Expenditures for the assembly and installation of the ROWEI are estimated to increase business output by more than $457 million in Massachusetts over the anticipated three-year projected period of construction, provide over 1700 person years of employment, and generate nearly $163 million in household income statewide. Construction of the Port of Boston Dry Dock #4 facility is expected to increase business output by nearly $19 million, provide over 100 person years of employment and $9.1 million of additional household income in Suffolk County. Construction of the South Terminal project in New Bedford Harbor is estimated to expand business output by more than $44 million, provide nearly 400 person years of employment, and $19.2 million of additional household income in Bristol County over its estimated 2-year construction period.

Each year following completion of the ROWEI, expenditures for servicing and maintaining the wind turbines is estimated to expand business output in Massachusetts by $27.5 million, provide 110 permanent jobs, and generate $6.8 million in household income annually. New Bedford South Terminal port facility operations, specifically the handling, storage, and transshipment of prospective new container, break bulk, and bulk cargoes, are estimated to expand business output in Bristol County by $15.6 million, provide over 130 permanent jobs, and generate $5.9 million in additional household income each year.

Construction and Operating Periods- Fiscal Effects

The total direct, indirect, and induced tax effects correspond to the economic effects discussed above. Local taxes include property and excise taxes paid to municipalities by workers in the jobs generated by construction and operating period employment effects, as well as property and other local taxes paid by the companies employing those individuals. State taxes include income and sales taxes paid by individuals as well as payroll, income, and other taxes paid by the companies that employ those individuals.

During the assembly and installation phase of the ROWEI nearly $9 million in taxes to municipalities throughout Massachusetts are estimated to be attributable to the direct, indirect and induced economic effects discussed above over the projected 3-year construction period of the ROWEI. More than $10 million in taxes paid to the Commonwealth of Massachusetts over this 3- year period would be attributable to the economic effects of construction, and almost $46 million in federal taxes would be stimulated by the construction period economic effects. Some additional local, state, and federal taxes would be generated by activity at the staging ports. Servicing and maintaining the exemplified offshore wind energy project would generate an annually recurring amount of $390,000 in municipal tax receipts throughout Massachusetts, $433,000 in state taxes annually, and $2.2 million in new federal taxes each year.

As can be seen from these projections, the economic and fiscal effects of port development and use are roughly comparable for both ports. Therefore, the selection of one port over the other is more likely to be determined by the balancing of the soft criteria.

8 Summary and Recommendation

In Massachusetts there are no port facilities ready for turnkey support of offshore wind energy facility development at this point in time. However, the opportunity to attract offshore wind deployment exists if appropriate investment in relevant port upgrades is made. The Team performed a side-by-side comparison of the two short-listed ports and has concluded that the expansion of the South Terminal in the Port of New Bedford represents the best opportunity for a Massachusetts port facility to accommodate assembly and installation of offshore wind energy projects. Table 9 summarizes the comparison between Dry Dock #4 at the Port of Boston and the South Terminal at the Port of New Bedford relative to the hard and soft evaluation criteria developed for this study.

Table 9 Comparison of the Two Short-Listed Ports

	Port of Boston Dry Dock #4	New Bedford Harbor South Terminal	Comments
1st TIER HARD CRITERIA			
Protected Harbor	●	●	Both ports are acceptable.
Shipping Channel Depth	●	●	Both ports are acceptable.
Overhead Clearance	●	●	Both ports are acceptable.
Horizontal Clearance	●	●	Both ports are acceptable.
24/7 Operational Ability	●	●	Both ports are acceptable.
Exclusive Use of Port Facility	●	●	Both ports are acceptable.
2nd TIER HARD CRITERIA			
Berth Length	●	●	Both ports are acceptable.
Shipping Vessel Water Depth	●	●	Both ports are acceptable.
Total Wharf and Yard Upland Area	●	●	Both ports are acceptable.
Rail Access	●	⊙	BRA has a design to expand rail access to Dry Dock #4. New Bedford submitted TIGER application to extend rail line to State Pier, but not to South Terminal.
Highway Access	⊙	●	Despite adequate highway access to port area, the Boston Haul Road currently has vertical/ horizontal limitations; however, a new freight roadway system is planned.
Proximity to Construction Site	⊙	●	South Terminal is closer to the planned offshore sites than Dry Dock #4 (as of January 2010).
SOFT CRITERIA			
Workforce Availability	●	●	
Education and Training Facilities	⊙	⊙	In U.S., education and training programs are now being developed for nascent offshore renewable energy industry. Given extensive research facilities, in-depth industry expertise, and trained, flexible work force, Massachusetts will be able to successfully meet education and training needs.

Table 9 Comparison of the Two Short-Listed Ports (continued)

	Port of Boston Dry Dock #4	New Bedford Harbor South Terminal	Comments
Political Climate/Community Acceptance	⊙	●	New Bedford has a Green Port initiative in place, has done study on South Terminal development, has submitted various proposals for infrastructure grants, and has the goal of strengthening its economy by focusing on renewable energy such as offshore wind. The BRA has emphasized a commitment to sustainability but may not be focused on the seaport. Dry Dock #4 currently has a tenant.
Regulatory Considerations	⊙	●	Required permits could include, but are not limited to: MEPA review; CZM Consistency Certification; USACE Section 404 and 10 Permits, FAA approval; Chapter 91 License/Permit; Water Quality Certification; NPDES Permit; Order of Conditions. Certain circumstances at each port may eliminate or reduce regulatory process. FAA approval at Dry Dock #4 may be problematic.

LEGEND:
- ● Acceptable / Most Supportive of offshore wind farm development
- ⊙ Qualified Acceptability / Degree of Supportiveness of offshore wind farm development
- ○ Unacceptable / Not Supportive of offshore wind farm development

With specifically targeted upgrades, both Dry Dock #4 and the South Terminal would have acceptable harbor access and the navigational parameters needed to accommodate wind turbine delivery and installation vessels (1st Tier Hard Criteria), and both ports are capable of accommodating the assembly and installation of offshore wind turbines and foundations (2nd Tier Hard Criteria). An exception at the present time may be Rail and Highway Access; however, it is unlikely that rail and highway delivery would be used for large offshore wind generation components due to weight and dimensional constraints. Based on available public information as of January 2010 regarding proposed offshore wind farm sites, the South Terminal at New Bedford Harbor is closer to these potential installation sites than is Dry Dock #4 at the Port of Boston.

With regard to soft criteria, the City of New Bedford is moving ahead with its goal of strengthening its economy by focusing on supporting the renewable energy industry at the Port of New Bedford. In Boston, the BRA has demonstrated its commitment to environmental sustainability by launching a pilot program to help small businesses improve their energy efficiency and sustainability practices. However, this initiative is not focused specifically on the seaport.

Another soft criterion, Regulatory Considerations, involves the environmental review and permitting processes that may be required for the port projects. Work in and around Massachusetts waters may require state environmental review, if one or more MEPA review thresholds is met or exceeded. Installing and operating an offshore wind farm also will require obtaining a number of federal, state, and local permits. MEPA review of a major port improvements project could take between six months and one year, depending on the type of MEPA review triggered and the amount and intensity of political and community support for the project. Permitting such

a project may require a similar amount of time, depending on (among other factors) the complexities of the project, the number and length of public comment periods, and the duration of mitigation negotiations that must be conducted between the project proponent and the regulatory agencies.

Since some of the environmental impacts of the South Terminal site have already been assessed by the Commonwealth as part of the Superfund cleanup response for the site, MEPA review of the South Terminal expansion may be streamlined or limited. The permits required for this project are contingent on its projected impacts on regulated resources. The dredging component of the port expansion project may be covered under the State Enhanced Remedy CAD Cell Dredge Disposal Approval for the cleanup. However, other permits/approvals may still be required.

If the required upgrades to Dry Dock #4 at the Port of Boston can be defined as maintenance activities authorized under existing permits, the regulatory process may be circumvented or limited. Nevertheless, because of its proximity to Logan International Airport, obtaining FAA approval of crane heights at Dry Dock #4 could prove to be a lengthy process. The level of MEPA review required for the Dry Dock #4 improvements also would depend on which thresholds were exceeded, if any. Other permits/approvals may be required.

Determining the permits applicable to either project was not within the scope of this report. Additional research would be required to verify which, if any, permits would be needed. If support of renewable energy and immediate job creation are important political objectives in the Commonwealth, it would follow that the port project with the shortest regulatory track and the greatest political and community support would emerge as the best project to meet those objectives.

Based on this comprehensive side-by-side comparison, the Team has concluded that the expansion of the South Terminal at the Port of New Bedford represents the best opportunity for a Massachusetts port facility to accommodate assembly and installation of offshore wind energy projects. In addition, the new facility will provide sufficient economic and fiscal benefits to Bristol County and the Commonwealth of Massachusetts to make the investment attractive and worthwhile. This recommendation does not preclude and should not discourage possible future upgrades to Dry Dock #4 at the Port of Boston to service the offshore wind industry as the level of offshore construction activities increases and other roles become available. However, at this time, the political support, advanced planning effort, proximity to offshore sites, and absence of FAA obstacles have led the Team to recommend the South Terminal expansion.

9 Path Forward – Preliminary South Terminal Business Plan

As a follow-up to the recommendation presented above, the Team prepared portions of a preliminary business plan for an offshore wind deployment/multi-use cargo facility at the South Terminal at the Port of New Bedford (see *Port of New Bedford South Terminal Business Plan* [FXM Associates 2009], which is Appendix K of the Final Report). Specific objectives of this effort were to (1) identify potential cargoes and revenues for the South Terminal facility, in addition to those associated with a ROWEI; (2) identify an appropriate governance model for multi-use terminal ownership and management; and (3) prepare a preliminary terminal business plan with operating pro forma. In addition to the economic and tax effects discussed in Section 7 above, the Team made the following findings:

- A new multi-use cargo facility at the South Terminal site represents the best option in the Port of New Bedford for servicing offshore wind energy development projects during the assembly and installation phases;
- A new multi-use port facility at the South Terminal can capture container, break bulk, and bulk cargoes not now handled in New Bedford or other Massachusetts ports and can generate income for the Harbor Development Commission (HDC) with or without offshore wind energy development projects;
- The optimal model for governance of a new facility at the South Terminal would be ownership by the New Bedford HDC, which would lease offshore wind energy staging and other cargo handling, storage, and related facility operations to a qualified private operator.
- Capital costs for a new multi-use port facility at the South Terminal are estimated to total about $44 million (in 2009 dollars). Approximately $32 million of this total investment is for land acquisition, bulkhead construction and dredging, buildings and site improvements to support offshore wind energy installation projects, with an additional $5 million in capital expenditures ($37 million total) functionally necessary to attract and support new bulk, break bulk, and container cargoes;
- Average net operating income to the HDC from the fully-developed South Terminal port facility would total about $1.2 million per year during a projected 3-year ROWEI and about $622,000 per year with full cargo operations. Potential operating revenues and costs are shown in Table 10; and
- The South Terminal can cover all of its operating expenses during the ROWEI use of the facility and annually thereafter based on non-ROWEI cargo operations. Approximately $12 million of the capital costs for the new facility can be supported by annual net operating income combined with income from the 3-year ROWEI use of the facility. This leaves $32 million of debt that would require financing from other sources.

These components of a “path forward” relative to the development of an expanded multi-use cargo facility at the South Terminal address the key findings of a preliminary business plan for port expansion. This study demonstrated that the South Terminal at the Port of New Bedford meets the necessary requirements and possesses a number of the advantageous characteristics needed to successfully support a developing offshore commercial wind farm. The study also identified some areas where this port could make modifications and improvements to its harbor or wharf facilities that would further enhance the port’s ability

to support offshore wind energy. The path forward would continue the process outlined here, more fully develop the elements that were addressed in this study, and consider other important aspects of the port's development that were not considered to be critical to the scope of this study.

Table 10 South Terminal Operating Income and Expenses

SOUTH TERMINAL OPERATING INCOME & EXPENSES	Offshore Wind Installation	Non-Offshore Wind Cargoes
Average Year Annual Operating Income		
Offshore Wind Energy Development (ROWEI)	$ 1,500,000	
Container Service		$ 280,000
Break Bulk Program		$ 240,000
Bulk Cargo		$ 432,500
Total Non-ROWEI Cargo		$ 952,500
Average Year Annual Operating Expenses		
HDC Personnel (contract/lessee management)	$ 140,000	$ 140,000
HDC Capital/maintenance reserve at 20% income	$ 190,500	$ 190,500
Average Year Annual Expenses	$ 330,500	$ 330,500
Average Year NET Operating Income		
Offshore Wind Energy Development (ROWEI)	$ 1,169,500	
Total Non-ROWEI Cargo		$ 622,000

Source: FXM Associates, RECON™ Input Output Model

Section 9 of the Final Report provides details of the Team's findings as a result of our preliminary business plan for a multi-use cargo facility at the South Terminal at the Port of New Bedford.

These components of a "path forward" relative to the development of an expanded multi-use cargo facility at the South Terminal address only a few of the key elements of a comprehensive, fully developed business plan for port expansion. Additional information relative to these components can be found in the Final Report and a number of its appendices. This study demonstrated that the South Terminal at the Port of New Bedford meets the necessary requirements and possesses a number of the advantageous characteristics needed to successfully support a developing offshore commercial wind farm. The study also identified some areas where this port could make modifications and improvements to its harbor or wharf facilities that would further enhance the port's ability to support offshore wind energy. The path forward would continue the process outlined here, more fully develop the elements that were addressed in this study, and consider other important aspects of the port's development that were not considered to be critical to the scope of this study.

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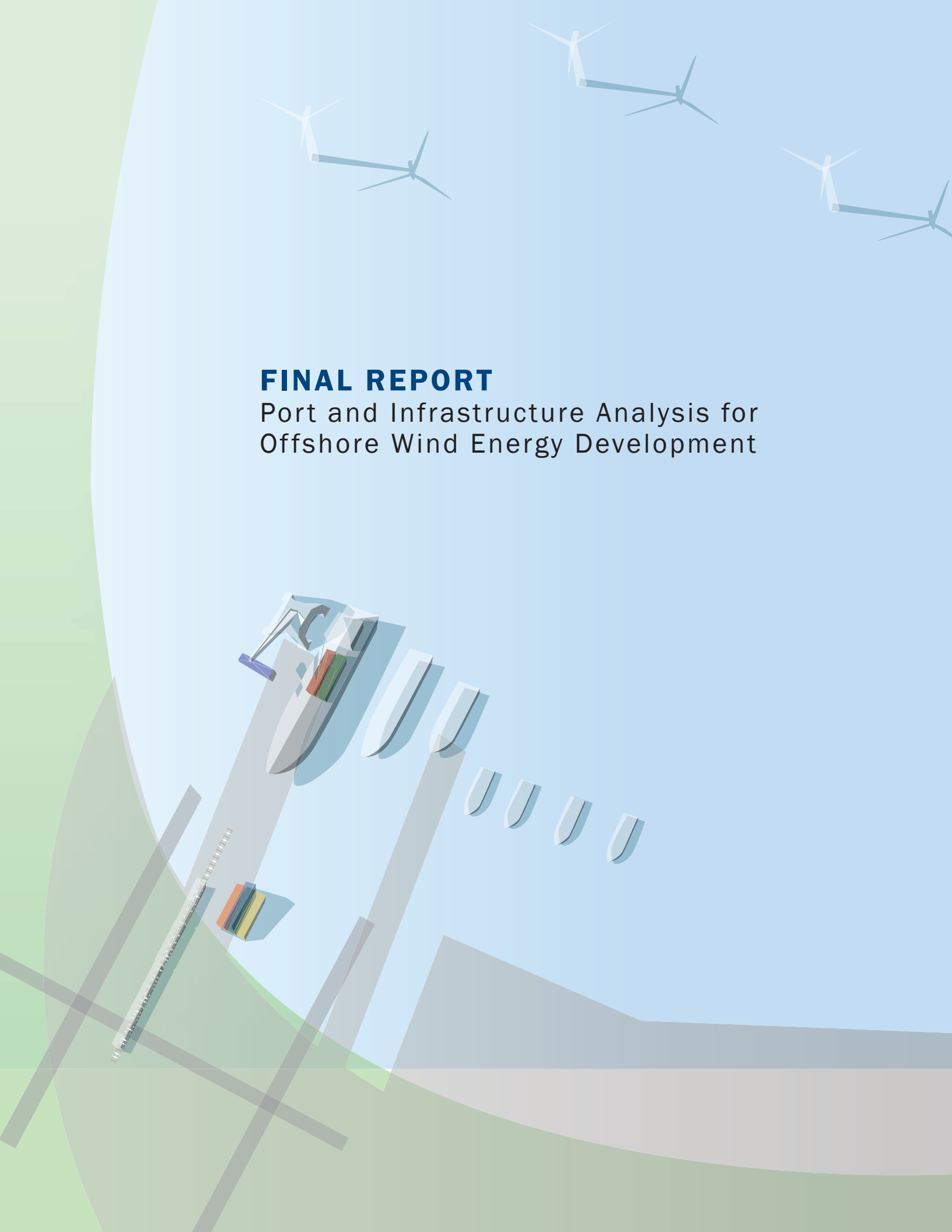
FINAL REPORT

Port and Infrastructure Analysis for Offshore Wind Energy Development



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ACRONYMS AND ABBREVIATIONS

ABS	American Bureau of Shipping
ATR	above the rail
BRA	Boston Redevelopment Authority
DP	dynamic-positioning
DPA	Designated Port Area
Dry Dock #4	Boston Port Facility
EOEEA	Energy and Environmental Affairs
EEZ	Exclusive Economic Zone
EMEC	European Marine Energy Center
EPA	Environmental Protection Agency
EWEA	European Wind Energy Association
FAA	Federal Aviation Administration
GDP	Gross Domestic Product
GW	gigawatt
HDC	Harbor Development Commission
hp	horsepower
H_S	wave height
Hz	hertz
IBEW	International Brotherhood of Electrical Workers
km	kilometers
KTH	KTH Royal Institute of Technology (Sweden)
kV	kilovolt
kW	kilowatt
LNB	Lighted Whistle Buoy N
LNG	liquified natural gas
LOA	length overall
M	million
MassDEP	Massachusetts Department of Environmental Protection
Massport	Massachusetts Port Authority
MBTA	Massachusetts Bay Transportation Authority
MBTA	Massachusetts Bay Transportation Authority
MCEC	Mass Clean Energy Center
MCZM	Massachusetts Coastal Zone Management
MDOT	Massachusetts Department of Transportation
MEPA	Massachusetts Environmental Policy Act
MIT	Massachusetts Institute of Technology
MLW	mean low water
MMA	Massachusetts Maritime Academy
MMS	Minerals Management Service
MREC	Marine Renewable Energy Center
MRET	Massachusetts Renewable Energy Trust
mt	metric tons
MTC	Massachusetts Technology Collaborative
MW	megawatt

NaREC	New and Renewable Energy Center
NEG	Northeast Gateway
NOREIZ	National Offshore Renewable Energy Innovation Zone
NPDES	National Pollutant Discharge Elimination System
nm	Nautical mile
O&M	Operation and Maintenance
OCS	Outer Continental Shelf
OMP	Ocean Management Plan
OSHA	Occupational Safety and Hazards Administration
OSV	offshore support vessel
P&W	Providence & Worcester
PCB	polychlorinated biphenyls
psf	pounds/square foot
QDC	Quonset Development Corporation
RFI	Requests for Information
RFP	Request for Proposal
ROWEI	Representative Offshore Wind Energy Installation
RWU	Roger Williams University
SMAST	School for Marine Science and Technology
TEU	twenty-foot equivalent units
TIGER	Transportation Investment Generating Economic Recovery
TIVs	turbine installation vessels
U.S.	United States
UMaine	University of Maine
UMass/Dartmouth	University of Massachusetts/Dartmouth
UNH	University of New Hampshire
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
V AC	volts alternating current
V_W	average wind speed
WHOI	Woods Hole Oceanographic Institution
WTTC	Wind Technology Testing Center

1.0 INTRODUCTION

In January, 2009, the Massachusetts Clean Energy Center (MCEC)[1] acting in concert with Massachusetts Renewable Energy Trust (MRET) issued a Request for Proposals for Port and Support Infrastructure Analysis for Offshore Energy Development No. 2009-IId-01 ("RFP"). This RFP outlined the context for this study, stating "Offshore wind energy is the most viable option available for developing utility-scale renewable energy electric generating facilities to the densely populated states along the Eastern seaboard in the near term." In the context of a widespread, growing interest in reversing the climate effects of fossil fuels and federal and state incentive policies and programs that promote growth in the use of renewables for electricity generation, the overall goal of this study is to identify port facilities in Massachusetts that have the ability to support offshore renewable energy development. This study also seeks to explore the feasibility and economic development potential, as well as the economic impacts, of planned and potential port and landside facilities at short-listed Massachusetts ports.

For this first-of-its-kind study of infrastructure to support offshore wind, the MCEC contracted with Tetra Tech EC, Inc. and a team of specialized professionals (collectively "the Team") to analyze the ability of Massachusetts port facilities to support the anticipated development of commercial scale offshore wind generation facilities along the northeast Atlantic coast. This study provides the results of the Team's efforts to analyze and integrate information from current industry participants, such as potential developers and turbine manufacturers, with information from ongoing European offshore energy developments (see Figure 1-1) to characterize the parameters of ports and associated facilities. These parameters for existing ports and facilities in Massachusetts were then compared to determine which facilities may best be able to support commercial offshore wind development and what specific improvements may be required to better support offshore wind and other marine energy projects. This report presents the approach, analysis, and findings of the study that resulted in the identification of two Massachusetts port facilities, which were subsequently evaluated in more depth. This report further provides the MCEC with recommendations for direct port investment in support of offshore wind energy generation.

Marine-based wind energy generation has the advantage as a renewable energy source because it is closer to commercial deployment than other marine-based renewable energy generation approaches, such as tidal and wave technology. Furthermore, the large scale of equipment and components required for wind generation (i.e. the blades, foundations and towers) means that if a port could physically support offshore wind generation it also would likely meet the requirements for other offshore renewable energy technologies. Therefore, this study focused primarily on how Massachusetts ports can meet the requirements of offshore wind energy generation projects. The needs related to transmission line construction and interconnection to the power grid are outside the scope of this report. Integrating power from offshore wind generation into the Massachusetts power transmission system raises other issues of concern in terms of who should invest in such construction and how the costs of such investments might be allocated. A separate report administered by MCEC analyzes the issues related to offshore wind power transmission investment. *The 2009 Summary Report - Strategic*

[1] The RFPs for both studies were originally advertised and the selection process administered by the Massachusetts Technology Collaborative (MTC), MTC subsequently transferred staff and the project to the MCEC.

Options for Investments in Transmission in Support of Offshore Wind Development in Massachusetts provides an analysis of the transmission investment issues (The Analysis Group, Inc. et al. 2009).

Figure 1-1 Installed Nysted Windfarm
(Source: A2Sea)

The focus of this analysis was to specifically determine:

- The required characteristics of a port facility to be considered an appropriate staging point for construction of offshore wind generation facilities;
- The primary differences between traditional port facility features and those required for delivery, storage, handling and deployment of very large wind farm components;
- The potential impacts to ports resulting from purpose-built installation and component delivery vessels (now and in the future);
- The set of port facilities in the Commonwealth of Massachusetts that could be upgraded or expanded to be considered relevant staging points;
- The estimated costs for required upgrades or expansions at the ports that are the leading candidates for supporting offshore wind development; and
- The ability of facility improvements to attract wind farm developers, government investment, and ensure an appropriate return on investment.

2.0 BACKGROUND AND CONTEXT

The Northeast Atlantic coastal waters, including those off Massachusetts, are a national focus of the offshore wind industry. This interest is based primarily on the relatively shallow water of the continental shelf, favorable wind characteristics, and relative proximity to large electrical load centers. Those Massachusetts ports possessing the facilities, land area, and navigational characteristics necessary for the assembly and transport of wind turbine components, and for long-term operation and maintenance needs, are well-positioned to serve the emerging demands of the offshore wind energy industry.

In April 2009 the United States (U.S.) Department of the Interior, Minerals Management Service (MMS) issued final regulations on "Renewable Energy and Alternative Uses of Existing Facilities on the Outer Continental Shelf (Final Rule)," establishing a process for leasing submerged lands for renewable energy projects on the Outer Continental Shelf (OCS). The Final Rule outlines the requirements for limited (short-term – for testing and characterizing) and commercial (long-term – for power generation) leases and the bidding and regulatory procedures a wind developer must follow to obtain rights to a wind farm development site on the OCS. Current and future activities of potential developers of offshore wind generation facilities and MMS's Final Rule provide a context within which to evaluate offshore wind energy development in waters off the Massachusetts Coast and along the Atlantic Seaboard.

The Massachusetts Ocean Management Plan (OMP) was released on January 4, 2010 by the Commonwealth's Executive Office of Energy and Environmental Affairs (EEA OMP 2009). The OMP establishes new protections for environmental resources and sets parameters for the development of community-scale and commercial-scale offshore wind energy and other infrastructure in Commonwealth waters.

OMP identifies and designates areas such as:

- Prohibited Areas;
- Renewable Energy Areas; and
- Multi-Use Areas.

Offshore Wind Energy Areas identified in the OMP are specifically designated for commercial wind energy facilities, which are defined as eleven or more turbines. This designation recognizes the need to provide opportunity for renewable energy generation at a meaningful scale while being cognizant of potential environmental impacts. Two Offshore Wind Energy Areas were identified in the OMP based on the presence of suitable wind resource and water depth and the absence of conflict with other uses or sensitive resources. These areas are located approximately one nautical mile offshore in the vicinity of the southern end of the Elizabeth Islands and southwest of Nomans Land Island (located just southwest of Martha's Vineyard) (see Figure 2-1). These areas could accommodate approximately 150 3.6 MW turbines at full build-out (EOEEA OMP pp 2-2). Commercial scale wind farms are restricted to the Wind Energy Areas.

This study considered the OMP Offshore Wind Energy Areas as possible offshore wind construction sites. Distances to the these sites (measured in nautical miles) were calculated from the ports of Gloucester, Salem, Boston, Fore River, Fall River, and New Bedford, MA, and from Portland, ME, Quonset/Davisville, RI, Philadelphia, PA, New York, NY, and Norfolk, VA.

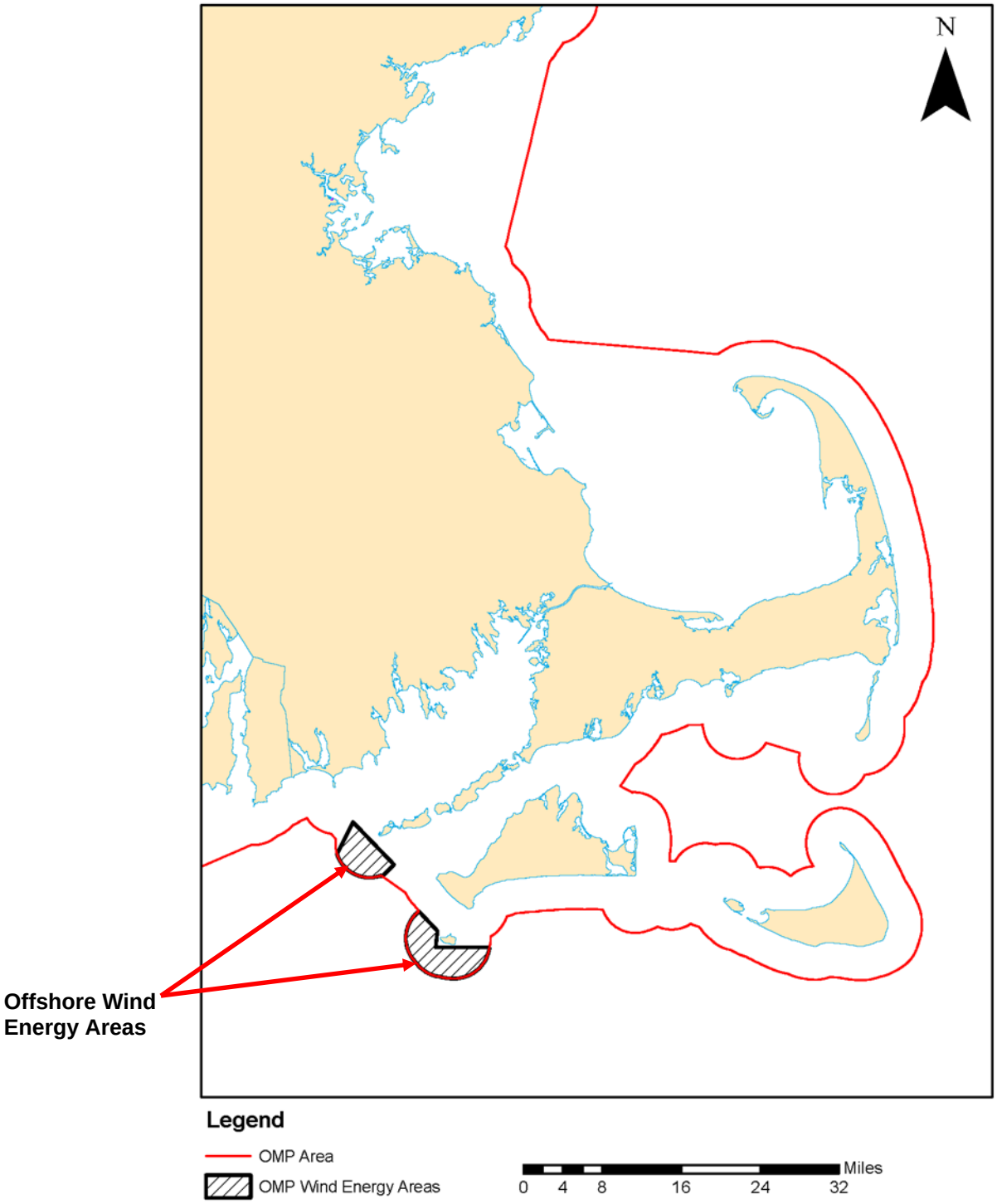


Figure 2-1 Massachusetts Ocean Management Plan Offshore Wind Energy Areas
(Source: Based on EOEEA OMP, 2009)

The Team recognized the potential for these sites to be developed for offshore wind energy and the implications of that development on the demand for port and offshore support infrastructure. Massachusetts ports with the potential to satisfy the infrastructure requirements of the offshore wind energy industry would be well-positioned to support construction in the Offshore Wind Energy Areas.

Developers have yet to construct any offshore wind commercial generation facilities in U.S. waters (so far only meteorological towers have been constructed to test wind characteristics). As such, U.S. port facilities have yet to stage construction for any offshore wind farms. Other than the import of landside wind farm components, East Coast ports have no experience in handling, storing or assembling offshore wind generation components. Therefore, the experience gained at European ports that are servicing offshore wind facilities and at the U.S. Gulf of Mexico ports staging construction for the offshore petroleum industry have formed the basis of the Team's analysis of the port infrastructure needed to support the East Coast offshore wind industry. The combination of massive turbine component sizes, the trend toward production of much larger components (such as blades with lengths approaching 90 meters), and the expectation that stateside developers intend to skip pilot scale offshore facilities (which would present learning opportunities) in favor of full-scale production projects, complicates the Commonwealth's preparation for this new industry. The physical constraints in and around Massachusetts ports also suggest that their ability to cost-effectively stage such offshore construction will take both physical improvements and attentive problem solving.

The Team's approach to addressing these questions and specific needs of the industry involved a sequential approach that considered:

- Assessment of Offshore Wind Energy Port Infrastructure Needs – Section 3.0 of this study provides an overview of the current industry, site conditions along the eastern U.S. coastline, and vessel characteristics and constraints for transport, installation and maintenance of offshore wind farms.
- Evaluation Criteria – Section 4.0 describes the "hard" and "soft" criteria that were used to evaluate specific port facilities. These criteria include port utilization, staging requirements, navigational access, distance to the installation site, and rail/highway access for component delivery to port facilities.
- Inventory of Port Facilities in the Commonwealth of Massachusetts – Section 5.0 outlines the general characteristics of six port facilities, along with their navigational constraints and rail and highway access. This section also provides the distance from each port to a Representative Offshore Wind Energy Installation (ROWEI) 130-turbine wind farm.
- Short-listing of Ports for Further Evaluation – Section 6.0 considers the information developed in the needs assessment and the port inventory against the evaluation criteria to short-list two ports for further consideration. Section 6.0 also includes an engineering cost analysis of port upgrades, along with a description of educational, training and research organizations that will support offshore wind energy activities in the Commonwealth of Massachusetts.
- Economic and Tax Effects of Construction and Operating Expenditures – Section 7 provides an analysis of the estimated costs for required upgrades at the two short-listed

ports, in addition to the economic and tax effects of these activities on the Commonwealth.

- Summary and Recommendation – Section 8.0 contains a summary of the Team's findings, along with a final comparison of the two short-listed port facilities to the evaluation criteria developed for this study.
- Path Forward – Section 9.0 contains a preliminary high-level business plan for the recommended port and suggests a path forward that would consider other important aspects of the port's development that were not within the scope of this study.
- References cited in this report are listed in Section 10.0.

3.0 ASSESSMENT OF OFFSHORE WIND ENERGY PORT INFRASTRUCTURE NEEDS

Any port to be used to support offshore wind energy development must be capable of meeting a number of physical and operational requirements relating to navigation, scale of operations, physical space, ancillary support facilities, and other considerations. This section reviews a number of the key features and characteristics of commercial offshore wind farm development to provide a basis for identifying port criteria that would be either required or highly desirable for supporting that development.

3.1 Introduction to Offshore Wind Energy and Similar Offshore Activities

This section provides a description of wind farm components and the issues affecting their delivery and deployment, explains how other offshore industries offer insight into navigational and port requirements for offshore wind development, discusses proposed offshore wind projects and site conditions at these locations, provides an overview of currently available vessels, and discusses the constraints and requirements of installation, import and auxiliary vessels for the offshore wind industry.

3.1.1 Wind Farm Components

A wind energy system transforms the kinetic energy of the wind into mechanical or electrical energy that can be harnessed for practical use. Mechanical energy is most commonly used for pumping water in rural or remote locations. The "farm windmill" that is still seen in many rural areas of the United States is a wind-powered water pumper, but it can also be used for many other purposes (e.g., grinding grain, sawing). If this mechanical energy is converted into electricity, the machine is called a wind turbine. Wind electric turbines generate electricity for homes and businesses and for sale to utilities. Wind turbines, including offshore wind turbines, primarily consist of a rotor (with blades on a hub), a nacelle, tower, foundation and associated electronic equipment (see Figure 3-1). Most turbines use a three-bladed rotor that is connected through the drive train to the electrical generator that is housed in the nacelle. Offshore wind turbines are typically designed to also have extra space within the nacelle to allow access for maintenance. The associated electronic controls for the system are housed in the nacelle and in land-based control buildings. The cylindrical, self-supporting, tubular tower supports the turbine rotor and nacelle

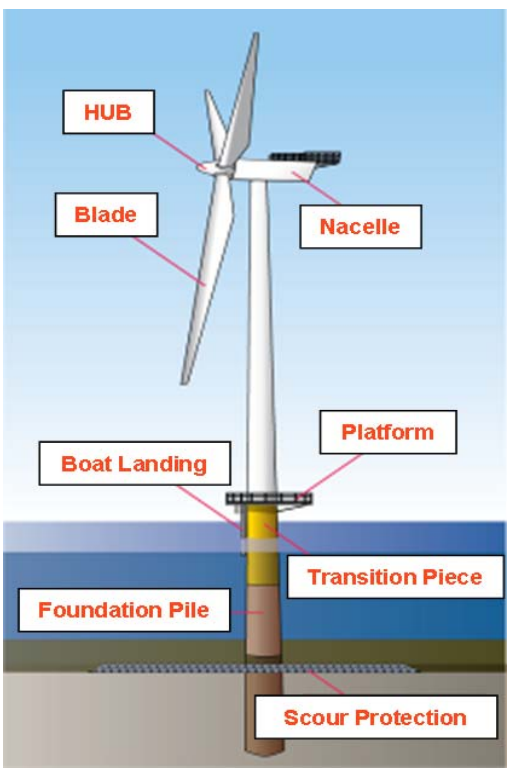


Figure 3-1 Primary Components of an Offshore Wind Turbine

and provides a sheltered interior for the cables, controls and access way to the nacelle for maintenance and repairs. Cabling, transformers, interconnect equipment, meteorological tower(s) and a substation are the major components of any wind turbine system.

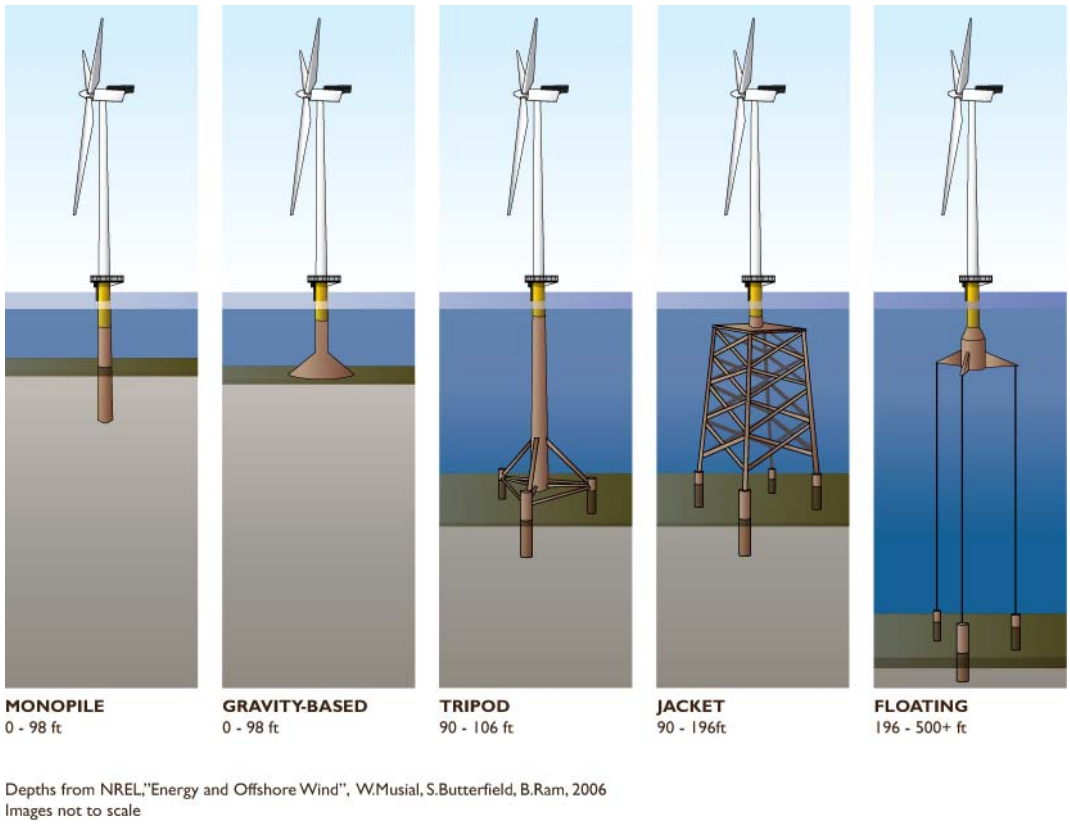


Figure 3-2 Types of Foundation for Offshore Wind Turbines

Offshore wind turbines are typically larger than 2 MW in generation capacity. In this analysis, the Team primarily considered 3 MW or 3.6 MW turbines, as these are typical of the sizes currently being deployed. Examples of current wind turbines in this range are the Siemens SWT-3.6-107 turbine or the Vestas V112- 3MW turbine. Next generation wind turbines for offshore deployment are expected to be 5 MW and greater in generation capacity. For the purposes of this study, a minimum offshore wind turbine array was assumed to consist of ten turbines. Based upon discussions with current and future developers, larger wind farm arrays would include from 60 to 150 turbines.

Various foundation structures can be used depending on the seabed geology, the wind/wave conditions, and water depth at the site. Four standard types of offshore foundations currently exist (see Figure 3-2):

- Monopile;
- Gravity-Based;
- Multi-Leg – Tripod or Jacket; and
- Floating.

Offshore wind turbine foundation technology is being developed from the structural foundations already in use in the offshore petroleum extraction industry, mainly from the use of piles and jackets. Foundation types for wind turbines, like those for petroleum extraction platforms, vary with water depth. Deep water technologies, such as semi-submersible and floating platform technologies, are being explored for the offshore wind industry. However, there are differences between stabilization requirements of petroleum extraction platforms and wind turbine towers. The torque of the rotating blades of the wind turbine adds stresses to the structure that makes stabilization of the towers more difficult. The State of Maine is currently exploring the use of floating turbine technology, specifically because of the deep water environment found in the Gulf of Maine (University of Maine 2009). The technology used for floating and anchored structures has also been modified for new applications such as deep water Liquified Natural Gas (LNG) ports. Anchor systems used for petroleum and LNG ports could also be adapted for wind turbine applications to anchor structures at deep water locations.

Monopiles and gravity-based foundations are commonly used in shallow and transitional water with water depths up to 30 m (approximately 100 feet). Monopile foundations are already heavily used for offshore wind in Europe. Multi-pile configurations with broader bases (such as tripods, jackets, mono-towers and suction bucket support structures) are used where the water depth is 30 to 60 m (approximately 100 to 200 feet). Floating turbines may also become feasible long-term options for deep water installations greater than 60 m (200 feet) deep. These floating turbine structures would be secured to the ocean floor via guy wires, mooring lines, or taut tension legs, which in turn would be fastened to anchors or gravity-based platforms (U.S. Offshore Wind Collaborative 2009, p. 23). Most of the developers that were interviewed for this study indicated they plan to use monopiles for their currently proposed offshore wind farms. Deepwater Wind expects to use monopiles for its proposed Block Island project and jacket foundations for its deeper water Delaware project (Tetra Tech 2009b).

3.1.2 Wind Turbine Component Delivery and Deployment

Port infrastructure needs must consider the logistics of wind turbine component delivery and the sequencing of installation and construction. Currently, very few offshore wind turbine components are manufactured in the United States that are large enough to be suitable for a commercial offshore wind farm. Manufacturers such as Siemens, Vestas, REPower, Clipper Windpower, General Electric, Northern Power Systems, and Multibrid currently have little incentive to set up large scale offshore wind component manufacturing operations for offshore wind development in the United States until developers are ready to place orders and purchase components at a rate that makes the investment in a manufacturing facility financially attractive (based on Team discussions with manufacturers). Vestas has been manufacturing turbine components in the United States for a couple of years and Siemens and General Electric (among other manufacturers) are currently developing domestic manufacturing facilities for wind turbine towers and nacelles in the United States. Some of these new facilities are expected to become operational in 2010. However, these facilities will likely focus on landside wind turbines in the short term. Therefore, this analysis assumes that almost all turbine component pieces for offshore wind farms in the near future would be delivered from Europe.

Suppliers are expected to ship turbines from European manufacturing facilities to the United States in pieces (e.g., the tower sections, nacelle, hub, individual blades) aboard crane-equipped, open hatch cargo vessels. These vessels can accommodate from four to eight

nacelles, hubs and blades depending on the size of the vessel. As discussed below, the draft and beam of these vessels (referred to as either “import” or “delivery” vessels) must be accommodated by the port of delivery (see Appendix A, Vessel Requirements for Offshore Wind Farm Construction and Maintenance). Component pieces will be offloaded upon delivery and placed in a storage area. Onshore assembly of the wind turbine parts makes use of land-based cranes. Turbine towers have their own storage requirements, including specific brackets. Components assembled in the storage areas require relocation to the quayside via onshore cranes before being loaded onto the installation vessels. Smaller wind turbine component pieces and scour protection aggregate could be transported to the onshore staging port by existing rail or truck.

Foundations and transition pieces tend to be manufactured and delivered separately from the turbines, although there may be some manufacturing overlap with towers. Currently, no operational rolled steel manufacturing facilities on the East Coast have been identified that operate at a scale suitable for manufacturing the towers and structural components of a large offshore wind farm. Since there is still no firm demand for the number and size of monopiles necessary to construct a 60 to 150 turbine wind farm, foundation suppliers also currently lack an incentive to set up an East Coast production facility.

Existing domestic and foreign suppliers may deliver foundations fully assembled or ready for assembly. These sections or components would be shipped in on large barges from the Gulf of Mexico, Europe, or Malaysia. A potential scenario for monopiles delivery would include shipping ‘cans’ or small sections of rolled steel from Europe or Malaysia by barge for welding and assembly at the staging port. Similarly, jacket piles could be shipped as unassembled bars from the Gulf of Mexico to the staging port to save cargo space and be welded together there. Depending on the type and point of origin, foundation component delivery to the staging port may also be performed using more traditional means such as barges, rail, or truck. Rail and truck options are limited to bulk concrete components, or sectional pieces such as iron bars or flat sheets of steel. Fully assembled foundations have dimensions that preclude their delivery by rail and truck.

Developers do not necessarily have to stage foundations for offshore deployment out of the same port that is staging the turbine construction. The value of the convenience of utilizing a common port or port facility generally would not outweigh the cost savings associated with improved logistics, less assembly, and minimizing storage space and handling needs. Barges may also be used conveniently for foundation storage in certain situations. Foundations can be delivered and/or stored on barges fully assembled, then tugged out to the installation site with less handling.

Ample storage at the staging port is needed to support routine logistical inventories. For example, Vestas stated that it would generally require 20 turbines to be assembled ahead of time before transport to the installation site (Tetra Tech EC 2009-2010a). Weather conditions at the installation site, including wind and wave action, can disrupt deployment and installation activity. This possibility translates into a need for increased landside storage capacity to accommodate a backlog of turbine and foundation component deliveries.

3.1.3 General Sequence of Offshore Construction and Installation Activities

The sequence of offshore wind turbine construction begins with the installation of foundations. Foundations can be delivered from the staging port by either a standard barge or on the installation vessel. A jack-up barge with a crane creates a stable work platform for the placement. Traditionally, these vessels have been used in the U.S. marine construction industry in contrast to the specialized vessels that are generally preferred by European offshore wind developers for turbine installation. The foundation installation methodology depends on the foundation type. Each type of foundation requires tailored installation procedures and equipment. A monopile foundation, for example, would require pile drivers (see Figure 3-3). After foundation installation, the transition piece gets attached to the top of the foundation, creating a level connection surface for the towers. See Appendix A for details of other installation types.

Figure 3-3 Monopile Being Driven In with a Menck Hammer
(Source: Courtesy of A2Sea)

As previously noted, turbine components may be transported from the staging port to the installation site in various stages of assembly. Appendix A provides more details of these transport options. In general, options are defined by the capabilities of the particular installation vessel, preferences of the manufacturer for sub-assembly configurations, and site-specific navigation constraints. On-site assembly cuts down on transport risk, but entails other risks associated with assembly in the marine environment. Similarly, assembly in the controlled environment of the staging port results in more difficult and risky transport, but less risk at the installation site. Turbine manufacturers and contractors with experience in European wind farm construction prefer to use specialized vessels for turbine installation. Installation vessels need to be stabilized (i.e., with jack-up

legs) and have a crane or cranes able to lift a 3 MW or 3.6 MW nacelle (which weighs approximately 135 to 185 metric tons (mt) (approximately 150 to 200 tons)) into place so that the blades can be attached. Delivering and installing fully assembled turbines on towers requires greater lifting capabilities of up to 275 mt (approximately 300 tons). It should be noted that a 5 MW nacelle, which may be employed in future systems, weighs 360 to 390 mt (approximately 400 to 430 tons).

The unassembled deployed wind turbine components are then assembled at the offshore site. The foundations are installed first, followed by the transition piece, the tower, the hub, and the nacelle. Next the blades are attached to the hub and the assembled rotor is hoisted and attached to the nacelle. However, as was noted, the turbine components also can be transported partially or fully assembled to the site.

Purpose-built vessels (vessels designed specifically for the offshore wind industry) for wind turbine installation are not currently available in the United States. Additionally, it is not expected that a U.S. purpose-built vessel will exist in time for the initial construction of utility scale wind generation facilities on the East Coast. Construction costs for these vessels range from $40 million ($40M) to $80M for tugged vessels and $150M to $250M for self-propelled vessels (see Appendix A). Like other offshore wind turbine components, the incentive to build a purpose-built installation vessel will depend on the amount of actual demand for their use and the potential return on such investment. Existing U.S. built jack-up vessels were built for the oil and gas industry and are less than optimal for offshore wind turbine installation, but they could be used for the initial deployments for East Coast offshore wind construction. However, the use of these existing vessels involves more risk and would require more installation time than purpose-built vessels. Rental rates for installation vessels are high and developers will attempt to maximize the utilization of the vessels when leased. This factor, along with the ever present possibility of weather and seasonal delays, indicates that the staging port must be available 24 hours per day and 7 days per week. Both the availability of wind turbine components and delivery and construction vessels are critical elements of the offshore wind energy supply chain.

3.1.4 Forecasts and Future Trends in Offshore Wind Energy Affecting Port Requirements

Proposed offshore wind projects in Europe and North America for 2015 are forecasted to reach 40 gigawatt (GW), of which the United States is expected to undertake projects totaling more than 2 GW (Infocast, U.S. Offshore Wind Report 2009, p. 6). The European Wind Energy Association (EWEA) has set a target for 2020 of 40 GW of offshore wind capacity. European offshore demand for 2010 is forecasted to reach 10 GW. This implies a European need for 30 GW or more over a 5-year span, which cannot be supported by current manufacturing capacity (EWEA, Oceans of Opportunity 2009, p. 44). However, the offshore wind industry will need to deploy upwards of 10,000 structures by 2020 to meet the minimum forecasted European demand. The current offshore manufacturing industry cannot deliver this number of structures due to insufficient capacity. (EWEA, Oceans of Opportunity 2009, p. 49). Additional manufacturing facilities and related industrial capacity are needed to meet the forecasted European and North American demand.

Offshore development costs depend significantly on the price of the substructures. For example, foundations represent 25 percent and 34 percent of total investment costs for 5 MW and 2 MW

systems installed in 25 m of water, respectively (Papalexandrou 2008, Economic analysis of offshore wind farms, KTH Royal Institute of Technology [Sweden] (KTH) School of Energy and Environment, in partnership with Ecofys). The economics of offshore wind development tend to favor larger machines (potentially in the range of 5 MW to 10 MW in the future, with less emphasis on design features (such as aesthetics and sound emission level) than for onshore wind turbines (EWEA, Oceans of Opportunity 2009, p. 44). Current technology suggests that increases in turbine power rating are commensurate with incremental increases in turbine size.

3.1.5 Similar Offshore Activities

Offshore wind generation is a new marine industry on the Eastern Seaboard and will be added into a region that has historically been heavily dependent on maritime industry and commerce. As a new industry, however, offshore wind will require specialized equipment, services and labor not currently available in any U.S. ports. Understanding what will be needed to support both short-term construction and long-term operational and maintenance activities involves learning from the recent experience of European offshore wind projects, as well as identifying similar services and activities already associated with existing marine industries here in the United States.

There are a number of marine industries currently in operation in the waters offshore of the United States, each with its own specialized port requirements. These industries include, but are not limited to, petroleum extraction, LNG off loading or storage, commercial shipping, and commercial fishing. Each marine industry is specialized, requiring differing shore-side support as well as different configurations for the appropriate offshore environment. However, comparing and contrasting the needs of these industries with European experience can increase our understanding of the port-related requirements for offshore wind development and the potential utilization of the available marine industrial capabilities in the US. For instance, wind turbine foundations are comparable to offshore petroleum structures. Shore-side infrastructure for construction and maintenance of offshore wind farms is similar to that needed for commercial shipping and large-scale commercial fishing operations. Additionally, port requirements for maintenance and support of offshore wind farms would be similar to those for offshore LNG ports and petroleum platforms.

3.1.5.1 Offshore Energy Industry in the US

Petroleum Extraction

Petroleum extraction is well established in the United States, especially in the Gulf of Mexico. There is a broad range of off shore platform designs, and their structural design has evolved over time. In general, the petroleum extraction platforms in the Gulf of Mexico are designed for water depths of 60 to 190 m (approximately 200 to 600 feet) (MMS 2009). However, platforms in deeper water up to 2,450 m (approximately 8,000 feet) also exist (MMS 2009). These deep water platforms are built using pre-fabricated modules. The super-structure is pre-assembled on land and transported to the field site for final assembly. These structures are comprised of different modules, typically partitioned into crew housing and process or control functions. Petroleum platforms are often built in clusters, centered on a developed well. Assembly is intensive due to the multiple connections required between modules, clustered platforms, and the well. Steel construction is preferred for the platform superstructure while concrete is limited to the platform foundations. Shallow foundations are commonly constructed using piles that

anchor the superstructure or jack-up platforms on the seabed. Deeper platforms require semi-submersible elements or floating devices anchored to the seabed to fix the position of the platform. Platform assembly is generally accomplished using specialty vessels, including jack-up cranes, tow boats, and large barges. Special heavy lift vessels are needed to transport the large assemblies, such as the pre-fabricated modules. Jack-up cranes or crane vessels lift the pre-fabricated modules into place. Platform modules are purposefully designed to have a minimum number of tie-ins to minimize field assembly efforts.

Large ports play an important role in the operation and maintenance of these petroleum extraction platforms. Major petroleum companies with a number of offshore platforms maintain permanent access to their own shore-side terminals that are capable of berthing vessels from 90 to over 185 m (approximately 300 to over 600 feet) in length with drafts that can exceed 11 m (36 feet). The accessibility and use of onshore facilities is critical to supporting petroleum extraction. Considering the premium that is placed on the space available on offshore platforms, activities aboard are typically minimized to assure operational efficiency and safety. All other materials are supplied from storage facilities at nearby ports, ready to be shipped out when and as needed. Because of this, ports receiving and delivering large petroleum extraction components and platform modules require large areas for yard storage, large dock heavy lift capability, and berthing for other construction and maintenance vessels. These requirements are similar to those for supporting offshore wind development on a commercial scale.

LNG Ports

The importation of LNG into U.S. markets has recently begun to favor fixed locations in deepwater offshore locations. These deepwater ports offer easy access, improved safety and reduced visibility to coastal residents. Deepwater LNG ports typically consist of re-gasification equipment, LNG vessel anchorage, and pipeline delivery systems to shore-based storage and distribution pipelines. Many technologies have been proposed for re-gasification, including barged equipment, modified petroleum platforms, island structures, and underwater riser assemblies. Northeast Gateway (NEG) Deepwater LNG Port is currently operating off the Massachusetts coast. Another similar deepwater LNG port facility is being planned in the area by Neptune LNG. Both of these facilities are located approximately 8.7 nm (10 miles) due east of Boston. The technology used for the NEG port is an underwater riser assembly that acts as anchorage and gas delivery system to a sub-sea delivery pipeline. Two such riser assemblies were constructed, and are anchored in place much like anchored floating petroleum platforms. Construction of the NEG Port required a large 110 m (approximately 350 foot) pipeline lay barge for offshore pipeline construction, anchoring vessels, and diver support vessels. Crew vessels provided provisions, material and transit for the 150 to 300 person crew throughout the construction operations. Specialized 275 m (900 feet) long LNG re-gasification vessels moor to the riser/mooring assembly during gas delivery operation. Support and security vessels for the NEG Port are based out of Boston, and are deployed to provide safety and security. Shore-based facilities are minimal for operation of the NEG Deepwater Port. However, construction of the deepwater port required layout, staging areas, and crew deployment from multiple ports.

3.1.5.2 Commercial Shipping

Commercial shipping requires large, mobile vessels exporting and importing bulk cargo to ports throughout the world. Vessels range from under 215 to over 300 m (approximately 700 to over

1,000 feet) in length. Ports that receive and deliver cargo require large areas for yard storage and wharf frontage. Vessels calling on commercial shipping ports must also be able of pass under vertical obstructions such as bridges. In the United States, vertical obstructions are typically standardized by the U.S. Coast Guard (USCG) to maintain a minimum clearance of approximately 41 m (135 feet) (Coast Pilot specification).

Commercial shipping ports such as Boston require distribution and warehousing facilities for the handling of roughly 1.2 million mt (1.3M tons) of general cargo, 1.4 million mt (1.5M tons) of non-fuels bulk cargo, and 11.6 million mt (12.8M tons) of bulk fuel cargo per year (Massachusetts Port Authority 2009). The Port of New York and New Jersey handles 5.3 million loaded and unloaded twenty-foot equivalent units (TEUs) per year (Port Authority of New York and New Jersey 2009). Trucking and rail access facilitate shipment of cargo over land. The Port of New York and New Jersey also boasts 54 container cranes that can handle all types of cargo, 135 to 320 mt (approximately 150 to 350 ton) capacity cranes, and the largest heavy-lift crane on the East Coast (an approximately 900 mt (1,000 ton) rated-capacity Chesapeake 1000). Donjon Marine Co. Inc. cranes have handled large bulk cargo including 365 mt (400 ton) General Electric Co. and Siemens generator units that were transported to the port via oceangoing vessels (Port Authority of New York and New Jersey 2009).

3.1.5.3 Commercial Fishing Factory Vessels

Commercial fishing is conducted by vessels ranging from very small, 1 or 2 man crew ships to large factory vessels. Shore-based support for these operations varies widely considering the large diversity of vessel types. Large factory vessels have similar shore-side requirements as commercial shipping. Consequently, commercial fishing operation requirements are very comparable to offshore wind operational and maintenance needs. However, offshore wind generation support needs are much smaller in scale than the warehousing and wharf frontage needed for commercial shipping. Frozen fish products also require freezer containment for offloaded cargo. In Rhode Island, Seafreeze Ltd. utilizes berthing space for two 45 m (approximately 150 feet) processing vessels, warehousing cold storage capacity of approximately 10.4 million kg (23 million pounds), offloading cranes, and truck and rail access (Seafreeze Ltd. 2009).

3.1.5.4 Submarine Transmission Cables

Additionally, technologies and construction techniques used for submarine pipeline installation may have similarities, in terms of lay-down area and construction vessel size, to those needed for high-capacity submarine transmission cable installation required for the offshore wind industry.

3.1.5.5 Implications

Offshore wind power generation will require specialized labor and equipment for construction and operation. Specialized training will be required to successfully construct and operate safely and efficiently in the marine environment. The basic skill-set exists, to a certain extent, within the maritime industry and Merchant Marine. Local universities (including the Massachusetts Maritime Academy) and labor unions could modify existing training courses to create and maintain a qualified labor force specifically geared to service a growing offshore wind industry. But establishing programs in anticipation of the offshore wind industry is unlikely.

Petroleum extraction platforms are currently assembled using specialized heavy lift vessels. Similar vessels will be required for the construction of wind turbines. Vessels currently in the fleet (including jack-up cranes, tow boats, and large barges) have the potential to be modified for use as construction platforms for wind turbines (especially for initial installations). While such modifications can be made to existing vessels, the specialized construction techniques and heavy lift needs of offshore wind turbine construction may make the modification option expensive and potentially risky as compared to purpose-built vessels. The option of applying modified existing equipment may also be limited to smaller construction projects in near-shore environments. Purpose-built construction vessels for offshore wind turbine construction would most likely, be more cost effective, less risky, and flexible in terms of operational capabilities.

As with petroleum extraction, commercial shipping and factory fishing port facilities, offshore wind construction lay down and port requirements are fairly significant. To support the offshore wind industry, significant lay down areas will be required for the assembly and storage of large wind turbine components. It is estimated based on discussions with major offshore wind turbine manufacturers in Europe that a minimum of 8.1 hectares (approximately 20 acres) would be needed for assembly and storage of these components assuming component delivery is scheduled so that the portside assembly area only needs capacity for a fraction of the total wind farm components at any given time (based on interviews with developers). Large-capacity cranes will also be needed to move turbine components such as nacelles and tower pieces. Yard and wharf facilities will need to be sufficiently large to store, move and assemble turbine components with weights up to approximately 290 mt (320 tons). The large vessels needed for receiving and delivering such components require navigation channels of particular depth and clearance (both horizontal and vertical) to allow passage through/beneath obstructions such as bridges. Recent developments in offshore wind turbine size, coupled with evolving construction and component delivery techniques, may exceed the current 41 m (135 feet) vertical clearance of local, large fixed bridges.

An offshore wind farm, once constructed, will need routine maintenance and occasional component replacement, including major components such as a blade or nacelle. Maintenance vessels used during wind farm operations would be similar in size to those currently in use to support offshore LNG ports and petroleum extraction operations and, on rare occasion, would require the same or similar vessels to those used during construction for major maintenance. Berthing space for support vessels would be vital for these port facilities, as well as sufficient yard and warehousing space for components and other maintenance supplies and activities. The NEG Deepwater LNG Port operating off the coast of Massachusetts currently utilizes a 33 to 49 m (approximately 110 to 160 feet) long offshore support vessel (OSV) that makes roughly 65 round trips to the port site each year (U.S. Coast Guard 2006). For comparison, Cape Wind estimates that three maintenance vessels will be required each day, 252 days per year, for routine maintenance, resulting in an estimated 756 vessel trips per year. Commercial shipping and fishing vessel activity is similarly constant with vessels arriving and departing port facilities on a daily basis. Vessel activity during offshore wind project construction also would be constant, but short in duration during the one to two year long construction phase of a project (depending upon the size of the wind farm). Larger vessel activity would drop off considerably during operation and maintenance of offshore wind projects. However, major repair work would likely require a large vessel like the ones used during wind park construction. Vessels currently in the fleet, including jack-up cranes, tow boats, and large barges, can be modified for use as

construction/maintenance platforms. However, the availability of purpose-built construction vessels would be the preferred option in the long run.

3.2 Industry Overview

3.2.1 Development of the Port Criteria

To determine the port facility/land-based requirements for offshore wind development, the Team interviewed developers, obtained turbine manufacturer information, and had discussions with consultants with offshore wind farm construction experience in Europe. Through this information gathering, the Team identified:

- specific port- and land-based needs related to vessel requirements;
- component, materials and equipment storage and assembly requirements;
- preliminary estimates of potential through-put of wind turbines (e.g., the number of wind turbines deployed); and
- skilled labor needs and trades requirements.

The Team identified “hard” and “soft” criteria based on the stated requirements (see Section 4.0). These criteria were used to create a Criteria Evaluation Matrix as a tool for comparing and ranking Massachusetts port facilities (see Section 6.0) on the ability to serve as offshore wind construction and deployment ports.

3.2.2 Interviews with Developers

The Team contacted most of the current and prospective offshore wind farm developers on the East Coast to gain a deeper understanding of the requirements for supporting the construction, operation and maintenance of a utility scale offshore wind farm. The Team intended to use this developer input to identify an objective set of weighted criteria with which to compare and evaluate Massachusetts port facilities. However, many developers have yet to specify or disclose in detail the key parameters and characteristics of the port and other supply chain requirements. While cognizant of the need to solve logistical issues, negotiations between developers and various manufacturers and material suppliers are ongoing. Actual component manufacturing sites and delivery methods will be determined on a project- and item-specific basis. As a result, many of the detailed questions contained in the customized developer questionnaires were left unanswered (see Appendix B for the questionnaire). However, developers did identify and explain many aspects of the most important parameters that helped the Team establish the basic criteria. Developers identified general port staging needs against the characteristics of which current ports could be compared and ranked. Developers also were questioned about what would make one port more attractive than another. Cost control and risk avoidance emerged as key factors.

The Team’s interviews with developers provided insight into the principal issues concerning commercial offshore wind energy development off the Northeast Atlantic Coast. These insights provided a better understanding of wind farm components and the associated logistics of importing, storing, assembling and deployment to and installation at the project site. Table 3-1 below provides a quick summary of these proposed projects based on available public information. Projects are listed by developer with project particulars such as location, water depth, generating capacity, number of turbines, and distance from shore. Because these

projects are in various stages of development, not all information on every project is publicly available.

As the developer's needs were analyzed, the Team found that Massachusetts ports had clear, distinguishable differences relative to offshore wind development requirements, and that the ports could be compared in a straightforward manner relative to these parameters. Development of a more complex framework for the evaluation that made use of multi-variable, weighted criteria was unnecessary.

Table 3-1
Planned Offshore Wind Projects

Developer/ Project	Project Location	Water Depth at Proposed Location	Project Generating Capacity	Number of Turbines (Scale)	Foundation Type	Estimated Cost of Construction	Port Staging Area
Cape Wind Associates							
Cape Wind	4.5 NM (5.2 miles) from coast of Cape Cod, MA, 7.8 NM (9 miles) from Martha's Vineyard, 12 NM (13.8 miles) from coast of Nantucket Island	3.7 m (12 ft) MLLW (mean low low water) minimum depth	468 MW	130 (3.6 MW per turbine)	Monopile	$700 million	Quonset Davisville Port and Commerce Park, Quonset, Rhode Island
NRG Bluewater Wind							
Bluewater Delaware	11.3 to 19.1 NM (13 to 22 mi) east of Rehoboth Beach, DE (wind park); 14.3 NM (16.5 mi) due east Rehoboth Beach (met tower)	12.2m to 18.3m (40 to 60 feet)	200 to 450 MW	Up to 150	Monopile	$800 million	Port of Wilmington, Delaware; Delaware Bay Launch in Milford Delaware for crew boat and small cargo barge launch
Bluewater New Jersey	14 NM (16 mi) southeast of Atlantic City, NJ	21.3m to 30.5m (70 to 100 feet)	350 MW	116	Monopile	$1.4 billion	Port of Wilmington, Delaware; Delaware Bay Launch in Milford Delaware for crew boat and small cargo barge launch
Deepwater Wind							
Garden State Offshore Energy (Deepwater with PSEG Renewables)	13.6 NM (15.6 mi) from shore, 17.4 NM (20 mi) due east of Avalon, NJ	24.4m to 27.4m (80 to 90 feet)	350 MW	96	Jacket	$1 billion	Atlantic City, New Jersey

Developer/ Project	Project Location	Water Depth at Proposed Location	Project Generating Capacity	Number of Turbines (Scale)	Foundation Type	Estimated Cost of Construction	Port Staging Area
Deepwater Wind Rhode Island	2.6 NM (3 miles) off Block Island, RI for Phase 1; Phase 2 located 13 to 17.4 NM (15 to 20 mi) off RI coast (location TBD upon completion of RI Ocean Special Area Management Plan in 2010	'deeper' waters	20 MW (Phase I) 400 MW (Phase II)	Phase 1: 8 turbines Phase 2: 106 turbines	Jacket	$1 billion	Quonset, Rhode Island
Fisherman's Energy							
Fisherman's Energy of New Jersey Project	Phase 1: 2.6 NM (3 miles) off the coast of Atlantic City Phase 2: 6.1 NM (7 miles) off the coast	18.3m to 21.3m (60 to 70 feet)	Total: 350 MW Phase 1: 20MW Phase 2: 330 MW	Total: 74 Phase 1: 8 turbines Phase 2: 66 turbines	Monopile	$100 million for Phase 1 $1 to 1.5 billion for Phase II	Dorchester, Atlantic City, and or Cape May, New Jersey
Fisherman's Energy of Rhode Island Indepen-dence 1 Project	2.6 NM (3 miles) south off the southern coast of Block Island, RI	20 m to 30 m (65.6 to 98.4 feet)	400 MW	80	TBD	$1.25 to $1.5 billion	TBD

3.2.3 Conditions at Ports and Wind Farm Locations

Wave height, water depth and wind speed impose limitations on at-sea construction operations. The following subsections describe sea states, wind conditions, and water depths at a number of proposed wind farm sites along the U.S. East Coast. Transit distances[2] between proposed wind farm sites and potential staging ports also are evaluated.

Sea states are typically characterized by the significant wave height (H_S), which is the average of the largest one-third of the observed waves. H_S correlates very well to the sea state as observed by mariners. Wind is characterized by the 10-minute average wind speed (V_W).

The base line transit routes for cargo in the region track around the east end of Cape Cod. The primary alternative route is via the Cape Cod Canal (see Appendix C). Air draft (i.e., the free space above the water line below an overhead obstruction) in the Cape Cod Canal is limited to approximately 41 m (135 feet). In practice, this means vessels or barges transporting 5 MW turbines in the "bunny ear" configuration (especially the "fore-aft" configuration – see Figures 3-4 and 3-5) probably cannot expect to transit the Cape Cod Canal. Alternative turbine load-out

[2] Transit distances are in nautical miles and are based on typical shipping routes.

configurations (e.g., the “star” configuration – see Figure 3-6) and/or smaller turbines (e.g., 3.6 MW turbines) in the “bunny ear” configuration could probably utilize the Cape Cod Canal.

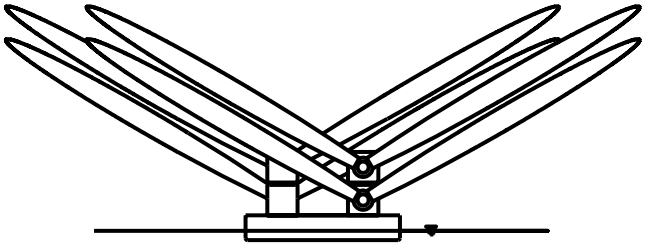


Figure 3-4 Bunny Ear Configuration (Lateral) – End view looking forward
(Source: The Glosten Associates 2009)

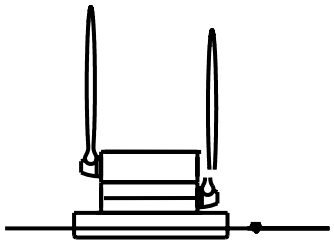


Figure 3-5 Bunny Ear Configuration (Fore-Aft) – End view looking forward
(Source: The Glosten Associates 2009)

Figure 3-6 Star Configuration – End view looking forward
(Source: The Glosten Associates 2009)

3.2.3.1 Nantucket Sound

Cape Wind Associates has proposed a project for Horseshoe Shoal in Nantucket Sound. The location for that project is shown below in Figure 3-7. The distances from the proposed project site to the potential staging port locations are listed below in Table 3-2.

Water depths in the proposed project area are approximately 3.6 to 18 m (approximately 12 to 60 feet). Information on wave heights and wind speeds is limited for this area. According to the Coast Pilot, during the winter (November-February), wave heights of 3.7 m (approximately 12 feet) can be expected 5 percent to 15 percent of the time. During the summer, wind speed rarely exceeds 15 knots, and wave heights are 1 m (approximately 3.2 feet) or less 98 percent of the time. Additionally, in the summer (May-July), thick fog frequently forms, which could complicate installation operations.

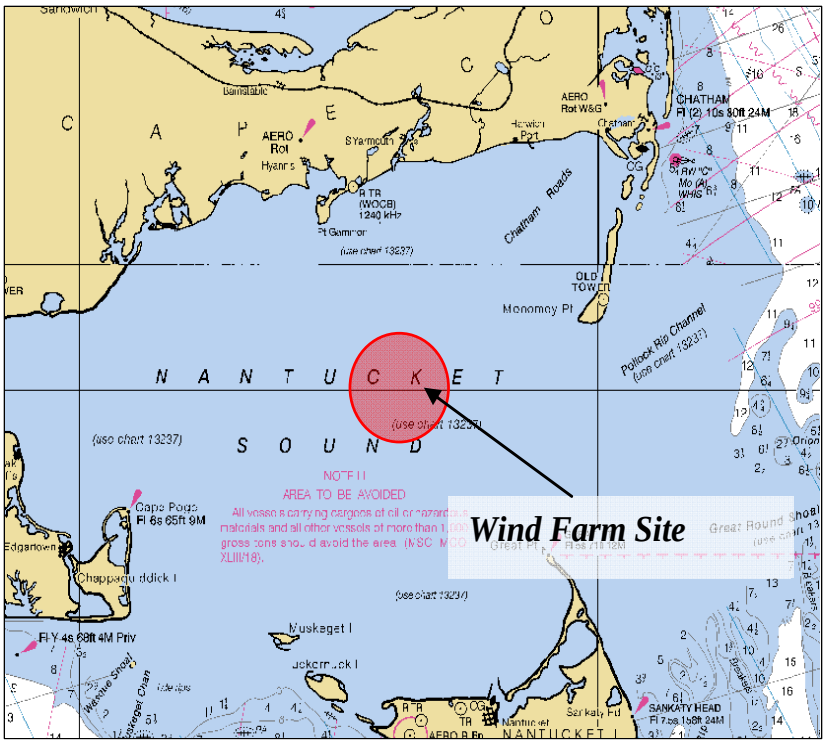


Figure 3-7 Cape Wind Proposed Horseshoe Shoal Site
(Source: The Glosten Associates 2009)

Table 3-2
Distances to Staging Port Locations from the Proposed Cape Wind Site
(Source: The Glosten Associates 2009)

Staging Location	Primary Route Distance [nautical miles]	Alternate Route* Distance [nautical miles]
Boston, MA	130	130
Gloucester, MA	105	130
New Bedford, MA	45	n/a
Fall River, MA	75	n/a
Portland, ME	160	200
Quonset/Davisville, RI	70	n/a

* Alternative route is via the Cape Cod Canal.

3.2.3.2 Rhode Island

Deepwater Wind, in collaboration with First Wind (a Massachusetts-based wind developer), is planning two projects off the Rhode Island coast. The first is a small-scale project, located three nautical miles off Block Island. The second is planned for a utility-scale project, located approximately 12 to 18 nm (15 to 20 miles) off the coast of Rhode Island[3]. This area is shown below in Figure 3-8. The distances from the sites to the potential staging port locations are listed

[3] The precise location of the second Deepwater Wind site will be established based of the results on the forthcoming Ocean Spatial Area Management Plan, which is expected to be completed in 2010.

in Table 3-3. Water depths are approximately 30 to 40 m (100 to 130 feet) at the proposed Rhode Island site. However, due to the large regional area being considered for the wind farm sites, water depths vary widely. Climatology for the general region is presented in numerical and graphical forms in Figure 3-9 and Table 3-4.

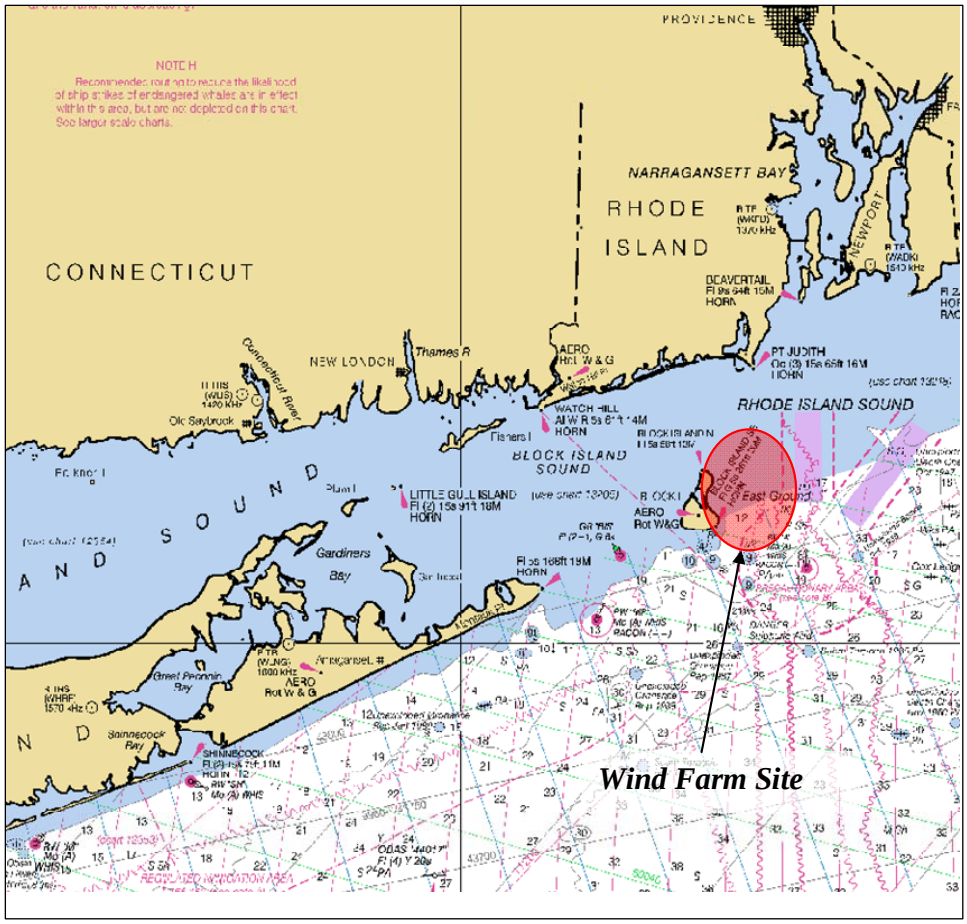
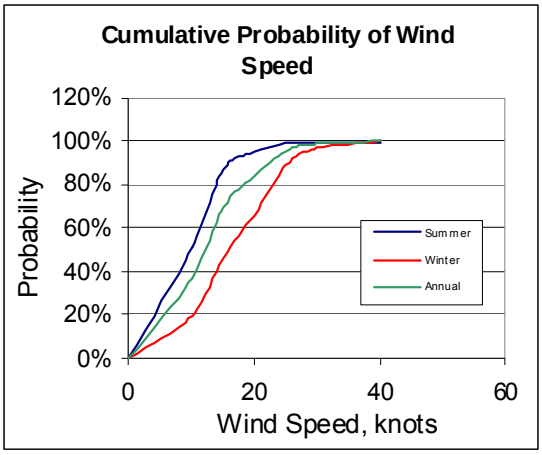


Figure 3-8 Deepwater Wind Proposed Rhode Island Site
(Source: The Glosten Associates 2009)

Table 3-3
Distances to Staging Port Locations from the Proposed Deepwater Site

Staging Location	Primary Route Distance [nautical miles]	Alternate Route* Distance [nautical miles]
Boston, MA	295	120
Gloucester, MA	270	120
New Bedford, MA	50	n/a
Fall River, MA	45	n/a
Portland, ME	325	190
Quonset/Davisville, RI	35	n/a

* Alternative route is via the Cape Cod Canal.



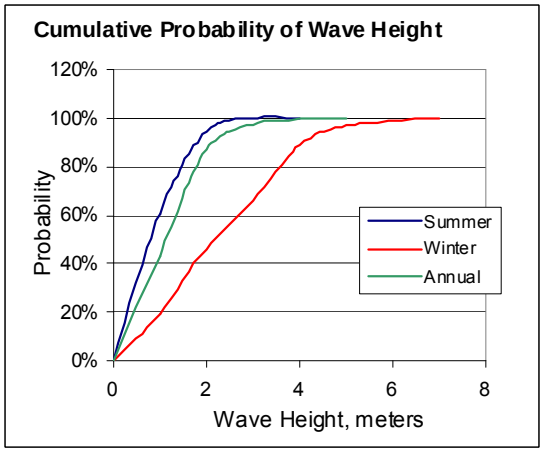


Figure 3-9 Cumulative Probability Graphs of Wind Speed and Wave Height for Coastal Rhode Island

(Source: The Glosten Associates 2009)

Table 3-4
Rhode Island Climatology Data
(Source: The Glosten Associates 2009)

Description	Annual	Winter (January)	Summer (August)
Probability {$H_S \leq 1$ meters}	43.5%	28.5%	60.3%
Probability { $H_S \leq 2$ meters}	86.7%	78.2%	94.3%
Probability { $H_S \leq 3$ meters}	97.2%	95.2%	99.8%
Probability { $H_S \leq 4$ meters}	99.4%	98.7%	99.9%
Probability {$V_W \leq 15$ knots}	36.9%	18.2%	52.6%
Probability {$V_W \leq 20$ knots}	69.3%	45.9%	87.5%
Probability {$V_W \leq 25$ knots}	83.9%	65.9%	95.9%
Probability {$V_W \leq 30$ knots}	95.6%	89.4%	99.8%

3.2.3.3 Delaware Bay

Bluewater Wind and Deepwater Wind have each proposed wind farm sites in the Delaware Bay and in the southern New Jersey coastal area, which are shown below in Figure 3-10. The distances from the sites to the potential staging port locations are listed below in Table 3-5. Water depth in the northwest field varies widely from 9 to 24 m (approximately 30 to 80 feet), and from to 12 to 21 m (approximately 40 to 70 feet) in the southeast field. Climatology for the general region is presented in numerical and graphical forms in Table 3-6 and Figure 3-11.

3.2.3.4 Other Areas

The Massachusetts OMP identified additional areas that could be suitable for commercial wind energy production. The two designated Wind Energy Areas are located near the southern end of the Elizabeth Islands and southwest of Nomans Land Island. Wind and wave conditions at

these sites are similar to the Rhode Island sites. Transit distances between these sites and potential staging areas are shown in Table 3-7.

Massachusetts, as well as other states on the Atlantic Seaboard, is working with the U.S. Interior Department, MMS to develop Requests for Information (RFIs) for potential wind projects in federal waters off their respective coasts.

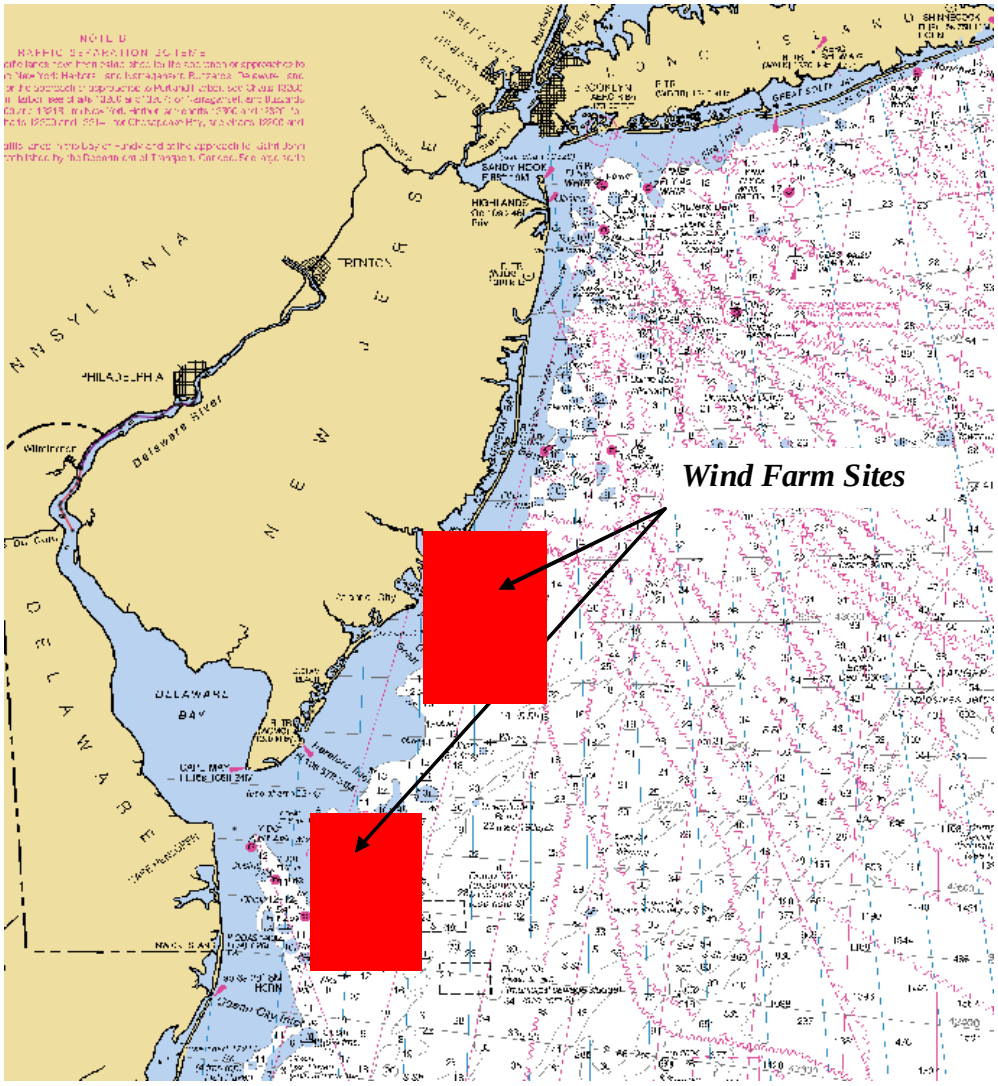


Figure 3-10 Bluewater Wind and Deepwater Wind Proposed Sites
(Source: The Glosten Associates 2009)

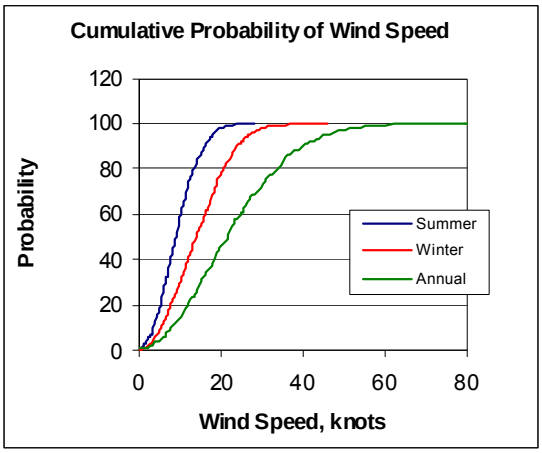
Table 3-5
Distances to Port Staging Locations from the Proposed Bluewater/Deepwater Sites

Staging Location	Primary Route Distance [nautical miles]	Alternate Route* Distance [nautical miles]
Boston, MA	470	330
Gloucester, MA	445	330
New Bedford, MA	260	n/a
Fall River, MA	250	n/a
Portland, ME	500	400
Quonset/Davisville, RI	280	n/a

* Alternative route is via the Cape Cod Canal.

Table 3-6
Delaware/New Jersey Climatology Data
(Source: The Glosten Associates 2009)

Description	Annual	Winter (January)	Summer (August)
Probability {$H_S \leq 1$ meters}	66.8%	53.3%	79.4%
Probability { $H_S \leq 2$ meters}	93.4%	88.8%	96.8%
Probability { $H_S \leq 3$ meters}	98.3%	96.7%	98.9%
Probability { $H_S \leq 4$ meters}	99.6%	98.7%	99.9%
Probability {$V_W \leq 15$ knots}	32.1%	21.8%	43.5%
Probability { $V_W \leq 20$ knots}	48.8%	36.6%	61.7%
Probability { $V_W \leq 25$ knots}	60.8%	47.4%	74.4%
Probability { $V_W \leq 30$ knots}	75.5%	61.3%	86.9%



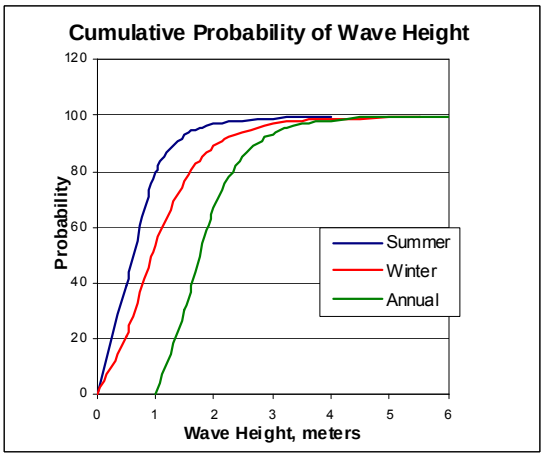


Figure 3-11 Cumulative Probability Graphs of Wind Speed and Wave Height for the Delaware/New Jersey Area
(Source: The Glosten Associates 2009)

Table 3-7
Distances to Staging Port Locations from the OMP Designated Sites
(Near the Elizabeth Islands and Nomans Land Island)

Staging Location	Primary Route Distance [nautical miles]	Alternate Route* Distance [nautical miles]
Boston, MA	260	100
Gloucester, MA	235	100
New Bedford, MA	35	n/a
Fall River, MA	50	n/a
Portland, ME	290	175
Quonset/Davisville, RI	40	n/a

* Alternative route is via the Cape Cod Canal.

3.3 Characteristics of Available Vessels

This section describes the marine vessels that are currently available for use in the construction and maintenance of offshore wind farms. Different vessels are required for the following specific activities:

1. Delivery of turbine components (e.g., tower sections, nacelles, blades) to the staging port;
2. Foundation delivery and installation;
3. Turbine erection;
4. Regular maintenance and personnel transport; and
5. Major maintenance.

The following subsections discuss the basic characteristics, capabilities, limitations, and general availability of the various types of vessels (see Appendix D, Potential Wind Turbine Delivery Vessels, for more details).

3.3.1 Turbine Import/Delivery Vessels

The turbines used for the first round of U.S. offshore wind farms will likely be imported from Europe. Turbines are generally shipped in pieces (e.g., tower sections, nacelle, hub, individual blades) from the point of origin directly to the project site aboard open hatch cargo vessels. Table 3-8 summarizes the principal dimensions of turbine import vessels. An example of this vessel type is shown in Figure 3-12 (Section 3 of Appendix A provides further details).

Table 3-8
Principal Dimensions for Turbine Import Vessels
(Source: The Glosten Associates 2009)

Length Overall	98 to 143 m (330’ to 470’)
Beam	20 to 23 m (66’ to 75’)
Design Draft	6.7 to 9.8 m (22’ to 32’)

Figure 3-12 BBC KONAN In Transit With Turbine Components (Nacelles Stowed Below Deck)
(Source: BBC KONAN)

3.3.2 Foundation Delivery and Installation Vessels

Foundations can be installed using either jack-up crane vessels or floating derrick barges. Jack-up crane vessels are described further below. Large floating derrick barges (as shown in Figure 3-13) are in service on all three major U.S. coastlines and could be mobilized to serve the U.S. East Coast offshore wind energy market.

Depending on the type of foundation being used (i.e., monopile, gravity-base, jacket, or tripod), a derrick barge could transport foundations between the staging port and the wind farm site on its own deck, or foundations could be transported using a separate barge. Floating derrick barges can lift up to 900 mt (approximately 1,000 tons), but a more common lifting capacity is 455 mt (500 tons) or less. Floating derrick barges could be used to install wind turbine foundations in up to 1.5 m (5 feet) seas, with a wind speed limit of around 20 to 30 knots.

Figure 3-13 Self-Propelled Crane Barge with 250 Ton Lifting Capacity
(Source: Marine Transportation Consultants http://www.tug-barge.com/p297.htm)

3.3.3 Wind Turbine Installation Vessels

European offshore wind turbines have been installed using a variety of specialized equipment, which generally falls into one of three categories:

- Leg-Stabilized jack-up crane ships ("partial jack-ups") (see Figure 3-14 for an example);
- Jack-up crane barges (see Figure 3-15 for an example); and
- Jack-up crane ships (see Figure 3-16 for an example).

Figure 3-14 Leg-Stabilized Crane Ship
(Source: A2Sea)

Figure 3-15 Jack-Up Crane Barge
(Source: A2Sea)

Figure 3-16 Jack-Up Crane
(Source: Offshore MPI)

For all three vessel types, the limiting wind speed for at-sea crane operations is approximately 15 to 20 knots. For the leg-stabilized vessels, the limiting sea state for crane operations is approximately 0.5 m (approximately 1.7 feet) seas, as the vessel's hull remains submerged and is subject to wave-induced motion. For the jack-up barges and ships (see Figure 3-17), the process of jacking up and down is limited to approximately 1.5 m (5 feet) seas. The crane can be operated in higher sea states once the vessel is jacked-up.

Figure 3-17 The Dixie Class Lift Boat Represents a Near-Term Option for U.S. Offshore Wind Turbine Installation
(Source: Superior Energy Services, Inc.)

The typical dimensions of wind turbine installation vessels are presented in Table 3-9. Further details are provided in Appendix A.

Table 3-9
Principal Dimensions for Turbine Installation Vessels
(Source: The Glosten Associates 2009)

Length Overall	91 to 137 m (300' to 450')
Beam	30 to 40 m (100' to 130')
Navigation Draft	3.7 to 4.9 m (12' to 16')
Air Draft (legs in up position)	varies, approximately 46 m (150')

No purpose-built wind turbine installation vessels exist that are compliant with U.S. coastwise trade laws (i.e., "Jones Act"). These laws require vessels to be U.S.-built, U.S.-owned, and U.S.-operated. A small number of Jones Act-compliant vessels that are currently operating in the Gulf of Mexico could be used to construct the first-generation U.S. offshore wind farms. These vessels lack the efficiency associated with purpose-built wind turbine installation vessels, such as the ability to transport multiple sets of turbine components and the ability to rapidly jack-up, pre-load the legs, erect the turbines, and jack-down. In order to economically and efficiently achieve GW-scale deployment of offshore wind in the United States, a fleet of purpose-built, Jones Act-compliant vessels will be needed. The industry recognizes this fact and is taking steps to develop the vessel infrastructure. NRG Bluewater Wind, for example, has teamed with the Aker Philadelphia shipyard to develop three purpose-built wind turbine installation vessels. (Bluewater Wind 2009b).

Future wind turbine installation vessels are expected to focus on improving construction efficiency through faster transit speeds, larger payload capacity, and ability to erect turbines in higher wind speeds and larger sea states. Some firms are developing designs that accommodate the transport and installation of fully assembled turbines (see Figure 3-18).

Figure 3-18 Glosten Turbine Installation Vessel Concept
(Source: The Glosten Associates 2009)

3.3.4 Maintenance Vessels

Regular, planned maintenance of offshore turbines requires personnel access to the wind farm facilities. Maintenance personnel for existing offshore wind farms are typically shuttled to the turbines by a crew boat or by helicopter. Specialized crew boats have been developed in Europe to increase the weather window during which maintenance personnel can safely access turbines.

Major maintenance or serial defects in turbines may require mobilization of a wind turbine installation vessel to reverse some or all of the installation process. There is an industry trend to develop maintenance-specific jack-up vessels that have highly capable cranes and limited cargo capacity but relatively slower transit speed. (Gusto MSC 2009).

3.4 Overview of Vessel Constraints and Requirements

The following sections evaluate the marine vessel requirements for deploying and maintaining offshore wind farms along the U.S. East Coast. Understanding the characteristics of these vessels is critical in the overall evaluation of a port's suitability as a staging area for offshore wind farm deployment and maintenance.

Vessel requirements are governed primarily by the following:

- Physical conditions at offshore wind farm sites (i.e., conditions in which vessels must operate);
- Navigational constraints in port and along transit route to the wind farm site;
- Size and weight of turbines being transported and installed; and
- Methodology for transporting and installing turbines.

The Team evaluated the physical conditions (e.g., wind speeds, wave regime and water depth) at proposed offshore wind farm sites along the U.S. East Coast. Navigational constraints in and near the Ports of New Bedford, Boston, Gloucester, and Fall River, MA also were evaluated. The physical properties of large offshore wind turbines (i.e., 3 MW to 5 MW) were reviewed, along with the demonstrated methodologies for transporting and installing these turbines.

The principal dimensions of wind turbine installation vessels/barges and import vessels are summarized below, as are the navigational constraints for all the analyzed ports. Appendix A discusses much of the information that is summarized in this section.

3.4.1 Installation and Transport Vessel Requirements

3.4.1.1 Flag and Class

The Merchant Marine Act of 1920, commonly known as the “Jones Act”, requires vessels engaged in the transport of passengers or cargo between U.S. places to be built and flagged in the United States, and owned and crewed by U.S. citizens. It was assumed for this study that the vessels discussed in this section would be subject to the Jones Act, as bottom-fixed foundations within the U.S. Exclusive Economic Zone (EEZ) are considered U.S. places. Vessels discussed in Appendix A, which are used to transport turbine components from overseas to a U.S. staging port, are not subject to the Jones Act. Therefore, the discussion of

turbine installation vessels provided below relates to purpose-built vessels currently operating in the North Atlantic.

Commercial vessels are typically certified by a classification society. The purpose of classing a vessel is to demonstrate compliance with an independent, accepted standard for vessel design, operation, inspection, and maintenance. Several options are available for classing the installation and transport vessels for offshore wind development. Existing European vessels are classed by Det Norske Veritas as "Self-Elevating Units," or by Germanischer Lloyd as "Special Type Offshore Unit – Surface Unit with Stabilizing Legs." Additionally, the American Bureau of Shipping (ABS) Rules for Mobile Offshore Units also are an appropriate classification avenue for installation vessels (see Appendix A and associated references).

3.4.1.2 Principal Dimensions

The key dimensions of a turbine installation and turbine transport vessel are beam, length, draft, and overhead clearance (a.k.a. "air draft"). The following summaries were extracted from Appendix A.

The beam (width) of the installation and transport vessels is largely dictated by the vessel's stability requirements during transit and, if applicable, the stability requirements and structural strength while elevated on legs (i.e., during "jack-up"). Pre-assembled tower components have a relatively high center of gravity, which increases the vessel stability requirements and, consequently, the required vessel beam. Typical European installation vessels, such as SEA JACK and RESOLUTION have a beam in the range of 30 to 40 meters (approximately 100 to 130 feet).

The length of the vessel is dictated by functional and cargo requirements and structural considerations. Typical European turbine installation vessels and barges have an overall length of 90 to 140 meters (approximately 295 to 460 feet).

The vessel's draft, or the required clearance between the waterline and sea bed, is dictated by the hull form and total weight, including the transported cargo. Wind turbine installation vessels and barges tend to have full hull forms with large beam and length. As such, the load-out of these vessels is typically governed more by space requirements than cargo weight. These factors lead to relatively shallow draft requirements. Typical European installation vessels have a draft in the range of 3.5 to 5 meters (approximately 11 to 16 feet).

Overhead clearance, or "air draft", is dictated by three factors: length of legs (for a jack-up barge or vessel), pre-assembly methodology, and crane height in stowed position. The methods of turbine component pre-assembly and transport can vary from project to project. The three most common methods for transporting pre-assembled components from the staging area to the wind farm site were illustrated in Figures 3-4 through 3-6: (1) the bunny ear configuration (lateral); (2) the bunny ear configuration (fore-aft); and (3) the star configuration. For purposes of context, the barge in Figures 3-4 through 3-6 and in the next few figures was drawn to have a beam (width) of approximately 30 m (approximately 100 feet) and an overall length of 122 m (approximately 400 feet). The nacelle and blade dimensions represented are based on a REPower 5 MW turbine (reflecting future equipment sizes). Figures 3-19 and 3-20 show a fully loaded barge with jack-up legs in the transit and jacked-up positions, respectively. Turbine tower sections are typically transported in the vertical orientation, with the maximum height

approximately even with the top of the blades in the bunny ear configuration. The legs of a jack-up vessel that is intended to operate in 25 m (approximately 80 feet) of water require an overhead clearance of about 45 m (approximately 150 feet) when the legs are in the up position4. If the barge is required to jack-up in water depths greater than about 45 m, then the leg towers will dictate the overhead clearance requirement. As shown in Figures 3-19 and 3-20, the required overhead clearance is approximately 45 m (150 feet). The star configuration (Figure 3-6) has the lowest overhead clearance requirement, except when transported aboard a jack-up vessel. Overall crane heights vary, but can be approximately as high off the deck in the stowed position as the tower sections. To navigate beneath bridges, the legs can be temporarily lowered if the channel depth is adequate.

The star and lateral bunny ear configurations require a lateral clearance of approximately 130 m (approximately 425 feet) for the 5 MW system components. The lateral clearance for the fore-aft bunny ear configuration is dictated by the barge or vessel beam, which is typically on the order of 30 to 38 m (approximately 100 to 125 feet).

Wind turbines are relatively lightweight for their size. Consequently, cargo vessels that carry turbine components are generally space-limited, rather than weight-limited. This means that these vessels can operate at a light draft of 9 m (approximately 30 feet) or less, even though the design draft may be greater. Table 3-10 presents the principal vessel dimensions for some specific existing turbine import vessels.

The principal dimensions and draft characteristics (navigational and air) of a typical installation or transport vessel are presented in Table 3-11.

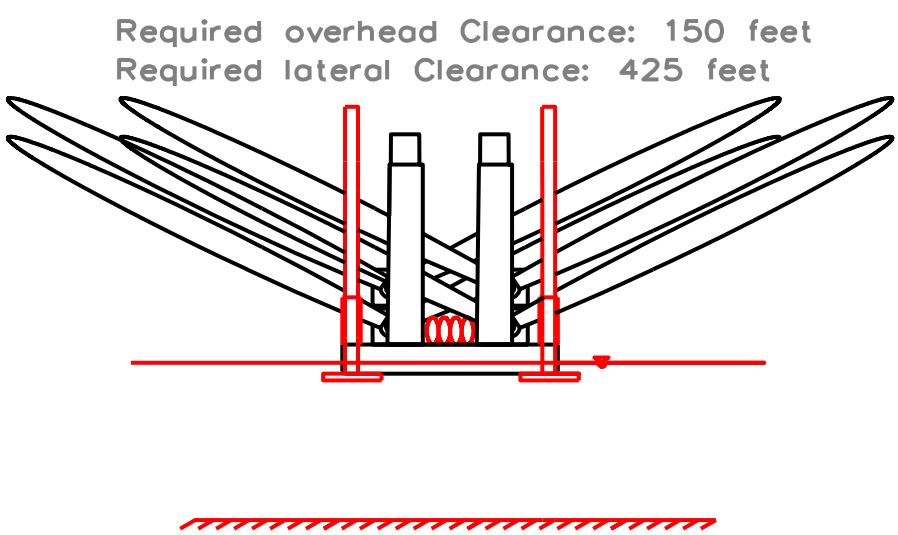


Figure 3-19 Loaded Barge in Transit
(Source: The Glosten Associates 2009)

[4] In general, the legs must be about 20 m (approximately 70 feet) longer than the operating water depth to account for soil penetration and the length of the legs inside the hull and jack house.

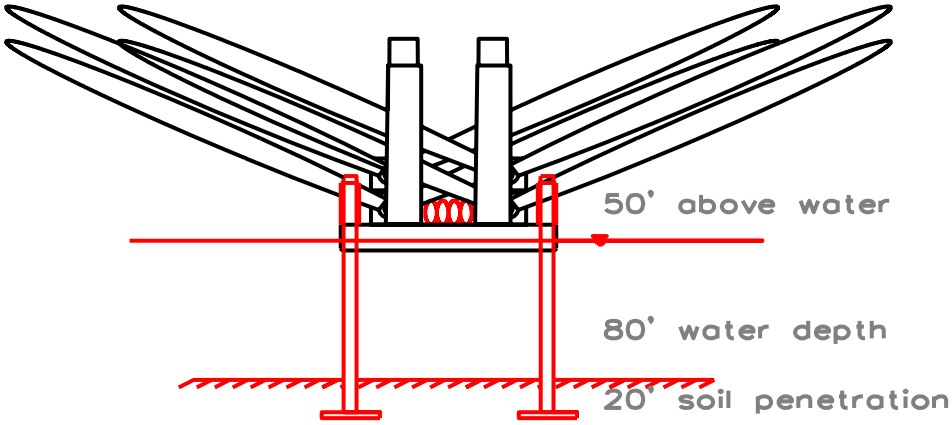


Figure 3-20 Barge Onsite with Legs Down
(Source: The Glosten Associates 2009)

Table 3-10
Principal Dimensions of Specific Turbine Import Vessels
(Source: The Glosten Associates 2009)

Vessel Name	Length Overall	Beam	Design Draft
BBC ELBE	143 m (470')	23 m (74.8')	9.7 m (31.8')
BBC KONAN	127 m (416')	21 m (68.2')	6.7 m (21.8')
Beluga F-Series	138 m (453')	21 m (68.9')	8.0 m (26.2')
Clipper MARINER	101 m (331')	20 m (66.3')	8.2 m (26.9')

Table 3-11
Typical Dimensions of Turbine Installation or Transport Vessels
(Source: The Glosten Associates 2009)

Length Overall	90 – 140 m (300' – 450')
Beam	30 – 40 m (100' to 130')
Navigation Draft	3.6 – 4.9 m (12' to 16')
Air Draft (legs in up position)	varies, approximately 46 m (150')
Air Draft (tower sections, bunny ears)	46 m (150')
Air Draft (crane in stowed position)	varies

3.4.1.3 Propulsion

Self-propelled ships and non-self-propelled barges have both been used successfully to install offshore wind farms in Europe. A self-propelled vessel with a dynamic-positioning system can cost three to five times as much as a barge with the same crane capacity and jacking system. However, a self-propelled vessel can achieve higher transit speeds than a towed barge and can work independently (i.e., without tug boats). It is currently unclear whether the U.S. market will prefer self-propelled ships or barges.

3.4.1.4 Crane Requirements

The key factors that dictate crane requirements for an installation and transport vessel are the:

- Maximum weight to be lifted (i.e., the "pick weight");
- Maximum height to be achieved above sea surface (i.e., "pick height"); and
- Required spatial clearance for objects being lifted.

The first U.S. offshore wind farms will likely use 2.5 MW to 3.6 MW wind turbines, with 5 MW turbines becoming commercially available within the next two years. Maximum pick weight and pick height generally increase with increasing turbine power rating. Table 3-12 summarizes the key crane requirements for two representative turbines (a Siemens 3.6 MW Offshore Turbine and a REPower 5 MW Offshore Turbine) and typical monopile components.

Table 3-12
Crane Requirements for 3.6 MW and 5 MW Turbines and Associated Monopile Foundations
(Source: The Glosten Associates 2009)

	Siemens 3.6 MW	REPower 5 MW	Monopiles
Max Pick Weight*	Nacelle: 125 mt (138 tons)	Nacelle: 290 mt (320 tons)	180 – 455 mt (200 – 500 tons)
Max Pick Height**	80 m (260 ')	85 – 95 m (280'-310')	Less than 30 m (100')

* 1 ton = 2000 pounds = 0.908 metric ton (mt)
** height above calm sea surface

Installation techniques vary for monopiles. A crane can lift the monopile or the monopile can be "tipped up" from the horizontal to the vertical position. Monopiles are often installed with a vibratory hammer, which itself can weigh up to 275 mt (approximately 300 tons) and must be lifted by the crane.

3.4.1.5 Jacking System Requirements

The current trend in turbine installation vessels is toward those vessels with a four-leg configuration. In contrast, the oil and gas industry typically uses three-leg jack-ups. The reason for using four legs is to reduce the time required to pre-load the legs (i.e., to test the soil on the sea bottom). A three-legged rig requires sea water ballasting to achieve pre-load position. With four legs, pre-loading can be achieved by lifting one leg at a time, thereby transferring loads to the other legs. A fourth leg also provides redundancy in the event of a leg failure.

3.4.1.6 Limiting Weather Conditions for Pile Driving and Crane Operation

The limiting sea state for monopile installation depends on the equipment used, but tends to be more sensitive to sea conditions than wind conditions. A robust monopile installation vessel can work in up to 2 to 3 m (6 to 10 feet) seas and wind speeds of up to 20-25 knots at the vessel deck level.[5]

[5] Wind speed increases as height above sea level increases. For example, a 20 knot wind at the deck could be a 24 knot wind at the height of the nacelle, as per DNV RP-C205 "Environmental Loads", Section 2.3.2.12.

Existing turbine installation vessels can operate their cranes in wind speeds of up to 15 knots at the deck level (approximately 23 knots at the crane tip) and can jack-up and down in seas as high as 1.5 to 3 m (5 to 10 feet).

3.4.1.7 Requirements for Accommodations

Installation vessels work around the clock when the weather permits, so personnel accommodations are needed aboard the vessel. Turbine installation vessels generally require accommodations for approximately 16 persons. The vessel/barge crew includes a master, an engineer, four to six mates or deck hands, and two stewards. The wind farm owner often requires accommodations for two to five representatives. This brings the total minimum complement of individuals on board to 30 to 35 persons. Many installation vessels in Europe have accommodations for 40 to 70 persons, and some planned new-build vessels are being designed to accommodate up to 200 persons.

3.4.1.8 Power Requirements

The primary systems that require power on a wind turbine installation vessel are the crane and the jacking system (see Appendix A). Since they do not operate simultaneously, a single power plant can be used for both systems. Cranes capable of lifting turbine components require up to 1,500 kilowatt (kW) (approximately 2,000 horsepower [hp]) power supply. This amount of power is generally also sufficient for a jacking system that meets the lifting capacity and jacking speed requirements for a vessel carrying three to four complete sets of turbine components. Heavier vessels with larger jacking systems will require more installed power, perhaps 3,000 to 4,000 kW (approximately 4,000 hp to 5,500 hp).

To achieve even heel and trim prior to jacking operations, the installation vessel must have a relatively robust ballasting system. A total pump capacity of 300 to 600 tons of water per hour (approximately 72,000 to 144,000 gallons of water per hour) would probably be needed, which would require up to 150 kW (approximately 200 hp) of supplied power.

A self-propelled installation vessel will require a separate power plant that can provide 3,000 to 5,200 kW (approximately 4,000 hp to 7,000 hp) of power to the propulsion system. This power plant can also be used to power a dynamic-positioning (DP) system or to power the crane, but is unlikely to suffice for simultaneous operation of the DP system and the jacking system.

Power generation also is required for “hotel loads”, deck lighting, and emergency systems. Existing vessels have installed auxiliary power of roughly 110 kW (approximately 150 hp) for these purposes.

3.4.1.9 Deck Load Requirements

Existing turbine installation vessels have deck capacities in the range of 1.5 to 20 tons/meter^2 (approximately 300 to 4,100 pounds/square foot (psf)). A 272 mt (approximately 300 ton) nacelle with a footprint of 17 m by 4 m (approximately 56 feet by 13 feet) requires a deck capacity of roughly 4.5 tons/meter^2 (925 psf). Typical ocean class deck cargo barges have a deck capacity of 10 tons/meter^2 (approximately 2,050 psf).

3.4.1.10 Safety Equipment

Marine installation vessels also must be equipped with life saving equipment (including life boats), a fire protection system, and pollution prevention equipment. These requirements would not be unique to turbine installation vessels.

3.4.1.11 Requirements Associated with Alternative and Future Vessel Uses

It is possible that a purpose-built wind turbine installation vessel could be employed in other services, such as general marine construction (e.g., harbors, wharfs, piers, bridges) or offshore oil and gas. In both of these industries, there currently exists a wide range of vessel types and capabilities in response to a diverse set of needs. A wind turbine installation vessel would be a highly capable marine construction vessel. For the oil and gas industry, a wind turbine installation vessel would fall in the middle of the "capability spectrum" (e.g., being able to out-perform smaller work boats, but being incapable of performing the most challenging operations). The economic viability of using a purpose-built wind turbine installation vessel in other industries is difficult to predict, since the market forces that generally drive charter rates are highly volatile and industry specific.

3.4.1.12 Parametric Cost Estimate

The capital cost for a new-build jack-up crane barge ranges from $40M to $80M (see Appendix A). New-build self-propelled jack-up crane vessels have been reported to cost between $150M and $250M. However, new-build cost estimates are few and difficult to verify. For perspective, a simple deck cargo barge 90 m (approximately 300 feet) in length x 27 m (approximately 90 feet) beam can cost up to $20M. A mid- to large-sized, state-of-the-art, ice-breaking arctic research vessel with several specialized onboard systems can cost between $100M and $150M.

3.4.2 Tugboat and Auxiliary Vessel Requirements

3.4.2.1 Tug Boat Requirements

Self-propelled wind turbine installation vessels will likely not require tug assistance, as they would be able to move and position themselves using their own propulsion and dynamic-positioning systems. Barges, on the other hand, would require at least one tug of 3,000 to 3,750 kW (approximately 4,000 to 5,000 hp) (see Appendix A). In addition, a smaller tug of around 745 kW (1,000 hp) may be needed to help position the vessel for jacking operations. If a feeder (shuttle) barge is used to transport turbine components from the port staging area to the wind farm site, a 1,500 to 3,750 kW (approximately 2,000 to 5,000 hp) tug would be required to tow and position the barge. These types of tugs are readily available for hire along the entire Northeast coast and should not be a limiting factor.

3.4.2.2 Crew Boat Requirements

For ongoing maintenance, a high-speed crew boat is an essential component of marine logistics. High-speed crew boats, capable of carrying 15 to 20 passengers, are required during wind farm construction. At the peak of construction activity, two boats may be required. Once again, this service is readily available along the entire East Coast and should not be a limiting factor. In Europe, special vessels and foundation boarding arrangements have been developed solely for accessing turbines in rough sea conditions.

3.4.2.3 Other Auxiliary Vessel Requirements

Several auxiliary vessels, which are readily available for hire, are needed to round out the marine fleet for the complex task of building an offshore wind farm. These auxiliary vessels include:

- dredging equipment;
- cable laying vessels;
- survey vessels; and
- rock laying vessels (to provide scour protection around turbine foundations).

Once again, these vessels are readily available along the entire East Coast and should not be a limiting factor.

3.5 Navigational Access and Transit Distances

The required navigational clearances for vessels involved in the construction and maintenance of offshore wind farms were evaluated. The key considerations for navigational access are:

- Vessel draft compared to navigable water depth;
- Vessel beam (including overhanging cargo) compared to channel width; and
- Vessel air draft compared to overhead clearance restrictions (e.g., bridges and aerial cables).

Turbine installation vessels govern the air draft and channel width requirements. Turbine import vessels govern the draft requirements (e.g., navigable water depth). Tables 3-10 and Table 3-11 summarized required vessel clearances for turbine import vessels and turbine installation vessels, respectively. Table 3-13 summarizes the navigational restrictions associated with selected Massachusetts ports. Further details are given in Appendix A.

Table 3-13
Summary of Navigational Constraints at Selected Massachusetts Ports

Staging Port	Potential Obstructions	Lateral Clearance	Overhead Clearance	Controlling Water Depth	Feasible Turbine Load-Out Configurations	Jack-Up Feasible?
New Bedford	Hurricane Barrier	45 m (150')	No Constraints	6.7-9.1 m (22'-30')	all	yes
Gloucester	water depth, channel width	61 m (200')	No Constraints	4.9-5.8 m (16'–19')	fore-aft bunny ear	Marginal (water depth)
Fall River	Mt. Hope Bridge	122 m (400')	41 m (135')	12.2 m (40')	star	Marginal (air draft)
South Boston	Logan Airport	over 150 m (500')	Report air draft to airport traffic control	12.2 m (40')	all	yes
Charlestown / East Boston (inner harbor)	Logan Airport	over 150 m (500')		12.2 m (40')	all	yes
Mystic River	Tobin Memorial Bridge	over 150 m (500')	41 m (135')	7.6-10.7 m (25-35')	star	Marginal (air draft)

Staging Port	Potential Obstructions	Lateral Clearance	Overhead Clearance	Controlling Water Depth	Feasible Turbine Load-Out Configurations	Jack-Up Feasible?
Chelsea River (West of Chelsea St. Bridge)	Andrew McArdle Bridge	53 m (175')	No Constraints	8.8-12.2 m (29-40')	fore-aft bunny ear	yes
Chelsea River (East of Chelsea St. Bridge)	Chelsea St. Bridge	28 m (93')	25 m (83')	8.8-12.2 m (29-40')	rotor disassembled	no

Transit distances from potential New England staging ports to the proposed or possible offshore wind farm sites are included in Table 3-14.

Table 3-14
Distances from Regional Ports to Proposed Wind Farms

Staging Location	Ports	Distance (nautical miles)	Alternative Route A [Around Nantucket Island] Distance (nautical miles)	Alternative Route B [Through the Cape Cod Canal] Distance (nautical miles)
Delaware Bay (Deepwater)	Boston, MA	470		330
	Gloucester, MA	445		330
	New Bedford, MA	260		Not Applicable
	Portland, ME	500		400
	Fall River, MA	250		Not Applicable
	Quonset/Davisville, RI	280		Not Applicable
Block Island (Deepwater/Northwind)	Boston, MA	295		120
	Gloucester, MA	270		120
	New Bedford, MA	50		Not Applicable
	Portland, ME	325		190
	Fall River, MA	45		Not Applicable
	Quonset/Davisville, RI	35		Not Applicable
Nantucket Sound (Cape Wind)	Boston, MA	130	270	130
	Gloucester, MA	105	240	120
	New Bedford, MA	60	n/a	Not Applicable
	Portland, ME	160	295	200
	Fall River, MA	75	Not Applicable	Not Applicable
	Quonset/Davisville, RI	70	Not Applicable	Not Applicable
MA OMP Wind Sites (Nomans Land Island)	Boston, MA	260		100
	Gloucester, MA	235		100
	New Bedford, MA	35		Not Applicable
	Portland, ME	290		175
	Fall River, MA	50		Not Applicable
	Quonset/Davisville, RI	40		Not Applicable

3.6 Staging Port Through-Put Estimates

This section examines the expected level of activity at a port serving as a staging area for offshore wind farm development. Multiple wind farm construction scenarios were considered in order to develop upper and lower bounds of expected port activity. For this analysis the primary metric of port activity is the number of wind turbines deployed per month, which is referred to as "through-put."

A desktop tool for estimating the construction time line for an offshore wind farm was applied. This time line tool considers numerous parameters representing vessel characteristics, climatology, at-sea construction capabilities, and other project considerations. Using this tool, the expected through-put of wind turbines at a staging port was estimated for a range of wind farm construction scenarios. Each scenario was defined by vessel type, transit distance, and the length of the construction season. The methodology and analysis are detailed below.

Table 3-15
Excerpt from Time Line Model Illustrating the Typical Work Breakdown Structure
(Source: The Glosten Associates 2009)

Cycle Start Time	**10/14/12 20:22**
Cycle #	1
Supply Chain Delay at Staging Area [hours]	0.0
Load Vessel [hours]	24.0
VESSEL LOADED	**3/25/13 18:21**
Vessel Transit to Wind Farm Site [hours]	25.0
Weather Availability for Jacking Up	86%
Jack Up [hours] (includes weahter delay)	9.3
Weather Availability for Installation	61%
Installation of Monopile/Turbines [hours] (includes weather delays)	88.5
Jack Down [hours] (includes weather delays)	4.6
INSTALLATION COMPLETE	**3/31/13 1:48**
Vessel Transit to Staging Area [hours]	25.0
VESSEL ARRIVES AT STAGING AREA	**4/1/13 2:48**
Turbines Installed (total)	3
Cycle Start Time	**4/1/13 2:48**
Cycle #	2
Supply Chain Delay at Staging Area [hours]	0.0
Load Vessel [hours]	24.0
VESSEL LOADED	**4/2/13 2:48**
Vessel Transit to Wind Farm Site [hours]	25.0
Weather Availability for Jacking Up	93%
Jack Up [hours] (includes weahter delay)	8.6
Weather Availability for Installation	72%
Installation of Monopile/Turbines [hours] (includes weather delays)	74.6
Jack Down [hours] (includes weather delays)	4.3
INSTALLATION COMPLETE	**4/6/13 19:16**
Vessel Transit to Staging Area [hours]	25.0
VESSEL ARRIVES AT STAGING AREA	**4/7/13 20:16**
Turbines Installed (total)	6

3.6.1 Methodology and Assumptions

The desktop time line model breaks down the overall wind farm construction process into discrete tasks, assigns a time requirement to each task, and builds a sequential time line for the principal activities. Some tasks have a limiting weather criterion, such as maximum wind speed for conducting crane operations. The time line model cross-references each weather-dependent task with site-specific monthly climatology data to determine whether that task is subject to weather delay.

The work breakdown model is illustrated by the excerpt presented in Table 3-15.

The following is a list of the assumptions that were used in the time line modeling:

1. Study considers turbine construction only. Foundation installation is accomplished independently and with different marine equipment.
2. One installation vessel is utilized at a time.
3. Foundation construction does not delay turbine installation.
4. Operations (and delays) at the staging area do not delay turbine construction. In other words, the turbine installation vessels (TIVs) do not "wait" for the staging area operations.
5. Staging area has 24-hour / 365-day operation.
6. Existing Vessels are capable of transporting 3 turbines.
7. Future Vessels are capable of transporting 5 turbines.
8. Installation vessels are capable of 6-10 knots transit speed.
9. Limiting wind speed for Existing Vessels is 15 knots.
10. Limiting wind speed for Future Vessels is 25 knots.
11. Limiting wave height for jack-up operations (all vessels) is 2.0 m.
12. For Existing Vessels, time to erect one turbine is 12 hours, once on-site and vessel is jacked-up (excluding weather delays).
13. For Future Vessels, time to erect one turbine is 8 hours, once on-site and jacked-up (excluding weather delays).
14. Wind and wave conditions based on U.S. East Coast from Delaware Bay to Cape Cod.

3.6.2 Analysis

The potential utilization of a single port for three different staging scenarios was modeled for this analysis. These scenarios, which all assumed New Bedford, MA as the staging port, were:

- Baseline - The Baseline scenario was defined as:
  - One offshore wind farm project staged out of New Bedford, MA, using Existing Vessel type.
  - Number of turbines: 130
  - Transit distance from staging area to wind farm site: 50 nautical miles
- Optimistic - The Optimistic scenario was defined as:
  - Two projects staged out of New Bedford, MA, using Existing Vessel type.

- Projects are sequential in time (not concurrent).
- Number of turbines for Project 1: 130
- Number of turbines for Project 2: 100
- Transit distance from staging area to wind farm for Project 1: 50 nm
- Transit distance from staging area to wind farm for Project 2: 50 nm

- Aggressive - The Aggressive scenario was defined as:
  - Three projects staged out of New Bedford, MA, using combination of Existing and Future Vessel types.
  - Projects are sequential in time (not concurrent).
  - Projects 1 and 2 use conventional vessel type.
  - Project 3 uses future vessel type.
  - Number of turbines for Project 1: 130
  - Number of turbines for Project 2: 100
  - Number of turbines for Project 3: 200
  - Transit distance from staging area to wind farm for Project 1: 50 nm
  - Transit distance from staging area to wind farm for Project 2: 50 nm
  - Transit distance from staging area to wind farm for Project 3: 150 nm

These scenarios are based on development plans discussed during interviews with project developers in July and August of 2009.

3.6.3 Results

The results of the desk top time line modeling of these scenarios for New Bedford, MA were as follows:

- The time line modeling of the Baseline scenario for turbine staging and installation yielded an expected through-put of 15-18 turbines per month for 6-9 months.
- The time line modeling of the Optimistic scenario for turbine staging and installation yielded an expected through-put of 16-22 turbines per month for 12-15 months.
- The time line modeling of the Aggressive scenario for turbine staging and installation yielded an expected through-put of 15-20 turbines per month for 12-15 months; Thereafter, a through-put of 21-25 turbines per month was expected for an additional 8-10 months.

Additional wind farm construction scenarios were evaluated to develop a better estimate of the potential ranges of through-put that may be required at regional staging ports. Each scenario was defined by a vessel type, a transit distance and a length of the construction season. The results of these multiple modeling runs are summarized in Table 3-16.

Table 3-16
Expected Through-Put at Staging Port for Various Construction Scenarios
(Source: The Glosten Associates 2009)

Transit Distance (staging port to wind farm site*)	Existing Vessels**		'Future' Vessels***	
	Summer	Winter	Summer	Winter
50 nautical miles	20-22 turbines/month	16-18 turbines/month	30 turbines/month	30 turbines/month
150 nautical miles	18-20 turbines/month	15-17 turbines/month	21-25 turbines/month	21-25 turbines/month
250 nautical miles	15-17 turbines/month	12-15 turbines/month	16-20 turbines/month	16-20 turbines/month

Notes:
* The transit distance from New Bedford to the Cape Wind site is approximately 60 nm. The transit distance from Boston to Cape Wind is approximately 130 nm. The transit distance from New Bedford to the Deepwater sites near Delaware Bay is approximately 260 nm.
** Existing Vessels means jack-up vessels or barges with slewing cranes, typical of present European offshore wind farm construction practice.
*** Future Vessels means vessels or barges that transport and install fully assembled turbines.

It should be noted that the above through-put estimates are for turbine installation only. Foundation installation is typically completed in advance of turbine installation and can utilize a wider range of vessels and staging ports than turbine installation. For U.S. offshore wind farms, foundation installation can be completed using existing equipment.

3.6.4 Near-Term and Long-Term Demands on Staging Port Support Infrastructure

In the near term (i.e., now through year 2013), a port supporting offshore wind farm development is expected to handle approximately 18 to 22 turbines per month. This estimate assumes that projects are within 150 nautical miles (i.e., a transit distance) of the staging area and that construction operations will take place during spring, summer and fall using conventional methods (see Appendix A). Based on the above turbine through-put estimates, the near-term demand for support infrastructure at an offshore wind farm staging port is approximately as follows:

- 40-90 annual port calls (for cargo vessels delivering components);
- 70-90 annual port calls (for wind turbine installation vessel); and
- 54,500-81,700 mt (approximately 60,000-80,000 tons) of cargo loaded and discharged annually.

These near-term estimates assume:

- 18-22 turbines deployed per month for 12 months;
- cargo vessels deliver 3-5 turbines per port call;
- installation vessel loads 3 turbines per port call; and
- total turbine weight is 272 mt (approximately 300 tons).

Looking ahead to year 2014 and beyond, a port activity level as high as 30 turbines per month may be expected assuming an increase in vessel capabilities compared to the present technology. Based on the above turbine through-put estimates, the long-term demand for support infrastructure at an offshore wind farm staging port is approximately as follows:

- 90-120 annual port calls (for cargo vessels delivering components);
- 120 annual port calls (for wind turbine installation vessel); and
- 99,900-227,000 mt (approximately 110,000-250,000 tons) of cargo loaded and discharged annually.

These long-term estimates assume:

- 30 turbines deployed per month for 12 months;
- cargo vessels deliver 3-5 turbines per port call;
- installation vessel loads 3 turbines per port call; and
- total turbine weight is 272-635 mt (approximately 300-700 tons).

3.7 Staging Port Support Facility Requirements

One developer that was interviewed provided a description of the "ideal" port facility to support offshore wind. In their view, the port would have: a 910 mt (approximately 1,000 ton) crane on rolling tracks that would carry components from a delivery vessel to a storage location; enough linear water front footage or berthing to efficiently load/unload one vessel (with a preference for multiple deepwater berths to potentially unload several vessels concurrently); and about 80 hectares (approximately 200 acres) for assembly and storage.

While no existing Massachusetts port facility has an assembly and staging area this large, the existing Commonwealth facilities could be repaired, upgraded, or expanded to provide sufficient area to meet the other requirements for staging offshore wind farm construction. If it is necessary to provide a larger area at these existing facilities, then a combination of properties at these marine parks or a combination of ports would have the ability to provide additional space. If the berthing area is sufficient, moored barges also could be used for storage.

3.7.1 Physical Considerations Relative to Staging Turbines

There are a few minimum physical port characteristics that are necessary to stage offshore wind farm development. Based on a review of various European projects and available manufacturers, as well as discussions with potential U.S. offshore wind developers, the minimum desirable characteristics include:

1. 7.3 m (approximately 24 feet) depth of water at low tide;
2. minimum 137 m (approximately 450 feet) berth;
3. minimum channel clearance to harbor of 40 m (approximately 150 feet);
4. no restriction or air draft limitation on vertical clearance (in anticipation of a future need to transport fully assembled turbines to the installation site); and
5. relatively short distance in open water to project site.

3.7.1.1 Harborside Area

The harborside characteristics of a staging port facility present the most pertinent information to determine whether a port is worthy of consideration for wind farm construction staging. Water depth criteria directly dictate options with respect to the vessel type, draft and function. Tidal fluctuations change the water depth twice a day. Therefore, the minimum water depth at low tide is the appropriate characteristic to consider with respect to the navigation channel and berth.

The deepest draft vessel used for transporting offshore wind components sets the navigation depth criteria. Horizontal channel clearance not only depends on vessel beam, but also on component overhang during transport to the installation site. An unobstructed vertical clearance is highly recommended. Turbine manufacturers expect 60 m (approximately 197 feet) tall tower sections to be transported to the installation site in the upright position. If the turbines are fully assembled for transport, then the nacelle and blade would add significantly to this height. Furthermore, various installation tasks require jack-up vessels, the retracted legs of which would be in the 'up' position. The Philadelphia Regional Port Authority has submitted a Transportation Investment Generating Economic Recovery (TIGER) application to build a purpose-built wind turbine installation vessel; the jack-up legs are 75 m (approximately 246 feet) long. However, there may be methods for working around vertical obstructions, such as placing a connector pin in the legs or utilizing a hydraulic leg that compresses within itself. The salient point, however, is that vertical obstructions can limit the range of acceptable assembly, transport, and vessel options.

With visits from import vessels and transport or installation vessels overlapping, multiple berths or longer berths become more desirable. The required length of berthing at a staging port is linked to the size of the project and the delivery schedule for its components. If the project is "fast track", the actual amount of material at the staging site might be small in comparison to what is there for a "normal" project. The material would arrive as soon as complete, rather than being stored at the manufacturer's facility, and would be shipped in the most cost-efficient manner in a vessel filled to capacity. The larger berth would also allow for delivery vessels to operate concurrently with the jack-up or other purpose vessels at the dock.

3.7.1.2 Landside or Lay Down Area

The landside or lay down area required for a project is also tied to the project size. More turbine units will require more space. One of the ways that a lack of space at a given site has been addressed in the past is to use alternate sites for different functions. The needs of the foundation contractor may be different from those of the turbine assembly contractor. One approach would be to stage these two functions from different sites. Although the port criteria for turbine assembly may be slightly different from those for foundation assembly, since there is some overlap in the type of vessels used for these different functions, in general, the same or similar staging criteria can be applied to both.

The interviews with developers indicated that the lay down area is seen as one of the most important logistical elements for a staging port facility. It is crucial to have sufficient space to efficiently store and assemble turbine or foundation components. The developers that were interviewed provided the information contained in Table 3-17 regarding indoor/outdoor storage requirements:

Table 3-17
Indoor/Outdoor Storage Requirements
(Source: Developer interviews)

Landside Requirements / Staging Area	4 to 10 hectares (approximately 10 to 25 acres) (Bluewater, Cape Wind)
Quayside Area	150 to 300 m (approximately 500 ft to 1,000 ft) (Cape Wind)
Inside Storage Area	Approximately 465 m^2 (5,000 sq. ft.) (Cape Wind) to up to 929 m^2 (10,000 sq. ft.) (Bluewater Wind with regard to European Experience)
Accommodation Area (e.g., for offices and dormitories for workers)	Approximately 1,400 m^2 (15,000 sq. ft.) (Deepwater)

3.7.1.3 Onshore Construction Area

Developer needs for onshore construction include space for delivery, storage and assembly of turbine components. The estimates obtained for the amount of onshore construction area needed varied widely among the developers, manufacturers and representatives of European staging facilities, but a minimum of 4 hectares (approximately 10 acres) was indicated to be required with 6 to 10 hectares (approximately 15 to 25 acres) of available space being more desirable. If a large development (e.g., 110 turbines) were to be fully accommodated on land, including both assembly and foundation components, the area required would be about 80 hectares (roughly 200 acres). However, the logistics of manufacture, assembly and installation would never require all units to be co-located on the ground at one time.

To maximize the use of construction equipment, vessels and crews, turbine suppliers require storage based on two factors: (1) having a supply of turbine components ready for assembly and deployment; and (2) having an additional area ready for instances where weather precludes deployment to the installation site while import vessels continue to deliver components to the staging port. While turbine assembly continues, the newly arrived unassembled turbine components would need to be stored. Based on manufacturer's recommendations, and assuming storage of 20 or more turbines, the minimum space needed in this scenario is about 3.4 hectares (approximately 8.5 acres). One of the foundation manufacturers suggested that lay down (not manufacturing) might require 1.5 to 2.0 hectares (approximately 4 to 5 acres). Another manufacturer suggested that each turbine (and its components, except foundation) would require about 6,500 sf, which would require an additional 1.2 hectares (approximately 3 acres). The pre-assembly area based on one manufacturer's recommendation would be 200 m x 50 m or 1.0 hectare (or 650' x 165' or 2.5 acres). This suggests that, without foundations, the minimum space needed is about 8.5 acres. Additional area (possibly 0.4 to 3.2 hectares [1 to 8 acres]) would also be needed for parking, field trailers, traffic lanes, and other support functions.

If a through-put of 18 to 22 turbines per month would be deployed to the installation site (based on the results of the time line modeling discussed above), the turbine manufacturer would want 20 nacelles stored at the staging port in advance of assembly and deployment. As workers assemble the turbines in preparation for loading onto the installation vessel, and bad weather hits the installation site, the assembled turbines would have to be stored at the port.

Unassembled turbine components would continue to arrive from the manufacturer and require additional storage space for 20 more turbines.

The preferences for features outlined below for the onshore construction area are based on an offshore wind farm consisting of 30 to 60 turbines and describe a port staging area for wind turbines only. The following information was drawn from one manufacturer's specifications (Vestas Offshore A/S 2008). There may be engineering solutions that could provide alternative arrangements to meet the parameters discussed below.

General

Total onshore area	4.5 to 7 hectares (10 to 17 acres)
Variation factors	Shape of area, Number of turbines, Delivery sequence of turbines
Pier length	Minimum 150 m (495'), preferably 200 m 650') or more
Water depth at pier	Minimum 6.0 m (20')
Assembly area	Pier Length and 40 m (130') behind pier

Details

Electrical

Electrical power supply should be 3 x 400 volts alternating current (V AC) (60 hertz [Hz]) and at least 200 amp capacity. Major power consumers would be offices, welding and machining, and air compressors. It is preferred that the entire site be fully illuminated to facilitate safe night work.

Area Details

Assembly Area	0.5 – 1.0 hectares (1.5-2.5 acres)		
Storage Area	3.5 – 5.0 hectares (9-12.5 acres)	400 m^2 (4,300 ft^2) sheltered with a minimum clear height of 3.5 m (12 ft)	100 m^2 (1,100 ft^2) secured and dry
Access, Office, Parking	0.5 – 1.0 hectares (1.5-2.5 acres)	About 200 m^2 (2,200 ft^2) office and social area.	For minimum 20 persons
Total Site Area	4.5 – 7.0 hectares (11-17.5 acres)		

The area should be enclosed by fencing with a guard or some type of security system. Water supply for fire fighting and general consumption should be available, as well as a wastewater system. A suitable drainage system should be installed that meets all regulatory requirements for stormwater discharge effluent limits.

Onshore Handling Equipment

The following equipment most likely would be necessary for offloading, assembling, and deploying offshore wind turbines:

1	Large crawler crane (DEMAG CC2800 or similar with 78 m boom length), approximately 2,500 tm as 250 mt at 10 m radius
1	Medium crawler crane (Liebherr LR1400 or similar with 42 m boom length), 600 to 800 tm capacity
1	Truck mounted crane, 150 tm capacity
1	Cherry picker (telescopic personnel lift for min 2 persons)
1	Forklift (3 mt (3.5 ton) capacity)
1	Terrain moving telescopic forklift (3 mt (3.5 ton) capacity)
1	Terrain moving telescopic forklift with turntable (3 mt (3.5 ton) capacity)
1	Terrain moving transport vehicle (2-3 persons and minor parts and equipment)
1	Triple axel trailer (suitable for blade transport) moveable with crane truck or similar
1	Self propelled low loader (suitable for tower transport, 150 – 200 mt (165-220 ton) capacity)

3.7.1.4 Inside Storage / Assembly Space

Some interior storage and/or fabrication space is required for most projects. Developers, contractors and manufacturers also have a strong preference for onsite office space. Again, estimates of this requirement varied significantly among those interviewed. While some suggested 464 m^2 (approximately 5,000 square feet) would be adequate for interior storage, assembly and office space, a minimum of 930 m^2 (approximately 10,000 square feet) with appropriate access characteristics was the consensus. Facilities for worker accommodations at the staging location or on a 'hotel' ship at the installation site have been used for some offshore wind farm constructions overseas. One developer suggested an accommodation area of 1,400 m^2 (approximately 15,000 square feet) for office space and worker dormitories. The amount of available inside storage or assembly space did not emerge as a major factor in staging facility selection decisions. None of the Massachusetts Designated Port Areas (DPAs) has such a convenient facility. At this stage of planning, most of the developers had given little thought to such needs. Nevertheless, the DPAs in Massachusetts do have nearby accommodations. Construction workers at the offshore installation site would expect to work in shifts for a 24-hour operation. Crews can travel back and forth on fast transport vessels from the construction site to various points on land, thereby eliminating the need for on-site accommodations (Vestas 2008).

3.7.1.5 Load Capacity

Based on the weight of many of the components, the lay down space may require very high capacity ground or deck. Using a simple "footprint" analysis, these loads can reach over 9.8 mt/m^2 (approximately 2,000 psf). As with many of the facility needs, the deck/ground capacity issue can be accommodated by using certain types of equipment or by placing "load spreading" mats or slabs. Various cranes and other types of material handling equipment will be needed, but it is anticipated that the fabrication or erection contractor would provide these items.

The need for high ground or deck capacity suggests that perhaps a solid fill backland is more appropriate than an open pier type structure, which provides an opportunity for the contractor to establish high load zones as necessary in its lay down configuration. Open pier structures require high capacity piles relatively closely spaced. Historically general cargo and container terminal wharves and piers have load capacities of approximately 2.9 metric tons/m^2

(approximately 600 psf, with the exception being 4.9 mt/m^2 (approximately 1,000 psf) at some terminals. From a cost standpoint, this is often impractical for pile supported structures. Solid fill structures, once out of the active earth zone, can easily have 9.8 metric tons/m^2 (approximately 2,000 psf) load capacity. Load capacity was not used as a criterion to short-list the ports, but rather was a consideration that was further analyzed in the engineering review of the short-listed facilities.

3.7.2 Physical Considerations Relative to Staging Foundations

Some of the harborside restrictions set out for turbine transport may not apply to foundations, because foundations are less delicate and can be transported flat on barges. Barge transport of foundations would not entail the same height, draft or clearance requirements as turbine transport. However the foundation installation vessel may have similar characteristics as the turbine installation vessel. If the foundation installation jack-up vessel was at the construction site and barges were used to transport foundations to the site, then there would be more options for the staging facility. Facilities that are not suitable to stage turbine construction/installation because they are upstream of a bridge with a 41 m (approximately 135') clearance height or require 7.3 m (24') draft or other restrictions could possibly stage foundation deployment.

The review of the currently planned projects indicated that roughly 744 or more turbines would be deployed off the Northeast Coast of the United States (Delaware to Massachusetts). The planned projects examined would create a combined need for 544 monopile foundations and 200 jacket foundations. Monopile foundations are basically large diameter rolled steel piles. Monopiles are comprised of rolled steel plate (3.8 to 12.7 cm (1.5 to 5 inches) thick) components between 2.1 and 5.5 m (approximately 7 feet and 18 feet) in diameter, and often fabricated in 4.5 to 4.6 m (15' to 16') long sections. Jacket foundations are lattices of steel members. Both types of foundations require a transition piece which is also a rolled steel pipe section, with additional add-ons such as electric cable tubes, climbing ladders, platforms and docking areas. Tower sections are also rolled steel. These tend to be supplied by the turbine manufacturers along with the other turbine components.

The staging requirements for foundations depend upon the stage of assembly as they arrive and the size and type of foundation. The size of the foundation depends on the size of the assembled turbine with tower, transition and blades and the maximum wind load imposed on them, as well as the geotechnical conditions at the installation site. The staging facility will need landside areas for loading and unloading, storage, and potentially for assembly of foundations components

Partially assembled foundations would still likely arrive at a Massachusetts facility by vessel. Steel sections for jacket assembly might come from the Gulf of Mexico or overseas. Shipping the steel sections allows for maximizing cargo space and minimizes shipping costs relative to transporting a fully assembled jacket foundation. A factor in selecting a shipping method is the difference between the shipping cost and the labor cost of field welding the bars together. The selection also may depend on the availability of a skilled labor force of welders at the assembly location.

3.7.2.1 Manufacturing and Assembly Requirements

Monopile manufacturing utilizes a series of specialized machines. Modern versions of this equipment are not currently available on the East Coast of the United States. The industry views the potential market as lucrative enough to consider opening facilities in anticipation of offshore wind energy development. However, the investment risk remains similar to that felt by turbine manufacturers and the purpose-built vessel industry. Until a demand for product emerges sufficient to project a profitable return on investment, monopiles for East Coast offshore wind farms will probably come from elsewhere. The difference here is that a piecemeal approach can reduce the initial investment risk. Initial wind farm construction will probably see monopile pieces shipped to a staging facility as 'cans', or basically smaller sections of rolled steel. At the staging location the 'cans' would be welded together to form the pile sections appropriate for the installation.

One European steel fabrication firm expects that a functional facility would need roughly 16,900 m^2 (approximately 182,000 ft^2) of production floor. The facility would require high capacity floors and fabrication cranes with 136-182 mt (150 - 200 ton) capacity, rail access, and water access. Like the foundation assembly facility, the required water depth for a foundation staging facility would likely be less than is required for a turbine staging facility.

3.7.2.2 Storage Requirements

The storage requirements for foundations are more flexible than the turbines since they are less sensitive structures. The foundation elements will be exposed to the harsh marine environment during their life, and are designed to be exposed to these harsh conditions. If there is a backlog of deployment causing foundation storage to overlap significantly with turbine component storage, then the required storage area could increase by 2 to 4 hectares (approximately 5 to 10 acres). Potentially, barges also could provide additional storage in a sheltered bay or harbor area.

3.8 Rail and Road Access

Issues of port access for the large offshore wind generation components being delivered via rail and highway are unique for each port. There is the potential for delivery of components from domestic North American suppliers, such as those located in the State of Colorado. Height, width, curve radius, and weight limitations associated with rail or roadways are potential constraints. Turbine pieces could potentially be transported by component or sections (including tower sections, wind blades, and nacelles). Turbine sections and wind blades would be transported horizontally and nacelles vertically on transport units, at least for current wind turbines being deployed. This will become less viable as the larger, next generation offshore wind turbines become available.

Shipment specifications (dimensions and weights) for typical offshore nacelle components are presented in Table 3-18.

Table 3-18
Dimensions and Weights of Turbine Components
Technical Data for Vestas V112-3.0 MW
(Source: Vestas 2009a)

Turbine Component	Dimensions			
	Weight	Length	Height	Width/Diameter
Monopile Foundation	150 to 210 mt (165 to 231 ton) for 28 to 40 m (92' to 132') long monopile 500 mt (551 ton) for 60 m (200') long monopile	Varying 28 - 40 m (92' to 131') up to 60 m (197')	N/A	d: 5 m to 5.5 m (16.75' to 18')
Transition Piece	170 mt (187 ton)	17 m (56') per unit	N/A	d: 4.2 m (13.8')
Nacelle (including hub)	125 - 150 mt (138 to 165 ton)	14 m (46')	3.3 m (10.8')	w: 3.9 m (12.8')
One Blade	12.5 to 18 mt (13.77 to <20 ton)	54.6 m (179')	N/A	Max. w: 4.2 m (13.8')
Tower Section	Approximately 70 mt (77.16 ton)	32.5 m (106.6')	N/A	d: 4.2 m to 4.5 m (13.7' to 14.76')

N/A = Not applicable

3.8.1 Overview of Rail

In general, the weight and length proposed for the units (excluding blades) can be handled by rail in the nationwide system depending on how finite certain components can be broken down. There are various routes throughout the United States that can be employed for shipments of oversized shipments. Main line route movement is easier to address than final delivery by rail to the various ports. In Massachusetts, delivery to central distribution points would include Beacon Park Yard in Allston (which is operated by CSX) or Ayer (which is operated by Pan Am Railways in conjunction with Norfolk Southern). From this point, equipment would travel on secondary routes to each of the port areas. There are differences in right of ways, bridge clearances and secondary access corridors for rail lines throughout the United States and in the region. It can be assumed that if the rail link between the manufacturer and a main line rail corridor can handle the equipment that the main line corridor can move the equipment anywhere in the country. For the most part, if there are any unique choke points, there are sufficient other corridors available to handle the move. All of the ports in Massachusetts have rail access. However, direct waterfront access varies by area.

The ability to move component parts via rail is determined by rail corridor track curvatures, component weights, and loaded height on the rail car.

Curvature: The lines to port facilities vary in terms of curvature, so specific routing and the need for single overhang vs. double overhang vs. bolster load loadings must be considered to address any length issues associated with the specific equipment being shipped. Overhang is simply the extension beyond the limits of the rail car either at one end or both. The overhang depends upon the length of the item carried and where the center of gravity is for the load.

Weight: In general, a weight of 81.7 mt (90 tons) can be loaded onto a standard rail car. Heavier loads would require either special equipment that is available in various configurations (including a bolster load and are able to carry up to about 363 mt (400 tons)). The bolster is the part of a railroad car body underneath that connects the truck's pivot to the body (see

Figure 3-21). The bolster also includes and refers to the cross members which provide the frame for the rail trucks which is the piece between the side frames. The bolster load is the maximum weight that the bolster frame and truck assembly can support. Boston and New Bedford's rail network would support standardized loads up to the limits indicated for the rail system. New Bedford track conditions are, in general, not as good as in Boston.

Figure 3-21 Rail Trucks
(Source: MARPRO Associates International 2009)

Height: Heights limitations are very route specific. Overall first generation clearances for container doublestack cargo movement are 5.8 m (19 feet) "above the rail" (ATR). Second generation clearances are approximately 6.8 m (22' 6") ATR. In most cases, Massachusetts rail lines to ports average 5.2 m (17 feet) ATR.

In general, components can be designed to be transported on the national rail system (see Figure 3-22). They can be broken down to insure they do not exceed rail system limitations on weight or clearance. It can be clearly seen in Figure 3-22 that component heights, when loaded on rail equipment, generally average a similar height to standard rail box cars.

Figure 3-22 Broken Down Wind Components on Rail Cars
(Source: MARPRO Associates International 2009)

3.8.2 Overview of Road Transport Requirements

Overweight and large shipment units are limited to State permitting requirements. These requirements allow an excess of 1,240 kg (88,000 pounds) only on roadways either specially designated for such shipments or with the use of specialized equipment such as tri-axle trailers. Shipments are generally limited to a maximum of 1,410 kg (100,000 pounds) and are often only permitted during certain time periods (such as off-peak or overnight periods). Infrastructure is also considered in permitting applications including limitations from overhead utilities, road lighting, road curvatures and intersections.

3.9 Implications of Distance

Developers identified cost as a critical consideration. Under the precept of “time equals money”, schedule generally has a strong impact on project cost. The distance between a staging port and the installation site affects costs both in terms of fuel schedule. Distance also has an effect on controlling the risk of damage or loss during transport. When expensive turbine components are in transit from the staging port to the installation site they are more vulnerable to ocean and weather effects and motion accidents than when they are being managed from a vessel stabilized by jack-up legs. The proximity of the staging port to the installation site, therefore, is a factor in reducing risks and costs and risk.

In terms of component delivery to the staging port, distance also is an important factor, but not typically an overriding factor for the project. Required components and raw materials for a project may come from Europe, Colorado, or Brazil. One manufacturer that was interviewed advised that industry on the Gulf Coast is already set up to manufacture the steel pieces needed for jacket piles. This manufacturer expects to barge the fabricated pieces to a location closer to the installation site for assembly. He believes that manufacturing and shipping is more cost-effective than setting up a manufacturing facility in the region. However, at the same time, the manufacturer wants an assembly location relatively close to the fabrication site so that he does not have to “ship air” (i.e., the spaces between the framework members).

4.0 EVALUATION CRITERIA

The information presented earlier in this report was developed to identify a broad set of direct requirements and highly desirable characteristics of port facilities relative to supporting offshore wind farm construction and operation. In this section, the broad list of considerations is analyzed and further distilled down to a smaller set of criteria that can be used to effectively and adequately differentiate the identified Massachusetts port facilities from each other based on their potential to support offshore wind energy development.

4.1 Summary of Requirements and Desirable Characteristics

Previous sections of this report have discussed the multiple roles a port plays in staging the construction and maintaining the operation of an offshore wind farm. Particular features and characteristics of the port either enhance the port's ability to perform these roles or represent obstacles to providing those services and supporting those functions. The direct requirements and highly desirable characteristics of port facilities were identified through interviews with developers and wind turbine manufactures and then compiled and evaluated. To facilitate review, these requirements and characteristics were grouped into five general categories:

- Aspects associated with the wharf and yard portions of the port;
- Aspects associated with the berthing facilities of the port;
- Aspects associated with navigation into and out of the port;
- Aspects associated with the geographic location of the port relative to potential projects; and
- Aspects and characteristics of the region in the vicinity of the port.

Table 4-1 lists these grouped requirements and characteristics.

Table 4-1
Groupings of Port Characteristics

Aspects of the Port	Requirement or Characteristic
Wharf and Yard	• Has available inside storage capacity • Has sufficient lay down area for required storage and assembly • Would be able to expand the scale of operations • Has adequate rail or road access • Has previously staged offshore projects or development • Has ready access for and experience with large tugs and support vessels
Berthing Facilities	• Has sufficient berth (length and depth) • Already has large cranes of sufficient size and type • Has piers with high load carrying capacities • Has capacity to handle hundreds of additional port calls/year
Navigation	• Has operations 24 hours/day and 365 days/year • Is in a sheltered harbor • Has no restrictive lateral clearance constraints • Has no restrictive air draft constraints • Has sufficient draft at low tide • Has a short route to open water

Aspects of the Port	Requirement or Characteristic
Geographic Location	• Is located proximate to related marine infrastructure and equipment • Is as close as possible to component manufacturers • Is not subject to excessive extreme weather that can adversely affect operations • Is as close as possible to proposed project sites (including MA OMP Wind Energy Areas)
Region in the Vicinity of the Port	• Has accommodations for workers and visitors • Has, or can quickly develop, a trained work force • Has access to a sufficient workforce • Development is welcomed by the community • Development is welcomed by regulators • Development will contribute to economic growth

First, it should be noted that not all of these collected requirements and characteristics were identified to be equally as critical to a port's ability to successfully support offshore wind farm development. Some are "must have" physical requirements, while others represent desirable characteristics that potentially could be worked around provided other features are present and compensate for their absence. Second, a few of the listed characteristics are complementary and linked. For example, ports with ready access to large tugs and support vessels would almost certainly be located proximate to other related marine infrastructure and equipment. As such, the presence of one generally ensures the presence of the other. Third, some characteristics would be shared by any larger port or any port in the Eastern U.S. For example, all port locations in the region have accessible accommodations for workers and visitors and have access to a sufficient work force. Therefore, these characteristics would not enable one to meaningfully discriminate between the ports being comparatively evaluated.

In consideration of these factors, the requirements and characteristics were distilled down into a smaller set of critical criteria appropriate for the comparative evaluation of the ports. The distillation process was conducted so that all of the considerations that were identified as critical or important were preserved as "hard" requirements, as distinguished from softer trade-off characteristics. The criteria that were developed are presented in the next section.

4.2 Criteria Development

Upon further consideration of the requirements and characteristics identified above, two sets of "hard" requirements were identified for comparing the ports: (1) those related to harbor access (referred to as the 1st Tier Criteria) and (2) those related to the port facilities' attributes needed to meet specific developer and turbine supplier needs (referred to as the 2nd Tier Criteria). In addition, a set of "soft" criteria was developed that is somewhat more subjective but nevertheless allows ports to be distinguished from one another relative to supporting offshore wind farm development. Soft criteria attributes may attract developers to consider one port over another, and the absence of these criteria is likely to have financial consequences to port projects.

4.2.1 1st Tier Hard Criteria Relating to Harbor Access

The 1st Tier Hard Criteria identified relative to harbor access were:

- Sheltered harbor (protected from bad weather by means of a barrier);
- Unobstructed vertical (overhead) clearance;
- Minimum horizontal clearance greater than 40 m (approximately 150 feet);
- Minimum low tide navigational channel depth of 7.3 m (24 feet);
- 24/ hour/day and 7 days/week operational availability; and
- Exclusive use of the staging facility.

Ensuring port access as dictated by developer and turbine supplier needs is essential. Hard criteria related to the logistics of the origin of the turbine components and their method of delivery to the staging port and the installation (construction) site are crucial. Possible delivery modes include seafaring vessels, rail, and trucking (see Section 3). Physical parameters for marine vessels to access a harbor emerge as critical criteria, while rail and trucking access were believed to be present or more easily attainable at the set of ports being compared. Staging ports need to accommodate vessels shipping and handling the large components used for commercial scale wind farms. The greatest vessel draft (depth) establishes the criteria for the shipping or navigation channel depth. The widest vessel beam (width) along with the method of component transport, which may involve overhang, establishes horizontal clearances. Along with vessel height, the options for method of transport also contribute to vertical clearance criteria. The potential for bad weather interruptions and the need to maximize labor and equipment availability makes a sheltered harbor an essential criterion, especially for the barges that are adapted as near-term delivery and installation vessels.

Implications of the cost of contractor mobilization, vessel and equipment utilization combined with weather and seasonal limitations on the construction window result in developers and turbine suppliers requiring a port facility that allows operations 24 hours a day, seven days a week. Given that optimal operations would entail moving large components around the clock, the staging port must also provide exclusive use of the staging facility.

A systematic evaluation of these 1st tier hard criteria will address the navigational considerations identified in Table 4-1.

4.2.2 2nd Tier Hard Criteria Relating to Port Facilities

The 2nd Tier Hard Criteria identified relative to the port facilities were:

- Minimum berth length of 138 m (approximately 450 feet);
- Minimum berth water depth of 7.3 m (24 feet);
- Lay down storage and assembly backland area larger than 4 hectares (10 acres); and
- Proximity to likely offshore wind farm site.

These 2nd tier criteria establish port facility attributes that would accommodate industry vessels. Primarily, these 2nd tier hard criteria must include the water depth at and overall length of the facility berth. Water depth must be sufficient to accommodate industry vessel drafts or must be attainable through routine dredging. Additionally, vessel length and the number of vessels operating simultaneously establish the parameters needed for length of the berth.

The size of the backland area landside of the bulkhead for storage and assembly of the turbine components and the ability to handle the loads of components and construction equipment are significant criteria. The requirements of foundation storage and assembly can increase the area requirements, but foundations do not necessarily need to be staged from the same port or have the same delivery vessel-related restrictions. Port proximity to the construction site can affect operational logistics, risks, and significantly costs. The distance from a port facility to potential wind farm sites, therefore, has significance but becomes secondary to the parameters discussed above. If a maximum distance is established to screen ports, it may follow, however, that closer ports have limitations that could have a persuasive effect on logistics, risks, or costs, thereby making more distant ports the more viable option. This has recently been true for the U.K. where deployment operations have been staged out of Denmark in some cases.

A systematic evaluation of these 2nd tier hard criteria will address the wharf and yard and berthing facility considerations identified in Table 4-1.

4.2.3 Soft Criteria

Soft criteria parameters, as noted above, are other port area attributes that may attract developers to consider one port over another. The Soft Criteria identified were:

- Workforce availability;
- Education and training facilities;
- Political climate/community acceptance; and
- Regulatory considerations.

The location of education or training facilities and work force availability, including various skilled labor trades, could be an important factor in port selection. Soft criteria are discussed in more detail in Section 6.4. European offshore wind developers have reported shortages among skilled workers in related trades. Massachusetts ports have ready access to considerable education and training resources that are geared to offshore and underwater construction, seamanship, and technical trades and services. Taking into consideration the nine-plus years' approval process of the Cape Wind project, which was greatly affected by opposition to the project, political climate and community acceptance of a large scale industrial operation to support potentially controversial projects also must be evaluated.

A systematic evaluation of these soft criteria will address the aspects of the region in the vicinity of the port identified in Table 4-1.

4.2.4 Screening and Short-Listing the Ports

The set of ports considered in this study were analyzed using these criteria. Those ports that did not meet minimum thresholds were eliminated from further consideration by the Team. Section 5 provides an overview of Massachusetts ports that could support staging and installation of offshore wind farms, as well as other regional ports that could meet the assembly, construction, and/or servicing needs of the offshore wind industry.

Section 6 describes the process that resulted in the two short-listed ports - the potential South Terminal area in the Port of New Bedford Renewable Energy Marine Park and the existing Dry Dock #4 in the Port of Boston Marine Industrial Park.

5.0 INVENTORY OF PORTS

The following sections provide an overview and general description of Massachusetts ports, as well as regional ports that could support offshore wind development activities. This section also provides an overview of the capability of East Coast and Gulf Coast shipyards to construct new vessels, modify existing vessels, provide support vessels, and provide repair services.

5.1 Profiles of Port Facilities in Massachusetts

The Commonwealth of Massachusetts has a varied mix of marine activities in its five key port areas, with connections to both international and domestic markets. Primarily, these ports serve as transition points where cargo moves to and from marine modes including ship and barge to land-based modes, in particular truck or rail. Appendices F and G provide more detail on these ports and modes of transportation.

Massachusetts has a number of ports that, because of their existing or proposed marine terminals, geographic location, proximity to regional commercial activity, and access to land-based transport to more distant inland markets, already have substantial marine activity including a wide range of freight activity. The Commonwealth has one major tonnage and diversified seaport and five smaller niche ports that operate within the marine network. The major Commonwealth seaport is Boston, and the five niche ports include Gloucester, Salem, the Fore River Shipyard, Fall River, and New Bedford. From north to south, profiles of these Massachusetts ports and their potential for expanded marine industrial activity are presented below.

5.1.1 Gloucester, Massachusetts

Background

The Port of Gloucester is located on Cape Ann and is approximately 22.6 nm (26 miles) north of Boston. Cape Ann is located adjacent to the main shipping routes between Southern and Northern New England. The port is historically known for its fishing industry. See Appendix E for the extent of the Gloucester Designated Port Area (DPA).

Gloucester still has a large fishing industry and the potential to develop an all water ferry connection to the Province of Nova Scotia in Canada. The port has some land area available to develop a new marine facility for commercial activities. It has a readily available skilled work force and diverse marine service sector. It also has a rail line that would provide access to the national rail system, and the Route 128 corridor provides excellent highway connections to the New England highway network.

Facilities

The primary marine industrial facilities in the port are within the Industrial Port (see Figure 5-1). The principal businesses are fishing, fish processing, recreational boating, marine repair and supply, and a fledgling cruise ship business. The Industrial Port has become the city's primary marine industrial area with 98% of the land and pile-supported area within this district dedicated to industrial and accessory-to-industrial uses. It has recently experienced several significant changes, including the opening of the Gloucester Seafood Display Auction, modernization of Americold's and Gorton's waterfront infrastructure, and significant expansion of facilities on the

State Fish Pier. Most recently, the development of the Gloucester Marine Terminal at Rowe Square offers important new opportunities for the port (Garcia et al. 2009). The Gloucester Marine Terminal, the cruise ship facility, is accessed via the North Channel of Gloucester Inner Harbor and can accommodate vessels up to 152.4 m (500 feet) in length and drawing up to 5.5 m (18 feet). The facility is owned by the City of Gloucester and is limited to tourism activities. Larger vessels up to 244 m (800 feet) in length and drawing up to 7.9 m (26 feet) can be accommodated inside the breakwater at Gloucester Harbor.

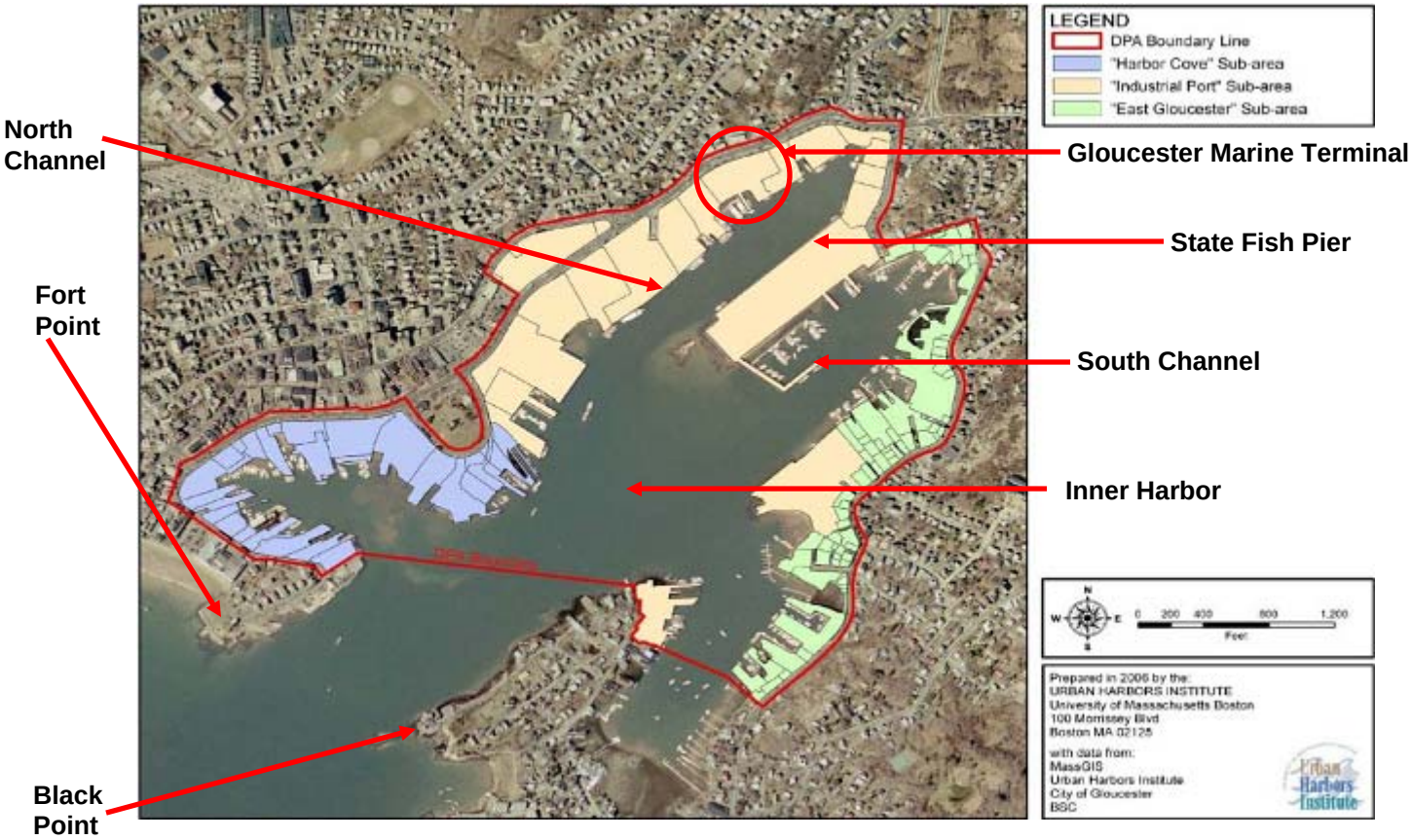


Figure 5-1 Layout of the Inner Harbor at the Port of Gloucester
(Source: City of Gloucester Harbor Plan and Designated Port Area Master Plan 2009)

The largest facility is the State Pier, which is dedicated to fishing activities. The 3.1 hectares (7.8 acre) facility has a 410 m^2 (approximately 4,400 sf) wharf with 425 m (approximately 1,400 feet) of berthing with depths of between 5.2 and 6.1 m (17 and 20 feet) at mean low water (MLW). A dredged channel of 6.1 m (20 feet) at MLW provides access to the pier.

There are several buildings that support the fishing industry onsite, and a number of businesses that support marine activities, including several small boat marinas. There are also a number of repair yards and associated businesses. There is little capability at existing facilities for ROWEI staging.

Harbor Profile

Gloucester Harbor is a well protected harbor with an easily navigable entrance and broad inner harbor located on the south shore of Cape Ann. The entrance to the port is close to the pilot station located in Massachusetts Bay.

The outer harbor has a protective breakwater that extends from the east side of the harbor entrance at Easter Point. Primary access is on the western side of the harbor entrance. The harbor becomes progressively shallower from about 5.5 to 15.8 m (18 to 52 feet) outside the entrance to 7.6 to 9.1 m (25 to 30 feet) within the harbor to less than 4.5 to 7.3 m (15 to 24 feet) in the inner reaches. The channel entrance is approximately 365 m (approximately 1,200 feet) wide with depths of 11.6 to 14.3 m (38 to 47 feet) into the outer harbor.

Tidal range is about 2.65 m (approximately 8.7 feet) average, and currents within the harbor are nominal. Parts of the harbor entrance are difficult to traverse due to breaking waves in severe weather and a number of shoals and submerged obstacles. There is a dredged anchorage for vessels with up to 4.9 m (16 feet) of draft about 275 m (approximately 900 feet) southwest of the State Fish Pier.

The inner harbor is defined by a line between Fort Point and Black Point. The approaches to the inner harbor have water depths ranging from 6.7 to over 12.2 m (22 feet to over 40 feet). Water depths range from 4.72 to 5.8 m (15.5 to 19 feet) in the inner harbor. The lateral clearance is approximately 61 to 76 m (approximately 200 to 250 feet). Gloucester harbor has inner areas known as the Western Harbor (which is closest to the town center) and Southeast Harbor (which is closest to the entrance) (see Figure 5-2). Shoreline areas in the Western Harbor and Southeast Harbor have very shallow water depths. There are shallow channel (6.1 m (20 feet) at MLW) accesses to the State Fish Pier, Gloucester Marine Terminal and East Gloucester.

Advantages

The port is well sheltered and has support mechanisms in place for commercial and industrial activities. No overhead clearance constraints were identified in the approaches to the Port of Gloucester. The port has both rail and highway access which supports the traffic associated with the fish processing industry. There is a waterfront commercial roadway connecting to Route 128.

Disadvantages

Water depth and lateral clearance are the most significant constraints for the inner harbor at the Port of Gloucester (see Figure 5-2). The harbor entrance is narrow and deep, but becomes shallow quickly. There is little deep water access to shore areas for large vessels, but access is suitable for barges Turbine installation vessels should be able to navigate the Port of Gloucester, but turbine import vessels most likely would not be able to call at this port. The lateral clearance limits turbine load-outs in the fore-aft bunny ear configuration. The immediate area in and around the shoreline is congested and has mixed traffic flow. Although there is rail service to the City, it is limited at this time to commuter rail.

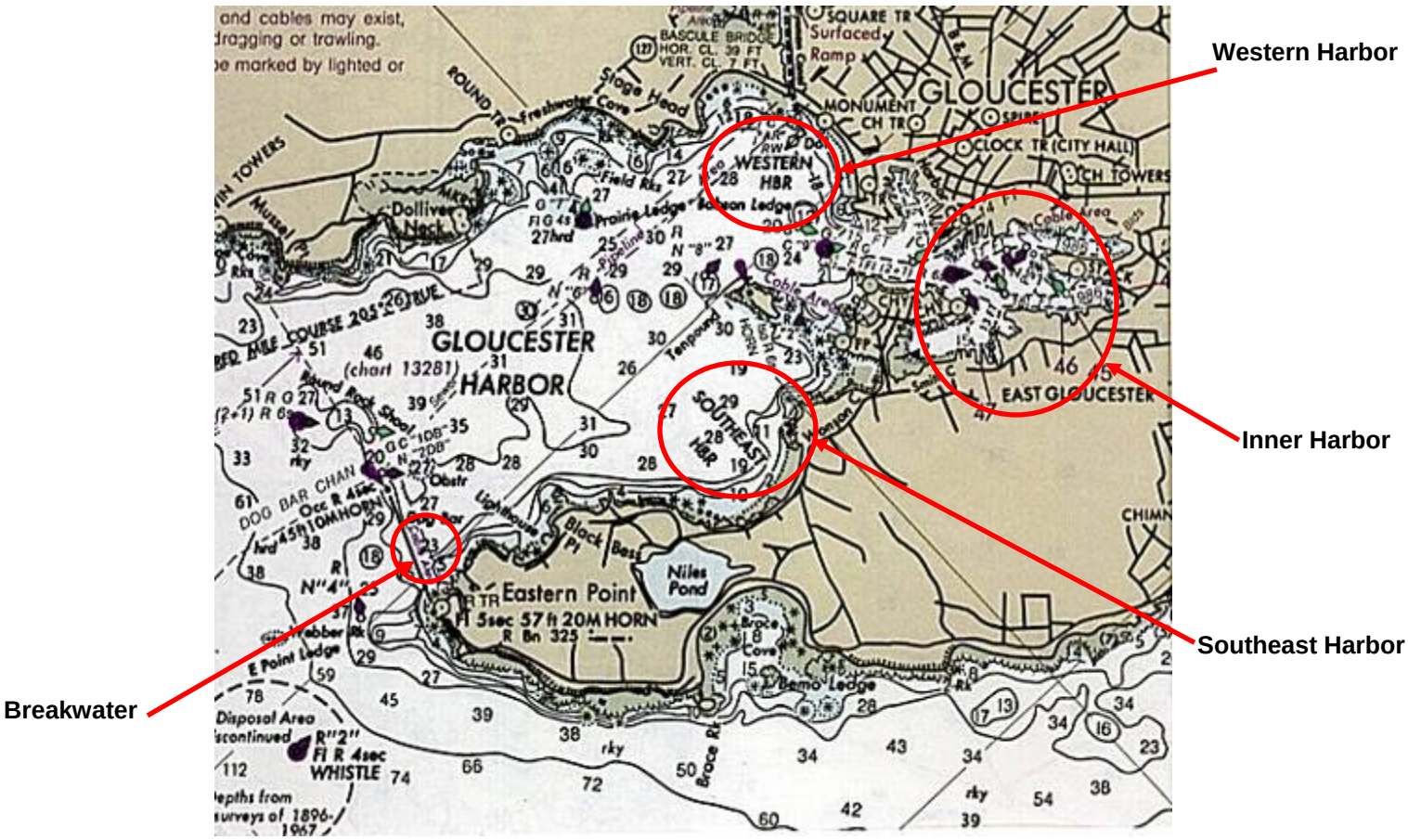


Figure 5-2 Gloucester Harbor and Shoreline Areas
(Source: MARPRO Associates International 2009)

Potential

There are limited areas for industrial growth adaptable to ROWEI staging. It is unlikely that a suitable location within the port of sufficient size could be identified to handle processing and assembly. To take advantage of existing water depth, highway connections and other access issues, any facility should be located on the west side of the harbor.

5.1.2 Salem, Massachusetts

Background

The Port of Salem is located 9.6 nm (11 miles) southwest of Cape Ann and is approximately 10.4 nm (12 miles) northeast of Boston. It is a small harbor, part of an irregular indentation in the shoreline of Massachusetts Bay (see Figure 5-3). The watershed area also includes Manchester, Beverly and Marblehead Harbors. The port is primarily known for its recreational and yachting industry. It also has a deepwater oil facility and commuter passenger service connecting to Boston. See Appendix E for the extent of the Salem DPA.

Figure 5-3 Aerial View of Salem Harbor
(Source: MARPRO Associates International 2009)

Facilities

The principle deepwater facility in Salem Harbor, Salem Terminal, is located at the head of the harbor. The facility handles petroleum for the 27 hectares (approximately 67 acre) New England Power Company plant owned by Dominion Energy. In addition, Key Span Energy operates the adjacent 6 hectares (15 acre) support facility for an offshore liquefied natural gas handling platform. The port has a 0.8 hectares (approximately 2 acre) commuter ferry facility with connecting service to Boston. There are several fishing and recreational boat slips in the harbor, and the National Park Service has a 244 m (800 foot) berth that is used for historic vessels.

The port has fuel, water, provisions, and general marine services available, including several small machine shops that mostly service smaller craft. There are no dry-dock or shipyard facilities in the port for large commercial craft.

Salem has limited potential for substantial expanded marine industrial activities. The Salem Waterfront is shallow and has poor road connections to the waterfront. The port already provides supplemental marine support for the expanding petroleum and gas network in New England. The port's only deepwater commercial terminal is situated at the head of the harbor, and there are several former rail rights-of-way that connect to inland points. The expansion of pipeline connections from the terminal into the gas and petroleum network was first identified in the study conducted in 1994 by the Governor's Commission on Commonwealth Port

Development (MARPRO Associates International 2009). While the terminal is primarily used to supply the needs of the Salem Power Plant, it has the capacity to handle additional marine operations, including ROWEI staging. The port, however, does not have enough of a transportation network to meet a wide range of industrial needs, which would require adequate waterfront property, deep water access, unencumbered road access, and direct highway and rail connections. It does have the potential for other water based activities not dependant on road or rail connectivity.

Harbor Profile

Salem Harbor is a well protected harbor with three main channels that serve the watershed area. The Salem Channel, which is 9.4 m (approximately 31 feet) deep, is the primary access channel for deep draft vessels and passes through Salem Sound for approximately 3 nm (see Figure 5-4). The channel connects to a turning basin at the west side of the harbor at the Salem Terminal Wharf. The turning basin has a controlling depth of 8.2 m (approximately 27 feet). The harbor also has a special anchorage area. The harbor extends to the Salem Waterfront where the National Park Service's recreational and fishing piers and ferry terminal are located. Depth in most cases at the Salem Waterfront is less than 5.5 to 6.1 m (18 to 20 feet).

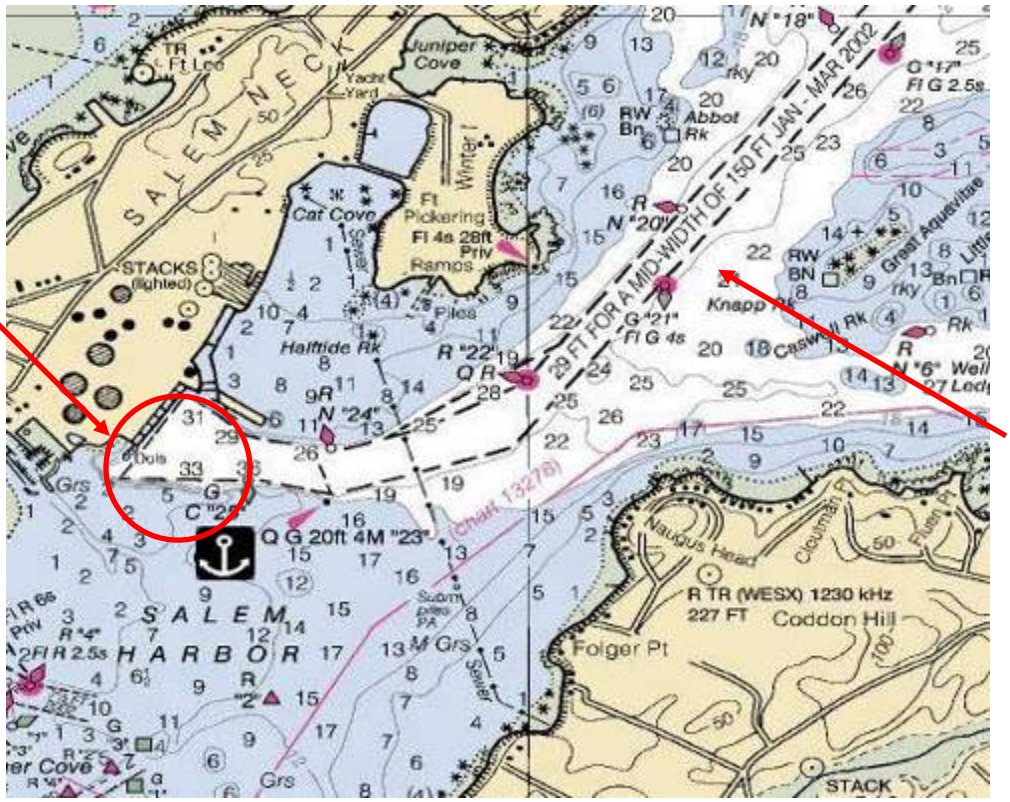


Figure 5-4 Salem Harbor and Shoreline Areas
(Source: MARPRO Associates International 2009)

The overall range of the tide in the harbor is between 2.6 and 2.75 m (8.5 and 9 feet). Within the harbor the current has minimal velocity. There is ice buildup at the head of the harbor during

very cold winter months, mostly in January and February. Tug services are available out of Boston, and Salem is a U.S. Customs Port of Entry.

Advantages

The port is well sheltered and has some commercial vessel activity. The Salem Terminal site is underutilized and may be adaptable for some ROWEI staging activities. No overhead or lateral clearance constraints were identified in the approaches to the Port of Salem.

Disadvantages

The community is a popular tourist destination, and the surrounding waterfront communities have significant recreational vessel activities that have hindered industrial waterfront development. A potential focus of Salem Harbor is developing the emerging pocket cruise ship industry.

Water depth is a constraint. There is little deep water access to shore areas near the center of the waterfront. There is also very little area outside of Salem Terminal where large vessels can handle ROWEI components. The immediate area in and around the waterfront is congested, has poor capacity for high volume traffic flow, and does not have adequate and acceptable truck access. Although there is rail service to the City of Salem, it is limited at this time to commuter rail. The rail does not extend to the harbor areas, but there are former rail rights of way that connect to the harbor area. There is little space around the harbor for the development of additional freight activities other than what is currently handled at Salem Terminal.

Potential

The main area for commercial growth lies with the tourism-based cruise business. The community is well known and has good growth opportunity in marine based tourism activities. There is limited capacity for ROWEI staging or fabrication.

5.1.3 Boston, Massachusetts

Background

The Port of Boston is located north of Cape Cod and is adjacent to the main shipping routes between Southern and Northern New England. Within New England, the Port of Boston is the second largest tonnage port (after the Port of Portland, Maine,) the largest container port, the largest international passenger port and the largest oil port in Massachusetts. The port is historically known for its diverse maritime mix. The port has two shipyard facilities, hosts several commuter ferry operations, marine research activities, marinas, and the largest U.S. Coast Guard facility in New England (see Figure 5-5). While in recent years some segments of the port's activities have declined, notably fishing, the Port of Boston remains the largest of the Commonwealth's five major seaports. See Appendix E for the extent of the Boston DPA.

Boston is the largest and most prominent freight port in the Commonwealth. It has the most diversified port mix and handles the largest volume of containers in New England and the second largest amount of petroleum cargo. The port mix includes containers, general cargo, automobiles, scrap metal, road salt, project cargo, refined petroleum products, liquefied natural gas, international port of call and homeport cruise passengers, and domestic commuter and outer harbor ferry operations. Including liquid bulk cargo, the Port of Boston handled over

13.6 million mt (approximately 15 million tons) of cargo in 2007. Only the Port of Portland handled more, approximately 22.7 million mt (25 million tons) of cargo, mostly crude oil bound for Canada. Of the Port of Boston's total tonnage, 1.54 million mt (1.7 million tons) were containerized cargo representing 216,434 intermodal shipping container TEUs. With 4 container cranes, the annual port throughput averages 5,288 containers per hectare (2,140 containers per acre). The port hosted over 1,000 vessel calls in 2007.

Figure 5-5 Aerial View of Boston Harbor
(Source: http://www.mappingboston.org/html/map20-a.htm)

Boston has some critical key advantages and some distinct disadvantages for potential growth (see Figure 5-6). The port is situated within one of New England's largest market areas for products and commodities, and there is a significant amount of related port business, a wide range of diversity in the port operational mix, and a strong commitment to expanding activities. The port also has numerous terminals, deep water access, full marine services, and a large and skilled work force. The port has enhanced the economies of scale at its two major freight

terminals, Conley and Moran Terminals, by consolidating container operations at Conley Terminal in South Boston, nearest the open seas and deep water areas, and shifting auto import and processing operations to Moran Terminal in Charlestown. This has resulted in lower overall operating costs and has enhanced the Moran Terminal operating authority's ability to attract and retain auto carrier and processing services. This trade suits the terminal's draft limitations and longer port transit.

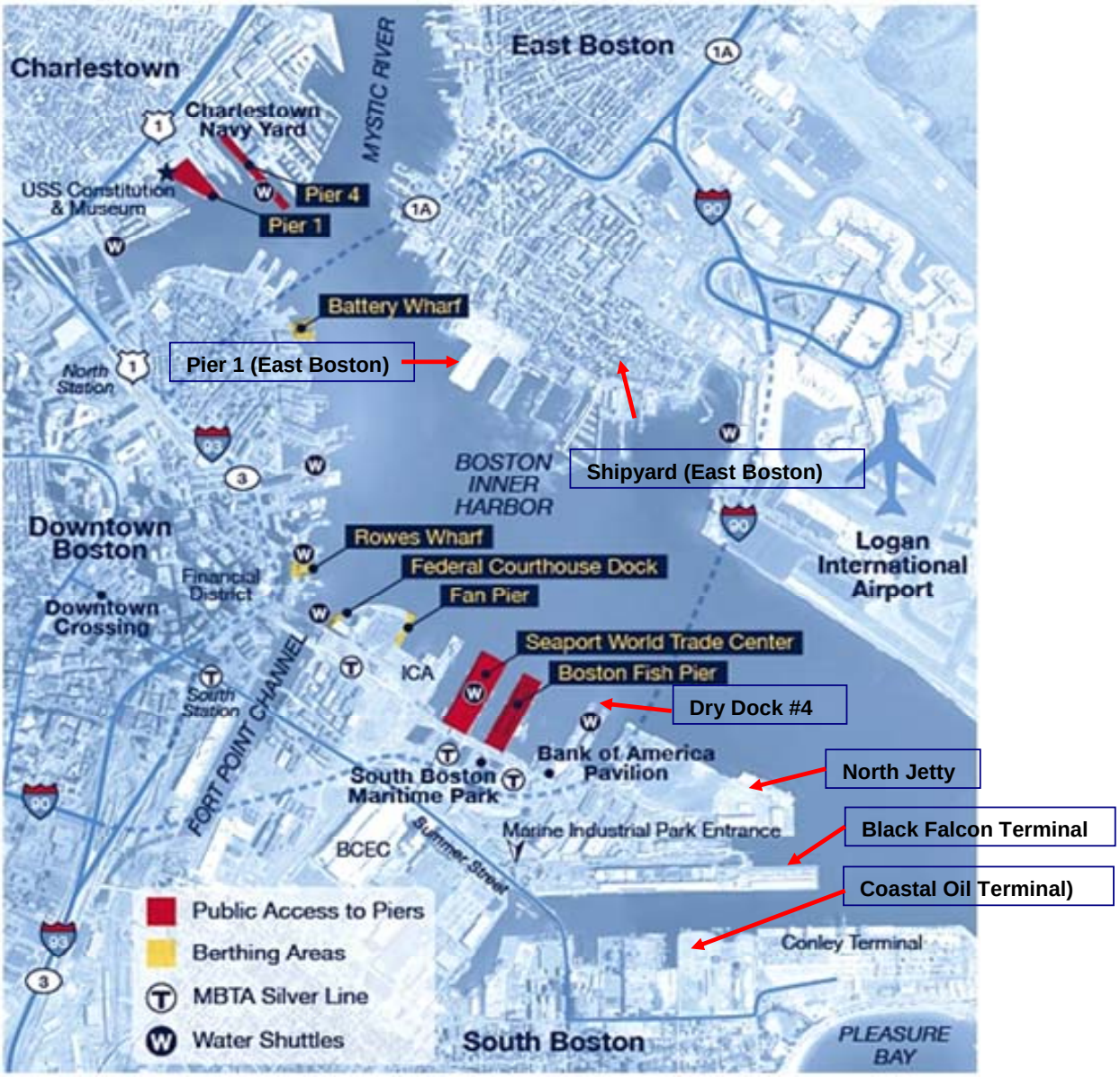


Figure 5-6 Massport Facilities
(Source: http://www.massport.com/business/pic/c_haarborwide.pdf)

Boston has been limited in its ability to take full advantage of significant industrial growth. A series of development projects has gentrified port areas, which has created choke points for the marine terminals. South Boston, for example, had been developed by the railroads for the

handling of freight at numerous piers, but most of the original infrastructure has been replaced by new and non-related commercial and residential development. The result is that most of the rail infrastructure has been removed and direct rail connections to the waterfront are gone. Roadways are congested and direct street connections between the terminal and highway connectors are inefficient. The nearest major rail terminal is located at Allston Yard, some 14 miles from the port, which would make transport and transfer of turbine components or ancillary material expensive.

Facilities

The public marine passenger and cargo facilities in the Port of Boston are managed by the Massachusetts Port Authority (Massport). Massport is an independent public authority that develops, promotes and manages Massachusetts' airports, seaport and transportation infrastructure. Massport owns, operates and leases approximately 202 hectares (500 acres) of property in Charlestown, East Boston, and South Boston. Most of the properties are located within the Commonwealth's regulated DPAs, which are restricted to maritime industrial activities. These facilities include the Boston Autoport located at the combined Mystic River Piers and Moran Terminal in Charlestown and East Boston Pier 1 and adjacent properties in East Boston. Massport also owns the Paul W. Conley Container Terminal, the Black Falcon International Cruiseport, the North Jetty cargo facility, and the Boston Fish Pier all located in South Boston.

The 41 hectares (101 acre) Paul W. Conley Container Terminal South Boston is the largest marine facility in the harbor and is utilized for cargo container operations. The facility has 610 m (approximately 2,000 linear feet) of berthing with depths of between 12.2 and 13.7 m (40 and 45 feet). The terminal is equipped with four, low profile gantry cranes capable of 30 moves an hour, and the terminal can handle vessels up to an average of 5,000 TEUs, considered mid-size in the current vessel market. The container terminal handled nearly 220,000 TEUs in 2007, up 10% from 2006. The North Jetty is located on the waterfront in the Marine Industrial Park next to the Black Falcon Cruise Terminal. It offers 245 m (approximately 800 feet) of berthing space with a depth of 12.2 m (40 feet) at MLW (Massport website accessed February 2010). The North Jetty facility in South Boston is underutilized and adaptable to ROWEI assembly.

Boston Autoport in Charlestown is primarily used for automobile import, processing and distribution and has capacity for approximately 50,000 cars per year. It is also the location for the Wind Technology Testing Center (WTTC), a joint project with the U.S. Department of Energy to build a large wind turbine blade testing facility. There is some covered storage for high-value automobiles on site in the former Mystic Pier transit shed. The property encompasses approximately 20.2 hectares (50 acres) of land, not all of which is actively utilized and is consequently potentially suitable for ROWEI staging. The facility is also equipped with a shore-side gantry crane. The Boston Autoport is upstream of the Tobin Bridge and, therefore, is subject to vertical navigational constraints.

Another Massport facility in Charlestown is the former Revere Sugar site, now known as the Medford Street Terminal, which comprises approximately 5.7 hectares (14 acres) of waterfront industrial property with deepwater access. The Medford Street Terminal is being utilized for some storage and has good potential for ROWEI assembly. This terminal is upstream of the Tobin Bridge, which imposes a vertical constraint of approximately 41 m (135 feet). This

restriction makes navigation marginal for jack up vessels and limits turbine load-outs in the star configuration.

The East Boston Shipyard is located on Marginal Street in East Boston between Piers Park and the site of the former Navy Fuel Pier. The shipyard is the only ship repair facility in Boston Harbor equipped to serve mid-sized commercial vessels. Features include: 3.6 hectares (9 acres) of backland, including 4 piers and approximately 8.1 hectares (20 acres) of water sheet, 18,580 m^2 (200,000 square feet) of commercial office and industrial building area in 12 structures, and 762 m (approximately 2,500 linear feet) of commercial berthing space (Massport website accessed February 2010).

Moran Terminal has rail access through Sullivan Square, and Massport owns the freight rail line from Sullivan Square into the Terminal. Conley Terminal does not have rail access and there are no identified plans for extending rail service into the facility. There is a proposed rail line connection that would provide access from the North Jetty for bulk, project and other cargos. Most of the roadway system in and around Massport's South Boston and Charlestown facilities is heavy weight rated for handling oversized loads up to 45.4 mt (approximately 100,000 pounds or 50 tons). The port has handled a number of project cargos using specialized tri-axle road trailers and has received State permits for transportation out of the terminal areas. Massport and the Boston Redevelopment Authority, which would have a approximately 15.25 m (50 foot) wide right-of-way and would eliminate some potential limitations with local utility infrastructure for very large component pieces. The roadway would provide better and unencumbered access to the Central Artery/Tunnel connections in South Boston. Massport also has proposed the extension of Cypher Street and the reconstruction of E Street as part of the freight roadway system with adequate turning curvatures and heavyweight access up to State authorized permit levels.

Harbor Profile

Boston Harbor is the largest physical harbor in New England and is well protected with a wide and easily navigable entrance and large inner harbor with deep water access. The entrance to the harbor has numerous shoals and islands. There are two dredged channels and two traffic separation schemes which define the approaches to and into the harbor for deep draft vessels. The entrance is well marked by navigational aids, and the entrance to the port is close to the pilot station located in Massachusetts Bay.

Boston's Main Ship Channel extends from the harbor entrance to the mouths of the Mystic and Chelsea Rivers and to the Charlestown Bridge on the Charles River. The Federal project channel depth is 12.2 m (40 feet) deep from the harbor entrance to the mouth of the Mystic River and is 10.6 m (35 feet) in areas near the south side of the harbor to just seaward the location of the Third Harbor. The Boston Harbor Deep Draft Navigation Improvement Project proposes to deepen the existing channel (USACE 2008). There are several deep draft ship anchorages in the harbor with the anchorage on the north side of President Roads used most frequently for ships and barges. Tidal range is around 2.75 to 2.9 m (9 to 9.5 feet) with two highs and two lows per day. Harbor currents are generally less than 1 knot.

Table 5-1 below summarizes the navigational constraints in the Port of Boston and their operational implications. This report focuses on the port facilities in South Boston, Charlestown, and East Boston discussed above. Other facilities on the Chelsea River currently are not

considered feasible for ROWEI staging due to lateral and overhead restrictions, which are shown in Table 5-1, and are not discussed further.

Table 5-1
Summary of Navigational Constraints in Boston

Staging Port	Potential Obstructions	Lateral Clearance	Overhead Clearance	Controlling Water Depth	Feasible Turbine Load-Outs	Jack-Up Feasible ?
South Boston (all ports)	Logan Airport	over 152 m (500')	report air draft to airport traffic control	12.2 m (40')	all	yes
Charlestown / East Boston (inner harbor ports)	Logan Airport	over 152 m (500')		12.2 m (40')	all	yes
Medford Street Terminal and Mystic River	Tobin Memorial Bridge	over 152 m (500')	41 m (135')	7.6 – 10.7 m (25'-35')	star	marginal
Chelsea River (west of Chelsea St. Bridge)	Andrew McArdle Bridge	53.3 m (175')	none	8.8 – 12.2 m (29'-40')	fore-aft bunny ear	yes
Chelsea River (east of Chelsea St. Bridge)	Chelsea St. Bridge	28.3 m (93')	25.3 m (83')	8.8 – 12.2 m (29'-40')	rotor disassembled	no

Advantages

The port is well sheltered and has significant support mechanisms in place for commercial vessel activity and ROWEI assembly. There are numerous roadway connections to most of the main marine terminals which are heavily used. The port is the largest support center for marine activities in New England with a diversified mix of services and associated businesses.

Disadvantages

Boston is a typical metropolitan port, with gentrification pressures and limited ability to expand marine activities. The Port of Boston is affected by air traffic at Logan Airport. While maritime operations are not restricted, according to the Coast Pilot®[6], all vessels with air draft greater than approximately 25.9 m (85 feet) must advise air traffic control of their presence (U.S. Department of Commerce, National Oceanic and Atmospheric Administration and National Ocean Service 2009). South Boston facilities do not have significant navigational constraints. All turbine load-out configurations (i.e., bunny ear fore-aft, bunny ear lateral, and star) can be accommodated. Jack-up vessels can navigate between these ports and the sea. Long-term staging operations in South Boston should be evaluated in the context of the vertical limitations due to proximity to Logan airport and related FAA regulations.

While there are numerous road connections to terminals, many are congested and pass through residential areas creating potential conflicts with pedestrian and automobile traffic. Rail connectivity is very limited in several areas including South Boston, Charlestown and East

[6] The United States Coast Pilot® consists of a series of nautical books that cover a variety of information important to navigators of coastal and intracoastal waters and the Great Lakes. Coast Pilot 1 covers the coasts of Maine, New Hampshire, and part of Massachusetts, from West Quoddy Head in Maine to Provincetown in Massachusetts. Major ports are at Portsmouth, NH and Boston, MA.

Boston. Boston's container and auto terminals have no direct access to the nation's doublestack (Gen2) rail network. Boston is considered to be a high cost port due to existing labor agreements and work rules, expensive infrastructure and limited volume capacity. The marine terminals, particularly Conley Terminal, have limited area to expand their property boundaries, which would affect utilization for other activities. Vessel access to the inner harbor, specifically, Charlestown and Chelsea Creek is draft and length limited.

Potential

There is adjacent property that can be purchased and added to the existing terminal footprints to allow for expanded yard area allowing for dedicated ROWEI processing. Roadway connections to the terminals in most cases also need to be improved to provide appropriate capability.

Boston's industrial marine growth is tied to three major areas to expand marine activities. These include:

- Expansion of terminal size;
- Improvement of roadway connections to main highways that avoid the inner city roadways; and
- Creation of a better connection to the national rail network.

5.1.4 Fore River Shipyard

Background

Fore River Shipyard is less than 10 miles south of Boston. This approximately 45 hectares (111 acre) site is situated partially in both Quincy (2/3) and Braintree (1/3) (see Figure 5-7). Fore River Shipyard was once a prominent shipyard in the United States, producing ships for World War II (WWII), peaking with approximately 50,000 employees during this time. In the 1970s, the 1,200 ton "Goliath" crane (since removed in 2008) was built specifically to place aluminum spheres (pressure vessels) on the LNG vessels constructed there. Recently, Fore River Shipyard has served as the Central Receiving Point for new car delivery to local dealerships. See Appendix E for the extent of the Fore River (Weymouth, Quincy and Braintree) DPA.

The site is currently undergoing an initial planning process to determine potential new uses for the site, including marine-related, residential, retail, office, and entertainment. Current planning goals are to create a mixed-use, working waterfront development at the site. At this time, the Shipyard is actively seeking industrial tenants for both indoor and outdoor space. The Fore River which flows directly into Boston Harbor has recently been dredged by the Army Corps of Engineers, and can accept "Panamax" class vessels (i.e., vessels of a maximum size to fit through the existing Panama Canal).

Figure 5-7 Aerial View of Fore River Shipyard
(Source: Google Earth, Fore River Shipyard, 2010)

Facilities

The site is currently owned by Daniel Quirk, a local auto dealer, and is used as the Central Receiving Point for new car delivery. The port area also contains a ferry terminal for commuter boats to Boston and Hull that is run by Harbor Express for the Massachusetts Bay Transportation Authority (MBTA). The yard also is used by Jay Cashman, Inc., for heavy construction and marine equipment services, the Massachusetts Water Resources Authority, as a sewage sludge heat-drying and pelletizing facility, and by the Fore River Transportation Corporation for short line freight rail service to CSXT South Braintree (discussion with Daniel Quirk).

The site currently features rail and roadway access, a 41,800 m^2 (450,000 square foot) open floor building, a 9,290 m^2 (100,000 square foot) open floor building, and additional buildings for a total of 55,740 m^2 (600,000 square feet). The site also includes a 11,150 m^2 (120,000 square foot) Wet Basin with a current 6.1 m (20 foot) draft that can be dredged to deeper than 9.1 m (approximately 30 feet).

Shipyard Profile

The Shipyard is located in a well protected area with adequate draft to accept “Panamax” class vessels. The entrance to the Shipyard is narrow, restricted by the Fore River Bridge, which currently has a 53.3 m (175 foot) vertical clearance and a 53.3 m (175 foot) horizontal

clearance. This bridge is a temporary lift bridge and plans are not yet finalized as to whether the replacement bridge will be a lift style or bascule style drawbridge. North and East of the bridge, the approach channel ranges from 41 to 183 m (136 feet to 600 feet) wide and is approximately 9.75 m (32 feet) deep. South of the bridge, the channel opens to 122 m (400 feet) wide. Channel depth is 9.75 m (32 feet). Tidal range is around 3 to 3.1 m (9.8 to 10.2 feet).

Advantages

The port is well sheltered and has significant support mechanisms in place for commercial vessel activity. There are numerous roadway connections and an active railroad line.

Disadvantages

The entrance to the Shipyard is laterally and vertically constrained by the Fore River Bridge. Additionally, the site is currently undergoing an initial planning process to determine new potential uses for the site, including marine-related, residential, retail, office, and entertainment. Currently, the site is serving as the Central Receiving Point for new car delivery to local Quirk car dealerships. Much of the infrastructure is significantly aged.

Potential

New bridge design for the Fore River Bridge is yet to be finalized. Additionally, improvements could include the following:

- Improvement of roadway connections to main highways that avoid the inner city roadways;
- Creation of a better connection to the national rail network; and
- Facilities to support secondary functions associated with offshore wind deployments.

5.1.5 Fall River, Massachusetts

Background

The Port of Fall River is located at the mouth of the Taunton River at the head of Mount Hope Bay, at the northeast side of Narragansett Bay, near the Massachusetts-Rhode Island border. The port is approximately 18 nm from the south entrance of Narragansett Bay, which flows into Rhode Island Sound, 17 nm west of the Cape Cod Canal and approximately 90 nm south of Boston. It is geographically located about 74 kilometers (km) (46 miles) south of Boston, 26 km (16 miles) southeast of Providence, RI and 19 km (12 miles) west of New Bedford. The port is historically known for its manufacturing and distribution and has developed an active break-bulk trade. Cargo operations have included handling mostly break-bulk cargoes such as bananas, wallboard, heavy equipment, automobiles, wood pulp, chemicals, newspaper and seafood. See Appendix E for the extent of the Mount Hope Bay (Fall River and Somerset) DPA.

The Port encompasses the waterfronts of Fall River and Tiverton, Rhode Island on the east side of the Taunton River and the waterfront of Somerset, MA on the west side of the river. The port has good highway access and is served by U.S. Route 6, Routes 24, 79 and 138 and Interstate 195 that connects to Providence, RI with Cape Cod. There are rail freight activities through CSX connecting to several industrial sites in Fall River. In addition to freight activities, there are

several cruise ship visits each year and a number of recreational vessels activities supported by marina facilities at several locations.

Fall River is also an active niche port serving several international markets. The area is ringed with liquid bulk terminals and has the potential for expanded industrial activities at the State Pier. The State Pier has available storage and land area for operations but is used for both industrial and tourism based activities. One way of enhancing Fall River's ability to handle more marine industrial operations is to remove tourism-based activities from the State Pier. The port has good highway access and a rail corridor that requires additional infrastructure improvements.

Facilities

The port has a number of active private facilities and one principal public facility (see Figure 5-8). The Borden and Remington Corporation Wharf is 116 m (380 feet) long with a water depth of 8.5 m (28 feet) alongside. The pier is currently used for handling of latex and caustic soda, is owned by the Tillotson Co., and is operated by the Borden and Remington Corp.

The primary marine facility for the City of Fall River is the State Pier and is located on the site of the former Fall River Line Pier, which was a major steamship operator in New England. The State-owned general marine terminal provides two deep-water berths, a 120 m (398 foot) berth with a depth of 4.5 to 10.7 m (15 to 35 feet) alongside, and a 189 m (620 foot) berth with a 10.7 m (35 foot) water depth alongside. There is also a 7,900 m^2 (85,000 sf) terminal and roll-on/roll-off facility, as well as 2.8 hectares (7 acres) of open storage yards. The terminal is equipped with an approximately 24 m (80 foot) roll-on/roll-off ramp and a 45 mt (50 ton) truck scale. There are three rail spurs, which provide direct on-dock rail connections, but only one is currently operable. The State Pier handles break-bulk and containers. This cargo comes primarily from the Cape Verde Islands, and vehicles and equipment from Angola. The port also handles frozen fish, totaling approximately 680 mt (750 tons) per year, from a fish processing vessel as well as petroleum products at several private terminals. The State Pier represents the best alternative for ROWEI staging.

Just north of the State Pier is the *USS MASSACHUSETTS* Battleship Memorial where a number of former naval vessels are berthed. The Memorial is an active museum that is open to the public and cannot be utilized for marine industrial activities. Two miles above the State Pier is the former Shell Oil Company Wharf that has a 213 m (700 foot) berth with a 9.1 m (30 foot) water depth alongside. Shell Oil discontinued the petroleum products operations in the 1990s, and it is now owned by Fall River Marine, LLC. This site, which is the proposed location of the Weaver's Cove LNG Terminal, could be adaptable for ROWEI staging if it is abandoned by Weaver's Cove. The Mt. Hope, Braga and Brightman Street bridges would impose navigational restrictions. The Mt. Hope and Braga bridges each have a 41.1 m (135-foot) vertical clearance and a 121.9 m (400-foot) horizontal clearance. The Old Brightman Street Bridge has a 29.9 m (98-foot) horizontal clearance but no vertical restriction, and the New Brightman Street Bridge has a 18.3 m (60-foot) vertical and 61 m (200-foot) horizontal clearance.

On the west side of the Taunton River is the Brayton Point Station Dock which has a 310 m (1,017 foot) berth with a 10.6 m (34 foot) water depth alongside. The facility is designed to handle fuel oil and coal and is owned by New England Power Company. Montaup Electric

Company owns and operates a wharf with a 197 m (645 foot) berth and an alongside depth of 10.6 m (34 feet). The facility is designed for handling fuel oil and coal.

The rail line that serves New Bedford also serves Fall River and extends to the State Pier facility in the harbor. Wind turbine components could be delivered to Fall River via road or rail as long as they do not exceed dimension and weight limitations.

Harbor Profile

The main access to the Port of Fall River is from the shipping lanes of the Atlantic Ocean, into Narragansett Bay, through Mount Hope Bay, and down the Taunton River. The harbor is a medium deep-water harbor with a 10.7 m (35 foot) deep federal channel through Mount Hope Bay to about 0.9 nm (approximately 1 mile) above the Brightman Street Bridge (See Figure 5-8). There are additional deep dredged channels near the north Tiverton waterfront with between 6.1 and 10.1 m (20 and 33 feet) of water depth. The harbor has no designated anchorages.

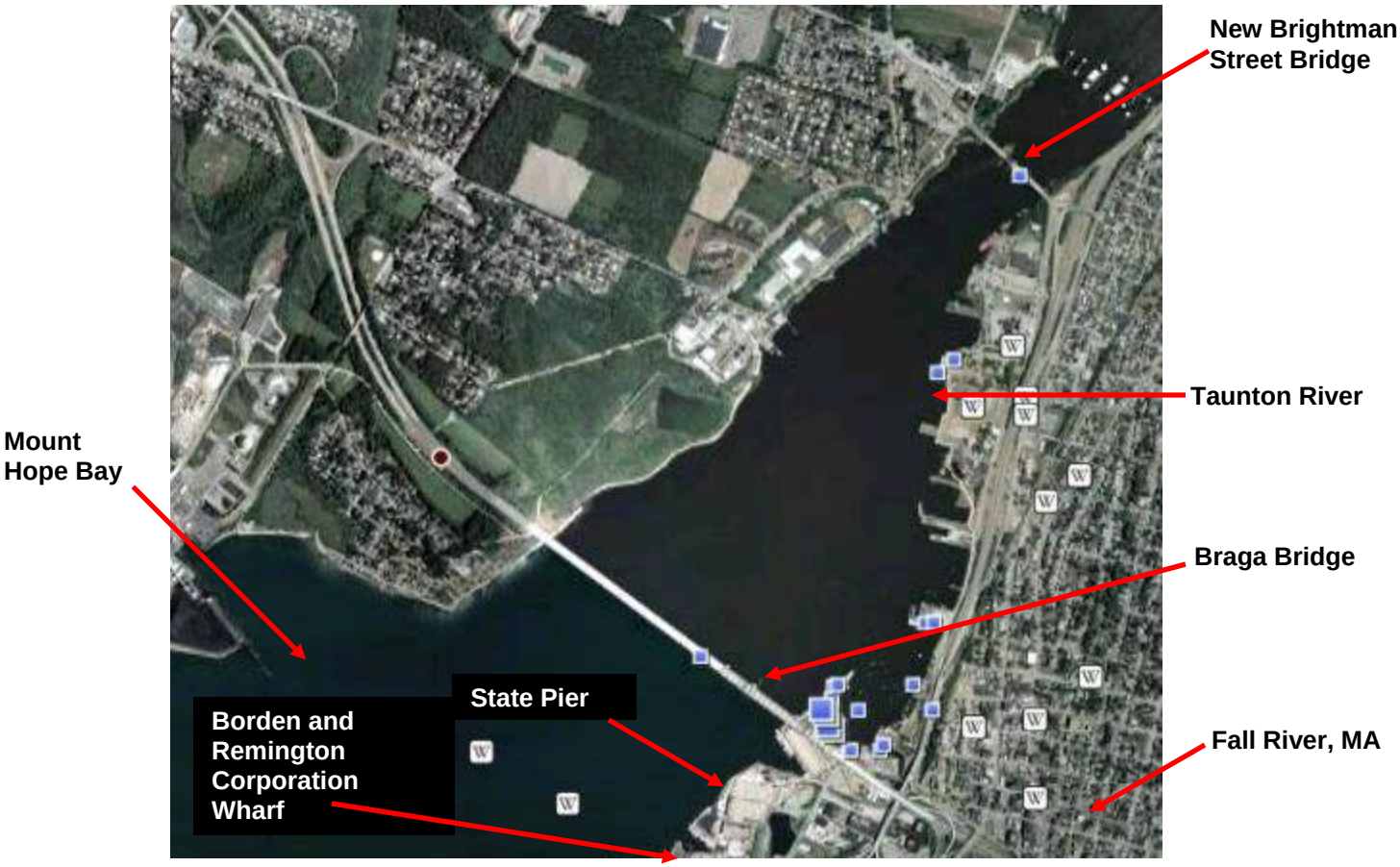


Figure 5-8 Aerial View of Fall River Harbor
(Source: Google Earth, Fall River, MA, 2010)

There are two bridges which cross the Taunton River. They include a fixed bridge at the State Pier with an air draft clearance of approximately 41 m (135 feet). The second bridge is a bascule style bridge with a 18.3 m (60 foot) clearance about 1.1 nm (approximately 1.3 miles)

the bascule style New Brightman Street Bridge with a 18.3 m (60 foot) clearance about 1.1 nm (approximately 1.3 miles) above the fixed bridge. There are additional bridges upstream on the Taunton River but outside of the deepwater port.

Tidal currents are generally not a problem for navigation. The mean range of the tide is around 1.4 m (4.5 feet). Pilotage is compulsory for foreign and U.S. vessels under register of 356 mt (392 tons) or more. Pilotage is provided by Northeast Marine Pilots. The Port has U.S. Customs port of entry capability through New Bedford. Tug services are available in the port from Providence, RI. There are some repair services but no dry-docking capability. There are two small shipyards in the port on the west side of the harbor that provide skilled workforce capability for wind projects.

Advantages

The port is well protected and has support mechanisms in place for commercial vessel activity, including ROWEI assembly and staging. There is cargo storage and handling capacity that can be utilized for fabrication, and the area is supported by good road and reasonable rail access. The port has a roll-on/roll-off facility at the State Pier, which can be used for handling wheel-based industrial components. There is also capacity at some of the private terminals for new industrial development. Water depth is not a significant constraint for Fall River, as dredged channels have water depth in excess of 9.1 m (30 feet). The lateral clearance at the Braga and Mt. Hope Bridges is 122 m (400 feet).

Disadvantages

Vertical clearance is the most significant navigational constraint for the Port of Fall River with respect to deployment configurations for offshore wind turbines and assemblies. The Braga Bridge and Mt. Hope Bridge each impose a height restriction of approximately 41 m (135 feet). This restriction makes navigation marginal for jack-up vessels and limits turbine load-outs in the star configuration. Vessel draft is limited to a 10.7 m (35 foot) overall depth that restricts large vessel access. The State Pier can only handle small cargo ships. The warehouse space at the terminal is unheated and provides only temporary storage, but does provide weather protection for project assembly. Most of the critical infrastructure in the port is aging and in need of repairs and improvements.

The port's commercial and industrial expansion is also hindered by gentrification and a focus on tourism-based activities on the Fall River waterfront. There have been a number of proposals for expanded industrial development, including a proposal for developing an LNG import facility that has been met with significant local opposition.

Potential

There are several main areas for industrial growth well suited to ROWEI staging. Its proximity to the major shipping route near the Cape Cod Canal places the Port of Fall River in a position to facilitate ROWEI staging using smaller ships and barges.

One of the most significant opportunities is the stalled construction of a LNG facility in the port. If not completed, this could potentially provide a parcel of available land for ROWEI staging. However, the Mt. Hope, Braga, and New Brightman Street Bridges, all seaward of the LNG

terminal, have vertical and horizontal clearance restrictions that could preclude certain turbine import and installation vessels and load-out configurations.

Required Improvements

The State Pier requires additional investment to bring it up to industry standards for expanded cargo handling, and there are several other facilities that require infrastructure improvements, including bulkheads, piers and wharves. The site needs to be expanded, and there is an unused salt storage area near the State Pier that could be annexed to create increased capacity. The rail line needs to be restored in some areas and the trackage improved to accommodate increased cargo shipments. An estimated $15 million is required for State Pier improvements (MARPRO Associates International 2009).

5.1.6 New Bedford, Massachusetts

Background

The Port of New Bedford is located on the northwestern side of Buzzard's Bay and is approximately 83 miles south of Boston. The port, encompassing the City of New Bedford and the Town of Fairhaven (see Figure 5-9), is historically known for its fishing industry connections but has developed a significant break-bulk trade. The harbor, considered to be small geographically, is located at the mouth of the Acushnet River, and has direct access into Buzzards Bay, Vineyard Sound and the Atlantic Ocean. The harbor entrance is approximately 10 nm from the beginning of the south entrance of the Cape Cod Canal. See Appendix E for the extent of the New Bedford - Fairhaven DPA.

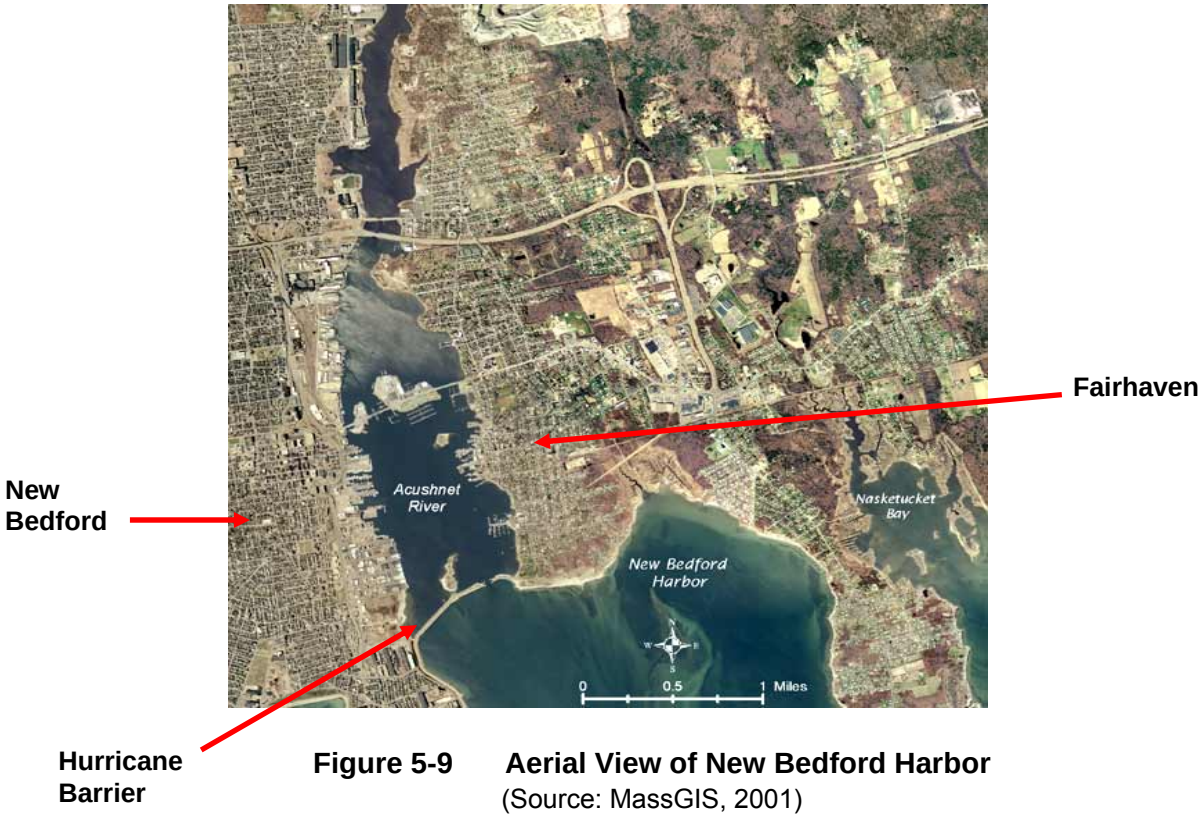


Figure 5-9 Aerial View of New Bedford Harbor
(Source: MassGIS, 2001)

The Port of New Bedford is a deepwater port and is one of the nation's major fishing ports. The fishing fleet includes more than 500 vessels operating out of the port. The Port of New Bedford also supports a diverse market of cargo transport. Barge operations move aggregate and break-bulk cargo to the Islands of Martha's Vineyard and Nantucket. Shipments of break-bulk cargo consisting primarily of house goods are exported to Cape Verde and Angola. The Port of New Bedford has the largest throughput tonnage of break-bulk perishable commodities in New England.

The port hosts reefer (refrigerated) vessels that handle fresh fruit and fresh and frozen fish. The labor force consists of approximately 30 International Longshoreman's Association personnel for vessel operations and 20 Teamsters for warehouse operations. The port currently handles around 25 freighters per year (MARPRO Associates International 2009).

New Bedford is already an active freight seaport and is a major logistical connection for agricultural products entering the New England market. Highway connections are good, and the port could benefit from expanded and improved rail connections to meet freight needs. New Bedford is a small niche port that can continue to expand activities with some infrastructure improvements and investment. It has sufficient deep water access for the size and type of vessel common to most break-bulk and project cargo and has available property for expansion.

Facilities

The New Bedford waterfront has a number of large and small piers and wharves that are primarily used by the commercial cargo and fishing industry (see Figure 5-10). Most facilities have good highway connections as well as rail connections. Harbor regulations and berthing limits, except berthing for private terminals, are enforced by the Harbor Development Commission (HDC) and the Port Maritime Security Unit.

New Bedford South Terminal Wharf has a 488 m (approximately 1,600 foot) berth with 9.1 m (30 feet) of water depth and serves as the major off-loading center for fish product. The wharf has 7,080 m^3 (250,000 cubic feet) of refrigerated storage on site and handles primarily seafood. The southernmost portion of the facility has the potential to build out a 122 m (400 foot) solid fill bulkhead. The site currently has 4.0 hectares (approximately 10 acres) of backland.

Sprague Terminal just North of South Terminal has a 225 m (740 foot) berth with an 8.2 m (27 foot) water depth alongside. The pier primarily handles petroleum products, but was originally part of the operations of a defunct electric power plant (the building is still standing on site.)

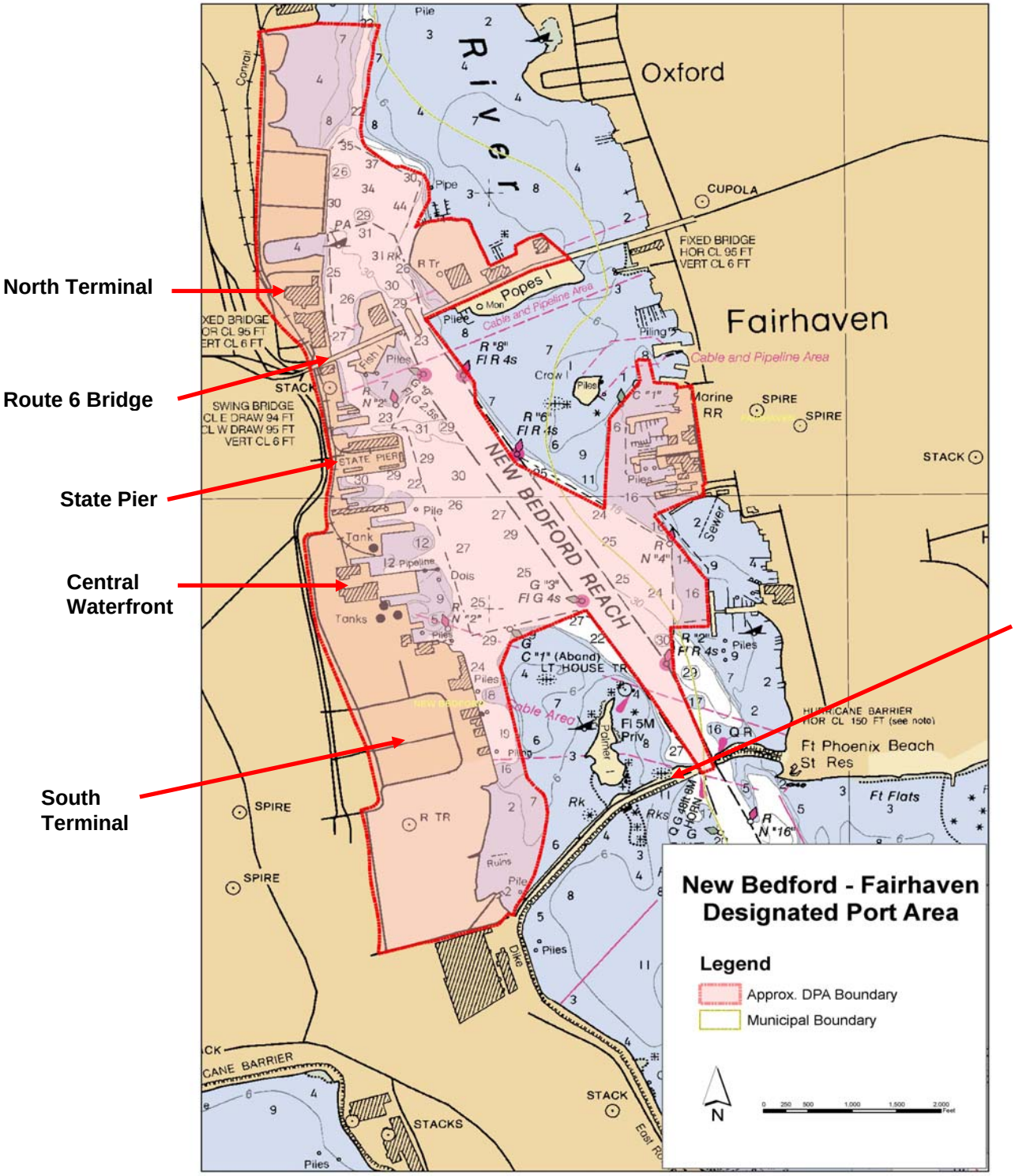


Figure 5-10 Navagational Map of New Bedford Harbor

The State Pier Terminal at the center of the Inner Harbor has three berths measuring 137 m (450 feet), 183 m (600 feet), and 236 m (775 feet) with a 9.1 m (30 foot) water depth alongside. There are 11,610 m^2 (125,000 square feet) of covered storage for general cargo. The facility can support freighter service and store over 135 containers. American Cruise Lines operates out of the facility with a minimum of 20 ports of call on an annual basis and up to 89 passengers per trip. Ferry services also operate out of the State Pier, including passenger and cargo service to Cuttyhunk Island and passenger service to Martha's Vineyard. Ferry service brings over 115,000 passengers through the port annually. The Quick Start Ferry facility on the State Pier allows intermodal transfers of waterborne freight and freight carried by truck and rail. This terminal features an 8.2 m (27 foot) pier depth, roll on/roll off capability, offsite cold storage, and easy access to the interstate highway system. The ramp is approximately 30.5 m (100 feet) long and 5.5 m (18 feet) wide and will hold up to 182 mt (approximately 200 tons). The State Pier requires a significant amount of investment to bring it up to industry standards for cargo handling (see Section 7).

Above the Route 6 Bridge are the Maritime Terminal, Bridge Terminal and North Terminal. The Maritime Terminal Wharf, operated by Maritime Terminal International, has a 183 m (600 foot) berth with a 9.5 m (31 foot) water depth alongside. The facility has 84,960 m^3 (3 million cubic feet) of refrigerated storage and is one of the largest U.S. Department of Agriculture-approved cold treatment centers on the East Coast for use with controlled imported agricultural products. The terminal receives approximately 25 vessels a year, each carrying between 1,362 and 3,630 mt (1,500 and 4,000 tons) of fish or, approximately 1,816 to 2,723 mt (2,000 to 3,000 tons) of fruit.

The Bridge Terminal Wharf, on the northeast side of the harbor, is 137 m (450 feet) long with a 8.5 m (28 foot) water depth alongside. The wharf has a 14,160 m^3 (500,000 cubic foot) refrigerator warehouse and handles frozen and chilled food products. The facility is owned and operated by Bridge Terminal Inc.

American Pride Seafood is a private facility operating out of the North Terminal and one of the world's leading seafood product processors. The bulkhead supporting this operation is 177 m (580 feet) long with a 7.6 m (25 foot) water depth alongside. The facility has 5,890 m^2 (63,400 square feet) of refrigerated warehouse space, 5,342 m^2 (57,500 square feet) of freezer space and 3,224 m^2 (34,700 square feet) of covered warehouse space.

Within the New Bedford North Terminal Wharf are commercial properties managed by the HDC. These properties cover 10.1 hectares (approximately 25 acres) of land. Tenants include the seafood processors Eastern Fisheries and Seawatch International, barge operators, ship repair facilities, and other maritime service businesses. A 0.8 hectares (2 acre) terminal site is proposed to come on-line over the next 5 years. This facility is currently operated by the EPA as part of the superfund clean-up will revert back to the City of New Bedford in the next few years. The facility has rail connections that lead directly to the water's edge.

The port is considered a full service port with associated maritime industries include vessel maintenance and repair conducted at dockside or at repair facilities in New Bedford or in Fairhaven. The port has two moderate size shipyards, and equipment and provisions to support commercial and recreational vessels.

New Bedford is served by a rail line operated by CSX. Roadway bridge constraints prohibit doublestack (Gen2) access to the port. However, this is not a problem limited to New Bedford. An application has been submitted for TIGER Grant money to extend the rail line to the State Pier, but further extension to the proposed South Terminal Development site is unrealistic. The port has handled overweight and oversized project cargo in the range of 45.4 mt (approximately 50 tons) out of the northern part of the harbor. Wind farm components could be moved by road into New Bedford as long as the loaded units do not exceed permit requirements for oversized loads, including weight and overall dimensions. The highway system accessing New Bedford conforms to federal standards that allow a minimum vertical clearance under overhead structures of 4.88 m (16 feet) in rural areas and 4.27 m (14 feet) in urban areas. Routes into New Bedford include US I-195 and Route 18 which connects the west and south port areas to the main highways system.

The Port of New Bedford is considered a moderately deep-water port with overall depths of 9.1 m (30 feet). The harbor is protected by a hurricane barrier (see Figures 5-9 and 5-10) that is constructed across the harbor entrance and is equipped with an opening that can be closed during hurricane conditions and severe coastal storms. The port is considered a harbor of refuge for vessels in the region.

The harbor approach is characterized by a number of ledges and shoals. The approach channel allows for safe navigation and avoids most of the obstructions. The hurricane barrier entrance is 45.7 m (approximately 150 feet) wide and opens up to a 107 m (350 foot) wide channel, at a depth of 9.1 m (30 feet), extending to a turning basin approximately 305 m (1,000 feet) above the New Bedford-Fairhaven Bridge. The range of the tide is 1.1 to 1.2 m (3.5 to 4.0 feet), and harbor currents are overall considered weak. Maximum ebb and flood tide currents are under an average of 2.5 knots.

There are vessel limitations due to the hurricane barrier and the Route 6 highway bridge in the Inner Harbor (see Figure 5-10). The hurricane barrier opening width is 45.7 m (approximately 150 feet) and the Route 6 New Bedford–Fairhaven Bridge is 28.0 m (approximately 92 feet) wide. All vessel transit to and from northern portion of the harbor (upstream of the Route 6 Bridge) is subject to daylight only restrictions for vessels with overall length above 121 m (400 feet) and/or beam above 18 m (59 feet) and to wind velocity restrictions

Advantages

The port is well protected by the hurricane barrier and has support mechanisms in place for commercial and industrial vessel activity, including ROWEI staging. The port is has good road and rail access, and adaptable warehouse capacity is significant. The port has several opportunities for expansion to accommodate ROWEI assembly.

The harbor is challenged by a significant pollution problem due to local industries which up until the 1970s discharged wastes containing polychlorinated biphenyls (PCBs) and toxic metals into New Bedford Harbor. There are high levels of contamination throughout the waters and sediments of the harbor that extend into Buzzards Bay. This contamination led to New Bedford Harbor being designated as a Superfund Site. Since 2004 the EPA has been dredging to remove the PCBs in contaminated sediments. The EPA is expected to explore new technologies (confined aquatic disposal) that will reduce the demand for land-side facilities. This

could accelerate the process of bringing the terminal facility under City control and opening other waterfront parcels up for development.

As a result of the contamination, no maintenance dredging has occurred for over 50 years. The port faced the loss of waterfront business unless maintenance dredging could be implemented. In 2005, the first navigational maintenance dredging was conducted restoring portions of the harbor to useable depths. This has allowed business to increase and larger commercial vessels to return to the harbor.

The navigational draft within the Port of New Bedford is sufficient for turbine installation and import vessels. As turbine components are relatively lightweight for their size, import vessels are space-limited, rather than weight-limited. As such, they would be able to enter New Bedford Harbor with a draft of less than 9.1 m (30 feet). No overhead clearance constraints were identified in the approaches to the Port of New Bedford.

Disadvantages

While advantageous to port safety, the hurricane barrier however is a significant navigational constraint for the southern section (i.e., seaward of the swing bridge) of the Port of New Bedford (see Figure 5-10). The lateral (horizontal) clearance is 45.7 m (150 feet), which restricts turbine load-outs in the fore-aft bunny ear configuration. The Route 6 New Bedford–Fairhaven Bridge has a lateral clearance of 28 m (92 feet), which makes turbine transport above (i.e., upstream of) the swing bridge marginal. The Route 6 Bridge not only imposes lateral constraints for vessels transiting to and from the northern section of the harbor but also is outmoded and causes delays in travel time. The turning basin can only handle small cargo ships.

Potential

There are several port areas adaptable for marine terminal expansion capable of supporting ROWEI staging. The State Pier requires a significant amount of investment to bring it up to industry standards for cargo handling. However, there are several other facilities, including the South Terminal that could accommodate ROWEI staging with infrastructure improvements. The rail corridor needs to be extended and trackage improved to accommodate increased and oversized shipments. Commuter rail improvements are being planned, and the engineering of the commuter rail should include upgrades for freight transport. Development and of staging areas for trucks is also critical for increased activity in the port.

The South Terminal is convenient to the mouth of the harbor. Expansion of, and repairs to, the South Terminal would create a multi-use manufacturing and shipping facilitate suitable for ROWEI staging. Dredging along the bulkhead, improvements to the pier structure, and an extension of the existing bulkhead would allow for larger deeper-draft vessel berthing and expanded use of the South Terminal facility.

The North Terminal can be improved for handling of ROWEI fabrication and staging. Terminal facilities should be equipped with a versatile mobile harbor crane and ground support equipment. This equipment can be used for both cargo handling and wind farm components. Additional dredging to provide better access to all deepwater berths could be completed, and the turning basin could be lengthened to accommodate longer, higher tonnage cargo vessels. Improvements to the Route 6 Bridge are critical to the passage of vessels to North Terminal and maximizing vessel access.

5.2 Profiles of East Coast Ports Outside of Massachusetts

The other East Coast ports that were evaluated in this study are described briefly below.

5.2.1 Portland, Maine

Portland Harbor, at the western end of Casco Bay, is the most important port on the coast of Maine (see Figure 5-11). The ice-free harbor offers secure anchorage to deep draft vessels in all weather. The harbor is home to significant domestic and foreign commerce in petroleum products, paper, wood pulp, scrap metal, coal, salt and containerized goods. It is also the Atlantic terminus pipeline for shipments of crude oil to Montreal and Ontario. In 1998, Portland became the largest port in the Northeast based on throughput tonnages.

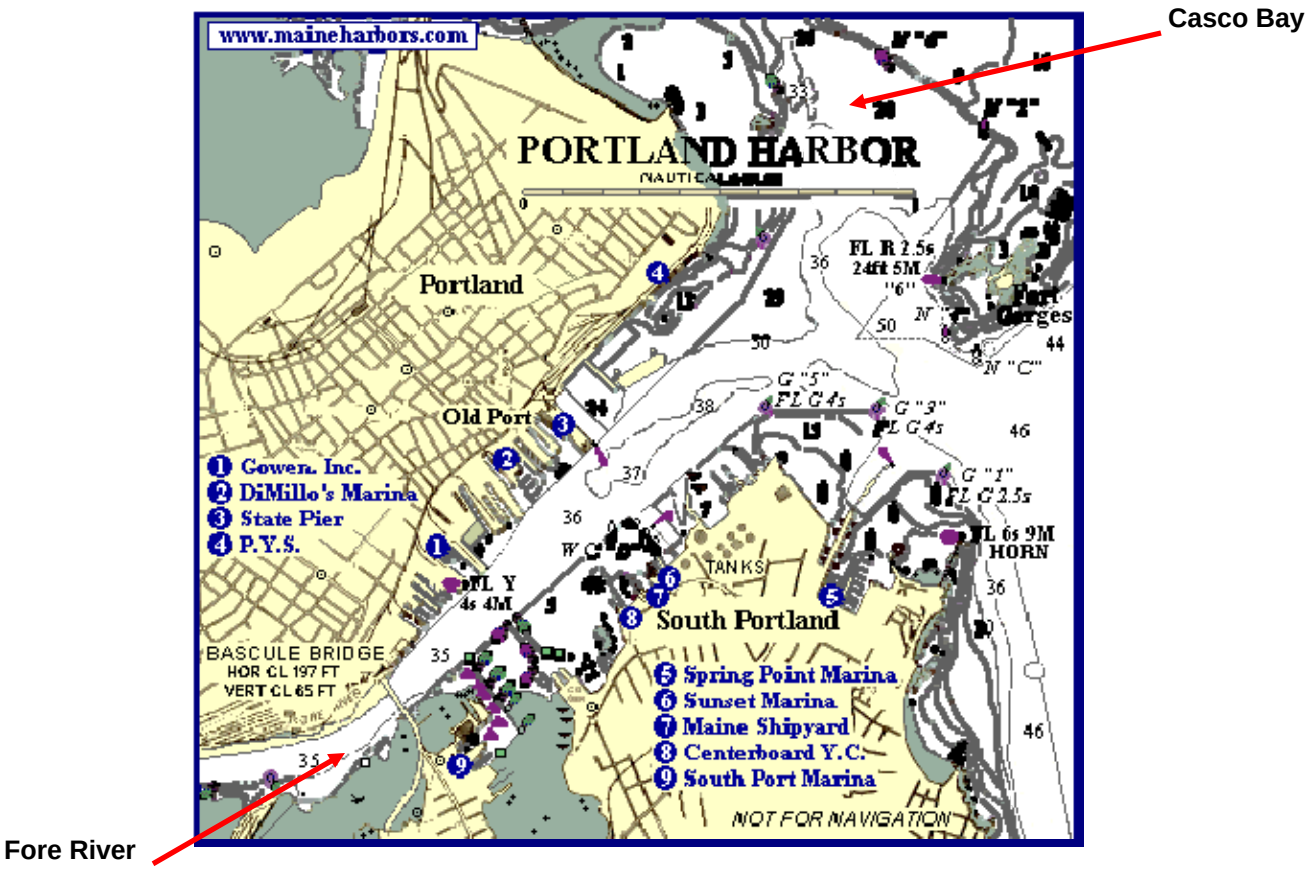


Figure 5-11 Portland Harbor and Shoreline Areas
(Source: www.maineharbors.com)

Portland is served by Pan Am Railways and the St. Lawrence and Atlantic Railroad, connecting the Port to a national network that also reaches into Canada. Passenger and freight ferries serve the nearby islands. Three scheduled airlines operate from the airport, and charter and air taxi service is available. Numerous truck lines serve the greater Portland area with interstate and intrastate service.

Although Portland is equipped to handle above-water hull and engine repairs of deep-draft vessels, major repairs to large vessels are typically made in Boston or, to a lesser extent, in

Bath. Deepwater facilities at Portland include seven petroleum terminals, one general cargo terminal, and one international ferry terminal. All have highway connections and most have railroad connections.

The channel from the sea to Fort Gorges has a depth of 13.7 m (45 feet), continuing at 10.7 m (35 feet) in the Inner Harbor and Fore River to a turning basin seaward of the railroad/highway bridge. The harbor includes two well-protected deepwater anchorages. Casco Bay Bridge, approximately 1.3 nm (approximately 1.5 miles) above the entrance to the Fore River, has a bascule span with a clearance of approximately 16.7 m (55 feet).

5.2.2 Portsmouth, New Hampshire

Portsmouth Harbor, located approximately 3 nm inland of the mouth of the Piscataqua River, is the only harbor of refuge for deep-draft vessels between Portland, ME and Gloucester, MA (see Figure 5-12). The harbor has sufficient depth to accommodate large deep-draft ships and is open throughout the year. The north side of the river, on Seavey Island in Kittery, ME, is occupied by the U.S. Navy and the Portsmouth Naval Shipyard. Foreign trade includes petroleum products, gypsum, frozen fish, fish products, and salt. Oil shipments in tankers drawing as much as 10.7 m (35 feet) arrive frequently in the fall, winter, and spring. The Division of Ports and Harbors of the Pease Development Aurhority oversees the maintenance, development and use of the port.

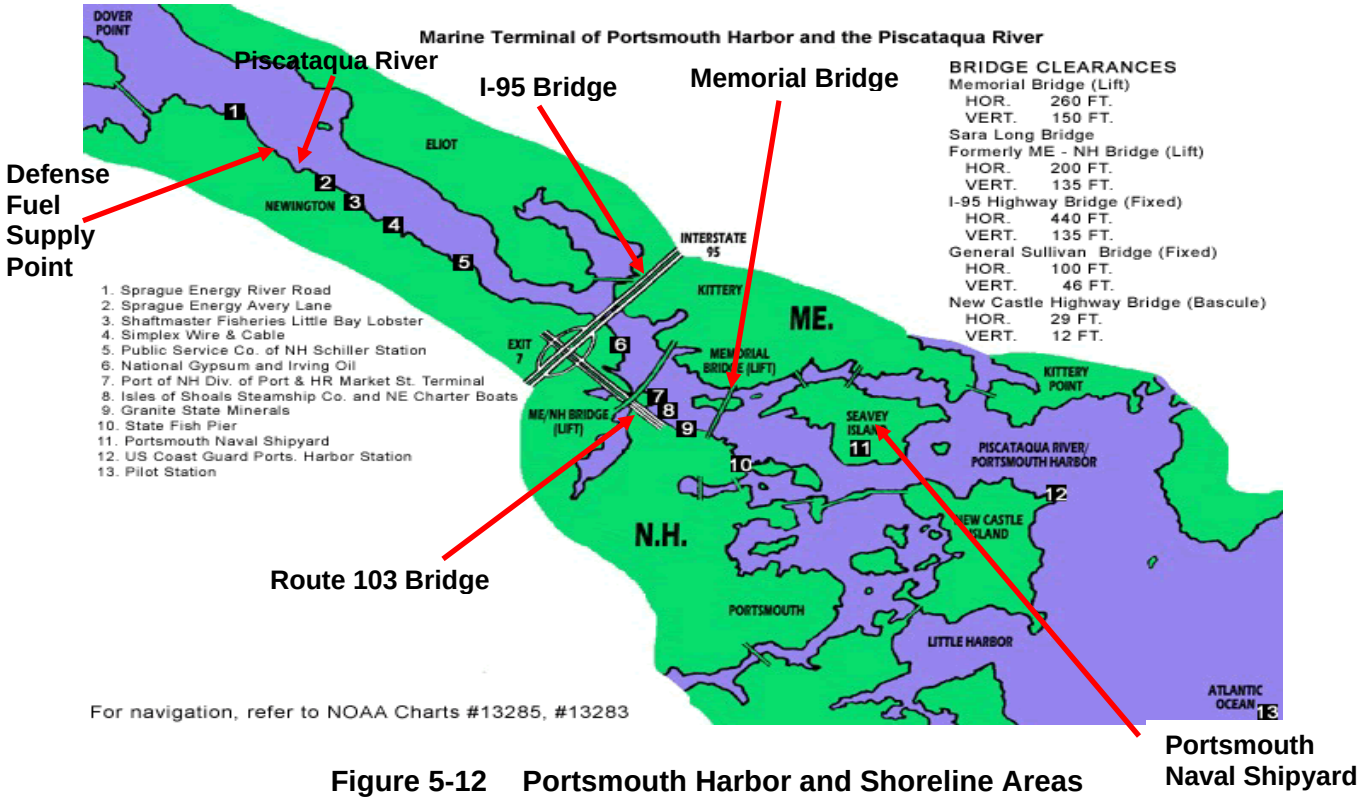


Figure 5-12 Portsmouth Harbor and Shoreline Areas

The port is served by a freight branch of the Boston and Maine Railroad, local and interstate highways, and is located within a mile of the International Airport on the Pease International Trade Port (formerly the Pease Air Force Base). There are no facilities for dry-docking deep-draft vessels in Portsmouth Harbor (the nearest for large vessels is Boston). However, local machine shops can make minor repairs to machinery, and several boatyards are capable of hauling out boats up to approximately 26 m (85 feet) in length.

All active commercial deep-draft facilities are located on the south bank of the Piscataqua River between the first bridge, Memorial Highway Bridge, and Dover Point and have highway connections, and all except the Defense Fuel Support Point Newington Dock have rail connections. Deepwater facilities at Portsmouth include seven petroleum terminals and 3 general cargo terminals.

Depths of about 10.3 m (34 feet) are present in the marked channel through Portsmouth Harbor to the Memorial (U.S. Route 1) Highway Bridge. From this bridge, a dredged marked channel with a depth of 7.9 m (26 feet) leads for about 3.0 nm (3.5 miles) to a turning basin about 0.35 nm (0.4 mile) above Frankfurt Island in the Piscataqua River. The controlling depth in the turning basin is 10.7 m (35 feet).

The principal bridges in Portsmouth Harbor are Memorial (U.S. Route 1) Highway Bridge, which has a lift span with clearances of 5.8 m (19 feet) down and 45.7 m (150 feet) up, and the combined U.S. Route 1 Bypass highway and Boston and Maine railroad bridge, which also has a lift span with clearances of 3 m (10 feet) down and 41 m (135 feet) up.

5.2.3 Providence, Rhode Island

Providence is located at the head of navigation on the Providence River, approximately 6 nm (7 miles) above the junction of the Seekonk River, which empties into the head of Narragansett Bay between Nayatt Point and Conimicut Point. The port's chief waterborne commerce includes petroleum products, cement, lumber, steel scrap metal, general cargo, and automobiles. Providence is served by rail, highway, and air.

The piers and wharves of the Port of Providence are located along both sides of the Providence River below Fox Point. Deepwater facilities at Providence include six petroleum terminals, one LNG terminal, and six general cargo terminals. The alongside water depths range from 8.5 to 12.2 m (28 to 40 feet) with berth lengths ranging from 152 to 396 m (approximately 500 feet to 1,300 feet). All the facilities described have highway connections, and most have rail connections.

The port contains 42.5 hectares (105 acres) of on-dock rail, open storage areas and covered warehouses, and is a fully licensed, bonded deep water port specializing in dry, liquid bulk, and break-bulk commodities (see Figure 5-13). Among the principal products moving through the port are chemicals, heavy machinery, lumber, coal, scrap metal and steel products. The Providence and Worcester Railroad's on-dock rail facilities allow direct vessel to rail transfer, indoor rail for warehouse loading, and a rail line alongside 8.1 hectares (20 acres) of open lay down area. The Providence and Worcester rail line connects to all major rail carriers offering service from the Providence area to anywhere in the contiguous U.S. and Canada.

Figure 5-13 Port of Providence
(Source: http://www.provport.com)

The East Passage, the principal passage in Narragansett Bay, has a depth of about 18.3 m (60 feet) for approximately 9.6 nm (11 miles) up the marked channel to the entrance of the dredged channel to Providence. The Newport Bridge, a fixed highway suspension bridge, crosses East Passage about 3.1 nm (3.6 miles) above the entrance. Vertical clearance through the 457 m (1,500 foot) wide center span is 64.9 m (213 feet) at the center, with lower clearances towards the outside of the center span.

The Providence River has a 12.2 m (40 foot) deep channel from just below Prudence Island Light to Fox Point near the junction of Providence and Seekonk Rivers. A hurricane barrier crosses the Providence River about 183 m (600 feet) above Fox Point. The hurricane barrier has a group of three large movable gates that span the Providence River. Each of the three gates is 12 m (40 feet) wide. The narrow gates prohibit large ships from passing into the inner downtown harbor. However, modern ocean-going vessels now dock at the Port of Providence, located south of the barrier (Schachterle et al 2010). There are no bridges over Providence River between the mouth and the principal wharves.

5.2.4 Quonset Point / Davisville, Rhode Island

Situated between New York and Boston and at the entrance of Narragansett Bay, the Port of Davisville in Rhode Island provides one of the best deep water ocean ports on the east coast. Major cargo arriving at the port includes automobiles, quarried stone, and general cargo. The port has three major piers with over 2,073 m (approximately 6,800 linear feet) of deep water dockage and onsite rail tracks. The Port of Davisville is operated by the Rhode Island Economic Development Corporation (see Figure 5-14).

Figure 5-14 Quonset Business Park
(Source: RI Department of Environmental Management)

Quonset Point is located on the north side of Wickford Harbor, with Quonset Point Business Park located near the eastern end of the point. The site of two former U.S. Naval installations, Quonset Business Park comprises over 1,214.1 hectares (3,000 acres) of land. This land is currently administered by the Quonset Development Corporation (QDC), a subsidiary of the Rhode Island Economic Development Corporation. Land uses within the Park currently consist of mixture of industrial (light, heavy, and waterfront), office uses and public amenities, in addition to the Port of Davisville. The Port of Davisville offers 1,371.6 m (4,500 feet) of berthing space, consisting of two Piers (each 365.8 m [1,200 feet] in length), a bulkhead, 8.8 m (29-foot) channel draft, on-dock rail and a 5.7 hectare (14 acre) lay down area (Quonset Development Corporation website). Currently under construction at the Business Park is a mixed-use project with hotel, retail, restaurant, and office space. The piers at Quonset Point and Davisville are usually approached from East Passage and through a buoyed dredged channel with a depth of 10 m (33 feet) to a turning basin with depths between 9.75 and 10.7 m (32 and 35 feet), from which a channel leads to the piers at Davisville.

Rail service, provided daily by the Providence & Worcester (P&W) Railroad, consists of approximately 14 miles of track in two branches. The P&W rail network allows access to the entire United States and Canadian rail system. The railroad offers double-stack intermodal transportation services and provides a custom-house broker, shipping agent and forwards foreign freight for its customers. Interstate Routes 95, 195 and 295 allow access to regional and national markets. Direct trucking service is available to every state, Mexico, and most of the Canadian Provinces.

5.2.5 New Haven, Connecticut

New Haven Harbor, an important harbor of refuge, is located about 59 nm (68 miles) from New York, 155 nm (179 miles) from Boston via the Cape Cod Canal, and 149 nm (171 miles) from the Nantucket Shoals Lighted Whistle Buoy N (LNB). It is the largest deep water port in Connecticut and comprises all the tidewater northward of breakwaters constructed across the mouth of the bay, including the navigable portions of the West, Mill, and Quinnipiac Rivers. The inner harbor, northward of Sandy Point and Fort Hale, is shallow for the most part, except where the depths have been increased by dredging. Waterborne commerce in the harbor consists of petroleum products, scrap metal, lumber, automobiles, gypsum, paper and pulp products, steel products, chemicals, rock salt, and general cargo.

The main channel has a depth of 10.7 m (35 feet) and a width of 122 to 244 m (400 to 800 feet) to a point just below the junction of Mill River and Quinnipiac River (see Figure 5-15). This channel depth is sufficient for accommodating ships in the range of 18,156 to 36,312 mt (approximately 20,000 to 40,000 deadweight tons). Tomlinson Bridge, at the head of the main harbor at the confluence of Mill and Quinnipiac Rivers, is a vertical lift span with a horizontal clearance of 73.1 m (240 feet) and a vertical clearance of 4.0 m (13 feet) down and 18.6 m (61 feet) up. Just above this bridge is a fixed highway bridge with a clearance of 18.3 m (60 feet).

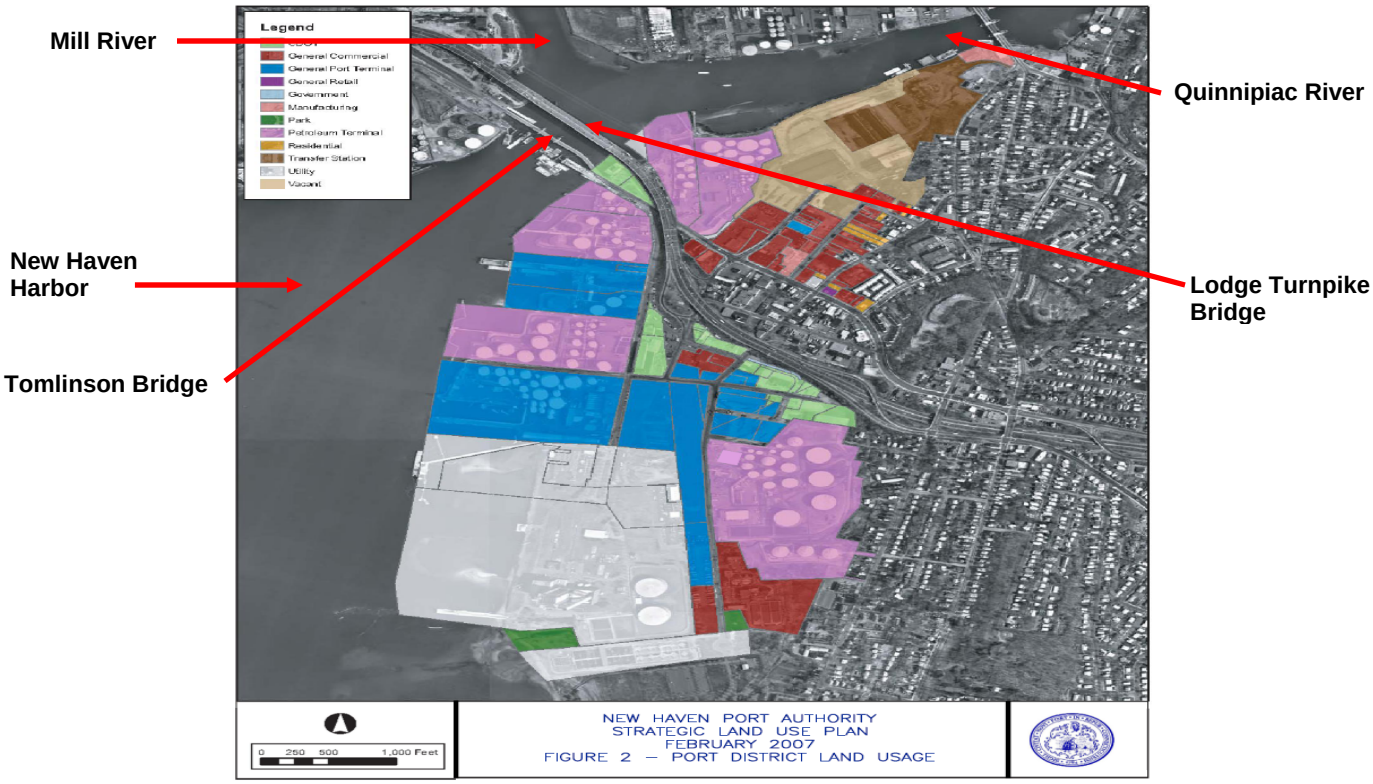


Figure 5-15 Aerial View of New Haven Harbor
(Source: http://www.cityofnewhaven.com/PortAuthority)

The deep draft facilities at the Port of New Haven are along the north and east sides of the inner portion of New Haven Harbor. Facilities for smaller vessels and barges are along the sides of the harbor and in Mill, Quinnipiac, and West Rivers. All deep draft facilities have direct highway connections, and most have railroad connections. The port is proximate to the regional highway network and I-95. Rail service is being restored to the port along with a series of siding tracks proposed for the private terminals. Rail service is provided by the P&W Railroad, and, although not serving the port directly, CSX provides rail freight service in the New Haven area.

New Haven has no facilities for making major repairs or for dry-docking deep draft vessels. However, machine shops in the area can make limited repairs to machinery and boilers and fabricate shafts and other pieces of equipment.

5.2.6 New York and New Jersey

New York Harbor is the principal entrance by water to New York City and the surrounding ports. The harbor is divided by The Narrows into Lower Bay and Upper Bay. The Battery, the southern tip of Manhattan, is at the junction of East River and Hudson River. The main channel from the sea to the deep water terminals in the Hudson River has a depth of 13.7 m (45 feet).

The Verrazano-Narrows Bridge between the Lower Bay and the Port of New York and New Jersey has vertical clearances of between 55.8 and 66.5 m (183 feet and 215 feet). There also are three fixed bridges with vertical clearances ranging from 127 feet to 135 feet.

The Port of New York and New Jersey (see Figure 5-16) has over 1,100 waterfront facilities. Most of these facilities are privately owned and operated, and the rest are owned or operated by either the railroads serving the port, the Port Authority of New York and New Jersey, the City of New York, the States of New York or New Jersey, the Federal Government, or other municipalities. This bi-state port includes terminals in New York City and across New York Harbor in Elizabeth, NJ and Newark, NJ. The port has a major steamship passenger terminal, containership terminals, break-bulk general cargo terminals, and petroleum and other liquid cargo facilities. Most of the waterfront facilities throughout the port have highway and railroad connections. The Port Authority is undertaking a $600 million ExpressRail project to build or expand on-dock and near-dock rail terminals. The Port of New York and New Jersey is served by three trunk line railroads and one short-line railroad, numerous trucking firms engaged in long-haul and short-haul freight service, and several bus companies. Elizabeth, NJ offers the only double-stack intermodal rail access to the port.

Figure 5-16 Terminal Areas at the Port of New York and New Jersey
(Source: http://www.panynj.gov/port)

5.2.7 Philadelphia, Pennsylvania

Philadelphia is one of the chief ports of the United States and is located at the junction of the Delaware and Schuylkill Rivers (see Figure 5-17). Philadelphia's seaport focuses on several areas of international trade, such as the importing of perishable cargoes from South America and high-quality paper products from Scandinavia. Philadelphia has both container and break-bulk terminals, along with good rail and highway connections. It is especially strong as a Northeast departure point for carriers in the Caribbean islands trades, and for inbound fruit shipments (from Latin America) and meats (from Australia). There have been efforts for years to create a bi-state port with the Port of South Jersey across the Delaware River in Camden, NJ.

The main channel from the sea to the Philadelphia Naval Shipyard has a depth of 12.2 m (40 feet), with the other channels through Philadelphia Harbor having varying depths. The Port of Philadelphia is in the process of deepening the main channel to 13.7 m (45 feet). There are four bridges between Delaware Bay and the Port of Philadelphia with vertical clearances ranging from 39 to 57.9 m (128 feet to 190 feet).

Figure 5-17 Port of Philadelphia
(Source: http://aapa.files.cms-plus.com/SeminarPresentations/07_OPSAFIT_Walsh_Jim.pdf)

The Port of Philadelphia is operated by the Philadelphia Regional Port Authority. Philadelphia has more than 45 deep water piers and wharves along its Delaware River waterfront and along the Schuylkill River. Port facilities can be accessed by vessel, rail and highway. The port facilities are serviced by three railroads. Norfolk Southern provides double-stack intermodal service between Philadelphia and major Midwest destinations. Terminal facilities are located in close proximity to interstate highways.

5.2.8 Baltimore, Maryland

The Port of Baltimore is located at the head of tidewater navigation on the Patapsco River. Baltimore Harbor consists of the entire Patapsco River and its tributaries. While part of the waterfront lies outside the municipal limits of Baltimore, by state law the port is within the

jurisdiction of the Maryland Port Administration. When compared to other East Coast ports, Baltimore has a logistical disadvantage as it is 109 nm (125 miles) inland from the ocean, up the Chesapeake Bay.

The main channel between the Virginia Capes and Fort McHenry, Baltimore has a depth of 15.2 m (50 feet), and other channels in the harbor have depths ranging from 12.2 to 15.2 m (approximately 40 to 50 feet). The main channel between the Delaware Capes and Baltimore via the Chesapeake and Delaware Canal is 10.7 m (35 feet) deep.

Principal imports include general cargo, petroleum products, coke of coal, iron ore, aluminum manganese, inorganic chemicals, salt, gypsum, lumber, motor vehicles, fertilizers and sugar; exports are chiefly: general cargo, coal, automobiles and machinery. Most of the piers and wharves in Baltimore Harbor have direct connections with mainline railroads. CSX offers double-stack intermodal service at the 28.3 hectares (70 acre) Seagirt Marine Terminal. More than 100 steamship companies connect Baltimore with principal U.S. and foreign ports. About 150 motor truck carriers service the port.

Baltimore is well equipped to make major repairs to large vessels. The largest graving dock and the largest floating dry-dock in the area are located at the Bethlehem Steel Sparrows Point yard. Marine railways can haul out vessels up to approximately 38 m (125 feet) and up to 270 mt (approximately 300 tons). A plan to dredge the port's berths to 15.2 m (50 feet), the same depth as the main channel, is under consideration (see Figure 5-18).

Figure 5-18 Port of Baltimore
(Source: http://en.wikipedia.org/wiki/File:Baltoport.jpg)

5.2.9 Wilmington, Delaware

The Port of Wilmington is a full-service deep water port and marine terminal handling over 400 vessels per year. This port has an annual import/export cargo tonnage of over 3.63 million mt (4 million tons). Today, Delaware's port is the busiest terminal on the Delaware River. Located at the confluence of the Delaware and Christina Rivers, 56.5 nm (65 miles) from the

Atlantic Ocean, the port is owned and operated by the Diamond State Port Corporation (see Figure 5-19). The Port of Wilmington has wharves that support barge traffic as well as deep water facilities. The Port facilities include seven deep water general cargo berths, a tanker berth, a floating berth for roll on/roll off vessels on the Christina River, and an automobile and roll on/roll off berth on the Delaware River. The Port of Wilmington has the nation's largest dock-side cold storage facility.

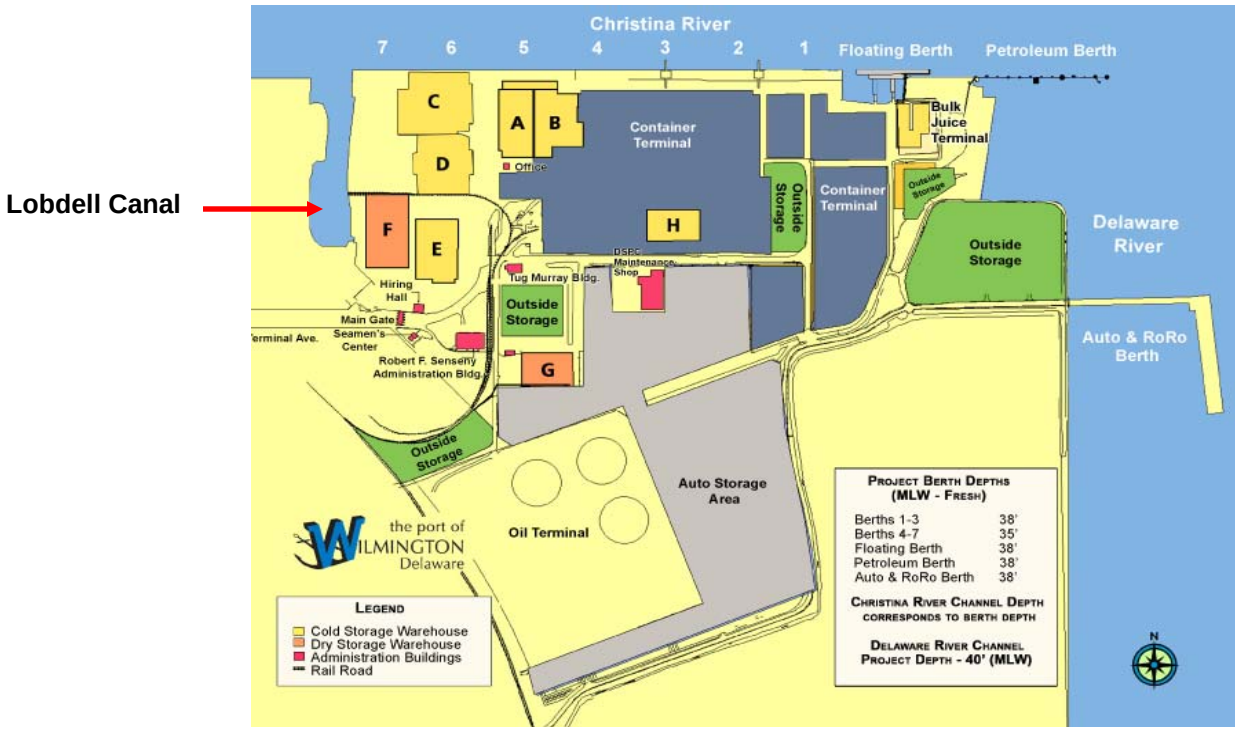


Figure 5-19 Terminal Areas at the Port of Wilmington
(Source: http://dedo.delaware.gov)

There are no bridges or overhead power cables over the deep water section of the Christina River. The Delaware Memorial Bridge has twin suspension spans over the main channel with a clearance of 57.3 m (188 feet). There is a 10.7 m (35 foot) channel from the Delaware River to Lobdell Canal and a 11.6 m (38 foot) deep turning basin opposite the Wilmington Marine Terminal.

Since it was founded in 1923, the Port of Wilmington has been a major Mid-Atlantic import/export gateway for a wide variety of maritime cargoes and trade. Future expansion is planned to provide more storage capacity for existing and future commercial businesses. Rail access to the port is available via Norfolk Southern and CSX Transportation, with railcar loading docks located next to terminal warehouses.

5.2.10 Virginia Port Authority

Chesapeake Bay, the largest inland body of water along the Atlantic coast of the United States, is 146 nm (168 miles) long with a width of 20 nm (23 miles). The bay is the approach to Norfolk, Newport News, Baltimore, and many lesser ports. Deep-draft vessels use the Atlantic entrance, which is about 8.7 nm (10 miles) wide between Fisherman's Island on the north and Cape

Henry on the south. Medium-draft vessels can enter from Delaware Bay on the north via Chesapeake and Delaware Canal, and light-draft vessels can enter from Albemarle Sound on the south via the Intracoastal Waterway. The Port of Virginia has the advantage of being served by the deepest ice-free channels on the East Coast. When the harbor is dredged to a 15.2 m (50 foot) depth, Norfolk will be the first East Coast port able to accommodate a fully loaded 8,000-TEU ship, which means the port would be able to accommodate large purpose-built offshore wind vessels (see Figure 5-20).

Figure 5-20 Port of Virginia
(Source: Google Earth)

Hampton Roads, at the southwest corner of Chesapeake Bay, is entered 13.9 nm (16 miles) westward of the Virginia Capes. It includes the Port of Norfolk and the Port of Newport News. Hampton Roads is the world's foremost bulk cargo harbor. Coal, petroleum products, grain, sand and gravel, tobacco, and fertilizer constitute more than 90 percent of the cargo handled at Hampton Roads ports. Hampton Roads ports are served by a terminal beltline, several large railroads, and by more than 50 motor carriers. In addition, over 90 steamship lines connect Hampton Roads with the principal U.S. and foreign ports.

Norfolk Harbor comprises a portion of the southern and eastern shores of Hampton Roads and both shores of the Elizabeth River. Norfolk Harbor has numerous wharves and piers of all types, the majority of which are privately owned and operated. All have freshwater connections and access to highways and railroads.

The Virginia Port Authority is expanding capacity to meet increased demand for terminal space. When this renovation is complete, it will be home to eight of the largest cranes in the world and the wharf will be a state-of-the-art facility capable of handling the heaviest cargo in the world. In addition, Maersk Sealand plans to invest a total of $450 million for a new terminal on approximately 100 hectares (250 acres) of Virginia Port Authority property in nearby Portsmouth, Virginia, the first major privately developed terminal in the United States.

Hampton Roads has extensive facilities for dry-docking and making major repairs to large deep-draft vessels. The shipyard at Newport News has one of the largest and best equipped graving docks in the United States. There are many other yards that are especially equipped to handle medium-sized and small vessels.

The approach to Hampton Roads is through the 16.7 m (55 foot) Thimble Shoal Channel. There are natural depths of 6.1 to 24.2 m (20 to 80 feet) in the main part of Hampton Roads, but the harbor shoals to less than 3 m (10 feet) toward the shores. Dredged channels lead to the principal ports. Two main Federal channels, marked by buoys, lead through Hampton Roads.

5.3 U.S. East and Gulf Coast Shipyard Construction and Repair Capacity

The construction of new tonnage and repair of marine equipment in both the propelled and non-propelled market has become an issue in recent years because of shifting shipyard capacity throughout the world. While new capacity in other parts of the world has replaced lost capacity in the U.S., declining domestic demand has reduced the number of available shipyards in this country for new construction or repair of large vessels. At the same time, recent regulations such as the Jones Act, require vessels in domestic service or operating in domestic waters to be built and serviced in U.S. yards. As the number of yards available for new construction or repair decreases due to declining demand, the number of yards able to comply with Jones Act requirements also decreases. This is particularly evident in the Northeast U.S. where shipyards able to handle large tonnage vessels, including deep water cargo ships, tankers and specialty vessels such as offshore delivery and support vessels, have dramatically decreased.

While yards that handle large tonnage vessels have decreased, the demand has remained relatively stable for yards that handle smaller vessels such as tugs, offshore service vessels and barges. Current and anticipated demand for commercial construction of cargo and petroleum vessels has been addressed by fewer facilities that have increased their size and capability in some cases.

Specialty wind farm vessels have unique construction and servicing requirements. For the purpose of this analysis, a purpose-built vessel with a length overall (LOA) of 143 m (470 feet) and a width (beam) of 39.6 m (130 feet) was selected to establish the largest dimensions for representative turbine import and installation vessels. Smaller service vessels including offshore supply boats (that can be readily adapted for serving offshore wind farm equipment) and tug and barges also were considered as they are employed regularly in offshore activities. Whereas installation and service vessels handling offshore wind turbine components within the territorial waters of the U.S. would be subject to the Jones Act, import/delivery vessels could be foreign flagged if their operation were limited to equipment delivery at a single U.S. port.

The following analysis assesses construction capacity and repair capacity at U.S. shipyards. See Appendix H for more detail.

5.3.1 Construction Demand and Capacity

Construction demand for small vessels over the last nine years in the U.S. has been steady and has increased due to the fact that numerous vessels are reaching the end of their serviceable life. A growing number of stricter regulations and replacement requirements have increased demand for new small vessel construction in recent years, particularly in the tug and barge industry. Tug and barge construction demand is illustrated in Table 5-2.

Table 5-2
Nine Year Tug and Barge Construction Demand-U.S. Shipyards
(Source: MARAD Shipbuilding Statistics)

Vessel Type	2000	2001	2002	2003	2004	2005	2006	2007	2008	9-Year Totals	Average per Year
Tugs and Towboats	72	63	73	60	73	70	94	121	165	791	88
Dry Cargo Barges >5000 Gross Tons	1	3	2	0	4	1	3	2	4	20	2
Inland Dry Cargo Barges	775	609	672	217	427	219	672	846		4,427	553

Vessel construction has begun to increase over the last several years as the need for larger and more versatile vessels has risen. Towing and offshore supply companies are replacing smaller horsepower vessels with larger units, such as tractor tugs or higher capacity, higher horsepower supply vessels.

Barge construction is of particular importance as the servicing and installation of offshore renewable energy facilities may well be handled by tugs and barges because of their lower operational costs. The demand for barge construction is using up ship construction capacity in the yards where offshore specialty vessel construction could take place. Production of tank barges has increased to meet regulatory requirements for double-hulled barges under the Oil Pollution Act of 1990 (OPA 90). The age comparison between the overall barge fleet and tank barges is of note. Only 30% of all barges are more than 25 years old, whereas fully 50% of tank barges are 25 years or older. This is expected to result in a surge of tank barge orders in the next 5 years to replace existing barges aging past their prime. In 2008 alone more than 132 new tank barges were built, increasing delivery times and reducing capacity for other types of construction. While shipyards are positioned to meet most vessel construction demands, there are longer delivery times for new vessels. At present there is sufficient building capability to meet both new construction demands with backlogs running six months to one year. This is considered by the industry to be reasonable for vessel orders and deliveries. Due to the complexity and unique nature of specialty offshore vessels, a significantly longer lead time should be considered when calculating construction cycles and delivery needs.

There were recently 63 vessels under construction that have been delivered or planned for delivery by U.S. shipyards by the end of 2009, most being tugs and towboats. A compilation of the results of a survey conducted of shipyards with recently completed contracts is presented in Table 5-3.

Table 5-3
Recent Shipyard Contracts as of 2009
(Source: MARAD Shipyard Statistics)

Vessel Name	Shipyard	Owner	Type	GT	Delivery
Safety Team	B. & B. Boatbuilders	AEP River Operations	1,550-hp Towboat	157	May-09
Miss Lucy	B. & B. Boatbuilders		Pushboat	29	May-09
Shiney V. Moran	C. & G. Boat Works	Moran Towing	5,360-hp Tug	192	May-09
Roger Binsfeld	Hope Services	Brennan Marine	Towboat	144	May-09
Mountain State	Quality Shipyard	AEP River Operations	6,000-hp Towboat	774	May-09
Coon Wise	GNOTS Marine	GNOTS Reserve	2,400-hp Towboat	107	May-09
Blake Boyd	Eastern Shipbuilding	Florida Marine	2,600-hp Towboat	260	May-09
Pat Voss	Verett Shipyard		Towboat	347	Apr-09
Yellowfin	Thoma-Sea Shipbuilders	Penn Maritime	4,000-hp ATB Tug	223	Apr-09
San Brendan	Bludworth Shipyard	Buffalo Marine	1,320-hp Towboat	185	Apr-09
Elvis	Inland Boat Works		Pushboat	52	Apr-09
Hunter M	Orange Shipbuilding	Bay-Houston Towing	6,300-hp Escort Tug	425	Mar-09
Salvation	Raymond & Associates	Eckstein Marine	2,000-hp Towboat	167	Feb-09
Greg McAllister	Eastern Shipbuilding	McAllister Towing	6,000-hp Tug	172	Jan-09
Severn	Thoma-Sea Boatbuilders	Vane Brothers	4,200-hp Tug	341	Jan-09
Corpus Christi	Eastern Shipbuilding	US Shipping	12,000-hp ATB Tug	919	Jan-09
C-Tractor 19	GulfShip	Alpha Marine Services	Tractor Tug	298	4-May-09
Parker A. Settoon	Eastern Shipbuilding	Settoon Towing	3,000-hp Towboat	289	22-Apr-09
Joshua Caleb	A. & B. Industries	CLM Marine	Towboat	95	22-Apr-09
Lamar Golding	D.E.S. Boatworks	Golding Barge Line	Towboat	277	20-Apr-09
Susanne T	Hardrock Marine Services	Endeavor Marine		21	16-Apr-09
Scott Stegbauer	Steiner Shipyard	Southern Towing	3,200-hp Towboat	402	14-Apr-09
George	Main Iron Works	Harbor Docking	6,140-hp Harbor Tug	734	10-Apr-09
Miss Cassie	Robert Crawley	Robert Crawley	Pushboat	13	9-Apr-09
Safety Forever	B. & B. Boatbuilders	AEP River Operations	1,550-hp Towboat	157	9-Apr-09
Janis R. Brewer	Eastern Shipbuilding	Crounse Corp.	4,000-hp Towboat	472	9-Apr-09
Ruth M. Reinauer	SENESCO	Reinauer Transportation	4,000-hp ATB Tug	485	8-Apr-09
Capt C H Guidry	Eastern Shipbuilding	Florida Marine	2,600-hp Towboat	260	7-Apr-09
Mannie Cenac	Intracoastal Iron Works	Cenac Towing	Pushboat	95	3-Apr-09
Captain Robert	A. & B. Industries	Odyssea Vessels	4,200-hp Towboat	97	31-Mar-09
Anacostia	Thoma-Sea Boatbuilders	Vane Brothers	4,200-hp Tug	341	30-Mar-09
Genie Cenac	Tres Palacios Marine	Cenac Towing	3,200-hp Towboat	189	27-Mar-09
Delta Billie	Nichols Bros Boatbuilding	Bay Delta Marine	6,800-hp Escort Tug	194	26-Mar-09
Commitment	VT Halter Marine	Crowley Marine	9,280-hp ATB Tug	465	26-Mar-09
Holy Cross	Raymond & Associates	Eckstein Marine	2,000-hp Towboat	167	16-Mar-09
Affirmed	C. & C. Boat Works	Turn Services	Towboat	147	10-Mar-09
Kyle A Shaw	Hope Services	Maryland Marine	1,800-hp Towboat	144	4-Mar-09
Capt Dean	Eastern Shipbuilding	Florida Marine	2,600-hp Towboat	260	27-Feb-09
AK Hotchkiss	Progressive Industrial	Riverside Basin Marine	Pushboat	17	26-Feb-09
W. J. Authement	Intracoastal Iron Works	Intracoastal Iron Works	Towboat	95	25-Feb-09
Patuxent	Thoma-Sea Boatbuilders	Vane Brothers	4,200-hp Tug	341	25-Feb-09

Vessel Name	Shipyard	Owner	Type	GT	Delivery
Morgan City	Raymond & Associates	Kirby Inland Marine	1,800-hp Towboat	223	26-Feb-09
Austin C. Settoon	Eastern Shipbuilding	Settoon Towing	3,000-hp Towboat	289	19-Feb-09
Alton St. Amant	Sneed Shipbuilding	Blessey Marine	1,700-hp Towboat	249	19-Feb-09
Ted	Main Iron Works	Harbor Docking	6,140-hp Habor Tug	481	17-Feb-09
Safety Priority	B. & B. Boatbuilders	AEP River Operations	1,550-hp Towboat	157	17-Feb-09
Sesok	Diversified Marine	Vessel Mgmt. Svces.	1,362-hp Tug	143	12-Feb-09
Nachik	Diversified Marine	Vessel Mgmt. Svces.	1,362-hp Tug	133	12-Feb-09
Orca One	Geo Shipyard	Orca Maritime	Towboat	299	10-Feb-09
Panther	Serodino	Serodino	Towboat	75	10-Feb-09
Gladiator	Gulfbound	Dragnet Seafood	Towboat	90	10-Feb-09
Mr Nelson	Diversified Marine	AC Marine	Towboat	77	4-Feb-09
Danny L Whitford	Gulf Inland Marine	Hunter Marine Transport	Towboat	445	3-Feb-09
Celine B	Inland Boat Works	Joseph B. Fay Co.	Pushboat	23	29-Jan-09
Anna Marie	A. & B. Industries	Terral Riverservice	Towboat	80	29-Jan-09
Donnie Verret	Verret Shipyard	T & B Towing	Towboat	73	23-Jan-09
Cynthia G Esper	Marine Builders	SCF Marine	3,200-hp Towboat	256	23-Jan-09
Holy Rosary	Raymond & Associates	Eckstein Marine	2,000-hp Towboat	167	14-Jan-09
Perry M D	Perry & Son Towing	Perry & Son Towing	Towboat	82	12-Jan-09
Lady Loren	Lockport Fabrication	LA Carriers	1,980-hp Towboat	96	12-Jan-09
Blessed Trinity	Raymond & Associates	Eckstein Marine	2,000-hp Towboat	167	7-Jan-09
Citation	C. & C. Boat Works	Turn Services	Towboat	147	6-Jan-09
Safety Challenger	B. & B. Boatbuilders	AEP River Operations	1,550-hp Towboat	157	6-Jan-09
GT = Gross Ton = Long Ton = 1,016 kg = 2,240 pounds					

5.3.2 Shipyard Availability

The number of shipyards that have current capacity for large specialty vessel construction is limited within the U.S. Of the 350 active vessel construction companies in the U.S., only 52 have a history of significant vessel construction in the Eastern or Southern regions of the country. Eight are located on the U.S. Atlantic Coast and the rest on the U.S. Gulf Coast. Because of their proximity to potential offshore installation sites, Atlantic and Gulf coast shipyards were examined in more detail. A limited number of yards are capable of handling large specialty vessels based on yard size, but a number of them could handle smaller specialty vessels. The yards that can build vessels on the Atlantic and Gulf Coasts are highlighted in Table 5-4.

Table 5-4
Active East Coast and Gulf Coast Shipyards with Significant Construction Records
(Source: MARPRO Associates International 2009)

Shipyard	Location
Atlantic Coast	
Blount Boats	Warren RI
Chesapeake Shipbuilding	Salisbury, MD
Cianbro	Portland, ME
Derecktor Shipyards	Bridgeport, CT
Gladding-Hearn	Somerset, MA

Shipyard	Location
SENESCO	North Kingstown, RI
Washburn & Doughty	East Boothbay ME
Yank Marine	Tuckahoe, NJ
Gulf Coast	
A & B Industries	Morgan City, LA
B. & B. Boat Builders	Bayou La Batre AL
Bludworth Shipyard	Corpus Christi, TX
Boconco	Bayou La Batre, AL
C. & C. Boat Works	Belle Chase, LA
C. & C. Marine and Repair	Belle Chase, LA
C. & G. Boat Works	Bayou La Batre, AL
C. & G. Boat Works	Mobile, LA
Candies Shipbuilders	Houma LA
Conrad Industries	Morgan City, LA
Duckworth Steel Boats	Tarpon Springs, FL
Eastern Shipbuilding	Panama City FL
Eymard & Sons Shipyard	Harvey LA
Gulf Island Marine Fabrication	Houma, LA
Gulf Ship	Gulfport, MS
Halimar Shipyard	Morgan City, LA
Hope Services	Dulac, LA
Horizon Shipbuilding	Bayou La Batre, AL
Inland Marine	Bridge City, TX
Intracoastal Iron Works	Bourg, LA
Leevac Industries	Jennings LA
Lockport Fabrication	Lockport, LA
Main Iron Works	Houma LA
Marine Inland Fabricators / Sisco Marine	Panama City, FL
Master Marine	Bayou La Batre, AL
Master Boat Builders	Coden AL
Orange Shipbuilding	Orange TX
Patti Shipyard	Pensacola, FL
Portier Shipyard	Chauvin, LA
Progressive Industrial	Palmetto, FL
Quality Shipyards	Houma LA
Raymond & Associates	Bayou La Batre AL
Rodriguez Boatbuilders	Bayou La Batre, AL
Rodriguez Boatbuilders	Coden AL
SEMCO	Lafitte, LA
Sneed Shipbuilding	Channelview, TX
Sneed Shipbuilding	Orange, TX
Southwest Shipyard	Houston, TX
Steiner Shipyard	Bayou La Batre, AL

Shipyard	Location
Thoma-Sea Boatbuilders	Houma, LA
Thoma-Sea Shipbuilders (formerly Halter Lockport)	Lockport, LA
Trinity Madisonville	Madisonville, LA
Trinity Port Allen	Port Allen, LA
Verret Shipyard	Plaquemine, LA
West Gulf Marine	Galveston, TX

5.3.3 Capacity and Delivery Estimations

In the Northeast, many of the yards have compressed operations due to increasing environmental concerns and gentrification of industrial areas. Several of the yards confine activities to repair and have refocused their efforts on small craft (such as ferries, yachts and similar commercial watercraft). In the Gulf of Mexico, a number of the shipyards have not fully restored operations to pre-Katrina levels primarily due to a shortage of qualified personnel and absence of infrastructure.

The Gulf of Mexico region still has the highest percentage of multi-purpose construction and repair yards in the country. Average small vessel construction, such as tugs or offshore supply/service vessels, can run from six months to a year depending on complexity. Barge construction can run from 3 to 9 months depending on size and function. Construction of larger specialty vessels can exceed 12 to 18 months and run up to 24 months. There are several smaller yards in the Northeast and Gulf that have no backlogs and have immediate capacity for new vessel orders. Very few have multiple vessel capacity, and backlogs do not extend beyond 2011.

5.3.4 Vessel Repair Capacity

Most of the shipyards on the Atlantic Coast that build vessels also have some level of repair capacity. There is only limited repair capacity in New England. Some yards only handle military contracts. However, in recent weeks, General Dynamics has announced an expansion of its facilities in Bath, Maine to accommodate the construction of components for offshore wind farms. Atlantic Coast repair yards are listed in Table 5-5.

Table 5-5
Listing of Shipyards on the Atlantic Coast with Build and/or Repair Capacity
(Source: MARPRO Associates International 2009)

US Atlantic Coast	Type	Size	Location	State
Atlantic Marine Boston	R	L	Boston	MA
Atlantic Marine Florida	B	M	Jacksonville	FL
Bayonne Drydock	R	L	Bayonne	NJ
Blount Boats	B	S	Warren	RI
Broward Marine	B	Y	Dania Beach	FL
Caddell Dry Dock	R	S	Staten Island	NY
Chesapeake Sbldg.	B	S	Salisbury	MD
Cianbro	BR	S	Portland	ME
Davis Boat Works, Inc.	R	S	Newport News	VA
Derecktor Shipyard Connecticut	B	S	Bridgeport	CT

US Atlantic Coast	Type	Size	Location	State
Derecktor Shipyard Florida	BR	S	Dania	FL
Derecktor Shipyard New York	BR	S	Mamaroneck	NY
Detyens Shipyards	R	L	N. Charleston	SC
Detyens Shipyards	R	S	Jacksonville	FL
Fairhaven Shipyard	R	S	Fairhaven	MA
Fore River Dock and Dredge	BR	S	South Portland	ME
G.M.D. Shipyard	R	L	Brooklyn	NY
GD/Bath Iron Works	B	L	Bath	ME
GD/Electric Boat	B	L	Groton	CT
General Ship Repair Corp.	R	S	Baltimore	MD
Gladding-Hearn	BR	S	Somerset	MA
Global Ship Systems	R	S	Savannah	GA
Kelley Shipyard, D. N.	R	S	Fairhaven	MA
Lyon Shipyard	R	S	Norfolk	VA
Marine Hydraulics	R	T	Norfolk	VA
May Ship Repair Contracting	R	S	Staten Island	NY
Metro Machine of VA	R	L	Norfolk	VA
Muller Boat Works	R	S	Brooklyn	NY
Newport Shipyard Company	R	S	Newport	RI
Scarano Boat Building	B	S	Albany	NY
Seaboats	BR	S	Fall River	MA
SENESCO	B	S	North Kingstown	RI
Thames Shipyard & Repair Co.	R	S	New London	CT
Union Dry Dock & Repair	R	S	Hoboken	NJ
Washburn & Doughty	B	S	East Boothbay	ME
KEY Type Codes: B = Build; R = Repair Size Codes: S = small; M = medium; L = large				

5.3.5 Conclusions Relative to Construction and Repair Capacities on the Atlantic Coast

Large vessel construction and small vessel construction most likely would be handled by different shipyards. Yard capacity varies from region to region. The industry can meet the demand for a phased-in cycle of new vessels on a limited basis up to approximately three units per year using multiple yards in various regions of the U.S. Barge construction demand is expected to increase, thereby reducing overall new vessel construction capability. This will affect the ability of some shipyards to meet larger specialty vessel construction. New England has new construction capability limited to smaller vessels, but adequate repair capability for smaller vessels and some capacity for larger vessels. Both Atlantic and Gulf Coast shipyards will need to be considered to meet vessel construction and demand requirements. A developer should anticipate an 18-month lead time for design, contracting, construction and delivery of small vessels and up to 24 months for larger vessels.

6.0 SHORT-LISTING OF PORTS FOR FURTHER EVALUATION

Based on the evaluation criteria developed in Section 4 and analysis, the Team has concluded that New Bedford and Boston Harbor have the best potential to support the assembly and deployment of the planned and prospective offshore wind energy projects. The process by which these two short-listed ports were identified is described below.

6.1 Massachusetts Port Criteria Evaluation Matrix

As described in Section 4, the Team identified a broad set of direct requirements and highly desirable characteristics of port facilities relative to supporting offshore wind farm construction and operation. This list was further distilled down to a smaller set of criteria that could be used to differentiate the candidate port facilities based on the potential of that port to support offshore wind energy development. These criteria included some “hard” criteria that had minimum quantitative measures with which to judge the feasibility or suitability of a port relative to that consideration. Those ports that failed to meet the majority of our hard criteria (recognizing that modifications, upgrades or work arounds could potentially be made to ports relative to one or two characteristics to allow them to achieve the minimum threshold criteria) were eliminated from the evaluation process. This screening resulted in the selection of six Massachusetts ports (located in DPAs) for further consideration. The Massachusetts Port Criteria Evaluation Matrix (see Table 6-1) clearly demonstrates how these six Massachusetts ports compare against each other with respect to our established “hard” criteria. Application of the identified “soft” criteria was reserved for only the short-listed ports and is discussed later in this report.

Table 6-1
Massachusetts Port Criteria Evaluation Matrix

PARAMETERS		PORTS					
Criteria	**Recommended Values/Ranges**	**Boston**	**New Bedford**	**Fall River**	**Gloucester**	**Salem**	**Fore River**
First Tier Harbor Navigational Access							
Protected Harbor	Sheltered from Weather Conditions	Yes	Yes	Yes	Yes	Yes	Yes
Shipping Vessel Channel Depth	Minimum 7.3 m (24’)	12.2 – 13.7 m (40' - 45')	9.1 m (30')	10.7 m (40')	4.9 - 5.8 m (16' - 19')	9.4 m (31’)	9.8 m (32')
Overhead Clearance	No Vertical Obstruction	NVO, but FAA approval required	NVO	41 m (135')	NVO	NVO	53.3 m (175')
Horizontal Clearance	40 m (130') (beam plus overhang)	131 m (430')	45.7 m (150')	122 m (400')	61 m (200')	85.3 m (280')	53.3 m (175')
24/7 Operational Ability	24/7 operations	Yes	Yes	Yes	No	Yes	Yes
Exclusive Use of Port Facility	Ability to Offer Exclusive Use	Yes	Yes	No	No	No	Yes
Comments				Mt Hope Bridge height restriction	Navigational constraints	Salem DPA in full use by power plant	Fore River Bridge height restriction
Second Tier Port Facilities							
Berth Length	Minimum 138 m (450’)	549 m (1,800')	488 m (1,600')	189 m (620')	427 m (1,400')	177 m (580')	244 m (800')
Shipping Vessel Water Depth	Minimum 7.3 m (24’)	12.2 – 13.7 m (40' - 45')	9.1 m (30')	10.7 m (40')	4.9–5.8 m (16'-19')	9.4 m (31')	9.8 m (32')

Table 6-1
Massachusetts Port Criteria Evaluation Matrix

PARAMETERS		PORTS					
Criteria	**Recommended Values/Ranges**	**Boston**	**New Bedford**	**Fall River**	**Gloucester**	**Salem**	**Fore River**
Total Wharf and Yard Upland Area	4.0 hectares (10 ac)	5.7 – 6.9 hectares (14-17 ac)	4.0+ hectares (10+ ac)	2.8 hectares (7 ac)	3.2 hectares (7.8 ac)	NA	44.9 hectares (111 ac)
Rail Access	Rail Access	Limited	Limited	Yes	Yes	No	Yes
Highway Access	Highway Access	Yes	Yes	Yes	Yes	No	No
Comments				State Pier can only accommo date small cargo vessels.	Limited adaptable area	Insufficie nt work area; additional focus on tourism	Multiple berths/ rough estimate; plans for mixed-use waterfront development

Legend NVO = No vertical obstruction
= Criteria not met
NA = Not available for ROWEI staging

6.2 Implications of Applying the Hard Criteria Relating to Navigational Access and Port Facilities

6.2.1 Evaluation of Each Hard Criterion

Protected Harbor: All of the six Massachusetts ports are in protected harbors. The hurricane barrier in New Bedford adds an additional layer of protection for portside operations during inclement weather.

Shipping Channel Depth and Overhead Clearance: Navigational access to Fall River and Fore River is constrained by the overhead height restrictions of existing bridges (indicated by a shading of the matrix cell in Table 6-1), and the Port of Gloucester does not meet the minimum shipping channel depth of 24 feet. On the other hand, the shipping channels of New Bedford and Boston Harbors meet the minimum depth criterion. New Bedford's navigation channel is 30 feet deep, and the New Bedford HDC is proposing to dredge to extend the 30 foot channel to the planned bulkhead extension at the South Terminal. Navigation channels to Boston Harbor's DPA are between 40 feet and 45 feet deep. Both New Bedford and Boston Harbor have unobstructed overhead clearance. There are no vertical obstructions, such as bridges and/or power lines, which would prohibit offshore wind component delivery and installation vessels, including jack-up vessels, from accessing either harbor. However, as noted previously, FAA approval may be required in Boston Harbor because of the harbor's proximity to Logan International Airport.

Horizontal Clearance: None of the selected ports are restricted by horizontal (lateral) clearances less than 130 feet. The minimum horizontal clearance criterion eliminated facilities in New Bedford upstream of the New Bedford-Fairhaven Bridge (92 feet of lateral clearance). However, the South Terminal at New Bedford Harbor is downstream of the New Bedford-Fairhaven Bridge and upstream of the Hurricane Barrier.

24/7 Operational Ability and Exclusive Use of Port Facility: All ports being evaluated, with the exception of the Port of Gloucester, can operate around the clock and all year. The Ports of Gloucester and Salem also did not have the ability to offer exclusive use of their facilities.

Berth Length and Shipping Vessel Water Depth: Off-shore wind farm construction is associated with multiple berthing operations, including offloading of parts for final assembly or pre-assembly; loading of special barges with the pre-assembled or assembled elements (rotor with blades, foundations or tower sections); mooring of jack-up vessels, crane vessels or any type of specialty purpose-built vessel for service (fuel and maintenance), preparation and deployment; mooring and service of crew boats; emergency response support; and any other activity supporting staging and construction. The established berth length and channel and portside depth criteria reflected minimum requirements for accommodating these operations. The Port of Gloucester failed to meet the depth criterion. All other ports had sufficient length and depth.

Total Wharf and Yard Upland Area: Landside (upland) port facilities provide storage, staging and assembly work areas to facilitate offshore wind farm installation. To fulfill these tasks it is important that landside facilities have adequate acreage, warehouse space, onsite equipment, and high load bearing capacity. Most working ports have existing equipment that could be used or adapted to offload, assemble and load some or all current turbine and foundation components. The Team determined that given sufficient land area, storage, assembly, and load bearing issues could be addressed with improvements to the port. Neither Fall River, Gloucester, nor Salem has sufficient adaptable space for the work area required to support offshore wind farm staging.

Rail Access: None of the Massachusetts ports evaluated for this study has second generation rail access[7]. Existing tracks will not be able to handle the expected size of future generation nacelles and rolled steel components. Existing rail lines could be used primarily for delivery of aggregate and related products rather than turbine or foundation components. Whereas Fall River, Gloucester, and Fore River have existing freight rail lines to the waterfront, Boston and New Bedford currently have limited rail access, and Salem has none. Boston has active rail to the Boston Marine Industrial Park, but not to the North Jetty or Dry Dock #4. Boston has designed the rail extension to the North Jetty and Dry Dock #4, and funding for construction has been requested through a TIGER application[8]. New Bedford has rail access to the waters' edge, and there is a pending TIGER request[9] to connect the existing tracks to the State Pier, but not the South Terminal.

Highway Access: Road connections are important for transport of ancillary material and equipment, as well as personnel. Overweight and large shipment units are subject to state permitting requirements, which also take into account possible roadway infrastructure

[7] First generation rail clearance for container doublestack cargo is 19 feet above the rail (ATR). Second generation doublestack clearance is 22.5 feet ATR.

[8] The Boston Redevelopment Authority has requested a grant of $84 million for expansion of the Black Falcon Cruise Terminal; track improvements to the Boston Marine Industrial Park rail line; improvements to the East, North and South Jetties; and reconstruction of the FID Kennedy West and Access Roads.

[9] The New Bedford HDC has requested a grant of $36.4 million to improve North Terminal infrastructure; rehabilitate the rail line to the State Pier; update and rehabilitate Herman Melville Boulevard; procure cranes and modify terminals for roll on-roll off capability; and develop the southern portion of the South Terminal.

constraints, such as overhead utilities, road lighting, road curvatures and intersections. Neither Salem Harbor nor the Fore River Shipyard has capacity for high volume traffic flow due to local roadway congestion. There is no direct interstate highway access from the City of Salem; the nearest highway access to Route 128 is along Route 114 in neighboring Peabody. Fore River's access to the interstate highway network is via Route 3, a limited-access roadway that is about two miles away from the Shipyard.

6.2.2 Results of the Evaluations

Based on the hard criteria established in Section 4 and displayed in Table 6-1, the ports of Fall River, Gloucester, Salem, and Fore River fell short of the minimum requirements for navigational access and port infrastructure to support offshore wind development activities. The ports of New Bedford and Boston emerged as the two short-listed ports.

6.3 Engineering Cost Analysis of Port Upgrades at Short-Listed Ports

This section provides a further evaluation of the two short-listed ports and rough order of magnitude estimate of the required maintenance and upgrades that would improve the ability of those ports to serve offshore wind farm development.

6.3.1 New Bedford Harbor

The Team identified two possible locations in New Bedford Harbor that might reasonably support offshore wind farm construction. One is the South Terminal area (Figure 6-1) and the other is the State Pier facility (Figure 6-2). Both facilities failed to meet all of the hard criteria discussed above, and demonstrated some level of deficiency in their current physical condition.

6.3.1.1 South Terminal

The City of New Bedford has identified the expansion of the South Terminal (Figure 6-1) as a major priority. The City has applied for a TIGER grant to expand the berth by approximately 245 m (800 feet) and dredge a 9 m (approximately 30 feet) deep channel from the main channel to the new berth. The new facility would have significant backland load bearing capacity. There are between 5.6 and 8.1 hectares (14 and 20 acres) of land adjacent to the berth. The proposed rebuild would utilize a tied-back steel sheet pile bulkhead backfilled with the dredge spoils. The cost of the new bulkhead and dredging is estimated to be approximately $20 million. Table 6-2 presents the cost estimate for the South Terminal expansion.

Additional improvements, including paving, utilities and site equipment (such as a large crane), could add an additional $15 million and would provide a "future" life as a general cargo or container handling facility. The new bulkhead construction would allow the terminal to be designed to a high live load capacity, which will provide a significant number of options for material handling. Immediately adjacent to the site (across the street) there are several warehouses of approximately 930 m^2 (10,000 square feet) or more. There would be ample space to construct a shelter on the site without reducing the outside lay down space.

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Figure 6-1 South Terminal Port of New Bedford
(Source: Childs Engineering Corporation)

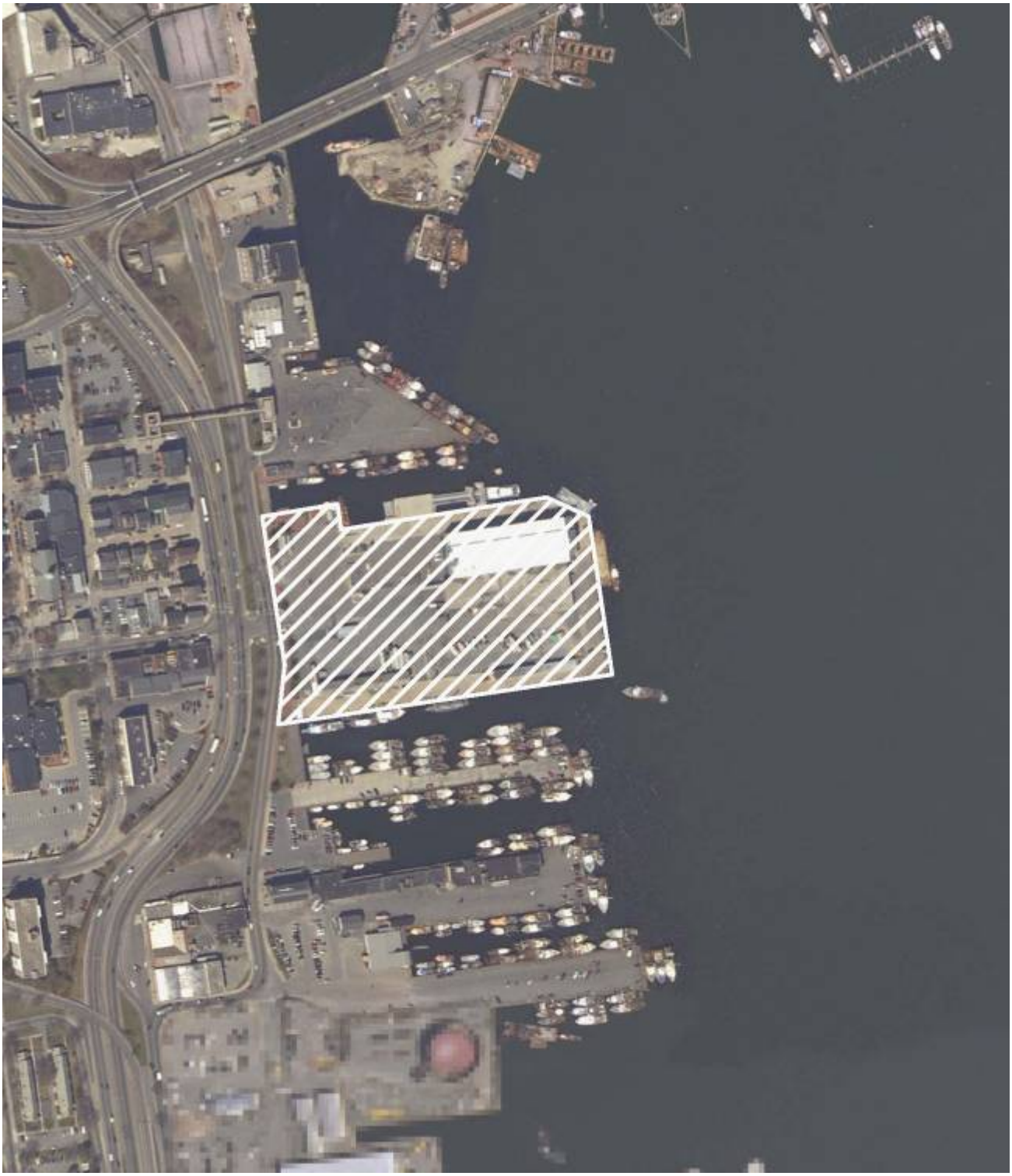

Figure 6-2 State Pier Port of New Bedford
(Source: Childs Engineering Corporation)

Table 6-2
Cost Estimate for New Bedford Harbor South Terminal Expansion
(Source: Childs Engineering Corporation 2009)

Item Description	Quantity	Units	Unit Cost	Item Cost
Harbor Development Commission Staff	3	LS	$ 40,000	$ 120,000
Final Engineering/Procurement	1	LS	$ 1,000,000	$ 1,000,000
Organics Removal	15,185	CY	$ 35	$ 531,481
Organics Disposal (CAD Cell)	15,185	CY	$ 55	$ 835,185
Sheeting - PZ40	1,706,940	LB	$ 3	$ 4,267,350
Shoes for Sheets	273	EA	$ 250	$ 68,333
Mudslab Installation	3,796	CY	$ 200	$ 736,158
Wale -][MC12x31	42,813	LB	$ 3	$ 128,438
Weep Drains @ 10' o.c.	83	EA	$ 150	$ 12,410
Steel Sheeting Deadmen	246,000	LB	$ 3	$ 737,389
Excavation - Tie-Rods	3,677	CY	$ 15	$ 55,157
Tie-Rod	53,593	LB	$ 6	$ 321,559
Structural Fill - Tie-Rods	3,677	CY	$ 35	$ 128,700
Concrete Bulkhead Cap	103	CY	$ 650	$ 66,625
Concrete Slab	1,063	CY	$ 500	$ 531,345
Bollards, 61 ton/bitt	29	EA	$ 5,500	$ 161,794
12" Dia. Timber Piles (Fender)	86	EA	$ 3,000	$ 258,032
Timber Bracing				
12" X 12" Fender	665	BFM	$ 4.50	$ 2,992
8" X 12" Fender	867	BFM	$ 4.50	$ 3,902
Dredge/Placement of Material Behind Bulkhead	153,000	CY	$ 40	$ 6,120,000
Dredging Channel to South Terminal	62,963	CY	$ 50	$ 3,148,148
			Total South Terminal Extension:	$ 19,235,000

6.3.1.2 State Pier

The State Pier (Figure 6-2) is constructed with a solid fill core surrounded by a marginal wharf. This construction is typical of many old New England ports. The solid fill is contained within an old stone seawall. The marginal wharf is comprised of treated timber piles and superstructure. The marginal wharf extends seaward from the stone seawall and allows the berth to be dredged without undermining the seawall. Table 6-3 presents the cost estimate for the needed improvements identified for the State Pier.

Table 6-3
Cost Estimate for Improvements to State Pier at New Bedford Harbor
(Source: Childs Engineering Corporation)

	Description	Initial Construction Cost	Contingency @ 15%	Total Initial Construction Cost	30th Year	40th Year	Estimated Maintenance Cost (Present Worth Cost)						Total Cost of Alternatives
							50th Year	60th Year	70th Year	80th Year	90th Year	100th Year	
1	Timber Piles, Concrete Deck	$13,340,031	$2,001,005	$15,341,036			Replace					Replace	$41,512,087
	Timber Piles - Replace 20% every 10 years starting 30th year				$2,668,006	$2,668,006	$13,340,031	$ -	$ -	$2,668,006	$2,668,006	$13,340,031	
	Gangway and Float System - Replace 10% every 10 years starting at year 10				$390,000	$130,000	$1,560,000	$130,000	$130,000	$130,000	$130,000	$1,560,000	
2	Refurbish Timber Piles, Concrete Deck	$12,139,965	$1,820,995	$13,960,960			Replace					Replace	$38,151,902
	Timber Piles - Replace 20% every 10 years starting 30th year				$2,427,993	$2,427,993	$12,139,965	$ -	$ -	$2,427,993	$2,427,993	$12,139,965	
	Gangway and Float System - Replace 10% every 10 years starting at year 10				$390,000	$130,000	$1,560,000	$130,000	$130,000	$130,000	$130,000	$1,560,000	
3	Steel Piles, Concrete Deck	$20,347,152	$3,052,073	$23,399,225				Replace					
	Steel Piles - Replace 20% every 10 years starting 40th year				$ -	$4,069,430	$4,069,430	$20,347,152	$ -	$ -	$ -	$4,069,430	$36,715,443

Table 6-3 (continued)

	Description	Initial Construction Cost	Contingency @ 15%	Total Initial Construction Cost	30th Year	40th Year	Estimated Maintenance Cost (Present Worth Cost)						Total Cost of Alternatives
							50th Year	60th Year	70th Year	80th Year	90th Year	100th Year	
3	Gangway and Float System - Replace 10% every 10 years starting at year 10				$390,000	$130,000	$1,560,000	$130,000	$130,000	$130,000	$130,000	$1,560,000	
4	Steel Bulkhead - Lightweight Fill - 1 Row Tiebacks	$31,058,195	$4,658,729	$35,716,924					Replace				
	Sheet Piles - Replace 10% every 10 years starting 40th year				$ -	$3,105,820	$3,105,820	$3,105,820	$31,058,195	$ -	$ -	$ -	$44,535,654
	Gangway and Float System - Replace 10% every 10 years starting at year 10				$390,000	$130,000	$1,560,000	$130,000	$130,000	$130,000	$130,000	$1,560,000	
5	Combi-Wall - 1 Row Tiebacks	$35,977,044	$5,396,557	$41,373,601					Replace				
	Sheet Piles - Replace 10% every 10 years starting 40th year				$ -	$3,597,704	$3,597,704	$3,597,704	$35,977,044	$ -	$ -	$ -	$50,930,157
	Gangway and Float System - Replace 10% every 10 years starting at year 10				$390,000	$130,000	$1,560,000	$130,000	$130,000	$130,000	$130,000	$1,560,000	

Table 6-3 (continued)

	Description	Initial Construction Cost	Contingency @ 15%	Total Initial Construction Cost	30th Year	40th Year	Estimated Maintenance Cost (Present Worth Cost)						Total Cost of Alternatives
							50th Year	60th Year	70th Year	80th Year	90th Year	100th Year	
6	Soldier Piles, Concrete Lagging - 1 Row Tiebacks	$30,819,869	$4,622,980	$35,442,849					Replace				
	Sheet Piles - Replace 10% every 10 years starting 40th year				$ -	$3,081,987	$3,081,987	$3,081,987	$30,819,869	$ -	$ -	$ -	$44,225,830
	Gangway and Float System - Replace 10% every 10 years starting at year 10				$390,000	$130,000	$1,560,000	$130,000	$130,000	$130,000	$130,000	$1,560,000	
7	Cellular Cofferdam - Sand Backfill	$50,716,366	$7,607,455	$58,323,821					Replace				
	Sheet Piles - Replace 10% every 10 years starting 40th year				$ -	$5,071,637	$5,071,637	$5,071,637	$50,716,366	$ -	$ -	$ -	$70,091,276
	Gangway and Float System - Replace 10% every 10 years starting at year 10				$390,000	$130,000	$1,560,000	$130,000	$130,000	$130,000	$130,000	$1,560,000	
8	Cellular Cofferdam - Gravel Backfill	$51,588,891	$7,738,334	$59,327,225					Replace				
	Sheet Piles - Replace 10% every 10 years starting 40th year				$ -	$5,158,889	$5,158,889	$5,158,889	$51,588,891	$ -	$ -	$ 71,225,558	

Table 6-3 (continued)

	Description	Initial Construction Cost	Contingency @ 15%	Total Initial Construction Cost	30th Year	40th Year	Estimated Maintenance Cost (Present Worth Cost)						Total Cost of Alternatives
							50th Year	60th Year	70th Year	80th Year	90th Year	100th Year	
8	Gangway and Float System - Replace 10% every 10 years starting at year 10				$390,000	$130,000	$1,560,000	$130,000	$130,000	$130,000	$130,000	$1,560,000	
9	Diaphragm Cofferdam - Sand Backfill	$51,402,764	$7,710,415	$59,113,179					Replace				
	Sheet Piles - Replace 10% every 10 years starting 40th year				$ -	$5,140,276	$5,140,276	$5,140,276	$51,402,764	$ -	$ -	$ -	$70,983,593
	Gangway and Float System - Replace 10% every 10 years starting at year 10				$390,000	$130,000	$1,560,000	$130,000	$130,000	$130,000	$130,000	$1,560,000	
10	Diaphragm Cofferdam - Gravel Backfill	$52,275,289	$7,841,293	$60,116,582					Replace				
	Sheet Piles - Replace 10% every 10 years starting 40th year				$ -	$5,227,529	$5,227,529	$5,227,529	$52,275,289	$ -	$ -	$ -	$72,117,876
	Gangway and Float System - Replace 10% every 10 years starting at year 10				$390,000	$130,000	$1,560,000	$130,000	$130,000	$130,000	$130,000	$1,560,000	

The wharf structure is in poor condition according to recent inspections and must be replaced or a modified rebuild must be undertaken. The rebuild options include a repair/replace in kind, which would result in a low deck load capacity. The preferred alternatives would eliminate the wharf structure and replace it with solid fill behind a new bulkhead. A recent study suggested rebuild costs in the range of approximately $12.1 million to more than $52 million.

The immediate backland at State Pier is about 2.8 to 3.2 hectares (approximately 7 to 8 acres), which does not meet the landside criterion (see Table 6-1 above). This lack of space probably would result in material rehandling costs that would not be incurred at a larger site. The rehandling costs could result from offsite storage at other adjacent land facilities or perhaps from barge-based storage. There is covered space in the form of two small warehouses and the marine terminal building. The State Pier would be best described as a short-term, but immediately available, site. This also anticipates that no repairs are performed and a larger land-based unloading crane is employed inshore sufficiently of the wharf structure, which may require a higher-rated crane than would otherwise be needed to clear the low load bearing areas.

The Team believes the preferred option for New Bedford is the South Terminal. The site is the most desirable in terms of meeting the port criteria established by the Team. The South Terminal expansion cost is similar to the repair cost for the State Pier; however, the South Terminal has significantly more laydown area, which offsets any potential cost savings from the State Pier repair/rebuild.

6.3.2 Boston Harbor

The Team identified three possible locations in Boston Harbor that reasonably meet the established criteria. These include the North Jetty (Figure 6-3), Dry Dock #4 in the Boston Marine Industrial Park (Figure 6-4), and the former Coastal Oil site adjacent to Conley Terminal on the Reserved Channel (Figure 6-5). None of these facilities met all of the hard criteria discussed above, and demonstrated some level of deficiency in their current physical condition.

6.3.2.1 North Jetty

The North Jetty (Figure 6-3) is constructed with a solid fill core supported by a steel sheet pile bulkhead fronted by a marginal wharf. This construction was undertaken in the 1940s to meet the needs of the Department of Defense during World War II. The marginal wharf is comprised of steel h-piles supporting a reinforced concrete super structure. The wharf structure is currently in poor condition and must be replaced or rebuilt to be usable for offshore wind staging. A 1996 design suggested rebuild costs (in current dollars) of about $15 million. The immediate backland is about 2.8 to 3.2 hectares (approximately 7 to 8 acres) with an additional 4.0 m (10 acres) or more immediately adjacent.

The City has included the North Jetty rebuild in its application for a TIGER grant. Although the rebuild will correct current deficiencies, it will still leave the wharf with a deck capacity of only 2,930 kg/m^2 (approximately 600 lb/ft^2), which is insufficient for unit loading under certain situations. Depending on the developer's operations, this capacity may require the use of a high capacity crane set up on the solid fill backlands.

Figure 6-3 North Jetty Port of Boston
(Source: Childs Engineering Corporation)

6.3.2.2 Dry Dock #4

The BRA has identified a 5.2 to 5.7 hectares (13 to 14 acre) parcel at the Dry Dock #4 site in the Marine Industrial Park in South Boston (Figure 6-4) for possible expansion. The existing dry dock is in very poor condition, but could be rebuilt to provide a two-sided solid fill pier with almost 549 m (1,800 feet) of berthing. Table 6-4 presents the cost estimate for the improvements to Dry Dock #4 identified to be necessary to support offshore wind farm development.

Figure 6-4 Dry Dock #4 at the Port of Boston
(Source: Childs Engineering Corporation)

Table 6-4
Cost Estimate for Improvements to Dry Dock #4 at the Port of Boston
(Source: Childs Engineering Corporation)

COST ESTIMATE							DATE PREPARED Nov-09	SHEET 1 OF 1
ACTIVITY AND LOCATION Boston Harbor Drydock #4 Parcel - South Boston Install repair bulkhead, fender system, Fill drydock and pave Estimated in 2009 prices				CEC JOB NUMBER 2178-09 ESTIMATED BY DLP STATUS OF DESIGN _X_ PED ___ 35% ___ 65% __ 100% ___ FINAL ___ OTHER			IDENTIFICATION NUMBER CATEGORY CODE NUMBER JOB ORDER NUMBER	
	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
ITEM DESCRIPTION	NO.	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
Soft Costs								
Engineering/Permits/Procurement	1	LS					$1,000,000	$1,000,000
Site Prep								
Site cleanup	1	LS					$250,000	$250,000
Bulkhead								
Sheeting- PZ27	3,500,000	LB					$3	$10,500,000
Mudslab Installation	6,000	CY					$200	$1,200,000
Wale-][MC 12x31	100,000	LB					$3	$300,000
Weep Drains @ 10' o.c.	200	EA					$150	$30,000
Tie- Rod	100,000	LB					$6	$600,000
Structural Fill- btween old and new sheets	10,000	CY					$35	$350,000
Concrete Bulkhead Cap	200	CY					$650	$130,000
Concrete Slab	1,050	CY					$500	$525,000
12" Dia.Timber Piles (Fender)	200	EA					$3,000	$600,000
Drydock fill								
Placement of Material in Drydock	116,665	CY					$30	$3,499,950
Pave surface	70,000	SF					$10	$700,000
							Total Drydock Parcel Repair:	$19,684,950

Table 6-4 (continued)

	COST ESTIMATE					DATE PREPARED Oct-09	SHEET 1 OF 1	
ACTIVITY AND LOCATION Boston Harbor Drydock 4 Repair Estimated Maintenance Costs Estimated in 2009 prices				CEC JOB NUMBER 2178-09 ESTIMATED BY DLP STATUS OF DESIGN _X_ PED ___ 35% ___ 65% __ 100% ___ FINAL ___ OTHER			IDENTIFICATION NUMBER CATEGORY CODE NUMBER JOB ORDER NUMBER	
	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
ITEM DESCRIPTION	NO.	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
Soft Costs								
Engineering/Permits/Procurement	1	LS					$500,000	$500,000
Bulkhead Annual								
Recoating and anode replacement	25	EA	1% of cost				$105,000	$2,625,000
Fender system repair etc								
Bulkhead Five Year								
Recoating and anode replacement	1	EA	5% of cost				$525,000	$525,000
Fender system repair etc								
Bulkhead Ten Year								
Recoating and anode replacement	1	EA	5% of cost				$525,000	$525,000
Fender system repair etc								
Bulkhead Fifteen Year								
Recoating and anode replacement	1	EA	5% of cost				$525,000	$525,000
Fender system repair etc								
Bulkhead Twenty Year								
Recoating and anode replacement	1	EA	5% of cost				$525,000	$525,000
Fender system repair etc								
Bulkhead cost base is $10,500,000 Anticpated 25 year life no salvage						Total Drydock Parcel Maintenance:		$5,225,000

The dry dock would be filled with gravel, and new steel sheet piling would be installed around the deteriorated bulkheads. The estimated cost to rebuild the site is approximately $20 million.

This site would provide nominal laydown space, but the solid fill pier has very high ground capacity and the berth has “bonus” length. Although the site does not have covered space, there are such structures and warehouses in the Boston Marine Industrial Park that could be used or converted for use for this purpose.

Dry Dock #4 could accommodate the staging of offshore wind development with improvements at a reasonable cost. However, from a planning perspective, there are potentially permitting issues associated with these improvements due to Dry Dock #4’s proximity to Logan Airport. Tall equipment, such as cranes, as well as future installation vessels transporting assembled turbines in a vertical configuration, may require approvals from the FAA. Furthermore, the potential wind farm locations are much closer to New Bedford Harbor than Boston Harbor.

6.3.2.3 Coastal Oil Site

The Massachusetts Port Authority owns the former Coastal Oil Terminal in South Boston (Figure 6-5). The site is approximately 14.2 hectares (approximately 35 acres) and has a former oil tanker berth with a water depth in excess of 10.3 m (34 feet). The facility would require a new steel sheetpile bulkhead to be adequate for laydown. It also would need regrading and paving to “cap” any environmental contamination. The site does not have any covered space, and there is no covered space on the immediately adjacent parcel. The berth is a mooring dolphin-type structure seaward of an old seawall. The estimated cost for the repairs is approximately $20 million. Table 6-5 is the cost estimate for improvements to the Coastal Oil Terminal.

The Team believes the preferred option at the Port of Boston is Dry Dock #4. The site meets most of the established criteria. The rebuild cost is similar to the cost of repairs for the North Jetty. However, Dry Dock #4 has significantly more berthing space, which more than offsets any potential repair/rebuild cost savings.

Table 6-5
Cost Estimate for Improvements to the Coastal Oil Site at the Port of Boston
(Source: Childs Engineering Corporation)

COST ESTIMATE		DATE PREPARED Dec-09	SHEET 1 OF 1
ACTIVITY AND LOCATION Boston Harbor Coastal Oil - South Boston Install repair bulkhead, fender system, Fill between existing and new sheet piling, grade and pave Estimated in 2009 prices	CEC JOB NUMBER 2178-09 ESTIMATED BY DLP STATUS OF DESIGN _X_ PED ___ 35% ___ 65% __ 100% ___ FINAL ___ OTHER	IDENTIFICATION NUMBER CATEGORY CODE NUMBER JOB ORDER NUMBER	

ITEM DESCRIPTION	QUANTITY NO.	UNIT	MATERIAL COST UNIT COST	MATERIAL COST TOTAL	LABOR COST UNIT COST	LABOR COST TOTAL	ENGINEERING ESTIMATE UNIT COST	ENGINEERING ESTIMATE TOTAL
Soft Costs								
Engineering/Permits/Procurement	1	LS					$1,000,000	$1,000,000
Site Prep								
Site cleanup	1	LS					$250,000	$250,000
Bulkhead								
Sheeting- PZ27	1,700,000	LB					$3	$5,100,000
Mudslab Installation	4,000	CY					$200	$800,000
Wale-][MC 12x31	35,000	LB					$3	$105,000
Weep Drains @ 10' o.c.	80	EA					$150	$12,000
Tie- Rod	40,000	LB					$6	$240,000
Structural Fill- between old wall and new sheets	30,000	CY					$35	$1,050,000
Concrete Bulkhead Cap	100	CY					$650	$65,000
Concrete Slab	1,050	CY					$500	$525,000
12" Dia.Timber Piles (Fender)	80	EA					$3,000	$240,000
Regrade and Pave								
Grade	80,000	SY					$15	$1,200,000
Pave surface	900,000	SF					$10	$9,000,000
							Total Coastal Oil Repair:	$19,587,000

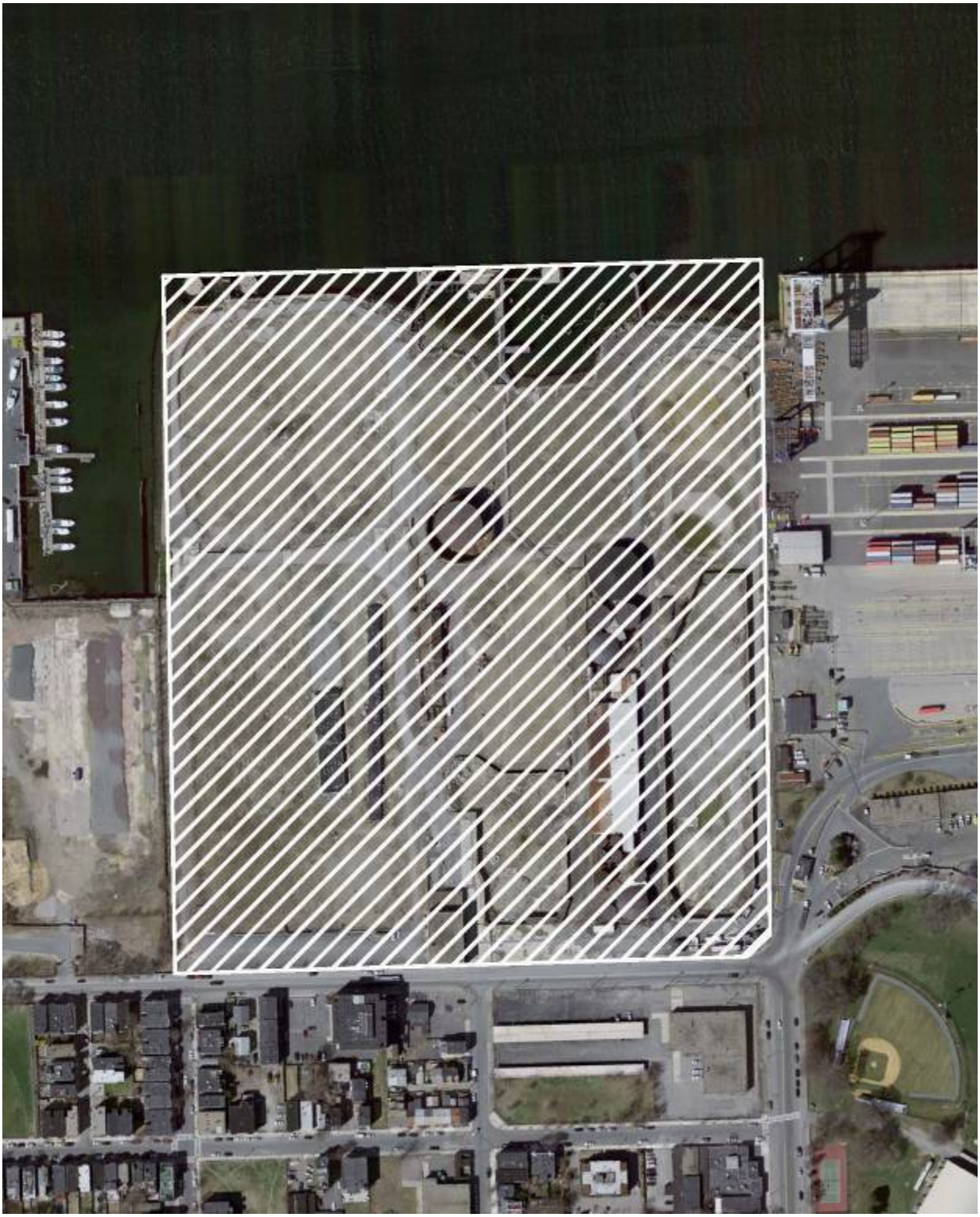

Figure 6-5 Coastal Oil Terminal Port of Boston
(Source: Childs Engineering Corporation)

6.4 Implications of Applying the Soft Criteria

The Team examined education and training needs required to support the offshore wind energy industry. See Appendix I for the questionnaire used to interview various educational and training institutions. More effective state support for renewable energy has encouraged investment in workforce training at many levels. The Massachusetts Maritime Academy (MMA) is nationally known for its mariner training programs, and a regional Marine Renewable Energy Center (MREC) at the University of Massachusetts/Dartmouth (UMass/Dartmouth) joins the resources of some of the region's leading academic institutions, community colleges, and trade unions to coordinate and plan appropriate training for this emerging industry. Given the relative proximity of the ports in this study to these educational resources, Massachusetts is well-positioned to assess the work force needs of each offshore wind energy developer and provide responsive, high-quality training.

Massachusetts has long been recognized as an international center for science, technology, and oceanography. There is considerable local and regional interest in developing technology and the necessary trade skills to harness renewable energy from the ocean. Since the late 1990s, when the idea of offshore wind energy projects first began to surface in Massachusetts, academic institutions and unions representing trade industries identified offshore renewable energy as an important field that would require new technologies and a corresponding demand for new training. Additional focus on Massachusetts as an emerging center for offshore construction occurred in 2004, when plans were developed for the first LNG deepwater port on the east coast of the United States, and the second such facility worldwide. The Northeast Gateway Deepwater Port was completed in 2007 and another similar facility is nearing completion. Both projects utilized local trade and construction workers to complete sub-sea pipelines and buoys.

A lengthy list of public and private academic institutions, including the Amherst and Dartmouth campuses of the University of Massachusetts system, Harvard University, the Massachusetts Institute of Technology, the Massachusetts Maritime Academy, and the Woods Hole Oceanographic Institute, (as well as other institutions in the region) have examined and will continue to explore numerous issues related to offshore renewable energy generation. These issues include energy production, facility design, transmission issues, and maritime training. These institutions, with evolving degree programs, unrivalled intellectual capital, and interest in furthering the development of offshore renewable energy, are an exceptional resource for policy makers, developers, builders, and maintenance firms.

State government, academic institutions, and local unions have all recognized the importance of offshore sites along the Massachusetts coast for both traditional and renewable sources of energy. At the state level, Governor Deval Patrick reversed the prior Administration’s opposition to the Cape Wind project and moved quickly to combine energy and environmental agencies in a cabinet-level secretariat with an emphasis on renewable energy. State agencies worked closely with the Massachusetts Renewable Energy Trust, part of a quasi-state agency funded through an excise tax on electricity consumption, and the Commonwealth’s Clean Energy Center to provide resources and expertise to move the Commonwealth toward the Patrick Administration’s 2020 goal of providing 2,000 MW of land- and ocean-based wind energy. With relatively shallow offshore waters and excellent wind resources, offshore wind energy became an increasing focus of renewable energy efforts. In a coordinated effort, the Patrick

Administration also pushed for passage of the Massachusetts Ocean Management Act, under which it has developed a plan that identifies sites within state waters for new offshore wind farm development, in addition to potential federal sites in adjacent waters that come under the jurisdiction of the U.S. Minerals Management Service.

The emerging field of offshore wind energy has already led to the development of a number of new technologies and applications, requiring a trained workforce to assemble, construct, operate, and maintain offshore wind turbines. Based on European experience, an eighty-turbine offshore wind energy project, for example, would typically need a number of trained individuals for the installation phase as presented in Table 6-6.

Table 6-6
Workers Required for Typical 80-Turbine Offshore Wind Energy Project
(Source: Thomsen 2009)

Turbine Installation	
Type of Worker	Number of Workers Required
Vessel officers and crew	25 people per shift per day
Installation crew	12 people per shift per day
Preassembly	12 people per shift per day
Harbor workers	12 people per shift per day
Project management	25 people to plan and execute all work
Crane and truck rental	25 people (e.g., crane operators, forklift/truck drivers)
Foundation Installation	
Vessel officers and crew	25 people per shift per day
Installation crew	18 people per shift per day (piling operations are more manpower intensive than turbine installation)
Preassembly	25 people per shift per day
Harbor workers	12 people per shift per day
Project management	25 people to plan and execute all work
Assistance from agents and port authorities	20 people
Crane and truck rental	25 people (e.g., crane operators, forklift/truck drivers)
Cable Installation	
Vessel officers and crew	25 people per shift per day
Diving crew	10 people
Installation crew	12 people per shift per day
Preassembly	12 people per shift per day
Harbor workers	12 people
Project management	25 people to plan and execute all work

Based on these figures, each phase of the construction process for offshore wind farms could require as many as 150 skilled workers, with another 80 workers for each additional daily shift.

European offshore wind developers have reported shortages among skilled workers in related trades, and potential offshore wind energy developers in the United States have described similar concerns. While the two short-listed Massachusetts ports have characteristics that make

them suitable for the construction, operation, and maintenance of offshore wind energy facilities, they also have ready access to considerable education and training resources that are geared to offshore and underwater construction, seamanship, and technical trades and services. Given the relative proximity of these ports (as well as all of the Massachusetts ports considered in this study) to these education and training resources, Massachusetts is uniquely situated to respond to developers' needs for a variety of construction and operational technologies.

Recognizing that a wide variety of skill sets would be needed to construct, operate, and maintain offshore renewable energy facilities in Massachusetts, the MREC, an organization of industry, academia, government agencies, municipalities, public interest groups, and concerned individuals, was established at the UMass Dartmouth in 2006. MREC's goal is to foster the development of ocean-based renewable energy, including wave, tidal current and offshore wind, and is unique in that it brings together the knowledge and needs of science, technology, and training in order to successfully maximize renewable energy resources from the ocean. MREC seeks to develop a network of technology developers and energy users who will collectively define the needs of this nascent industry and bring together the required technology, capital, infrastructure, and human resources to implement ocean-based renewable energy in the most economically, environmentally, and socially sustainable manner for the region.

MREC has also proposed a National Offshore Renewable Energy Innovation Zone (NOREIZ) and is working with state and federal agencies to designate an area off of Nantucket and Martha's Vineyard for this purpose. The proposed project would provide demonstration and training sites for marine renewable energy, particularly offshore wind, and is envisioned as a critical asset for training, technology development, and small scale energy generation.

In addition to UMass/Dartmouth, MREC's university research consortium partners include:

- the University of New Hampshire (UNH);
- the University of Rhode Island (URI);
- the University of Maine (UMaine);
- the Massachusetts Institute of Technology (MIT);
- the Woods Hole Oceanographic Institution (WHOI);
- the Massachusetts Maritime Academy (MMA);
- Roger Williams University (RWU); and
- other schools within the University of Massachusetts system.

MREC corporate partners include:

- Battelle;
- Alden;
- Raytheon;
- National Grid;
- NStar;
- Lockheed/Martin;
- the New England Clean Energy Council; and

- the Ocean Renewable Energy Coalition.

Understanding that the offshore energy industry is evolving within the United States and New England, MREC joined forces with Cape Wind, Resolute Marine Energy, Ocean Renewable Power Company, Local 56 Pile Drivers Union, the MMA, the New Bedford Department of Workforce Development, and the community college system to form the Ocean Energy Training Task Force. The Task Force meets regularly to identify issues and to discuss how best to meet the needs of offshore energy developers, and draws on the expertise of each of its members.

Under the MREC/Task Force umbrella, significant education and training programs related to offshore renewable energy are being developed and some are currently offered. It is anticipated that these courses will evolve significantly to address future development needs. The Task Force, in discussions with the European Marine Energy Center (EMEC) and the New and Renewable Energy Center (NaREC) UK, have developed framework for education and training that encompasses three elements:

1) University level education to produce a cadre of researchers, engineers, and other professionals for the development of new technologies.
2) Construction skills training by unions and Workforce Investment Boards to support the construction and installation of ocean based turbines.
3) Operation and Maintenance (O&M) technician training and certification following the NaREC model of instruction at community colleges and training/certification at the MMA and MREC-developed ocean test sites.

At the University level, Oceanography and Ocean Engineering programs are in place with MREC Research University Consortium members. UMass/Dartmouth offers masters and doctorates in marine science and technology through the School for Marine Science and Technology (SMAST), has a range of sustainability courses that can be tailored to address ocean renewable energy, and offers a masters degree in public policy with concentrations in economic development, marine science, and technology policy. As with other MREC members, UMass/Dartmouth is very much interested in the national effort to establish a certificate program aimed at training oceanographic science and technology operations personnel to service ocean observatories, many of the skills that are transferable to offshore energy projects.

The MMA is well-known for its traditional courses in seamanship for maritime officers, which are essential to the construction and maintenance of offshore energy facilities. MMA also offers established training for power plant operations and has aggressively implemented renewable energy on campus with wind, solar, tidal, and geothermal projects. Located at the west end of the Cape Cod Canal, MMA will be a key asset in any training program that would require water access. As with other MREC partners, MMA will revise, as appropriate, existing energy-related courses to address ocean energy needs and issues.

Two MREC partners, Cape Cod Community College and Bristol Community College, have joined forces to provide clean energy workforce training, have a proven track record of providing targeted training to their local communities, and have offered training programs in the marine technology subject area. Bristol Community College currently has a grant with the National Science Foundation to offer certificates in environmental technology, marine technology and geographic information systems and offered a pilot tidal energy technician training program in

2009 that will be expanded in the future. The MMA is a partner in this effort and has tailored existing energy-related courses to address ocean energy, as appropriate.

At the construction skills level, Massachusetts trade unions have been very active in identifying offshore energy construction needs and developing appropriate training courses. For example, Local 56 of the Massachusetts Pile Drivers is a statewide organization that has been at the forefront of training workers for offshore energy. Targeting vocational technical school students, Local 56 either currently offers, or is planning to offer, training in the following areas:

- Four-year apprenticeships in pile driving and marine construction, including rigging, welding burning and fitting, and marine construction safety;
- Commercial diving training, for the inspection, trenching, and maintenance of sub-sea electrical cables;
- Pile driving and welding for wind turbine towers;
- Rigging and material handling for loading and unloading; and
- Rigging for tower, nacelle, and blade assembly.

Local 56 has a proven track record in responding to industry needs by providing high-quality training. Since January, 2007, Local 56 has offered training for commercial divers and pile drivers to work in the offshore natural gas industry, with 60 commercial divers working on four different offshore pipeline jobs along the Massachusetts coast. Its training programs have expanded to include underwater welding, with successful graduates completing over 60,000 hours on eight different construction contracts since May, 2007. Local 56 is currently working with the Occupational Safety and Hazards Administration (OSHA) and the Carpenters International Training Fund to develop a course on Marine Construction Safety.

Similarly, the International Brotherhood of Electrical Workers (IBEW) Local 103 has demonstrated its leadership in support of the renewable energy industry through the erection of a publicly visible 100 kilovolt (kV) wind turbine and the installation of a 5.4 kV solar roof at its headquarters and Apprentice Training Facility in Dorchester. As the IBEW increases its focus on renewable energy, it uses working non-fuel energy systems for training and will open its “Big Green Room” in 2010 to present a variety of different training tools that relate to hydro, wind, and solar generation technologies. The union’s strong commitment to safety, and current training certifications in tower climbing, working in confined spaces, and scuba proficiency, all have direct applications in the emerging offshore wind generation industry. Currently one half of IBEW local workers are trained in scuba and wind technology. In addition, the IBEW has been working with the MMA on wind generation construction and marine training.

With the state aggressively supporting the development of offshore wind energy through policy initiatives, expertise, and financial support, and with academic institutions and trade unions actively developing and improving training opportunities, Massachusetts is well situated to respond to a wide variety of technologies used to harness renewable energy in offshore waters. Given its broad geographic coverage, extensive research facilities, in-depth industry expertise, and a trained, flexible work force, Massachusetts is in a unique position to successfully meet the needs of the offshore wind energy industry.

Soft criteria also include regulatory considerations. Port facility upgrades may require Massachusetts environmental review if the project meets or exceeds certain thresholds

established by the Massachusetts Environmental Policy Act (MEPA). A variety of federal, state and local permits also may be required, including, but not limited to:

- U.S. Army Corps of Engineers (USACE) Section 10 permit for structures in navigable waters;
- USACE Section 404 permit for discharge of dredged or fill materials into waters of the U.S.;
- Federal Aviation Administration (FAA) Determination of No Hazard;
- Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) permit;
- EPA Air Emission permit;
- Massachusetts Coastal Zone Management (MCZM) Consistency Determination;
- Massachusetts Department of Environmental Protection (MassDEP) Water Quality Certificate;
- MassDEP Chapter 91 License for work in, under, or over flowed or filled tidelands;
- Massachusetts Department of Transportation (MDOT) oversize/overweight vehicle permit;
- Local Conservation Commission Order of Conditions for alteration of “any bank, fresh water wetland, coastal wetland, beach, dune, flat, marsh, meadow, or swamp bordering on the ocean or on any estuary (a broad mouth of a river into which the tide flows.), creek, river, stream, pond, or lake, or any land under said waters or any land subject to tidal action, coastal storm flowage, or flooding”; and
- Local zoning, building or utility permits.

7.0 ECONOMIC AND TAX EFFECTS OF CONSTRUCTION AND OPERATING EXPENDITURES

Based on the criteria presented above, the New Bedford South Terminal and Boston Dry Dock #4 were selected for further evaluation and analysis. This section discusses the economic and fiscal effects of construction and operation of these ports to support a ROWEI 130-turbine wind farm. See Appendix J for a more detailed analysis of economic and tax effects.

7.1 Construction and Operating Period Economic Effects

Data in Table 7-1 show the estimated total direct, indirect, and induced economic effects of expenditures made to construct the New Bedford South Terminal port facility, Boston Dry Dock #4, and the ROWEI 130-turbine installation. These are one-time, non-recurring projected economic effects that are expected to accrue within the Massachusetts economy during a 3 to 5 year period that includes port facility construction and the ROWEI offshore wind turbine installation.

Table 7-1 also shows the annually recurring economic effects of maintaining a ROWEI and of handling, storing, and transshipping non-offshore wind related cargo at a multi-use South Terminal port facility in New Bedford. In the case of the Boston and New Bedford port facilities, economic effects during construction are shown for Suffolk and Bristol counties, respectively. The annually recurring economic effects of new non-offshore wind-related cargo operations at the South Terminal are shown for Bristol county as well as Massachusetts overall.

The measures of economic effects are:

- Output – which comprises business sales less the costs of materials and equipment produced outside Massachusetts;
- Employment – the full-time equivalent jobs expected to be held by Massachusetts residents;
- Income – the payroll and self-employment earnings of households; and
- GDP (Gross Domestic Product) – which measures the value added to the Massachusetts economy in terms of labor and proprietors' income, corporate profits, dividends, interest, rent and taxes.

The county-level economic effects in Table 7-1 are a subset of the Massachusetts totals and show the amounts of local and state direct, indirect, and induced economic effects that would accrue within communities in Bristol and Suffolk counties.

Table 7-1
Total Direct, Indirect, and Induced Economic Effects of Offshore Wind Installation and Related Port Facilities Construction and Operation
(Sources: FXM Associates, R/ECON™ Input Output Model, Tetra Tech Team, City of Boston, City of New Bedford, Cape Wind)

		Output (000 $)	Employment (Jobs)	Income (000 $)	GDP (000 $)
Construction Period Effects					
South Terminal Port Facility					
	Bristol County	*$ 44,100*	*380*	*$ 19,200*	*$ 26,100*
	Massachusetts	$ 65,500	540	$ 26,100	$ 36,200
Boston Port Facility					
	Suffolk County	*$ 19,800*	*110*	*$ 9,100*	*$ 12,400*
	Massachusetts	$ 30,100	190	$ 12,500	$ 17,200
Representative Offshore Wind Installation					
	Massachusetts	$ 457,300	1700	$ 162,900	$ 200,100
Annual Operating Effects					
South Terminal Port Cargo Operations					
	Bristol County	*$ 15,700*	*130*	*$ 5,900*	*$ 9,700*
	Massachusetts	$ 20,200	170	$ 7,400	$ 11,900
ROWEI O&M					
	Massachusetts	$ 27,500	110	$ 6,800	$ 11,000

7.2 Construction and Operating Period Fiscal Effects

The total direct, indirect, and induced tax effects shown in Table 7-2 correspond to the economic effects shown in Table 7-1. Local taxes include property and excise taxes paid to municipalities by workers in the jobs generated by the construction and operating period employment reflected in Table 7-1, as well as property and other local taxes by the companies employing those individuals. State taxes include income and sales taxes paid by individuals as well as payroll, income, and other taxes paid by the companies that employ those individuals. The taxes are thus proportional to the total direct, indirect and induced economic effects shown in Table 7-1. However, these totals do not represent all taxes paid by companies whose output is only partly affected by the changes in demand attributable to construction and operating periods of offshore wind energy installation and maintenance, port construction and terminal operation.

Table 7-2
Total Direct, Indirect, and Induced Tax Effects of Offshore Wind Installation and Related Port Facilities Construction and Operation
(Sources: FXM Associates and R/ECON™ Input Output Model)

		Local Taxes (000 $)		State Taxes (000 $)		Federal Taxes (000 $)
Construction Period Effects						
South Terminal Port Facility						
Bristol County	*$*	*480*	*$*	*440*	*$*	*1,820*
Massachusetts	$	1,190	$	1,440	$	7,280
Boston Port Facility						
Suffolk County	*$*	*190*	*$*	*220*	*$*	*1,290*
Massachusetts	$	500	$	640	$	3,540
Representative Offshore Wind Installation						
Massachusetts	$	8,850	$	10,090	$	45,940
Annual Operating Effects						
South Terminal Port Operations						
Bristol County	*$*	*300*	*$*	*240*	*$*	*730*
Massachusetts	$	480	$	500	$	2,180
ROWEI O&M						
Massachusetts	$	390	$	430	$	2,230

As shown in Table 7-2, nearly $9 million in taxes to be paid to municipalities throughout Massachusetts are estimated to be attributable to the direct, indirect and induced economic effects shown in Table 7-1 over the projected 3-year construction (assembly and installation) phase of the ROWEI. More than $10 million in taxes paid to the Commonwealth of Massachusetts and almost $46 million in federal taxes over this same 3-year period would be attributable to the economic effects of construction. Servicing and maintaining the ROWEI is projected to generate an annual amount of $390,000 in municipal tax receipts throughout Massachusetts, $433,000 in state taxes, and $2.2 M in federal taxes. The county-level tax totals in Table 7-2 are a subset of the Massachusetts totals and show the amounts of local, state and federal tax effects that would accrue within communities in Bristol and Suffolk Counties.

7.3 Summary

As can be seen from these projections, the economic and fiscal effects of port development and use are roughly comparable for both ports. Therefore, the selection of one port over the other is more likely to be determined by the balancing of the soft criteria.

8.0 SUMMARY AND RECOMMENDATION

There are no port facilities in Massachusetts that are currently ready to provide staging, installation, and operations and maintenance support to a commercial scale offshore wind farm development project in the region. However, if investment in targeted port upgrades is made, the opportunity to attract offshore wind developers exists.

Table 8-1 provides a summary of the side-by-side comparison between Dry Dock #4 at the Port of Boston and the South Terminal at the Port of New Bedford based on the hard and soft evaluation criteria developed for this study. With specifically targeted upgrades, both Dry Dock #4 and the South Terminal would have acceptable harbor access and the navigational parameters needed to accommodate wind turbine delivery and installation vessels (based on a comparison of port characteristics to the 1st Tier Hard Criteria).

For the most part, both ports also are capable of accommodating the assembly and installation of offshore wind turbines and foundations (based on a comparison of port characteristics to the 2nd Tier Hard Criteria). An exception at the present time may be Rail and Highway Access. The Boston Redevelopment Authority (BRA) has a “shovel-ready” design for modifications to expand the existing rail line to Dry Dock #4. New Bedford has submitted a TIGER application to extend the existing rail line to the State Pier, but not to the South Terminal (Mayor Scott Lang, 2009). Highway Access to both port areas is adequate. The Boston Haul Road currently has several bridges that would impose limitations on the transport of large turbine and/or foundation components. However, Massport and the BRA have plans to expand the freight roadway network at the Port. Despite the relative advantages and disadvantages associated with current rail/highway access at each port, neither port becomes a clear frontrunner based on these two criteria. Because rail and highway delivery of offshore wind generation components would be constrained by the weight and dimensions of the foundations and turbines, it is unlikely that this means of delivery would be used for these large primary components. And the distinction becomes less of an issue as the larger next generation wind turbine components currently in development will only be able to be transported by water.

Table 8-1
Comparison of the Two Short-Listed Ports

	Port of Boston Dry Dock #4	New Bedford Harbor South Terminal	Comments
1st TIER HARD CRITERIA			
Protected Harbor	●	●	Both ports are acceptable.
Shipping Channel Depth	●	●	Both ports are acceptable.
Overhead Clearance	●	●	Both ports are acceptable.
Horizontal Clearance	●	●	Both ports are acceptable.
24/7 Operational Ability	●	●	Both ports are acceptable.
Exclusive Use of Port Facility	●	●	Both ports are acceptable.
2nd TIER HARD CRITERIA			
Berth Length	●	●	Both ports are acceptable.
Shipping Vessel Water Depth	●	●	Both ports are acceptable.
Total Wharf and Yard Upland Area	●	●	Both ports are acceptable.

	Port of Boston Dry Dock #4	New Bedford Harbor South Terminal	Comments
Rail Access	●	⦿	BRA has a design to expand rail access to Dry Dock #4. New Bedford has submitted TIGER application to extend rail line to State Pier, but not to South Terminal.
Highway Access	⦿	●	Despite adequate highway access to port area, the Boston Haul Road currently has vertical/ horizontal limitations; however, a new freight roadway system is planned.
Proximity to Construction Site	⦿	●	South Terminal is closer to the planned offshore sites than Dry Dock #4 (as of January 2010).
SOFT CRITERIA			
Workforce Availability	●	●	
Education and Training Facilities	⦿	⦿	In U.S., education and training programs are now being developed for nascent offshore renewable energy industry. Given extensive research facilities, in-depth industry expertise, and trained, flexible work force, Massachusetts will be able to successfully meet education and training needs.
Political Climate/Community Acceptance	⦿	●	New Bedford has a Green Port initiative in place, has done study on South Terminal development, has submitted various proposals for infrastructure grants, and has the goal of strengthening its economy by focusing on renewable energy such as offshore wind. The BRA has emphasized a commitment to sustainability but may not be focused on the seaport. Dry Dock #4 currently has a tenant.
Regulatory Considerations	⦿	●	Required permits could include, but are not limited to: MEPA review; CZM Consistency Certification; USACE Section 404 and 10 Permits, FAA approval; Chapter 91 License/Permit; Water Quality Certification; NPDES Permit; Order of Conditions. Certain circumstances at each port may eliminate or reduce regulatory process. FAA approval at Dry Dock #4 may be problematic.

LEGEND:
- ● Acceptable / Most Supportive of offshore wind farm development
- ⦿ Qualified Acceptability / Degree of Supportiveness of offshore wind farm development
- ○ Unacceptable / Not Supportive of offshore wind farm development

The proximity of a port to prospective offshore wind farm sites is important in terms of minimizing cost and controlling transportation-related risk. These considerations indicate an advantage to the closer staging port. Based on available public information as of January 2010

regarding proposed offshore wind farm sites, the South Terminal at New Bedford Harbor is closer to these potential installation sites than is Dry Dock #4 at the Port of Boston.

A key soft criterion is Political Climate/Community Acceptance of the cities and towns associated with each port. The City of New Bedford has established a goal of strengthening its economy by focusing on supporting the renewable energy industry. New Bedford already has completed a study on development of the South Terminal as a port facility to support renewable energy technology companies (*Port of New Bedford Massachusetts, South Terminal Development, Renewable Energy Marine Park*, dated March 2009). The New Bedford HDC has received grant money from the Governor's Seaport Council for navigational dredging, identifying port infrastructure needs, and evaluating potential markets for the Port of New Bedford, among other projects. New Bedford has applied for a TIGER grant of approximately $36M for integrated intermodal transportation infrastructure improvements, which include expansion of the South Terminal. In Boston, the BRA has demonstrated its commitment to environmental sustainability by launching a pilot program to help small businesses improve their energy efficiency and sustainability practices. However, this initiative is not focused specifically on the seaport.

Another soft criterion, Regulatory Considerations, involves the environmental review and permitting processes that may be required for the port projects. Work in and around Massachusetts waters may require state environmental review, if one or more MEPA review thresholds is met or exceeded. Installing and operating an offshore wind farm also will require obtaining a number of federal, state, and local permits. MEPA review of a major port improvements project could take between six months and one year, depending on the type of MEPA review triggered and the amount and intensity of political and community support for the project. Permitting such a project may require a similar amount of time, depending on (among other factors) the complexities of the project, the number and length of public comment periods, and the duration of mitigation negotiations that must be conducted between the project proponent and the regulatory agencies.

Since some of the environmental impacts of the South Terminal site have already been assessed by the Commonwealth as part of the Superfund cleanup response for the site, MEPA review of the South Terminal expansion may be streamlined or limited. The permits required for this project are contingent on its projected impacts on regulated resources. The dredging component of the port expansion project may be covered under the State Enhanced Remedy CAD Cell Dredge Disposal Approval for the cleanup. However, other permits/approvals may still be required.

If the required upgrades to Dry Dock #4 at the Port of Boston can be defined as maintenance activities authorized under existing permits, the regulatory process may be circumvented or limited. Nevertheless, because of its proximity to Logan International Airport, obtaining FAA approval of crane heights at Dry Dock #4 could prove to be a lengthy process. The level of MEPA review required for the Dry Dock #4 improvements also would depend on which thresholds were exceeded, if any. Other permits/approvals may be required.

Determining the permits applicable to either project was not within the scope of this report. Additional research would be required to verify which, if any, permits would be needed. If support of renewable energy and immediate job creation are important political objectives in the Commonwealth, it would follow that the port project with the shortest regulatory track and the

greatest political and community support would emerge as the best project to meet those objectives.

Upon review of the side-by-side comparison of the two short-listed ports presented in Table 8-1, it is seen that:

- Both ports and highlighted wharf areas are equally acceptable with regard to the 1st Tier Hard Criteria relating to navigation.
- The South Terminal at the Port of New Bedford displays a slight advantage over Dry Dock #4 at the Port of Boston with respect to the 2nd Tier Hard Criteria associated with Highway Access and Proximity to Construction Sites.

Both ports are equally acceptable with regard to the Soft Criteria relating to Workforce Availability and Education and Training Facilities. In addition, the comparison of the projected economic and fiscal impacts (Section 7) indicated that the two short-listed ports also were very comparable relative to these projections as well.

- The South Terminal at the Port of New Bedford is indicated to be advantageous relative to Dry Dock #4 with respect to the Soft Criteria of Political Climate/Community Acceptance and Regulatory Considerations.

Based on this comprehensive side-by-side comparison, the Team has concluded that the expansion of the South Terminal at the Port of New Bedford represents the best opportunity for a Massachusetts port facility to accommodate assembly and installation of offshore wind energy projects. In addition, the new facility will provide sufficient economic and fiscal benefits to Bristol County and the Commonwealth of Massachusetts to make the investment attractive and worthwhile. This recommendation does not preclude and should not discourage possible future upgrades to Dry Dock #4 at the Port of Boston to service the offshore wind industry as the level of offshore construction activities increases and other roles become available. However, at this time, the political support, advanced planning effort, proximity to offshore sites, and absence of FAA obstacles have led the Team to recommend the South Terminal expansion.

9.0 PATH FORWARD – HIGH-LEVEL SOUTH TERMINAL BUSINESS PLAN

Based on the recommendation presented above, the Team prepared portions of a preliminary business plan for a multi-use cargo facility at the South Terminal in the Port of New Bedford (see Appendix K). Some specific objectives of this effort were to establish an initial path forward and identify:

(1) potential cargoes and revenues for the South Terminal facility, in addition to those associated with the staging, installation, and operations and management of a ROWEI;

(2) independent estimates of costs for facility upgrades;

(3) an appropriate governance model for multi-use terminal ownership and management; and

(4) preliminary standards of operation for the expanded facility.

Toward this end, the Team examined:

- prospective cargo demand;
- port governance/terminal management options;
- potential capital and operating costs;
- overall development feasibility; and
- potential economic effects associated with developing and operating a multi-use renewable energy terminal and general cargo facility at the South Terminal in the Port of New Bedford.

Sources for the analysis included: prior and ongoing studies (conducted by the New Bedford HDC and others); information obtained from offshore wind energy developers; and the relevant experience and related work of consultant team members and outside logistics experts. The following bullets summarize the findings of this effort:

- A new multi-use cargo facility at the South Terminal site represents the best option at the Port of New Bedford for servicing offshore wind energy development projects during the assembly and installation phases.
- A new multi-use port facility at the South Terminal can capture container, break-bulk (e.g., drums or crates), and bulk cargoes not now handled in New Bedford or other Massachusetts ports, and can generate economic development benefits and net operating income to the HDC with or without offshore wind energy development projects.
- The optimal model for governance of a new facility at the South Terminal would be ownership by the New Bedford HDC, which would lease offshore wind energy staging and other cargo handling, storage, and related facility operations to a qualified private operator.
- Capital costs for a new multi-use port facility at the South Terminal are estimated to total about $44 million ($44M) (in 2009 dollars). Approximately $32M of this total investment would be for land acquisition, bulkhead construction and dredging, and the buildings and site improvements that would be functionally necessary to attract and support offshore wind energy development projects (not including the Optional Fabrication Building for

offshore wind installation use). Approximately an additional $5M in capital expenditures would be for improvements necessary to attract and support new bulk, break-bulk, and container cargoes. Capital costs are shown in Table 9-1:

Table 9-1
South Terminal Capital Costs
(Source: FXM Associates, RECON™ Input Output Model)

SOUTH TERMINAL CAPITAL COSTS	Offshore Wind Installation	Non-Offshore Wind Cargoes
Bulkhead and Dredging	$ 19,990,977	$ 19,990,977
Site Acquisition	$ 2,100,000	$ 2,100,000
Backland Site Improvements (drainage, utilities, surfacing)	$ 6,000,000	$ 6,000,000
SUBTOTAL Basic Infrastructure	**$ 28,090,977**	**$ 28,090,977**
Buildings and structures (35,000 SF)	$ 3,500,000	$ 3,500,000
Crane		$ 3,000,000
Ground Equipment (fork lifts, trucks, etc.)		$ 1,500,000
Other Equipment & Fencing, Security	$ 485,000	$ 485,000
SUBTOTAL with Support Facilities & Equipment	**$ 32,075,977**	**$ 36,575,977**
Optional Fabrication Building (75,000 SF)	*$ 7,500,000*	*$ 7,500,000*
TOTAL with Fabrication Building	***$ 39,575,977***	***$ 44,075,977***

- Average net operating income to the HDC from a fully-developed South Terminal port facility is expected to total approximately $1.2M per year during a projected 3-year ROWEI and about $622,000 per year with full cargo operations. Projected operating revenues and costs are shown in Table 9-2 below:

Table 9-2
South Terminal Operating Income and Expenses
(Source: FXM Associates)

SOUTH TERMINAL OPERATING INCOME & EXPENSES	Offshore Wind Installation	Non-Offshore Wind Cargoes
Average Year Annual Operating Income		
Offshore Wind Energy Development (ROWEI)	**$ 1,500,000**	
Container Service		$ 280,000
Break Bulk Program		$ 240,000
Bulk Cargo		$ 432,500
Total Non-ROWEI Cargo		**$ 952,500**
Average Year Annual Operating Expenses		
HDC Personnel (contract/lessee management)	$ 140,000	$ 140,000
HDC Capital/maintenance reserve at 20% income	$ 190,500	$ 190,500
Average Year Annual Expenses	*$ 330,500*	*$ 330,500*
Average Year NET Operating Income		
Offshore Wind Energy Development (ROWEI)	**$ 1,169,500**	
Total Non-ROWEI Cargo		**$ 622,000**

- Based on the net operating income projected for the South Terminal, annual operating subsidies for either offshore wind energy development support or long term cargo operations are not anticipated to be required.

- The South Terminal can cover all of its operating expenses during the ROWEI use of the facility and annually thereafter based on non-ROWEI cargo operations. Approximately $12M of the capital costs for the new facility can be supported by annual net operating income combined with income from the 3 year ROWEI use of the facility. This leaves $32M of debt that would require financing from other sources.

- Construction of the South Terminal port facility is estimated to expand business output in Bristol County by approximately $44.1M over the projected 2-year construction period of the terminal, and provide 380 person years of employment and $19.2M in household income over the construction period. These projected economic impacts include total direct, indirect and induced economic effects within Bristol County. These effects are summarized in Table 9-3.

Table 9-3
Construction and Annual Direct, Indirect and Induced Economic Effects Associated with South Terminal Construction
(Source: FXM Associates)

		Output (000 $)	Employment (Jobs)		Income (000 $)
Construction Period Effects					
South Terminal Port Facility					
Bristol County	*$*	*44,100*	*380*	*$*	*19,200*
Massachusetts	$	65,500	540	$	26,100
Annual Operating Effects					
South Terminal Port Cargo Operations					
Bristol County	*$*	*15,700*	*130*	*$*	*5,900*
Massachusetts	$	20,200	170	$	7,400

- Construction of the South Terminal port facility is estimated to expand business output in Massachusetts overall (including Bristol County) by about $65.5M over the projected 2-year construction period of the terminal, and provide 540 person years of employment and $26.1M in household income over the construction period. These projected economic impacts include total direct, indirect and induced economic effects within Massachusetts over the construction period (see Table 9-3).

- The handling of cargoes not related to an offshore renewable wind energy installation (non-ROWEI), including container, break-bulk, and bulk cargoes, is estimated to expand business output in Bristol County by $15.7M annually, and provide 130 permanent jobs and $5.9M per year in new household income. These projected economic impacts include total direct, indirect, and induced economic effects within Bristol County estimated to recur annually following facility construction and do not include support of offshore wind energy projects (see Table 9-3).

- The handling of non-ROWEI container, break-bulk, and bulk cargoes at the South Terminal is estimated to expand business output in Massachusetts overall (including Bristol County) by approximately $20.2M annually, and provide 170 permanent jobs and $7.4M in new household income each year. These projected economic impacts include total direct, indirect, and induced economic effects within Massachusetts estimated to recur annually and do not include support of offshore wind energy projects (see Table 9-3).
- During the construction period for the South Terminal facility about $480,000 in local/municipal revenues within Bristol County communities would be attributable to the total projected direct, indirect and induced economic effects of construction. Within Massachusetts communities approximately $1.2M in municipal receipts (including Bristol County) would be attributable to the construction period economic effects (see Table 9-4).

Table 9-4
Construction and Annual Direct, Indirect and Induced Tax Effects
(Source: FXM Associates)

	Local Taxes (000 $)	State Taxes (000 $)	Federal Taxes (000 $)
Construction Period Effects			
South Terminal Port Facility			
Bristol County	*$ 480*	*$ 440*	*$ 1,820*
Massachusetts	$ 1,190	$ 1,440	$ 7,280
Annual Operating Effects			
South Terminal Port Operations			
Bristol County	*$ 300*	*$ 240*	*$ 730*
Massachusetts	$ 480	$ 500	$ 2,180

- During the construction period for the South Terminal facility about $1.4M in tax revenues to the Commonwealth of Massachusetts and approximately $7.3M in federal taxes would be attributable to the construction period economic effects (see Table 9-4).
- The handling of non-ROWEI container, break-bulk, and bulk cargoes at the South Terminal is expected to generate about $300,000 in new tax receipts annually for municipalities in Bristol County and $480,000 annually for municipalities statewide (including Bristol County) based on the projected annual economic effects attributable to cargo operations (see Table 9-4).
- The handling of non-ROWEI container, break-bulk, and bulk cargoes at the South Terminal is projected to generate about $500,000 in new tax receipts annually for the Commonwealth of Massachusetts and approximately $2.2M in federal taxes each year (see Table 9-4).

These components of a “path forward” relative to the development of an expanded multi-use cargo facility at the South Terminal address the key findings of preliminary business plan for

port expansion. (Appendix K provides a more detailed financial analysis of port expansion and operation.) This study demonstrated that the South Terminal at the Port of New Bedford meets the necessary requirements and possesses a number of the advantageous characteristics needed to successfully support a developing offshore commercial wind farm. The study also identified some areas where this port could make modifications and improvements to its harbor or wharf facilities that would further enhance the port's ability to support offshore wind energy. The path forward would continue the process outlined here, more fully develop the elements that were addressed in this study, and consider other important aspects of the port's development that were not considered to be critical to the scope of this study.

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APPENDIX 2

Apex Companies, LLC

Memo

To: File

From: Chet Myers, P.E., LSP

Date: April 8, 2010

List of Attendees:

Kristin Decas, Executive Director, NBHDC

Matt Morrissey, Executive Director, NBEDC

Craig Olmstead, Vice President, Projects, Cape Wind

David G. Inman, Key Account Manager, Siemens Energy, Inc., Power Systems

Jesper Pedersen, Tender Manager, Siemens Power Generation

Poul Martin Wael, Director Offshore Projects & Logistics, Siemens Wind Power

Preben Straarup, Tender Manager, Siemens Wind Power

Lars Humlebaek, Technical Project Manager, Siemens Wind Power

Jay Borkland, Division Manager, Apex Companies, LLC

Chet Myers, Senior Engineer, Apex Companies, LLC

Re: Summary of Meeting with Cape Wind and Siemens Personnel

Meeting was held at New Bedford City Hall at approximately 1 PM. NBHDC and NBEDC presented the plans for the expansion of South Terminal to support the offshore renewable energy industry. Cape Wind and Siemens described the needs of the offshore renewable energy industry for a shore-side support facility, based upon the needs of similar projects in Europe.

The following information was provided by Cape Wind and Siemens as crucial for the new facility to be feasible.

- There are a few types of vessels that would be used to transport wind turbine components from the manufacturer to the support facility. However, the approximate range in sizes of an international vessel is between 140 - 150

meters (460 – 490 feet) in length, 30 - 35 meters (98 - 115 feet) in width and requires 7 – 9 meters (23 – 29.5 feet) of draft.

- The international vessel would only carry components for 6 turbines. Therefore, for constructing an offshore wind energy facility for 130 turbines, 22 separate shipments from international vessels would need to be received at the support facility. The international vessel will require 3-4 days of docking for unloading each trip.
- Offshore renewable energy facility installation ships would consist of jack-up barges that would be approximately 91 meters (300 feet) in width and 30 meters (100 feet) in width.
- In order to keep the installation vessels stable during dockside loading, the barges would be deploy their spuds to "jack-up" the vessel for stability. This is to prevent the vessel from tipping over from uneven loading. Due to the loads anticipated to be borne by the spuds, it is necessary to ensure that the harbor floor at the quae-side is of a stable material. An unstable harbor bottom could cause the spuds to sink unevenly, which could tip the vessel and sink it. Harbor bottoms consisting of a thick layer of silt or clay could also cause the spuds to sink too deeply as it is loaded, and prevent the spuds from being withdrawn, which will trap the vessel at the facility.
- In order to efficiently run construction of the offshore renewable energy facility, multiple installation vessels must be utilized. At a minimum, one installation vessel will be at the construction site, one installation vessel will be loading at quae-side, and one installation vessel will be returning from the construction site. During much of construction, at least two installation vessels will be at quae-side either being loaded or arriving from the construction site and awaiting loading. Therefore, it is required that berthing space for the international vessel and two installation vessels be available.
- Vertical restrictions of any kind are not acceptable. This criteria is primarily in place due to the extremely large cranes (600 ton crawler cranes, which have boom lengths of up to 475 feet) necessary for loading and unloading of vessels and pre-assembly of wind turbines prior to delivery, the large spuds that are integral to the functioning of jack-up barges, which, as stated before, have multiple spuds that extend up to 250 feet above the barges when they are mobile) that will be utilized to transport pre-assembled wind turbines to the wind farms during construction, as well as the pre-assembled wind turbines themselves that will extend up to 250 feet into the air above the barges as they are transported to the construction site.
- The anticipated loading requirements for the entire facility will be 20 tonnes/square meter (4,000 pounds/square foot), due to the use of 600 ton crawler cranes (an example of which is a Lieberr 750 Crane) anticipated to be utilized throughout the facility to transport, stack, load, and unload renewable energy facility components.
- Due to the anticipated loading requirements, an asphalt or concrete surface would not work. The heavy cranes would demolish such a surface in very short order. Therefore, the preferred surface is crushed stone.

- If possible, it is preferred to have a facility closer to 35-40 acres in size (the specific request was for 150,000 square meters for an ideal facility); however, 20 acres is the minimum amount of space required for the staging, preconstruction, and storage of renewable energy components for the construction of a 130 wind turbine offshore renewable energy facility.
- The heavy cranes must be able to reach within a meter of the target loading area on the installation vessels.
- Interest was expressed for an area (outside of the 20 acre facility) for parking for up to 200 people. A 20 acre facility would not be large enough to accommodate parking as well as storage, assembly, etc.
- A high priority is to find a location within which vessels can dock and exit the harbor without waiting for other vessels.

APPENDIX 3

SIEMENS **Energy**

Cape Wind
Att.: Craig Olmsted

Name	Thomas Mousten
Department	E R WP AM
Telephone	
Mobile	+1 (617) 943-8043
E-mail	tmo@siemens.com
Date	August 24, 2010

Pre-construction stating area for offshore wind turbines

Dear Sirs,

Over the past several years, Siemens has routinely identified, managed and utilized staging areas for offshore wind projects. This letter summarizes some of the key specifications that are necessary for a staging area to be adequate and practicable, and comments on whether the proposed South Terminal meets these specifications.

The following activities summarize the anticipated operations on the site:

- Delivery of all wind turbine parts and material by international cargo vessel. This comprises tower sections, electronics components, nacelles, hubs and blades. These items will be off loaded by shore-based cranes to the quayside, for movement to their designated storage locations.
- Assembly of the electronic components inside a building, and transfer outside for installation of the assembled electronics in the lower tower sections.
- Final assembly of nacelle components, including attachment of the hub and installation of aviation lighting etc.
- Assembly all components in complete sets for loading onto the assembly vessel.
- Loading assembled components onto the installation vessel, using both on-shore and vessel-mounted cranes as appropriate.

It is critically important that the staging area be dedicated to the wind farm activities with unrestricted access on a 24-hour per day basis during pre-assembly and installation operations. Locations that would require Siemens to share space with other unrelated ongoing uses would not be feasible or practicable. The South Terminal meets these criteria, because it can be made available for wind farm use on a 24 hour exclusive basis.

Siemens Energy, Inc.

45 Fairfield st.
Boston, MA 02116
United States

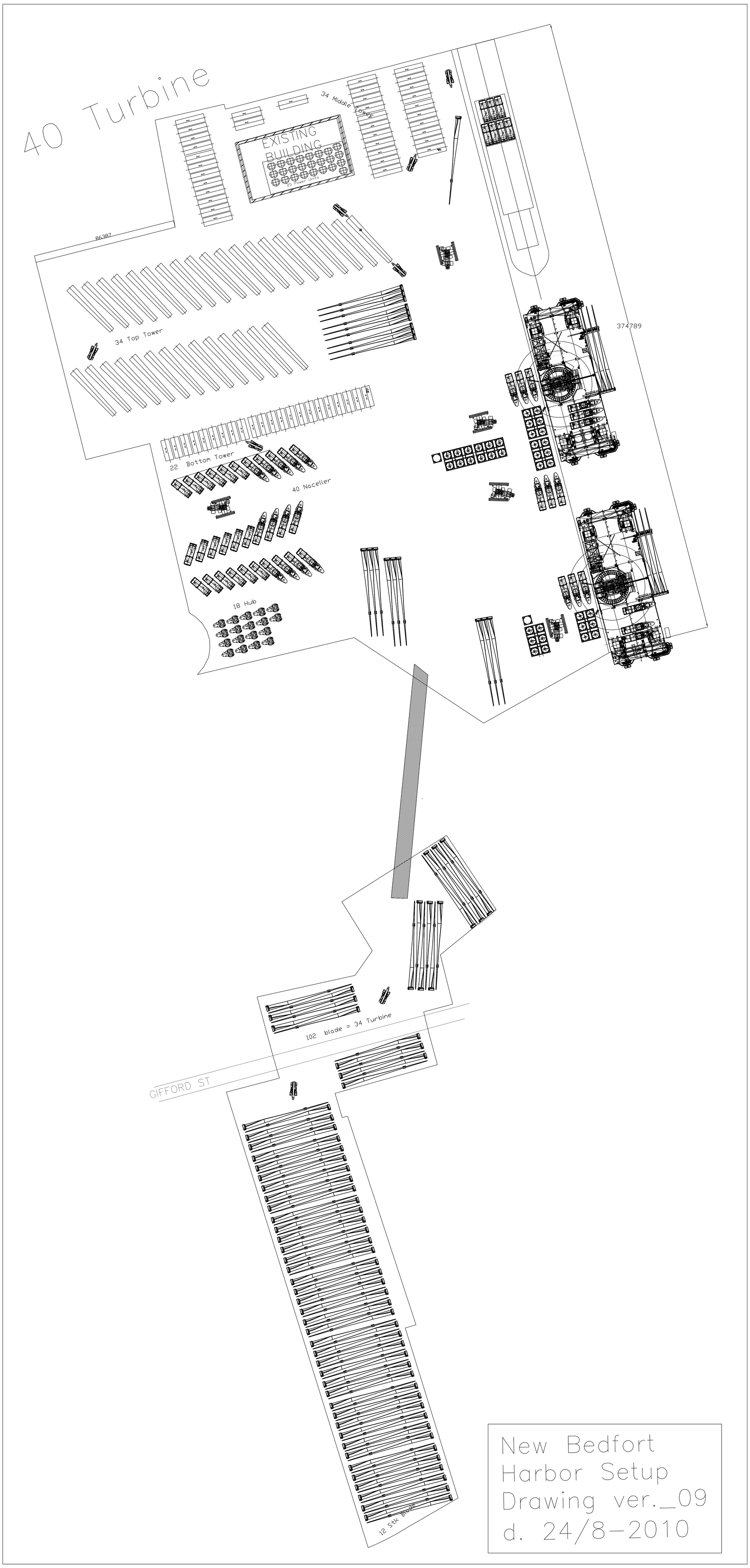
It is also vital that a minimum of 1200 linear feet of quayside at required depths be dedicated to the wind farm activities. Efficient operation requires the continuous access to three vessels. This is because, among other reasons, due to weather and other variables, arrivals and departures cannot be scheduled with precision, and we need to have enough space so that all three vessels can operate on the site simultaneously, so that they are not turned away when they arrive. This will likely be one international cargo vessel and two installation vessels. These vessels would be approximately 480 feet in length (requiring -30 foot depth) and 300 feet in length (requiring -20 foot depth) respectively. In addition, the vessels require about 60 linear feet between them for a total of 1200 feet minimum. It is not possible to use fewer vessels and install a 100+ turbine project in one construction season. Siemens understands that the proposed South Terminal will meet these criteria.

Available land contiguous to the quayside is a third important asset of an efficient staging area. For economic operations, to construct a 100+ turbine project in one season will require a minimum area of 25 to 30 acres contiguous with the quayside. The exact size depends on many variables, but as an example, Siemens has carefully considered the proposed build out of the South Terminal at New Bedford and determined that 28 acres is a minimum requirement for efficient operation at that location. We have carefully considered the way we would utilize a parcel of this size and shape, and have worked with the city and it's consultants to consider all feasible options for use of the site to minimize the amount of dredging and filling. In order to perform the operations listed above, we need storage space for an absolute minimum of 40 complete sets of turbine components (consisting of 3 tower sections, 1 nacelle, 1 hub, 3 blades and 2 electrical components per turbine). This is because we need to have a certain backlog of complete sets to ensure that when the installation vessels are present, there are complete sets to load on to them. Again, due to weather variables that are particularly problematic during the winter, we need to ensure that these installation vessels are not delayed for use in their intended purpose whenever they arrive. To ensure sufficient space for the storage, assembly, and loading of forty turbines, we need 7 acres for tower lay down, 2 acres for hub and nacelle lay dawn, 5 acres for loading and unloading operations, 5 acres for pre-assembly activities and 1 acre for buildings and services, and an additional 8 acres of contiguous, or directly accessible land for wind blade lay down. Attached is a conceptual diagram showing how Siemens would use the 28 acres for this purpose. Note that the diagram includes no vacant or idle space. It also details an arrangement of how 40 full sets of components are stored and worked on. For illustration purposes, note that we have shown some tower sections upright, ready to placed on board the installation vessel.

Vertical clearance is also an issue in the long run. As the offshore industry matures in the US, for Siemens to operate efficiently and competitively, we must begin to assemble the towers fully on shore. This would require 250 feet or more of vertical clearance both at the pre-assembly area and the transit route to the wind farm site. If the South Terminal is built out as proposed, it will be suitable for the staging of multiple projects along the East coast because there are no vertical restrictions of any kind. In the coming years, larger turbines, 6 MW or greater, will become available and the South terminal will be suitable for their pre-assembly. Limited vertical access either at the pre-assembly area or the route to the installation site would cause an unacceptable impediment to future installations.

Sincerely yours,

Thomas Mousten



New Bedfort
Harbor Setup
Drawing ver._09
d. 24/8-2010

APPENDIX 4

Magazine
Jobs Board
RFP
Audio/Video
Super Search
Shipbuilding
Free Newsletter

ARM MERCHANT SHIPS?

Should merchant ships transiting high risk areas carry small arms for defense against pirates?

- Selected crew should be trained and have guns available
- Professional armed security teams should be hired
- No guns on merchant ships, ever

Submit Vote

Current Results

Powered by SPARKLIT

July 23, 2009

Jack-Up Barge installs Germany's first offshore wind turbine

Jack-Up Barge B.V. recently marked a major milestone. On its maiden assignment, the company's newbuild monohull jack-up platform JB-114 completed the installation of Germany's first offshore wind turbine.

After mobilization in Eemshaven, the Netherlands, the JB-114 was towed to the offshore location, about 45 km north of the island of Borkum in the North Sea. Within 36 hours of arrival it installed the tower, turbine and rotor blades of the first wind turbine in the **Alpha Ventus wind farm**.

Ronald Schukking, Managing Director of Jack-Up Barge B.V., said: "The installation could not have gone any better. This project once again proves that our jack-up platforms are extremely suitable for utilization in the offshore wind turbine construction industry."

The JB-114 and twin sister the JB-115 **were both delivered last month by Drydocks World Nanindah** (former Labroy Shipyard) at Batam, Indonesia as part of an extensive newbuild program.

Both jack-ups will be working on the construction of the Alpha Ventus wind farm this summer. The JB-114 is chartered by German company Prokon Nord, which is responsible for the installation of six 5 MW Multibrid wind turbines on tripod foundations. The JB-115 is chartered by DOTI and will be installing the slots and templates on the seabed in preparation for the jacket foundations of the six remaining 5 MW REpower turbines.

The Alpha Ventus wind farm, with a total capacity of 60 MW, is expected to be completed before the end of this year, making it the first operational wind farm in German waters.

Jack-Up Barge B.V. specializes in the manufacturing, sales and rental of standard and modular self-elevating platforms and is a member of the Van Es Holding Group.

EVAC

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For Immediate Release

Drydocks World delivers two self-elevating platforms for wind farm installation

Singapore, 10 June 2009 – Drydocks World – Southeast Asia ("DDW-SEA"), the Southeast Asian subsidiary of Drydocks World, has announced the recent delivery of JB-114 and JB-115 from it's Drydocks World – Nanindah yard on Batam Island, Indonesia, to Self Elevating Platforms N.V. The unit will be operated by subsidiary company, Jack-Up Barge B.V., a leading supplier to the oil & gas, wind farm and civil construction industries and wind turbines market, as well as for the heavy civil construction market.

Ronald Schukking, Managing Director of Jack-Up Barge B.V. said, "Drydocks World has once again met our expectations – the quality and finish of JB-114 and JB-115 is excellent. We definitely look forward to working closely with Drydocks World in the future. "

Designed by Holland's GustoMSC and of the SEA 2000 design, JB-114 and JB-115 are the third and fourth of this type successfully built by DDW-SEA. Similar to the first and second vessels, which have now been renamed 'Sea Worker' and 'Seafox 7' respectively; the monohull jack-up barges JB-114 and JB-115 will be deployed in European waters involved in wind farm installations and related activities.

Designed with a 55.5 m x 32.2 m x 5 m hull, a 300 tonnes-capacity mounted pedestal crane together with four cylindrical legs, 3.0m in diameter and 78.85m in length, each platform is designed for operations in water depths up to 40m - in and around the Southern North Sea.

Mr. Denis Welch, CEO of Drydocks World – Southeast Asia said, "Both JB-114 and JB-115 are part of a series of sophisticated barges contracted by Self Elevating Platforms N.V., and we are pleased to have successfully delivered four of them to date. These barges will be used specifically for wind farm installation activities, which is one of the industries (alternative energy or power generation) that we are actively pursuing, given that ––our ship repair, conversion and new building capabilities can be easily extrapolated to suit this growing industry's requirements.

I would like to express my appreciation to our team in Drydocks World-Nanindah, the client's site team and our vendors and partners throughout the world for the successful delivery of this project."

Drydocks World - Southeast Asia, established in April 2008, is a member of the Drydocks World group of companies and a sister operation to Drydocks World – Dubai (formerly known as Dubai Drydocks). The Drydocks World Group has an esteemed heritage of providing a full spectrum of integrated maritime and offshore solutions in strategic locations in the Middle East and Far East. Currently housing four of Asia's premier shipyards in one of the world's busiest seaways, Drydocks World - Southeast Asia specialises in rig and shipbuilding as well as conventional ship repair and conversion, wholly supported by world-class engineering and design capabilities. With quality workmanship and competitive pricing, Drydocks World is one of the most prominent names in the maritime industry today.

- Ends -

About Drydocks World

Drydocks World, a Dubai World company, is one of the most prominent names in the maritime industry. Over the past 25 years, Drydocks World has established itself as a leading, and fast growing international player in ship repair, shipbuilding, rig building, FPSO conversion, offshore fabrication and fleet operations with facilities in the Middle East and Southeast Asia.

Drydocks World - SE Asia, brings together established offshore rig construction, shipbuilding, conversion, and ship repair expertise located at crossroads of the world's busiest shipping lanes and close to major offshore oil & gas field developments. Marine activities are focused on 4 shipyards, namely, Drydocks World – Graha / Nanindah / Pertama / Singapore, which house 29 building berths, 8 floating docks, and a specialized rig building yard. Extension plans are in place to expand operations further on Batam Island with the construction of a new yard PT Batam Maritime Centre.

For more information, please refer to the www.drydocks-sea.com, www.drydocks.gov.ae

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Issued for and on behalf of Drydocks World - Southeast Asia Pte Ltd

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APPENDIX 5

Allens Harbor Rd
Tidal Dr
Rudder St
Ash St
Nerove St
Keel St
Cooper St
Magnolia St
Plum St
Broadway
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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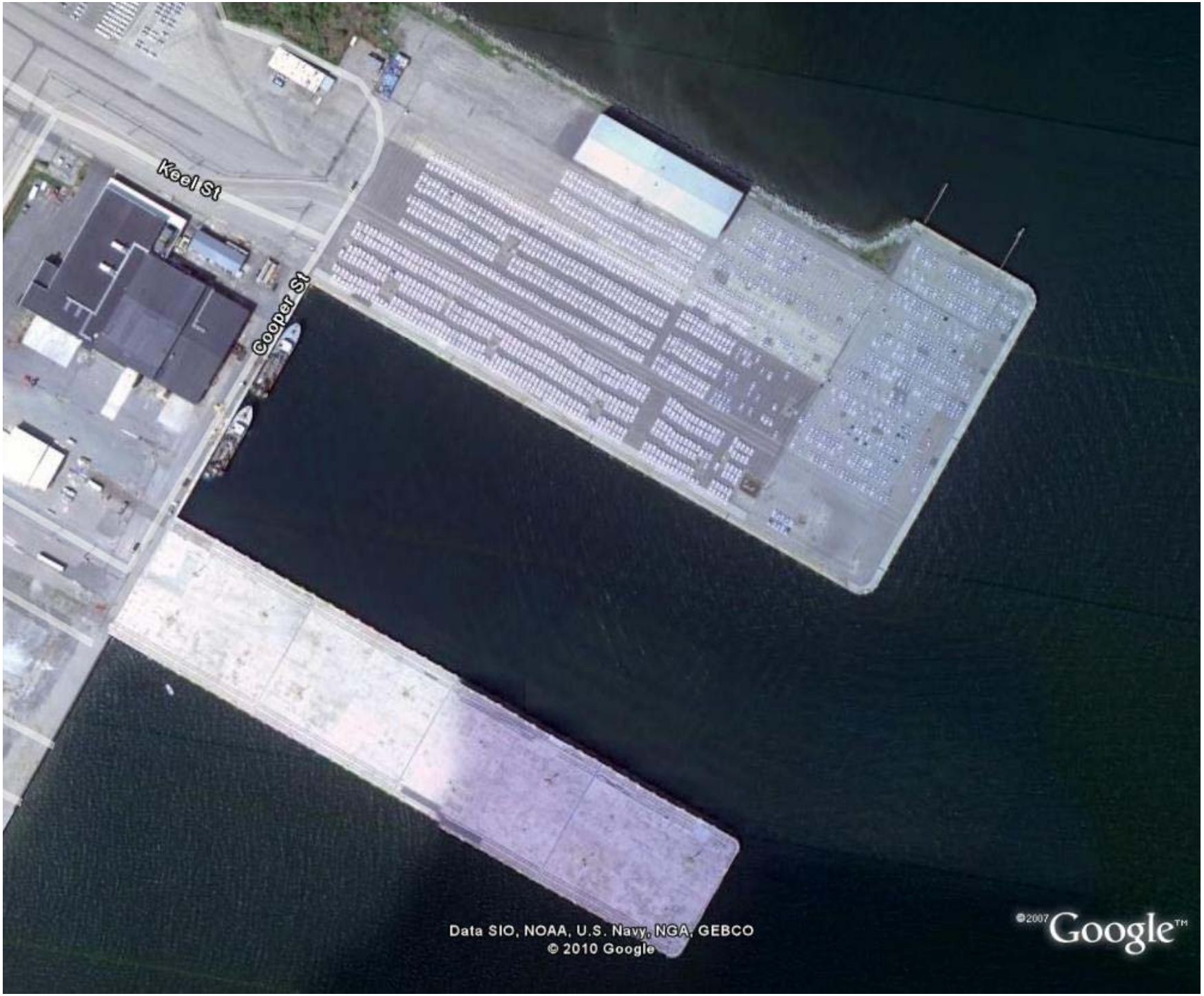
Keel St
Cooper St
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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Picture 1: Picture of New Car Storage on Pier 1. Note concrete surface of Pier 1.

Picture 2: Photo of new car staging/storage on Pier 2.

Photo 3: Photo of car importation vessel docked at Pier 2. Note concrete surface of Pier 2.

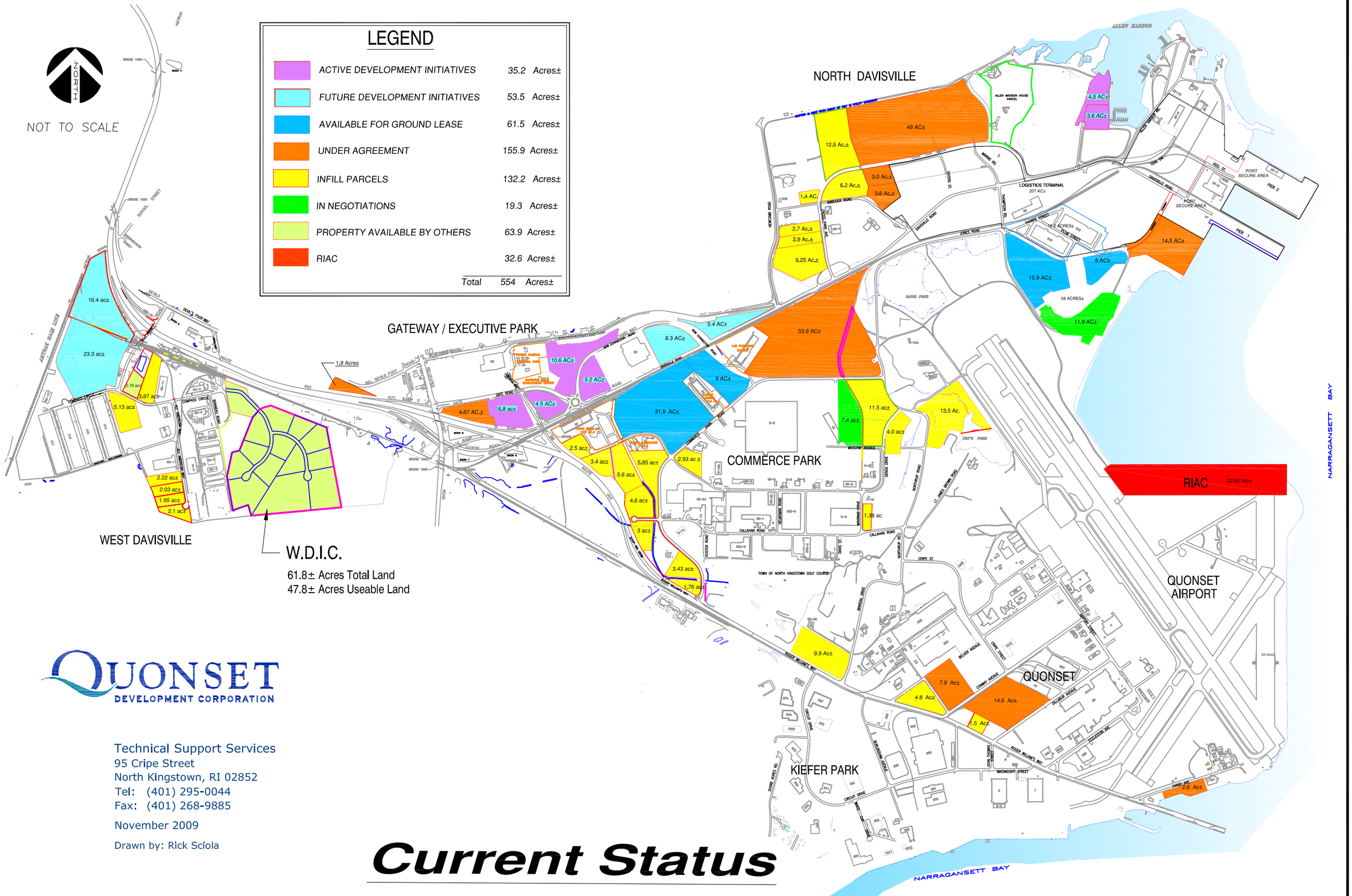
Photo 4: Photo of car storage within upland areas at Port of Davisville.

APPENDIX 6

NOT TO SCALE

LEGEND

ACTIVE DEVELOPMENT INITIATIVES	35.2	Acres±
FUTURE DEVELOPMENT INITIATIVES	53.5	Acres±
AVAILABLE FOR GROUND LEASE	61.5	Acres±
UNDER AGREEMENT	155.9	Acres±
INFILL PARCELS	132.2	Acres±
IN NEGOTIATIONS	19.3	Acres±
PROPERTY AVAILABLE BY OTHERS	63.9	Acres±
RIAC	32.6	Acres±
Total	554	Acres±



QUONSET DEVELOPMENT CORPORATION

Technical Support Services
95 Cripe Street
North Kingstown, RI 02852
Tel: (401) 295-0044
Fax: (401) 268-9885

November 2009

Drawn by: Rick Sciola

Current Status

APPENDIX 7

Airspace Issues in Wind Turbine Siting

Wind turbine projects need to clear many hurdles before they can proceed to construction. One of the most important milestones in any wind project is securing a determination from the Federal Aviation Administration (FAA) that the project does not adversely affect air traffic or radar systems. This can be a complicated and uncertain process, and many projects have run into unexpected delays. The primer below explains how anticipate and avoid some of these conflicts, and how the FAA review process works. Several case examples are presented.

The FAA's Role and Procedures

The FAA has oversight of any object that could have an impact on the navigable airspace or communications/navigation technology of aviation (commercial or military) or Department of Defense (DOD) operations. The FAA requires that a Notice of Proposed Construction (Form 7460-1) be filed for any object that would extend more than 200 feet above ground level (or less in certain circumstances, for example if the object is closer than 20,000 feet to a public-use airport with a runway more than 3,200 feet long). As wind turbine heights have increased during the past couple of decades, this filing requirement has applied to increasing numbers of projects.

For any filed project, the FAA undertakes an initial aeronautical study within the relevant FAA region, and issues either a Determination of No Hazard to Air Navigation (DNH) — the "green light" for the project — or a Notice of Presumed Hazard (NPH). If an NPH is issued, the FAA will then initiate an in-depth technical analysis (commonly called an extended study), which will explain the cause of the NPH and evaluate impacts on air operations. If after the extended study, which may include a public comment period, there remains an operational impact, the FAA will try to negotiate an acceptable height for a project that has received a DNH. If no agreement can be reached, FAA will issue a Determination of Hazard (DOH). A DOH can be appealed to FAA Washington Headquarters. If the appeal does not secure a DNH, the proponent's main recourse is to bring the issue before a Federal Court.

The FAA analysis considers several types of airspace impacts: (1) imaginary surface penetration, (2) operational impacts, and (3) electromagnetic interference. A primer is helpful:

(1) **Imaginary Surfaces**: Both aircraft flight routes and the airspace near airports require great swaths of defined space dedicated to the takeoff, travel, and landing of aircraft. We might imagine these spaces as giant rooms and tunnels of airspace with very specific boundaries. The walls, ceilings, and floors of those rooms and tunnels are defined as imaginary surfaces. If an imaginary surface is penetrated by a constructed object (e.g., a turbine), the FAA then does an extended study to determine whether the turbine poses an operational problem for the relevant airport or for a specific visual flight route between airports. If the penetration does not pose an operational impact it may be determined not to be a hazard.

(2) **Operational Impacts**: The thousands of flights that leave and arrive each day at large airports, such as Boston's Logan International Airport (Logan), are possible because of very complex and exacting protocols known as visual flight rules (VFR) and instrument flight rules (IFR). Operational impacts are those that affect VFR and IFR operations. Examples of operational impacts include increasing the minimum flight altitude in a specific area (either for "enroute" air traffic or for circling at an airport),

diverting air traffic away from an obstacle, increasing the minimum climb gradient (steepness) for airport departure, or increasing the minimum descent altitude at the obstacle location for airport arrivals. For obvious reasons, the air transport industry is generally resistant to operational changes that would increase workload in the cockpit during critical takeoff and landing periods or impose non-standard flight restrictions.

(3) **Electromagnetic Interference** (EMI): Experience has shown that wind turbines can degrade performance of air traffic control (ATC) or air defense radar. The phenomenon can include sudden or intermittent appearance of radar contacts at the location of the wind turbine because of blade motion or rotation of the turbine to face the wind. For ATC radar the interference is generally limited to wind turbines that are within the radar line of sight. Studies indicate that this problem may be minimal for turbines more than 5 nautical miles from the radar.

A September 27, 2006 Department of Defense (DOD) report titled *The Effect of Windmill Farms on Military Readiness* identifies similar conflicts with air defense radar. These conflicts can extend for tens of miles from the radar facility due to atmospheric refraction).

And finally, interference with microwave transmissions is another form of EMI that is of concern because public safety radio systems typically use microwave-based technologies.

Resolving Adverse Impacts. As part of a Notice of Presumed Hazard or Determination of Hazard, the FAA may suggest modifications that could render the project acceptable – for example, a change in the height of a proposed turbine or the re-siting of a turbine at a greater distance from an airport. Such modifications can make a project possible while accommodating regulatory needs and preserving the quality of airspace or navigational operations at the nearby airport. For wind project proponents, these modifications often represent a tradeoff of efficiency for safety. In rare cases the FAA might agree to a procedural change that would sidestep the problem.

For conflicts with radar systems, there are technologies, such as geosensor mapping and "masking" that may prevent air traffic control (ATC) radar from picking up wind turbines as targets. However, masking also renders the radar ineffective in the subject area. DOD's recent report concludes that the only way to prevent signal degradation of air defense radar is to keep wind turbines out of the radars' lines of sight.

Identifying Potential Conflicts Early. Wind project developers may find it beneficial to consider how the FAA evaluates potential airspace obstruction as they screen potential sites for wind projects. MTC has found it useful to obtain an "Airspace Obstruction Report and Opinion Letter" from a qualified consultant at an early stage in a project. This relatively low-cost effort can help project proponents identify potential airspace conflicts early and avoid wasting time and effort on a dead-end project. It is important to note that the FAA's evaluation of potential conflicts with air traffic is significantly more predictable than its evaluation of radar issues. At present, the only reliable approach to identifying radar issues is to have the FAA conduct a "propagation study" as part of its formal review of a Notice of Proposed Construction.

Case Examples: Learning by Doing

MTC's understanding of airspace siting issues has evolved through experience with some early wind projects in Massachusetts. The following case examples provide some history and context for current conversations about securing approval for wind turbine sites, especially in the Boston Harbor area.

Hull and the IBEW: Early Successes

• The Hull Municipal Light Plant installed Massachusetts' first large scale wind turbine, a 164-foot turbine located at Windmill Point, in 2001. Five years later, it installed a 340 foot turbine on the site of a town landfill. Happily, both received DNH status from the FAA and are operational. It is unclear whether the FAA will ultimately conclude that these turbines have some effect on Logan Airport air traffic control radar.

• In 2005, Local 103 of the International Brotherhood of Electrical Workers received a DNH for a 150-foot wind turbine at their Dorchester office site. Today the turbine spins away. It is unclear whether the FAA will ultimately conclude that this turbine has some effect on Logan Airport air traffic control radar.

Boston Harbor: Airspace Concerns

Wind projects in the vicinity of Logan Airport raise special concerns, since Logan is one of the nation's busiest and most compact airports. MTC and project proponents filed Notices of Proposed Construction near the beginning of the development process for several Boston Harbor area projects so that any airspace or radar problems would be known early in the development process. For the Deer Island, Long Island, and Lynn projects (see below), the FAA had initial concerns about the heights of turbines.

• In late 2005 the Massachusetts Water Resource Authority (MWRA) filed a Notice of Proposed Construction for 394-foot turbines at five possible locations at the wastewater treatment plant on Deer Island in Boston. When the FAA concluded that turbines at the proposed heights were a potential hazard to aviation, the MWRA and MTC revised the project to use 190-foot turbines. As of February 2007, FAA has not issued an official determination on that plan. It is possible that the FAA will issue a DOH for any Deer Island turbines, regardless of height, because of radar impacts on Logan.

• The City of Boston, with support from MTC's Community Wind Collaborative, proposed a series of up to four 394-foot turbines on Long Island in Boston Harbor, a bit more than three nautical miles from Logan airport. Notices of proposed construction were filed on October 15, 2005. On February 10, 2006 the FAA issued initial NPH designations for all four locations based on its finding that "the structure[s] as described exceed[s] obstruction standards and/or would have an adverse physical or electromagnetic interference effect upon navigable airspace or air navigation facilities." (The FAA identified reduced heights at which the turbines may have been acceptable as 190, 233, 256, and 247 feet.) At that point, MTC hired an airspace specialist to determine whether there were options for overcoming the FAA's concerns. That specialist proposed a "step-down fix" by which minimum aircraft heights over Long Island would be increased. The FAA conducted an extended study of this proposal including a public comment process. In September of 2006, the FAA issued a DOH for the Long Island sites, saying that the "cumulative impact of the proposed structure[s] . . . is considered to be significant." It cited, among its reasons: the turbines would be in the only remaining quadrant around Logan that is not currently impacted by obstructions; building a step down fix would increase cockpit workload during final approach; and that, without complex geosensor mapping for each turbine, interference with air traffic control radar was likely. MTC and the City of Boston elected not to appeal those FAA determinations.

• The City of Lynn Community Wind Collaborative wind turbine project is slated for a regional wastewater treatment plant site. The initial FAA filing for the 397-foot structure resulted in a NPH, in part because of turbine height. Subsequent evaluation by an airspace specialist under contract to MTC indicated that the FAA would be unlikely to accept a modification of minimum aircraft altitudes for the Lynn location. Informal contact with the FAA indicated that there might also be conflicts with Logan

Airport air traffic control radar. MTC and the City then accepted a lower wind turbine height (254 feet) and asked that the FAA investigate the radar issue in greater depth. After further FAA study, the FAA issued a DNH in January 2007.

Outside the Boston Area: Barnstable and Paxton

• MTC is collaborating with Cape Cod Community College on a wind project to be built on the College's campus in West Barnstable. Initially, the project involved a 397-foot turbine on the east side of the campus. Early in the project development process, MTC and the college discussed the project with authorities at the local airport, and received informal assurances that the project should not raise airspace concerns. However, a subsequent filing with the FAA resulted in, first, a NPH, and then, a DOH. In response to the FAA's evaluation, the College modified the proposal to a 253-foot turbine on the west side of the campus. As of February 2007 the College and MTC are waiting for final FAA approval of this smaller turbine in the alternate location.

• In mid-2005 MTC filed a Notice of Proposed Construction for two wind turbine locations on Asnebumsket Hill in Paxton, Massachusetts. There are currently several telecommunications and radio transmitter towers at the site, one of which is 366 feet above ground level. In December 2005 the FAA issued NPH's for the two locations indicating that any object greater than 200 feet above ground level would result in a DOH. Subsequent evaluation by MTC airspace consultants led us to the conclusion that there was little change of mitigating FAA concerns. (This evaluation also concluded that the minimum height for one turbine location should have been 125 feet above ground level.) An important aspect of the Paxton situation is that the proposed wind turbine locations were closer to Worcester airport than the existing radio/telecommunications towers. Thus, wind turbines at the proposed heights would have constituted an additional deterioration of navigable airspace which was unacceptable to the FAA.

Guidelines and "Best Practice" Recommendations

It is not possible to predict perfectly the outcome of an FAA determination on a given project. However, from the above project experiences (and others), MTC has generated the following recommendations for the planning and development of wind turbine projects.

(1) Review airspace considerations early in the project development process; this increases efficiency, saving time, money, and stress.

(2) Be aware of the following general guidelines: a turbine under 200 feet in height is rarely problematic for navigable airspace, and a turbine site more than five nautical miles from an airport runs the least risk of a NPH or DOH on radar issues.

(3) Conduct, as early as possible, due diligence with local authorities, proponents, and stakeholders. This avoids, among other challenges, unanticipated opposition at the public comment stage of an FAA study.

(4) Enlist the services of professional aviation consultants, and bring them into the process early to advise on the technicalities of FAA regulations, which can be daunting. (A report commissioned by MTC states that FAA criteria "are highly complex, especially as they relate to operational impacts on air traffic. There are many instances where[in] FAA operational criteria . . . are modified on a case-by-case basis . . . . only an experienced airspace analyst should attempt to apply the Operational Impact criteria."). The consultant's analysis is relatively inexpensive (approximately $500) and results will be available quickly, whereas the FAA review process takes considerable time.

With this information in hand, you will be better prepared to tackle the exhilarating (and sometimes cumbersome) task of bringing a wind turbine project to life. At MTC we are constantly striving to provide accurate and current information regarding your wind turbine siting and permitting needs — please do not hesitate to contact us!

Resources/Links

This summary of FAA considerations in the siting of wind power projects draws on numerous resources and technical reports, available below:

Airspace Obstruction and Electromagnetic Interference Considerations for Wind Power Projects, prepared by Aviation Systems, Inc. for MTC, January 2007.

Filing with the FAA

- FAA Obstruction Evaluation / Airport Airspace Analysis web site.
- Notice of Propose Construction (form 7460-1). This form must be submitted for any structure that exceeds 200 feet above ground level, no matter where it is located.
- Advisory Circular – Proposed Construction or Alteration of Objects that May Affect the Navigable Airspace
- Part 77 Airspace Obstruction Analysis – This webpage provides contact information, contains links to form 7460-1 and provides a concise description of how the FAA application & notification process works.
- All determined and proposed air obstruction cases filled with the FAA can be found here. You can also file your 7460-1 form electronically from this webpage. However, you do need to register as a new user.

Table 1 – Summary of Wind Projects in Massachusetts and FAA Determinations

Project/Location	Proposed Structure Height (feet)[1]	Distance from Airport Center (Nautical Miles)	Status
Eastern Massachusetts			
Boston (IBEW)	150	4.2 Logan	DNH
Boston (Long Island[2])	394	3.47 Logan	Determination of Hazard (DOH)
Boston (MWRA[3] Deer Island)	1st Filing – 394 2nd Filing - 190	2.19 Logan	1st - DPH 2nd - Pending
Cape Cod Community College	1st Filing – 397 2nd Filing – 253	2.75 3.1 Barnstable	1st - DOH 2nd - Pending
Falmouth	394	3.8 Otis	DNH
Gloucester (Varian)	480	12.0 Beverly	DNH

Project/Location	Proposed Structure Height (feet)[1]	Distance from Airport Center (Nautical Miles)	Status
Hull - 1	241	5.5	DNH not available
Hull - 2	340	9.05 Logan	Determination of No Hazard (DNH)
Lynn	1st Filing - 397 2nd Filing - 254	5.7 Logan	1st – Determination of Presumed Hazard (DPH) 2nd - DNH
Orleans	340	4.9 Chatham	DNH
Central Massachusetts			
Paxton	397	2.24 Worcester	DPH
Western Massachusetts			
Florida and Monroe (Hoosac Wind Project)	340	6.3 Harriman (North Adams)	DNH
Hancock (Berkshire Wind Project)	338	8.6 Harriman (North Adams)	DNH
Hancock (Jiminy Peak)	394	7.0 Pittsfield	DNH

1 – This includes the height of the turbine only (blade tip at highest point) and not the elevation of the site which FAA analysts include in their study.
2 – The City of Boston considered 4 different locations, all of which received a DOH.
3 – MWRA considered 5 locations at the wastewater treatment plant on Deer Island, all of which received a DPH.

X:\Green Power Program\Community Wind\Airspace - Logan\Web language - Debra Simes\MTC FAA website text v4.doc

APPENDIX 8

PORT OF BOSTON ANALYSIS

An analysis was conducted to assess the magnitude of cost and logistical inefficiencies associated with utilizing the Port of Boston as a location for a support facility for offshore renewable energy. The basis for preparing this analysis were determinations made by the developers of the two closest proposed offshore renewable energy developers. However, beyond the opinion of the developers, there are elements which can be used to quantifiably disqualify a port for use as a staging facility. These are: Cost and Logistics, Increased Carbon Dioxide Emissions, Speed Restrictions, Potential Right Whale Ship Strikes, and Risks to Personnel and Material. These considerations are outlined in more detail below.

WIND ENERGY DEVELOPER'S DETERMINATIONS

The most important consideration for determining the Port of Boston's viability is the opinion of the developers who intend to undertake the development of offshore renewable energy projects. If the offshore renewable energy developers would not utilize a facility within the Port of Boston, construction of a facility at that location would be infeasible. Each offshore renewable energy project has specific requirements based on the conditions known to exist at the development site. The project proponents spend considerable time formulating plans which rely on carefully prepared schedules to solve complex logistical problems. Often the developers will not divulge all of the reasons that factor into their determination as to why a particular port is not viable for their project

because it reveals information and investments which are considered proprietary, nevertheless a developer's reasoned opinion is the most critical element in determining a ports' viability for use as a land side staging facility. During the assembly of the Tetra Tech report, officers from two of the proposed offshore renewable energy projects nearest to the Port of Boston, were asked about the potential use of the port as a staging area. Cape Wind's Vice President of Development, Craig Olmstead, told the Tetra Tech team that "Boston is too far away" to be used as a staging port (interview conducted by Tetra Tech on Tuedsy July 28, 2009). Subsequent to this interview, Tetra Tech interviewed Deepwater Wind's Chief Operating Officer, Chris Wissemann, who stated that the "major constraint for Boston is proximity."

COST AND LOGISTICS

For the purposes of evaluating the increased costs associated with the logistics of utilizing the Port of Boston, a simplified scenario was evaluated wherein wind turbine parts would be shipped to the Port of Boston for partial assembly prior to sortie to the Horseshoe Shoal site within Nantucket Sound (which the proposed location of the Cape Wind project). The Cape Wind project was utilized for this analysis because of the currently proposed off-shore wind development sites in Southeastern Massachusetts, Rhode Island, Connecticut and further South, the Horseshoe Shoal site is the closest project site to the Port of Boston; therefore, if costs and logistical concerns make the Port of Boston infeasible for the Horseshoe Shoal site, the Port of Boston would be infeasible for the other above-mentioned sites as well. For the purposes of this assessment, costs were compared with comparable costs from an alternate location (in this case a facility

located within New Bedford, Massachusetts). Certain assumptions were made in the preparation of this scenario including that each jack up barge would transport enough material to complete the installation of an entire Wind Turbine. Overtime rates for the barge crew and prevailing wage differences for the two ports were not considered or included in the evaluation. The cost of transport from the Port of Boston is contrasted with the costs associated with delivery and partial assembly into New Bedford in the table below:

Travel Logistics and Costs	
Distance and Fuel	• Distance between NBH and Horseshoe Shoals – 45 nautical miles • Distance between Boston and Horseshoe Shoals – 130 nautical miles • Average push speed for a tug is 10 knots/11.5 mph • Average Fuel consumption for a EMD 12-567C 1,200 HP (average barge pushing tug) is 68 Gallons/Hour • Price today for fuel at Sea Fuels in NBH is $2.83/gallon
New Bedford Harbor to Horseshoe	• Trip from NBH to Horseshoe Shoals – One way at an average of 10 knots • Trip would take approximately 4.5 hours, • One way trip would use 306 gallons of fuel costing $865.98 • A crew of 4 members would cost approximately $773.40 at prevailing wage. • Total for fuel and crew one way from NBH to Horseshoe Shoals

Shoals	= $1,639.38 • Round trip = $3,279.00 • Equipment cost for 10-hour trip = estimated to be $20,000. • Total Fuel and Transport Estimate (each Barge) = $23,279
Port of Boston to Horseshoe Shoals	• Trip from Boston to Horseshoe Shoals – One way at an average of 10 knots • Trip would take approximately 13 hours • One way trip would use 884 gallons of fuel costing $2,502.00 • A crew of 4 members would cost approximately $2011.00 at prevailing wage. • Total for fuel and crew one way from NBH to Boston = $4513.00 • Round trip = $9,026.00 • Equipment cost for 26-hour trip = estimated to be $52,000. • Total Fuel and Transport Estimate (each Barge) = $60,026

Based on the travel and logistical considerations noted, the round trip additional expense for each barge of material for transportation alone is approximately:

- $36,747 for the round trip to Horseshoe Shoal from Boston.

The additional transport costs associated with partial assembly in the Port of Boston would amount to $4,777,110 over the course of the 130 barge trips required to construct the proposed Cape Wind energy project evaluated in this scenario. In order to maintain the same shipping schedule as could be attained by locating the shore facility in New

Bedford, the project would need to add at least 2 additional tugs and jack-up barges. This would triple equipment costs during the project resulting in a total project cost increase of $18,297,110, without considering the additional personnel costs.

INCREASED CO_2 EMISSIONS

The same set of assumptions in the above table can also be used to estimate the potential increase in carbon dioxide emissions generated from locating the shore side staging facility further from the installation area. Using the fuel consumption figures calculated above, the transport of the wind turbine sections from Boston to Horseshoe Shoal, would require 496.4 gallons more fuel than the trip from New Bedford, resulting in the production of 11,020 pounds of carbon dioxide, per one way trip (U.S. Environmental Protection Agency, Office of Transportation and Air Quality. (2005) "Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel". EPA420-F-05-001). Over the course of the project this would add up to 2,865,220 pounds of additional carbon dioxide emitted to the atmosphere.

SPEED RESTRICTIONS

In addition to the additional distance and time associated with transporting the partially assembled windmills from Boston to the assembly site, the international delivery vessel will travel through a NOAA Mandatory Speed Restriction Area on its way past Cape Cod to Boston Harbor. This will require the delivery vessel to reduce its velocity to 10 knots or less, during specific dates, through a portion of the shipping channel.

Great South Channel Precautionary Area to Port of Boston	• Trip from Great South Channel Precautionary Area to the Port of Boston = 166 nautical miles • Average international vessel speed = 19 knots • Anticipated 22 vessel trips to complete project • Portion of year when NOAA 10 knot Mandatory Speed Restriction is in effect along the route of the Great South Channel = 41.6% and approximately half of the distance is subject to speed restrictions. • Trip would take 8.75 hours 58.3% of the time. • Trip would take 12.7 hours 41.6% of the time. • Total Project time = (22 vessel trips x 58.3% x 8.75 hours) + (22 vessel trips x 41.6% x 12.7 hours) = 238.7 hours
Great South Channel Precautionary Area to New Bedford	• Trip from Great South Channel Precautionary Area to the Port of New Bedford = 155 nautical miles • Average international vessel speed = 19 knots • Anticipated 22 vessel trips to complete project • Trip would take approximately 8.16 hours • Total Project Time = (22 vessel trips x 8.16 hours) = 179.5 hours

Based on the travel details noted in the table above, travel though the Mandatory Speed Restriction Area (MSRA) for the offloading of wind turbine equipment in the Port of Boston will add an additional 59 hours of international vessel travel time during the project. A survey of off-shore wind developers suggests that operating costs for the

international delivery vessels are approximately $40,000 per day, assuming that the only delay along this congested route is the speed restriction area, the MSRA' scan be expected to add $98,333 to the cost of the project. The actual cost of this change is difficult to quantify especially when compared with the potential for additional traffic delays within the Port of Boston caused by the 3,500 vessels which are already serviced by the Port and its shipping lanes (NOAA Press Release, "Changes in Vessel Operations May Reduce Risk of Endangered Whale Shipstrikes", May 26, 2009). These delays could also be compounded by the uncertain delays resulting from Liquified Natural Gas tanker arrivals (for which all traffic within the Port of Boston is stopped).

POTENTIAL RIGHT WHALE SHIP STRIKES

The Mandatory Speed Restriction Areas (and the associated Area To Be Avoided) established by NOAA were put in place in order to reduce the frequency of ship strikes to the endangered North Atlantic Right Whale. Although the speed restrictions and the Area to be Avoided do reduce the chances of a ship strike, they do not eliminate the chances of such an event. According to information published by NOAA reducing vessel speeds from 19 knots to 10 knots reduces the mortality rate of ship strikes of whales from 90 to 50 percent. Certainly from the perspective of protecting the endangered Right Whale reducing the volume of traffic which passes through its seasonal feeding grounds along the Great South Channel would provide greater benefit than reducing the speed of those vessels. Use of the Port of New Bedford for the receipt and partial assembly of wind turbines, will reduce the chances of a fatal ship strike within this critical habitat by both reducing the volume of traffic passing through this critical habitat, and also by

reducing the time and distance that vessels will be operating in waters which are outside of the habitat.

RISKS TO PERSONNEL AND MATERIAL

The time that each delivery vessel spends transporting the Wind Turbines to the construction site exposes the personnel, vessel and equipment to potential inclement weather. The use of jack-up barges allows the contractor to mitigate some of the risk of damage or loss during loading and unloading, however the loaded barges are not designed for long open ocean crossings. While transiting from the harbor to the construction site, the barge and tugboat are more vulnerable to dangerous sea conditions than when the barge is in port or jacked above the level of the water during installation of the turbine. The less time the barge spends in transport, the less risk of encountering dangerous weather conditions.

Placing hard dollar costs on the value of proximity for mitigating potential loss due to weather or rough seas is difficult because the variable nature of weather, and because the value of an unassembled turbine varies by manufacturer, size and project. In order to partially quantify the economic benefit of locating the shore side facility near to the installation site, a scenario in which a turbine is lost during transport to the installation point after partial assembly at the shore facility. Although each developer negotiates their own purchase price for a wind turbine from a selected manufacturer published costs for an installed on-shore 1.8 mega-watt turbine are approximately $3 million (T.Brenner, “Four more wind turbines planned off Nantasket”, Patriot Ledger, Jan 15, 2008), and estimates for a 2.3 mega-watt turbine are in the range of $5.5 million,

published costs for off-shore turbines were unavailable. Since the unit is partially assembled when it is placed on the jack-up barge for transport to the construction site, a portion of the installation cost has already been expended, and so the loss at this stage would include the manufacture and transportation costs, and a portion of the installation cost. If an assumption that three quarters of the installation cost have been expended and that the negotiated installed cost equals $5.5 million, then the loss of a turbine at the partially assembled transport stage would amount to $4.13 million. The value does not include any damage to the transport vessels, which may also result during such an event.

The risk of loss or interruption due to sea conditions is dependent on the time of transport and the expected sea conditions along the transport route. Although there is no data available on the frequency of losses or interruptions in the installation of off-shore wind turbines caused by sea or weather conditions, there is reliable historic sea condition data available from NOAA buoys in the area of the Great South Channel and between Buzzards Bay and Horseshoe Shoals. The use of the historic buoy data allows relative comparisons of conditions between the shipping routes from Boston and New Bedford to Horseshoe Shoals. Data available from Buoy 44018 which is located 30 miles East of Nantucket, showed that average wave heights were 50% higher on average than heights recorded between Buzzards Bay and Vineyard Sound (1.5 meters compared to 1.0 meters respectively) (NOAA, National Buoy Data Center, Stations BUZM3 and 44018.13 July, 2010). Additionally the Maximum Significant Wave height was 36% higher East of Nantucket and Cape Cod than those recorded between Buzzards Bay and Vineyard Sound (8.6 meters compared to 6.3 meters respectively)(ibid). In order for a developer to ensure the safety of the crew and cargo, transportation of wind turbines will have to be

scheduled during calm weather windows, and the longer the route the longer the opening in this weather window will have to be. With sea conditions 36% to 50% more severe East of Nantucket and Cape Cod, and the transportation route more than twice the distance, it is more likely that sea or weather conditions will cause delays or losses if partially assembled turbines are transported from Boston to Horseshoe Shoals.

CONCLUSION

The 130 mile distance from the Post of Boston to the nearest currently proposed off-shore renewable energy development site, makes its use as a shore side support site infeasible. The critical reason for this is a determination by both of the initial offshore renewable energy developers that the Port of Boston would present too many transportation inefficiencies to be a practicable alternative due to its proximity to the proposed construction sites; however, the basis for the decisions made by the renewable energy developers has been illustrated within the previous sections. The Port of Boston is revealed as an infeasible location for a support facility and the least desirable location for a off-shore wind energy support terminal due to the proximity criteria.

SUB-COMMITTEE ON SAFETY OF NAVIGATION
54th session
Agenda item 3

NAV 54/3/xx
15 March 2008
Original: ENGLISH

ROUTEING OF SHIPS, SHIP REPORTING, AND RELATED MATTERS

Area to be Avoided "In the Great South Channel"

Submitted by the United States

SUMMARY

***Executive summary*:** This document sets forth a proposal to establish a recommendatory, seasonal area to be avoided "In the Great South Channel" off the east coast of the United States for consideration and approval, and forwarding to the Maritime Safety Committee for adoption. The objective of this proposal is to significantly reduce the likelihood of ship strike deaths and serious injuries to North Atlantic right whales during the time when a large percentage of right whales are in the Great South Channel and are engaged in activities that make them particularly susceptible to ship strikes.

Strategic Direction: 5.2

High-level Action: 5.2.4

Planned Output: 5.2.4.1

Action to be taken: Paragraph 21.

Related documents: General Provisions on Ships' Routeing, Eighth Edition, Regulation 10 of Chapter V of the International Convention on the Safety of Life at Sea, MSC 83/28, MSC 82/24, MSC 76/23, MSC 70(23), MSC 69/Inf. 21, MEPC 56/Inf.10, MEPC 55/22, MEPC 40/Inf. 9, NAV 54/3/xx (Note to IMO Secretariat: TSS proposal), NAV 53/3/13, NAV 52/18, NAV 52/3/3, NAV 48/3/5, NAV 47/Inf. 2, NAV 44/3/1.

Introduction

1 The United States proposes to establish a recommendatory, seasonal area to be avoided (ATBA) "In the Great South Channel" for ships 300 gross tons and above as set forth in annex 1. A chartlet of the area is attached to annex 1[1]. This proposal is related to the U.S. proposal to amend the Boston Traffic Separation Scheme (TSS), NAV 54/3/x, because the western boundary of the ATBA is directly adjacent to the Traffic Separation Scheme.

[1] The charlet and Annexes 2 and 3 include the proposed change to the Boston Traffic Separation Scheme set forth in NAV 54/3/XX.

2 The primary area proposed for the establishment of the ATBA is one of the most important feeding habitats for right whales within the species' range and has thus been designated by the United States as "critical habitat" under domestic law necessary for the survival and recovery of the highly endangered North Atlantic right whale. Extensive data show the need for establishing this ATBA (annex 2). The United States proposes that it have a seasonally limited effective period for four months each year (April 1st – July 31st) when a large percentage of the right whale population is in the area. The configuration and limited seasonal duration will minimize the impact on the shipping industry. Maritime safety considerations have also been taken into account in determining the boundaries of the proposed ATBA.

3 Right whales have long been the subject of international protection. The species is listed internationally as endangered on Annex I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora and in the International Union for the Conservation of Nature's Red Book. Additionally, a group of international scientists, convened by the International Whaling Commission (IWC) to evaluate the global status of all right whale species, has recognized the urgent need for protective measures to prevent the demise of this species in the North Atlantic. Moreover, most recently, the report of the Ship Strikes Working Group of the IWC's Conservation Committee was submitted to the October 2006 meeting of the Marine Environment Protection Committee (MEPC)(MEPC 55/22). The MEPC agreed with the IWC's Working Group that the International Maritime Organization is the competent body to address ship strikes of cetaceans and invited delegations to submit proposals to relevant Committees and Sub-committees for consideration. This proposal is in accordance with that invitation.

Background

4 The North Atlantic right whale is one of the world's most endangered large whale species and is in serious jeopardy of extinction. Ship collisions are the greatest known source of human-induced mortality of this whale; such collisions are a major contributing cause to the decline of the right whale and a significant obstacle to the species' recovery. The right whale population is estimated to consist of less than 350 individuals[2] and has either declined in size or remained static since the 1980s.

5 Right whales are especially vulnerable to ship strikes due to their distribution, behavior, and physical attributes. Right whales have a largely coastal, continental shelf distribution, thereby bringing them into contact with human population centers and major shipping lanes. They are highly buoyant and spend long periods resting at or just below the water's surface. Right whales may occur in surface active groups (*i.e.*, four to twenty individuals engaging in frequent physical contact and courtship behavior), and engage in skim feeding, in which they gather plankton by swimming slowly near the surface with their mouths open. During resting, feeding and surface active situations, whales may be unaware of approaching ships. Mothers nursing calves are frequently observed at the surface, and calves have limited diving capacities so they are the most vulnerable to ship strikes. Right whales are slow-moving, with occasional speeds of up to only five to six knots. They are also difficult for mariners to see, especially in rough seas and at night, due to their low profile and dark coloration. They are black in color, have a broad back, and no dorsal fin.

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[2] Waring GT, Josephson E, Fairfield CP, Maze-Foley K, editors. 2007. See www.nmfs.noaa.gov/pr/pdfs/sars/ao2006_whnr-w.pdf. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments (2006); NOAA Tech Memo NMFS NE 201, 378 See www.nmfs.noaa.gov/pr/sars/species.htm.

6 The Great South Channel off the U.S. east coast is one of the most important habitats for right whales within the species' range, including mothers and nursing calves. More than a third of the world's population of these whales aggregate there from April through July each year to feed on dense patches of their preferred prey, copepods, which are concentrated in this area because of sea floor bathymetry, water convergences driven by coastal and tidal currents, and other oceanographic features. Some individually identified right whales observed in the Great South Channel are seen rarely or not at all in other areas such as the Bay of Fundy, emphasizing the importance of the Great South Channel to the population. Annex 2 provides a map of right whale sighting densities from 1999-2005. In the Great South Channel, the distribution and movements of the whales coincide with substantial commercial ship traffic, leading to a serious risk of collision. This risk is likely exacerbated by right whales engaging in feeding and courtship behavior in this area, because these activities appear to render right whales less aware of sources of impending danger, such as approaching ships. Given the critical importance of this area to right whales and the high percentage of the population that occur there during the four month period from April through July, it is imperative that action be taken to reduce the threat of ship strikes.

7 The risk of ship strikes of right whales has been well demonstrated. Massive wounds (*e.g.*, fractured skulls, severed tails) found on right whale carcasses suggest that collisions with large ships were responsible for the deaths. Two right whales, on average, are known to be killed or seriously injured each year as a result of collisions with ships. During a 15 month period from February 2004 to April 2005, at least four adult females—three of which were carrying near term fetuses—were killed by ship strikes. The loss of these reproductive females is significant, particularly because two of them were at the beginning of their calf-bearing years. Necropsies performed on right whales have shown that over 50% of deaths can be attributed to ship strikes; however, the actual number of deaths from ship strikes may even be higher because many deaths likely go unrecorded as carcasses drift out to sea or the cause of death is undetermined.

8 The proposed ATBA "In the Great South Channel" is an integral part of the United States' approach to reducing the risk of ship strikes. The United States has held a significant number of consultations, public hearings, workshops, and industry and stakeholder meetings on this issue with representatives of the shipping industry, master mariners, harbor pilots, environmental interests, marine mammal researchers, and representatives of national and local governments. These stakeholders' concerns were carefully considered and taken into account in the development of this ATBA proposal, including the impact on industry and the protection of right whales. The United States Coast Guard also conducted a Port Access Route Study in which various options for routing measures were considered as well as the impact on maritime safety of this proposed measure. Additionally, by using information gained from the U.S. Northeast Mandatory Ship Reporting System (MSR),[3] it was possible to take into account the burden on, and practical navigation aspects for, the shipping industry.

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[3] In 1998, the Maritime Safety Committee approved the establishment of two Mandatory Ship Reporting systems off the U.S. east coast, one in the northeast United States (off the coast of Boston and Cape Cod) and one in the southeast United States (off the coasts of Georgia and Florida). Ships of 300 gross tons and above are required to participate in these systems when they cross into the reporting system and report such things as course, speed, entry into system, destination, and route. In response to a ship's report, the shore-based authority sends information to assist mariners navigating through the area, such as the latest known location of the whales and other guidance on ways to avoid a ship strike. GPSR, Part G, I/13-1.

Traffic considerations

9 The Great South Channel is the passage between the easternmost point of the Nantucket Shoals and the westernmost shoals of Georges Bank. The channel is approximately 27 miles wide and has depths of 19 fathoms and greater throughout, with lesser depths along the eastern and western edges. The bottom topography and related features in the area contribute to the presence of the right whales' preferred prey, copepods.

10 Container ships, bulk carriers, passenger ships, cargo ships, and tankers pass in and around the area of the proposed ATBA. Although the exact number of ships that actually transit the area is difficult to determine,[4] extrapolation from the data obtained from the MSR provides an estimate that around 200 vessels of 300 gross tons and above transit through the proposed ATBA each year during the four month period from April 1st - July 31st. Vessels bound for the port of Boston to and from points to the east, follow the Great Circle route to and from Europe and transit just north of Georges Bank to enter the Boston TSS well north of the proposed ATBA. Using data from the MSR for the period of April-July 1999-2005, it is estimated that there were approximately 1,400 voyages that passed through the proposed area during the four month season over this seven year period. The routes that will be affected by the proposed ATBA can be divided into three major categories:

a. Vessels that enter or leave points south of Cape Cod appear to follow the Ambrose-Nantucket TSS and then steer a northeasterly course into or out of the associated precautionary area to Europe. These vessels may transit from the southwest to the northeast, cutting across a small portion of the southeastern portion of the proposed area (526 vessel voyages or, if averaged over the 7 year period of the available data, approximately 75 voyages per season). See Annex 3, the area between points A and B;

b. Vessels coming from Cape Hatteras, Chesapeake Bay, Delaware Bay, or New York usually pass Nantucket Shoals Lighted Whistle Buoy N, and then go though the Great South Channel to Cape Cod or the Gulf of Maine. Some of these vessels transit just east of the Boston TSS (171 vessel voyages or approximately 24 voyages per season) while others use the Boston TSS (335 inbound voyages or approximately 48 inbound voyages per season). These numbers are based on an assumption that only those vessels inbound to Boston from the south through the TSS are reporting and, since the MSR does not require that vessels report in twice, these vessels would not report in on their outbound voyage. Therefore, based on this assumption, the number of actual voyages through the TSS over the seven year period may be double that reported into the MSR or 670 voyages or 96 voyages per season). See Annex 3, the area between points C and D; and

c. Some vessels proceed from east to west or vice versa across the proposed area (21-28 vessel voyages or approximately 3-4 voyages per season). See Annex 3.

[4] These difficulties include that some of the reports from ships are duplicative, some ships are simply in transit while others transit the reporting area both inbound and outbound, and, while compliance is increasing each year, it can be expected that some ships do not comply with the MSR. In developing this proposal, the United States attempted to take into account these difficulties by providing a higher estimate of the number of ships that might be impacted by the proposed ATBA.

11 There are adequate surveys and charts of the area and, with modern navigation equipment, mariners are able to determine their positions in relation to the proposed area to be avoided. There are appropriate aids to navigation in place and there is also complete differential GPS coverage and LORAN-C coverage. With respect to environmental conditions during the time of applicability for the proposed ATBA, the weather is highly variable, fluctuating from fair to cloudy to stormy. During April and May, low-pressure systems pass fairly regularly and produce precipitation on an average of one day in three. Much of the rainfall in June and July comes from showers and thunderstorms. The heaviest gales are usually from the northeast or east. The predominant wind direction is west through northwest. Fog is prevalent throughout the year, particularly so in the months of April through July.

Proposal

12 The United States proposes to establish a recommendatory, seasonal ATBA for ships of 300 gross tons and above for the four month period from April 1st– July 31st to significantly reduce the risk of ship strikes of right whales in the Great South Channel. As noted above, this area is of vital importance to right whales, and the whales engage in behavior in this area that makes them particularly susceptible to ship strikes. Right whales face their highest risk of ship strikes in this area during this four month period because of the significant seasonal whale aggregations that occur and their close proximity to ship traffic. Moreover, it is important to note that there are right whales in this area that are rarely, if ever, seen elsewhere. This was one of the bases for establishing right whale critical habitat in this area under U.S. domestic law.

13 The United States has carefully considered the impact on ship traffic that would result from the proposed ATBA. First, the time that the ATBA would be operational has been constrained to address an industry concern that the measure should be limited to that which is strictly necessary to accomplish the biological objectives of protecting the remaining right whales while minimizing the adverse impact on shipping.

14 Second, the ATBA has been configured to minimize adverse impacts on shipping and to take into account maritime safety considerations. For instance, the eastern boundary of the proposed ATBA aligns with part of the MSR boundary. The United States deviated from the right whale critical habitat boundary in this area to avoid mariner use of dangerous waters of the Cultivator Shoals. Additionally, the southern boundary of the proposed ATBA also deviates from the critical habitat boundary to provide an additional margin of protection to the greatest density of right whales and to safeguard maritime safety by aligning the ATBA boundary so that ships will enter the precautionary area at the seaward terminus of the traffic separation scheme.

15 Third, the ship tracks through the proposed ATBA have been carefully examined. The proposed ATBA affects the three major routes differently:

a. Ships cutting across the proposed area in a southwest to northeasterly direction would have to adjust their bearing to avoid this area for the applicable four month period. The boundary is configured to accommodate ships on this bearing and to reduce the adverse impact on this traffic. The increase in distance is estimated to be approximately 7 nautical miles;

b. For ships navigating to the east of the Boston TSS, they would presumably not join the TSS until approximately a point south of the major turn in the TSS, where they

would then continue their journey north or south. Since there are clear navigational and operational rules applicable for ships operating in the TSS, maritime safety would be safeguarded and possibly improved for these ships. Additionally, it is estimated that only approximately 24 vessels per season would be moved from navigating in the proposed ATBA to navigating in the TSS. It is not expected that this slight increase in the number of ships per year would adversely affect maritime safety. The increase in distance is estimated to be approximately 14 nautical miles; and

c. The relatively small number of ships that travel from east to west or vice versa (e.g., 3-4 voyages per season) would be impacted the most by the proposed ATBA. The increase in distance is estimated to be approximately 55 nautical miles.

16 Maritime safety considerations have been carefully taken into account in the development of this proposal, in particular through a Port Access Route Study conducted by the U.S. Coast Guard which considered various alternatives and scenarios. Maritime safety should be enhanced because of a decrease in the potential for any damage to a ship from hitting these large whales. Also, if there is a decrease in ship encounters with whales, there will be a decreased risk of collisions between a ship taking avoidance action and another vessel.

Additional Actions

17 In recognition of the significance of this area to right whales, the United States has taken several measures under domestic law to protect this endangered species. In 1994, the United States designated the area as "critical habitat" for right whales. Under U.S. law, critical habitat is a geographically defined area that is designated because it has physical and biological features essential to the survival and recovery of threatened or, as in the case of the right whale, endangered species. In designated critical habitat, special management considerations apply and special protections can be adopted. In the Great South Channel Right Whale Critical Habitat, the United States has adopted several restrictions to protect right whales, including measures applicable to U.S. fishermen. Examples include: closing the area to gillnet fishing during the spring to reduce the potential for entanglement in gillnet gear; in other times and places there are required gear modifications such as breakaway buoys, weak vertical lines, or sinking lines designed to allow whales to break through encountered gear or reduce the severity of an entanglement; and periodic workshops are conducted to increase awareness of fishing practices and gear technology that reduce entanglements of right whales.

18 The United States has also taken a number of steps internationally to identify and implement measures to reduce ship strikes of right whales. Importantly, the United States sought—and achieved—approval by this Sub-committee of its proposals to amend the Boston TSS to significantly reduce ship strikes of right and other large whales (COLREG.2/Circ. 58) and to establish two mandatory ship reporting systems which educate mariners about the threat of ship strikes and provide them with the last known location of right whales (GPSR, Part G, I/13-1).

19 Other steps that the United States has taken include the examination and identification of relevant information and management options. These options have formed the basis for the development of the U.S. Right Whale Ship Strike Reduction program, which addresses such issues as research and development of technologies to reduce the risk of ship strikes, a merchant mariner education and outreach program, and targeted operational measures. Guidelines for measures that mariners may take to avoid right whales are now published in various navigational aids such as U.S.

Coast Pilots, Notices to Mariners, Sailing Directions, and Admiralty Publications and broadcast over VHF radio by NOAA weather radio and U.S. Coast Guard facilities. Information brochures, placards, and computer CDs are also being distributed to mariners. Additionally, a combination of aerial and vessel surveys are conducted seasonally to attempt to locate right whales and this information is provided via various telecommunication networks to mariners operating in the vicinity of whales. While these surveys cannot result in a comprehensive picture of whale locations due to whale movement and weather limitations, they are the best means currently available for detecting the location of right whales and thus provide valuable information to mariners.

20 In addition to the actions taken by the United States, Canada—as the other State where the North Atlantic right whale occurs—has taken extensive measures to protect right whales, in particular from ship strikes. It sought—and achieved—approval by this Sub-committee and adoption by the Maritime Safety Committee of its proposal to amend the Bay of Fundy Traffic Separation Scheme (COLREG.2/Circ.52) and the establishment of a recommended, seasonal area to be avoided in Roseway Basin to reduce the risk of ship strikes (SN.1/Circ. 263).

Action requested of the Sub-Committee

21 The Sub-Committee is asked to approve this proposal for the establishment of a recommendatory, seasonal area to be avoided "In the Great South Channel" as set forth in the annex and forward the proposal to the Maritime Safety Committee for adoption. The United States also requests that the effective date of implementation be six months after adoption.

***

ANNEX 1

IN THE GREAT SOUTH CHANNEL

(Reference charts: United States 13009, 2007 edition; 13200, 2007 edition. ***Note***: These charts are based on North American 1983 Datum which is equivalent to WGS 1984 datum.)

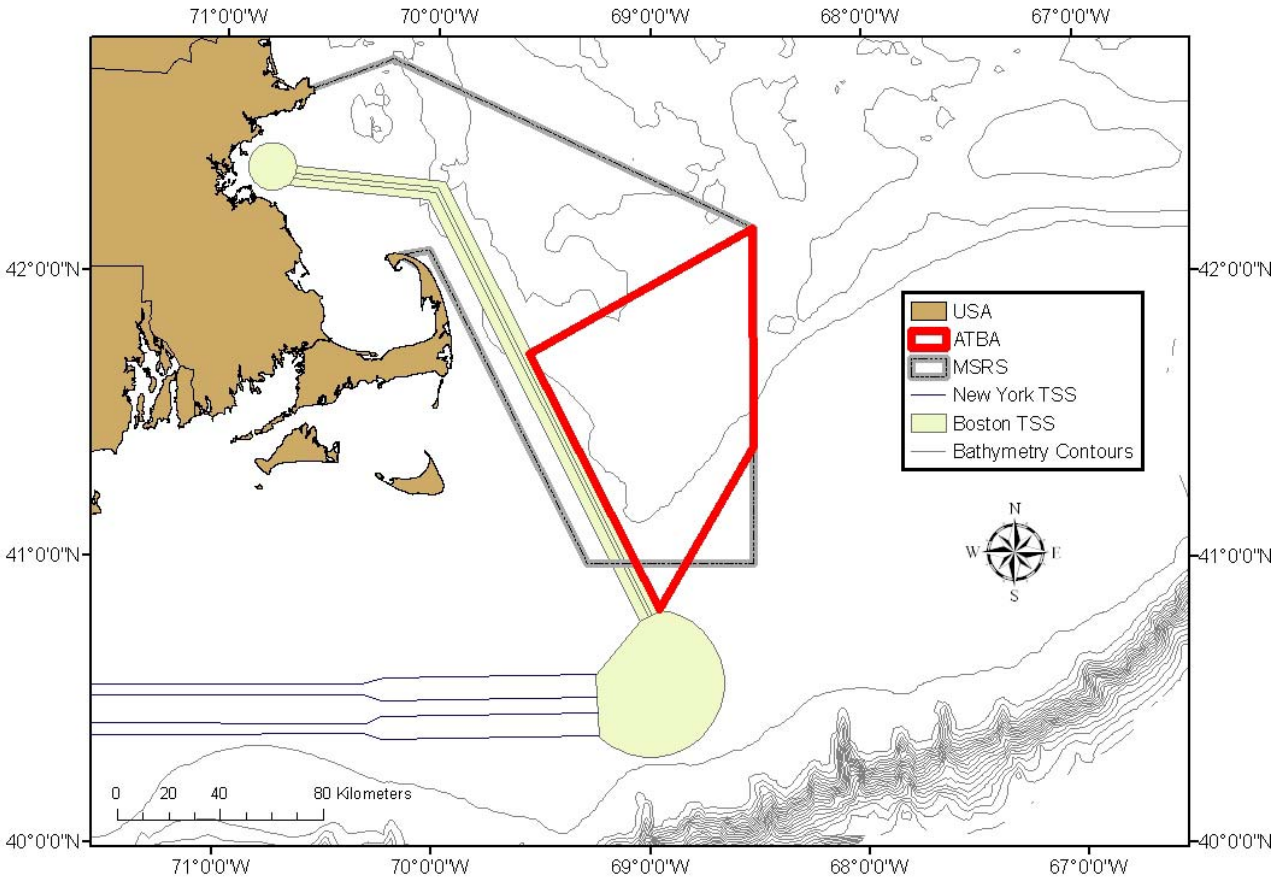
Description of the Area to be Avoided

In order to significantly reduce ship strikes of the highly endangered North Atlantic right whale, ships of 300 gross tons and above—during the period of April 1st through July 31st —should avoid the area bounded by lines connecting the following geographical positions:

(1) 41° 44'.08 N - 069° 34'.97 W
(2) 42° 10'.00 N - 068° 31'.00 W
(3) 41° 24'.89 N - 068° 31'.00 W
(4) 40° 50'.47 N - 068° 58'.67 W

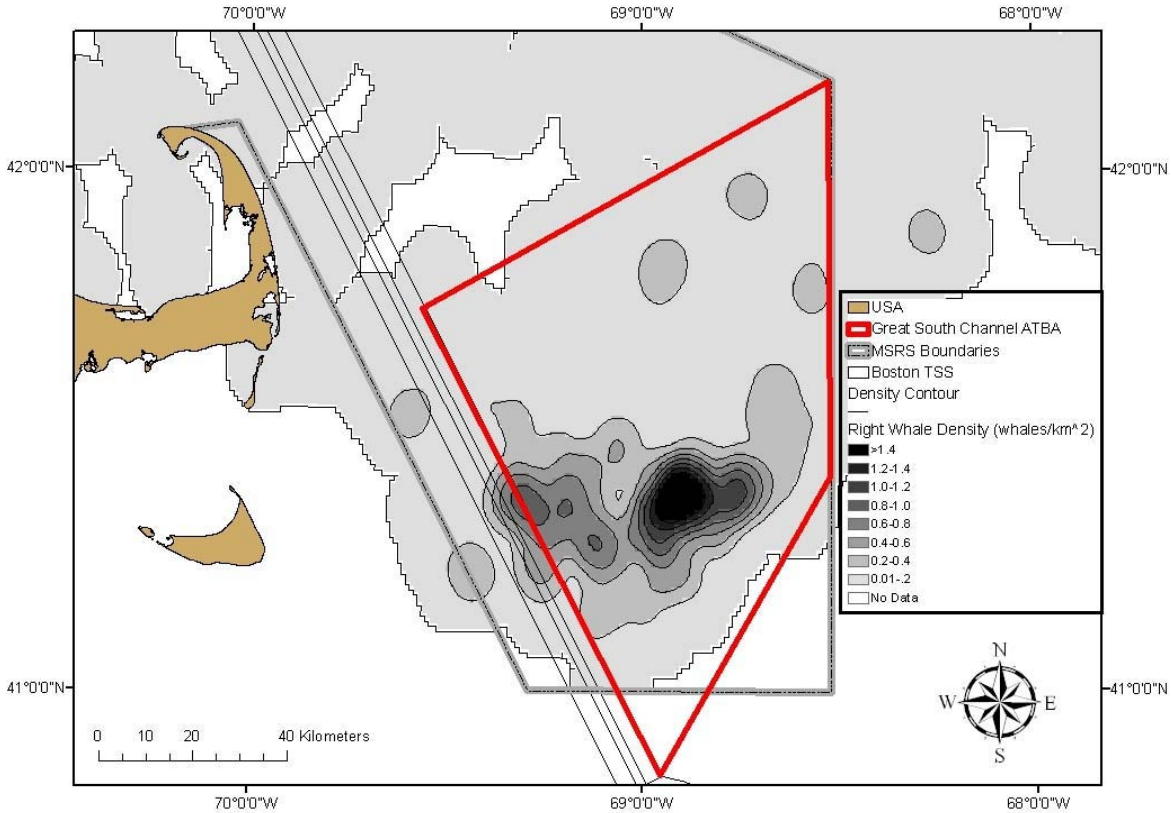
Annex 1

Chartlet



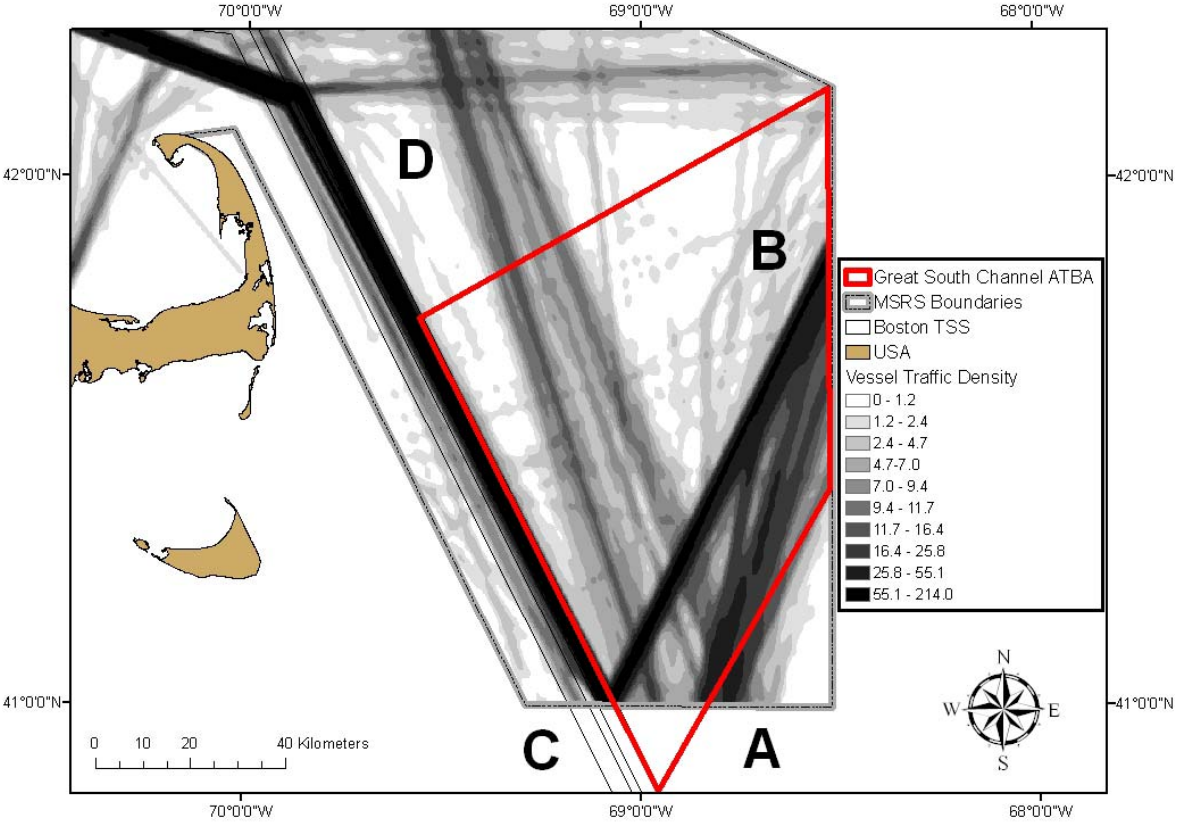
ANNEX 2

Northern right whale sighting densities (whales/km^2) in the Great South Channel during April-July, 1999-2005.



ANNEX 3

Mandatory ship reporting system boundaries and densities of ship track (km of ship track/km^2) through the proposed ATBA and existing TSS for April-July, 1999-2005.



NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

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FOR IMMEDIATE RELEASE
May 26, 2009

Changes in Vessel Operations May Reduce Risk of Endangered Whale Shipstrikes

Years of study and effort by NOAA and the U.S. Coast Guard will pay off this summer when two changes to shipping lanes into Boston are implemented. Both changes significantly reduce the risk of collisions between large ships and whales.

Beginning on June 1**,** ships 300 gross tons and above will be asked to avoid an area in the Great South Channel from April through July, when right whales face the highest chance of being struck by ships. The channel is a feeding area for the endangered North Atlantic Right Whale.

Also, ships transiting primarily from the south and entering Boston Harbor in shipping lanes will travel a slightly different path. The north-south traffic lanes have been modified to reduce the threat of ship collisions with endangered right whales and other whale species.

The width of the north-south portion of the lanes will narrow from a total of four miles to three miles. The width of the east-west portion of the lanes was narrowed and modified in 2007.

Implementing the “Area To Be Avoided” and narrowing the “Traffic Separation Scheme” by one nautical mile will reduce the relative risk of right whale ship strikes by an estimated 74 percent during April-July (63 percent from the area to be avoided and 11 percent from the narrowing of the Traffic Separation Scheme).

Slow moving North Atlantic right whales--among the most endangered whales in the world--are highly vulnerable to ship collisions, since their primary feeding and migration areas overlap with major East Coast shipping lanes. Along with existing measures to prevent entanglement of right whales in fishing gear and regulations to reduce ship strikes by slowing ships, these changes in vessel operations are a part of the comprehensive approach that NOAA has taken in its effort to help right whales recover.

“Through years of study we have determined that these changes will likely provide a safer environment for whales and mariners, and at the same time, provide the least amount of disruption and impact to the economy,” said Jim Balsiger, NOAA’s acting assistant administrator for NOAA’s Fisheries Service. “NOAA and our partners are working extremely hard to do all we can to help save this critically endangered species, while helping mariners stay safe and productive.”

Approximately 3,500 ships move through the entire Boston shipping lanes area every year, and more than half of the world’s North Atlantic right whales are known to be in this area during the spring. NOAA researchers used more than 20 years of sighting data to determine the risk of whales being struck by ships in and around the Boston shipping lanes to help develop these changes. Working with the Coast Guard, which assessed safety and navigational effects of ship lane modification to the shipping industry, NOAA proposed the changes to the International Maritime Organization in March 2008.

The International Maritime Organization adopted both of these changes, so they will be reflected on all charts globally and used by the international shipping industry. NOAA’s Fisheries Service is working with NOAA’s Ocean Service and the U.S. Coast Guard to have these changes added to nautical charts and to the U.S. Coast Pilot as well.

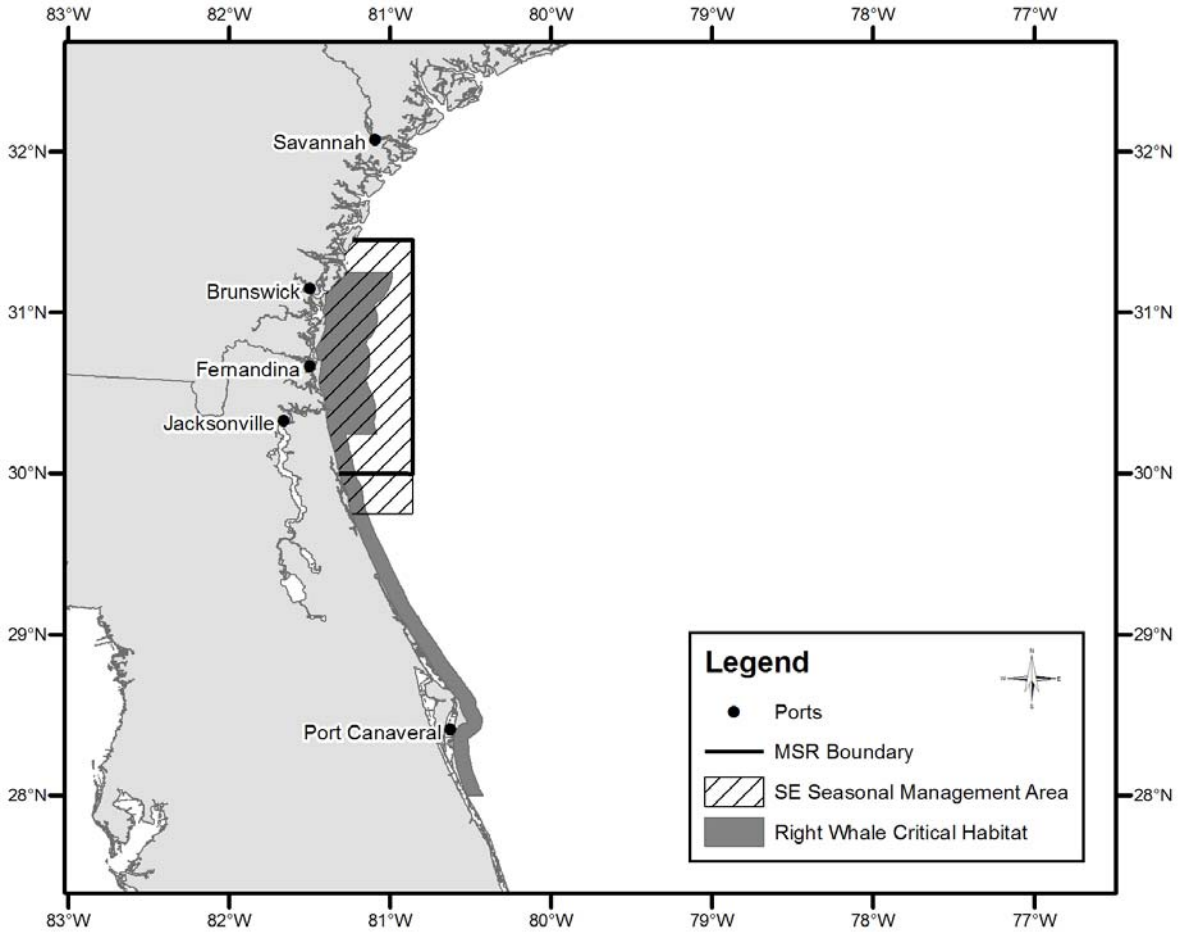
“NOAA's scientific expertise and their investment in research into the seasonal distribution of right whales provided the Coast Guard with valuable data and information and helped identify shipping lanes that reduce the likelihood of vessel interactions with this protected species. Fewer collisions involving commercial shipping vessels and right whales will be a great outcome for the agencies, for mariners and coastal commerce and for the public," said Steven Tucker, deputy chief for marine protected species, U.S. Coast Guard Law Enforcement Office.

Existing protective actions also include seasonal and dynamic vessel speed restrictions in selected areas, mandatory lanes into certain ports, surveying whale migration routes by aircraft and mandatory ship reporting systems that provide advisories and information on right whale locations to mariners.

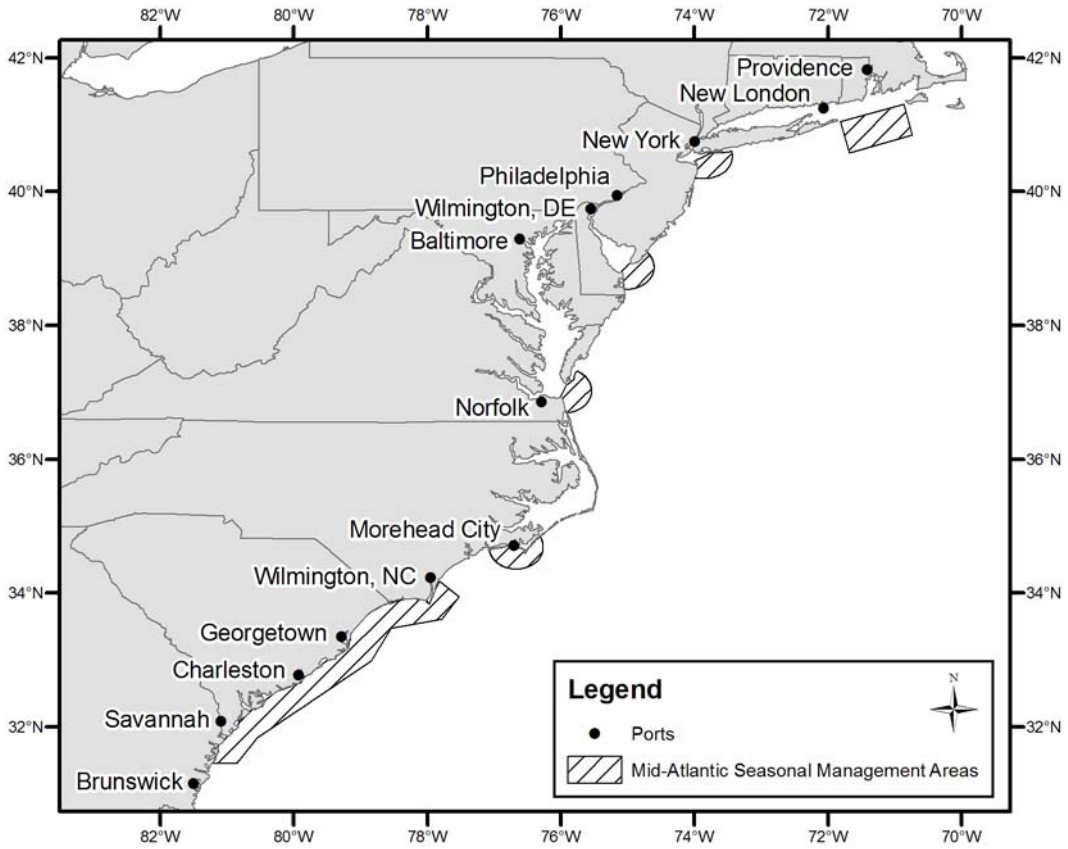
NOAA understands and predicts changes in the Earth's environment, from the depths of the ocean to the surface of the sun, and conserves and manages our coastal and marine resources. Visit http://www.noaa.gov.

- 30 -

Southeastern U.S. Area
Mandatory Speed Restriction **November 15th through April 15th**
Calving and Nursery Grounds

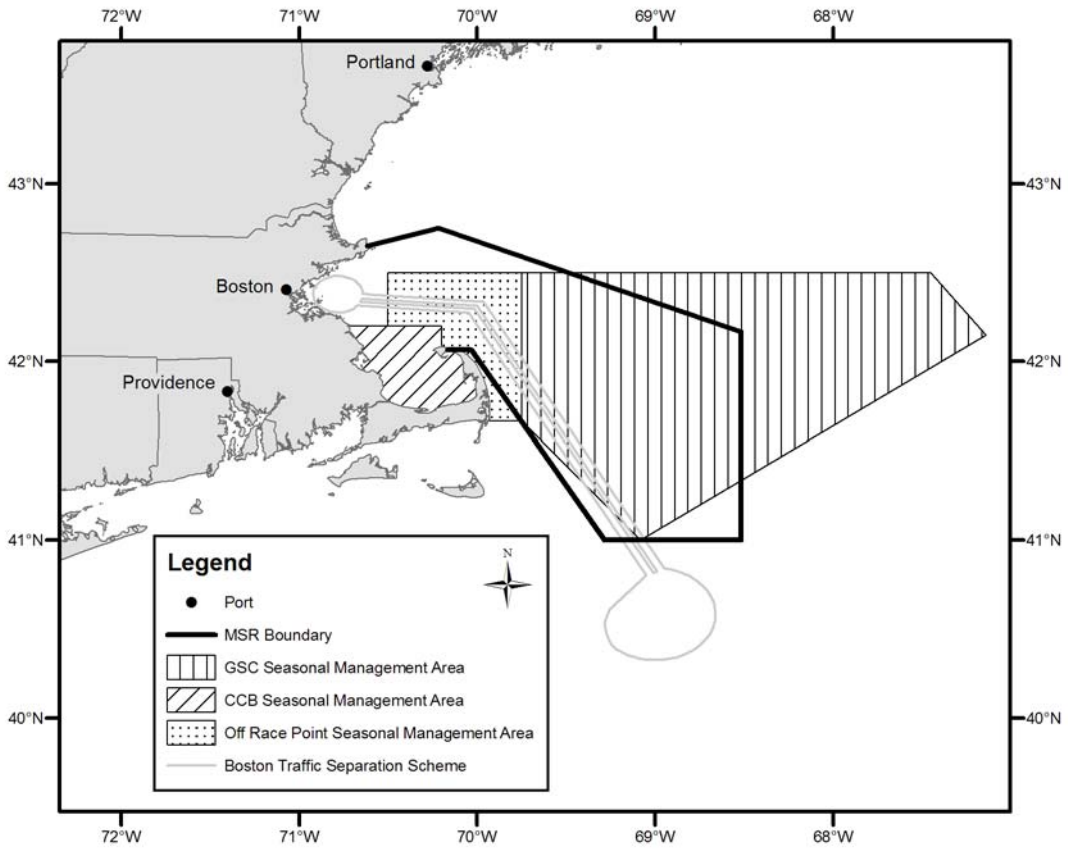


Mid-Atlantic U.S. Area
Mandatory Speed Restriction **November 1 through April 30**
Migratory Route



Vessel speed is restricted around each of the port or bay entrances identified and the designated area around Block Island Sound (a box with a 30 nm width extending south and east of the mouth of the Sound--reference points: Montauk Point and the western end of Martha's Vineyard). The areas are defined as the waters within a 20-nm area with an epicenter located at the midpoint of the COLREG demarcation line crossing the entry into the designated ports or bays.

Final Northeastern U.S Area
Mandatory Speed Restriction Times Vary
Feeding Areas



Right whales occupy and forage in four distinct areas in the NEUS from January through July: Cape Cod Bay; the area off Race Point at the northern end of Cape Cod; the Great South Channel; and the northern Gulf of Maine. Little is known about recurring whale presence or density, and vessel traffic patterns (besides Portland transits) are not consistent or predictable, in the northern Gulf of Maine. No seasonal speed restrictions are imposed in the northern Gulf of Maine. For the other three areas:

Cape Cod Bay	**Off Race Point**	**Great South Channel**
January 1st through May 15th	**March 1 through April 30**	**April 1st through July 31st**

	556	-	-	555	714	711	741	733	711	712	687	697	6817
2006 MEAN	21.8	23.0	18.6	17.3	15.4	14.2	12.0	12.5	14.0	19.1	15.8	21.2	17.0
# OBS	48.2	50.5	43.2	37.1	40.6	41.8	43.2	27.0	32.1	50.2	37.9	38.5	50.5
	18-20	13-00	01-03	24-05	14-08	07-14	21-09	07-12	11-14	29-14	23-19	08-22	FEB
	4.5	1.9	0.6	2.3	2.3	4.1	0.2	2.5	1.9	3.7	2.3	3.3	0.2
MAXIMUM	03-00	21-11	29-10	27-16	28-20	15-00	16-00	18-13	27-10	08-23	07-05	07-22	JUL
DAY-HR	703	623	705	690	716	715	735	732	689	675	642	644	8269
MINIMUM													
2007 MEAN	22.7	25.0	21.5	19.7	12.4	15.0	11.0	11.3	13.6	15.8	19.8	21.8	17.5
# OBS	44.9	51.5	44.7	42.2	18.1	33.0	29.4	26.8	36.4	33.0	62.2	50.2	62.2
	21-02	14-20	06-22	16-04	31-07	13-20	05-14	08-19	15-12	20-06	03-23	04-08	NOV
	4.1	3.1	4.7	0.2	6.8	1.9	1.9	2.1	1.7	3.3	3.9	1.4	0.2
MAXIMUM	07-22	28-13	26-02	12-00	31-12	01-03	17-09	30-07	21-08	30-23	20-20	26-17	APR
DAY-HR	604	590	617	325	24	707	734	725	708	719	687	703	7143
MINIMUM													
2008 MEAN	21.8	20.3	20.5	14.9	16.4	11.9	10.9	11.5	15.1	18.4	17.9	22.7	16.8
# OBS	53.5	46.3	46.7	34.0	36.9	27.8	27.0	23.7	36.9	46.3	39.7	51.1	53.5
	28-00	14-01	09-09	02-05	12-20	01-00	28-02	12-02	07-05	29-02	16-07	22-04	JAN
	2.7	1.9	1.7	1.7	1.2	2.1	1.2	2.3	1.9	2.3	2.3	3.3	1.2
MAXIMUM	24-15	04-18	24-20	25-22	06-14	14-18	11-21	01-20	18-04	05-12	04-11	06-14	JUL
DAY-HR	707	662	724	704	739	712	739	736	711	737	690	699	8560
MINIMUM													
POR MEAN	22.7	23.4	19.9	17.2	14.7	13.0	11.5	11.9	13.5	17.9	19.2	22.9	16.9
# OBS	53.5	51.5	46.7	51.7	42.6	42.4	43.2	49.0	44.9	53.3	63.4	60.5	63.4
	2008	2007	2008	2003	2005	2003	2006	2003	2004	2005	2005	2004	NOV/2005
	1.2	1.9	0.6	0.2	1.2	0.8	0.2	1.2	1.6	1.2	2.1	1.4	0.2
MAXIMUM	2005	2008	2006	2007	2008	2003	2006	2003	2005	2004	2004	2007	APR/2007
YEAR	3315	2542	2780	2988	3216	4283	4453	5151	4967	5059	4854	4953	48561
MINIMUM													
YEAR													
# OBS													

STATION: 44018 -- POR (7/2002 - 12/2008)

2 - MEANS & EXTREMES BASED ON HOURLY (GMT) OBSERVATIONS -- MONTHLY & ANNUAL BY YEAR

ELEMENT: SIGNIFICANT WAVE HEIGHT (METERS)

YEAR ELEMENT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
2002 MEAN	-	-	-	-	-	-	0.8	0.8	1.2	1.7	2.0	2.3	1.6
	-	-	-	-	-	-	0.9	2.3	5.1	5.4	6.6	8.2	8.2
	-	-	-	-	-	-	31-08	31-20	12-08	16-21	07-05	26-13	DEC
	-	-	-	-	-	-	20	738	717	732	716	732	3655
MAXIMUM		-											
2003 MEAN	2.2	2.2	1.7	2.0	1.3	1.1	1.0	0.9	1.5	1.6	1.8	2.5	1.7
# OBS	6.5	6.6	4.4	4.9	4.2	4.8	2.4	2.2	3.8	4.2	5.7	7.6	7.6
	02-17	18-04	03-17	08-15	03-17	02-02	23-23	06-07	29-01	16-04	29-18	06-21	DEC
	733	665	733	712	708	720	742	743	710	734	715	731	8646
MAXIMUM													
2004 MEAN	1.5	-	-	-	1.0	0.9	1.0	0.9	1.4	2.0	1.8	2.1	1.4
# OBS	2.6	-	-	-	1.6	2.7	2.7	2.7	4.9	5.8	6.0	8.6	8.6
	07-13	-	-	-	29-22	01-22	20-04	31-13	30-00	24-09	14-04	27-08	DEC
	68	-	-	-	309	717	742	742	715	740	709	730	5472
MAXIMUM		-											
2005 MEAN	2.2	2.1	2.0	1.7	1.5	0.9	0.8	0.9	1.3	1.9	1.5	1.9	1.5
# OBS	8.6	4.0	6.0	5.3	5.9	2.2	2.2	2.4	2.8	6.9	6.5	5.3	8.6
	23-19	04-22	09-10	03-20	25-02	15-11	01-21	16-00	27-11	25-15	22-23	09-23	JAN
	719	652	720	675	683	710	731	731	700	672	672	671	8336
MAXIMUM													
2006 MEAN	2.1	2.0	1.6	1.6	1.6	1.2	1.1	0.8	1.4	1.6	1.6	1.6	1.5
# OBS	5.7	6.6	3.8	3.7	4.5	3.2	4.9	2.1	4.1	5.4	5.3	4.4	6.6
	04-03	12-15	26-22	24-09	02-04	07-20	21-09	29-19	12-17	29-05	09-09	02-09	FEB

MAXIMUM
DAY-HR

	669	599	673	678	703	711	729	718	676	647	583	595	7981
2007 MEAN	1.8	2.1	1.9	1.7	0.6	1.1	1.0	1.0	0.9	1.1	1.8	1.9	1.4
# OBS	4.3	6.1	4.8	4.1	0.8	3.5	2.4	2.8	2.2	3.0	8.5	5.7	8.5
MAXIMUM	21-06	14-20	17-03	16-04	31-15	05-03	21-07	18-18	29-02	29-06	04-04	17-06	NOV
DAY-HR	558	544	559	302	24	687	704	705	686	651	602	606	6628
2008 MEAN	2.0	1.9	2.0	1.6	1.5	0.9	1.1	0.9	1.5	1.7	1.8	2.0	1.6
# OBS	8.1	5.9	5.8	3.6	4.9	2.5	2.4	2.0	4.3	5.7	4.8	5.2	8.1
MAXIMUM	28-08	14-06	09-12	07-15	10-19	01-09	22-15	26-11	07-09	29-02	26-10	20-05	JAN
DAY-HR	605	588	632	662	708	701	704	715	687	701	622	622	7947
POR MEAN	2.1	2.1	1.8	1.7	1.4	1.0	1.0	0.9	1.3	1.7	1.8	2.1	1.5
# OBS	8.6	6.6	6.0	5.3	5.9	4.8	4.9	2.8	5.1	6.9	8.5	8.6	8.6
MAXIMUM	2005	2006	2005	2005	2005	2003	2006	2007	2002	2005	2007	2004	JAN/2005
YEAR	3352	3048	3317	3029	3135	4246	4372	5092	4891	4877	4619	4687	48665
# OBS													

STATION: 44018

3 - PERCENT FREQUENCY OF AVERAGE WIND SPEED(KNOTS) VS AVERAGE WIND DIRECTION(TENS OF DEGREES)

Month: JAN

WIND SPEED	CALM	35-01	02-04	05-07	08-10	11-13	14-16	17-19	20-22	23-25	26-28	29-31	32-34	TOT %	TOT N
0 - 3	0.1	0.1		*	-	*	-	0.1	-	0.1		0.1	0.1	0.5	18
4 - 6		0.5		0.4	0.4	0.2	0.2	0.2	0.2	0.3		0.3	0.5	3.7	129
7 - 10		0.5	0.3	0.2	0.5	0.4	0.4	0.2	0.6	0.7	0.3	0.4	0.3	5.5	191
11 - 15		0.8	0.7	0.5	0.6	0.5	0.8	0.7	1.3	1.3	0.6	1.1	1.0	11.1	387
16 - 20		1.7	0.7	0.9	0.7	0.6	0.7	2.0	2.6	2.8	1.8	3.0	2.4	22.2	776
21 - 24		1.5	1.3	1.4	0.7	0.5	0.8	1.5	2.5	3.0	3.4	4.4	2.8	23.9	834
25 - 33		1.4	1.2	0.5	0.7	0.5	0.6	0.6	0.9	0.8	3.6	4.5	4.1	17.9	625
34 - 47		1.8	0.5	0.8	0.9	0.1	0.5	0.3	0.3	0.4	2.6	3.8	3.3	14.5	506
> 48		0.1	0.9	*	-	-	-	-	-	-	1.5	*	-	0.5	18
		-	0.3	-	*	-	-	-	*	-	-	-	0.1	0.1	4
TOTAL %	0.1	8.4	-	4.8	4.6	2.8	3.9	5.5	8.5	9.4	13.9	17.7	14.6	100.0	
TOTAL N	2	293	5.7	169	160	99	137	193	295	328		618	509		3488
(* < 0.05%)			200								485				

WIND DIRECTION

STATION: 44018

3 - PERCENT FREQUENCY OF AVERAGE WIND SPEED(KNOTS) VS AVERAGE WIND DIRECTION(TENS OF DEGREES)

Month: FEB

WIND SPEED	CALM	35-01	02-04	05-07	08-10	11-13	14-16	17-19	20-22	23-25	26-28	29-31	32-34	TOT %	TOT N
0 - 3	0.0	-		-	-	*	*	0.1	-	-		-	-	0.2	5
4 - 6		0.1		0.3	0.2	0.3	0.2	0.2	0.2	0.3		0.2	0.3	2.6	69
7 - 10		0.6	0.2	0.4	0.2	0.3	0.3	0.5	0.8	0.6	0.2	0.5	0.6	6.4	171
11 - 15		0.9	0.3	0.6	0.7	0.6	0.5	0.9	1.1	1.0	1.4	2.1	1.4	12.2	325
16 - 20		0.5	0.6	1.4	1.2	1.1	0.5	1.1	1.0	3.7	1.8	3.6	2.6	21.3	567
21 - 24		1.1	0.9	0.7	0.8	1.1	0.9	0.7	1.1	3.0	3.8	4.3	3.1	22.4	596
25 - 33		0.8	0.8	0.9	0.4	0.3	0.6	0.8	0.4	1.0	4.9	5.7	2.2	16.9	451
34 - 47		0.7	0.6	0.9	0.4	0.2	0.1	0.5	0.5	1.3	3.3	6.3	1.8	17.0	452
> 48		0.1	0.2	0.1	0.1	0.1	-	-	*	*	4.0	0.2	0.1	0.9	25
		-		*	-	-	-	-	-	-	0.2	-	-	0.0	1
TOTAL %	0.0	4.6	-	5.4	3.9	3.9	3.2	4.7	5.2	10.9	19.5	23.0	12.1	100.0	
TOTAL N	1	123	3.5	143	104	105	86	126	138	290		612	321		2662
(* < 0.05%)			93								520				

WIND DIRECTION

	53.5	49.4	47.2	51.7	47.8	43.4	35.4	30.3	50.3	47.0	52.9	51.9	53.5
	13-19	11-07	10-11	26-03	02-16	17-01	24-09	23-19	11-23	26-16	18-23	26-03	JAN
	4.5	3.1	3.1	3.9	1.9	2.5	1.7	3.1	3.7	5.6	2.7	1.4	1.4
MAXIMUM	06-20	17-09	13-05	28-07	27-05	21-05	21-13	27-14	29-19	25-05	03-23	13-17	DEC
DAY-HR	740	670	742	711	736	717	732	677	720	736	720	740	8641
MINIMUM													
2003 MEAN	24.2	22.3	18.2	20.1	16.2	14.3	14.8	15.0	15.4	20.9	21.4	25.8	19.0
DAY-HR	52.9	45.1	39.3	48.2	36.2	33.6	34.2	28.2	41.8	50.3	56.6	50.0	56.6
# OBS	02-08	12-16	03-10	26-20	26-22	22-19	27-19	17-20	23-21	15-17	14-05	07-01	NOV
	1.4	2.5	1.6	2.7	1.7	1.2	1.2	2.3	1.0	2.9	1.7	1.9	1.0
MAXIMUM	06-01	26-20	28-17	25-11	07-05	26-16	20-12	12-15	22-06	09-18	27-19	20-00	SEP
DAY-HR	744	672	744	716	743	719	743	743	709	742	720	739	8734
MINIMUM													
2004 MEAN	25.8	19.5	20.9	19.2	15.4	15.5	14.2	15.0	16.0	19.4	21.1	22.9	18.7
DAY-HR	57.5	49.4	48.2	41.0	34.2	32.1	34.2	41.4	52.1	42.2	51.3	59.5	59.5
# OBS	14-00	06-22	12-18	14-02	08-05	06-14	13-18	15-12	29-12	17-01	05-05	01-19	DEC
	4.5	1.6	3.9	2.9	1.2	2.1	2.5	1.4	1.7	1.6	2.3	2.7	1.2
MAXIMUM	02-10	02-18	09-15	21-08	20-04	16-16	03-15	25-08	24-08	07-15	18-06	03-08	MAY
DAY-HR	744	689	742	719	738	718	742	740	720	743	717	741	8753
MINIMUM													
2005 MEAN	22.1	18.9	19.6	18.4	18.3	15.5	14.3	13.4	15.1	22.1	22.5	23.0	18.6
DAY-HR	68.0	43.0	57.0	50.9	54.2	30.7	29.9	36.5	38.9	57.9	50.2	69.4	69.4
# OBS	23-13	15-10	09-03	03-07	07-17	30-15	25-17	31-22	29-21	25-15	03-20	09-20	DEC
	2.5	2.5	2.1	2.1	1.7	3.9	2.7	3.1	0.8	2.5	3.7	1.9	0.8
MAXIMUM	08-08	02-00	21-15	01-06	04-14	04-17	05-04	25-02	07-08	01-04	19-16	25-06	SEP
DAY-HR	744	670	741	720	731	720	735	742	718	742	718	743	8724
MINIMUM													
2006 MEAN	22.4	24.5	19.9	18.7	18.8	17.5	16.4	13.9	16.2	22.6	18.3	21.8	19.7
DAY-HR	53.5	56.4	45.7	40.4	42.2	46.3	35.4	33.2	38.1	57.2	48.4	53.8	57.2
# OBS	19-01	12-15	16-03	04-23	02-04	07-18	03-03	20-13	02-22	28-18	23-23	02-00	OCT
	2.1	1.7	1.7	3.7	3.3	3.1	4.1	2.9	2.7	3.1	3.5	0.0	0.0
MAXIMUM	02-17	23-08	29-09	15-05	28-04	02-22	07-16	18-14	13-05	14-13	30-00	31-23	DEC
DAY-HR	740	668	743	717	732	706	276	300	640	657	712	735	7626
MINIMUM													
2007 MEAN	18.0		17.8	19.9	16.4	17.5	14.1	13.9	16.0	18.6	22.7	22.3	17.9
DAY-HR	43.9		35.2	62.6	39.9	44.7	36.5	46.9	39.7	42.4	58.5	53.3	62.6
# OBS	08-11	-	28-23	12-20	19-01	02-00	05-12	08-15	15-18	20-04	03-21	17-05	APR
	0.0	-	3.7	1.7	1.7	1.9	2.1	0.8	2.9	1.9	3.5	3.3	0.0
MAXIMUM	16-07	-	28-02	11-14	13-12	03-15	17-15	19-15	02-04	03-03	14-07	19-16	JAN
DAY-HR	320	-	168	701	735	712	736	736	709	741	717	669	6944
MINIMUM		-											
2008 MEAN	21.9	21.3	21.5	16.5	18.9	14.5	14.0	12.6	16.0	19.9	20.8	25.0	18.6
DAY-HR	50.7	56.4	56.2	43.2	42.2	35.6	50.9	39.9	45.3	51.9	42.0	55.6	56.4
# OBS	30-20	11-05	09-07	02-01	13-15	24-20	27-20	11-15	07-09	29-04	16-14	22-05	FEB
	3.9	2.1	2.5	2.9	3.1	1.9	2.3	1.9	1.6	2.9	2.7	4.5	1.6
MAXIMUM	26-18	26-11	27-13	17-04	05-14	19-15	06-08	21-16	13-17	16-02	08-07	26-20	SEP
DAY-HR	737	688	735	708	738	719	739	740	714	734	701	727	8680
MINIMUM													
POR MEAN	22.8	21.3	20.9	18.8	17.4	15.9	14.9	14.2	16.2	20.3	21.8	23.1	18.9
DAY-HR	75.4	56.4	58.1	62.6	54.2	48.0	52.9	52.9	57.2	57.9	66.3	69.4	75.4
# OBS	1999	2008	1999	2007	2005	2000	2001	1998	1999	2005	1997	2005	JAN/1999
	0.0	1.6	1.6	1.7	1.2	1.2	1.2	0.8	0.8	1.6	1.7	0.0	0.0
MAXIMUM	2007	2004	2003	2007	2004	2003	2003	2007	2005	2004	2003	2006	JAN/2007
YEAR	7373	6735	7521	7828	8488	8574	7656	8279	8489	8618	8571	8782	96914
MINIMUM													
YEAR													
# OBS													

STATION: BUZM3 -- POR (10/1990 - 5/2006)

2 - MEANS & EXTREMES BASED ON HOURLY (GMT) OBSERVATIONS -- MONTHLY & ANNUAL BY YEAR

ELEMENT: SIGNIFICANT WAVE HEIGHT (METERS)

YEAR	ELEMENT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1990	MEAN	-	-	-	-	-	-	-	-	-	1.1	1.1	1.4	1.2
		-	-	-	-	-	-	-	-	-	3.0	4.1	3.3	4.1
		-	-	-	-	-	-	-	-	-	19-14	11-04	24-16	NOV
		-	-	-	-	-	-	-	-	-	506	679	633	1818
MAXIMUM			-					-						
1991	MEAN	1.2	-	-	-	-	-		-	-	-			1.2
DAY-HR		2.8	-	-	-	-	-	-	-	-	-	-	-	2.8
# OBS		13-00	-	-	-	-	-	-	-	-	-	-	-	JAN
		290	-	-	-	-	-	-	-	-	-	-	-	290
MAXIMUM			-					-						
1992	MEAN	-	1.1	1.5	1.1	-	-		-	-	-			1.3
DAY-HR		-	2.9	4.4	1.6	-	-	-	-	-	-	-	-	4.4
# OBS		-	16-18	12-05	03-23	-	-	-	-	-	-	-	-	MAR
		-	457	400	29	-	-	-	-	-	-	-	-	886
MAXIMUM								-						
1997	MEAN	-	-	-	1.3	1.1	0.7	0.7	0.7	0.8	0.8			0.8
DAY-HR		-	-	-	2.6	3.7	1.5	1.7	2.5	3.1	2.6	1.2	-	3.9
# OBS		-	-	-	29-11	03-22	22-09	25-23	21-22	29-23	28-02	3.9	-	NOV
		-	-	-	75	702	700	709	723	692	685	02-00	-	4793
MAXIMUM			-					-				507	-	
1998	MEAN	1.2	1.2	1.3	1.0	0.9	0.5	0.4	0.6	0.4	0.5			0.8
DAY-HR		3.6	3.3	4.4	2.9	3.3	1.9	1.2	2.1	1.4	1.5		-	4.4
# OBS		25-01	13-08	10-10	23-23	02-14	01-02	01-11	26-08	02-12	10-11	-	-	MAR
		340	588	621	567	551	576	598	634	410	429	-	-	5314
MAXIMUM												-	-	
1999	MEAN	-	0.9	1.3	0.8	0.7	0.7	0.8	0.8	1.1	1.0	1.2	1.2	0.9
DAY-HR		-	2.5	5.1	2.2	2.3	2.0	2.7	1.8	2.7	2.8	4.1	3.6	5.1
# OBS		-	13-03	04-17	08-22	25-19	28-23	02-19	14-13	30-15	19-04	03-08	30-11	MAR
		-	389	691	692	707	695	699	418	202	276	369	548	5686
MAXIMUM														
2000	MEAN	1.3	1.2	1.0	1.3	0.8	0.8	0.7	0.8	0.8	0.7	0.9	1.3	1.0
DAY-HR		5.9	4.2	3.0	3.9	3.5	2.0	0.8	1.8	2.8	1.9	2.7	6.3	6.3
# OBS		26-09	14-21	29-12	09-20	19-01	07-03	01-02	07-11	20-17	11-14	27-03	18-06	DEC
		558	513	487	426	352	314	9	591	684	658	614	611	5817
MAXIMUM														
2001	MEAN	0.9	1.1	1.2	0.8	0.7	0.7	0.8	0.8	0.7	1.0	1.0	1.0	0.9
DAY-HR		2.7	3.7	3.8	1.9	1.5	1.6	2.2	1.9	2.1	2.8	2.2	2.2	3.8
# OBS		31-15	10-13	22-10	01-00	30-21	12-11	05-22	14-02	30-16	17-17	20-08	29-12	MAR
		529	464	487	400	342	550	512	610	503	557	718	738	6410
MAXIMUM														
2002	MEAN	1.3	1.2	1.3	0.9	0.9	0.9	0.7	0.6	0.8	0.9	1.3	1.2	1.0
DAY-HR		2.9	3.1	3.7	2.3	2.4	1.8	1.6	1.4	2.9	3.3	3.2	3.1	3.7
# OBS		14-05	13-00	04-04	29-10	15-03	28-18	24-09	23-09	16-16	20-00	30-20	22-02	MAR
		740	664	732	699	721	676	683	683	566	683	585	654	8086
MAXIMUM														
2003	MEAN	1.1	1.1	0.9	0.9	0.7	-		-	-	-			1.0
DAY-HR		2.6	3.5	2.3	2.1	1.1	-	-	-	-	-	-	-	3.5
# OBS		20-18	05-08	22-02	27-06	03-16	-	-	-	-	-	-	-	FEB
		720	607	653	557	121	-	-	-	-	-	-	-	2658
MAXIMUM								-						
2005	MEAN	-		-	-	0.7	0.7	0.6	0.6	0.9	1.1			0.9
DAY-HR		-	-	-	-	2.0	1.3	1.7	2.0	2.6	3.4	1.3	1.3	4.5
# OBS		-	-	-	-	26-02	30-15	25-19	31-23	27-08	26-08	4.5	3.6	NOV
		-	-	-	-	498	707	709	730	718	731	22-17	16-16	5546
MAXIMUM			-									717	736	
2006	MEAN	1.3	1.3	0.9	0.9	1.1	-		-	-	-			1.1
DAY-HR		4.6	3.7	2.4	2.2	1.6	-	-	-	-	-	-	-	4.6
# OBS		19-04	06-13	11-01	04-21	02-05	-	-	-	-	-	-	-	JAN
		739	668	736	707	46	-	-	-	-	-	-	-	2896
MAXIMUM								-						
FOR	MEAN	1.2	1.1	1.2	0.9	0.9	0.7	0.7	0.7	0.8	0.9	1.1	1.2	1.0
DAY-HR		5.9	4.2	5.1	3.9	3.7	2.0	2.7	2.5	3.1	3.4	4.5	6.3	6.3
# OBS														
MAXIMUM														

Port Statistics

CARGO VOLUMES AT MASSPORT FACILITIES

Containerized Cargo (Conley Terminal)

Category	Mar 08 – Feb 09	Mar 07 – Feb 08	% Change
Containerized Cargo Import TEUs * (Fulls)	100,013	107,559	-7.0%
Containerized Cargo Export TEUs * (Fulls)	60,535	70,681	-14.4%
Containerized Cargo Empty TEUs *	43,479	44,853	-3.1%
Containerized Cargo Total TEUs*	204,027	223,093	-8.5%
Containerized Import Short Tons	1,039,035	1,117430	-7.0%
Containerized Export Short Tons	540,578	631,181	-14.4%
Total Containerized Short Tons	1,579,613	1,748,612	-9.7%

Non-Containerized Cargo (Massport Marine Facilities)

Category	Mar 08 – Feb 09	Mar 07 – Feb 08	% Change
Automobiles Processed	28,974	9,769	196.6%
Cruise Passengers	272,548	234,284	16.3%
Cement Short Tons	169,613	194,804	-12.9%

* TEU (20-foot equivalent unit)
* Totals do not include Over-the-Road containers

Port Of Boston Activity

All Volumes in Metric Tons Unless Otherwise Indicated
Volumes Reported for Public & Private Terminals*

	2008	2007	% Change
Containerized Cargo			
Public & Private Terminals			
Import Metric Tons	973,409	1,113,654	-13%
Export Metric Tons	496,311	620,303	-20%
Total Containerized Cargo	1,469,720	1,733,957	-15%
Container Ships (includes barges)	242	281**	-14%
Auto Vessels	32	20	60%
Bulk Cargo Imports in Metric Tons			
Petroleum Products	6,837,017	7,679,205	-11%
Liquefied Natural Gas	2,556,039	3,154,858	-19%
Salt	688,695	715,339	-4%
Cement *	161,656	257,508	-37%
Automobiles(Autoport)	29,150	10,971	166%
Gypsum	27,692	159,055	-83%
Other	2,105,133	1,223,565	72%

Sub-total Bulk Imports	12,405,382	13,200,501	-6%
Bulk Cargo Exports in Metric Tons			
Scrap Metal	643,217	539,966	19%
Automobiles (Autoport)	21,736	2,804	675%
Other	135,571	29,659	357%
Sub-total Bulk Exports	800,524	572,429	40%
Total Bulk Cargo	13,205,906	13,772,930	-4%
Bulk Cargo Vessels/Arrivals	435	481	-10%
Total Port of Boston Cargo	14,675,626	15,506,887	-5%
Container TEUs (Fulls Only)	164,548	177,013	-7%
Automobiles Processed (units)	26,779	10,079	166%
Cruise Passengers	269,911	234,284	15%
Cruise Vessel Sailings	113	101	12%

NOTES:
Container TEUs do not include Over-the-Road boxes
* Private Terminal Volumes are as reported by PIERS.
**Vessel arrivals for 2007 were previously reported in error as 361.
*** Cement includes barge volumes at Massport facilities.
Other bulk import cargoes include chewing gum, dyes, vegetable oil, putty and caulk, and adhesives.
Other bulk export cargoes include steel and used automobiles.

APPENDIX 9

The properties surrounding Fall River State Pier were carefully looked at to determine ownership, location and use. These properties from plot maps N-13, N-15, N-16, and T-03 were compared from the MassLandRecords 20/20 system to the Massgov PatriotProperties to ensure proper accuracy. Noted in the map below are the plot and lot numbers for the area surrounding Fall River State Pier.

- Map ID 1 N-13-0020 is owned by the Commonwealth of Massachusetts. This property encompasses State Pier. This property contains 7.180 acres; with one warehouse style building that is noted 'Fall River State Pier'. The area of State Pier is used for cargo shipment container storage.

- Map ID 2 N-13-0021 is owned by the Commonwealth of Massachusetts. This property contains 2.020 acres and is located to the northeast of the State Pier property. This property was also referred to as Steamship Dock; sign on property image states 'Battleship Massachusetts – Welcome Aboard'.

- Map ID 3 N-16-0016 is owned by Nasser Real Estate Trust. This property encompasses 0.744 acres; the property image states Waterfront Café.

- Map ID 4 N-15-0002 is owned by Borden & Remington F R LLC. This property is classified as industrial with 14 mill style buildings on 29.220 acres. This land is used for

industrial waterfront for textile rubber and chemical manufacturing. This property encompasses from 63 Water Street west to the north side of Ferry Street.

- Map ID 5 N-16-0030 and T-03-0019 are both owned by New York Central Lines LLC. These properties combined are 2.013 acres southeast of State Pier. These properties are noted to be undeveloped.

- Map ID 6 N-13-0003 is owned by the Commonwealth of Massachusetts C/O Department Environmental Management. This property is to the north of State Pier – opposite the 195 bridge. This property contains 2.060 acres; with one museum style building that is noted 'Fall River State Pier'.

- Map ID 7 N-13-0001 is owned by Jobs For Fall River Inc. This property encompasses the land beneath the 195 bridge directly north of State Pier. It is not noted how much land is contained only a museum style building.

- Map ID 8 N-16-0011 is owned by Azar Jeanne Etali. This property is classified as Restaurant/Bar and is located on 0.396 acres.

- Map ID 9 N-16-0001 is owned by Fall River Inc. Marine Museum. This property contains 0.438 acres and is noted as being the Marine Museum at Fall River.

APPENDIX 10

LEASE AGREEMENT

AGREEMENT made and entered into this 31st day of March 1986 by and between the CITY OF NEW BEDFORD, a municipal corporation established under the laws of the Commonwealth of Massachusetts, by and through its HARBOR DEVELOPMENT COMMISSION, hereinafter referred to as the "LESSOR", and HERMAN MELVILLE SHIPYARD, INC., a Massachusetts corporation having a usual place of business in Fairhaven, Massachusetts, hereinafter referred to as the "LESSEE".

WHEREAS, the LESSOR has available for occupancy and development a certain parcel of land in New Bedford, Massachusetts; and

WHEREAS, the LESSEE is desirous of leasing and developing a portion of said land in New Bedford; and

WHEREAS, the LESSOR is aware of the desire of the LESSEE to occupy and develop said land in New Bedford for the primary purpose of operating a shipyard including the sale, repair, and outfitting of vessels;

NOW, THEREFORE, in consideration of their mutual promises, covenants, and agreements herein contained, the parties hereto agree as follows:

ARTICLE I
PREMISES

The LESSOR does hereby let, lease, and demise unto the LESSEE for its exclusive use and that of its successors, and assignees a certain parcel of land as fully described in Schedule A attached hereto and hereby incorporated into this Agreement.

ARTICLE II
TERM OF LEASE

TO HAVE AND TO HOLD the demised premises unto the LESSEE for the term of ninety-nine (99) years commencing on March 31, 1986. The term of this lease is subject to the

first or any succeeding twenty-five (25) year term. In the event that the LESSEE elects to so terminate, he shall notify the LESSOR in writing at least twelve months prior to the end of the respective term. In the event that the LESSEE does not notify the LESSOR of termination, the parties hereto shall be bound each to the other for the next succeeding term of twenty-five years except for the last term which shall be twenty-four years.

ARTICLE III

RENT

The LESSEE covenants and agrees to pay the LESSOR at City Hall in New Bedford, Massachusetts, or at such other place as the LESSOR shall designate in writing, rent as hereinafter set forth:

a) For the first twenty (20) years of the term hereof Eight Thousand Four Hundred Thirty-one and 20/100 Dollars ($8,431.20) per annum in equal monthly installments of Seven Hundred Two and 60/100 Dollars ($702.60);

b) For the next succeeding five (5) years of the term hereof, the sum of Eight Thousand Four Hundred Thirty-one and 20/100 Dollars ($8,431.20) per annum payable in equal monthly installments of Seven Hundred Two and 60/100 Dollars ($702.60);

c) For the succeeding fifteen (15) years of the term hereof, the parties shall use their best efforts to agree to the annual rental applicable thereto at least eighteen (18) months prior to the commencement of said term. In the event that the parties cannot agree to the rental the LESSOR shall select one arbitrator and the LESSEE shall select one arbitrator at least seventeen (17) months prior to the commencement of the instant term and shall so notify the other of their respective choice. The two arbitrators so selected shall determine a third arbitrator

that the arbitrators selected by the parties cannot agree to a third arbitrator, the arbitrators shall select a third arbitrator from a panel of three disinterested nominees to be selected by the American Arbitration Association. If at the end of one week after the designation of such panel there remains disagreement as to which of said nominees shall serve, the LESSOR'S and LESSEE'S arbitrators, in that order, shall each strike the name of one of the nominees and the remaining nominee shall be the third arbitrator. The rental that shall be determined by a majority of the arbitrators in a decision of the arbitrators made at least fourteen (14) months prior to the commencement of the instant fifteen (15) year term shall be binding on all parties except that the rental so determined shall not exceed that of comparable land of the LESSOR leased for similar purposes, and in no event shall the rent for said term exceed Twelve Thousand Six Hundred Forty-six and 80/100 Dollars ($12,646.80) per annum, subject to subparagraph F herein. The arbitration proceeding shall be conducted under the rules of the American Arbitration Association.

d) For the succeeding twenty (20) years of the term hereof, the parties shall use their best efforts to agree to the annual rental applicable thereto at least eighteen (18) months prior to the commencement of said term. In the event that the parties cannot agree to the rental, then the same procedure as set out in (c) of this ARTICLE III shall be applicable, except that in no event shall the rental for said term exceed Twelve Thousand Six Hundred Forty-six and 80/100 ($12,646.80)Dollars per annum for the first ten (10) years of said twenty (20) year term.

e) For the succeeding twenty (20) year and nineteen (19)

year rental periods, the rental shall be determined in the same manner as set forth in paragraph (c) and (d) of this ARTICLE III, except that the arbitrators shall not be limited to the maximum of Twelve Thousand Six Hundred Forty-six and 80/100 Dollars ($12,646.80) per annum set forth therein.

f) In addition to the procedures for rental increases set out in Paragraphs (c), (d), and (e) of this ARTICLE III, said rental shall be adjusted upward at the end of each period specified, if the cost of living index of the Bureau of Labor Statistics discloses an increase in the cost of living index, according to the United States Consumer Price Index. Said rental shall be adjusted upward by the percentage which said price index has moved upward during the past rental period or past year, whichever is greater. It is agreed and understood that said rental figure may therefore, with application of the cost of living increase, exceed the Cap set out in paragraphs (c) and (d).

g) It is specifically understood that said rental is exclusive of taxes on the structures on the demised premises which shall be treated as realty for taxation purposes, which taxes shall be assessed by the City of New Bedford.

ARTICLE IV
LESSEE'S USE OF PREMISES

The LESSEE shall have unrestricted right to build and install on the demised premises such structures, improvements, machinery and equipment as he may desire, but solely for the purpose of operating a shipyard, including the sale, repair, and outfitting of vessels and/or other water dependent activities, and use same for any purpose in conformance with all zoning and building regulations applicable thereto, all of which shall at all times remain the property of the LESSEE. A breach of said use shall be cause for termination hereunder by the LESSOR. In the event that

this Agreement is terminated for any reason, said structures, improvements, machinery and equipment may be removed by the LESSEE, provided the premises are put back in the same condition as they were at the time of the execution of the Lease and provided that all taxes and monies due to the City of New Bedford, the LESSOR, have been paid.

The LESSEE shall commence construction of the building on the demised premises within 180 days from the date of the execution of the Lease. Construction shall proceed, without delay, and be completed in accordance with the LESSEE'S Application Plan, as submitted to the Harbor Development Commission.

ARTICLE V

LESSOR'S REPRESENTATION AS TO THE DEMISED PREMISES

Section 1. The LESSOR hereby jointly and severally warrants and represents that:

a) It has a good, clear, and merchantable title to the demised premise and has at the execution of this Agreement delivered to the LESSEE a complete physical property survey of the demised premises prepared and certified by a land surveyor registered by the Commonwealth of Massachusetts.

b) The demised premises are free and clear of all encumbrances and liens and that upon notice by the LESSEE at any time of any undisclosed liens or defects the LESSOR will cause said liens to be removed or cleared.

c) The LESSOR represents and warrants that it has no knowledge of any circumstances which would prohibit construction, support or utilization of the demised premises or any portion thereof. However, the LESSEE shall make his own engineering determinations as to the structural suitability, the land having been created by the depositing of unclassified fill.

d) It has good and proper power and authority to enter into and to perform its warranties, representations and undertakings, all as set forth in this Agreement and will execute and deliver

to the LESSEE any further written certificates and authorizations reasonably required by counsel for the LESSEE at any time so as to further evidence its power and authority.

ARTICLE VI

LESSEE'S RIGHT TO ASSIGN OR SUBLEASE

Section 1. Notwithstanding any provision of this Agreement, the LESSEE shall at all times have the right, in his sole discretion, to assign the lease or sublease the demised premises, subject to all provisions hereunder. In the event of such sublease or assignment, the LESSEE shall at all times be responsible for the payment of the rentals due hereunder and all other provisions. Any sublease or assignment shall not relieve the LESSEE of any liabilities hereunder.

Section 2. In the event that the LESSEE does sublease all or any part of the demised premises, the LESSEE hereby represents and agrees that the rent to be received by him for the demised premises, shall not exceed one hundred ten percent (110%) of the rental then being paid by the LESSEE to the LESSOR for that portion so subleased. It is expressly understood and agreed that the provisions of Article VI, Section 2 shall not apply to any entity owned by the LESSEE hereunder.

ARTICLE VII

INDEMNITY AND PUBLIC LIABILITY INSURANCE

Section 1. The LESSEE agrees to indemnify and hold harmless the LESSOR from and against all claims of whatever nature arising from any act, omission, or negligence of the LESSEE or LESSEE'S sublessee, or their respective contractors, licensee, agents or employees, or arising from any accident, injury or damage whatsoever caused to any person, or to the property of any person occurring during the term hereof in or about the LESSEE'S demised premises or any improvements thereon except to the extent that such claim results from the LESSOR'S negligence or fault.

Section 2. The LESSEE agrees to maintain in full force,

during the term hereof, policies of public liability and property damage insurance under which the LESSOR (and such other persons as are in priority of estate with LESSOR as may be set out from time to time) and the LESSEE are named as assureds and under which the insurer agrees to indemnify and hold harmless the LESSOR from any liability arising out of or based upon any and all claims, accidents, injuries and damages set forth in Section 1. of this ARTICLE VII. Each such policy shall be non-cancellable with respect to the LESSOR and the LESSOR'S designees without ten (10) days prior notice to LESSOR, and a duplicate original or certificate thereof shall be delivered to LESSOR. The minimum limits shall be One Million Dollars ($1,000,000.00) combined single limit covering personal injury liability and property damage. Certificates of such insurance coverage shall be delivered to LESSOR not later than ten (10) days after LESSEE has first taken possession of demised premises. It is expressly understood and agreed that LESSEE shall be responsible for the payment of all premiums for insurance coverage hereunder.

ARTICLE VIII
DEFAULT

In the event of failure by the LESSEE to perform, fulfill, or observe any of the terms, covenants, agreements and conditions of this Agreement continuing for a period of 120 days after written notice from the LESSOR to the LESSEE specifying such failure without such failure being waived or its effect cured or the cure thereof commenced and diligently prosecuted thereafter, the LESSOR may, by written notice to the LESSEE, terminate this Agreement whereupon all of the LESSEE'S rights, obligations, and liabilities under this Agreement shall cease except that the LESSEE shall continue to be liable to the LESSOR for the obligations of the LESSEE which arose prior to such termination; provided, however, that the rights of the LESSOR under this Article shall be subordinate and subject to any and all mortgages, deeds of trust and other instruments in the nature of a mortgage or

LESSEE, including any rights of the holders of bonds or other obligations issued by the City of New Bedford, acting by and through its Industrial Development Financing Authority or otherwise, to finance facilities or equipment for use by the LESSEE on the demised premises, including the right of any such holders to cure any default by the LESSEE within thirty (30) days after the receipt by such holders of notice by the LESSOR of such default; and, provided further, that the LESSOR will permit any purchaser at a foreclosure or other sale or disposition of the demised premises or any of the facilities or equipment used or made a part of the demised premises by or on behalf of any such holders to fully perform, fulfill, and observe all of the terms, covenants agreements and conditions of the LESSEE under this Agreement and in such case such purchaser shall be entitled to all the rights of the LESSEE under this Agreement.

ARTICLE IX
MISCELLANEOUS PROVISIONS

Section 1. LESSEE, subject to the terms and provisions of this Agreement on paying of rent and keeping and performing all of the terms and provisions of this Agreement on his part to be observed, kept, and performed shall lawfully, peaceably, and quietly hold occupancy and enjoy the demised premises during the term hereof without hindrance or ejection by the persons or entitities claiming under the LESSOR.

Section 2. LESSEE agrees to make every reasonable effort to discharge any mechanics, materialman or other liens against the demised premises and/or the LESSOR'S interest therein, which may arise out of any payment due for or purported to be due for any labor, services, materials, supplies or equipment alleged to have been furnished for the LESSEE in, upon, or about the demised premises.

Section 3. In addition to the rents and covenants contained herein to be paid and performed by the LESSEE, the LESSEE agrees

to pay, when due, all real estate taxes on the demised premises and any improvements thereto and any utility charges pertaining thereto.

Section 4. Except as herein otherwise expressly provided, the terms hereof shall be binding upon and inure to the benefit of the successors and assigns respectively of the LESSOR and LESSEE.

Section 5. This Lease Agreement shall be governed exclusively by the provisions hereof and by the laws of the Commonwealth of Massachusetts.

Section 6. The parties hereto agree, upon request of the other, to execute a notice of a lease or short form lease in recordable form and complying with applicable local laws:

Section 7. Whenever by the terms of this Agreement, notice shall or may be given whether to the LESSOR or LESSEE, such notice shall be in writing and shall be sent by registered or certified mail, postage prepaid, and if to the LESSOR:

New Bedford Harbor Development Commission
Pier 3 - Wharfinger Building
New Bedford, MA 02740

and if to the LESSEE:

Herman Melville Shipyard, Inc.
42 Water Street
Fairhaven, MA 02719

Section 8. The LESSEE shall be subject to the following provisions:

1. Any additional structures within the waterways shall be subject to all local, state and federal rules, regulations, licenses and requirements.

2. Said premises shall be subject to the Army Corps of Engineers Permit, including Compliance for Contribution to Mitigation. Said contribution shall be determined by the Harbor Development Commission.

ARTICLE X

ADDITIONAL LEASE AND PURCHASE PROVISIONS

1. In the event the LESSOR substantially improves the area shown on the plan mentioned in Schedule A of this lease and offers for sale any portion of the land in the area shown on the plan mentioned in Schedule A, it shall forthwith notify the LESSEE of the terms and conditions of said sale and such notice shall automatically grant the LESSEE the right to purchase for the same cost per square foot as required of any third party purchaser. The area shown on the plan mentioned in Schedule A shall mean that area of land of which the demised premises are a part. The LESSEE shall have one hundred twenty (120) days from the date of receipt of said notice to exercise his right to purchase, by sending written notice to LESSOR. In the event of the LESSEE'S decision to so purchase, the LESSOR and LESSEE shall use their best efforts to complete the sale and purchase in a proper and orderly fashion.

2. The LESSEE shall have an option of first refusal to obtain any future land to be created or developed directly abutting his land. This option is subject to the LESSEE presenting an acceptable development plan to the Harbor Development Commission showing a continuation of or extension of his then existing business and is further subject to the sale or lease terms then being offered by the Harbor Development Commission.

3. Any additional filled land created as a result of future bulkheading shall remain solely the property of the LESSOR.

Any improvements made to the land seaward of the present mean high water line of the Acushnet River as indicated on the Plan referred to in Schedule A, shall be at the sole risk of the LESSEE and no compensation shall be due from the LESSOR in the event of the creation of said additional filled land.

ARTICLE XI

CONSTRUCTION

The LESSEE agrees that in the event that construction of a

to dispossess and remove therefrom any and all occupants and their effects without being liable to any prosecution therefor, and to hold premises as if this Lease had not been made. LESSEE expressly waives, in behalf of himself and all persons claiming under him, all rights of notice to quit or intention to re-enter under provisions of any statute or of this Lease, in case of such failure to commence construction.

IN WITNESS WHEREOF, the parties have hereunto caused these presents to be executed by their duly authorized officers and their seals to be affixed, duly attested as of the day and year first above written. This lease and execution thereof being duly authorized by Order of the City Council of the City of New Bedford and approval of the Mayor, and Vote of the New Bedford Harbor Development Commission, certified copies of such Order and Approval and Vote of the New Bedford Harbor Development Commission being attached hereto and made a part hereof.

APPROVED as to form
and legality

City Solicitor

Thomas R. Hunt
Counsel for H.D.C.

CITY OF NEW BEDFORD

By:
John K. Bullard, Mayor

NEW BEDFORD HARBOR DEVELOPMENT COMMISSION

By:
Vice Chairman

HERMAN MELVILLE SHIPYARD, INC.

By:
Feener, President

SCHEDULE "A"

BOUNDARY DESCRIPTION

A certain parcel of land situated in the City of New Bedford, County of Bristol, and the Commonwealth of Massachusetts, being particularly bounded and described as follows:

BEGINNING at a point in the easterly line of Herman Melville Boulevard, said point forming the southeasterly point in the intersection of North Front Street, Wamsutta Street and Herman Melville Boulevard;

Thence north 82° 53' 29" east for a total of 465.00 feet to a point;

Thence south 7° 31' 59" east for a total of 250.00 feet to a point;

Thence south 26° 18' 45" west for a total of 314.00 feet to a point;

Thence north 88° 04' 00" west for a total of 310.00 feet to a point in the easterly line of said Herman Melville Boulevard;

Thence along the easterly line of said Herman Melville Boulevard in a northwesterly direction a total of 173.72 feet on a curve with a radius of 960.00 feet to a point in the said easterly line of Herman Melville Boulevard;

Thence north 7° 31' 59" west a total of 290.47 feet along the easterly line of said Herman Melville Boulevard to the point of beginning;

CONTAINING two hundred nine thousand, eight hundred sixty-six square feet, more or less (209,866 ±) , a total of four point eight one eight (4.818) acres, more or less;

Being part of lot 248 on Assessors Plot 72, as shown on a plan entitled "Plan of Land in New Bedford belonging to City of New Bedford", dated March 30, 1985.

ASSIGNMENT OF LEASE

KNOW ALL MEN BY THESE PRESENTS, THAT WE, DONALD GREEN of 26 Holly Drive, Fairhaven, Massachusetts, and SHERMAN C. SMITH of 1136 Russells Mills Road, So. Dartmouth, Massachusetts, in consideration of ONE DOLLAR and other valuable consideration assign and transfer to ACUSHNET RIVER SHIPYARD, INC., a corporation duly organized under the laws of the Commonwealth of Massachusetts, a certain lease dated June 20, 1988 made by HERMAN MELVILLE SHIPYARD, INC., to DONALD GREEN and SHERMAN C. SMITH of the following premises:

BEGINNING at a point in the east line of Herman Melville Boulevard, said point being the northwest corner of Lot #2 as shown on "Subdivision Plan of Land in New Bedford, Mass. located at Herman Melville Shipyard, Scale 1" = 30' dated 1 June 1988" drawn by Benchmark Surveying and Engineering Assoc., 667 Cottage Street, New Bedford, MA; thence

NORTH 82° 26' 38" east one hundred twenty and 42/100 (120.42) feet to an angle;

Thence proceeding north 86° 56' 27" east three hundred forty-five and 46/100 (345.46) feet to the west bank of the Acushnet River;

Thence turning and proceeding south 24° 4' west forty-one and 6/100 (41.6) feet to an angle;

Thence proceeding south 37° 38' west seventy-three and 1/10 (73.1) feet to an angle;

Thence proceeding south 45° 15' west eighty-seven and 9/100 (87.9) feet to an angle.

Thence proceeding south 72° 36' west seventy and 2/10 (70.2) feet to an angle;

Thence proceeding south 86° 44' west fifty-six and 5/10 (56.5) feet to an angle;

Thence proceeding north 84° 41' west twenty-six and 8/10 (26.8) feet to an angle;

Thence proceeding south 69° 27' west twenty-one and 7/10 (21.7) feet to an angle;

Thence proceeding south 85° 52' west eighty-one and 6/10 (81.6) feet to an angle;

Thence proceeding north 89° 23' west sixty-five and 6/10 (65.6) feet to an angle;

Thence proceeding north 55° 32' west twenty-three and 0/100 (23.0) feet to a point in the easterly line to Herman Melville Boulevard;

Thence along the easterly line of said Herman Melville Boulevard in a northerly direction a total of one hundred forty-five and 19/100 (145.19) feet on a curve with a radius of 60' to a point in the said easterly line of Herman Melville Boulevard to the point of beginning,

CONTAINING sixty six thousand seven hundred three (66,703±) square feet more or less.

and recorded in Bristol County (S.D.) Registry of Deeds Book 2191, page 0242 with all and singular the premises therein mentioned.

TO HAVE AND TO HOLD the same to ACUSHNET RIVER SHIPYARD, INC. and its assigns from September 1, 1988 for and during all the rest and remainder yet to come of the lease, subject to the rents, agreements, and conditions contained in the lease.

IN WITNESS WHEREOF the parties have hereunto set their hands and seals this 15th day of November 1988.

DONALD GREEN

SHERMAN C. SMITH

ACUSHNET RIVER SHIPYARD, INC.

By: _____

Pres.

Title

CONSENTED TO:
HERMAN MELVILLE SHIPYARD, INC.

By: _____

President

Title

The CITY OF NEW BEDFORD, a municipal corporation established under the laws of the Commonwealth of Massachusetts acting by and through its HARBOR DEVELOPMENT COMMISSION, hereby consents to the assignment of lease of a portion of the premises leased by it to HERMAN MELVILLE SHIPYARD, INC., on March 31, 1986 to DONALD GREEN, 26 Holly Drive, Fairhaven, Massachusetts and SHERMAN SMITH, 136 Russells Mills Road, So. Dartmouth, Massachusetts.

In consideration of consent to this assignment of lease (partial) by the City of New Bedford, LESSEE/ASSIGNOR guarantees performance by ASSIGNEES, or by their heirs, executors, administrators, successors, or assigns of all agreements and conditions contained in said lease as applies to that portion assigned, on the part of ASSIGNEES to be performed.

WITNESS our hands and seals this 23rd day of November 1988.

APPROVED as to form and legality:

Asst. City Solicitor

CITY OF NEW BEDFORD

By: John K. Bullard, Mayor

NEW BEDFORD HARBOR DEVELOPMENT COMMISSION

Vice-Chairman

APPENDIX 11

New Bedford State Pier Excerpt from the New Bedford Harbor Plan

The State Pier program represents another of the major initiatives proposed along the New Bedford waterfront. Numerous individual projects are proposed that collectively form the basis for a programmatic modification to the form and use of the Pier. This effort began with the new Ferry Terminal and roll-on/roll-off freight ramps added in the early 2000's, the establishment of a waterfront visitor center, and the startup of the annual Working Port Festival. Further improvements anticipated will enhance the Pier's ability to handle import and export cargo, service cruise ships and support tourism initiatives such as an open air seasonal market, facilities for Schooner Ernestina, an area to view the fishing fleet, and other facilities of public accommodation.

The projects range from replacing the pile supported portion of the Pier with a solid fill structure to improving buildings and other support facilities so that they can support new uses.

Specific infrastructure work includes pier rehabilitation and building reconfiguration. The plan is for the north, south, and east faces of State Pier to be demolished and replaced by a new filled-pier structure. The filled-pier structure will be comprised of a bulkhead that will be filled and capped by a concrete slab. With a few exceptions, the edge of the bulkhead will generally follow the edge of the existing pier. The two exceptions are:

- The northeast corner of the north and east faces of the Pier, which will be squared in order to accommodate the turning radius of future truck traffic;
- The southwest corner of the south face of the Pier, at which the bulkhead will be installed further north to accommodate, proposed floating excursion piers in that area.

The plans also call for building reconfiguration. A portion of the east side of Building 1 would be demolished. The remainder of Building 1 would be rehabilitated. Building 2 would be expanded to the south. A second floor would be added to Building 2. The former Coast Guard Building would be demolished. Building 3, previously demolished, would be replaced with a new, two story building with a larger footprint. An elevated walkway would be installed between Building 2 and Building 3. A floating excursion pier would be added in the southwest corner. The excursion pier would consist of two sets of multiple floating pier structures, the outer edge of which would be aligned with the former southern edge of the Pier.

The new building structure would allow the separation of public and cargo areas by keeping public areas primarily on the second floor of most buildings. Cargo would be handled and stored primarily on the first floor of most site buildings. Future public use of the Pier would be maximized by keeping cargo areas isolated from public areas. Flexibility goals would be met by creating multiple-use facilities in site buildings, by using pier structures for multiple types of vessels (cruise ship vessels, fishing vessels, and shipping vessels), by preserving space in the southwest corner of the facility to potentially add finger piers in the future, and by maximizing the flexibility of the types of cargo (roll-on/roll-off, break-bulk, and load-and-go/inter-modal) that can be accommodated at the Pier. The north, south, and east faces of the Pier would be replaced to prevent the gradual collapse of those structures. Site security and site safety concerns would be met by installing a filled pier structure when rehabilitating the north, south, and east faces of the Pier.

Proposals have also been made to establish the southwest corner of the State Pier as a publicly accessible waterfront destination space with berthing for commercial charter fishing and excursion vessels, interpretive facilities associated with the Schooner Ernestina and the National Park combined with other visitor facilities including an open air market incorporated within temporary structures.

Ferry Terminal/North Side

The Ferry Terminal was constructed in 1999 with service commencing in 2000. The Ferry Terminal currently provides passenger ferry service to Martha's Vineyard and Cuttyhunk Island. It is currently anticipated that this ferry service will continue. This Plan supports the further expansion of ferry service as opportunities are presented including possible service to Block Island, Providence, Nantucket and/or Woods Hole.

Cargo Shipments/East Side

The East Side (as well as portions of the North and South sides) of the State Pier will continue to be primarily used for cargo shipments. The City wishes to maximize the flexibility of the types of cargo (roll-on/roll-off, break-bulk, and load-and-go/inter-modal) that can be accommodated at the Pier. The City of New Bedford has completed a Memorandum of Understanding, along with the Cities of Fall River, Salem, and Gloucester, with the City of Cape Canaveral in Florida to facilitate the creation of a Short-Seas Shipping corridor in order to by-pass shipping along the eastern coast of the United States. Specific needs for accommodation of short-seas shipping vessels will need to be taken into account during the redevelopment of

the pier. In order to facilitate the flow of truck traffic on the pier that will be involved in loading and unloading of cargo, this Plan supports the extension of the Harbor Line located proximate to the northeast corner of the State Pier, in order to square the corner off during rehabilitation.

Storage Facilities

This Plan supports the expansion of warehouse and storage space on the eastern end of State Pier, particularly on the first floor of the building. The existing 30,000 square foot cooler storage facility on the State Pier was too small to attract significant cargo to the State Pier, as the storage space is smaller than the size of typical vessels that would transport goods and services to the City. Ultimately, the coolers were removed, and the facility now accommodates general cargo. New refrigerated facilities will need to be sufficiently large to accommodate typical cargo loads. Therefore, expansion of these facilities wherever possible will allow increased cargo shipments to arrive to the City and will allow for increased economic activity.

Cruise Ship Terminal/East Side and South Side

Cruise ship operations were first accommodated at the New Bedford State Pier in July of 2002, at which time the Regal Empress docked at State Pier. The visit was a success, but revealed the problems associated with the existing pile-supported structure of the south side of State Pier, when exposed to significant lateral loads from a large vessel.

Since 2002, a vessel of the size of the Regal Empress has docked only rarely at the State Pier (due to the damage such a vessel would cause); however, multiple smaller cruise ships have arrived and been serviced. DCR intends to upgrade the facilities at the pier such that cruise ship operations with larger vessels, such as the Regal Empress, can continue in the future.

Pursuant to the Cruise Ship Initiative, the City and the HDC have been actively marketing the Port of New Bedford as a full service port of call for appropriate cruise and other transient vessels. For the coming year, the City has signed a contract with American Cruise Lines for up to 25 cruise vessels per year to arrive in the Port. As a result of this increase in Cruise Ship activity and marketing efforts by the State to attract more cruise ships to the region under Historic Ports of Massachusetts initiative, the HDC would like to see the redevelopment of State Pier to include a Cruise Ship Terminal that will allow for waiting areas, refreshments, and tourist-themed areas that would allow for increased economic activity associated with the arrivals.

Southwest Corner/National Whaling Historical Park

The Harbor Plan designates an area on the southwest corner of the State Pier to function as a waterfront destination area for harbor visitors. The Harbor Plan supports continued use of the central berthing area in the southwest corner of the pier for commercial excursion and charter vessels, and the Ernestina, the official vessel of the Commonwealth (see below). The south wharf building will include a center for visitor services, programs, and support for the Schooner Ernestina, ticketing facilities for the excursion vessels, offices and classrooms to help support education of commercial and marine industrial uses of the Harbor, and will also include a fish market that will serve as a centralized location for Citizens to purchase fish for consumption at home. The south wharf will also include a harbor viewing area, allowing visitors to view the fishing fleet berthed on Steamship Wharf. This initiative will attract substantial numbers of visitors to the waterfront, enhancing its vitality and providing direct benefits to the downtown area as a whole.

Schooner Ernestina

The Schooner Ernestina is a National Historic Landmark and the official vessel of the Commonwealth; it was a gift from the Cape Verde government and is owned by the Department of Conservation and Recreation. It is currently berthed on the southwest corner of the State Pier. A center for visitor services, programs and support for the Schooner Ernestina will be developed on the southwest corner of the State Pier. The Harbor Plan concept for the southwest corner of the State Pier includes a berth for the Ernestina adjacent to its proposed visitor service facilities. The Ernestina anticipates a need for 5,000 square feet of support space onshore, some portion of which including interpretive facilities and storage space will be provided on the State Pier.

Floating Dock for Excursion/Charter Boats and Water Taxi/Shuttles

A substantial floating dock system is proposed to be placed adjacent to a portion of the Southwest Side of the State Pier to serve the Ernestina, and to establish an accessible central berthing area for charter fishing boats, excursion vessels, and other commercial boating services. These services have strong market support and will be the catalyst that establishes the waterfront as a visitor destination attracting visitors to the community and contributing directly to downtown revitalization goals. Establishing a critical mass of vessels in a central location will also bring tangible benefits to boat owners based on shared ticketing, shared advertising, and an established destination. Several such services currently exist around the harbor but they are dispersed and lack critical mass. Development of the proposed floating

dock system would be subject to any applicable leases and would require approval from the Commonwealth or its designee.

A similar opportunity exists on the northwest (inland) corner of State Pier including Tonnesson Park and adjacent to the existing Waterfront Visitor Center, where docking facilities should be improved to adequately support excursion boats and water shuttle/taxi services. Currently New Bedford/Fairhaven Harbor lacks the ability to provide adequate berthing for water taxis and launch service, excursion boats and space to berth security and port operational vessels.

> The City of New Bedford has requested $75,000 from the Massachusetts Seaport Council to build two (2) launch/berthing facilities that would support maritime operations and tourism on the waterfront. One site would support access from launch and excursion services to a newly built waterfront restaurant in the working port and access to the historic downtown area. The other site would support access by launch and excursion service to the historic down town area as well as berthing for the Port's security vessels (police patrol, harbor master, and fire boat). The project is considered critical to support commercial and recreational boating activities in the Harbor. Studies sponsored by the Maritime Trades Association indicate that for each $1 spent by a boater there is an $8 economic return to the community. By not having an adequate water/land interface to support water taxi, excursion, and recreational boating operations, the Port loses the opportunity for this economic spin-off. Further and equally important, this project would meet some of the security goals critical to the maritime operations of this Port.

Water Taxi/Launch Dock

A water taxi/launch dock will be provided on the northwest corner of the State Pier,

Use of the State Pier for Special Events

As efforts proceed to revitalize the State Pier through development of freight ferry service and with renewed efforts to attract break bulk cargoes, full use will be made of the Pier on an interim basis for special events, waterfront festivals, and related activities including parking. These activities may make use of exterior Pier areas, the Cooler Storage Facility and both levels of the Transit Shed to the extent that they are not otherwise in use. Incorporation of these activities will not require any significant alterations to Pier facilities and will not impede use of the Pier for its primary users. Temporary uses will be limited to activities that are fully compatible with the needs of other Pier users and consistent with any applicable leases.

APPENDIX 12

Apex Companies, LLC

184 High Street, Suite 502, Boston, MA 02110

(617) 728-0070

DATE: Tues. Aug. 10th, 2010

TIME: 3:33pm

☐ Incoming Call X Outgoing Call ☐ Return Call

CONTACT:

Name: US Coast Guard

Address: 918 S Rodney French Blvd

New Bedford, MA 02744

Project Name: New Bedford Harbor Phase IV

Project No.: 6690

Phone: 508-991-6812

SUMMARY OF CONVERSATION:

Contacted the U.S. Coast Guard to determine whether there were any restrictions upon the size of vessels that can enter or exit New Bedford Harbor due to the New Bedford Hurricane Barrier. Administrator on duty that answered the phone discussed the issue with other personnel available at the facility and answered that the Coast Guard does not impose these restrictions. She gave me the number for the U.S. Army Corps of Engineers in New Bedford (508-994-4243) and directed me to contact them instead.

184 High Street, Suite 502, Boston, MA 02110

(617) 728-0070

DATE: Fri. Aug. 13th, 2010

TIME: 12:20pm

☐ Incoming Call X Outgoing Call ☐ Return Call

CONTACT:

Name: Sgt. Jill Simmons

Address: Port Security Team
New Bedford Harbor
New Bedford, MA 02746

Project Name: New Bedford Harbor Phase IV

Project No.: 6690

Phone: 508-989-2925

SUMMARY OF CONVERSATION:

Unable to get in contact with representatives from the US Army Corps of Engineers. Instead spoke with Sgt. Jill Simmons, a member of the Port Security Team in New Bedford Harbor. I asked her about any restrictions imposed on vessels by the Hurricane Barrier (length, width, and draft of vessels) coming into New Bedford Harbor. She stated that there is no regulation on the length of a vessel coming through the barrier, and that draft and width are the deciding dimensions.

Additionally, she stated that the maximum vessel draft that the channel through the Hurricane Barrier allows is between approximately 30 and 35 feet, depending upon the tide. She also stated that the width of the opening in the hurricane barrier is 150 feet, and that any vessel with a width smaller than this is allowed through the barrier. When requested to evaluate whether a vessel with a width of 115 feet would be allowed through the barrier, she concurred.

Sgt. Simmons stated that the Hurricane Barrier manager for the US Army Corps of Engineers New Bedford could be reached at: 508-994-4243. She also stated that Mr. Bill Norman could be contacted for additional information: 978-318-8609, Willam.F.Norman@usace.army.nil.

Apex Companies, LLC

184 High Street, Suite 502, Boston, MA 02110

(617) 728-0070

DATE: Mon. Aug. 16th, 2010

TIME: 3:00pm

☐ Incoming Call X Outgoing Call ☐ Return Call

CONTACT:

Name: Marine Traffic Control Center Dispatcher

Address: Marine Traffic Control Center
US Army Corps of Engineers
Academy Drive
Buzzards Bay, MA 02532

Project Name: New Bedford Harbor Phase IV

Project No.: 6690

Phone: 978-318-8500

SUMMARY OF CONVERSATION:

Spoke with Maurice Beaudoin, Resident Engineer at the U.S. Army Corps of Engineers' New Bedford Resident Office. Mr. Beaudoin told me to call the dispatcher at the Marine Traffic Control Center to get information concerning restrictions on vessels going through the Hurricane Barrier in New Bedford.

Called the dispatcher at the Marine Traffic Control Center of the US Army Corps of Engineers and asked him about the Hurricane Barrier restrictions on the length, width, and draft of vessels coming into New Bedford Harbor. He told me that the US Army Corps of Engineers manages the hurricane barrier in New Bedford and that they have no specific restrictions on vessels passing through the barrier. He told me that the opening in the hurricane barrier is 150 feet wide and that any vessel with a width smaller than 150 feet the U.S. Army Corps of Engineers allows through. He then told me that the depth of the channel through the hurricane barrier fluctuates with the tide, and that any vessel with a draft small enough to pass through the barrier at that given time the U.S. Army Corps of Engineers allows through. He also told me that the U.S. Army Corps of Engineers does not restrict the length of vessels traveling through the hurricane barrier. He made it clear that any vessel that can physically fit through the hurricane barrier is allowed to navigate though, and that any other specific restrictions would come from the destination of the vessel in New Bedford Harbor.

APPENDIX 13

Apex environmental, inc.	PROJECT	BORING NO. B-101
374 Congress Street, Suite 508 Boston, MA 02210 Phone: 617.728.0070	Rehabilitation of the North, East and South Piers State Pier, New Bedford, Massachusetts DCR Project Number 3540-D	SHEET 1 of 2 FILE NO. 6570.005 CHKD. BY KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692690.5		Easting: 814567.65
Driller	R. Eastwood	Mudline El.	-20.8	Datum	MLW
Logged By	C. Myers	Date Start	6/27/2005	Date End	6/27/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	SAMPLE INFORMATION Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMARKS
1	Push	S-1	24/1	0-2	WOR/24"	0	Black SILT and organics; very soft.		
2	Push						Advance PW drill casing to 5.5 ft. Advance HW drill casing to 5.5 ft.	ORGANIC SILT	
3	Push								
4	Push						Change of drilling resistance at 4 feet.		4.0'
5	Push							GLACIO-FLUVIAL	
6	Push	S-2	24/2	5.5-7.5	21-18-12-8	30	Dark grey fine SAND, trace silt, medium dense.		
7	7						Advance PW drill casing to 10 ft. Advance HW drill casing to 10 ft.		
8	16								
9	14								
10	9								
11	15	S-3	17/13	10-12	84-56-120/6"	176	Top 2": Coarse black SAND, medium dense. Bottom 10": Dark grey fine GRAVEL, some fine to coarse sand, trace silt, gravel subangular and angular (weathered bedrock).		10.5'
12	1						Advance PW drill casing to 18 ft. Advance HW drill casing to 18 ft.	WEATHERED BEDROCK	
13	12								
14	46								14.0'
15							Top of Bedrock at 14 ft. Begin HV rock core at 14 ft. (boring log continued on next page)		
16									
17									
18									
19									
20									

0 to 4 - Very Loose 5 to 10 - Loose 11 to 30 - Medium Dense 31 to 50 - Dense Over 50 - Very Dense	0 to 2 - Very Soft 3 to 4 - Soft 5 to 8 - Medium Stiff 9 to 15 - Stiff 16 to 30 - Very Stiff Over 30 - Hard	1. S denotes split-barrel sampler. 2. U denotes 3-inch O.D. undisturbed sample. 3. UO denotes 3-inch Osterberg undisturbed sample. 4. PEN denotes penetration length of sampler. 5. REC denotes recovered length of sample. 6. SPT denotes Standard Penetration Test.	7. PID denotes Photoionization Detector 8. PPM denotes parts per million. 9. PP denotes Pocket Penetrometer. 10. FVST denotes field vane shear test. 11. RQD denotes Rock Quality Designation. 12. R denotes core run number.

REMARKS:

Apex environmental, inc.	PROJECT	BORING NO.	B-101
374 Congress Street, Suite 508 Boston, MA 02210 Phone: 617.728.0070	Rehabilitation of the North, East and South Piers State Pier, New Bedford, Massachusetts DCR Project Number 3540-D	SHEET	2 of 2
		FILE NO.	6570.005
		CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692690.5	Easting: 814567.65	
Driller	R. Eastwood	Mudline El.	-20.8	Datum	MLW
Logged By	C. Myers	Date Start	6/27/2005	Date End	6/27/2005

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH (feet)	VISUAL REPRESENTATION	CORE INFORMATION: CORE RUN	CORE INTERVAL	CORE TIME	ROCK CORE DESCRIPTION	REMARKS
15		R1	14-15	6 mins.		
16			15-16	5 mins.		
17			16-17	10 mins.	Hard, pink/grey fractured, chrystalline GRANITE; Porphorytic to pegmatitic (in places), medium to coarse grained; quartz, k-spar, plagioclase, biotite visible; 17 fractures (most sub-vertical).	
18			17-18	8 mins.		
19			18-19	5 mins.		
					REC = 100%.	
					RQD = 40% (three sections between 4 and 9 inches in length).	
					End R1 at 19.0 ft.	
					Bottom of exploration at 19.0 ft.; boring terminated in bedrock.	

GRANULAR SOIL DENSITY	COHESIVE SOIL CONSISTENCY		
0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
1)
2)
3)

Apex Environmental, Inc.
374 Congress Street, Suite 608
Boston, MA 02210
Phone: 617.728.0070

PROJECT
Rehabilitation of the North, East and South Piers
State Pier, New Bedford, Massachusetts

BORING NO.	B-102
SHEET	1 of 3
FILE NO.	3540-D
CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692725.36 Easting: 814803.76
Driller	R. Eastwood	Mudline El.	-27.2 Datum MLW
Logged By	C. Myers	Date Start	6/28/2005 Date End 6/28/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMARKS
1	Push	S-1	24/8	0-2	WOR/24"	0	Black SILT and organics; very soft. Strong sulfur odor. Advance PW drill casing to 6 ft.	ORGANIC SILT	
2	Push								
3	Push								
4	Push								
5	Push								
6	Push								
7	Push	S-2	24/8	6-8	WOR-6-13-8	19	Top of split spoon: Black SILT and organics, trace coarse sand, trace fine gravel (up to 1/8" dia.); very soft. Strong sulfur odor.		6.5'
8	Push						Bottom of split spoon: Dark grey coarse sand, trace fine gravel (up to 1/2" dia.), medium dense.	GLACIO-FLUVIAL	
9	30						Advance PW drill casing to 12.5 ft. Advance HW drill casing to 12.5 ft.		
10	30								
11	28						Change in drilling resistance at 10.5 feet.		
12	23								
13		S-3	24/18	12.5-14.5	4-10-12-9	22	Light brown fine SAND, some silt, trace fine gravel (up to 1/8" dia.), lenses of clay; medium dense.		
14	6						Advance PW drill casing to 16.5 ft. Advance HW drill casing to 16.5 ft.		
15	14								
16	25								
17		S-4	24/18	16.5-18.5	WOR-6-12-10	18	Light brown fine SAND, some silt, trace fine gravel (up to 1/8" dia.), lenses of clay; medium dense.		
18	22						Advance PW drill casing to 21 ft. Advance HW drill casing to 21 ft.		
19	24								
20	24								

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
1. Casing blows not recorded below 22 ft. depth.

Apex Environmental, Inc.	PROJECT	BORING NO.	B-102
374 Congress Street, Suite 508	Rehabilitation of the North, East and South Piers	SHEET	2 of 3
Boston, MA 02210	State Pier, New Bedford, Massachusetts	FILE NO.	6570.005
Phone: 617.728.0070	DCR Project Number 3540-D	CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692725.36	Easting: 814803.76	
Driller	R. Eastwood	Mudline El.	-27.2	Datum	MLW
Logged By	C. Myers	Date Start	6/28/2005	Date End	6/28/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMARKS
21	50								
22		S-5	24/18	21-23	1-1-4-5	5	Light brown medium SAND, trace fine gravel (up to 1/8" dia.); loose.		
							Advance PW drill casing to 26.5 ft.		
23							Advance HW drill casing to 26.5 ft.		
24									
25									
26								GLACIO-FLUVIAL	
27		S-6	24/4	26.5-28.5	31-17-10-5	17	Light brown coarse SAND, some fine gravel (up to 1/2" dia.); medium dense.		
28							Advance PW drill casing to 31.5 ft.		
							Advance HW drill casing to 31.5 ft.		
29									
30									
31									
32		S-7	24/0	31.5-33.5	14-9-8-10	21	No recovery. Screening of wash water indicates presence of fine brown SAND.		
33							Advance PW drill casing to 38 ft.		
							Advance HW drill casing to 38 ft.		
34									
35									
36									
37							Change in drilling resistance at 37 feet.		37.0'
38								GLACIAL TILL	
39		S-8	3/3	38-40	120/3"	120	Grey and brown, fine to coarse SAND, little silt, little fine to coarse gravel; very dense.		
							GLACIAL TILL.		
40							Top of Bedrock at 39.5 ft. Begin HV rock core at 39.5 feet. (boring log continued on next page).		39.5'

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
1. Casing blows not recorded below 22 ft. depth.

Apex Environmental, Inc.
374 Congress Street, Suite 508
Boston, MA 02210
Phone: 617.728.0070

PROJECT
Rehabilitation of the North, East and South Piers
State Pier, New Bedford, Massachusetts

BORING NO.	B-102
SHEET	3 of 3
FILE NO.	3540-D
CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692725.36	Easting: 814803.76	
Driller	R. Eastwood	Mudline El.	27.2	Datum	MLW
Logged By	C. Myers	Date Start	6/28/2005	Date End	6/28/2005

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH (feet)	VISUAL REPRESENTATION	CORE INFORMATION: CORE RUN	CORE INTERVAL	CORE TIME	ROCK CORE DESCRIPTION	REMARKS
40.5		R1	39.5-40.5	10 mins.		
41.5			40.5-41.5	10 mins.	Moderately hard to moderately soft blue/grey GNEISS. Foliated and laminated, moderately	
42.5			41.5-42.5	6 mins.	weathered. Easily broken with pressure. Highly fractured (some with slickensides), no section longer than 3 inches.	
43.5			42.5-43.5	7 mins.	REC = 78%.	
44.5			43.5-44.5	7 mins.	RQD = 0%.	
					End R1 at 44.5 ft.	
					Bottom of exploration at 44.5 ft.; boring terminated in bedrock.	
					Boring completed in 3rd gear of drill rig.	

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
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Apex environmental, inc.	PROJECT	BORING NO. B-103
374 Congress Street, Suite 508 Boston, MA 02210 Phone: 617.726.0070	Rehabilitation of the North, East and South Piers State Pier, New Bedford, Massachusetts DCR Project Number 3540-D	SHEET 1 of 3 FILE NO. 6570.005 CHKD. BY KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692743.43	Easting: 814920.4	
Driller	R. Eastwood	Mudline El.	-30.3	Datum	MLW
Logged By	C. Myers	Date Start	6/23/2005	Date End	6/24/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	SAMPLE INFORMATION Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMARKS
1	Push	S-1	24/6	0-2	WOR/24"	0	Black organic SILT, trace fine gravel (up to 1/8" dia.); very soft. Strong sulfur odor.		
							Advance PW drill casing to 6 ft.		
2	Push						Moderately hard, blue/dark grey foliated GNEISS; foliations and fractures on approximately angles, some laminations. Approximately 15 fractures (some with slickenslides).		
3	Push								
4	Push							ORGANIC SILT	
5	Push								
6	Push								6.0'
7	33	S-2	14/0	6-8	10-29-120/6"	149	No recovery. Change in drilling resistance at 6.0 feet. Screening of wash water indicates presence of coarse SAND, trace gravel (up to 1/8" dia.).		
8	30						Advance PW drill casing to 12 ft.		
9	36						Advance HW drill casing to 12 ft.		
10	45								
11	33								
12	57								
13		S-3	24/6	12-14	20-15-9-5	24	Light grey fine to coarse SAND, trace fine gravel (up to 1/8" dia.); medium dense.		
							Advance PW drill casing to 17 ft.		
14							Advance HW drill casing to 17 ft.	GLACIO-FLUVIAL	
15									
16									
17									
18		S-4	24/24	17-19	14-20-28-24	48	Top 18": Light grey fine to coarse SAND, trace gravel (up to 1/8" dia.); dense.		
19							Bottom 6": Fine to coarse GRAVEL, some silt, trace fine sand.		
20							Advance PW drill casing to 24.5 ft. Advance HW drill casing to 24.5 ft.		

0 to 4 - Very Loose 5 to 10 - Loose 11 to 30 - Medium Dense 31 to 50 - Dense Over 50 - Very Dense	0 to 2 - Very Soft 3 to 4 - Soft 5 to 8 - Medium Stiff 9 to 15 - Stiff 16 to 30 - Very Stiff Over 30 - Hard	1. S denotes split-barrel sampler. 2. U denotes 3-inch O.D. undisturbed sample. 3. UO denotes 3-inch Osterberg undisturbed sample. 4. PEN denotes penetration length of sampler. 5. REC denotes recovered length of sample. 6. SPT denotes Standard Penetration Test.
		7. PID denotes Photoionization Detector 8. PPM denotes parts per million. 9. PP denotes Pocket Penetrometer. 10. FVST denotes field vane shear test. 11. RQD denotes Rock Quality Designation. 12. R denotes core run number.

REMARKS:
1. Casing blows not recorded below 12 ft. depth.

Apex environmental, inc.
374 Congress Street, Suite 508
Boston, MA 02210
Phone: 617.728.0070

PROJECT		
Rehabilitation of the North, East and South Piers	BORING NO.	B-103
State Pier, New Bedford, Massachusetts	SHEET	2 of 3
	FILE NO.	6570.005
DCR Project Number 3540-D	CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692743.43		Easting: 814920.4
Driller	R. Eastwood	Mudline El.	-30.3	Datum	MLW
Logged By	C. Myers	Date Start	6/23/2005	Date End	6/24/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV.
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH (ft)	Casing Blows (ft)	SAMPLE INFORMATION Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMKS
21									
22								GLACIO-FLUVIAL	
23									
24							Top of Bedrock at 23.5 ft.	WEATHERED BEDROCK	23.5'
25							Begin HV rock core at 24.5 ft. (boring log continued on next page)		24.5'
26									
27									
28									
29									
30									
31									
32									
33									
34									
35									
36									
37									
38									
39									
40									

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
1. Casing blows not recorded below 12 ft. depth.

Apex environmental, inc.	PROJECT	BORING NO.	B-103
374 Congress Street, Suite 508 Boston, MA 02210 Phone: 617.728.0070	Rehabilitation of the North, East and South Piers State Pier, New Bedford, Massachusetts DCR Project Number 3540-D	SHEET	3 of 3
		FILE NO.	6570.005
		CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692743.43	Easting: 814920.4	
Driller	R. Eastwood	Mudline El.	-30.3	Datum	MLW
Logged By	C. Myers	Date Start	6/23/2005	Date End	6/24/2005

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH (feet)	VISUAL REPRESENTATION	CORE INFORMATION: CORE RUN	CORE INTERVAL	CORE TIME	ROCK CORE DESCRIPTION	REMARKS
25.5		R1	24.5-25.5	5 mins.		
26.5			25.5-26.5	7 mins.	Moderately hard, blue/dark grey foliated GNEISS; foliations and fractures on approximately 45°	
27.5			26.5-27.5	8 mins.	angles, some laminations. Approximately 15 fractures (some with slickenslides).	
28.5			27.5-28.5	3 mins.	REC = 90%.	
29.5			28.5-29.5	9 mins.	RQD = 52% (five sections from 4-6 inches in length).	
					End R1 at 29.5 ft.	
					Bottom of exploration at 29.5 ft.; boring terminated in bedrock.	
					Boring completed in 3rd gear of drill rig.	

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
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Apex environmental, inc.	PROJECT	BORING NO.	B-104
374 Congress Street, Suite 508 Boston, MA 02210 Phone: 617.728.0070	Rehabilitation of the North, East and South Piers State Pier, New Bedford, Massachusetts DCR Project Number 3540-D	SHEET	1 of 2
		FILE NO.	6570.005
		CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692751.14		Easting: 815139.5
Driller	R. Eastwood	Mudline El.	-31.6	Datum	MLW
Logged By	C. Myers	Date Start	6/24/2005	Date End	6/24/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	SAMPLE INFORMATION Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMKS
1	Push	S-1	24/1	0-2	WOR/12"-4-6	4	Black organic SILT, trace shell hash; very soft. Wooden timbers at mudline interefered with initial boring attempt.	ORGANIC SILT	
2	Push						Advance PW drill casing to 6.5 ft. Advance HW drill casing to 6.5 ft.		
3	Push								
4	Push								
5	30								
6	42						Change of drilling resistance at 5 feet.	GLACIO-FLUVIAL	
7	22	S-2	24/2	6.5-8.5	25-24-12-5	36	Light grey fine GRAVEL (up to 1/2" dia.), trace coarse sand; dense.		
8	18						Advance PW drill casing to 12.5 ft. Advance HW drill casing to 12.5 ft.		
9	17								
10	40								
11	117								
12	15								
13	8	S-3	24/12	12.5-14.5	42-62-56-49	118	Fine SAND and SILT, some weathered bedrock fragments (up to 3/4" dia.), trace coarse sand and fine gravel (up to 1/8" dia.), trace clay; very dense.	WEATHERED BEDROCK	
14	5						Tip of split spoon contains weathered bedrock.		
15	4						Advance PW drill casing to 16.4 ft. Advance HW drill casing to 16.4 ft.		
16	12								
17	33						Top of Bedrock at 16.4 ft.		16.4'
18							Begin HV rock core at 16.4 ft. (boring log continued on next page)		
19									
20									

0 to 4 - Very Loose 5 to 10 - Loose 11 to 30 - Medium Dense 31 to 50 - Dense Over 50 - Very Dense	0 to 2 - Very Soft 3 to 4 - Soft 5 to 8 - Medium Stiff 9 to 15 - Stiff 16 to 30 - Very Stiff Over 30 - Hard	1. S denotes split-barrel sampler. 2. U denotes 3-inch O.D. undisturbed sample. 3. UO denotes 3-inch Osterberg undisturbed sample. 4. PEN denotes penetration length of sampler. 5. REC denotes recovered length of sample. 6. SPT denotes Standard Penetration Test.
		7. PID denotes Photoionization Detector 8. PPM denotes parts per million. 9. PP denotes Pocket Penetrometer. 10. FVST denotes field vane shear test. 11. RQD denotes Rock Quality Designation. 12. R denotes core run number.

REMARKS:
1. Recovery for S-2 may be wash from a higher layer.

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PROJECT
Rehabilitation of the North, East and South Piers
State Pier, New Bedford, Massachusetts
DCR Project Number 3540-D

BORING NO.	B-104
SHEET	2 of 2
FILE NO.	6570.005
CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692751.14	Easting: 815139.5	
Driller	R. Eastwood	Mudline El.	-31.6	Datum	MLW
Logged By	C. Myers	Date Start	6/24/2005	Date End	6/24/2005

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH (feet)	VISUAL REPRESENTATION	CORE INFORMATION: CORE RUN	CORE INTERVAL	CORE TIME	ROCK CORE DESCRIPTION	REMARKS
17.4		R1	16.4-17.4	6 mins.	Hard grey/white pegmatitic GNEISS; coarse grained, mostly quartz and feldspar, 4 fractures, sections up to 2 inches in length.	
18.4			17.4-18.4	7 mins.	Hard foliated grey GNEISS with pegmatite stringers in flow structures. GNEISS is fine-medium grained and laminated, pegmatite is mostly quartz and feldspar; 3 fractures, sections up to 5 inches in length.	
19.4			19.4-20.4	5 mins.		
20.4			20.4-21.4	5 mins.	Pink and grey pegmatitic GRANITE; coarse grained; quartz, feldspar, biotite visible; 1 fracture, sections 6 inches in length.	
21.4			21.4-22.4	5 mins.	GRANITE and GNEISS, 1 fracture, sections 6 inches in length.	
					REC = 105%.	
					RQD = 55% (six sections four to six inches in length).	
					End R1 at 22.4 ft.	
					Bottom of exploration at 22.4 ft.; boring terminated in bedrock.	

GRANULAR SOIL CONSISTENCY	COHESIVE SOIL CONSISTENCY		
0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
1)
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Apex environmental, inc.	PROJECT	BORING NO.	B-105
374 Congress Street, Suite 508 Boston, MA 02210 Phone: 617.728.0070	Rehabilitation of the North, East and South Piers State Pier, New Bedford, Massachusetts DCR Project Number 3540-D	SHEET	1 of 3
		FILE NO.	6570.005
		CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692607.71	Easting: 815193.65	
Driller	R. Eastwood	Mudline El.	-29.3	Datum	MLW
Logged By	C. Myers	Date Start	6/21/2005	Date End	6/21/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	SAMPLE INFORMATION Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMKS
1	Push	S-1	24/4	0-2	WOR/24"	0	Black organic SILT, trace fine gravel (up to 1/8" dia.); very soft. Strong sulfur odor.	ORGANIC SILT	
							Advance PW drill casing to 6 ft.		
2	Push								
3	Push								
4	Push								
5	Push								
6	Push								
7	Push	S-2	24/24	6-8	0-0-6-10	6	Top 18": Black organic SILT, trace fine gravel (up to 1/8" dia.); very soft.		
8							Bottom 6": Dark grey coarse SAND, trace fine gravel (up to 1/8" dia.); loose.		7.5'
9							Advance PW drill casing to 12 ft. Advance HW drill casing to 12 ft.	GLACIO-FLUVIAL	
10									
11									
12									
13		S-3	24/24	12-14	3-7-19-45	26	Light grey medium SAND, trace to coarse gravel (up to 1/8" dia.); medium dense.		
							Advance PW drill casing to 18 ft.		
14							Advance HW drill casing to 18 ft.		
15									
16									
17									
18									
19		S-4	24/8	18-20	7-12-9-7	21	Top 4": Light grey fine to coarse SAND, trace fine gravel (up to 1/8" dia.); medium dense. Bottom 4": Black fine to coarse GRAVEL; medium dense.		
20							Advance PW drill casing to 24 ft. Advance HW drill casing to 24 ft.		

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
1. Casing blows not recorded.

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PROJECT
Rehabilitation of the North, East and South Piers
State Pier, New Bedford, Massachusetts
DCR Project Number 3540-D

BORING NO. B-105
SHEET 2 of 3
FILE NO. 6570.005
CHKD. BY KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692607.71	Easting: 815193.65	
Driller	R. Eastwood	Mudline El.	-29.3	Datum	MLW
Logged By	C. Myers	Date Start	6/21/2005	Date End	6/21/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMARKS
21									
22								GLACIO-FLUVIAL	
23									
24									
25		S-5	23/8	24-26	27-20-56-120/5"	76	Light brown fine to coarse SAND, some fine gravel (up to 1/4" dia.), trace silt; very dense.		
26							Weathered bedrock at bottom of split spoon.	WEATHERED BEDROCK	25.5'
27									27.0'
28							Top of Bedrock at 27 ft. Begin HV rock core at 27 ft. (boring log continued on next page)		
29									
30									
31									
32									
33									
34									
35									
36									
37									
38									
39									
40									

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
1. Casing blows not recorded.

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PROJECT
Rehabilitation of the North, East and South Piers
State Pier, New Bedford, Massachusetts
DCR Project Number 3540-D

BORING NO. B-105
SHEET 3 of 3
FILE NO. 6570.005
CHKD. BY KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692607.71	Easting: 815193.65	
Driller	R. Eastwood	Mudline El.	-29.3	Datum	MLW
Logged By	C. Myers	Date Start	6/21/2005	Date End	6/21/2005

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH (feet)	VISUAL REPRESENTATION	CORE INFORMATION: CORE RUN	CORE INTERVAL	CORE TIME	ROCK CORE DESCRIPTION	REMKS
28		R1	27-28	5 mins.		
29			28-29	3 mins.	Hard, grey/pink GRANITE; Porphorytic to Pegmatitic medium grained; quartz, k-feldspar, plagioclase	
30			29-30	6 mins.	and biotite visible. Approximately 13 near-vertical to sub-horizontal (45°) fractures, some with striations/slickensides.	
31			30-31	6 mins.	REC = 100%.	
32			31-32	4 mins.	RQD = 35% (with 5 sections between 4-5 inches in length).	
					End R1 at 32 ft.	
					Bottom of exploration at 32 ft.; boring terminated in bedrock.	
					Boring completed in 3rd gear of drill rig.	

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
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Apex environmental, inc.	PROJECT	BORING NO. B-106
374 Congress Street, Suite 508 Boston, MA 02210 Phone: 617.728.0070	Rehabilitation of the North, East and South Piers State Pier, New Bedford, Massachusetts DCR Project Number 3540-D	SHEET 1 of 2 FILE NO. 6570.005 CHKD. BY KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692450.02		Easting: 815217.24
Driller	R. Eastwood	Mudline El.	-28.6	Datum	MLW
Logged By	C. Myers	Date Start	6/22/2005	Date End	6/22/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	SAMPLE INFORMATION Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMARKS
1	Push	S-1	12/0	0-1	120/6"	0	No recovery. Obstruction present below split spoon.		
2	Push	S-2	24/0	1-3	WOR/24"		Obstruction passed, no recovery for second sample. Water from split spoon indicates presence of black SILT and organics; very soft.	ORGANIC SILT	
3	Push								
4	Push						Change of drilling resistance at 3.5 feet. Advance PW drill casing to 6.5 ft. Advance HW drill casing to 6.5 ft.		3.5'
5									
6									
7		S-3	24/4	6.5-8.5	16-11-13-14	24	Light grey fine to coarse SAND, some fine to coarse (up to 1" dia.); medium dense. Advance PW drill casing to 12.5 ft. Advance HW drill casing to 12.5 ft.		
8									
9									
10									
11								GLACIO-FLUVIAL	
12									
13		S-4	24/12	12.5-14.5	10-9-7-14	16	Light brown fine SAND, trace silt, trace fine to coarse gravel (up to 1" dia.); medium dense.		
14									
15							Advance PW drill casing to 18 ft. Advance HW drill casing to 18 ft.		
16									
17									17.0'
18								WEATHERED BEDROCK	18.0'
19							Top of Bedrock at 18 ft; Begin HV rock core at 18 ft. (boring log continued on next page)		
20									

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
1. Casing blows not recorded.

Apex environmental, inc.	PROJECT	BORING NO.	B-106
374 Congress Street, Suite 508 Boston, MA 02210 Phone: 617.728.0070	Rehabilitation of the North, East and South Piers State Pier, New Bedford, Massachusetts DCR Project Number 3540-D	SHEET	2 of 2
		FILE NO.	6570.005
		CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692450.02	Easting: 815217.24	
Driller	R. Eastwood	Mudline El.	-28.6	Datum	MLW
Logged By	C. Myers	Date Start	6/22/2005	Date End	6/22/2005

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH (feet)	VISUAL REPRESENTATION	CORE INFORMATION: CORE RUN	CORE INTERVAL	CORE TIME	ROCK CORE DESCRIPTION	REMARKS
19		R1	18-19	4 mins.		
20			19-20	8 mins.	Hard pink pegmatitic GRANITE (mostly plagioclase feldspar). Clean (little weathering).	
21			20-21	6 mins.	Approximately 24 fractures (mostly horizontal to sub-horizontal (45°)). Five sections up to 7 inches in length.	
22			21-22	8 mins.	REC = 95%.	
23			22-23	11 mins.	RQD = 50%.	
					End R1 at 23 ft.	
					Bottom of exploration at 23 ft.; boring terminated in bedrock.	

GRANULAR SOIL DENSITY	COHESIVE SOIL CONSISTENCY		
0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
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Apex environmental, inc.	PROJECT	BORING NO. B-107
374 Congress Street, Suite 508 Boston, MA 02210 Phone: 617.728.0070	Rehabilitation of the North, East and South Piers State Pier, New Bedford, Massachusetts DCR Project Number 3540-D	SHEET 1 of 2 FILE NO. 6570.005 CHKD. BY KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692299.25		Easting: 815186.99
Driller	R. Eastwood	Mudline El.	-29.5	Datum	MLW
Logged By	C. Myers	Date Start	6/22/2005	Date End	6/23/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	SAMPLE INFORMATION Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMKS
1	Push	S-1	24/6	0-2	WOR/24"	0	Black organic SILT; very soft. Strong sulfur odor.		
							Advance PW drill casing to 6 ft.		
2	Push						Advance HW drill casing to 6 ft.		
3	Push								
4	Push							ORGANIC SILT	
5	Push								
6	Push								6.0'
7	Push	S-2	24/6	6-8	10-40-30-15	70	Light grey coarse SAND, some gravel (up to 1/8" dia.); very dense.		
							Advance PW drill casing to 10 ft.		
8	38						Advance HW drill casing to 10 ft.		
9	31								
10	37								
11	0	S-3	24/18	10-12	33-33-30-23	63	Light grey to light brown medium to coarse SAND, some fine gravel (up to 1/2" dia.); trace silt; very dense.		
							Advance PW drill casing to 15 ft.		
12	55						Advance HW drill casing to 15 ft.	GLACIO-FLUVIAL	
13	90								
14	61								
15	43								
16	0	S-4	24/8	15-17	26-11-14-31	25	Light brown fine to coarse SAND, few fine (up to 1/4"); medium dense. (top of split spoon)		
17	0								
18	126						Cobble or boulder encountered at 17 ft.		
19									
20							Top of Bedrock at 19.4 ft; Begin HV rock core at 19.4 ft.		19.4'
							(boring log continued on next page)		

0 to 4 - Very Loose 5 to 10 - Loose 11 to 30 - Medium Dense 31 to 50 - Dense Over 50 - Very Dense	0 to 2 - Very Soft 3 to 4 - Soft 5 to 8 - Medium Stiff 9 to 15 - Stiff 16 to 30 - Very Stiff Over 30 - Hard	1. S denotes split-barrel sampler. 2. U denotes 3-inch O.D. undisturbed sample. 3. UO denotes 3-inch Osterberg undisturbed sample. 4. PEN denotes penetration length of sampler. 5. REC denotes recovered length of sample. 6. SPT denotes Standard Penetration Test.	7. PID denotes Photoionization Detector 8. PPM denotes parts per million. 9. PP denotes Pocket Penetrometer. 10. FVST denotes field vane shear test. 11. RQD denotes Rock Quality Designation. 12. R denotes core run number.

REMARKS:

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PROJECT
Rehabilitation of the North, East and South Piers
State Pier, New Bedford, Massachusetts
DCR Project Number 3540-D

BORING NO.	B-107
SHEET	2 of 2
FILE NO.	6570.005
CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692299.25		Easting: 815186.99
Driller	R. Eastwood	Mudline El.	-29.5	Datum	MLW
Logged By	C. Myers	Date Start	6/22/2005	Date End	6/23/2005

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH (feet)	VISUAL REPRESENTATION	CORE INFORMATION: CORE RUN	CORE INTERVAL	CORE TIME	ROCK CORE DESCRIPTION	REMARKS
20.4		R1	19.4-20.4	6 mins.		
21.4			20.4-21.4	6 mins.	Moderately hard dark blue/grey GNEISS. Foliation apparent. Some pegmatitic stringers (mostly quartz and feldspar). Approximately 16 fractures (foliations and fractures mostly at 45° angles), some slickensides. Seven sections between 4 and 8 inches in length.	
22.4			21.4-22.4	4 mins.		
23.4			22.4-23.4	6 mins.		
24.4			23.4-24.4	7 mins.	REC = 95%. RQD = 75%. End R1 at 24.4 ft. Bottom of exploration at 24.4 ft.; boring terminated in bedrock.	

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
1)
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Apex environmental, inc.
374 Congress Street, Suite 508
Boston, MA 02210
Phone: 617.728.0070

PROJECT
Rehabilitation of the North, East and South Piers
State Pier, New Bedford, Massachusetts
DCR Project Number 3540-D

BORING NO. B-108
SHEET 1 of 3
FILE NO. 6570.005
CHKD. BY KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2892266.67	Easting: 814958.77	
Driller	R. Eastwood	Mudline El.	-29.1	Datum	MLW
Logged By	C. Myers	Date Start	6/20/2005	Date End	6/21/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMARKS
1	Push	S-1	24/12	0-2	WOR/24"	0	Black organic SILT, trace fine gravel (up to 1/8" dia.); very soft. Strong sulfur odor. Advance PW drill casing to 5 ft.	ORGANIC SILT	
2	Push								
3	Push								
4	Push								
5	Push								5.0'
6		S-2	24/8	5.5-7.5	12-60-72-54	132	Dark grey fine SAND, little silt, trace fine gravel (up to 1/2" dia.); very dense. Faint sulfur smell. Advance PW drill casing to 12 ft. Advance HW drill casing to 12 ft.	GLACIO-FLUVIAL	
7									
8									
9									
10									
11									
12									
13		S-3	24/18	12-14	0-8-16-8	24	Light brown fine SAND, trace medium to coarse sand, trace silt, trace fine to coarse gravel (up to 1" dia.); medium dense. Advance PW drill casing to 18 ft. Advance HW drill casing to 18 ft.		
14									
15									
16									
17									
18									
19		S-4	24/8	18-20	13-10-13-37	23	Brown fine to coarse SAND, few silt, little fine to coarse gravel; medium dense.		
20							Advance PW drill casing to 21.6 ft. Advance HW drill casing to 21.6 ft.		

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
1. Casing blows not recorded.

Apex Environmental, Inc.	PROJECT	BORING NO. B-108
374 Congress Street, Suite 508 Boston, MA 02210 Phone: 617.728.0070	Rehabilitation of the North, East and South Piers State Pier, New Bedford, Massachusetts DCR Project Number 3540-D	SHEET 2 of 3 FILE NO. 6570.005 CHKD. BY KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692266.67	Easting: 814958.77	
Driller	R. Eastwood	Mudline El.	-29.1	Datum	MLW
Logged By	C. Myers	Date Start	6/20/2005	Date End	6/21/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings				
Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	SAMPLE INFORMATION: Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMKS
21									
22							Top of Bedrock at 21.6 ft.		
							Begin HV rock core at 21.6 ft.		
23							(boring log continued on next page)		
24									
25									
26									
27									
28									
29									
30									
31									
32									
33									
34									
35									
36									
37									
38									
39									
40									

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
1. Casing blows not recorded.

Apex environmental inc.
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PROJECT
Rehabilitation of the North, East and South Piers
State Pier, New Bedford, Massachusetts
DCR Project Number 3540-D

BORING NO.	B-108
SHEET	3 of 3
FILE NO.	6570.005
CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692266.67	Easting: 814958.77	
Driller	R. Eastwood	Mudline El.	-29.1	Datum	MLW
Logged By	C. Myers	Date Start	6/20/2005	Date End	6/21/2005

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH (feet)	VISUAL REPRESENTATION	CORE INFORMATION: CORE RUN	CORE INTERVAL	CORE TIME	ROCK CORE DESCRIPTION	REMARKS
22.6		R1	21.6-22.6	6 mins.	Cobbles and weathered, moderately hard, foliated dark grey-black SCHIST and light grey granitic GNEISS; multiple fractures (top one foot).	
23.6			22.6-23.6	7 mins.	Fractured, Hard, Grey/Pink GRANITE; Porphorytic, medium to fine grained; quatrz, k-spar, plagiochase, biotite visible. Numerous near-vertical to sub-horizontal (45°) fractures (next six inches)	
24.6			23.6-24.6	4 mins.	Highly fractured and broken, foliated GNEISS and dark-grey SCHIST; moderately hard (next four inches).	
25.6			24.6-25.6	12 mins.	Fractured, hard, grey/pink GRANITE; porphorytic medium grained; quartz, k-spar, plagioclase, biotite visible. Four fractures (near vertical to sub-horizontal). REC = 90%.	
26.6			25.6-26.6	6 mins.	RQD = 50% (three sections between four and ten inches long).	
					End R1 at 26.6 ft.	
					Bottom of exploration at 26.6 ft.; boring terminated in bedrock.	
					Boring completed in 3rd gear of drill rig.	

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
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PROJECT
Rehabilitation of the North, East and South Piers
State Pier, New Bedford, Massachusetts
DCR Project Number 3540-D

BORING NO. B-109
SHEET 1 of 2
FILE NO. 6570.005
CHKD. BY KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692238.07		Easting: 814779.88
Driller	R. Eastwood	Mudline El.	-26.3	Datum	MLW
Logged By	C. Myers	Date Start	6/20/2005	Date End	6/20/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMARKS
1									
2		S-1	24/6	1-3	WOR/24"	0	Black organic SILT, trace fine gravel (up to 1/4" dia.); very soft. Strong sulfur odor. Advance PW drill casing to 4.5 ft.		
3								ORGANIC SILT	
4									
5		S-2	24/24	4.5-6.5	WOR/18"-6	0	Black organic SILT, trace fine gravel (up to 1/4" dia.); very soft. Strong sulfur odor. Advance PW drill casing to 10 ft. Advance HW drill casing to 10 ft.		
6									
7							Change in drilling resistance at 7 ft.		7.0'
8									
9									
10									
11		S-3	24/6	10-12	2-6-120/4"		Light brown fine to coarse SAND, trace silt, trace fine to coarse gravel (up to 1 1/2" dia.); loose. (Split spoon completed with 300 lb. hammer after refusal.) Advance PW drill casing to 13 ft. Advance HW drill casing to 13 ft.		
12								GLACIO-FLUVIAL	
13									
14							Roller bit through probable boulder from 13 to 14 feet. Advance PW drill casing to 16 ft. Advance HW drill casing to 16 ft.		
15									
16							Roller bit through probable boulder from 15 to 16 feet. Advance PW drill casing to 17 ft. Advance HW drill casing to 17 ft.		
17									17.0'
18							Top of Bedrock at 17.0 ft. Begin HV rock core at 17.0 ft. (boring log continued on next page)		
19									
20									

0 to 4 - Very Loose
5 to 10 - Loose
11 to 30 - Medium Dense
31 to 50 - Dense
Over 50 - Very Dense

0 to 2 - Very Soft
3 to 4 - Soft
5 to 8 - Medium Stiff
9 to 15 - Stiff
16 to 30 - Very Stiff
Over 30 - Hard

1. S denotes split-barrel sampler.
2. U denotes 3-inch O.D. undisturbed sample.
3. UO denotes 3-inch Osterberg undisturbed sample.
4. PEN denotes penetration length of sampler.
5. REC denotes recovered length of sample.
6. SPT denotes Standard Penetration Test.
7. PID denotes Photoionization Detector
8. PPM denotes parts per million.
9. PP denotes Pocket Penetrometer.
10. FVST denotes field vane shear test.
11. RQD denotes Rock Quality Designation.
12. R denotes core run number.

REMARKS:
1. Casing blows not recorded.

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PROJECT
Rehabilitation of the North, East and South Piers
State Pier, New Bedford, Massachusetts
DCR Project Number 3540-D

BORING NO.	B-109
SHEET	2 of 2
FILE NO.	6570.005
CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692238.07	Easting: 814779.88	
Driller	R. Eastwood	Mudline El.	-26.3	Datum	MLW
Logged By	C. Myers	Date Start	6/20/2005	Date End	6/20/2005

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH (feet)	VISUAL REPRESENTATION	CORE INFORMATION: CORE RUN	CORE INTERVAL	CORE TIME	ROCK CORE DESCRIPTION	REMARKS
18		R1	17-18	6 mins.		
19			18-19	5 mins.	Hard, grey/pink, fractured, GRANITE; porphorytic medium grained; quartz, k-spar, plagioclase,	
20			19-20	3 mins.	biotite visible. Approximately 15 fractures (near vertical to sub-horizontal).	
21			20-21	8 mins.	REC = 90%.	
22			21-22	6 mins.	RQD = 80% (six sections between 4 and 8 inches in length).	
					End R1 at 22 ft.	
					Bottom of exploration at 22 ft.; boring terminated in bedrock.	

STANDARD DESCRIPTION			
0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
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PROJECT
Rehabilitation of the North, East and South Piers
State Pier, New Bedford, Massachusetts
DCR Project Number 3540-D

BORING NO.	B-110
SHEET	1 of 3
FILE NO.	6570.005
CHKD. BY	KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692181.33		Easting: 814470.54
Driller	R. Eastwood	Mudline El.	-6.3	Datum	MLW
Logged By	C. Myers	Date Start	6/15/2005	Date End	6/16/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	SAMPLE INFORMATION Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMARKS
1	Push	S-1	24/0	0-2	WOR/24"	0	No recovery.		
2	Push						Advance PW drill casing to 3 ft.		
3	Push	S-2	24/12	3-5	WOR/24"	0	Black organic SILT, trace fine gravel (up to 1/4" dia.); very soft. Strong sulfur odor.	ORGANIC SILT	
4	Push						Advance PW drill casing to 8 ft. Advance HW drill casing to 8 ft.		
5	Push								5.0'
6								MARINE SAND	
7									
8		S-3	24/18	8-10	12-4-1-1	5	Dark grey SILT and fine to medium SAND, trace shell hash; loose. Faint sulfur smell.		
9							Advance PW drill casing to 12.5 ft. Advance HW drill casing to 12.5 ft.		
10									10.0'
11								GLACIO-FLUVIAL	
12		S-4	24/24	12.5-14.5	24-24-29-18	53	Light brown fine to medium SAND, trace coarse sand, trace fine gravel (up to 1/8" dia.); very dense.		
13							Advance PW drill casing to 19 ft. Advance HW drill casing to 19 ft.		
14									
15									
16									
17									
18							Change in drilling resistance at 18 ft.		
19		S-5	24/12	19-21	70-74-58-57	132	Light brown fine to coarse SAND and fine to coarse gravel (up to 1" dia.), little silt; very dense.		
20							Advance PW drill casing to 24 ft. Advance HW drill casing to 24 ft.		

KEY TO SYMBOLS AND ABBREVIATIONS

0 to 4 - Very Loose
5 to 10 - Loose
11 to 30 - Medium Dense
31 to 50 - Dense
Over 50 - Very Dense

0 to 2 - Very Soft
3 to 4 - Soft
5 to 8 - Medium Stiff
9 to 15 - Stiff
16 to 30 - Very Stiff
Over 30 - Hard

1. S denotes split-barrel sampler.
2. U denotes 3-inch O.D. undisturbed sample.
3. UO denotes 3-inch Osterberg undisturbed sample.
4. PEN denotes penetration length of sampler.
5. REC denotes recovered length of sample.
6. SPT denotes Standard Penetration Test.
7. PID denotes Photoionization Detector
8. PPM denotes parts per million.
9. PP denotes Pocket Penetrometer.
10. FVST denotes field vane shear test.
11. RQD denotes Rock Quality Designation.
12. R denotes core run number.

REMARKS:
1. Casing blows not recorded.

Apex Environmental, Inc.	PROJECT	BORING NO. B-110
374 Congress Street, Suite 508	Rehabilitation of the North, East and South Piers	SHEET 2 of 3
Boston, MA 02210	State Pier, New Bedford, Massachusetts	FILE NO. 6570.005
Phone: 617.728.0070	DCR Project Number 3540-D	CHKD. BY KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692181.33	Easting: 814470.54	
Driller	R. Eastwood	Mudline El.	-6.3	Datum	MLW
Logged By	C. Myers	Date Start	6/15/2005	Date End	6/16/2005

Sampler: 2-inch O.D. split-barrel sampler driven 24 inches with a 140 lb. center hole hammer free falling from a height of 30 inches.
Drill Rig: Barge Mounted ATV
Drilling Method: 5-inch (PW) flush joint casing advanced with a 300-lb. Center hole hammer free falling from a height of 24 inches. 4-inch (HW) flush joint drill stem advanced by spin and wash.

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH	Casing Blows (ft)	SAMPLE INFORMATION Type & No.	PEN/REC (inches)	DEPTH (feet)	BLOWS PER 6 INCHES	SPT N-Value	SAMPLE DESCRIPTION (ASTM D2488)	STRATUM DESCRIPTION	REMARKS
21									
22									
23									
24		S-6	6/0	24-24.5	120/6"	N/A	No recovery. Wash water contains coarse sand and fine gravel (1/8" to 1/4" dia.).		
25							Advance PW drill casing to 28.0 ft. Advance HW drill casing to 28.0 ft.	GLACIO-FLUVIAL	
26									
27									
28									28.0'
29							Top of Bedrock at 28.0 ft. Begin HV rock core at 28.0 ft. (boring log continued on next page)		
30									
31									
32									
33									
34									
35									
36									
37									
38									
39									
40									

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
1. Casing blows not recorded.

Apex environmental inc.	PROJECT	BORING NO.	B-110
374 Congress Street, Suite 508 Boston, MA 02210 Phone: 617.728.0070	Rehabilitation of the North, East and South Piers State Pier, New Bedford, Massachusetts DCR Project Number 3540-D	SHEET FILE NO. CHKD. BY	3 of 3 6570.005 KH

Boring Co.	GeoLogic Earth Exploration Services	Boring Location	Northing: 2692181.33	Easting: 814470.54	
Driller	R. Eastwood	Mudline El.	-6.3	Datum	MLW
Logged By	C. Myers	Date Start	6/15/2005	Date End	6/16/2005

Groundwater Readings Not Applicable for Offshore Borings

Date	Time	Depth	Elev.	Stabilization Time

DEPTH (feet)	VISUAL REPRESENTATION	CORE INFORMATION: CORE RUN	CORE INTERVAL	CORE TIME	ROCK CORE DESCRIPTION	REMARKS
29		R1	28-29	2 mins.		
30			29-30	5 mins.	Moderately hard and severely weathered, dark grey and light grey foliated GNEISS. Moderate	
31			31-32	5 mins.	fabric, laminated texture apparent. Highly fractured, no portion longer than 3 inches.	
32			32-33	4 mins.	REC = 45%.	
33			33-34	3 mins.	RQD = 0%.	
34					End R1 at 34 ft.	
					Bottom of exploration at 34 ft.; boring terminated in bedrock.	

0 to 4 - Very Loose	0 to 2 - Very Soft	1. S denotes split-barrel sampler.	7. PID denotes Photoionization Detector
5 to 10 - Loose	3 to 4 - Soft	2. U denotes 3-inch O.D. undisturbed sample.	8. PPM denotes parts per million.
11 to 30 - Medium Dense	5 to 8 - Medium Stiff	3. UO denotes 3-inch Osterberg undisturbed sample.	9. PP denotes Pocket Penetrometer.
31 to 50 - Dense	9 to 15 - Stiff	4. PEN denotes penetration length of sampler.	10. FVST denotes field vane shear test.
Over 50 - Very Dense	16 to 30 - Very Stiff	5. REC denotes recovered length of sample.	11. RQD denotes Rock Quality Designation.
	Over 30 - Hard	6. SPT denotes Standard Penetration Test.	12. R denotes core run number.

REMARKS:
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APPENDIX 14

Apex Companies, LLC

184 High Street, Suite 502, Boston, MA 02110

(617) 728-0070

DATE: Wed. Aug. 11th, 2010

TIME: 12:45pm

☐ Incoming Call X Outgoing Call ☐ Return Call

CONTACT:

Name: Ed DeWitt, Manager

Address: New Bedford Airport
1569 Airport Road
New Bedford, MA 02746

Project Name: New Bedford Harbor Phase IV

Project No.: 6690

Phone: 508-991-6161

SUMMARY OF CONVERSATION:

Spoke with Ed DeWitt, the manager of the New Bedford Airport. Asked him whether there are any height restrictions surrounding the New Bedford Airport. He said that the New Bedford Airport's height restrictions involve a radius around the airport, and only reach as far south as Popes Island within New Bedford Harbor.

Specifically asked about the location within which the South Terminal CDF project is to occur. Mr. DeWitt stated that the proposed South Terminal CDF location does not lie within New Bedford Airport's height restricted area, and Mr. DeWitt agreed that since the South Terminal project will be located south of Popes Island, the New Bedford Airport will cause no overhead restrictions on the height of objects (i.e. cranes or spuds) on the South Terminal Project site.

APPENDIX 15

APPENDIX K

Port of New Bedford South Terminal Business Plan

Port of New Bedford South Terminal Business Plan

Prepared by

FXM ASSOCIATES
Po Box 660
53 County Rd
Mattapoisett, MA 02739

Massachusetts Port-Wind Energy Project

Technical Memorandum

Port of New Bedford South Terminal Business Plan

To: Ken Fields, Project Manager via e-mail: ken.fields@tetratech.com
TetraTech
From: FXM Associates
Date: December 22, 2009 (*Revised January 5, 2010)*

I. Introduction

This technical memorandum summarizes the analysis and findings of work accomplished by FXM Associates in preparing a preliminary business plan for a multi-use cargo facility at South Terminal in the Port of New Bedford. The context for the business plan is three-fold:

- The concurrent "Port and Support Infrastructure Analysis for Offshore Energy Development Study," commissioned by the Massachusetts Renewable Energy Trust, and being prepared by the TetraTech consultant team of which FXM Associates is the economic consultant;
- *2009 New Bedford/Fairhaven Municipal Harbor Plan,* prepared by the New Bedford Harbor Development Commission (HDC) which describes port assets, needs, and market opportunities with recommended port development initiatives and infrastructure projects to sustain, grow, and diversify the local maritime economy; and
- City of New Bedford's "Integrated Intermodal Transportation Infrastructure Improvements Plan" description of the South Terminal Renewable Energy Marine Park development in its recent application for US DOT TIGER Grant ARRA funding.

FXM's specific assignment is to (1) identify potential revenues and cargoes for the South Terminal facility, in addition to a Representative Offshore Wind Energy Installation (ROWEI); (2) identify an appropriate governance model for multi-use terminal ownership, development, and management; and (3) prepare a preliminary terminal business plan with operating *pro forma*. This Technical Memorandum incorporates portions of the draft report prepared by Captain Jeffrey Monroe that describes port management and terminal operation models, optimum and cost-effective models for support of offshore wind energy installation projects as well as other cargo types; the capital cost estimates for the South Terminal facility developed by Childs Engineering based on critical review of the City's TIGER Discretionary Grant application and other sources; and other capital and operating cost estimates prepared by the consultant team.[1]

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[1] *Comparison of Selected Northeast Ports for Potential Handling of Wind Power Offshore Energy Installations,* Captain Jeffrey Monroe, MAI (Draft October 2009); *South Terminal Capital and Maintenance Costs Spreadsheets,* Dave Porter, Childs Engineering (November 30, 2009).

FXM also considered input from its specialized affiliates regarding other potential cargo uses at the expanded South Terminal facility for the long term financial sustainability of the project.

FXM examined prospective demand, port governance/terminal management, overall development feasibility, and potential economic effects associated with developing and operating a multi-use Renewable Energy Terminal and General Cargo facility at South Terminal in the Port of New Bedford. This assessment was based on information obtained from the client/project consultant team, public and secondary data sources as referenced, as well as FXM independent research on potential cargo types and revenues to the facility owner other than those that are related to a representative offshore wind energy installation project(s). *An essential question to be answered in this report was whether and to what extent the South Terminal facility could be self-sufficient (that is, not require annual operating subsidies) during or after its use for offshore wind energy development*[2]. As such, this report focuses specifically on the proposed South Terminal project and does not address "quick response" or other possible options for handling Cape Wind's proposed project, or other prospective wind energy development projects that might be staged from New Bedford.

The following assumptions, drawn from related work of the consultant team, discussions with Cape Wind and City of New Bedford officials, underlie FXM's analysis:

- South Terminal represents the best option for the Port of New Bedford to capture off-shore wind developers, as well as other international and I-95 Coastal Highway cargo shipments.

- North Terminal may be useful for off-shore wind related or other cargo shipments to the port by rail until the Route 6 Bridge is replaced to eliminate current navigation/vessel impediments.

- The City of New Bedford or HDC will acquire an approximate 15-acre site in the South Terminal Area referenced in their TIGER grant application, finalize state/federal permit approvals in conjunction with the SER regulatory process, and complete final design and construction for a new, expanded South Terminal bulkhead, pier and dredged berthing areas, and other landside improvements to accommodate offshore wind energy installations and other potential cargo shipments/handling/storage/transshipments.

- Prospective South Terminal offshore renewable energy installation (OREI) users will have the technical capacity, permits, and financial capability to assemble/fabricate and ship to an offshore construction site OREI equipment and materials from a South Terminal facility. The South Terminal facility will include suitable depth of water, pier facilities, and backland/storage space to handle offloading, storage, assembly and loading of machinery and equipment to the offshore construction site. It is FXM's understanding, based on input received from other study team members, that all terminal operations, including contracted shipping, stevedoring and other labor, maintenance, insurance, equipment, and supplies will be borne by the Developer and that – based on ROWEI filings to date – the owner of the

[2] Cape Wind is the "representative" project example (ROWEI) used throughout this report but is not the only potential offshore wind energy development project that could be staged from South Terminal

South Terminal facility will receive approximately $1.5 million in lease payments for each year of the ROWEI's 3-year projected construction/installation period ($4.5 million total).

- A ROWEI may require the Developer to lease the entire South Terminal project area during the peak construction period, but the terminal facilities will accommodate other break-bulk, bulk, and container cargo as identified in this report. The Terminal owner will use suitable contracting/leasing and other arrangements as noted in this report to manage an effective multi-use terminal facility. Other prospective port calls related to reported HDC contacts with shipping companies, Port of Jacksonville, Port of Bayonne, and other American Maritime Highway (AMH) 'port pair' cities may represent additional cargo handling opportunities and potential revenue at the new South Terminal facility, although the cargo opportunities, business plan and operating *pro forma* developed in this report are sufficient to answer the questions FXM was contracted to address for this study.

This technical memorandum subsequently includes **Summary Findings** (Section II, page 4); and sections reporting the research and analyses accomplished on **Potential Cargo and Revenues** (Section III, page 8); **South Terminal Ownership, Development, and Management** (Section IV, page 12); **South Terminal Development Costs, Operating Income and Expenses** (Section V, page 19); and **Economic and Tax Effects of South Terminal Construction and Operation** (Section VI, page 22). It should be noted that economic effects of the ROWEI project's development and annual maintenance are NOT included in the economic and tax effects attributable specifically to South Terminal since at least one other Massachusetts port (Boston) may be capable of accommodating potential offshore wind energy development projects. Annual operating and maintenance economic and tax effects of the ROWEI are also not included in this report since they can be handled at other ports. In the event that the South Terminal facility represents an option for offshore wind energy developers that enables them to choose a Massachusetts port over a non-state facility – that is, Massachusetts facilities other than South Terminal are not competitive for a specific offshore wind energy development project – then the construction period effects of that project could be attributable to construction and operation of the South Terminal facility. Economic and tax effects of the ROWIE are discussed in FXM's technical memorandum "Economic Effects of Offshore Wind Energy and Related Construction and Operating Expenditures".

II. Summary Findings

- A new multi-use cargo facility at the South Terminal site represents the best option in the Port of New Bedford for servicing offshore wind energy development projects during assembly and installation phases.

- A new multi-use port facility at South Terminal can capture container, break bulk, and bulk cargoes not now handled in New Bedford or other Massachusetts ports, and can generate economic development benefits and net operating income to the HDC *with* or *without* offshore wind energy development projects.

- The optimal model for governance of the proposed new facility at South Terminal will be ownership by the New Bedford Harbor Development Commission (HDC) which would lease offshore wind energy installations and other cargo handling, storage, and related facility operations to a qualified private operator.

- Capital costs for a new multi-use port facility at South Terminal are estimated to total about $44 million (in 2009 dollars). Approximately $32 million of this total investment is for land acquisition, bulkhead construction and dredging, buildings and site improvements that are considered functionally necessary to attract and support offshore wind energy development projects, with an additional $5 million in capital expenditures ($37 million total) considered functionally necessary to attract and support new bulk, break bulk, and container cargoes. Capital costs are shown in the text table below:

SOUTH TERMINAL CAPITAL COSTS	**Offshore Wind Installation**	**Non-Offshore Wind Cargoes**
Bulkhead and Dredging	$ 19,990,977	$ 19,990,977
Site Acquisition	$ 2,100,000	$ 2,100,000
Backland Site Improvements (drainage, utilities, surfacing)	$ 6,000,000	$ 6,000,000
SUBTOTAL Basic Infrastructure	**$ 28,090,977**	**$ 28,090,977**
Buildings and structures (35,000 SF)	$ 3,500,000	$ 3,500,000
Crane		$ 3,000,000
Ground Equipment (fork lifts, trucks, etc.)		$ 1,500,000
Other Equipment & Fencing, Security	$ 485,000	$ 485,000
SUBTOTAL with Support Facilities & Equipment	**$ 32,075,977**	**$ 36,575,977**
Optional Fabrication Building (75,000 SF)	*$ 7,500,000*	*$ 7,500,000*
TOTAL with Fabrication Building	***$ 39,575,977***	***$ 44,075,977***

- *Net* operating income to the HDC from the fully-developed South Terminal port facility would total about $1.2 million per year during a projected 3-year representative offshore wind energy development project. Absent other wind energy developers use of the site, which might contribute higher net operating income, *net* income to the HDC is projected to average about $620,000 per year with full cargo operations. Potential operating revenues and costs are shown in the text table below:

SOUTH TERMINAL OPERATING INCOME & EXPENSES	Offshore Wind Installation	Non-Offshore Wind Cargoes
Average Year Annual Operating Income		
Offshore Wind Energy Development (ROWEI)	**$ 1,500,000**	
Container Service		$ 280,000
Break Bulk Program		$ 240,000
Bulk Cargo		$ 432,500
Total Non-ROWEI Cargo		**$ 952,500**
Average Year Annual Operating Expenses		
HDC Personnel (contract/lessee management)	$ 140,000	$ 140,000
HDC Capital/maintenance reserve at 20% income	$ 190,500	$ 190,500
Average Year Annual Expenses	*$ 330,500*	*$ 330,500*
Average Year NET Operating Income		
Offshore Wind Energy Development (ROWEI)	**$ 1,169,500**	
Total Non-ROWEI Cargo		**$ 622,000**

- Based on the net operating income projected for South Terminal, annual operating subsidies for either wind energy development support or long term cargo operations at South Terminal are not anticipated to be required.

- Net income from South Terminal operations could be used to stimulate additional economic development (jobs, income, business sales in the fishing and seafood or other industries) in the port of New Bedford as well as to finance some portion of South Terminal's capital cost.

- Construction of the South Terminal port facility is estimated to expand business output in *Bristol County* by about $44.1 million over the projected 2-year construction period, providing 380 person years of employment and $19.2 million in household income over the construction period. These economic impacts include total direct, indirect and induced economic effects within Bristol County.

- Construction of the South Terminal port facility is estimated to expand business output in *Massachusetts* overall (including Bristol County) by about $65.5 million over the projected 2-year construction period, providing 540 person years of employment and $26.1 million in household income over the construction period. These economic impacts include total direct, indirect and induced economic effects within Massachusetts over the construction period.

- The handling of cargoes not related to an offshore renewable wind energy installation (OREI) -- including container, break bulk, and bulk cargoes projected for South Terminal -- is estimated to expand business output in *Bristol County* by $15.7 million **annually**, providing 130 permanent jobs and $5.9 million in new household income each year. These economic impacts include total direct, indirect, and induced economic effects within Bristol County

estimated to recur annually following facility construction and do not include support of offshore wind energy projects.

- The handling of non-OREI container, break bulk, and bulk cargoes projected for South Terminal is estimated to expand business output in *Massachusetts* overall (including Bristol County) by $20.2 million **annually**, providing 170 permanent jobs and $7.4 million in new household income each year. These economic impacts include total direct, indirect, and induced economic effects within Massachusetts estimated to recur annually, not including offshore wind energy projects. Both construction period and annually recurring direct, indirect, and induced economic effects noted in the preceding bullet points are summarized in the text table below:

		Output (000 $)	Employment (Jobs)		Income (000 $)
Construction Period Effects					
South Terminal Port Facility					
Bristol County	*$*	*44,100*	*380*	*$*	*19,200*
Massachusetts	$	65,500	540	$	26,100
Annual Operating Effects					
South Terminal Port Cargo Operations					
Bristol County	*$*	*15,700*	*130*	*$*	*5,900*
Massachusetts	$	20,200	170	$	7,400

Source: FXM Associates, RECON™ Input Output Model

- During the construction period for the South Terminal facility about $480,000 in municipal revenues within *Bristol County* communities would be attributable to the total direct, indirect and induced economic effects of construction, and within *Massachusetts* communities overall $1.2 million in municipal receipts (including Bristol County) would be attributable to the construction period economic effects.

- During the construction period for the South Terminal facility about $1.4 million in tax revenues to the *Commonwealth of Massachusetts* and $7.3 million in federal taxes would be attributable to the construction period economic effects.

- The handling of non-OREI container, break bulk, and bulk cargoes projected for South Terminal would generate about $300,000 in new tax receipts **annually** to municipalities in Bristol County and $480,000 to municipalities statewide (including Bristol County) each year based on the annual economic effects attributable to cargo operations.

- The handling of non-OREI container, break bulk, and bulk cargoes projected for South Terminal would generate about $500,000 in new tax receipts **annually** to the Commonwealth of Massachusetts and $2.2 million in federal taxes each year. Both construction period and

III. Potential Cargo and Revenues

In a study comparing Northeast ports for OREI cargo handling, the Port of New Bedford is described as already an active freight seaport and a major logistical connection for agricultural products entering the New England market.[3] Highway connections are good and the port would benefit from expanded and improved rail connections to meet freight needs. New Bedford is a small niche port that can continue to expand activities with some infrastructure improvements and investment. The port has sufficient deep water access for the size and type of vessel common to most break-bulk and other cargo available to niche ports, and has available property for backland storage and expansion.

Related Reports by Others

In the City's TIGER Grant application, the HDC anticipates that the Renewable Energy Marine Park at the extended South Terminal will become a construction staging facility for offshore wind farm energy production in New England. The first offshore wind farm that is expected to be developed in New England (Cape Wind) is anticipated to generate up to 420 megawatts of clean, renewable energy. The planned infrastructure improvements and facility development could enable South Terminal Marine Park to become a key connection and marine terminus for renewable energy development projects on the coastline of New England, in addition to the Cape Wind project. Movement of container shipping from ports south of New Bedford will also help to reduce truck traffic on the heavily traveled I-95 corridor.

The HDC envisions development of South Terminal, a new deep water berth and cargo facility, to enhance and modernize the Port of New Bedford's vessel handling ability. The proposed development program for a multi-use South Terminal facility will service the Cape Wind 130 wind turbine project's assembly and installation phase and possibly foster additional local economic development. Following the completion (construction and installation) of the Cape Wind project, South Terminal will be available to other deep sea cargo operations for port services. The new customers will bring additional dockage, wharfage, and lease income to support HDC's long term port infrastructure investments. This section of the business plan identifies market opportunities and prospects for the new South Terminal facility which offer reasonably foreseeable cargo options for which the facility can be used after the completion of the proposed Cape Wind (and/or other) offshore renewable energy projects.

The City's TIGER Grant application references HDC's business development contacts with the Port of Jacksonville, the Port of Bayonne, and shipping companies as indicative of demand for AMH/SST (American Marine Highway/Short Sea Transport) services at the Port of New Bedford. The HDC has been approached by multiple shipping companies, some of which say they are willing to manufacture vessels especially for shipping to the Port of New Bedford. One shipping company indicated its willingness to transport up to 500 Container Equivalent Units (TEUs) per day to New Bedford once the proper facility improvements are in place to facilitate moving forward with shipping. The Reeve & Associates March 29, 2006 report estimated that

[3] *Comparison of Selected Northeast Ports for Potential Handling of Wind Power Offshore Energy Installations,* Captain Jeffrey Monroe, MAI (November 2009)

$45 million of direct income and $72 million indirect income per year in the New Bedford region would be generated by short-sea shipping. While AMH services have been slower than expected to materialize (based on unanticipated drops in oil prices compared to projections just 2 to 3 years ago), over the next several years these opportunities are expected to rekindle shipper interest.

Consultant Team Cargo and Revenue Projections

The following tables summarize three types of cargo potential based on the experience and judgment of existing operators in New Bedford and other port logistics experts. The types of cargoes projected for a fully developed South Terminal facility (see subsequent discussion in Section IV) include containers, break bulk, and bulk cargoes that are not now handled at the Port of New Bedford, and do not include the transfer of any cargo handling operations currently being carried out at other facilities in New Bedford (State Pier, Maritime Terminal, Fish Island, and North Terminal) or at other Massachusetts ports. Thus their economic and fiscal effects will be net new to New Bedford and to the State overall (see Section VI). The tables also identify the revenue implications for the facility owner assuming a public ownership/private lessee operating model (see subsequent discussion of port governance/management options in Section IV). *Revenues shown are net to the facility owner and the lessee is assumed to cover all operating, maintenance, insurance, and related costs of handling, storing, and transshipping the cargoes.* Data in Table 4 (page 19, Section V) summarize potential operating income and expenses, as well as capital costs, for South Terminal including the handling of a representative offshore wind energy installation project.

It is important to keep in mind that, in the experience of both niche and larger port operators, obtaining cargo for a port is a complex matching of pier and landside facilities and equipment, stevedoring and other labor costs, and point-to-point logistics involving specific shippers, carriers, and receivers. Cargoes can be won or lost to a port on very small variations in cost and delivery times, and success is largely driven by the motivation and skill of individual business entrepreneurs and public officials. Macro projections of commodity demands or cargo potential are not reliable for forecasting niche port operations.

annually recurring direct, indirect, and induced tax effects noted in the preceding bullet points are summarized in the text table below:

	Local Taxes (000 $)	State Taxes (000 $)	Federal Taxes (000 $)
Construction Period Effects			
South Terminal Port Facility			
Bristol County	*$ 480*	*$ 440*	*$ 1,820*
Massachusetts	$ 1,190	$ 1,440	$ 7,280
Annual Operating Effects			
South Terminal Port Operations			
Bristol County	*$ 300*	*$ 240*	*$ 730*
Massachusetts	$ 480	$ 500	$ 2,180

Source: FXM Associates, RECON™ Input Output Model

Table 1 – Potential Container Service at South Terminal

Program:	**Container Service**	
Mission:	Developing a terminal capable of handling a regular shipping service	
	for a small container route	
Goal:	Marketing a small container terminal which can bring 4,800	
	equivalent units (TEUs) per year	
Objectives:	Increase revenues for the South Terminal	
	Provide jobs and sales for local/regional/state businesses	
Revenues		
User fees per TEUs	$ 35	TEU
Yearly TEUs	4,800	
Total revenue	$168,000	
Dockage daily rate	$ 1,000	Daily
24 port calls at 2 days each	48	
Total dockage	$ 48,000	
Cross docking, wharfage	$ 2	Net ton
	2,500	
	$ 3,750	
Monthly licensing fees	$ 5,000	Monthly
Container yard	12	
Yearly revenue	$ 60,000	
Container revenue	**$279,750**	

Table 2 – Potential Break-Bulk Cargo at South Terminal

Program:	**Break-bulk Program**	
Mission:	Developing a terminal capable of handling refrigeration of dry	
	break-bulk cargo	
Goal:	Marketing a port terminal and warehouse which can bring 50,000	
	net metric tons of general break-bulk cargo per year	
Objectives:	Increase revenues for the South Terminal	
	Provide jobs and sales to local/regional/state businesses	
Revenues		
Wharfage per net metric ton	$ 2	Net ton
Yearly tonnage	50,000	
Total revenue	$ 75,000	
Dockage daily rate	$ 1,000	Daily
20 port calls at 2 days each	40	
Total dockage	$ 40,000	
Warehouse licensing fees	$ 2,500	Monthly
	12	
Yearly revenue	$ 30,000	
Storage revenue	$ 3	Net ton
	50,000	
	$125,000	
Break-bulk revenue	**$240,000**	

Table 3 -- Potential Bulk Cargo at South Terminal

Program:	**Bulk cargo**	
Mission:	Developing a terminal capable of handling bulk cargo including	
	aggregates and salt	
Goal:	Marketing a port terminal suitable for 150,000 metric tons of salt and	
	aggregates per year	
Objectives:	Increase revenues for the South Terminal	
	Provide jobs and sales to local/regional/state businesses	
Revenues		
Wharfage per net metric ton	$ 2	Net ton
Yearly tonnage	150,000	
Total revenue	$ 300,000	
Dockage daily rate	$ 1,000	Daily
10 port calls at 2 days each	20	
Total dockage	$ 20,000	
Gate fees per truck	$ 15	Per truck
20 tons per load	7,500	
Total gate fee	$112,500	
Bulk revenue	**$432,500**	

IV South Terminal Ownership, Development, and Management

Port Governance & Management

Ports need to function in a manner whereby they can control their finances, development, and management outside of unrelated political forces. The most effective port agencies are those that are self governing and self funding, and port management revolves around one essential factor: the ownership of property, which in most cases is retained for some public benefit. Quasi-governmental ports or commissions are created by State legislatures to allow separate governance but are dependent on the local or state government for funding and project approvals. Public port authorities are entities also created by state legislative action with independent management and bonding authority to focus on commercial marine terminal activities and can include other operations such as airports, marinas, real estate development, and rail or highway infrastructure.

Harbor Development Commission

The New Bedford Harbor Development Commission (HDC) was created by the Massachusetts General Court under Chapter 762 of the Acts of 1957 to serve as the governing entity for the Port. Chaired by the Mayor, the Commission consists of 7 members as appointed by the Mayor and approved by City Council. The crucial day-to-day operation and decision making are the responsibility of the HDC staff headed by the Executive Director. The HDC has jurisdiction over all the waters in New Bedford including the entire coastline of the peninsula, the harbor, and north along the Acushnet River to the City's boundaries. The HDC manages 20 commercial properties, a 198-slip marina on Pope's Island, the ferry terminal on State Pier and its supporting Whales Tooth Parking Lot, 5 piers and wharves, 10 mooring fields, and enforces rules regarding the use of piers, wharves, and adjacent parking areas under its jurisdiction. Being autonomous from City government, user fees, rents, and all other revenue streams do not go to the General Fund, but rather are reinvested by the HDC to support its operations, properties, infrastructure needs, and economic development initiatives. The HDC may borrow and issue municipal bonds for capital improvements. The goal of the HDC is to "support the maritime businesses of the Port, seek out new opportunities, and maximize the natural competitive advantage the Port provides to the New Bedford economy."

Optimal Port Governance Model

The HDC structure is an optimal management model for the Port of New Bedford governance, and the City of New Bedford and Town of Fairhaven have a long established inter-municipal approach to sustaining and growing the port. The *2009 New Bedford/Fairhaven Municipal Harbor Plan* identifies key port infrastructure/facility projects and port development priorities. The Port of New Bedford governance and management have many of the characteristics associated with optimal port models which are summarized below.

- *Separately Enabled*: An effective port agency is established as a separate incorporation with its own management, bonding authority, and ability to secure and retain revenue.

- *Community Connections*: Communities with port entities are best served when they have the ability to appoint governing boards with members who are committed to the vision and effective operation of the port.

- *Professional Staff:* Ports must hire and task professional port managers and staff who are trained and familiar with the port industry and its numerous complexities.

- *Effective Administration*: Agency administration should not be expansive but should be capable of supporting the mission of the port, including financial and legal services.

- *Optimized Assets*: Seaports are among several shared community assets, including airports, freight rail lines, public transit, and other transportation networks and services. Communities can optimize effectiveness by combining administration of some or all of these assets into an integrated system or into a single transportation authority.

- *Effective Marketing and Development*: Commercial growth is the result of an effective marketing plan coupled with an investment strategy that supports flexible development of assets. Many ports languish because they have limited staffs that are expected to manage, maintain, and market facilities. In most cases these efforts are unsuccessful because of insufficient resources.

- *Strategic Planning*: Port agencies need to have a concise strategic and business plan which is developed in cooperation with the local community and port stakeholders and has focused implementation.

South Terminal Ownership

Agency ownership includes port authorities or other agencies that are quasi-governmental and created by an act of a legislative body. Private ownership facilities are those that are fully in the control and ownership of a private corporation. Public ownership of the expanded South Terminal and OREI terminal facility is an underlying premise of this business plan, and the HDC will own and develop the terminal facility, and also may own/lease/rent terminal equipment such as mobile harbor cranes and load stackers.

South Terminal Development

The South Terminal Renewable Energy Marine Park is a component of the City's Integrated Intermodal Transportation Infrastructure Improvements Plan 2 for which the HDC has requested about $20 million of USDOT TIGER Discretionary Grant funds.[4] New Bedford seeks to emerge as a leader in alternative energy and build its Port and landside infrastructure to support the operations of renewable energy technology companies. Renewable energy industrial companies require waterfront support facilities for the manufacture, assembly, shipping, and maintenance of products such as wind blades, turbines, solar panels, wave energy turbines, and related products.

[4] *Integrated Intermodal Transportation Infrastructure Improvements,* New Bedford Harbor Development Commission (September 15,2009)

The HDC seeks to develop the southern portion of South Terminal to accommodate the nascent energy industry, with the long term goal of attracting a significant number of skilled manufacturing and operator jobs to the City of New Bedford. The project as proposed utilizes existing infrastructure which is to be enhanced and/or reconfigured. In-water and waterside development in New Bedford Harbor are afforded a unique permitting status so long as they are related to enhancements of the U.S. Environmental Protection Agency's ongoing superfund cleanup of the harbor. The expansion of South Terminal would require the filling of wetland resource area to create additional bulkhead space within the Harbor; however, portions of these resource areas are inundated daily with water and suspended sediment from the harbor which have elevated levels of heavy metals and PCBs. The bulkhead would allow for the construction of a Confined Disposal Facility (CDF), described by the City as a "Waterfront Development Facility (WDF)." The construction of the WDF would allow for continued confinement, monitoring and maintenance of contaminated sediments.

The City's TIGER Grant application characterized the southern portion of South Terminal as currently severely underutilized, and lacking sufficient space to utilize the area as a RO/RO terminal for prospective AMH cargo shipments. However, extension of the bulkhead will allow use of the contiguous 15-acre site as a multi-use marine terminal and potentially invite future renewable energy industry services, as well as provide additional storage and staging for containers and trucks at other port terminals (State Pier, North Terminal, Maritime Terminal). The new South Terminals facility also could be suitable for temporary relocation of maritime operations to expedite planned State pier reconstruction.

HDC procurement of heavy-lift cranes to unload containers and bulk goods and installation of RO/RO ramps are identified as very important steps in improving existing port facilities to be able to take advantage of anticipated AMH shipping as well as other container, break-bulk, and bulk cargoes. The multi-use South Terminal facility must also meet the OREI developer specifications, and be flexible and adaptable to short-sea shipping services, including the transport of ocean containers, aggregates, bulk, and dry break-bulk cargo as well as berth and vessel limitations with these requirements[5]. The development program outlined below will accommodate the longer term cargo opportunities identified earlier in this report.

Development Program

- An expanded 1,000 linear-foot bulkhead with a 50' apron to accommodate one large vessel and two small cargo vessels or barges simultaneously.

- Vessel operations involving container, bulk, break-bulk cargo, and sea barges need a depth of minimum 25' LLMW, and 30' LLMW is recommended for a maximum potential yield at this new facility in the years to come. The existing Federal channel and road from and to the port is at 30' of depth which allows any vessel and large barges to come into New Bedford Harbor with up to a 28' draft (8.50 meters) including a minimum allowance of 2' under the keel for safe navigation that accounts for the propeller wash. If the berth and the channel are dredged at only 25' (7.60 meters) a safe allowance for sailing would be 23' (7.0

[5] At the writing of this report, it is FXM's understanding that the development program specified also meets Cape Wind requirements.

meters) and at 22' (6.7 meters) the safe allowance is at 20' (6.0 meters). Additional details and guidance concerning vessel transit into New Bedford harbor can be obtained from the Northeast Marine Pilot Association.

- A 50' apron would be ideal to offload containers and other break-bulk commodities including over-dimensional cargoes. Container chassis could safely jockey under the vessel crane or a shore crane for the pickup and delivery of ocean containers.

- A 35,000 square feet (SF) building with office, shop, and storage spaces providing 5,000 SF of office and shop area, and a 30,000 SF cargo storage shed (about 20% larger than the existing State Pier building No. 2 building). A 35,000 SF facility with a minimum roof height of 27' would be ideal. It is imperative that this building design accommodate break-bulk cargo operations, and that the eastern end of the shed be at the same level as the berth apron. The western end should be where the loading docks are located at the standard 4' elevation. Roll-on and roll-off (RO/RO) transport units, trucks, and forklifts must be able to travel freely from the pier apron to the northern and southern entrances of the building.

- A building of 250' x 140' at a distance of no more than 100' from the berth fenders will be ideal for handling of break-bulk cargoes. The building must be built length parallel to the berth with the offices being located on a second level at the northwest corner, above a 60' x 40' shop for optimum space utilization. A loading dock with a least ten loading bays is to be located on the west side of the building. Doors at the north and south end of the cargo shed would allow for over-dimensional pieces to travel inside the cargo shed.

- The cargo shed's location to the 600' berth needs to be precise if the intent for the South Terminal is to be an efficient multi-purpose facility. The cargo shed's optimal position would be at the northeast section of the berth allowing for the southeast to be available for the handling of bulk aggregates or bulk salt.

Acreage

The expanded multi-use South Terminal facility will encompass a 15-acre terminal (about 653,400 SF) with the following land use allocations:

- 5 acres -- cargo shed operation including parking for 30 trucks and the needed space for maneuvering tractor trailers and the loading dock for 10 trucks is estimated to use about 5 acres of land.

- 10 acres -- available for paved container yard or to store bulk salt and aggregates and/or for other found purposes including additional cargo facilities.

A small container service of 200 forty-foot equivalents per vessel call will require about 2.5 acres of space for single stacked storage and less when the boxes are double stacked with a top pick forklift (empties stack three high). The concurrent inbound and outbound movement of containers, including the storage of empty boxes, would thus require 5 acres of land in total.

The vessels that carry bulk salts can no longer economically unload in New Bedford at a facility on the north side of the New Bedford-Fairhaven Bridge. The space allocation for this cargo assessed on the angle of repose can be supplied by the shipper, Morton Salt, which typically drops 50,000 MT or more per vessel call. For the purpose of this business plan, FXM has allocated 5 acres for all aggregates.

Development Schedule

The City of New Bedford TIGER Grant application presents a 24-month construction schedule for the South Terminal Renewable Energy Marine Park, with project closeout (availability to an OREI developer/terminal operator) targeted during the first quarter of 2013 (January to March).[6] As described in Section 7.0 and Appendix A of the City's TIGER Grant application the project may be authorized under a special expedited regulatory process referred to as the State Enhanced Remedy (SER) –Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, a SER project comes under the umbrella of a program where traditional local, State and Federal environmental permitting is not required for the waterways infrastructure portions of the project, relieving the project of conventional permitting process uncertainties.

The Application also states that the HDC is preparing specifications which will be completed in November 2009 for the project, and HDC will initiate project organization, construction bidding, and logistics to begin construction within two months of receiving the project funds.

South Terminal Operations

Consultant team research for this business plan indicated the level of direct control that a facility owner has over a terminal determines the level of income, expense, and liability the owner assumes. In the maritime industry, most private facility owners operate their own terminals while many public facility owners contract the facility out to the private sector. Generally, terminal operations are divided into several categories including:

- Facility Management
- Marine Operations
- Vessel Services
- Stevedoring Services
- Shoreside Terminal Operations
- Support and Maintenance Functions

A public entity that is also a terminal operating company may undertake all of the service areas, contract some services or lease the terminal to a third party operating entity. As the industry strengthened, many public entities that initially operated ports began leasing facilities to private sector firms, which are partners in both development and investment of publicly owned marine

[6] *Integrated Intermodal Transportation Infrastructure Improvements,* New Bedford Harbor Development Commission (September 15, 2009)

facilities. *A major reason for third party involvement is the limitation of liability for operating entities. Marine and terminal operations involve large numbers of personnel, and injuries, damage to facilities, cargo damage, and environmental issues pose a potential significant cost to terminal operators.*

Terminals that operate with multiple operators often face conflicts and control issues. Some terminals lease a portion of the facility out to a stevedore or terminal operator but this can often limit the port's utilization of space. The most effective models have a single entity handling all marine operations at the port and generally under license. The port has the right to set the terms of any license it issues and it can elect to control rates and limit cargo types. The terminal can also separate the marine component from the shoreside component particularly if the shoreside component involves a specialized field of cargo activity. The marine activities are contracted and the third party held responsible for performance, regulatory compliance, and liability.

Public entities that are 'landlord ports' often have a third party operator for cargo and marine operations, generally terminal operating companies that also serve as the terminal stevedore and handle all aspects of marine activities including administration. A terminal management company is the fully functional form of stevedoring operation that handles both the vessel and terminal cargo handling activities. To accomplish this successfully, a port needs to shift the cost center to the new operating entity. Many ports have structured agreements with operators in the following manner:

1. *Contract Operator* - The facility owner contracts a terminal operator to manage and control the facilities on a cost plus basis. All revenue and expenses are retained by the owner. Liability is assumed by the operator.

2. *Cost Share Operator* - The facility owner contracts a terminal operator to manage and operate the facilities based on a cost share formula. The owner assumes a portion of the infrastructure cost while the operator assumes the operating cost. The revenue is shared on a prorated basis and liability is assumed by the operator.

3. *Third Private Operator* - A private operator assumes full responsibility for the facilities and pays a fixed lease cost to the facility owner. This is only successful if there is adequate business revenue to justify the offsetting costs. In many cases, this is not generated solely by the marine activity.

A stevedore is an individual or firm employing longshoremen for the purpose of loading and unloading a vessel. Longshoremen are the personnel who handle the cargo aboard the vessel and ashore including yard and often ship equipment, as well as sort, check, stage, and manhandle when necessary all commodities in transit. The stevedore is the employing management firm while the longshoremen are employed on a regular or casual basis. While stevedoring is generally limited to cargo handling, line handling and other dockside services are generally handled by the same labor force. The stevedoring firm can either have regular employees or use contract labor. Personnel are often members of a longshoremen's union in the United States but there are also a number of non-union operations. The stevedore is responsible for all salaries, benefits, and care if a longshoreman is injured.

- When cargo (OREI components are considered to be project cargo) is received, the stevedore can act as the responsible receiving party or the cargo can be received by the terminal and handled on their behalf by the stevedore. Stevedoring arrangements can vary according to the practice and work arrangements in a port. The stevedore can have an exclusive or non-exclusive agreement for all cargo handling, may only handle one type of cargo on a terminal or may have leasehold on a portion of the terminal for a specific type of cargo handling, commodity, or operation.

- Based on the arrangement, a license fee, percent of gross, fixed leased area fee or per unit/tonne fee is collected by the port from the stevedoring company. Ports may also have the stevedore handle all billings and collections depending on the operation. In most cases, the stevedore will provide all ground equipment which includes forklifts, reach stackers or top loaders, yard hustlers, small cranes, and other basic pier handling equipment. Large cranes and similar equipment are generally provided by the port. Use time and a fuel surcharge are generally charged to the vessel along with other fees.

Terminal Lease

Most cargo terminals at US ports are leased or licensed to private operators for the purpose of economic development and the creation of local and regional jobs related to the logistics field. However, the port infrastructures are built with public funds as social/economic investment similar to the road system. For the governments to recover the financial investments in port facilities, infrastructure is considered payback in terms of job creation, taxes, etc., planned on a long term basis of 25 to 50 years. This regional investment and return to a region is compounded with the development of parallel business arising for the initial harbor investment.

In addition to the basic lease fees for the terminal, port authorities may also charge fees for activities associated with cargo handling. These include fees for wharfage, tonnage or container or user fees, lease rents, storage, dockage, equipment rental and other ancillary services and activities.

Security and US Customs

The HDC South Terminal will have to be in full compliance with the US Coast Guard, Customs and Border Protection, and any other governmental agency's laws and regulations.

V. South Terminal Development Costs, Operating Income and Expenses

The following Tables 4 and 5 show data that represent a composite and synthesis of detailed capital costs, income and expense estimates prepared by FXM Associates, other project team members, and outside logistics experts. It assumes that the optimal management model will be for the HDC to develop and own the South Terminal facility and then to lease its use to a qualified terminal operator(s) for offshore wind energy development and for the handling of non-OREI container, break bulk, and bulk cargoes. This approach is most likely to assure cargo opportunities will be realized, optimize net revenue to the HDC, and minimize liability and contingency costs, but it is not the only potential operating pro forma possible.

Table 4
Estimated Capital Costs of South Terminal Facility

SOUTH TERMINAL CAPITAL COSTS	Offshore Wind Installation	Non-Offshore Wind Cargoes
Bulkhead and Dredging	$ 19,990,977	$ 19,990,977
Site Acquisition	$ 2,100,000	$ 2,100,000
Backland Site Improvements (drainage, utilities, surfacing)	$ 6,000,000	$ 6,000,000
SUBTOTAL Basic Infrastructure	**$ 28,090,977**	**$ 28,090,977**
Buildings and structures (35,000 SF)	$ 3,500,000	$ 3,500,000
Crane		$ 3,000,000
Ground Equipment (fork lifts, trucks, etc.)		$ 1,500,000
Other Equipment & Fencing, Security	$ 485,000	$ 485,000
SUBTOTAL with Support Facilities & Equipment	**$ 32,075,977**	**$ 36,575,977**
Optional Fabrication Building (75,000 SF)	*$ 7,500,000*	*$ 7,500,000*
TOTAL with Fabrication Building	***$ 39,575,977***	***$ 44,075,977***

Capital Costs

As data in Table 4 indicate, capital costs for the multi-use South Terminal facility have been estimated by the consultant team to total approximately $44 million. Of this total, approximately $32 million is considered functional for servicing the offshore wind energy development cargo handling, assembly, and storage requirements required for a staging operation of similar scope to that shown for the Representative Offshore Wind Energy Installation (ROWEI). Approximately $20 million of this capital investment has been requested of the Federal government by the City of New Bedford in its TIGER grant application, which represents pier, bulkhead, and dredging cost estimates but does not include site acquisition or backland site improvements. The $6 million estimated for backland site improvements includes costs for drainage, utilities, surfacing, and mitigation. Experience of wind energy developers indicates that a fully paved backland area may not be necessary, but these costs have been included because of uncertainty over the condition of the site and whether or not paving or other mitigation measures may be required if contaminated soils or poor drainage areas are an issue. The $2.1 million acquisition costs assumes $150,000 per acre, a conservative high estimate given the $125,000 per acre costs reported by the New Bedford Economic Development Council (NBEDC)[7] for recent sales in this

[7] Conversation with Matthew Morrissey, Executive Director, NBEDC, November 2009.

area. Additional capital costs to competitively service offshore wind energy installation projects are estimated to include $3.5 million for a 35,000 SF building to provide interior storage and terminal operations space, and approximately $500,000 for security fencing and miscellaneous equipment.

Additional capital costs of approximately $4.5 million are estimated by the consultant team for the South Terminal facility to be able to competitively attract the container, break bulk, and bulk cargoes projected following the completion of offshore wind energy development operations. These include purchase of a 300-ton mobile crane ($3 million), other ground equipment ($1.5 million). Both the mobile crane and other ground equipment, if purchased prior to the facility's use for offshore wind energy development, could represent sources of net income to HDC. Currently, all equipment necessary for the offshore wind energy operation are assumed to be the cost of the developer and potential rental fees for such equipment are not included in the operating income shown in Table 5, below. A large transit shed/fabrication building has also been included in the multi-use facility building program at a cost of $7.5 million, primarily to handle break-bulk cargo storage or fabrication/assembly operations for offshore wind energy developers and could also represent a source of net income to the HDC not included in the Table 5 income estimates shown below.

Table 5
Potential Income and Expenses to the New Bedford Harbor Development Commission (HDC) Assuming Leasing of Terminal Operations

SOUTH TERMINAL OPERATING INCOME & EXPENSES	Offshore Wind Installation	Non-Offshore Wind Cargoes
Average Year Annual Operating Income		
Offshore Wind Energy Development (ROWEI)	**$ 1,500,000**	
Container Service		$ 280,000
Break Bulk Program		$ 240,000
Bulk Cargo		$ 432,500
Total Non-ROWEI Cargo		**$ 952,500**
Average Year Annual Operating Expenses		
HDC Personnel (contract/lessee management)	$ 140,000	$ 140,000
HDC Capital/maintenance reserve at 20% income	$ 190,500	$ 190,500
Average Year Annual Expenses	*$ 330,500*	*$ 330,500*
Average Year NET Operating Income		
Offshore Wind Energy Development (ROWEI)	**$ 1,169,500**	
Total Non-ROWEI Cargo		**$ 622,000**

Operating Income and Expenses

During the assembly/installation phase of Cape Wind's offshore wind farm development the HDC is expected to receive at least $1.5 million per year net of operating or maintenance costs for the developer's use of the facility ($4.5 million over the three year estimated construction period). In addition, the developer/facility operator under terms typical of such leases would assume all liability (insurance) costs, homeland security costs, and so forth. The HDC would be expected to receive about $950,000 per year in net income from the lease, dockage, wharfage, storage, equipment rental and so forth charges to a private facility operator shown by cargo type

in Section II of this report. As with the lease expected with the offshore wind developer (s), liability, homeland security, and maintenance costs would also be the responsibility of the private facility operator. The annual expenses to the HDC are estimated at $140,000 for personnel to administer and oversee the private lessee operations. Contributions to a capital/maintenance cost reserve fund by the HDC are shown as a $190,000 annual expense.

Net Income

As shown by the data in Table 5, annual income to the HDC net of projected expenses is estimated at about $1.2 million per year for the projected 3-year ROWEI and about $620,000 per year for the additional cargo handling, storage, and transshipment operations. The South Terminal port facility can thus cover its operating expenses during the offshore wind energy developer(s)' use of the facility and on an average annual basis without a wind energy installation project based on the container, break bulk, and bulk cargo opportunities identified.

VI. Economic and Tax Effects of South Terminal Construction and Operation

Data in Table 5 show the estimated economic effects attributable to the construction of the South Terminal port facility and the handling of non-offshore wind project related container, break bulk, and bulk cargoes identified in prior report sections. A complete discussion of the assumptions, data sources, and analytic methods used for the South Terminal project economic assessment, as well the economic assessments of offshore wind energy projects and other potential port construction in Massachusetts, is included in a separate FXM technical memorandum: "Economic Effects of Offshore Wind Energy and Related Construction and Operating Expenditures".

Table 6
Direct, Indirect and Induced Economic Effects of South Terminal Facility Construction and Annual Operations

	Output (000 $)	Employment (Jobs)	Income (000 $)	GDP (000 $)
Construction Period Effects				
South Terminal Port Facility				
Bristol County	*$ 44,100*	*380*	*$ 19,200*	*$ 26,100*
Massachusetts	$ 65,500	540	$ 26,100	$ 36,200
Annual Operating Effects				
South Terminal Port Cargo Operations				
Bristol County	*$ 15,700*	*130*	*$ 5,900*	*$ 9,700*
Massachusetts	$ 20,200	170	$ 7,400	$ 11,900

Source: FXM Associates and RECON™ Input Output Model

The construction period economic effects shown in Table 5 include a $65.5 million expansion in business output statewide ($44.1 million of that would accrue within Bristol County), 540 person years of employment statewide (380 person years in Bristol County), and $26.1 million in household income ($19.2 million in Bristol County) over the estimated 2-year construction period. Economic impacts attributable to construction expenditures are correctly interpreted as one-time, non-recurring economic effects.

Annually recurring economic effects of the non-OREI cargo handling operations at South Terminal, as shown in Table 5, include $20.2 million in expanded business output statewide ($15.7 million of that within Bristol County), 170 permanent jobs (130 within Bristol County), and $7.4 million in additional income each year to Massachusetts households ($5.9 million to households in Bristol County).

Data in Table 6 show the estimated tax effects attributable to the construction of the South Terminal port facility and the handling of non-offshore wind project related container, break bulk, and bulk cargoes identified in prior report sections.

Table 7
Direct, Indirect and Induced Tax Effects of South Terminal Construction and Operation

	Local Taxes (000 $)	State Taxes (000 $)	Federal Taxes (000 $)
Construction Period Effects			
South Terminal Port Facility			
Bristol County	*$ 480*	*$ 440*	*$ 1,820*
Massachusetts	$ 1,190	$ 1,440	$ 7,280
Annual Operating Effects			
South Terminal Port Operations			
Bristol County	*$ 300*	*$ 240*	*$ 730*
Massachusetts	$ 480	$ 500	$ 2,180

Source: FXM Associates and RECON™ Input Output Model

The construction period tax effects shown in Table 6 include $1.2 million in receipts to municipalities statewide ($480,000 of that would accrue to communities within Bristol County), $1.4 million in tax revenues to the Commonwealth of Massachusetts, and $7.3 million in federal taxes. These tax receipts are attributable to the economic impacts shown in Table 5 and are correctly interpreted as one-time, non-recurring tax effects.

Annually recurring tax effects attributable to the non-OREI cargo handling operations at South Terminal, as shown in Table 6, include $480,000 in receipts to municipalities statewide ($300,000 to communities within Bristol County), $500,000 in new tax revenues each year to the Commonwealth of Massachusetts, and $2.2 million in federal taxes annually.

Appendix A -- Port of New Bedford Description[8]

The Port of New Bedford is a deepwater commercial port with easy access to the maritime corridor from the Massachusetts coast, located on the northwestern side of Buzzard's Bay approximately 9 nautical miles from the Cape Cod shipping canal, 83 miles south of Boston and 166 miles north of New York. The Port serves as the City's greatest natural resource and most critical asset to stimulate investment, attract new industry, create jobs, and develop a healthy economy. Over 4,400 people are employed by the commercial port. New Bedford is the number one value fishing port in the nation generating economic activity in excess of $1 billion. The fishing fleet lands over 145 million pounds of product annually, leveraging $241 million in direct sales. New Bedford is connected to the world market through its port and can capitalize on unique import/export distribution opportunities developing rapidly in the free global marketplace. Currently, the Port of New Bedford supports a diverse market of cargo transport handling over $230 million in shipping of bulk commodities and break-bulk cargo. Barge operations move aggregate and break-bulk cargo to the Islands of Martha's Vineyard and Nantucket. Shipments of break-bulk cargo consisting primarily of household goods are exported to Cape Verde and Angola.

The Port of New Bedford has the largest throughput tonnage of break-bulk perishable commodities in New England. The Port handles reefer (refrigerated) vessels which handle fresh fruit as well as fresh and frozen fish. Fresh fruit is imported from North Africa, primarily clementines, and vessels are regularly loaded with New Bedford export herring product, direct call service from Norway handling product for Massachusetts fish processors and distributors. Each vessel load creates a $100,000 - $150,000 direct impact employing approximately 30 ILA for offloading and 20 teamsters for warehouse operations. Those vessels that include export fish product cargo generate a $3 million direct economic impact. Each shipment brings 100 to 150 truckloads of product through the Port. The Port currently sees up to 25 freighters per year and is implementing a rigorous marketing initiative to expand import/export opportunity looking at opportunities to support offshore energy farm developments and the emerging American Marine Highway. The maturing nexus between marine science and the fishing industry puts New Bedford on the forefront as a leader in marine education, research, and technology.

The Port also serves as an important land/sea intermodal center for ferry, cruise, excursion, water taxi, and other passenger operations bringing over 100,000 people through the Port annually. It is the charter of the HDC to support the maritime businesses of the Port, seek out new opportunities, and maximize the natural competitive advantage the Port provides to the New Bedford economy. Intermodal connections among port cargo facilities, rail, highway, and air freight are increasingly important as highways continue to become overly congested and the volume of East Coast ports goods movement is expected to realize exponential growth. The funding requested herein would be used to provide the intermodal connector infrastructure critical to supporting the existing significant fishing, bulk, and break-bulk cargo industries, expanding international trade, and capturing coastal trade opportunities from the emerging AMH market sector. Project elements incorporated into this work would seek to upgrade existing

[8] *Integrated Intermodal Transportation Infrastructure Improvements,* New Bedford Harbor Development Commission (September 15, 2009)

infrastructure to allow for full scale intermodal transport of goods. The proposal herein enables the Port to expand operations to include containerized cargo and oversized transport in addition to augmenting existing bulk and break-bulk shipping business.

Port of New Bedford Profile in Northeast Port Mix

The "Comparison of Selected Northeast Ports" study provides a description of New Bedford Harbor, and the Port of New Bedford in the terms of potential handling facilities for Offshore Renewable Energy Installation (OREI).[9] The report identifies a number of key ports in the Northeast with potential for handling wind generation units, including importing components, storage, assembly and exporting to the construction site. Massachusetts has a varied mix of marine activities in its five key port areas, and a number of ports that because of their existing or proposed marine terminals, geographic location and surrounding market area already have substantive marine activity including a wide range of freight activity. These ports serve as transition points where cargo moves to and from marine modes including ship and barge to land based modes, in particular truck or rail. This connection is being made to both international and domestic markets. The state has one major tonnage and diversified seaport and four smaller niche ports that operate in the marine network: Boston is the major seaport: and, the niche ports include Gloucester, Salem, New Bedford and Fall River.

Facilities

The New Bedford waterfront has a number of large and small piers and wharves which are primarily used by the commercial cargo and fishing industry. Most facilities have good highway connections as well as rail connections. Harbor regulations and berthing are enforced by the Harbor Development Commission (HDC) and the Port Maritime Security Unit except berthing for private terminals.

- New Bedford South Terminal Wharf has a 1,600 foot berth with 30 feet of depth and serves as the major offloading center for fish product. The wharf has 250,000 cubic feet of refrigerated storage on site and handles primarily seafood. The most southern portion of the facility has the potential to build out a 400 foot solid fill bulkhead and act as potential terminal. The site has 10 acres of backland.

- Sprague Terminal just North of South Terminal works off a 740 foot berth with 27 foot depth alongside. The pier primarily handles petroleum products.

- At the center of the inner Harbor is the State Pier Terminal which has three berths measuring 450 feet, 600 feet and 775 feet with 30 foot depth alongside. There is 125,000 square feet of covered storage for general cargo. Cargo service out of state pier includes the movement of break-bulk cargo to Cape Verde and Angola. The facility can support freighter service and store over 135 containers. American Cruise Lines operates out of the facility bringing in a minimum of 20 ports of call on an annual basis and up to 89 passengers per trip. Ferry services also operate out of State Pier, including passenger and

[9] *Integrated Intermodal Transpiration Infrastructure Improvements,* New Bedford Harbor Development Commission (September 15,2009)

cargo service to Cuttyhunk Island and passenger service to Martha's Vineyard. Ferry service brings over 115,000 passengers through the Port annually. The Quick Start Ferry facility on New Bedford State Pier allows intermodal transfers of waterborne freight and freight carried by truck and rail. The terminal features a 27-foot pier depth, roll on-roll off capability, offsite cold storage, and easy access to the interstate highway system. The ramp is 100 feet long and 18 feet wide and will hold up to 200 tons.

- Above the Route 6 Bridge are Maritime Terminal, Bridge Terminal and North Terminal. The Maritime Terminal Wharf, operated by Maritime Terminal International, has a 600 foot berth with 31 foot depth alongside. The facility has 3 million cubic feet of refrigerated storage and is one of the largest U.S. Department of Agriculture-approved cold treatment centers on the East Coast for the use of controlled imported agricultural products. The terminal receives approximately 25 vessels a year, each carrying between 1,500 and 4,000 tons of fish or approximately 2,000 to 3,000 tons of fruit.

- The Bridge Terminal Wharf, on the northeast side of the harbor, is 450 feet long with 28 foot depth alongside. The wharf has a 500,000 cubic foot refrigerator warehouse and handles frozen and chilled food products. The facility is owned and operated by Bridge Terminal Inc.

- American Pride Seafood is a private facility operating out of North Terminal and one of the world's leading seafood product processors. The bulkhead supporting their operation is 580 feet long with 25 foot depth alongside. The facility has 63,400 square feet of refrigerated warehouse space, 57,500 square feet of freezer space and 34,700 square feet of covered warehouse space.

- Within the New Bedford North Terminal Wharf are commercial properties managed by the HDC. These properties cover 25 acres of land. Tenants include the seafood processors Eastern Fisheries and Seawatch International, barge operators, ship repair facilities, and other maritime service businesses. A 2 acre terminal site is proposed to come on-line over the next 5 years. This facility is currently operated by the EPA as part of the superfund clean-up and will revert back to City in the next few years. The facility has rail connections that lead directly to the water's edge.

The port is considered a full service port and associated maritime industries include vessel maintenance and repair conducted at dockside or at repair facilities in New Bedford or in Fairhaven. The port has two moderate size shipyards, and equipment and provisions to support commercial and recreational vessels

Harbor Profile

The Port of New Bedford is considered a moderate deep-water port with overall depths of 30 feet at mean high water. The harbor is protected by a hurricane barrier that is constructed across the harbor entrance and equipped with a gate that can be closed during hurricane conditions and severe coastal storms. The port is considered a harbor of refuge for vessels in the region.

The Harbor approach is characterized by a number of ledges and shoals. The approach channel allows for safe navigation and avoids most of the obstructions. The hurricane barrier entrance is 150 feet wide and opens up to a 350 foot wide channel, at a depth of 30 feet, extending to a turning basin 350 yards (1,000 feet) just above the New Bedford-Fairhaven Bridge. The range of the tide is 3.5-4.0 feet and harbor currents are overall considered weak. Maximum ebb and flood tide currents are under 2.5 knots average.

There are vessel limitations due to the hurricane barrier and the highway bridge in the inner harbor. The hurricane barrier opening width is 150′ (45.7 meters), the New Bedford – Fairhaven Bridge is 92′ (28.0 meters) wide. All vessel transit from and to the New Bedford – Fairhaven Bridge are subject to daylight-only restrictions for vessels with overall length above 400′ (121 meters) and/or beam above 59′ (18 meters) and are subject to wind velocity restrictions.

Advantages

The port is well protected by the Hurricane Barrier and has support mechanisms in place for commercial and industrial vessel activity including OREI processing. The port is has good road and rail access, and adaptable warehouse capacity is significant. The port has excellent road and rail connections to its northern terminals and has several opportunities for expansion including OREI fabrication.

The harbor is challenged by a significant pollution problem due to local industries which up until the 1970's discharged wastes containing polychlorinated biphenyls (PCBs) and toxic metals into New Bedford Harbor. There are high levels of contamination throughout the waters and sediments of the Harbor which extends into Buzzards Bay. Hundreds of acres of marine sediment were highly contaminated. Biological effects of the contamination include reproductive impairment and death of marine life throughout the estuary, along with loss of marine biodiversity in areas of high contamination and gave New Bedford status as a Superfund Site. Since 2004 the EPA has been dredging to remove the PCBs through a complex process for dealing with contaminated sediments. The EPA is expected to explore new technologies (confined aquatic disposal) that will reduce the demand for land-side facilities bringing the terminal facility under City control and opening other waterfront parcels up for development.

Due to high levels of harbor contamination, no maintenance dredging had occurred for over 50 years and had become critical. The port faced the loss of waterfront businesses unless maintenance dredging could be implemented. In 2005, the first navigational maintenance dredging was conducted restoring portions of the harbor to useable depths. This has allowed business to increase and larger commercial vessels are returning to the harbor.

Disadvantages

Vessel draft is limited to 30 foot overall depth and the turning basin can only handle small cargo ships. The Route 6 Bridge limits the size vessel that can access the north terminal portion of the harbor and being an outmoded swing bridge causes delays in travel time. Some of the most critical infrastructure in the port is aging and in need of repairs and improvements.

Potential

There are several port areas adaptable for marine terminal expansion capable of supporting OREI processing. The State pier requires a significant amount of investment to bring it up to industry standards for cargo handling and there are several other facilities that require infrastructure improvements including bulkheads, piers and wharves. The rail corridor needs to be extended and track improved to accommodate increased and oversized shipments. Commuter rail improvements are being planned and the engineering of commuter rail should include freight adaptable considerations. Development and of staging areas for trucks is also critical for increased activity in the port.

The North Terminal owned by the Harbor Development Commission can be improved for handling of OREI fabrication and processing. Terminal facilities including the State Pier and North Terminal site should be equipped with a versatile mobile harbor crane and ground support equipment. This equipment can be used for both cargo handling and wind farm components. Additional dredging to provide better access to all deepwater berths should be completed and the turning basin should be lengthened to accommodate longer, higher tonnage cargo vessels. Improvements to the Route 6 Bridge are critical to the passage of vessels to North Terminal and maximizing vessel access. The suggested plan is to construct a double bascule bridge.

Appendix B -- Port Management and Governance Models[10]

Port Management Models

There are multiple models for port management which range from simple terminal management within a port to combined or collective port management which encompass multiple facilities or waterfront properties. Port management revolves around one essential factor, the ownership of property, which in most cases is retained for some public benefit. The amount of port property and jurisdictional locations often dictate how the management will be structured.

Ports or regions that manage their collective facilities cooperatively, or under the same management authority, often sustain growth more effectively. This is primarily because competition for public financial resources is limited. Over the last 50 years, public entities have taken over large expanses of waterfront property, including terminals and similar marine facilities, to insure the infrastructure was protected and allowed to provide public benefit. This was most significant during the transition from break-bulk to container operations in the maritime industry which stranded many waterfront properties and left many facilities with marginal use. In the United States, public entities include several types of management organizations:

- *Municipal ports* -- Municipal ports are more common in small port areas. The local municipal entity, town or city, provides management of the port's facilities. In most cases, the managers are a department of the local government, funded as part of the municipal budget. The advantage is cost effective management, the disadvantage is the port competes for funding with schools and community services. Portland, Maine is an example of a municipal port.

- *State ports* -- State ports are operated under the transportation department of a State and are managed or staffed with State employees. Many communities have State owned facilities which are either promoted by the State or leased to a public or private entity. In most cases State port management is limited to port promotion or infrastructure investment. The advantage is coordinated transportation programs under a single State entity. The disadvantage is funding competition. Connecticut has a program under its Department of Transportation similar to this model.

- *Federal ports* - Federal ports are owned and operated by the Federal government. They are used for specific purposes such as handling of military cargo. Earle, New Jersey is an example of a federal port.

- *Quasi-governmental ports or commissions* -- Quasi-governmental ports or commissions are ports created by State legislatures that have a form of separate governance but are dependent on the local or State government for funding and project approvals. They are intended to allow the local governmental entities to exert a level of local control over waterfront property

[10] *Comparison of Selected Northeast Ports for Potential Handling of Wind Power Offshore Energy Installations,* Captain Jeffrey Munroe, MAI (Draft October 2009)

in a community. The advantage is the involvement of local government in decision making. The disadvantage is that the waterfront issues can be so diverse that progress is often slow for industrial or commercial development. New Bedford's Harbor Development Commission is an example of this type of structure.

- *Public port authorities* -- Public port authorities are entities that are created or enabled by State legislative action and have independent management and bonding authority. They focus on commercial marine terminal activities but can often include other operations such as airports, marinas, real estate development, rail or highway infrastructure. The advantage is that they have the ability to promote their business activities with limited involvement from local government processes. The disadvantage is that they can have diverse policy from their host communities. The Massachusetts Port Authority (Massport) is an example of this type of entity.

- *Regional Ports* -- The regional port council concept includes independent port agencies that work together to achieve common regional goals. An effective model for a regional port cooperative is the Massachusetts Governor's Seaport Council. In this model each port is represented along with the key secretaries who have regulatory or development responsibilities for port areas, under the Office of the Governor. Acting similar to a Metropolitan Planning Office (MPO), the council reviews projects, coordinates State's response and allocates funding. The council also provides a policy development forum that is coordinated with other State objectives.

Ports themselves are a collection of marine terminals with associated landside transportation infrastructure. They are generally a collection of both publicly and privately owned facilities that have common interests in the growth and development of a port area. Public entities often have leadership roles in the port and work with private entities to foster growth and development. In many cases, public entities operate marine terminals in a similar fashion as the private entities. The primary difference is that public entities are generally willing to handle all types of operations including cargo, industrial activities, and other similar operations, where private terminals only handle their own cargoes or activities.

- Terminal ownership and management, public or private, along with their associated operational structures differ according to their location, historic staffing structure, and labor agreements.

A public entity that is also a terminal operating company may undertake all of the service areas, contract some out or in some cases lease the terminal out to a third party operating entity. Occasionally, the terminal owner will contract a third party management firm who will manage terminal staff and personnel on behalf of the owner. There was also a realization that ports needed to engage professional management and partner with the private sector to expand opportunities and create efficiencies. Rail and marine terminal operators began venturing into becoming transportation companies handling every aspect of cargo transportation "door to door." As the industry strengthened, many public entities that initially operated ports began leasing facilities out to the private sector who are becoming partners in both development and investment of publicly owned marine facilities.

Port Governance Models

To highlight how port governance might be best achieved for a potential port activity, several examples are available for review.

The Port of New Bedford is the first example. The New Bedford Harbor Development Commission (HDC) was created by the Massachusetts General Court under Chapter 762 of the Acts of 1957 to serve as the governing entity for the Port. Chaired by the Mayor, the Commission consists of 7 members as appointed by the Mayor and approved by City Council. The crucial day-to-day operations and decision making is the responsibility of the HDC staff headed by the Executive Director. The HDC has jurisdiction over all the waters in New Bedford, including the entire coastline of the peninsula, the harbor, and north along the Acushnet River to the City's boundaries. The HDC manages 20 commercial properties, a 198 slip marina on Pope's Island, the ferry terminal on State Pier and its supporting Whales Tooth Parking Lot, 5 Piers and Wharves, 10 mooring fields, and enforces rules regarding the use of piers, wharves, and adjacent parking areas under its jurisdiction. Being autonomous from City Government, user fees, rents, and all other revenues streams do not go to the General Fund, but rather are reinvested by the HDC to support its operations, properties, infrastructure needs and economic development initiatives. The HDC may borrow and issue municipal bonds for capital improvements. The goal of the HDC is to "support the maritime businesses of the Port, seek out new opportunities, and maximize the natural competitive advantage the Port provides to the New Bedford economy". Progress has been steady in achieving this goal.

Massport is another example. The Massachusetts Port Authority was created in 1956, when a politically encumbered and ineffective, locally-controlled port commission was replaced by the autonomous, self-supporting authority. Massport bought and rehabilitated abandoned or deteriorated property, began rebuilding rail and road connections and, invested in new facility development. In 1966 after the advent of containerization, Massport's built one of the first container terminals in the country at Castle Island in South Boston. In 1971, a second container terminal (Moran Terminal) was built by Massport in Charlestown. In 1980 and 1996, Massport rebuilt the container facility in South Boston expanding its footprint and upgrading its crane equipment. The terminal is now known as the Paul W. Conley Container Terminal.

In 1996, the process of optimizing Massport's marine terminals in Boston also began to occur. All of the container operations were shifted to Conley Terminal and Moran Terminal was converted to an auto import and processing facility. The newly expanded Conley Container Terminal and Boston Autoport were opened in 1997-1998. As a result of focused investment and dedicated efforts, marine traffic at Massport's terminals has increased substantially in the last thirty years. Container traffic has tripled and the cruise ship industry has also expanded from 28 ships in 1994 to over 100 ship calls in the last several years. Massport also operates two airports, a bridge and real estate development division in addition to port facilities. In general, port revenue covers most of the port's expenses, supplemented by revenue from other activities

applied to administrative expenses. Massport has bonding authority for financing of all capital improvements and repairs.

Portland, Maine, provides a third model. The port is municipally owned and operated and management was combined with the Portland International Jetport under the City's Department of Ports and Transportation. Port properties include a 15 acre cargo facility, 12 acre cruise ship and ferry facility and 12 acre fishing based industrial park. The fishing facility is managed by the Portland Fish Pier Authority while the other facilities re managed by the City. It just completed a State and federally funded $22 million ferry facility intended to be expanded into a new cruise ship terminal. All revenue from operations went into the City's general fund; all expenses were tax payer assessed. The port generated marginal income and recently, facing high infrastructure expenses, the City eliminated the marine division of the department and turned over control of the freight facilities to the Maine Port Authority. The City also had a process to offer development rights to a commercial developer for the former State pier, now the primary cruise ship terminal, which failed. Financial challenges and funding competition within the City have led to stagnant development in the port.

APPENDIX 16

Analysis of the Potential Market for Short Sea Shipping Services over the Ports of Fall River and New Bedford

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I. Executive Summary

This reports contains the findings and conclusions from a project funded by the Massachusetts Department of Business and Technology and Seaport Advisory Council (MSAC) to assess the market potential for short sea shipping operations (coastal shipping) to connect the ports of Fall River and New Bedford (ports of Bristol County) with other U.S. ports that would provide a new mode of transportation for freight that is currently moving over the highway.

This report specifically addresses six key issues concerning the prospects for short-sea shipping services over the Bristol County ports:

- What is the status of the emerging short sea network and its outlook for the future?
- What is the potential impact of this network and the factors driving its development on the ports of Fall River and New Bedford?
- What is the potential cargo hinterland for the ports?
- What highway freight is currently moving into and out of this hinterland?
- What type of freight is moving on these lanes and who is carrying it?
- What is the likelihood of different segments of this highway freight market being diverted to short sea shipping through the two ports and the consequent prospects for the two ports becoming successful short sea shipping hubs for the region?

The following are the conclusions of the project team on each of these issues based on the research and analyses that is described in the following pages of this report:

Probability of Success for Bristol County Ports as Short-Sea Shipping Hubs

- Several factors point to a strong probability of success for short-sea shipping services being developed to serve the ports of Fall River and/or New Bedford:
  - There are substantial cargo volumes of truck traffic moving along the Atlantic seaboard with origins or destinations within the hinterland served by the Bristol County ports – options for such services include a short haul operation connecting with northern New Jersey and a longer haul operation connecting with ports in the South Atlantic such as Jacksonville, FL, Wilmington, NC, and/or Norfolk, VA.
  - Truckers, particularly truckload operators, are becoming increasingly aware of the short-sea shipping option, and view it as an additional intermodal opportunity that may offset constraints on their ability to continue to grow pure truck transportation services due to increasing highway congestion and driver shortages as well as limits on hours of driver operation and rising fuel costs.
  - The economics of short-sea shipping appear to be competitive with alternative modes, particularly on long haul lanes provided that "best in class" practices can be implemented in terms of vessel costs and manning levels as well as stevedoring operations that will enable short-sea shipping to achieve its full potential in terms of both cost and service efficiency.
  - The primary competition to the Bristol County ports as short-sea hubs will come from the Rhode Island ports of Providence and Davisville (Quonset Point). Although these

ports are well positioned in terms of physical facilities, they are at a greater distance from the central and northern New England hinterland that may potentially be served by the Bristol County ports.

- However, there are also a number of factors that need to be addressed in order for short-sea shipping operations to be effectively realized in the ports of Bristol County:
  - Current port capacity in both Fall River and New Bedford is limited in its ability to accommodate a major short-sea shipping operation such as envisioned in this project.
  - Fall River's State Pier could accommodate short-sea operations moving the equivalent of 140 trailers into and out of the port on a daily basis but that would entail adding more trailer parking area to that within the current State Pier footprint and also possibly displacing some current users of the facility – in addition, the large volume of truck traffic into and out of the facility projected for the short-sea operation must be balanced with the needs of the adjoining Battleship Cove tourist facilities and other planned recreation activities in the area.
  - New Bedford's current cargo facilities in terms of berth and yard capacity need to be improved to effectively support a short-sea service. In the long term, if the North Terminal is developed as a RoRo berth and adequate access to it is provided by reconstructing or relocating the Route 6 bridge, New Bedford would be an ideal location for a short-sea shipping operation.
  - In addition, factors that add to the cost of short-sea shipping such as Harbor Maintenance Tax (HMT) and the extremely high cost of commercial vessels built by U.S. shipyards must be addressed:
    - The elimination of HMT on coastal domestic shipping services may prove to be revenue neutral as any foregone tax may be offset by funds saved in highway construction and repair as trailers are removed from the highways by short-sea shipping services.
    - The high cost of U.S.-built commercial vessels may be addressed by increasing the percentage of such vessels that may be built overseas, by improved purchasing and sourcing practices by U.S. shipyards, by the application of modern vessel construction practices and technologies by the shipyards, and/or by a waiver of the U.S. Jones Act restriction on domestic operators using foreign-built vessels.

Status of the emerging short sea network and its future outlook

- Despite a number of efforts to develop short-sea shipping services along the U.S. coasts, there have been few successes to date – high costs on both the vessel and port side and slow acceptance of this alternative transport mode were primary factors that undercut these efforts.
- Most of these earlier short-sea initiatives were carried out prior to the current conflux of highway congestion, driver shortages, and high fuel costs that are creating a more favorable environment for short-sea shipping transport alternatives.
- Successful "short-sea" operations in the noncontiguous U.S. domestic trade lanes such as between the continental United States and Puerto Rico, Alaska, and Hawaii provide a business model that is applicable to coastal routes.

- There appears to be a significant opportunity that short-sea shipping services may be successfully launched in the near future if the cost issues are solved on the basis of current best practices within the U.S. and carefully planned partnerships between marine and ground transportation operators are developed to provide a true short-sea/land intermodal service option.

Potential Impact on the Ports of Fall River and New Bedford

- Both ports are well positioned to be significant players as short-sea shipping hubs although constraints on their capacity need to be addressed. The proximity of the two ports to each other may be a plus in terms of sharing labor and services.
- The total economic impact of the development of short-sea shipping services over the ports of Bristol County could be as high as $120 million, creating up to 800 jobs – at least fifty percent of this impact would occur in the immediate area of the Bristol County ports.

Potential Cargo Hinterland for the Ports of Bristol County

- The potential cargo hinterland for the ports of Bristol County extends a relatively short distance to the south by approximately 50-miles including much of Rhode Island, but a significant distance to the north and west to include most of central and northern New England up to 250-miles.

Volume of Highway Freight into and out of the Bristol County Ports' Hinterland

- A total of 1.9 million trailer loads of highway freight move to destinations within the Bristol County ports' hinterland annually from origins within 200-miles of a port along the U.S. Atlantic and Gulf Coasts seaboard – a total of 1.4 million trailer loads moves out of the Bristol County ports' hinterland to destinations within 200-miles of a port along the U.S. Atlantic and Gulf Coasts seaboard.
- The major port-pair partners for the Bristol County ports for short-sea shipping services appear to be Bayonne, NJ (total volume of 787,000 trailer loads) and Jacksonville, Florida (total volume of 418,000 trailer loads).

Type of Freight and Carriers on these Routes

- A broad assortment of manufactured goods, foodstuffs, and basic commodities move by highway freight on these potential short-sea shipping lanes.
- Truckload carriers play a predominant role in these potential markets and also appear to have the greatest interest in short-sea shipping as an alternative mode to direct over the road transport.

In summary, the ports of Bristol County appear to have a significant opportunity to become terminuses for short-sea shipping services. Focusing on implementation strategies that address both the positive and negative factors listed above should enable this opportunity to be achieved.

II. The Emerging Short Sea Network

Background

The highway transportation system of the United States is coming under increasing pressure as growth in over the road traffic is exceeding the growth of capacity at the same time as truck driver shortages, restrictions on driver hours of service, and rising fuel prices are increasing the cost of trucking services. Coincident with these developments, many American companies' supply chains have become more complex as they have internationalized much of their sourcing and reduced inventory levels through such strategies as "Just in Time" parts delivery to manufacturing plants. This has had the effect of increasing these companies' reliance on fast reliable freight transport. The resultant strain from growth in freight transport activity has impacted all modes of transport, but none more than trucking. Significantly increased highway congestion has come from the compound influences of the growth in freight and passenger traffic, especially in densely populated regions such as along the U.S. Atlantic Coast, particularly on the I-95 corridor.

Given the current limited plans for new highway construction and likely ongoing federal and state fiscal constraints, it is likely that congestion on U.S. highways will continue to increase. This will have the virtually inevitable effect of degrading the productivity of the nation's businesses in terms of their transportation and logistics performance. At the same time, the traveling public will be inconvenienced by further increases in traffic delays and the environment will be subject to additional damage from vehicle emissions (especially freight diesel emissions) that reduce air quality.

One potential avenue that offers to relieve some of this strain on the nation's transport infrastructure is the diversion of truck traffic from congested highways to the open sea – that is, to use what is termed "short-sea shipping" operations along the nation's coasts as well as on inland waterways to absorb a significant part of the projected growth in highway freight traffic. These short-sea shipping operations would move freight on an intermodal basis by combining a relatively short overland "drayage" move by truck to transport goods from their origin to a nearby port from which a vessel would carry the freight to another port where a second truck would transport the load over another relatively short distance to its ultimate destination. This short-sea model for domestic freight has already had some success through such operators as Osprey Lines in the U.S. Gulf and inland waterways. However, its application on the Atlantic Coast has been very limited and with no real success stories to date.

Nevertheless, with the recent significant shift in the nation's transportation equilibrium – highway capacity not keeping pace with the growth in demand, labor shortages for truck drivers becoming increasingly acute, and fuel prices rising dramatically – it is timely to take an objective and pragmatic look at whether short-sea shipping can provide a means to relieve some of the pressure on the nation's highways and provide new business for shipping services and ports such as Fall River and New Bedford in Massachusetts.

The Potential Market

The great majority of U.S. intercity truck freight travels only a relatively short distance, and is thus not conducive to an intermodal transportation mode such as short-sea shipping. Likewise, many freight movements occur in volumes and at frequencies not generally appropriate for intra or inter-coastal ocean service. Consequently, successful market penetration by short-sea shipping will be a function of two primary factors: (1) relative length of haul, and (2) the level of concentration of volume in specific traffic lanes. As the distance between freight origin and destination increases and lane volume (density) grows, intermodal services – such as short-sea shipping – become more competitive relative to highway transport, and their cost advantage increases. Where significant highway congestion exists, such as in the U.S. Northeast corridor, the distance at which short-sea shipping may be competitive with pure highway traffic may decrease. Consequently, analyzing the relative lengths-of-haul and lane densities of truck traffic moving into and out of various regions of the U.S. with access to coastal ports was the first step in quantifying transportation market prospects for short-sea shipping services that may utilize the ports of Fall River and New Bedford ("Bristol County ports").

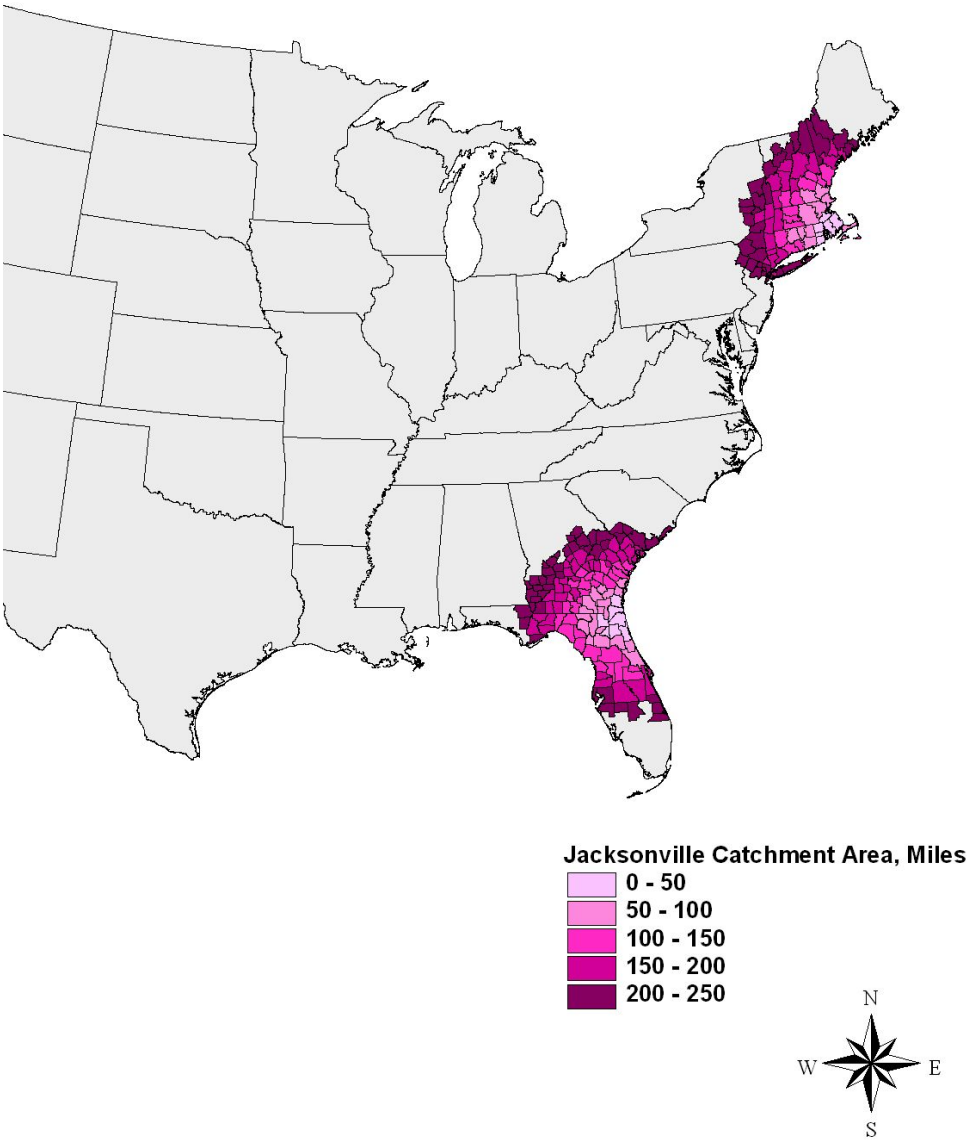
The key potential port partners of the Bristol County ports that were selected to be the focus of the market analysis were the following:

- Bayonne, NJ
- Norfolk, VA
- Wilmington, NC
- Charleston, SC
- Savannah, GA
- Jacksonville, FL
- Port Canaveral, FL
- Tampa, FL
- Pensacola, FL
- Mobile, AL
- New Orleans, LA
- Port Arthur, TX
- Galveston, TX
- Corpus Christi, TX

These ports were selected on an indicative basis only. Other neighboring ports (such as Fernandina Beach, Florida in the case of Jacksonville) that would have essentially the same cargo hinterland may be substituted for the selected port if so desired.

Cargo flows between the respective "hinterlands" of the various port-pairs were identified. The traffic flows were segmented at intervals of 50-miles as shown in the example of Exhibit II-1 below for traffic between the hinterlands of the Bristol County ports and the port of Jacksonville Florida. The analysis of potentially divertible traffic then focused on a "skewed" hinterland to reflect the key assumption that trucks would not backtrack very far to a port in the opposite direction of their desired direction of travel. Consequently, the scope of potentially divertible traffic was restricted to cargo moving between the respective port-pair hinterlands extending only 50-miles in the direction of travel (requiring a backtracking movement) and up to 250-miles in the opposite direction.

Exhibit II-1
Prospective Cargo Hinterlands for Short-Sea Shipping Traffic between Bristol County Ports and the Port of Jacksonville, Florida



Methodology

The purpose of the market-sizing task was to identify the U.S. East and Gulf Coast ports that, as trading partners of the ports of Fall River and New Bedford, may have the greatest potential for diverting current freight traffic from the highways to a short-sea shipping service between the respective port-pairs. Global Insight's TRANSEARCH ® database and ground freight analytical capabilities were used to size the potential short-sea shipping market for Bristol County ports.

TRANSEARCH is a commodity flow database that is produced annually from sample data provided by over 100 public and private data sources that is then subject to rigorous

economic modeling in order to develop an estimate of the total ground freight market on a county to county basis for North America. For this project, the starting point was truck traffic (truckload, private, less-than-truckload, and Canadian/Mexican movements) from the 2003 edition of county-level TRANSEARCH. A detailed description of TRANSEARCH and the methods used to create it is attached as Appendix 1. Traffic flow data from TRANSEARCH was analyzed for each port and its particular drayage hinterland, by direction for northbound and southbound traffic.

The key port-pair partners for the Bristol County ports were matched to corresponding Federal Information Processing Standards (FIPS) county definitions (as shown in Exhibit II-2 below). This geocoding process provided consistent geographic analysis regions for the various source data.

Exhibit II-2
Federal Information Processing Standards (FIPS) County Definitions for Selected Bristol County Port Partners

Port	State	FIPS
Bayonne	NJ	34017
Norfolk	VA	51710
Wilmington	NC	37129
Charleston	SC	45019
Savannah	GA	13051
Jacksonville	FL	12031
Port Canaveral	FL	12009
Tampa	FL	12057
Pensacola	FL	12033
Mobile	AL	1097
New Orleans	LA	22071
Port Arthur	TX	48245
Galveston	TX	48167
Corpus Christi	TX	48355

A sustainable short-sea shipping operation was assumed to provide a less expensive service alternative to other means of transportation, with the understanding that low costs may equate with longer cargo transit times. Reflecting this assumption, unique port catchment areas for a short-sea shipping service were determined using restrictions that take into account the characteristics of a short-sea shipping operation that must compete with the over the road transportation option.

The key assumption behind the determination of cargo hinterlands was that a viable short sea-shipping market may exist when sea/land intermodal transport is significantly cheaper than pure land transport. In our analysis, this was defined using the following criteria: a competitive market may exist when distance by land is greater than distance by sea (including land drayage) *and the unique aspects of sea/land intermodal transport are considered.* As mentioned, ocean transport is typically less expensive than truck transport. This means that, for the same price, goods transported by ship can travel

further than goods transported by truck. To capture these savings, the cost advantage accredited to sea travel is quantified by applying a factor of 0.6 to each port's Ocean Miles (i.e., the estimated transport miles by sea from each port to Bristol County, MA). Sea/land intermodal transportation may also have inherent disadvantages, such as additions to overall transit time due to marine terminal vessel loading and discharge and cargo receiving and delivery operations. In the potential market analysis, this disadvantage is accounted for by adding a 200-mile penalty (approximately four hours of drive time) to the calculated ocean miles for all ports except for Bayonne, which has a unique situation because of the highway congestion surrounding New York City. The application impact of quantifying these unique characteristics is shown in Exhibit II-3, in which Adjusted Ocean Miles are equal to 200 miles + (Ocean Miles × 0.6).

Exhibit II-3
Calculation of Adjusted Ocean Miles

Port	Ocean Miles	Adjusted Ocean Miles
Bayonne	223	134
Norfolk	408	445
Wilmington	644	586
Charleston	710	626
Savannah	784	670
Jacksonville	868	721
Port Canaveral	1,068	841
Tampa	1,477	1,086
Pensacola	1,682	1,209
Mobile	1,716	1,230
New Orleans	1,785	1,271
Port Arthur	1,945	1,367
Galveston	1,947	1,368
Corpus Christi	2,052	1,431

Under these restrictions, a county was included as part of a port's catchment area if the distance by truck to/from Bristol County, MA was greater than the distance of Adjusted Ocean Miles plus drayage distance (miles to/from port to ultimate origin/destination).

For each port catchment area, TRANSEARCH 2003 flow data for truck traffic, including origin, destination, mode, sub-mode, commodity, tons, and units, were extracted at the county level. The multiple layers of detail in the dataset provide the basis for a comprehensive analysis and for data and volume validations at a port-specific level. These extractions yielded a preliminary dataset of over one million records.

Once eligible flows were selected, flows that had a drayage distance of greater than 500-miles were eliminated, meaning if the flow originated or terminated within 500-miles of an eligible port, it was considered traffic available to that port. At this point, a commodity filter at the 2-digit Standard Transportation Commodity Code (STCC) level was applied to remove bulk commodities from the analysis. Specifically, STCCs 10, 11,

13, 14 representing Ores, Coal, Crude Oil, and Minerals were excluded, as those are not commodities likely to move in a short-sea shipping liner service and are likely to travel by water only in large bulk ships. In addition, traffic consisting of empty vehicles (STCC 4221) and secondary traffic (STCC 50) were also removed.

The database at this point contained "eligible flows," representing the traffic that could conceivably be captured by short-sea shipping services if certain other conditions were met. The other conditions, which were not analyzed in this assessment, would include scheduling concerns, transit time, commodity value, and other considerations.

Double-counting between port-pair flows was permitted, meaning one flow may be assigned as "available" to more than one port in the case where port hinterlands may overlap, for example between the ports of Jacksonville and Savannah, Georgia. This enables the comparison of traffic volumes between particular port-pair combinations in order to select those that may offer the greatest market. Of course, the port-pair combinations are not then additive if one were to seek to identify the total market.

A distinction should be drawn between the measurements of domestic truck volumes versus international container shipments. In the case of international traffic, volume is typically measured in Twenty-foot Equivalent Units (TEUs), which correspond to multiples of a standard twenty-foot ISO container. In contrast, domestic traffic is represented in truckloads as would be operated for a given commodity. For dry van traffic, this would typically be either a 48 or 53-foot long trailer. This difference in capacity must be taken into account when ship capacity requirements are examined. The traffic measures included in the market analysis in this report are in “truckloads.”

Findings on the Potential Market

The results of the port-pair traffic flow analysis are provided below in Exhibit II-4. Among the preselected prospective port partners, the largest single potential short-sea shipping market for the Bristol County ports is Bayonne, NJ followed by Jacksonville, FL and Corpus Christi, TX. It is noteworthy that traffic in all of the port-pairs is significantly imbalanced with northbound traffic invariably being the headhaul flow.

Exhibit II-4
Truckload Freight Movements between Bristol County Hinterland and Other Ports

	Southbound	Northbound	Total
Bayonne, NJ	190,342	596,972	787,314
Norfolk, VA	24,409	47,038	71,447
Wilmington, NC	20,909	91,637	112,546
Charleston, SC	41,517	222,536	264,053
Savannah, GA	66,267	218,970	285,237
Jacksonville, FL	140,773	277,086	417,859
Port Canaveral, FL	109,935	160,907	270,842
Tampa, FL	56,677	149,828	206,505
Pensacola, FL	24,711	113,975	138,686
Mobile, AL	70,539	307,285	377,824
New Orleans, LA	53,824	212,519	266,343
Port Arthur, TX	52,059	206,148	258,207
Galveston, TX	94,100	284,813	378,913
Corpus Christi, TX	158,594	258,382	416,976

Source: Global Insight Inc. TRANSEARCH database. See tables in the Appendix for supporting detail.

The TRANSEARCH data was also used to identify the type of commodities moving by truck on the selected Bristol County port-pairs. For example, as shown in Exhibit II-6 below, foodstuffs (no doubt, including large volumes of seafood) are the single largest commodity group moving from the Bristol County hinterland to the Jacksonville area.

Exhibit II-6
Commodities Shipped from Bristol County Hinterland to Jacksonville Hinterland

SOUTHBOUND

Port Name	Jacksonville

Loads	To South					
STCC 2	50 miles	100 miles	150 miles	200 miles	250 miles	Grand Total
Apparel Or Related Products	56	2	-	338	1,425	1,820
Chemicals Or Allied Products	90	658	1,959	3,385	5,764	11,856
Clay, Concrete,Glass Or Stone	156	1,078	555	1,502	5,957	9,248
Electrical Equipment	276	875	139	203	1,464	2,957
Fabricated Metal Products	712	697	2,870	2,641	4,368	11,288
Farm Products	4	8	4	-	31	47
Food Or Kindred Products	999	2,451	343	5,220	12,712	21,724
Forest Products	-	-	-	-	0	0
Fresh Fish Or Marine Products	-	-	-	-	83	83
Furniture Or Fixtures	20	378	10	82	2,117	2,607
Instrum, Photo Equip, Optical Eq	217	77	171	319	909	1,692
Leather Or Leather Products	64	92	80	146	130	513
Lumber Or Wood Products	3	49	2	500	2,565	3,119
Machinery	264	791	1,158	1,985	5,411	9,609
Misc Manufacturing Products	31	164	108	370	603	1,275
Petroleum Or Coal Products	3,162	11,288	14	2,564	1,099	18,127
Primary Metal Products	847	4,123	1,295	1,513	5,046	12,823
Printed Matter	1,866	584	43	1,821	1,515	5,830
Pulp, Paper Or Allied Products	172	2,286	333	3,121	5,817	11,729
Rubber Or Misc Plastics	965	4,228	2,173	3,626	863	11,855
Textile Mill Products	335	188	120	138	419	1,200
Transportation Equipment	6	49	120	15	1,179	1,368
Grand Total	10,243	30,066	11,497	29,488	59,479	140,773

Source: Global Insight Inc. TRANSEARCH database.

In the reverse “headhaul” direction, chemicals are the major single item moving from the Jacksonville hinterland to the Bristol County hinterland with foodstuffs (including citrus and beef) also accounting for a significant share as shown in Exhibit II-7 below.

Exhibit II-7
Commodities Shipped from Jacksonville Hinterland to Bristol County Hinterland

NORTHBOUND

Port Name	Jacksonville

Loads	To Bristol County					
STCC 2	50 miles	100 miles	150 miles	200 miles	250 miles	Grand Total
Apparel Or Related Products	1,085	1,051	731	254	3,441	6,563
Chemicals Or Allied Products	10,280	25,752	5,404	15,113	25,253	81,802
Clay, Concrete,Glass Or Stone	12,190	3,187	6,828	32,845	11,687	66,739
Electrical Equipment	238	1,013	583	349	757	2,940
Fabricated Metal Products	404	574	1,038	363	586	2,966
Farm Products	474	597	50	786	1,341	3,247
Food Or Kindred Products	8,043	9,421	3,720	5,531	9,093	35,808
Forest Products	-	-	-	-	6	6
Fresh Fish Or Marine Products	-	-	-	-	0	0
Furniture Or Fixtures	394	1,069	163	482	1,707	3,815
Instrum, Photo Equip, Optical Eq	117	253	317	1,025	220	1,932
Leather Or Leather Products	26	23	41	47	12	149
Lumber Or Wood Products	6,896	2,866	2,013	1,961	643	14,378
Machinery	669	1,978	1,178	1,174	1,393	6,392
Misc Manufacturing Products	117	505	91	24	673	1,410
Petroleum Or Coal Products	25	173	49	45	358	650
Primary Metal Products	562	524	382	439	2,668	4,575
Printed Matter	74	98	762	2,307	2,323	5,565
Pulp, Paper Or Allied Products	1,278	7,232	4,304	3,668	3,519	20,002
Rubber Or Misc Plastics	941	948	623	348	835	3,695
Textile Mill Products	725	1,182	246	168	875	3,196
Tobacco Products	5	-	-	-	-	5
Transportation Equipment	505	2,244	1,926	2,272	4,297	11,243
Waste Or Scrap Materials	-	-	-	-	9	9
Grand Total	45,050	60,690	30,449	69,202	71,695	277,086

Source: Global Insight Inc. TRANSEARCH database.

Given the type of commodities moving in the Bristol County/Jacksonville corridor, it is not surprising that tank and reefer trailers account for a significant share of the trailer loads in addition to the largest equipment type of dry vans as described in Exhibit II-8.

Exhibit II-8
Commodities Shipped from Jacksonville Hinterland to Bristol County Hinterland

SOUTHBOUND

Port Name	Jacksonville

Loads	To South					
Equipment Type	50 miles	100 miles	150 miles	200 miles	250 miles	Grand Total
Flat	724	2,499	1,623	2,675	6,993	14,513
Dry Van	6,151	16,031	8,274	21,141	44,716	96,313
Tank	2,793	10,817	1,200	3,728	3,092	21,630
Bulk	8	335	5	287	1,345	1,980
Reefer	568	384	395	1,656	3,333	6,336
Grand Total	10,243	30,066	11,497	29,488	59,479	140,773

NORTHBOUND

Port Name	Jacksonville

Loads	To Bristol County					
Equipment Type	50 miles	100 miles	150 miles	200 miles	250 miles	Grand Total
Flat	8,516	6,645	3,884	22,340	10,030	51,414
Dry Van	26,551	32,019	21,119	29,418	42,612	151,718
Tank	4,165	15,963	3,180	7,662	8,498	39,468
Bulk	1,390	2,046	758	6,622	2,640	13,456
Reefer	4,296	3,912	1,414	3,160	7,907	20,689
Auto	132	106	93	1	8	340
Grand Total	45,050	60,690	30,449	69,202	71,695	277,086

Source: Global Insight Inc. TRANSEARCH database.

Short-Sea Shipping Case Studies

Several recent examples of U.S. short-sea shipping operations were analyzed in order to identify key factors that contributed to their success or failure and their implications for the ports of Fall River and New Bedford. The examples are not intended to be a comprehensive listing of all recent short-sea shipping initiatives but were selected, rather, to reflect a range of type of operations and situations. The results of this analysis that was based on publicly available information as well as interviews with the companies involved are described in the following case studies.

Matson Navigation Company[1]

Background:

- Matson began operations in the U.S. mainland/Hawaii trade in 1882
- Matson has a major share of the U.S./Hawaii shipping market estimated at 70 percent
- Between 1994 and 1999 Matson ran a single surplus 2100 TEU container vessel on a Los Angeles/Seattle/Vancouver/Los Angeles weekly service
- Matson has recently taken delivery of two 2400 TEU U.S.-built container ships at a cost of $110 million each from Kvaerner Philadelphia Shipyard and another two 2400 TEU vessels on order at $140 million each from the same yard

Key Business Parameters:

- Service carried both international cargoes (as feeder vessel), empty containers requiring repositioning, and domestic loads (approximately 30 percent of total containers carried)
- Domestic loads increased from 25,000 to 45,000 annually between 1994 and 1997
- Service was priced at a discount to prevailing truck rates

Status:

- Service was discontinued in 1999 due to poor financial performance

Conclusions:

- Service failed primarily due to high stevedoring costs – ILWU was unwilling to provide concessions to enable the service to be economically viable
- Matson was able to gain a number of key accounts (e.g. Anheuser Busch)
- The service was difficult to sell to traffic managers – "required going further up the management chain"
- Matson was not successful in selling the service to truckers – many saw it as a "threat"

[1] Interview with Phil Grill, Vice President

Totem Ocean Trailer Express (TOTE)[2]

Background:

- Started roll-on/roll-off (RoRo) service between Tacoma, WA and Anchorage, AK in 1975
- Provides two sailings per week on 1,000-mile route
- Competes with AlCan Highway and container vessel and barge operators
- Took delivery of two new U.S.-built 600 trailer capacity RoRo vessels in 2003 at reported cost of $180 million each

Key Business Parameters:

- RoRo vessels complete cargo discharge and load (up to 1,200 trailer moves plus auto traffic) within eight hours at each port
- Primarily transports shipper-owned highway trailers

Status:

- Company has been consistently profitable
- Parent is also majority owner of Sea Star Line in U.S./Puerto Rico trade
- Possibly interested in other U.S. domestic shipping opportunities

Conclusions:

- Company gained strong market position by working closely with truckers and freight forwarders in the Alaska market
- RoRo operation provides truck-competitive transit times and costs for all types of cargo

Osprey Lines[3]

Background:

- Started business in 2000 as spin-off from Maersk's acquisition of Sea-Land in order to provide U.S. flag container feeder operation in the Gulf for mostly international cargoes
- Initially focused on shipping containers on barge between New Orleans and Houston
- Have recently expanded into domestic cargoes in containers – operating *Sea Trader* 13.5 knot 124 FEU containership (converted from an offshore service vessel) on weekly Houston/Tampa/ New Orleans deployment carrying a combination of domestic and international cargoes in containers

Status:

- Kirby Marine recently purchased majority holding in company – Osprey Lines founder has departed to form new company "Couch Lines"

[2] Interview with Bob Magee, CEO
[3] Interview with Rick Couch, CEO

- Couch reports he is currently working on a vessel newbuilding program with U.S. shipyards for four 125 FEU (13.5 knots) containerships and looking to enter new coastal markets on U.S. Gulf and East Coasts

Key Business Parameters:
- Loads/discharges containers in port using boom cranes
- Transported a total of 65,000 containers in 2004 (both international and domestic)

Conclusions:
- Domestic business built on incremental basis on top of international feeder loads
- Marketing focus on heavy and out of gauge cargoes – carry both in containers and as breakbulk
- Osprey seeks to control own terminals and trucking operations
- Sells service reliability and value – sees as more important than transit time
- However, believes still able to offer shippers truck-competitive transit time and significantly better transit time than rail intermodal

New England Fast Ferry[4]

Background:
- Operates passenger ferries (with limited cargo capacity) between New Bedford and Nantucket/Martha's Vineyard
- Subsidiary of Moran Towing
- Considering start-up of New Jersey (e.g. Bayonne)/New Bedford RoRo cargo service with medium speed vessels (catamaran hull design)

Key Business Parameters:
- Value proposition of new service is to provide truckers with overnight bypass of congested New York City/Connecticut area – e.g. depart New Jersey at 8 pm./ arrive New Bedford by 5 am next morning
- Two catamaran vessel designs under consideration
  - 260' RoRo with 24 trailer capacity at estimated capital cost of $25 million
  - 320' RoRo with 42 trailer capacity at estimated capital cost of $30 million
- Estimates economics of port to port move at $350 per trailer – key to holding down cost is using crew to load/discharge trailers

Status:
- Service still in planning stage

Conclusions:
- Looking for "cornerstone" contract with major trucker or truckers to provide base cargo volume
- Prefers New Bedford to Fall River as Massachusetts terminus due to perception of better highway access and terminal capacity at New Bedford (NEFF already operates over New Bedford's State Pier)

[4] Interview with James Barker, VP

- Proposed service offers opportunity for short-sea shipping start-up within relatively short term (2-3 years) if vessels are newbuilds in U.S. shipyard
- Service could build credibility with truckers before expanding into longer haul markets
- Question whether service economics can be achieved with small size of vessels – vessel with 150-trailer capacity may be able to operate at $300-350 per trailer load; smaller vessels may lack scale necessary to offset high fuel costs

Trailer Bridge[5]

Background:

- Runs both RoRo and LoLo container barges between U.S. mainland (New York and Jacksonville) and Puerto Rico
- Operated "Atlantic Highway" container barge service between Port Newark and Jacksonville from January to September, 1999 – service was terminated when hurricane delayed barge by four days leading to the loss of a major account (ToysRUs)

Key Business Parameters:

- Cargo on New York/Jacksonville service was entirely domestic
- Weekly capacity: 265 53' containers
- Major source of cargo was diversion from rail intermodal
- Pricing per container load was around $500
- New York/Jacksonville transit time was three days – comparable with rail intermodal but slower than truck
- Major southbound shippers included GM for cars relayed through Jacksonville to Puerto Rico
- Major northbound shippers included forest product shippers (packaging materials, lumber, and pulp)

Status:

- Service discontinued – no plans to restart

Conclusions:

- Service was sold primarily on price
- Relatively slow transit time was not a major disadvantage to a shipper such as Toys RUS but unreliability was
- Operating out of Port Newark added cost despite a "reasonable" deal with the ILA

The case studies lead to a number of important overall findings on the current state of short-sea shipping in the United States:

- Despite a number of recent efforts, domestic sort-sea shipping operations on the U.S. coasts have had only moderate success to date (e.g. Osprey Lines)
- Nevertheless, a number of major shippers have elected to support short-sea shipping services (e.g. ToysRUs, Anheuser Busch, General Motors)

[5] Interview with John McCown, CEO

- Osprey appears to have benefited from a dual marketing focus on selling domestic transportation to both shippers and truckers
- Truckers may be interested in the overall value proposition of adding short-sea shipping as an alternative mode, but they need to have the potential benefits clearly spelled out
- Close cooperation with trucking companies is essential in successfully developing and operating a short-sea service – a key asset is building base cargo support through commitments from major truckers on a particular route
- Schedule reliability may be at least as important a service factor in effectively marketing the service as door-to-door transit time
- Labor buy-in is critical to creating a cost-competitive short-sea service in terms of both vessel and marine terminal operations
- Short-sea shipping can be particularly competitive for heavy and/or hazardous shipments currently moving over the road such as chemicals
- Service frequency needs to be at least 2-3 sailings per week on relatively long haul routes – daily is probably not necessary except on short-haul routes (e.g. Bayonne/Bristol County)

In conclusion, there appear to be a number of factors that promote the emergence of a U.S. domestic coastal short-sea shipping network including increasing highway congestion (particularly in the Northeast), rising fuel costs, restrictions on truck driver hours of operation, and a shortage of drivers. In addition, there is a great deal of truck cargo moving to and from the Bristol County port hinterland along the Eastern seaboard, some of which may potentially be divertible to short-sea shipping services. However, despite the positive signs of a market opportunity, there is scant evidence of successful business plans being put in place to meet that market need. As both the Matson and Trailer Bridge attempts to put a short-sea service in place failed for economic reasons – primarily due to high costs – the next section of this report will analyze the economics of short-sea shipping, particularly as they relate to potential services utilizing the ports of Fall River and/or New Bedford.

The Economics of Short-Sea Shipping versus Alternative Modes

The market analysis of trucking movements into and out of the Bristol County ports' hinterland indicated that the prospective port partners of Bayonne, NJ and Jacksonville, FL had substantial potentially divertible traffic volumes. Consequently, an economic model was developed to calculate the cost to the shipper of moving a trailer load of freight on each of these corridors using a short-sea mode versus over the road trucking or rail intermodal where appropriate.

The economics of a short-sea shipping service include both direct vessel operating costs, capital costs, and other costs associated with the movement of a trailer-load of freight. Direct vessel operating costs include vessel manning, maintenance and repair, insurance (Hull & Machinery and P&I), capital, and vessel management costs, fuel and consumables, and port charges. These costs were developed based on information developed from ocean carrier and port operator interviews, and general industry knowledge of the project team.

Non-vessel operating costs for the short-sea shipping service include stevedoring and marine terminal operations, container, trailer, and chassis leasing and maintenance, drayage operations, and sales and general administrative overhead. These were developed from carrier and port operator interviews and the professional experience of the project team. In addition, the cost to shippers of Harbor Maintenance Tax (HMT) charged on shipments moving in and out of U.S. ports was also added as a line item in the model for short-sea shipping operations as would be applicable under the current U.S. tax regime.

The key assumptions concerning vessel operations for ships to be deployed on the short haul Bayonne potential service and the long haul Jacksonville service are summarized in the following Exhibit II-9.

Exhibit II-9
Key Assumptions on Potential Short-Sea Service Vessels

Vessel Operating Costs for Coastal Vessels

	Container Ship	**RoRo Vessel**	**RoRo Ferry**
Cargo capacity	200 Trailers	140 Trailers	40 Trailers
Key assumptions:			
Capital cost:	$38 million	$44 million	$30 million
Vessel speed:	25 knots	25 knots	20 knots
Fuel consumption:	30 TPD	30 TPD	4,300 gals MDO
Crew size:	10	10	8
Vessel expense per day			
Crew	$6,500	$6,500	$3,500
Maintenance & Repair	$875	$875	$700
Consumables	$600	$600	$250
Insurance & Other	$625	$625	$400
	$8,600	$8,600	$4,850
Depreciation	$4,164	$4,822	$3,288
Total	**$12,764**	**$13,422**	**$8,138**

*Assumes 25 years vessel life

The economics of the short-sea shipping option used in the transportation model are based on a theoretical level of costs that reflect some significant changes in current working practices that would need to be instituted by industry, labor, and government specifically for short-sea shipping but that are nevertheless reasonably achievable in the near term. The key areas for which such theoretical cost levels were used include vessel capital costs, vessel crew costs and manning levels, and port stevedoring costs. Although these cost levels are lower than those for most current Jones Act shipping operations, they should be attainable based on an analysis of current "best in class" industry practices within the U.S. today and U.S. and international benchmarks.

The following are the key assumptions made concerning the operations and costs for a prospective short-sea shipping service:

- Both RoRo trailer vessels and LoLo container vessels were tested for the long haul Jacksonville service but only a RoRo vessel was evaluated for the short haul Bayonne service given the relatively short steaming distance (less than 200-miles) and the consequent premium put on minimizing port time both for expediting vessel turnaround and cargo despatch
- Crew sizes of 10 for the larger container and RoRo vessels and 8 for the smaller RoRo vessel were based on the assumption that new manning agreements with the seafarer unions and the Coast Guard would be developed for a two-watch system for self-propelled vessels operating along the contiguous coasts of the U.S.
- Marine terminal loading and discharging costs are on an "all-in basis" and reflect current best practices that would require labor agreements specially designed for coastal short-sea shipping
- An average vessel operating speed of 25 knots was used for the Jacksonville service and 20 knots for the Bayonne service – this relatively high speed for conventional RoRo or container vessels on the Jacksonville service was deemed necessary to provide a "truck-competitive" transit time
- The vessel capital costs used are lower than current prices from U.S. shipyards but still substantially higher than international prices – the lower U.S. prices reflect the assumption that long vessel-building runs, more aggressive purchasing practices, and improved productivity by U.S. shipyards would bring down the cost of U.S.-built vessels

Similarly, the cost of trucking and rail intermodal operations on the respective Bayonne and Jacksonville corridors were also developed. For a truck operator, fully allocated cost data provided by a major motor carrier was used as the starting point in developing the truck economics. Truck operations were based on a single driver operating within current hours of service (HOS) restrictions. Future road congestion was not addressed – service and cost parameters are reflected as "current steady state". Additional highway cost data was developed using the TTS Blue Book of Trucking Companies (2004-2005 Edition) and allowed for the disaggregation of wages and benefits, equipment, insurance, fuel and other expenses. Global Insight's Intermodal Cost Analysis Model (ICAM) was used to prepare estimates of the rail intermodal door-to-door delivery costs for each of the pilot project corridors.

The key cost elements for motor carriers include pick-up and delivery, over the road vehicle operations, fuel, driver costs, dispatching, insurance, as well as other factors that would be directly affected by the choice of transport mode between the origin and destination markets in the particular lanes. Highway tolls are reflected as a separate cost item in the model, and are estimated based on average toll costs per mile and average toll miles adjusted for specific corridors. Sales and administrative overhead are also included. Source information was developed from public data, carrier interviews, and general industry knowledge of the project team.

Rail intermodal direct operating cost elements include locomotives and fuel, track and right-of-way, yard and terminal operations, lift-on and lift-off movements, railcar, crew, trailer/container, and drayage expense. Sales and administrative overhead are also included.

Again, this information was developed from public data, carrier interviews, and general industry knowledge of the project team.

The cost of repositioning trailers or containers in a particular corridor was also built into the model for each mode. Trucking and rail intermodal operations have an advantage in this area as they have greater latitude to search for return loads than the short-sea service that was assumed to be tied to a particular port-pair. In this case, the short-sea service was charged with the cost of vessel loading and discharging for all empty trailers/containers in the backhaul direction of each particular corridor.

A short-sea shipping carrier's cost of moving a trailer load of freight between Bristol County, MA and Jacksonville was calculated at approximately $1,100, as described in Exhibit II-10 below.

Exhibit II-10
Short-Sea Shipping Costs Between Bristol County and Jacksonville, Florida

US Coastal Liner Shipping Service Economic Model	Jacksonville/Bristol County				Jacksonville/Bristol County			
Origin:	**Jacksonville, FL**				**Jacksonville, FL**			
Destination:	**Bristol County, MA**				**Bristol County, MA**			
Ocean Transit (Nautical Miles):	993.00				993.00			
Vessel type:	**RoRo**				**Container**			
Vessel speed: (Knots)	25				25			
One Way Steaming Time (Hours)	40.0				40.0			
Frequency in R/T voyages per week:	3.00				3.00			
No. R/T voyages per year:	144				144			
R/T Ocean Transit Days:	3.50				3.50			
TTL Terminal Days:	1.50				1.50			
Total Ship Days	5.00				5.00			
TTL Drayage Days	2.00				2.00			
Total Container Days	7.00				7.00			
Total Volume of Lane Traffic (Truckloads):	**Truckloads**				**Truckloads**			
Northbound:	277,000				277,000			
Southbound:	141,000				141,000			
Share of Total Lane Traffic:	**Base**	**Freq. Adj**	**Net Share**		**Base**	**Freq. Adj**	**Net Share**	
Northbound:	7%	100%	7%		10.0%	100%	10.0%	
Southbound:	8%	100%	8%		11%	100%	11%	
Vessel Capacity (truckloads):	140				200			
NB capacity payload utilization:	96.2%				96.2%			
SB capacity payload utilization:	56.0%				53.9%			
	Per Unit	**Per Voyage**	**Per Year**	**Percent**	**Per Unit**	**Per Voyage**	**Per Year**	**Percent**
Freight Volumes (truckloads)								
Northbound Loads		135	19,390	50%		192	27,700	50%
Northbound Empties		-	-	0%		-	-	0%
Southbound Loads		78	11,280	29%		108	15,510	28%
Southbound Empties		56	8,110	21%		85	12,190	22%
Total Volumes		**269**	**38,780**	**100%**		**385**	**55,400**	**100%**
Service Economics								
Variable Costs								
Marine Terminal Cargo-Handling								
RoRo cost per unit (load & discharge): $100	$ 120	$ 32,317	$ 4,653,600		$ -	$ -	$ -	
LoLo cost per unit (load & discharge): $200	$ -	$ -			$ 200	$ 76,944	$ 11,080,000	
Mean terminal cargo handling cost per load	$ 152				$ 256			
Land Transportation								
Origin Dray	$ 193	$ 41,141	$ 5,924,290		$ 193	$ 57,962	$ 8,346,547	
Destination Dray	$ 228	$ 48,455	$ 6,977,549		$ 228	$ 68,267	$ 9,830,450	
Long haul drays	$ 70	$ 3,739	$ 538,374		$ 70	$ 5,267	$ 758,498	
Mean Truck Dray Expense	$ 438	$ 93,335	$ 13,440,213		$ 438	$ 131,496	$ 18,935,495	
Equipment Costs								
Container/Trailer	$51	$ 10,862	$ 1,564,170		$ 53	$ 15,904	$ 2,290,130	
Chassis	$ -	$ -	$ -		$ 18	$ 5,386	$ 775,600	
Mean Equipment Costs	$ 51	$ 10,862	$ 1,564,170		$ 71	$ 21,290	$ 3,065,730	
Total Variable Costs	**$ 641**	**$ 136,514**	**$ 19,657,983**		**$ 766**	**$ 229,731**	**$ 33,081,225**	
Fixed Costs								
Vessel	$ 315	$ 67,110	$ 9,663,840	28%	$ 213	$ 63,820	$ 9,190,080	20%
Vessel fuel*	$ 89	$ 18,900	$ 2,721,600	8%	$ 63	$ 18,900	$ 2,721,600	6%
Port Charges	$ 19	$ 4,000	$ 576,000	2%	$ 13	$ 4,000	$ 576,000	1%
Sales & Administration	$ 38	$ 8,000	$ 1,152,000	3%	$ 27	$ 8,000	$ 1,152,000	2%
Non-Vessel Depreciation	$ 5	$ 1,000	$ 144,000	0%	$ 3	$ 1,000	$ 144,000	0%
Total Fixed Costs	**$ 465**	**$ 99,010**	**$ 14,257,440**	**42%**	**$ 319**	**$ 95,720**	**$ 13,783,680**	**29%**
Total Operating Expenses	**$ 1,106**	**$ 235,524**	**$ 33,915,423**	**100%**	**$ 1,085**	**$ 325,451**	**$ 46,864,905**	**100%**
Operating Expense per Revenue Load:		**$ 1,106**				**$ 1,085**		

Operating Statistics	Jacksonville/Bristol County	Jacksonville/Bristol County
Number of Ships	2.00	2.00
Door-to-Door Transit (days)	6.00	6.00
Vessel Turns per Week	1.40	1.40

The cost of moving a trailer load of freight between Bristol County, MA and Northern New Jersey by short-sea shipping service was calculated at over $500 per trailer for a 40-trailer RoRo vessel and at around $260 for a 140-trailer RoRo vessel, similar to that tested for the Jacksonville run. The significant difference in the costs per trailer is due to the much greater scale economies that the larger vessel is able to achieve as well as its substantially greater fuel efficiency per unit of cargo. Given the volume of truck cargo moving in the Bayonne/Bristol County hinterlands corridor, the larger vessel would require a penetration rate of 7 percent of the total market versus 2 to 3.5 percent for the smaller vessel to achieve its projected cost per load as described in Exhibit II-11 below.

Exhibit II-11
Short-Sea Shipping Costs Between Bristol County and Bayonne, NJ

US Coastal Liner Shipping Service Economic Model	Bayonne, NJ/Bristol County Ocean Service Only				Bayonne, NJ/Bristol Larger Ship (140 Trailers)			
Origin:	**Bayonne, NJ**				**Bayonne, NJ**			
Destination:	**Bristol County, MA**				**Bristol County, MA**			
Ocean Transit (Nautical Miles):	178.00				178.00			
Vessel type:	RoRo				RoRo			
Vessel speed: (Knots)	21				21			
One Way Steaming Time (Hours)	8.5				8.5			
Frequency in R/T voyages per week:	7.00				7.00			
No. R/T voyages per year:	350				350			
R/T Ocean Transit Days:	0.70				0.70			
TTL Terminal Days:	0.30				0.30			
Total Ship Days	1.00				1.00			
TTL Drayage Days	2.00				2.00			
Total Container Days	3.00				3.00			
Total Volume of Lane Traffic (Truckloads):	**Truckloads**				**Truckloads**			
Northbound:	597,000				597,000			
Southbound:	190,000				190,000			
Share of Total Lane Traffic:	**Base**	**Freq. Adj**	**Net Share**		**Base**	**Freq. Adj**	**Net Share**	
Northbound:	2.0%	100%	2.0%		7.0%	100%	7.0%	
Southbound:	3.5%	100%	3.5%		7.0%	100%	7.0%	
Vessel Capacity (truckloads):	40				140			
NB capacity payload utilization:	85.3%				85.3%			
SB capacity payload utilization:	47.5%				27.1%			
	Per Unit	**Per Voyage**	**Per Year**	**Percent**	**Per Unit**	**Per Voyage**	**Per Year**	**Percent**
Freight Volumes (truckloads)								
Northbound Loads		34	11,940	64%		119	41,790	50%
Northbound Empties		-	-	0%		-	-	0%
Southbound Loads		19	6,650	36%		38	13,300	16%
Southbound Empties		-	-	0%		-	28,490	34%
Total Volumes		**53**	**18,590**	**100%**		**157**	**83,580**	**100%**
Service Economics								
Variable Costs								
Marine Terminal Cargo-Handling								
RoRo cost per unit (load & discharge): $100	$ 100	$ 5,311	$ 1,859,000		$ 100	$ 15,740	$ 5,509,000	
LoLo cost per unit (load & discharge): $200	$ -	$ -	$ -		$ -	$ -	$ -	
Mean terminal cargo handling cost per load	$ 100				$ 100			
Land Transportation								
Origin Dray		$ -	$ -		$ -	$ -	$ -	
Destination Dray		$ -	$ -		$ -	$ -	$ -	
Long haul drays		$ -	$ -		$ -	$ -	$ -	
Mean Truck Dray Expense	$ -	$ -	$ -		$ -	$ -	$ -	
Equipment Costs								
Container/Trailer	$ -	$ -	$ -		$ -	$ -	$ -	
Chassis	$ -	$ -	$ -		$ -	$ -	$ -	
Mean Equipment Costs	$ -	$ -	$ -		$ -	$ -	$ -	
Total Variable Costs	**$ 100**	**$ 5,311**	**$ 1,859,000**		**$ 100**	**$ 15,740**	**$ 5,509,000**	
Fixed Costs								
Vessel	$ 153	$ 8,138	$ 350	0%	$ 85	$ 13,422	$ 350	0%
Vessel fuel*	$ 154	$ 8,170	$ 2,859,500	41%	$ 25	$ 4,000	$ 1,400,000	15%
Port Charges	$ 19	$ 1,000	$ 350,000	5%	$ 10	$ 1,500	$ 525,000	6%
Sales & Administration	$ 94	$ 5,000	$ 1,750,000	25%	$ 32	$ 5,000	$ 1,750,000	19%
Non-Vessel Depreciation	$ 6	$ 300	$ 105,000	2%	$ 4	$ 600	$ 210,000	2%
Total Fixed Costs	**$ 426**	**$ 22,608**	**$ 5,064,850**	**73%**	**$ 156**	**$ 24,522**	**$ 3,885,350**	**41%**
Total Operating Expenses	**$ 526**	**$ 27,919**	**$ 6,923,850**	**100%**	**$ 256**	**$ 40,262**	**$ 9,394,350**	**100%**
Operating Expense per Revenue Load:		**$ 526**				**$ 256**		

Operating Statistics	Bayonne, NJ/Bristol County Ocean Service Only	Bayonne, NJ/Bristol County Full Service
Number of Ships	1.00	1.00
Door-to-Door Transit (days)	0.50	2.00
Vessel Turns per Week	7.00	7.00

In addition to the carrier's costs for the respective modes on each corridor, the total cost for moving a trailer-load of freight on the particular corridor that would be incurred by the shipper of that freight was also calculated. The cost to the shipper would include any "mark-up" or profit margin that the carrier would add to its costs as well as the incremental inventory carrying costs caused by the slower transit times of the rail intermodal and short-sea shipping service options versus trucking. In addition, Harbor Maintenance Tax (HMT) would apply to only the short-sea option. Carrier mark-ups were estimated based on current practices and conditions in the U.S. domestic freight markets for each of the modes.

As shown in Exhibit II-12 below, the short-sea shipping option on the Bristol County/Jacksonville Corridor is projected to achieve a significant cost advantage against both the truck and rail intermodal options, although with a longer transit time.[6]

Exhibit II-12
Comparative Performance of Short-Sea Shipping versus Alternative Modes on the Bristol County/Jacksonville Corridor

	Truck	Rail Intermodal	Short-Sea Shipping
Total miles (door to door)	1,183	1,340	1,342
Transit hours (door to door)	54.5	66.5	72.0
Carrier cost per highway mile	$1.59	$1.04	$0.90
Shipper cost per highway mile	$1.73	$1.26	$1.02
Differential versus Truck	--	-27%	-41%

In the case of the short haul Bayonne/Bristol County corridor, rail intermodal was not considered to be a viable option from a service viewpoint, so the service options were restricted to truck and short-sea shipping. A distance of 498 miles was used for the truck movement in order to represent traffic moving between the two port hinterlands, not simply between the ports. The impact of Harbor Maintenance Tax (HMT), an ad valorem duty, is immediately apparent when the short-sea costs for the Bayonne corridor are compared to truck as shown in Exhibit II-13 below. The cost advantage for short-sea service is increased from 17 percent to 31 percent with the simple exclusion of HMT.

[6] Details behind these calculations are included in Appendix VI-3.

Exhibit II-13
Comparative Performance of Short-Sea Shipping versus Alternative Modes on the Bristol County/Bayonne Corridor

	Truck	Short-Sea Shipping
Total miles (door to door)	498	558
Transit hours (door to door)	12	17.5
Carrier cost per highway mile	$1.49	$1.17
Shipper cost per highway mile	$1.62	$1.35
Shipper cost per highway mile (without HMT)	$1.62	$1.11
Differential versus Truck (with HMT)	--	-17%
Differential versus Truck (without HMT)	--	-31%

The results of the economic analysis demonstrate that short-sea shipping can be extremely competitive with other transportation options on key corridors into and out of the Bristol County ports' hinterland if certain key assumptions on vessel, crew, and stevedoring costs are met. This competitiveness is further enhanced by the waiving of HMT.

In order to further evaluate the commercial feasibility of short-sea shipping operations using the Bristol County ports, the competitiveness of short sea shipping economics and service levels versus alternative modes were tested in a number of interviews with prospective users. The results of this market research are described in the following chapter.

III. Market Feedback on Short-Sea Shipping Services over Bristol County Ports

Interviews were conducted in person and by phone with a total of seventeen prospective users of short-sea shipping services through the Bristol County ports that are described in Exhibit III-1. The interviewees consisted of twelve ground carriers (primarily truckers) and five shippers. The outline of the questionnaire as followed is included in Appendix VI-4. The output from the interviews is summarized in Exhibit III-2 (3 pages).

The following are the principal findings obtained from the interviews:

- All of the carriers interviewed, but only one of the shippers, professed some familiarity with short-sea shipping as a potential mode of transportation – a number of the carriers mentioned that they had been approached within the past year by groups looking for carrier support for a potential short-sea service start-up
- The potential level of possible support for a short-sea service over the ports of Bristol County varied widely – from a possible 150 trailer loads a day out of the Raritan Industrial Center (Raritan Central Railway) on the Bayonne/Bristol County overnight shuttle to a few trailers a week. In aggregate, however, the potential level of support based on this relatively small sample was very strong.
- In terms of the key requirements that a short-sea service must have in order to be considered a viable transportation option, the most frequently cited were the following:
  - Fast transit and reliable scheduling
  - Competitive price
  - Seamless service – "just like trucking…no port hang-ups"
- In probing on the issue of transit time for a short-sea service, the responses varied significantly
  - LTL operators tended to think that the multiple stages in a short-sea intermodal movement would not enable them to provide the "next day" delivery that their customers required, particularly on a regional basis
  - TL operators were less concerned over short-sea being able to match trucking transit times but required absolute schedule reliability and a competitive price – they tended to see short-sea as another intermodal option
  - The quoted transit times for both the Bayonne and Jacksonville short-sea prospective operations (10 hours port to port for Bayonne, 50 hours for Jacksonville) were generally acceptable to TL operators and most shippers
- Respondents' chief concerns varied widely
  - One carrier (US Express) that is well-informed on short-sea shipping felt that Jacksonville was not a good southern port partner and that Wilmington, NC or Norfolk, VA were better situated to service large volumes of truck freight from the Southeast, particularly Atlanta

Exhibit III-1
Commercial Feasibility of Short-Sea Shipping Interviewees

Ground Carriers

Company	Location	Person	Position	Phone
US Express Truckload operator	4080 Jenkins Road Chattanooga, TN 37421	Craig Fuller	President, Xpress Global Systems	(817) 829-5098
J.B. Hunt Truckload operator	615 J.B. Hunt Corporate Drv. Lowell, Arkansas 72745	Paul Bergant	EVP	(800) 643-3622
Schneider National Truckload & intermodal operator	3101 South Packerland Drive Green Bay, WI 54306	Brian Bowers	VP & GM of Intermodal Services	(920) 592-3584
Swift Transportation Co. Truckload operator	HQ in Phoenix, AZ	Mark Martin	EVP - East Coast	(602) 269-9700 ext. 17523
Wyatt Transfer Truckload operator	3035 Bells Road Richmond, VA 23234	Chick Rosemond	VP Sales	(804) 389-7299
Southeastern Freight Lines Primarily LTL operator	420 Davega Road Lexington, SC 29073	Bob Bullock	VP International Business & Partnerships	(704) 597-9828
Trimac Truckload bulk carrier	3663 N. Sam Houston Pkwy. Houston, TX 77032	David Perry	VP Business Development	(285) 981-0000
New England Motor Freight Regional LTL/TL carrier	1-71 North Avenue East Elizabeth, NJ 07201	John Karlberg	President & COO	(570) 386-4876
Werner Enterprises Truckload operator	14507 Frontier Road Omaha, NE 68138	Steve Phillips	SVP - Van Division	(800) 228-2240
DiSilva Transportation TL Specialist in Grocery Prod.	50 Middlesex Avenue Somerville, MA 02415	Tom DiSilva	CEO	(781) 229-6380
Heartland Express Regional TL operator	2777 Heartland Drive Coralville, IO 52241	Rich Meehan	VP Operations & Marketing	(800) 451-4621
Raritan Central Railway Short line RR & Warehouse operator	One Gateway Center Newton, MA 02458	Eyal Shapira	President	(617) 243-0137

Exhibit III-1
Commercial Feasibility of Short-Sea Shipping Interviewees

Shippers

Company	Location	Person	Position	Phone
Quaker Fabric	1082 Davoll Street	Mark Helwig	Supply Chain Manager	(508) 678-1951
Uphostlery fabric	Fall River, MA 02721			
Lightolier	631 Airport Road	Bill Torrens		(508) 679-8131
Lighting fixtures	Fall River, MA 02720	Bill Poole	Traffic Manager	(860) 886-2621
Titleist	333 Bridge Street	Jim Day	Footjoy Traffic Manager	(508) 979-2000
Golf equipment	Fairhaven, MA 02719			
Maritime International	276 MacArthur Drive	Pierre Bernier	Manager Shipping Ops	508 996-8500
Seafood	New Bedford, MA 02740		and Logistics	ext. 233
Weyerhaeuser	Federal Way, WA 98063	Craig Lawrence	CEO Westwood Shipping	(253) 924-4349
Forest Products		Mike Ocepek	Logistics Planner	

Exhibit III-2
Summary of Results from Market Research
Ground Carriers

Company	Familiarity with SSS	Volume of Potential Traffic	Key Requirements	Chief Concerns	Interest in Short-Haul Service	Interest in Long-Haul Service	Key Success Factors	Perceptions of Fall River/New Bedford
US Express TL operator	High	Most traffic from Wilmington NC/ Norfolk area to NE	Seamless service Excellent systems to track/manage freight	Jax may not be best southern port-does not serve Atlanta well	Very high-price is competitive, particularly on NB headhaul Maybe stop in Long Island	Also very high, although prefer service from NC or VA-weekly service with Friday NB departure would work	"Freight doesn't care about mode" - just make it work and SSS will succeed	No views
Swift Transportation Largest US TL operator (18,500 trucks)	High	Will not disclose	Most hauls less than 600 miles	Question feasibility "intermodal doesn't work well with short legs"	Low - too many handoffs	Low - don't have much longhaul freight	Focus on longer haul lanes-"intermodal doesn't work well with short legs"	No views
Wyatt Transfer Long distance TL operator	High	Low	Minimize trailer dwell time in port	Longer transit time with SSS	Low - sees cost about same	Higher - SSS cost is comp.	Make cost competitive	No views - thinks SSS will happen due to hwy congestion
Southeastern Freight Lines Primarily LTL operator with some TL as backhauls	High	Low Mostly shorthaul and limited in Atlantic corridor	Depends on customer requirements	Most of their traffic is LTL	Might work - need to minimize dray cost and time	Limited - little traffic with New England	Makes sense in NE due to congestion	No views
Raritan Central Railway Short line RR and warehouse/terminal operator	High	Possibly 150 TL's per day from Raritan Industrial Center	Reliable service Right economics	Availability of right vessels in Jones Act fleet	Very high-sees opportunity to cross-dock from NJ DC's to trailers run on overnight vessel SSS cost is comp. Working with truckers on concept	Medium-little freight in this lane Cost and transit time appear to be competitive Truck transit is 3 days and cost at $1.50/mile Rail intermodal cost is $1700 per TL	Need to get major truckers involved Deliver service at cost as estimated	Prefers FR location to NB - closer to NY and "less political" Has 10 acres site in Raritan for potential SSS terminal - next to Raritan Industrial Center
Werner Enterprises Truckload operator	Some familiarity	9,000 trucks Active in Atlantic corridor Started intermodal in 2004	Customer's needs for both transit time & reliability	Reliability is key - more important than transit time	Medium - price is in ballpark but does not offer major advantage	Higher - price is competitive Transit time is okay	"Absolute dependability" - then price advantage	No views
New England Motor Freight Regional LTL/TL carrier	Some familiarity	5 TLs/day in NE/Jax lane 40 TLs/night in NE/NY lane	Fast transit and absolute reliability necessary for LTL business	SSS may be most suitable for TL business, not LTL	Low-SSS cost is too high. NEMF does Pawtucket/ Plainfield NJ for $300/TL door to door Long Island service of more interest	Higher-cost and transit time are competitive Likes Jax as port-serve Puerto Rico	Focus on TL sector	No views
Heartland Express Short to medium haul TL carrier	Medium Feasible concept-depends on shipper's transit time requirements	86% freight is JIT - 30% volume is foodstuffs	Transit time	Driver shortage going to get worse	Low - likely to cost more	"Looks good on paper but may not work in practice" - concern about ILA slowing transit	Truck (single driver) costs need to rise by over 50% (from $1.45 per mile to $2.25) Mimimize port time Prove service reliability	No views

Exhibit III-2
Summary of Results from Market Research
Ground Carriers (continued)

DiSilva Transportation TL Grocery Specialist	High	25-30 trucks/ day to NY metro	Economics need to work	Increasing delays in CT and NY area	High-"very attractive" SSS cost and overnight transit are competitive	Lower-little freight in this lane Cost and transit time appear to be competitive Truck transit is 3 days and cost at $1.50/mile	Key is to be able to deliver service at costs as estimated	Both ports have good locations-fit well into current truck movements
Trimac Truckload bulk carrier	Very familiar	"Very active" along Eastern seaboard-currently not using intermodal	Competitive price and fast relaible transit	Increasing driver shortage Also concern that hazmat regs	Moderate-transit time okay but SSS price needs to be lower at $250-$300	No interest-very little chemical traffic from Jax hinterland	ISO containers may work for chemical traffic by SSS	No views
J.B. Hunt National truckload operator	Very familiar	High volumes of traffic along Eastern seaboard-currently major user of intermodal	Traffic density - ability to schedule and cost Consistency of service	Driver shortage Highway congestion - particularly on I-95	Pending review	Pending review	Motor carrier should play key role	No views

Exhibit III-2
Summary of Results from Market Research
Shippers

Company	Familiarity with SSS	Volume of Potential Traffic	Key Requirements	Chief Concerns	Interest in Short-Haul Svc	Interest in Long-Haul Svc	Key Success Factors	Perceptions of Fall River/New Bedford
Quaker Fabric Uphostelry fabric	Not familiar	Inbound: 10 TLs/wk from NC Outbound: Aprox same volume but consignee-controlled	Need service frequency 2-3/wk	Driver shortage Increasing hwy congestion	Limited interest-not much freight in the lane	High - but thinks Wilmington NC would be best port Price at $2200 roundtrip very competitive	Service must be door to door - sold by truckers	Prefers FR-good access from 195 and 24 Although NB a little further away, not a big difference
Lightolier Lighting fixtures	Not very	3-4 TLs/wk from CT to Fall River 90% of outbound from FR is LTL	Fast transit Safe handling Reliable service	Ocean may not be fast enough SSS does not fit well with LTL - too many handoffs	Cost sounds okay	Cost sounds okay Jax could serve all Florida	Ocean transits competitive with truck-adding any significant port time will kill competitiveness	Not sure ports have enough capacity
Maritime International Seafood processor Cold storage operator	Moderate	Ship total of 100 TLs/wk ex NB to all destinations ~5 TLs/day to NY ~1 TL/week to Fla	Need to make service operate just like trucking	Additional steps in process Costs of Jones Act vessels-need "proper vessel", not barge	High interest-use for Port Newark exports Useful for over-weight conts. Price okay-paying $800 NB and $550 SB	Also interested-price should work for drays up to 200 miles Service frequency of 3/wk is okay Good service for overweight TLs Jax is "good choice"	Get ships and port ops to function at competitive cost level	Either port okay Interested in participating in developing business-possibly in staging cargo or terminal ops
Weyerhaeuser Forest products	High - just implemented Canada/USWC short-sea service	Large vols lumber, pulp ex New Bern NC Also large vols lumber ex Valdosta GA Total traffic to NE region in area of 25-40 TLs per week	Match current intermodal service Service frequency of weekly for longhaul is okay	Lot of traffic controlled by major retailers (eg Home Depot)-need to integrate consol/ deconcolidation in service product	No real interest Not much traffic in this lane	Would consider-currently using rail intermodal and rates "not good" SSS price is very competitive Transit time is acceptable	Get major retailers to support-possibly by providing logistics services in addition to basic transportation	No views
Titleist Sports equipment	Not familiar	Inbound shipments are containerloads via Port Newark-ocean carriers arrange ground transport (18 TEU/wk)	Must be competitive with current service	All outbound shipments are LTL or parcel service-SSS may not be fast enough	No real interest	No real interest	Get ocean carriers to use from Port Newark	NB is convenient location

  - A number of interviewees believed that short-sea shipping services over Bristol County ports would be an important remedy to increasing road congestion in the New York and Connecticut metropolitan areas

- Although several of the carriers interviewed (primarily TL operators) voiced a strong interest in the Bayonne short haul service option, only one of the shippers (Maritime International, a seafood shipper) indicated a strong level of interest
  - Concerns over price competitiveness of the short-sea service (quoted at $300-$350 per trailer port to port) indicates that the service needs to be at the lower end of this range to be competitive with overnight truck prices
  - Late cut-offs and early deliveries will be important to make the short-sea service competitive – e.g. take deliveries up to 7pm in Bayonne, sail vessel at 8pm, arrive Bristol County at 5-6 am, commence deliveries at 7am
- For those with significant volumes of freight moving in the long haul Eastern seaboard truck market, the general feeling was that the economics of a Bristol County/Jacksonville short-sea service were very good ($1200 on a port to port basis)
- While daily frequency was considered necessary to be a credible player in the Bayonne short haul market, a frequency of 2 to 3 sailings a week was considered adequate in the long haul Jacksonville lane and two respondents (US Express and Weyerhaeuser) believed that one sailing per week, departing the South on a Friday evening in the headhaul direction, would be sufficient
- In terms of key success factors, several respondents noted that the service should be sold by truckers – that it was important to get the truckers involved at an early stage. The support of major retailer/shippers such as Home Depot and Stop and Shop was also noted as a potential major contributor to a successful launch, particularly if short-sea transportation operations could be effectively integrated with the shipper's total supply chain involving such steps as consolidation/ deconsolidation of loads at distribution centers at each end of the short-sea movement
- Of the interviewees that felt able to express an opinion between the ports of Fall River or New Bedford as a northern terminus of a short-sea service (over half the interviewees had no opinion between the two ports), the results were split fairly evenly
- Several interviewees expressed a strong interest in being involved in further steps on developing short-sea shipping services over the ports of Bristol County including US Express, Raritan Central Railway, DiSilva Transportation, and Maritime International

IV. Potential Impact on the Ports of Fall River and New Bedford

The short-sea potential market analysis, the economic analysis of short haul and long haul service options, and the market research with prospective service users, collectively demonstrate three key findings:

- There is substantial truck traffic they may be diverted to short-sea services over the Bristol County ports given the right economics and service levels
- The economics of long haul short-sea shipping operations over the Bristol County ports is very competitive with alternative modes and the short haul service economics are "in the ball park" of being competitive
- Service levels at least in terms of transit time are also within acceptable ranges of most of the prospective users interviewed, particularly among truckload carriers

Given these findings, it appears feasible that short-sea shipping services could be developed to operate over the Bristol County ports in the event that the contingency factors noted earlier in the economic analysis are effectively addressed, namely that vessels may be procured and manned on a cost-effective basis and that marine terminal operations are also carried out at a cost and productivity level consistent with high standards of performance currently being achieved at ports along the Atlantic seaboard.

Based on the findings of this project, the operational "footprint" of short-sea services over the ports of Bristol County would likely have the following characteristics:

- Short haul Bayonne RoRo shuttle service moving around 120 full trailers per voyage on average northbound and 40 full and 60 to 80 empty trailers southbound on a daily basis (may operate only 5-6 days per week depending on weekend demand)
- Long haul Jacksonville (or Wilmington NC/Norfolk VA depending on demand) RoRo service 2 to 3 times per week moving around 138 full trailers northbound and 78 full and 58 empty trailers southbound per voyage

The size of the vessels likely to be involved in such services would be similar with the following general characteristics:

- Length overall: 190-200 meters (623-656 feet)
- Beam: 24 meters (79 feet)
- Draft: 6.4 meters (21 feet)
- Deadweight: 12,000 DWT
- Road trailers: 140 –150 (primarily 48' and 53')
- Stern ramp or quarter ramp

Consequently, the key factors determining whether the ports of Fall River and New Bedford would be able to effectively handle one or more short-sea services as described above would be the following:

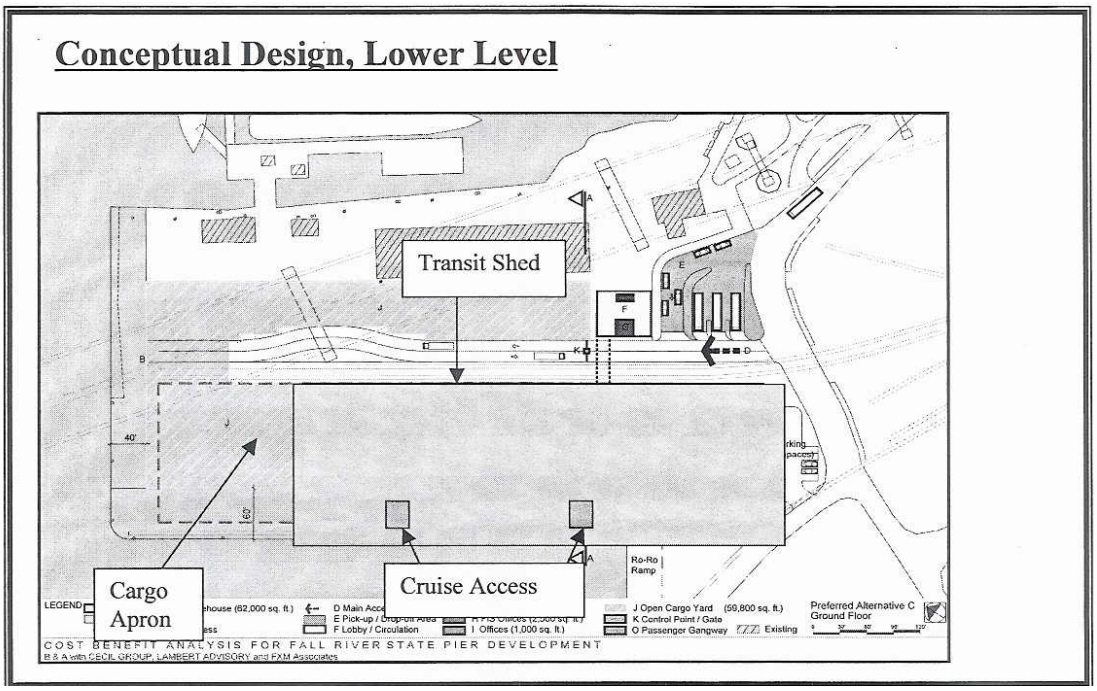
- Parking area for at least between 240 to 280 trailers requiring around 5.5 to 6.5 acres of open paved ground

- Local street access to the highway system that is able to accommodate a flow of up to 140 trailers into the terminal and out of the terminal (each direction) within a three to four hour period
- Vessel berthing facilities able to accommodate a RoRo vessel of the size noted above

The Port of Fall River

The primary facility being considered for use as a short-sea shipping facility within the port of Fall River is the State Pier. The current plans for the State Pier are for a multi-use facility combining marine cargo transportation, cruise ship visitation, and other public uses such as restaurants (see Exhibit IV-1 below). Proposed conversions to the State Pier facility that would convert current shed space into an open cargo apron and the available parking area within the existing marine terminal would provide approximately 2.5 acres of parking area for trailer staging. Use of the current CSX railroad area and Commonwealth of Massachusetts lots across Water Street would add close to another 2.5 acres of trailer parking area, bringing the Fall River facility close to the minimum requirement to handle one of the projected short-sea services. The space demands from either the short or long haul services would likely preclude the operation of other significant marine cargo businesses such as the current Atlantic Shipping tenant within the same facility.

Exhibit IV-1
Proposed Conversions to the Fall River State Pier



Source: Massachusetts Seaport Advisory Council

The South Berth appears to be suitable for RoRo vessel berthing and operations of the type projected, although the operational capability of the existing RoRo ramp is not known. However, high frequency/time sensitive calls of the type envisioned for a short-sea shipping operation may make it infeasible to berth cruise ships in the same location.[7]

Although access to Routes 195 and 24 is by local roads, the distance is relatively short at less than a mile. It is likely that the bulk of trailer traffic into and out of the marine terminal at Fall River would occur in the early morning (before 8:00 am) and/or in the evening (after 7:00 pm), so the disruption to local traffic should not be high despite the potentially large number of trailer movements into and out of the State Pier area.

The Port of New Bedford

Unlike Fall River, the port of New Bedford has extensive waterfront land that could potentially be used for a short-sea shipping terminal. However, use of this land in the near term (2-4 years) appears to be significantly inhibited by a number of factors:

- The existing State Pier facility is reportedly not in good condition,[8]and has minimal immediately adjacent RoRo trailer parking areas – the limited available parking areas are primarily required for current passenger and cargo ferry services (up to nine departures daily) to the Massachusetts Islands (see Exhibit IV-2 for a plan of the New Bedford State Pier)
- Substantial additional parking area is available in the North Terminal area of the port (future proposed Intermodal Transportation Center) but use of that facility would require trailers to be relayed over public roads approximately three-quarters of a mile, adding significantly to the cost of loading/discharging the vessels as well as road congestion
- There are substantial demands for existing port facilities from current users of the port including the fishing and fish processing industries as well as the ferry operators

The North Terminal itself appears to be an ideal long term solution as a short-sea shipping facility in view of its location in close proximity to Route 195 that could enable a direct roadway link to be built to carry trailer traffic removing the necessity of moving it over city streets – however, development of this facility as a major marine cargo terminal will require relocation of the current Route 6 swing bridge as the existing bridge openings are too narrow for vessels such as those considered for short-sea operation to safely pass through (see Exhibit IV-3).

[7] The reconfigured West Berth may be suitable for such a purpose.
[8] New Bedford/Fairhaven harbor Plan, 2002

Exhibit IV-2
New Bedford State Pier

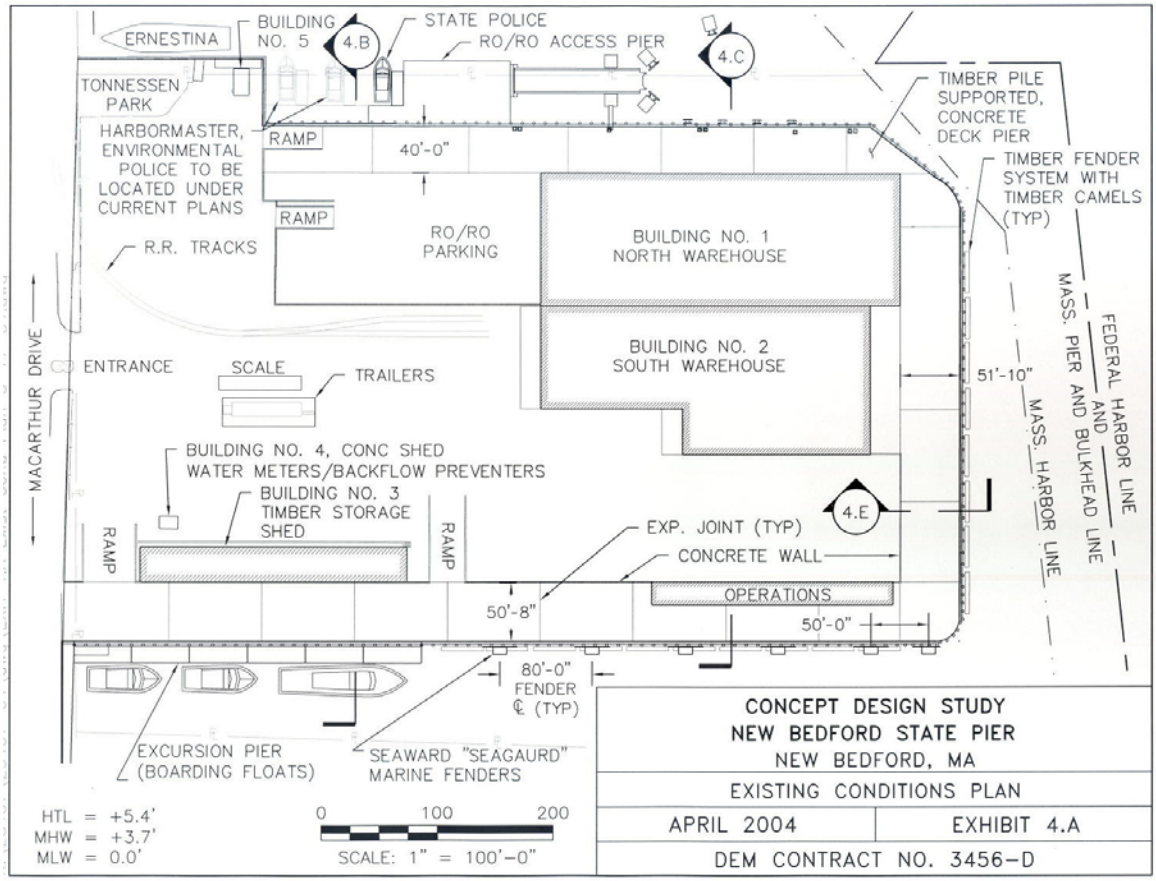
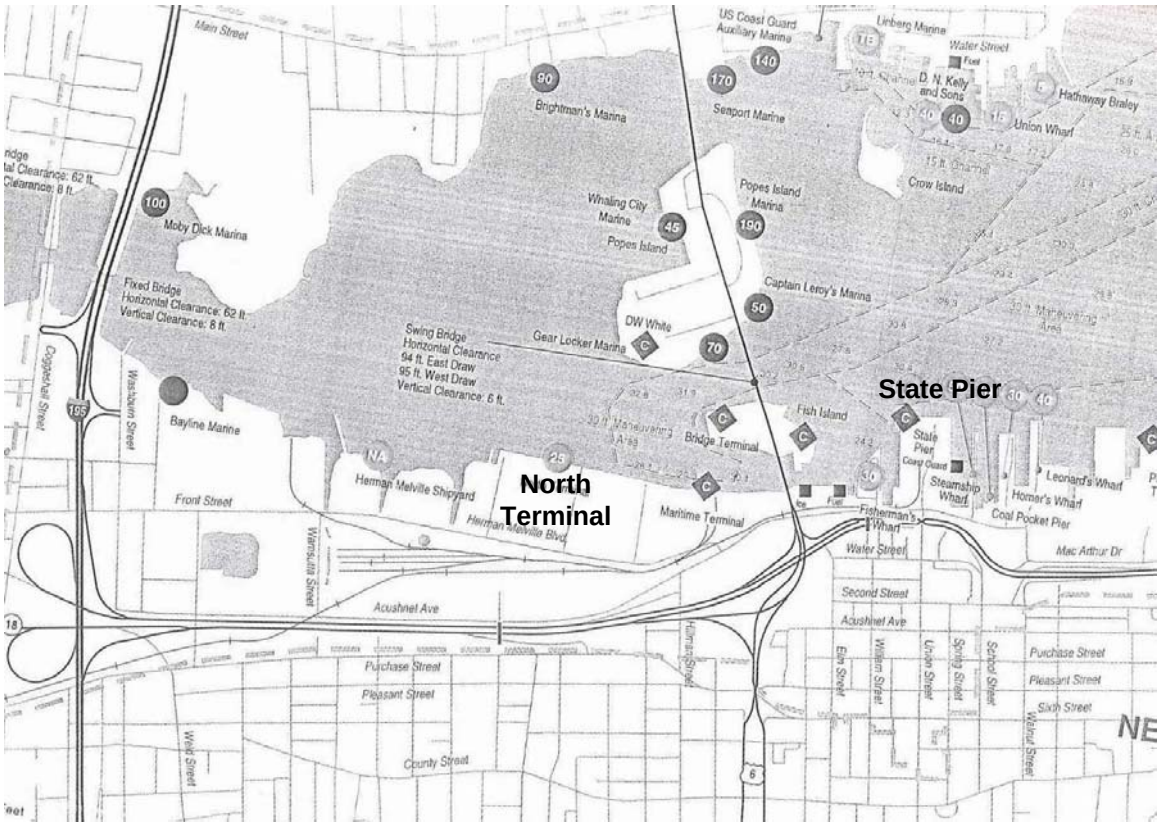


Exhibit IV-3
Inner New Bedford Harbor



Competitors to the Bristol County Ports

Although the Bristol County ports are well positioned geographically to serve the surrounding communities of greater Boston, Providence, and most of central and northern New England, neighboring ports in Rhode Island also have competitive locations and facilities:

- **Providence** is currently primarily a specialist in handling bulk and breakbulk cargoes – however, it has the basic infrastructure to serve as a short-sea terminus with six berths of 3,500 linear feet of berthing area and 20 acres of open paved storage area as well as onsite rail tracks. It also has good direct highway access to Routes 95 and 195.
- **Davisville/Quonset Point** is located at the entrance of Narragansett Bay and also offers deep-water cargo facilities. The port is currently handling large volumes of RoRo cargo (e.g. 80,000 automobiles per year) as well as bulk (e.g. quarried stone), and breakbulk general cargo. The port has three major piers with over 6,800 linear ft. of deep-water dockage with onsite rail tracks.

Further expansion of Davisville as a cargo facility faces major opposition from local environmentalists, which could inhibit the development of short-sea shipping operations at that port. There do not appear to be such limiting factors at Providence.

Ports further to the south in Connecticut such as New London, Bridgeport, and New Haven are potential short-sea terminuses as well, but they are better located to serve the southern New England market rather than the central and northern New England markets that are the natural hinterland of the ports of Bristol County. Longer highway times over the relatively highly congested roads of central Connecticut will substantially increase the drayage times and costs for short-sea cargoes moving over these ports to/from locations in central and northern New England

Economic Impact of Short-Sea Shipping Services over the Ports of Bristol County

The establishment of two short-sea shipping services operating over the ports of Bristol County as the northern terminus of (1) a daily short haul shuttle to a port in the northern New Jersey area, and (2) a twice weekly long haul service to ports in the South Atlantic such as Jacksonville or Wilmington, NC would have the following projected impact on local business activity and employment:

- The two short-sea services would generate an estimated total direct income of around $45 million per year – at least 50 percent of this would be generated within the Bristol County immediate area[9]
- Indirect income of $72 million would further be created by secondary spending by the companies and employees involved in short-sea shipping – at least 50 percent of this would be generated within the Bristol County immediate area.[10] Consequently, the total economic impact of the two short-sea services would be around $117 million per year, with at least 50 percent of this ($59-$60 million) generated within the Bristol County immediate area
- The creation of 300 jobs directly employed in short-sea shipping operations – at least 255 of these jobs would likely be in the Bristol County immediate area
  - 60 jobs manning the vessels (at least 50 percent within Bristol County region)
  - 30 jobs in shoreside and vessel management (at least 50 percent within Bristol County region)
  - 180 jobs in regional drayage operations as drivers and vehicle maintenance (100 percent within Bristol County region)
  - 30 jobs in longshore gangs (100 percent within Bristol County region)
- Another 500 jobs would be created in industries that provide goods and services to those directly involved in short-sea shipping – these additional jobs would include services such as shipbuilding and repair and financial services[11]
- Personal income for those directly employed in the short-sea shipping operations would be around $22.5 million and $35 million for those jobs that are indirectly created by the short-sea shipping operations[12]

[9] See details of economic analysis in the Appendix.
[10] Indirect economic multiplier for U.S. domestic shipping is 1.6 – source: Reeve & Associates, *Economic Impact of the U.S. Jones Act*, 2006
[11] Ibid
[12] Ibid

Of course, given that the intent of short-sea shipping is to remove trailers from the nation's highways, it can be argued that there will be a loss of jobs among long distance truck drivers that may partially offset the economic gains listed above. However, in view of the fact that there is an increasing shortage of long distance truck drivers within the U.S. and that trucking companies will be the primary marketers and operators of the overall door-to-door short-sea intermodal service, it is likely that any such job losses will be minimal, if they exist at all. In fact, it could rather be argued that the addition of transportation capacity through the provision of short-sea shipping traffic corridors will provide an economic stimulus by enabling the economy to continue to grow through the transport of goods that would otherwise be constrained by highway capacity limits.

V. Probability of Success of Short Sea Routes Serving Bristol County Ports

Several factors point to a strong probability of success for short-sea shipping services being developed to serve the ports of Fall River and/or New Bedford:

- There are substantial cargo volumes of truck traffic moving along the Atlantic seaboard with origins or destinations within the hinterland served by the Bristol County ports – options for such services include a short haul operation connecting with northern New Jersey and a longer haul operation connecting with ports in the South Atlantic such as Jacksonville or Wilmington, NC and Norfolk, VA
- Truckers, particularly truckload operators, are becoming increasingly aware of the short-sea shipping option, and view it as an additional intermodal opportunity that may offset constraints on their ability to continue to grow pure truck transportation services due to increasing highway congestion, increasing driver shortages and limits on hours of operation, and rising fuel costs
- The economics of short-sea shipping appear to be competitive with alternative modes, particularly on long haul lanes – provided that "best in class" practices can be implemented in terms of vessel costs and manning levels and stevedoring operations that will enable short-sea shipping to achieve its full potential in terms of cost and efficiency
- The primary competition to the Bristol County ports as short-sea hubs will come from the Rhode Island ports of Providence and Davisville (Quonset Point). Although these ports are well positioned in terms of physical facilities, they are at a greater distance from the central and northern New England hinterland that may potentially be served by the Bristol County ports.

However, there are also a number of factors that need to be addressed in order for short-sea shipping operations to be effectively realized in the ports of Bristol County:

- Current port capacity in both Fall River and New Bedford is limited in its ability to accommodate a major short-sea shipping operation such as envisioned in this project
  - Fall River's State Pier could accommodate a single short-sea operation but that would entail adding more trailer parking area to that within the current State Pier footprint and also possibly displacing some current users of the facility – in addition, the large volume of truck traffic into and out of the facility projected for the short-sea operation must be balanced with the needs of the adjoining Battleship Cove tourist facilities and other planned recreation activities in the area
  - New Bedford lacks berth and yard capacity to effectively support a short-sea service in its current configuration. In the long term, if the North Terminal is developed as a RoRo berth and adequate access to it is provided by reconstructing or relocating the Route 6 bridge, New Bedford would be an ideal location
- In addition, factors that add to the cost of short-sea shipping such as Harbor Maintenance Tax (HMT) and the extremely high cost of commercial vessels built by U.S. shipyards must be addressed

- The elimination of HMT on coastal domestic shipping services may prove to be revenue neutral as any foregone tax may be offset by funds saved in highway construction and repair as trailers are removed from the highways by short-sea shipping services
- The high cost of U.S.-built commercial vessels may be addressed by increasing the percentage of such vessels that may be built overseas, by improved purchasing and sourcing practices by U.S. shipyards, by the application of modern vessel construction practices and technologies by the shipyards, and/or by a waiver of the U.S. Jones Act restriction on domestic operators using foreign-built vessels

In summary, the ports of Bristol County appear to have a significant opportunity to become terminuses for short-sea shipping services. Focusing on implementation strategies that address both the positive and negative factors listed above should enable this opportunity to be achieved.

VI. Appendices

VI.1: Global Insight TRANSEARCH Methodology

VI.2: Port-Pair Truckload Volumes from TRANSEARCH

VI.3: Economic Analysis of Alternative Modes on the Jacksonville and Bayonne Lanes

VI.4: Market Research Questionnaire

VI.1: Global Insight TRANSEARCH Methodology

Transearch Database

Building from the original TRANSEARCH, the national database of freight traffic flows that Reebie Associates (and now Global Insight, Inc.) created and has maintained and provided to the transportation industry for 18 years and drawing on its experience with custom database development, the team researched information needs and data sources in the government and commercial markets and the capabilities of state-of-the-art software. The results of the effort have been to make available a national county-to-county and zip code-to-zip code data product. Key user needs like currency of the data, its reliability, flexibility in terms of seeing details of the traffic composition or relatively broad data summaries, and affordability can be satisfied.

Issued annually, the data can cover all modes and commodities, including empty truck movements, international shipping, and truck shipments of non-manufactured goods. Features like external trip ends, vehicle miles traveled, gross ton-miles, and forecasts can be provided, and traffic routed along major modal corridors can be displayed.

The database maps commodity flows (2, 3 and 4 digit STCC) in short tons between geographic entities (states, counties, BEAs) by mode (rail car, rail intermodal, truck load, less than truck load, private truck, air and water) for current year and forecast years. All volumes shown in tons are in short tons, for 2003.

A variety of data sources are used to compile the database ranging from government agencies to private sector industry associations and the carriers themselves, as shown in Figure A1.1.

The data sources vary by the different modes of transportation. The primary source for railroad data is the Carload Waybill Samples gathered from about 4% of total rail car traffic. Global Insight, Inc. sources this data from the Surface Transportation Board. This data is compiled to provide both volumes and patterns of flow.

The primary source for waterborne commodity flows is the Waterborne Commerce Statistics compiled by the Army Corps of Engineers. This data tracks the flow of commodities along domestic lakes, rivers and canals, and is used to develop both volumes and patterns of flow.

Figure A1.1
TRANSEARCH DATABASE DATA SOURCES

		Agency/Organization
Rail	– Carload Waybill Sample	– Surface Transportation Board
Water	– Waterborne Commerce Statistics	– U.S. Army Corps of Engineers
Air	– FAA Airport Originating Tonnages – Airport to Airport Flows – Commodity Flow Survey – TRANSEARCH	– Office of Airline Statistics (DOT Form 41) – BTS Office of Airline Information – Bureau of Transportation Statistics – Global Insight, Inc.
Truck	– Carrier Data Exchange Program – TRANSEARCH – Annual Survey of Manufactures – Freight Locater Data Service – General Statistics for Verification – Commodity Flow Survey	– Global Insight, Inc. – Global Insight, Inc. – U.S. Census Bureau – Global Insight, Inc. – Industry Associations – Bureau of Transportation Statistics

The air data is compiled from four major sources. The first is FAA (Federal Aviation Administration) airport originating tonnages primarily from Form 41 reports and compiled by the Office of Airline Statistics (Federal). This source establishes volume estimates at airports. The second source is airport-to-airport (ATA) flows compiled by the BTS Office of Airline information. These data are used to establish flow patterns. The third source is from Commodity Flow Survey (CFS) data, used to define the commodity types. The fourth source is Global Insight's TRANSEARCH Database, which supplements the CFS data.

The trucking data process is more complex and comes from a wide variety of sources developed over the course of 20 years. However, there are four primary sources. The first is a data exchange program Global Insight has with motor carriers, which is used to estimate patterns and volumes. The second source is a variety of industry associations (timber, plastics, chemical, automotive, etc.), which provide overall volume information for the respective industry sectors. The third major source is from the Annual Survey of Manufactures, primary employment and output data by industry, distributed at the state and local level. This data maps production and consumption of commodities and is used to calibrate the trucking flows. The Freight Locater data service is a database of industrial facilities and their exact location. This data supplements the previously mentioned sources to help calibrate the flows of goods between specific geographic entities.

TRANSEARCH Data Issues and Limitations – Reebie Associates recently developed a finer detailed version of its TRANSEARCH database in an FHWA sponsored project known as the Intermodal Freight Visual Database. It breaks down origin and destination market areas to the county level and is compatible with GIS applications. It has been incorporated into TRANSEARCH, with its most current base year as 2003.

For this study, TRANSEARCH data were identified at varying levels of detail. It is generally understood that large databases of this kind are never perfect, and TRANSEARCH is not an exception to the rule. It is, however, the best available source of its kind in the cognizance of the study team. TRANSEARCH is in use by virtually all major U.S. railroads and by more than a hundred motor carrier companies and several container shipping lines and air cargo carriers. State and federal planning agencies, as well as port authorities, equipment suppliers, investment banks and judicial and regulatory bodies also use it.

TRANSEARCH reports provide a broad picture of freight traffic movements in the United States. Various publicly available sources, as well as Global Insight's proprietary motor carrier data exchange information, are used in the development of the TRANSEARCH database. Understanding the nature of particular sources when using TRANSEARCH data is important to interpret the information correctly. The following guidelines should be helpful in gaining that understanding.

Freight Rehandled By Truck From Warehouse and Distribution Centers Is Identified as STCC 5010 and Referred to as Secondary Traffic at a 4-digit STCC level or STCC 50 at a 2-digit STCC level. Many of these types of facilities handle a wide range of different types of commodities, and outbound shipments may also be of mixed consists. For example, shipments from a supermarket chain distribution center are likely to contain a broad range of packaged food products and other consumer items.

The Truck Portion of Truck/Rail Intermodal Activity Is Shown as STCC 5020 at a 4-digit STCC level or STCC 50 at a 2-digit STCC level. This activity includes two segments: the truck shipment, by trailer or container, from true origin to the intermodal railhead, and from the intermodal railhead to final destination. The Rail Intermodal mode reveals the origin and destination points on the rail system, not the ultimate origin and destination.

STCC 5030 Is Used to Identify the Truck Drayage of Air Freight Traffic 5020 at a 4-digit STCC level or STCC 50 at a 2-digit STCC level. Both the true origin to airport, and airport to final destination are included. Origins and destination for movements classified in the air mode are airports. Volumes that are transloaded from one aircraft to another are not shown at the transloading point.

Large Portions of Today's Intermodal (TOFC or COFC) Traffic Are Reported In Non-Commodity Categories. Commercial arrangements in the railroad industry have fostered the use of "third parties" such as consolidators and forwarders. Such traffic typically is labeled as "Freight Forwarder Traffic", "FAK" (Freight: All Kinds), or "Miscellaneous Mixed Shipments". The specific commodities moving under these arrangements are not identified in the public use data sources.

Shipments Made Up Of Several Commodities Will Be Credited To The Dominant Commodity. This occasionally occurs in the commodity identification of rail shipments.

In these instances, the tonnage attributed to the predominant commodity is greater than it should be, and the other commodities in the shipment are understated.

To Provide Maximum Product Identification, Commodities Are Shown At the Greatest Level of STCC Detail For Each Code. Truck data is available and shown at the 4-digit level for the manufacturing sector. Rail data, however, can be shown at 5-digits. Because of the desire to include the greatest amount of detail possible, commodities in a traffic lane may be identified at different levels of detail for each mode. When this occurs, tonnages shown at the more detailed levels should be combined with those displayed at the more aggregate levels to gain a complete picture of modal share for the commodity. All freight traffic flow information in the study is expressed at the 4-digit STCC commodity code level, or consolidated to a 2-digit, or no commodity detail level.

Tonnage Data in Each Cell Should Be Used as an Indicator of Relative Value—since many of the sources for traffic flow information use sample data. Consequently, the more specific the definition of a particular flow, the greater its sampling variability. The more aggregated the definition of the Geography/Mode/ Commodity combination, the more reliable the results.

State-To-State Movements Of "Primary" Freight At The 2-Digit STCC (or SIC) Level Provide The Best Picture Of Primary Freight Moves In The Data Base. Analysts and planners, however, want and need more disaggregate pictures of the flow activity. Not all of the data used in TRANSEARCH comes into the process beneath the state level or with more than 2-digit commodity/industry classification.

VI.2: Port-Pair Truckload Volumes from TRANSEARCH

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Bayonne

Loads	Bristol County, MA Catchment					
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles	Grand Total
50 miles	27,058	49,881	7,209	7,713	8,895	100,756
100 miles	9,751	9,745	803	1,845	4,604	26,747
150 miles	9,330	7,507	263	712	1,660	19,471
200 miles	4,112	8,155	1,029	1,224	1,795	16,315
250 miles	9,851	10,213	1,858	3,403	1,726	27,052
Grand Total	60,103	85,501	11,162	14,897	18,680	190,342

NORTHBOUND

Port Name	Bayonne

Loads	Bristol County, MA Catchment					
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles	Grand Total
50 miles	78,780	87,694	94,587	18,218	12,463	291,741
100 miles	34,435	34,290	9,831	6,606	6,116	91,277
150 miles	39,426	30,490	2,271	5,474	4,047	81,707
200 miles	29,505	25,793	9,248	8,597	6,603	79,748
250 miles	13,667	23,370	4,919	5,245	5,298	52,499
Grand Total	195,813	201,637	120,856	44,141	34,526	596,972

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Charleston

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	255	1,138	490	164	443
100 miles	1,590	2,352	2,163	716	626
150 miles	1,922	2,769	5,393	1,411	1,405
200 miles	1,508	5,260	1,068	718	637
250 miles	2,650	3,224	939	773	1,903
Grand Total	7,925	14,743	10,053	3,783	5,014

NORTHBOUND

Port Name	Charleston

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	3,312	14,234	5,299	5,900	5,591
100 miles	8,680	10,087	4,823	1,195	2,875
150 miles	6,850	16,443	14,576	4,503	6,060
200 miles	17,535	15,386	14,750	9,328	8,260
250 miles	10,253	18,367	6,152	3,047	9,028
Grand Total	46,631	74,517	45,600	23,973	31,815

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Corpus Christi

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	227	327	457	2,650	1,365
100 miles	5,523	14,738	6,030	12,965	36,485
150 miles	3,802	5,600	3,682	6,084	23,459
200 miles	872	2,927	3,069	3,228	5,877
250 miles	1,154	4,974	2,408	6,389	4,301
Grand Total	11,579	28,565	15,647	31,316	71,488

NORTHBOUND

Port Name	Corpus Christi

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	3,924	2,954	1,909	5,220	12,145
100 miles	1,217	5,635	1,883	6,149	21,630
150 miles	3,315	6,267	3,830	92,475	12,764
200 miles	7,779	5,010	2,383	861	1,739
250 miles	15,536	20,657	13,540	4,829	4,730
Grand Total	31,771	40,523	23,546	109,535	53,008

Port-Pair Truckload Volumes from TRANSEARCH

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Galveston

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	428	2,826	1,325	2,058	7,893
100 miles	1,231	3,608	1,525	1,130	5,772
150 miles	2,157	2,241	899	2,494	7,166
200 miles	4,721	2,796	3,408	3,058	6,434
250 miles	2,219	8,946	3,854	6,833	9,079
Grand Total	10,757	20,417	11,011	15,572	36,343

NORTHBOUND

Port Name	Galveston

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	18,111	17,014	15,853	31,979	76,919
100 miles	5,236	6,710	4,178	7,391	3,162
150 miles	11,828	7,128	3,012	2,408	4,260
200 miles	2,435	1,620	678	756	773
250 miles	13,580	15,457	5,654	12,967	15,702
Grand Total	51,191	47,930	29,376	55,501	100,816

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Jacksonville

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	1,146	4,588	440	2,529	6,870
100 miles	1,446	2,694	2,437	3,958	9,128
150 miles	1,318	6,888	4,593	8,178	15,239
200 miles	2,904	8,346	2,406	6,715	15,001
250 miles	3,429	7,550	1,620	8,107	13,241
Grand Total	10,243	30,066	11,497	29,488	59,479

NORTHBOUND

Port Name	Jacksonville

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	2,117	5,137	4,119	35,471	10,267
100 miles	3,472	1,088	1,446	2,066	7,143
150 miles	7,609	25,837	7,351	12,158	21,574
200 miles	16,206	13,398	12,195	7,146	16,634
250 miles	15,647	15,229	5,337	12,362	16,077
Grand Total	45,050	60,690	30,449	69,202	71,695

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Mobile

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	184	245	26	18	10
100 miles	364	581	60	332	331
150 miles	955	1,223	293	347	83
200 miles	1,380	5,878	1,138	12,839	101
250 miles	4,999	3,530	14	264	77
Grand Total	7,882	11,457	1,530	13,800	601

NORTHBOUND

Port Name	Mobile

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	1,513	14,757	15,717	429	126
100 miles	6,144	5,204	1,464	3,806	21
150 miles	11,247	16,951	6,137	718	5,506
200 miles	21,978	25,089	2,837	1,650	3,969
250 miles	3,999	3,920	216	211	34
Grand Total	44,881	65,921	26,371	6,814	9,656

Port-Pair Truckload Volumes from TRANSEARCH

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	New Orleans				
Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	1,142	4,658	2,481	4,185	35
100 miles	4,016	7,700	3,423	9,700	151
150 miles	2,854	2,901	95	253	120
200 miles	1,857	1,942	526	1,594	15
250 miles	2,033	1,084	839	68	151
Grand Total	11,903	18,285	7,364	15,801	471

NORTHBOUND

Port Name	New Orleans				
Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	19,603	55,397	25,347	1,742	8,026
100 miles	14,982	36,728	13,137	2,289	2,422
150 miles	4,162	4,540	509	903	28
200 miles	951	762	2,999	1,226	29
250 miles	7,786	5,825	1,086	625	1,417
Grand Total	47,483	103,251	43,078	6,786	11,921

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Norfolk				
Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	1,532	1,568	1,559	1,136	634
100 miles	1,387	1,643	422	292	227
150 miles	1,316	1,016	579	297	356
200 miles	1,017	2,751	500	1,254	982
250 miles	641	1,428	309	792	772
Grand Total	5,894	8,406	3,369	3,771	2,970

NORTHBOUND

Port Name	Norfolk				
Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	7,511	3,957	328	1,771	1,422
100 miles	1,391	2,437	158	100	138
150 miles	2,422	2,194	694	1,415	208
200 miles	2,813	2,191	954	1,429	735
250 miles	6,104	4,337	1,019	943	365
Grand Total	20,241	15,116	3,153	5,658	2,869

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Pensacola				
Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	116	675	93	17	47
100 miles	219	389	12	194	57
150 miles	218	104	19	282	127
200 miles	701	964	86	166	12
250 miles	1,140	4,919	1,352	12,755	51
Grand Total	2,394	7,049	1,562	13,414	293

NORTHBOUND

Port Name	Pensacola				
Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	1,637	686	955	594	21
100 miles	2,228	8,700	1,034	475	210
150 miles	2,182	3,150	1,167	113	8
200 miles	7,309	10,544	4,777	3,448	4,178
250 miles	24,498	26,013	3,292	1,808	4,949
Grand Total	37,854	49,094	11,225	6,438	9,364

Port-Pair Truckload Volumes from TRANSEARCH

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Port Arthur

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	274	2,111	710	574	9
100 miles	3,653	2,422	1,708	1,228	847
150 miles	1,983	7,326	1,221	2,761	273
200 miles	3,016	4,059	2,020	1,711	92
250 miles	4,194	3,166	3,414	1,634	1,655
Grand Total	13,121	19,083	9,072	7,908	2,876

NORTHBOUND

Port Name	Port Arthur

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	4,604	4,791	2,649	2,840	1,448
100 miles	22,219	20,358	15,971	27,430	43,209
150 miles	10,529	7,005	3,072	6,507	2,823
200 miles	4,503	4,845	3,218	1,657	552
250 miles	6,760	3,547	1,655	1,615	2,340
Grand Total	48,615	40,546	26,565	40,049	50,372

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Port Canaveral

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	493	6,243	517	2,484	4,539
100 miles	1,705	2,638	3,293	7,753	9,715
150 miles	4,152	11,907	3,762	6,055	7,495
200 miles	2,247	5,632	1,622	7,740	14,150
250 miles	647	917	36	995	3,198
Grand Total	9,244	27,337	9,230	25,028	39,097

NORTHBOUND

Port Name	Port Canaveral

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	2,097	5,260	2,500	2,491	2,527
100 miles	8,355	21,636	6,078	6,000	12,384
150 miles	3,817	7,586	3,711	20,213	12,271
200 miles	6,465	8,212	8,613	4,269	10,143
250 miles	506	2,177	2,258	323	1,015
Grand Total	21,238	44,871	23,160	33,296	38,342

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Savannah

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	740	1,251	1,030	1,635	381
100 miles	626	1,986	1,552	759	1,295
150 miles	2,413	3,900	1,000	1,001	1,907
200 miles	2,363	7,944	5,605	3,600	3,926
250 miles	2,198	8,068	3,847	3,692	3,548
Grand Total	8,341	23,149	13,035	10,686	11,056

NORTHBOUND

Port Name	Savannah

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	6,659	11,858	2,603	3,869	4,776
100 miles	6,623	3,757	4,005	3,873	5,699
150 miles	13,063	26,692	19,027	12,635	16,227
200 miles	8,438	7,960	9,435	6,348	4,805
250 miles	11,957	9,971	7,324	4,430	6,935
Grand Total	46,740	60,238	42,395	31,155	38,443

Port-Pair Truckload Volumes from TRANSEARCH

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Tampa

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	739	5,932	1,705	1,272	904
100 miles	2,100	2,681	816	538	386
150 miles	1,580	3,145	203	216	558
200 miles	2,077	956	84	179	43
250 miles	370	1,127	307	72	349
Grand Total	6,867	13,840	3,115	2,277	2,240

NORTHBOUND

Port Name	Tampa

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	3,251	7,424	5,389	6,529	5,018
100 miles	6,214	7,786	979	667	397
150 miles	5,015	4,374	1,058	371	527
200 miles	663	967	370	14	215
250 miles	2,958	3,678	5,520	812	4,716
Grand Total	18,101	24,230	13,317	8,392	10,873

Truckload Volumes by Drayage Distance

SOUTHBOUND

Port Name	Wilmington, NC

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	418	1,012	114	172	277
100 miles	915	1,631	297	382	652
150 miles	1,569	863	176	117	484
200 miles	832	2,019	156	410	834
250 miles	1,485	1,656	3,092	637	709
Grand Total	5,219	7,182	3,835	1,717	2,956

NORTHBOUND

Port Name	Wilmington, NC

Loads	Bristol County, MA Catchment				
Southern Port Catchment	50 miles	100 miles	150 miles	200 miles	250 miles
50 miles	2,801	2,382	635	462	172
100 miles	2,900	4,026	951	1,038	395
150 miles	3,154	5,756	1,749	927	2,417
200 miles	7,728	22,572	6,245	3,709	2,822
250 miles	7,229	8,460	754	1,016	1,336
Grand Total	23,812	43,197	10,334	7,152	7,143

VI.3: Economic Analysis of Alternative Modes on the Jacksonville/Bristol County Lane

Jacksonville, FL to Bristol County, MA

Truck			Rail Intermodal			Short Sea Shipping		
OPERATING STATISTICS			**OPERATING STATISTICS**			**OPERATING STATISTICS**		
Highway Miles		1182.6	Rail and Dray Miles		1340.2	Ocean and Dray Miles		1341.95
Transit Hours		26.5	Transit Hours		66.5	Transit Hours		72.0
Projected Door-to-Door Transit (Hours)		54.5	Projected Door-to-Door Transit (Hours)		66.5	Projected Door-to-Door Transit (Hours)		72.0
ESTIMATED OPERATING COSTS (Per Load)			**ESTIMATED OPERATING COSTS (Per Load)**			**ESTIMATED OPERATING COSTS (Per Load)**		
Driver - Wages & Benefits	$	738	Locomotives & Fuel	$	207	Vessel Costs	$	213
Equipment (Tractor & Trailer)	$	121	Track & R.O.W	$	144	Fuel Costs	$	63
Fuel - Tires - Oil - Maint.	$	435	Yard & Terminal / Lift On/Lift Off	$	129	Port Charges	$	13
Insurances	$	81	Railcar Costs	$	57	All Other	$	30
Repositioning	$	85	Crew & Other	$	108	Marine Terminal Costs	$	256
Tolls	$	71	Trailer/Container Costs	$	57	Trailer/Container Costs	$	51
All Other	$	251	Drayage Expense	$	421	Drayage Expense	$	438
Depreciation	$	99	Depreciation	$	112	Depreciation (included in vessel costs)	$	-
Total	$	1,881	Total	$	1,235	Total	$	1,065
Estimated Operating Cost per HWY Mile	$	1.59	Estimated Operating Cost per HWY Mile	$	1.04	Estimated Operating Cost per HWY Mile	$	0.90
Estimated Markup	$	0.14	Estimated Markup	$	0.21	Estimated Markup	$	0.09
SHIPPER COSTS			**SHIPPER COSTS**			**SHIPPER COSTS**		
						Shipper HMT Expense	$	24
			Incremental Inventory Carrying Cost	$	11	Incremental Inventory Carrying Cost	$	15
Total	$	-	Total	$	11	Total	$	40
Estimated Shipper Cost per HWY Mile	$	1.73	**Estimated Shipper Cost per HWY Mile**	$	1.26	**Estimated Shipper Cost per HWY Mile**	$	1.02
			Discount vs. Highway Transport		27%	**Discount vs. Highway Transport**		41%

Economic Analysis of Alternative Modes on the Bayonne/Bristol County Lane

Bayonne, NJ/Bristol County, MA

Truck			Short Sea Shipping		
OPERATING STATISTICS			**OPERATING STATISTICS**		
Highway Miles		498.4	Ocean and Dray Miles		558.00
Transit Hours		12.0	Transit Hours		17.5
Projected Door-to-Door Transit (Hours)		12.0	Projected Door-to-Door Transit (Hours)		17.5
ESTIMATED OPERATING COSTS (Per Load)			**ESTIMATED OPERATING COSTS (Per Load)**		
Driver - Wages & Benefits	$	334	Vessel Costs	$	85
Equipment (Tractor & Trailer)	$	55	Fuel Costs (25 TPD)	$	25
Fuel - Tires - Oil - Maint.	$	197	Port Charges	$	10
Insurances	$	37	All Other	$	32
Repositioning	$	30	Marine Terminal Costs	$	100
Tolls	$	20	Trailer/Container Costs	$	-
All Other	$	32	Drayage Expense	$	333
Depreciation	$	38	Depreciation (Vessel included in vessel costs)	$	4
Total	$	742	Total	$	585
Estimated Operating Cost per HWY Mile	$	1.49	Estimated Operating Cost per HWY Mile	$	1.17
Estimated Markup	$	0.13	Estimated Markup	$	0.12
Estimated Operating Margin		10%	Estimated Operating Margin		10%
SHIPPER COSTS			**SHIPPER COSTS**		
			Shipper HMT Expense	$	24
			Incremental Inventory Carrying Cost	$	5
Total	$	-	Total	$	29
Estimated Shipper Cost per HWY Mile	$	1.62	**Estimated Shipper Cost per HWY Mile**	$	1.35

VI.4: Market Research Questionnaire

Massachusetts Seaport Advisory Council:
Study of Potential Market for Domestic Coastal Shipping

Shipper/Carrier Interview Guide

Interviewer _____

Firm _____

Phone _____

Contact 1 _____

Contact 2 _____

Contact 3 _____

Cold Calling - Getting to the right person

For Shippers

Hello, my name is _____. I'm calling on behalf of the Massachusetts Seaport Council. We are conducting a study of freight transportation options in the Eastern United States and would like to speak for a few minutes with the manager of your firm that handles shipping decisions.

For Carriers

Hello, my name is _____. I'm calling on behalf of the Massachusetts Seaport Council. We are conducting a study of freight transportation options in the Eastern United States and would like to speak for a few minutes with the manager of your firm that develops and evaluates new services and market opportunities.

When you reach the key individual

Name, Title and Phone _____

Date and Time _____

Good Day, my name is _____
I am working on a project for the Massachusetts Department of Business and Technology and Seaport Council. The study is evaluating the market potential for **domestic coastal shipping** services that would connect ports in Massachusetts such as New Bedford and/or Fall River with other U.S. ports on the east coast that would provide a new mode of transportation for freight that is currently moving over the highway. I would like to discuss this opportunity with you and get your reaction to how your firm might use this type of service. I expect that the conversation might require 20-30 minutes of your time.

Background Information to be used as necessary to advance conversation and define terms

What is Short Sea Shipping? Many in the transportation industry are concerned that growing highway congestion will continue to increase the costs and reduce the reliability of shipping by truck. Short Sea Shipping provides an opportunity to relieve some of this strain on the nation's transport

infrastructure by diverting truck traffic from highways to the open sea. With "short sea shipping" operations along the nation's coasts portions of the projected growth in highway freight traffic would move via an "ocean highway" with consequent reduced demand for land highway capacity as well as drivers.

Short sea shipping operations would move freight on an intermodal basis by combining a relatively short overland "drayage" move by truck to transport goods from their origin to a nearby port from which a vessel would carry the freight to another port where a second truck would transport the load over another relatively short distance to its ultimate destination. This mode of operation for domestic freight has already had some success through such operators as Osprey Lines in the U.S. Gulf. However, its application on the Atlantic Coast has been very limited to date. We are working for the Massachusetts Seaport Council to explore how such a service may work for Massachusetts.

Begin the interview……..
All topics below should be addressed but as the interviews are expected to be with fairly senior people, the interview should be allowed to proceed on a fairly unstructured basis enabling the interviewee to provide as much of their perspective on an "unscripted" basis wherever possible.

1. **Basic familiarity with "short-sea shipping" concept:** Ask open question – probe on relative level of interest

2. **Background on interviewee's current freight operations:**

   - Determine volume of road and rail intermodal traffic (trailer loads and type of freight) that could potentially be moved by SSS

   - Identify key requirements in terms of cost and service levels (e.g. transit time, schedule reliability, safety, etc.)

3. **Concerns:** Probe on any concerns that they may have on being able to meet key shipping requirements (e.g. restrictions on driver hours, driver shortages, highway congestion, rising fuel costs, etc.)

4. **Opportunity for short-haul SSS:**

   - **Describe Short Haul Service –** Daily roll on/roll off (RoRo) service for truck trailers would be offered between a Northern New Jersey port (say, Bayonne) and a port on the Southeastern Coast of Massachusetts, say Fall River or New Bedford. Northbound service would depart New Jersey each afternoon at approximately 5 pm and arrive in Massachusetts at 2 am. Southbound service would depart Massachusetts for New Jersey at 6 am, arriving in New Jersey by 3 pm. Trailers could be dropped off at the port terminals up to one hour before vessel departure and would be ready for pick up within one hour of the vessel's arrival at the other end. Service would be by roll-on/roll-off vessel carrying standard highway trailers. It is anticipated that the charge for the service would be approximately **$300 - $350** per trailer on a port-to-port basis not including local truck transportation at both ends of the trip.

   - Probe on reaction to daily Bayonne/FR-NB service – type of service, frequency, points served, pricing, etc.

   - Preference for door-to-door service (ocean plus drayage) or ocean only

5. **Opportunity for long- haul SSS:**

   - **Describe Long Haul Service** – Three departures per week service between Northern Florida (say Jacksonville) and a port on the Southeastern Coast of Massachusetts, say Fall River or

New Bedford, is envisioned. The service would utilize roll-on/roll-off vessels that can handle any highway trailer. Northbound service would depart Florida on a Monday, Wednesday or Friday afternoon and arrive in Massachusetts two days (50 hours) later (e.g. Monday departure would arrive on Wednesday). Again, trailers could be dropped off at the port terminals up to one hour before vessel departure and would be ready for pick up within one hour of the vessel's arrival at the other end. It is anticipated that the charge for the service would be around **$1,200** on a port-to-port basis not including local truck transportation at both ends of the trip.

- Probe on reaction to Florida service or similar service to other East Coast ports (please specify any other preferences) – type of service, frequency, points served, pricing, etc.

- Preference for door-to-door service (ocean plus drayage) or ocean only

6. **Key factors for success and obstacles:**

   - What has to happen for SSS to be a real modal choice for their business?

7. **Massachusetts ports:**

   - Probe on perceptions of Fall River and New Bedford as prospective SSS gateways – advantages/disadvantages, respective strengths/weaknesses in terms of road access, port facilities, labor, etc.

8. **Close:**

Thank interviewee and determine if interested in participating in further analysis of the SSS opportunity

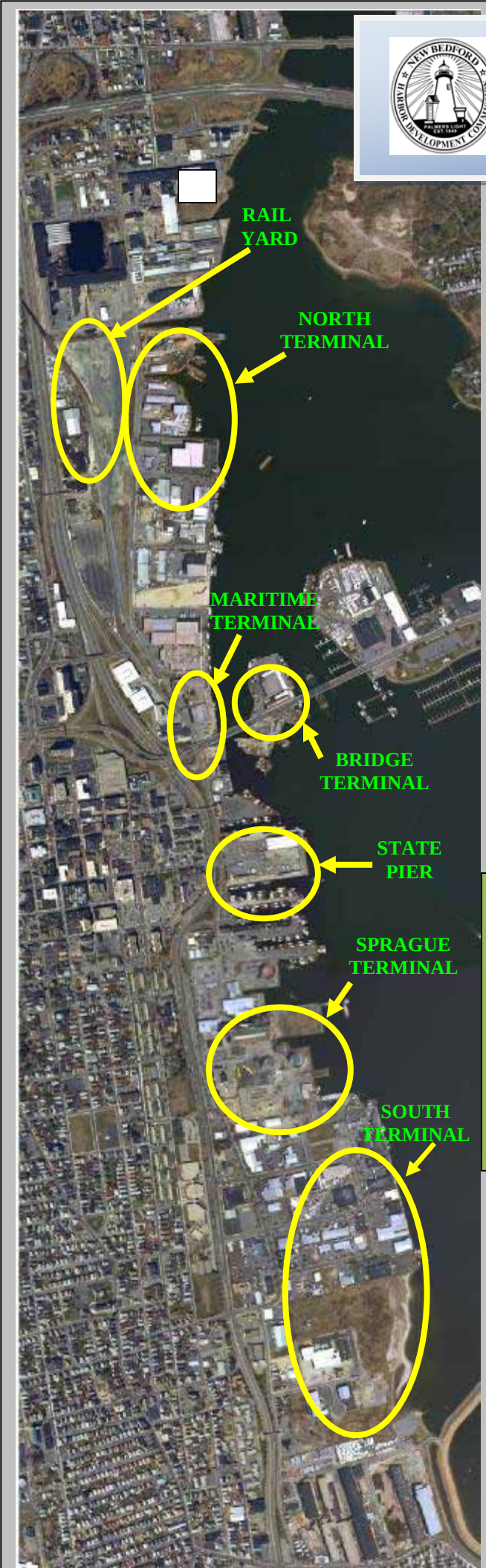
APPENDIX 17

PORT OF NEW BEDFORD MASSACHUSETTS

MAYOR SCOTT W. LANG

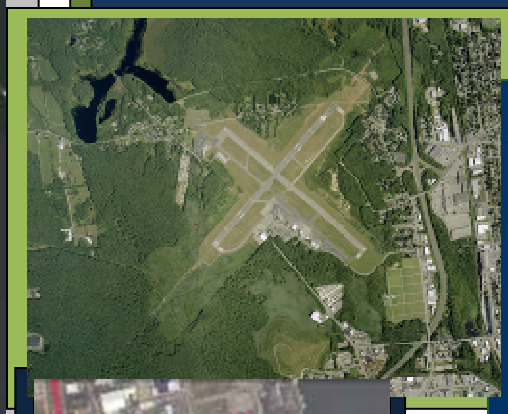
Port Infrastructure Assets

Contact: Kristin Decas, Port Director
(508) 961-3000 wk (508) 989-0103 cell



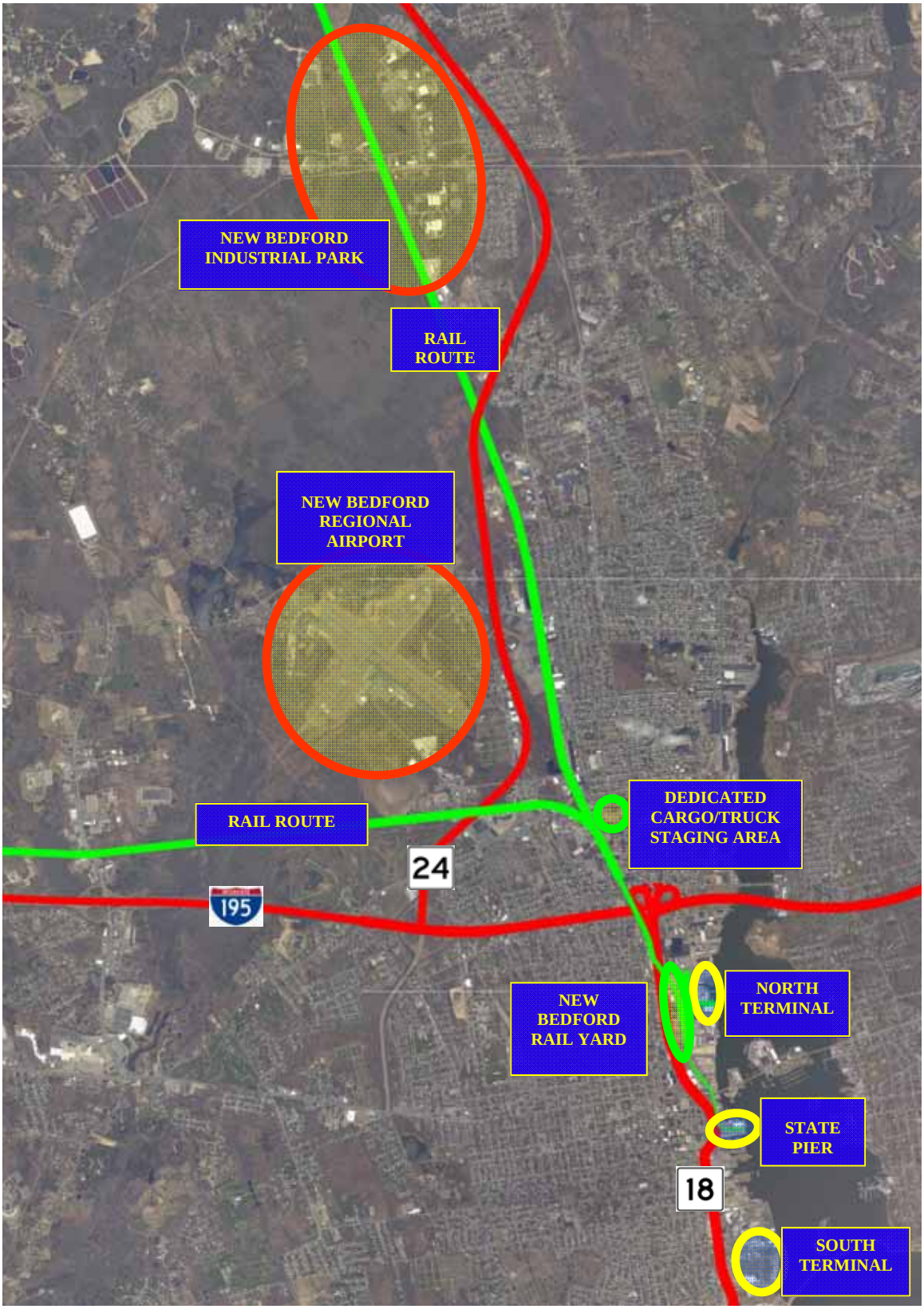
Staging and Lay–down areas at the Marine Terminals and within the Port Area

- North Terminal / Rail-yard = 33.5 acres
  - Paved Staging Area 7.5 acres
  - Unpaved Storage Area 14 acres
  - On Rail Railcar Storage = 12 acres
  - Staging for more than 100 Railcars
- State Pier / Fisherman's Wharf
  - 4 acres at State Pier
  - Room for 500 Stacked Containers
  - Staging for 70 Trucks
  - 1,000 lineal feet of bulkhead for vessel berthing
- New Bedford Industrial Park
  - 30 acres of staging and lay-down area
- New Bedford Regional Airport
  - 20 acres of staging and lay-down area outside the Terminal areas.
- (Future) South Terminal
  - 20 acres of paved staging and lay-down area
  - 1,000 lineal feet of bulkhead for vessel berthing



New Bedford Industrial Park: Within 6-miles of the docks, over 30-acres of Staging and Lay-down Area is available.
New Bedford Regional Airport: Located only 3.5 miles from the docks, the Airport has 30 additional acres of Staging and Lay-down Area.

(Future) South Terminal: The future planned expansion of the existing South Terminal calls for the development of over 20-acres of paved staging and storage area to support multiple uses.



New Bedford Is: *Local Connections = National Markets = International Trade.*

With Three full service Marine Terminals to support shipping, a strong Import/Export business, Rail Connections from the Port to all major Rail Corridors in the Northeast and to the rest of the Nation, and a major Regional Airport within 3.5 Miles of the Marine Terminals; The Port of New Bedford is Ideally Suited to play a major Intermodal Shipping Role.

Apex Companies, LLC

Memo

To: File

From: Chet Myers, P.E., LSP

Date: April 14, 2010

List of Attendees:

Ronald A. Klempner, Managing Principal, Jersey Harborside

Daniel J. Wahle, Vice President Marketing, Mass Coastal

Chet Myers, Senior Engineer, Apex Companies, LLC

Jessica Fernandes, Assistant Port Director, NBHDC

Re: Summary of Meeting with Jersey Harborside Personnel

Meeting was held at New Bedford Harbor Development Commission at approximately 12 PM. NBHDC was marketing the port to Jersey Harborside, which plans to import containers to southeast Massachusetts. Jersey Harborside was particularly interested in the new South Terminal extension, which is anticipated to create a significant amount of potential loading and unloading area.

Containers would be shipped into the harbor on a very large vessel (Panamax-sized vessels) that are approximately 500 tons. They anticipate shipping of 3,000,000 tons of cargo per year. Ideal space requirements are between 10 and 20 acres for staging of materials. Of particular interest to Jersey Harborside was the potential to capture shipment of seafood processing output on their out-bound trips (i.e. a cargo being shipped from New Bedford could double the profitability of the operation, rather than just shipping to New Bedford).

Ideal warehousing corridors for material shipped through New Bedford are along the 128 corridor, along the Route 95 Corridor south of Boston, and the 495 Corridor north of Route 90 and Worcester. Shipping containers would require between 15 ft and 30 ft of draft, depending upon the vessel utilized.

NBHDC took Jersey Harborside on a tour of available resources within the Harbor, including the New Bedford Railyard, North Terminal, State Pier, South Terminal, and the NSTAR facility. Jersey Harborside restated that South Terminal was the ideal location for their shipping operation once it was completed.

Currently the team is evaluating multiple ports, but once settled on a port, would take apporoximately 18-24 months to ramp up the operation. Therefore, construction of the facility, and use of the facility (initially) by offshore renewable wind energy would not prevent its future use by Jersey Harborside.

APPENDIX 18

Appendix A

New Bedford Harbor Development Commission

South Terminal CDF

Field Study of Soils – performed by Edward Pickering, P.E., CPSSc

On April 20, 2010, a field study was performed on the property of the proposed South Terminal Marine Infrastructure Park in New Bedford, MA to evaluate the presence and/or absence of hydric soil indicators in accordance with "*Field Indicators for Identifying Hydric Soils in New England*," Version 3, April 2004 (referred to herein as Field Guide). The gathering of soil information from the field study was intended to assist in the effort to estimate the extent of jurisdictional resource areas at this site, as defined by Wetlands Protection Act Regulations at 310 CMR 10.00, when compiled with observations of the relative abundance of wetland indicator plant species obtained by others. A tile spade was used to dig observation holes and obtain undisturbed soil samples to prepare soil pedon descriptions. These holes were approximately one foot in diameter and were advanced to a depth of up to three feet when possible or, more commonly, shallower depth upon refusal. Up to nine soil observation holes were attempted at selected locations of the subject property; all but the first encountered refusal at a depth of 15 inches or less due to the presence of buried manmade materials.

Access to the shoreline area of the property was obtained on foot by way of Blackmer Street, along a stormwater drain right of way, adjacent to property owned by the Commonwealth of Massachusetts Division of Marine Fisheries (DMF). The DMF property was enclosed by a chain-link fence within which the southern half of the property was developed into an asphalt paved surface, while the northern half remain undeveloped. Entry into the secured fenced-in area was not attempted and direct observation of subsurface soil conditions was not possible.

The first soil observation hole, Apex-1, was dug adjacent to the fencing near the northeast corner of the DMF fence-line, facing the harbor, within a natural beach area. No obstructions were encountered and the hole was advanced to three feet. Hydric soil features were observed at a depth of 13 inches, and the pedon most closely matched the description of hydric soil conditions in the Field Guide described as "X.C. Sandy with Redox." A gleyed horizon with abrupt upper and lower boundaries was observed at 13 to 15 inches, consisting of loamy fine sand with a matrix color of 10YR 6/1, gray-light gray. Additional common, fine, distinct redoximorphic features were identified below 15 inches with a color of 10YR 4/4, dark yellowish brown upon a matrix of 10YR 5/2, grayish brown loamy sand. The Ap horizon appeared to have been disturbed possibly by mixing due to beach vehicular traffic or anthropogenic addition of sandy material.

Besides the shoreline area, access to the remainder of the subject property was possible to observe soil conditions in an irregular-shaped area of the property bounded to the north by a fence-line running east-west along the Shuster property and bounded to the west by a partially-

fenced radio station property. Proceeding along a foot path adjacent to the north side of the DMF fence-line, the ground surface was hummocky and undulating on both sides of the fence due to irregular filling with construction debris; particularly with boulders, concrete slabs, and solidified liquid asphalt. Vegetation was very dense in the area closest to beach, and included briars and thorn bushes, which rendered the area essentially impenetrable. Halfway up the DMF fence-line, the ground surface leveled off although surface debris was still common. Repeated attempts to advance an observation hole were refused at 6 inches or less.

Apex-2 was located within a lobular, depression area adjacent to the fence-line along the northern boundary with the Shuster property, mostly open grass areas with a variety of shrubs. Underlying a 10-inch 10YR, 2/2 very dark brown Ap horizon, redoximorphic features due to wetness were encountered. Numerous cobble- and gravel-sized pieces of brick, concrete, tires, and other debris were observed, and refusal was encountered at a depth of 12 inches. The general area was impacted by mounds of construction debris, boulders of various size, tires, etc. Outside of this area, at slightly higher elevation of 6 inches or more, upland soils were thought to occur but shallow refusal denied confirmation.

Apex-3 was situated half of the distance between the northeast corner of the fence at the radio station property and the northern boundary fence-line, in an open, level landscaped area maintained in grass and occasional shrubs and trees. The observation hole was advanced to a depth of 15 inches, when refusal was encountered. Underlying an Ap horizon of 10 inches, was what appeared to be a well developed B horizon with a uniform matrix color of 10YR 4/3 brown/dark brown and no redoximorphic features. The position in the landscape, and appearance of subsoil material that could be observed, conformed to an upland location. The entire opening of the 1 foot diameter hole was obstructed by a smooth hard object that appeared to be concrete, indicating that deposition of manmade materials and historic fill activities had occurred throughout the subject property.

In addition to the three observation holes, where notes of soil characteristics were kept, attempts were made throughout accessible portions of the subject property to no avail. The entire site had been impacted by filling with construction waste and other material over a long period of time, and sufficiently long ago to permit growth of extensive opportunistic vegetation. In general, progressing from the west to the east, the property was more finished (i.e., level and maintained) around the radio station transitioning to the roughest part nearest to the beach, and groundwater fluctuations appeared to become closer to the surface. At two thirds of the distance to the beach, waste piles were more evident, the land surface became more hummocky, and the vegetation turned to an unkempt, scrub forest of low lying trees and shrubs.

In conclusion, no functioning wetlands were observed in the open (unfenced) areas of the subject property, although groundwater levels may fluctuate to the upper part of the soil in certain areas and some wetland plant species are present to some degree. The area qualifies as urban fill, reflecting its historic use as a construction debris landfill area and previous filling of what was long ago coastal wetlands. The subject property is not significant to the protection of any of the interests identified in the regulations at 310 C.M.R. § 10.01(2).

APPENDIX 19

NOx
Quantification of Output

Table 1: Calculation of NOx and Hydrocarbon Production During Construction of South Terminal CDF

Equipment	Anticipated Use of Equipment	Emission Type	HP	HC (Hydrocarbons)[8]	NOx[8]	Hours[1,2,3,4]	Percent Utilization[5,6]	Adjusted Hours[7]	Hydrocarbon Output (Tons)	NOx Output (Tons)
Lieberr 994	Dredging	Tier 2	2126	0.31	5.26	960	60	576	0.418	7.100
Pushboat	Dredging	Tier 2	600	0.2	6	960	30	288	0.038	1.143
Pushboat	Sheet Pile Wall	Tier 2	600	0.2	6	960	30	288	0.038	1.143
Dredge Power (HPU)	Dredging	Tier 2	512	0.2	6	960	10	96	0.011	0.325
Dredge Power (HPU)	Dredging	Tier 2	512	0.2	6	960	10	96	0.011	0.325
Dredge Power Operations	Dredging	Tier 3	185	0.31	5.91	960	90	864	0.055	1.041
Front End Loader (CAT)	Site Work	Tier 3	700	0.27	6.63	800	40	320	0.067	1.637
Front End Loader (CAT)	Site Work	Tier 3	700	0.27	6.63	800	40	320	0.067	1.637
Bulldozer	Site Work	Tier 3	540	0.1669	4.5331	960	50	480	0.048	1.295
Bulldozer	Site Work	Tier 3	540	0.1669	4.5331	960	50	480	0.048	1.295
Excavator	Site Work	Tier 3	700	0.27	6.63	960	50	480	0.100	2.456
Excavator	Site Work	Tier 3	700	0.27	6.63	960	50	480	0.100	2.456
Rubber Tired Excavator	Site Work	Tier 3	166	0.54	6.57	960	50	480	0.047	0.577
Roller/Compactor	Site Work	Tier 3	174	0.54	6.57	960	50	480	0.050	0.605
Roller/Compactor	Site Work	Tier 3	174	0.54	6.57	960	50	480	0.050	0.605
Articulated Dump Truck	Site Work	Tier 3	469	0.16	4.37	800	40	320	0.026	0.723
Articulated Dump Truck	Site Work	Tier 3	469	0.16	4.37	800	40	320	0.026	0.723
Grader	Site Work	Tier 3	540	0.169	4.3351	800	40	320	0.032	0.826
Grader	Site Work	Tier 3	540	0.169	4.3351	800	40	320	0.032	0.826
Paver	Site Work	Tier 3	223	0.22	6.23	160	90	144	0.008	0.221
Pile Driving Crane	Sheet Pile Wall	Tier 2	600	0.13	3.87	480	60	288	0.025	0.737

	HC	NOx
Total (Tons)	**1.30**	**27.70**

Assumptions:

1). Construction is approximately 9 months in length, average 4 weeks per month, with construction operating 8 hours per day on average, 5 days per week..
2). Dredging will take approximately 6 months.
3). Dewatering, soils management, and site grading will take approximately 6 months.
4). Sheet pile wall installation will take approximately 3 months.
5). Percent utilization assumes that, although equipment may be onsite, it will not necessarily be utilized 8 hours per day.
6). Percent utilization is based upon engineering experience on similar projects.
7). Adjusted hours includes percent utilization.
8). Emission factors from the USEPA document "Exhaust and Crank Case Emission Factors for Non Road Engine Modeling – Compression –Ignition", Table D6 dated July 2010.

Electronic Code of Federal Regulations
e-CFR ™

e-CFR Data is current as of August 10, 2010

Title 40: Protection of Environment

PART 93—DETERMINING CONFORMITY OF FEDERAL ACTIONS TO STATE OR FEDERAL IMPLEMENTATION PLANS
Subpart B—Determining Conformity of General Federal Actions to State or Federal Implementation Plans

Browse Previous | Browse Next

§ 93.153 Applicability.

(a) Conformity determinations for Federal actions related to transportation plans, programs, and projects developed, funded, or approved under title 23 U.S.C. or the Federal Transit Act (49 U.S.C. 1601 *et seq.*) must meet the procedures and criteria of 40 CFR part 51, subpart T, in lieu of the procedures set forth in this subpart.

(b) For Federal actions not covered by paragraph (a) of this section, a conformity determination is required for each criteria pollutant or precursor where the total of direct and indirect emissions of the criteria pollutant or precursor in a nonattainment or maintenance area caused by a Federal action would equal or exceed any of the rates in paragraphs (b)(1) or (2) of this section.

(1) For purposes of paragraph (b) of this section, the following rates apply in nonattainment areas (NAA's):

	Tons/year
Ozone (VOC's or NO_X):	
Serious NAA's	50
Severe NAA's	25
Extreme NAA's	10
Other ozone NAA's outside an ozone transport region	100
Other ozone NAA's inside an ozone transport region:	
VOC	50
NO_X	100
Carbon monoxide: All NAA's	100
SO_2or NO_2: All NAA's	100
PM–10:	
Moderate NAA's	100
Serious NAA's	70
$PM_{2.5}$:	
Direct emissions	100

SO_2	100
NO_X(unless determined not to be significant precursors)	100
VOC or ammonia (if determined to be significant precursors)	100
Pb: All NAA's	25

(2) For purposes of paragraph (b) of this section, the following rates apply in maintenance areas:

	Tons/year
Ozone (NO_X, SO_2or NO_2):	
All Maintenance Areas	100
Ozone (VOC's):	
Maintenance areas inside an ozone transport region	50
Maintenance areas outside an ozone transport region	100
Carbon monoxide: All Maintenance Areas	100
PM–10: All Maintenance Areas	100
$PM_{2.5}$:	
Direct emissions	100
SO_2	100
NO_X(unless determined not to be a significant precursor)	100
VOC or ammonia (if determined to be significant precursors)	100
Pb: All Maintenance Areas	25

(c) The requirements of this subpart shall not apply to the following Federal actions:

(1) Actions where the total of direct and indirect emissions are below the emissions levels specified in paragraph (b) of this section.

(2) Actions which would result in no emissions increase or an increase in emissions that is clearly de minimis:

(i) Judicial and legislative proceedings.

(ii) Continuing and recurring activities such as permit renewals where activities conducted will be similar in scope and operation to activities currently being conducted.

(iii) Rulemaking and policy development and issuance.

(iv) Routine maintenance and repair activities, including repair and maintenance of administrative sites, roads, trails, and facilities.

(v) Civil and criminal enforcement activities, such as investigations, audits, inspections, examinations, prosecutions, and the training of law enforcement personnel.

(vi) Administrative actions such as personnel actions, organizational changes, debt management or collection, cash management, internal agency audits, program budget proposals, and matters relating to the administration and collection of taxes, duties and fees.

(vii) The routine, recurring transportation of materiel and personnel.

(viii) Routine movement of mobile assets, such as ships and aircraft, in home port reassignments and stations (when no new support facilities or personnel are required) to perform as operational groups and/or for repair or overhaul.

(ix) Maintenance dredging and debris disposal where no new depths are required, applicable permits are secured, and disposal will be at an approved disposal site.

(x) Actions, such as the following, with respect to existing structures, properties, facilities and lands where future activities conducted will be similar in scope and operation to activities currently being conducted at the existing structures, properties, facilities, and lands; for example, relocation of personnel, disposition of federally-owned existing structures, properties, facilities, and lands, rent subsidies, operation and maintenance cost subsidies, the exercise of receivership or conservatorship authority, assistance in purchasing structures, and the production of coins and currency.

(xi) The granting of leases, licenses such as for exports and trade, permits, and easements where activities conducted will be similar in scope and operation to activities currently being conducted.

(xii) Planning, studies, and provision of technical assistance.

(xiii) Routine operation of facilities, mobile assets and equipment.

(xiv) Transfers of ownership, interests, and titles in land, facilities, and real and personal properties, regardless of the form or method of the transfer.

(xv) The designation of empowerment zones, enterprise communities, or viticultural areas.

(xvi) Actions by any of the Federal banking agencies or the Federal Reserve Banks, including actions regarding charters, applications, notices, licenses, the supervision or examination of depository institutions or depository institution holding companies, access to the discount window, or the provision of financial services to banking organizations or to any department, agency or instrumentality of the United States.

(xvii) Actions by the Board of Governors of the Federal Reserve System or any Federal Reserve Bank necessary to effect monetary or exchange rate policy.

(xviii) Actions that implement a foreign affairs function of the United States.

(xix) Actions (or portions thereof) associated with transfers of land, facilities, title, and real properties through an enforceable contract or lease agreement where the delivery of the deed is required to occur promptly after a specific, reasonable condition is met, such as promptly after the land is certified as meeting the requirements of CERCLA, and where the Federal agency does not retain continuing authority to control emissions associated with the lands, facilities, title, or real properties.

(xx) Transfers of real property, including land, facilities, and related personal property from a Federal entity to another Federal entity and assignments of real property, including land, facilities, and related personal property from a Federal entity to another Federal entity for subsequent deeding to eligible applicants.

(xxi) Actions by the Department of the Treasury to effect fiscal policy and to exercise the borrowing authority of the United States.

(xxii) Air traffic control activities and adopting approach, departure, and enroute procedures for aircraft operations above the mixing height specified in the applicable SIP or TIP. Where the applicable SIP or TIP does not specify a mixing height, the Federal agency can use the 3,000 feet above ground level as a default mixing height, unless the agency demonstrates that use of a different mixing height is appropriate because the change in emissions at and above that height caused by the Federal action is *de minimis.*

(3) Actions where the emissions are not reasonably foreseeable, such as the following:

(i) Initial Outer Continental Shelf lease sales which are made on a broad scale and are followed by exploration and development plans on a project level.

(ii) Electric power marketing activities that involve the acquisition, sale and transmission of electric energy.

(4) Actions which implement a decision to conduct or carry out a conforming program such as prescribed burning actions which are consistent with a conforming land management plan.

(d) Notwithstanding the other requirements of this subpart, a conformity determination is not required for the following Federal actions (or portion thereof):

(1) The portion of an action that includes major or minor new or modified stationary sources that require a permit under the new source review (NSR) program (Section 110(a)(2)(c) and Section 173 of the Act) or the prevention of significant deterioration program (title I, part C of the Act).

(2) Actions in response to emergencies which are typically commenced on the order of hours or days after the emergency and, if applicable, which meet the requirements of paragraph (e) of this section.

(3) Research, investigations, studies, demonstrations, or training (other than those exempted under paragraph (c)(2) of this section), where no environmental detriment is incurred and/or, the particular action furthers air quality research, as determined by the State agency primarily responsible for the applicable SIP;

(4) Alteration and additions of existing structures as specifically required by new or existing applicable environmental legislation or environmental regulations (e.g., hush houses for aircraft engines and scrubbers for air emissions).

(5) Direct emissions from remedial and removal actions carried out under the Comprehensive Environmental Response, Compensation and Liability Act and associated regulations to the extent such emissions either comply with the substantive requirements of the PSD/NSR permitting program or are exempted from other environmental regulation under the provisions of CERCLA and applicable regulations issued under CERCLA.

(e) Federal actions which are part of a continuing response to an emergency or disaster under paragraph (d)(2) of this section and which are to be taken more than 6 months after the commencement of the response to the emergency or disaster under paragraph (d)(2) of this section are exempt from the requirements of this subpart only if:

(1) The Federal agency taking the actions makes a written determination that, for a specified period not to exceed an additional 6 months, it is impractical to prepare the conformity analyses which would otherwise be required and the actions cannot be delayed due to overriding concerns for public health and welfare, national security interests and foreign policy commitments; or

(2) For actions which are to be taken after those actions covered by paragraph (e)(1) of this section, the Federal agency makes a new determination as provided in paragraph (e)(1) of this section and:

(i) Provides a draft copy of the written determinations required to affected EPA Regional office(s), the affected State(s) and/or air pollution control agencies, and any Federal recognized Indian tribal government in the nonattainment or maintenance area. Those organizations must be allowed 15 days from the beginning of the extension period to comment on the draft determination; and

(ii) Within 30 days after making the determination, publish a notice of the determination by placing a prominent advertisement in a daily newspaper of general circulation in the area affected by the action.

(3) If additional actions are necessary in response to an emergency or disaster under paragraph (d)(2) of this section beyond the specified time period in paragraph (e)(2) of this section, a Federal agency can make a new written determination as described in (e)(2) of this section for as many 6-month periods as needed, but in no case shall this exemption extend beyond three 6-month periods except where an agency:

(i) Provides information to EPA and the State or Tribe stating that the conditions that gave rise to the emergency exemption continue to exist and how such conditions effectively prevent the agency from conducting a conformity evaluation.

(ii) [Reserved]

(f) Notwithstanding other requirements of this subpart, actions specified by individual Federal agencies that have met the criteria set forth in either paragraphs (g)(1), (g)(2), or (g)(3) of this section and the procedures set forth in paragraph (h) of this section are “presumed to conform,” except as provided in paragraph (j) of this section. Actions specified by individual Federal agencies as “presumed to conform” may not be used in combination with one another when the total direct and indirect emissions from the combination of actions would equal or exceed any of the rates specified in paragraphs (b)(1) or (2) of this section.

(g) The Federal agency must meet the criteria for establishing activities that are “presumed to conform” by fulfilling the requirements set forth in either paragraphs (g)(1), (g)(2), or (g)(3) of this section:

(1) The Federal agency must clearly demonstrate using methods consistent with this subpart that the total of direct and indirect emissions from the type of activities which would be presumed to conform would not:

(i) Cause or contribute to any new violation of any standard in any area;

(ii) Interfere with provisions in the applicable SIP for maintenance of any standard;

(iii) Increase the frequency or severity of any existing violation of any standard in any area; or

(iv) Delay timely attainment of any standard or any required interim emission reductions or other milestones in any area including, where applicable, emission levels specified in the applicable SIP for purposes of:

(A) A demonstration of reasonable further progress;

(B) A demonstration of attainment; or

(C) A maintenance plan; or

(2) The Federal agency must provide documentation that the total of direct and indirect emissions from such future actions would be below the emission rates for a conformity determination that are established in paragraph (b) of this section, based, for example, on similar actions taken over recent years.

(3) The Federal agency must clearly demonstrate that the emissions from the type or category of actions and the amount of emissions from the action are included in the applicable SIP and the State, local, or tribal air quality agencies responsible for the SIP(s) or TIP(s) provide written concurrence that the emissions from the actions along with all other expected emissions in the area will not exceed the emission budget in the SIP.

(h) In addition to meeting the criteria for establishing exemptions set forth in paragraphs (g)(1), (g)(2), or (g)(3) of this section, the following procedures must also be complied with to presume that activities will conform:

(1) The Federal agency must identify through publication in theFederal Registerits list of proposed activities that are “presumed to conform” and the basis for the presumptions. The notice must clearly identify the type and size of the action that would be “presumed to conform” and provide criteria for determining if the type and size of action qualifies it for the presumption;

(2) The Federal agency must notify the appropriate EPA Regional Office(s), State, local, and tribal air quality agencies and, where applicable, the agency designated under section 174 of the Act and the MPO and provide at least 30 days for the public to comment on the list of proposed activities “presumed to conform.” If the “presumed to conform” action has regional or national application (*e.g.,* the action will cause emission increases in excess of the *de minimis* levels identified in paragraph (b) of this section in more than one of EPA's Regions), the Federal agency, as an alternative to sending it to EPA Regional Offices, can send the draft conformity determination to U.S. EPA, Office of Air Quality Planning and Standards;

(3) The Federal agency must document its response to all the comments received and make the comments, response, and final list of activities available to the public upon request; and

(4) The Federal agency must publish the final list of such activities in theFederal Register.

(i) Emissions from the following actions are “presumed to conform”:

(1) Actions at installations with facility-wide emission budgets meeting the requirements in §93.161 provided that the State or Tribe has included the emission budget in the EPA-approved SIP and the emissions from the action along with all other emissions from the installation will not exceed the facility-wide emission budget.

(2) Prescribed fires conducted in accordance with a smoke management program (SMP) which meets the requirements of EPA's Interim Air Quality Policy on Wildland and Prescribed Fires or an equivalent replacement EPA policy.

(3) Emissions for actions that the State or Tribe identifies in the EPA-approved SIP or TIP as “presumed to conform.”

(j) Even though an action would otherwise be “presumed to conform” under paragraph (f) or (i) of this section, an action shall not be “presumed to conform” and the requirements of §93.150, §93.151, §§93.154 through 93.160 and §§93.162 through 93.164 shall apply to the action if EPA or a third party shows that the action would:

(1) Cause or contribute to any new violation of any standard in any area;

(2) Interfere with provisions in the applicable SIP or TIP for maintenance of any standard;

(3) Increase the frequency or severity of any existing violation of any standard in any area; or

(4) Delay timely attainment of any standard or any required interim emissions reductions or other milestones in any area including, where applicable, emission levels specified in the applicable SIP or TIP for purposes of:

(i) A demonstration of reasonable further progress;

(ii) A demonstration of attainment; or

(iii) A maintenance plan.

(k) The provisions of this subpart shall apply in all nonattainment and maintenance areas except conformity requirements for newly designated nonattainment areas are not applicable until 1 year after the effective date of the final nonattainment designation for each NAAQS and pollutant in accordance with section 176(c)(6) of the Act.

[58 FR 63253, Nov. 30, 1993, as amended at 71 FR 40427, July 17, 2006; 75 FR 17274, Apr. 5, 2010]

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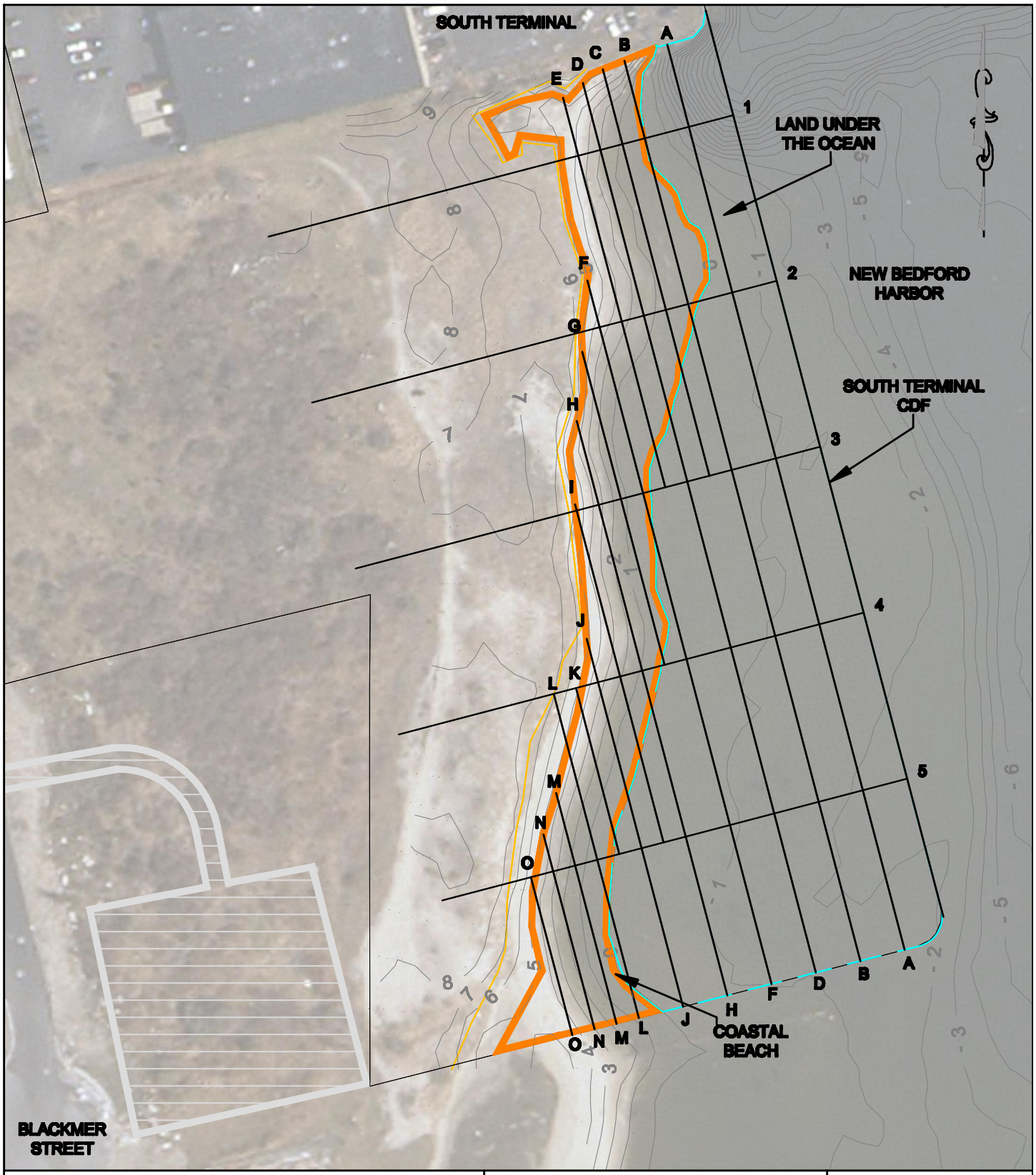
Section 508 / Accessibility

APPENDIX 20



APEX COMPANIES, LLC
184 HIGH STREET, BOSTON, MA. 02110
1 WAMSUTTA STREET, NEW BEDFORD, MA 02740

SCALE: 0 30 60 120 240 FEET

NEW BEDFORD HARBOR DEVELOPMENT COMMISSION

PROJECT TITLE:
SOUTH TERMINAL CDF SHELLFISH SURVEY

FIGURE
1

DRAWING TITLE:
SHELLFISH SURVEY GRID AND SAMPLE LOCATIONS

Table 1: Recovered Shellfish and Invertebrate Data

Sample Location	Organism	Size (inches)	Number
A1	Quahog	2 1/2	2
	Quahog	2 1/4	2
	Quahog	2	1
	Quahog	2 3/4	3
	Quahog	3 3/4	1
	Common Oyster	2 1/2	1
A2	Quohog	2 7/8	1
	Quohog	1 1/2	1
	Quohog	3/4	1
A3	Quohog	2 1/2	1
A4	Hermit Crabs		7-10
	Shrimp	1 - 1 1/4	7-10
A5	Quohog	3	2
	Quohog	2 1/2	1
	Quohog	3 1/2	1
	Quohog	3 3/4	1
	Quohog	3 5/8	1
	Long Clawed Hermit Crab in Perwinkle Shell	1 1/2	1
B1	Common Oyster	2	1
	Common Oyster	2 1/4	1
	Common Oyster	3	1
	Common Oyster	4	1
	Common Oyster	2 7/8	1
	Common Oyster	2 3/4	1
	Quohog	2 1/4	1
	Quohog	2 5/8	1
	Quohog	1 7/8	1
	Quohog	3 1/2	1
	Quohog	2 3/8	1
	Quohog	2 1/2	1
	Quohog	1	2
	Quohog	1 1/2	2
	Quohog	1 1/4	1
	Quohog	1 3/8	1

Table 1: Recovered Shellfish and Invertebrate Data

Sample Location	Organism	Size (inches)	Number
B2	Common Oyster Quohog	3 1/8 2 3/8	1 1
B3	Common Oyster Common Oyster Smooth Periwinkle	2 3/4 3 3/8	1 1 2
B4	Quohog Quohog	3 1/2 3 1/8	1 1
B5	Quohog Quohog Quohog	2 1/2 3 3 1/2	2 1 1
C1	Smooth Periwinkle Common Oyster Common Oyster Common Oyster Common Oyster Quohog	3/8 2 1/2 2 1/8 1 7/8 2 1/4 2 7/8	2 1 1 1 1 1
C2	Milky Ribbon Worm Smooth Periwinkle Common Oyster	10 1/4 - 3/8 2 1/2	1 36 1
D1	Quohog Smooth Periwinkle	3 1/4 - 3/8	1 3
D2	Ribbed Mussel Ribbed Mussel Smooth Periwinkle	1 7/8 2 1/4 - 3/8	1 1 17
D3	No Findings		

Table 1: Recovered Shellfish and Invertebrate Data

Sample Location	Organism	Size (inches)	Number
D4	No Findings		
D5	Quahog	1 7/8	1
E1	No Findings		
E2	No Findings		
F2	No Findings		
F3	No Findings		
F4	No Findings		
F5	Smooth Periwinkle Quahog Quahog Quahog Quahog	5/8 3 2 3/8 2 5/8 3 1/8	1 2 1 1 1
G3	Dog Winkle/Young Waved Whelk Dog Winkle/Young Waved Whelk	7/8 7/8	1 1
H3	Soft-Shelled Clam Soft-Shelled Clam Smooth Periwinkle	1 2 1/4 3/8	1 1 1
H4	Dog Winkle/Young Waved Whelk Dog Winkle/Young Waved Whelk Quahog Unknown Polychaete	7/8 1 2 3	7 1 1 1
H5	Quahog Quahog Quahog Quahog Quahog	1 1/8 1 1/2 1 3/4 2 2 1/2	1 1 2 1 1

Table 1: Recovered Shellfish and Invertebrate Data

Sample Location	Organism	Size (inches)	Number
I3	No Findings		
I4	Soft-Shelled Clam Soft-Shelled Clam	2 3	1 1
J4	No Findings		
J5	No Findings		
K5	No Findings		
L5	No Findings		
M5	Quahog Quahog Quahog Quahog Unknown Polychaete	1 1/8 7/8 1 1/4 2 1/4 4 1/4	1 1 1 1 1
N5	No Findings		
O5	No Findings		

Table 2: Quahog Data

Sample Location	Organism	Size (inches)	Number	Class Size
A1	Quahog	2 1/2	2	Cherrystone
	Quahog	2 1/4	2	Littleneck
	Quahog	2	1	Littleneck
	Quahog	2 3/4	3	Chowder
	Quahog	3 3/4	1	Chowder
A2	Quohog	2 7/8	1	Chowder
	Quohog	1 1/2	1	Seed
	Quohog	3/4	1	Seed
A3	Quohog	2 1/2	1	Cherrystone
A4	No Quahogs Found Within Sample			
A5	Quohog	3	2	Chowder
	Quohog	2 1/2	1	Cherrystone
	Quohog	3 1/2	1	Chowder
	Quohog	3 3/4	1	Chowder
	Quohog	3 5/8	1	Chowder
B1	Quohog	2 1/4	1	Littleneck
	Quohog	2 5/8	1	Cherrystone
	Quohog	1 7/8	1	Seed
	Quohog	3 1/2	1	Chowder
	Quohog	2 3/8	1	Cherrystone
	Quohog	2 1/2	1	Cherrystone
	Quohog	1	2	Seed
	Quohog	1 1/2	2	Seed
	Quohog	1 1/4	1	Seed
	Quohog	1 3/8	1	Seed
B2	Quohog	2 3/8	1	Cherrystone
B3	No Quahogs Found Within Sample			

Table 2: Quahog Data

Sample Location	Organism	Size (inches)	Number	Class Size
B4	Quohog Quohog	3 1/2 3 1/8	1 1	Chowder Chowder
B5	Quohog Quohog Quohog	2 1/2 3 3 1/2	2 1 1	Cherrystone Chowder Chowder
C1	Quohog	2 7/8	1	Chowder
C2	No Quahogs Found Within Sample			
D1	Quohog	3	1	Chowder
D2	No Quahogs Found Within Sample			
D3	No Findings			
D4	No Findings			
D5	Quahog	1 7/8	1	Seed
E1	No Findings			
E2	No Findings			
F2	No Findings			
F3	No Findings			
F4	No Findings			

Table 2: Quahog Data

Sample Location	Organism	Size (inches)	Number	Class Size
F5	Quahog Quahog Quahog Quahog	3 2 3/8 2 5/8 3 1/8	2 1 1 1	Chowder Cherrystone Cherrystone Chowder
G3	No Quahogs Found Within Sample	7/8	1	Seed
H3	No Quahogs Found Within Sample			
H4	Quahog	2	1	Littleneck
H5	Quahog Quahog Quahog Quahog Quahog	1 1/8 1 1/2 1 3/4 2 2 1/2	1 1 2 1 1	Seed Seed Seed Littleneck Cherrystone
I3	No Findings			
I4	No Quahogs Found Within Sample	2	1	Littleneck
J4	No Findings			
J5	No Findings			
K5	No Findings			
L5	No Findings			
M5	Quahog Quahog Quahog Quahog	1 1/8 7/8 1 1/4 2 1/4	1 1 1 1	Seed Seed Seed Littleneck
N5	No Findings			
O5	No Findings			

Table 3a: Intertidal Relative Abundance Survey Calculations

Intertidal Shellfish Survey Statistics

Total Intertidal Survey Area[7]:	5,140 m^2
Intertidal Survey Area With No Quahogs[5]:	3,141 m^2
Percentage of Intertidal Survey Area With No Quahogs:	61%
Intertidal Survey Area With Quahogs[5]:	1,999 m^2
Percentage of Intertidal Survey Area With Quahogs:	39%

Average Shellfish Count Per Square Meter in Intertidal Survey Area[1,7]

Sample Location	Number Per Quadrat[1]					
	Quahogs				Oysters	Soft-Shelled Clam
	"Seed"	"Littlenecks"	"Cherrystones"	"Chowder"		
B2	0	1	0	0	1	0
C1	0	0	0	1	4	0
C2	0	0	0	0	1	0
D1	0	0	0	1	0	0
D2	0	0	0	0	0	0
H3	0	0	0	0	0	2
H4	0	1	0	0	0	0
I4	0	0	0	0	0	2
M5	3	1	0	0	0	0
Average Count per Intertidal Survey Quadrat[1]	0.33	0.33	0	0.22	0.67	0.44
Average Count per Intertidal Survey Square Meter:	1.33	1.33	0	0.89	2.67	1.78
Adjusted Average Count in Intertidal Survey Area[6,7,8]:	**0.52**	**0.52**	**0**	**0.35**	**1.04**	**0.69**

Notes:
1). Average Shellfish Count Per Square Meter in Intertidal Survey Area = Frequency of Shellfish In Intertidal Areas When Shellfish Present X Percentage of Impacted Area with Shellfish.
2). Percentage of Intertidal Survey Area with Shellfish assumed to be the same as the percentage of Intertidal Impacted Area with Shellfish.
3). Survey Area with (or without) Shellfish estimated based on recovery during shellfish survey.
4). Estimated count in Intertidal Impacted Area = Intertidal Average Count per Square Meter in Survey Area X Estimated Intertidal Impacted Area.
5). Impacted Area = Shellfish habitat to be impacted during New Bedford South Terminal CDF Project
6). Quahog Classifications from Table 1: Class Size Lengths, page 4, Quahog Standing Crop Survey, New Bedford/Fairhaven Inner and Outer Harbors, David K. Whittaker, Massachusetts Division of Marine Fisheries, June 6, 1999.
7). Survey Area = Area in which a manual shellfish survey was conducted on 5/2/2010 and 5/3/2010
8). Adjusted Average Count = Average Count X Percent of Survey Area with Quahogs, Oysters or Clams.

Table 3b: Subtidal Relative Abundance Survey Calculations

Subtidal Shellfish Survey Statistics

Total Subtidal Survey Area[7]:	12,100 m^2
Subtidal Survey Area With No Quahogs[5]:	3,361 m^2
Percentage of Subtidal Survey Area With No Quahogs	28%
Subtidal Survey Area With Quahogs[5]:	8,739 m^2
Percentage of Subtidal Survey Area With Quahogs:	72%

Average Shellfish Count Per Square Meter in Subtidal Survey Area[1,7]

Sample Location	Number Per Quadrat[1]					
	Quahogs				Oysters	Soft-Shelled Clam
	"Seed"	"Littlenecks"	"Cherrystones"	"Chowder"		
A1	1	2	1	1	1	0
A2	2	0	0	1	0	0
A3	0	1	0	0	0	0
A5	0	1	0	4	0	0
B1	5	2	2	1	6	0
B2	0	1	0	0	1	0
B3	0	0	0	0	2	0
B4	0	0	0	2	0	0
B5	0	0	1	2	0	0
D5	1	0	0	0	0	0
F5	0	1	1	2	0	0
H5	3	2	1	0	0	0
Average Count per Subtidal Survey Quadrat[1]:	1.00	0.83	0.50	1.08	0.83	0.00
Average Count per Subtidal Survey Square Meter:	4.00	3.33	2	4.33	3.33	0.00
Adjusted Average Count in Subtidal Survey Area[6,7,8]:	**2.89**	**2.41**	**1.44**	**3.13**	**2.41**	**0.00**

Notes:
1). Average Shellfish Count Per Square Meter in Subtidal Survey Area = Frequency of Shellfish In Subtidal Areas When Shellfish Present X Percentage of Impacted Area with Shellfish.
2). Percentage of Subtidal Survey Area with Shellfish assumed to be the same as the percentage of Subtidal Impacted Area with Shellfish.
3). Survey Area with (or without) Shellfish estimated based on recovery during shellfish survey.
4). Estimated count in Subtidal Impacted Area = Subtidal Average Count per Square Meter in Survey Area X Estimated Subtidal Impacted Area.
5). Impacted Area = Shellfish habitat to be impacted during New Bedford South Terminal CDF Project
6). Quahog Classifications from Table 1: Class Size Lengths, page 4, Quahog Standing Crop Survey, New Bedford/Fairhaven Inner and Outer Harbors, David K. Whittaker, Massachusetts Division of Marine Fisheries, June 6, 1999.
7). Survey Area = Area in which a manual shellfish survey was conducted on 5/2/2010 and 5/3/2010
8). Adjusted Average Count = Average Count X Percent of Survey Area with Quahogs, Oysters or Clams.

Table 4: Estimated Total Count of Shellfish in Impacted Area

Shellfish Count in Survey Area[1] (From Tables 3a and 3b)

	Number Per Quadrat						Total
	Quahogs				Oysters	Soft-Shelled	
	"Seed"	"Littlenecks"	"Cherrystones"	"Chowder"			
Adjusted Average Count in Intertidal Survey Area:	0.52	0.52	0.00	0.35	1.04	0.69	3.11
Adjusted Average Count in Subtidal Survey Area:	2.89	2.41	1.44	3.13	2.41	0.00	12.28

Impacted Area[2]

Intertidal Impacted Area:	6,516 m^2
Subtidal Impacted Area:	81,425 m^2

Estimated Count in Impacted Area[a]

	Number Per Quadrat						Total
	Quahogs				Oysters	Soft-Shelled	
	"Seed"	"Littlenecks"	"Cherrystones"	"Chowder"			
[3]:	3,378	3,378	-	2,252	6,757	4,505	20,271
Estimated Count in Intertidal Impacted Area [4]:	235,227	196,023	117,614	254,829	196,023	-	999,715
Estimated Count in Subtidal Impacted Area	238,605	199,401	117,614	257,082	202,779	4,505	**1,019,986**

Estimated Total Count in Impacted Area :

Notes:
1). Survey Area = Area in which a manual shellfish survey was conducted on 5/2/2010 and 5/3/2010
2). Impacted Area is the full area within which shellfish will be impacted (i.e. the full project area vs. the area within which the shellfish survey was conducted). The Impacted Area is an area larger than the Survey Area. It is assumed that the Average Count per Intertidal/Subtidal Survey Square Meter (obtained using the results from the shellfish survey within the Survey Area) are consistent with the Average Count per Intertidal/ Subtidal Square Meter in the portions of the Impacted Area that were not included in the Survey Area.
3). The Estimated Count in Intertidal Impacted Area = Adjusted Average Count in Intertidal Survey Area X Intertidal Impacted Area
4). The Estimated Count in Subtidal Impacted Area = Adjusted Average Count in Subtidal Survey Area X Subtidal Impacted Area

APPENDIX 21

TABLE 1A: SUMMARY SITE SPECIFIC AVIAN INFORMATION (RAW)

(BIRD CONSERVATION REGION 30 SPECIES SIGHTED BY MASS AUDUBON BIRD WATCHERS WITHIN BRISTOL COUNTY BETWEEN 2000-2010 PER MASS AUDUBON EBIRD DATA)

Species Name	Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)	Number of Mass Audubon Sightings Within Bristol County Between 2000-2010	Sighted Within New Bedford Harbor Between 2005-2008 By New Bedford Amateur Bird Watcher Dan Harper*
Acadian Flycatcher		2	
Accipiter sp.		6	
American Bittern	M	6	
American Black Duck	HH	9793	X
American Black Duck x Mallard (hybrid)		13	
American Coot		295	
American Crow		2423	X
American Golden-Plover	H	4	
American Goldfinch		2797	X
American Kestrel		23	
American Oystercatcher	HH	347	X
American Pipit		135	
American Redstart		160	
American Robin		10264	X
American Tree Sparrow		505	
American White Pelican		3	
American Wigeon	M	619	
American Woodcock	HH	15	
Arctic Tern		1	
Bald Eagle	M	29	
Baltimore Oriole	H	342	X
Bank Swallow		129	
Barn Swallow		1871	
Barnacle Goose		1	
Barred Owl		3	
Barred Owl		3	
Barrow's Goldeneye		16	X
Bay-breasted Warbler	H	3	
Belted Kingfisher		98	X
Black Guillemot		1	
Black Scoter	H	6135	
Black Skimmer	M	2	
Black Tern		16	
Black Vulture		40	
Black-and-white Warbler	H	53	
Black-bellied Plover	H	416	
Black-billed Cuckoo		11	
Blackburnian Warbler	M	1	
Black-capped Chickadee		3021	X
Black-crowned Night-Heron	M	48	
Black-headed Gull		3	
Black-necked Stilt		45	
Blackpoll Warbler		76	
Black-throated Blue Warbler		7	
Black-throated Green Warbler		13	

TABLE 1A: SUMMARY SITE SPECIFIC AVIAN INFORMATION (RAW)

(BIRD CONSERVATION REGION 30 SPECIES SIGHTED BY MASS AUDUBON BIRD WATCHERS WITHIN BRISTOL COUNTY BETWEEN 2000-2010 PER MASS AUDUBON EBIRD DATA)

Species Name	Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)	Number of Mass Audubon Sightings Within Bristol County Between 2000-2010	Sighted Within New Bedford Harbor Between 2005-2008 By New Bedford Amateur Bird Watcher Dan Harper*
Blue Grosbeak		1	
Blue Jay		1932	X
Blue-gray Gnatcatcher		79	
Blue-headed Vireo		6	
Blue-winged Teal		24	
Blue-winged Warbler	HH	148	
Bobolink		106	
Bonaparte's Gull		159	X
Brant	HH	2899	X
Broad-winged Hawk	H	25	
Brown Creeper		49	
Brown Thrasher	H	58	X
Brown-headed Cowbird		2574	
Bufflehead	H	8219	X
Buteo sp.		5	
Cackling Goose		1	
Calliope Hummingbird		4	
Canada Goose	H	21380	X
Canada Warbler	M	5	
Canvasback	H	619	
Carolina Wren		1234	X
Cattle Egret		2	
Cave Swallow		2	
Cedar Waxwing		1505	X
Chestnut-sided Warbler		9	
Chimney Swift	H	245	X
Chipping Sparrow		987	X
Clapper Rail	H	2	
Clay-colored Sparrow		3	
Cliff Swallow		6	
Common Eider	H	46554	X
Common Goldeneye	M	6862	X
Common Grackle		4374	X
Common Loon		840	X
Common Merganser		665	X
Common Nighthawk		2	
Common Raven		15	
Common Redpoll		48	
Common Tern	M	4564	X
Common Yellowthroat		545	
Cooper's Hawk		148	X
Dark-eyed Junco		2207	X
Dickcissel		2	
Double-crested Cormorant		9039	X
Downy Woodpecker		787	

TABLE 1A: SUMMARY SITE SPECIFIC AVIAN INFORMATION (RAW)

(BIRD CONSERVATION REGION 30 SPECIES SIGHTED BY MASS AUDUBON BIRD WATCHERS WITHIN BRISTOL COUNTY BETWEEN 2000-2010 PER MASS AUDUBON EBIRD DATA)

Species Name	Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)	Number of Mass Audubon Sightings Within Bristol County Between 2000-2010	Sighted Within New Bedford Harbor Between 2005-2008 By New Bedford Amateur Bird Watcher Dan Harper*
Dunlin	H	6103	
Eastern Bluebird		444	
Eastern Kingbird	H	183	X
Eastern Meadowlark		182	
Eastern Phoebe		191	
Eastern Screech-Owl		32	
Eastern Towhee	H	583	
Eastern Wood-Pewee		82	
Empidonax sp.		8	
Eurasian Wigeon		7	
European Starling		45904	X
Field Sparrow	H	146	
Fish Crow		73	
Forster's Tern	H	15	
Fox Sparrow		40	
Gadwall	M	87	
Glaucous Gull		2	
Glossy Ibis	H	150	
Golden-crowned Kinglet		401	
Grasshopper Sparrow	M	5	
Gray Catbird	M	1790	X
Great Black-backed Gull		4222	X
Great Blue Heron		522	
Great Cormorant		771	
Great Crested Flycatcher	H	181	X
Great Egret		1226	
Great Horned Owl		23	
Greater Scaup	H	3158	X
Greater White-fronted Goose		6	
Greater Yellowlegs	H	593	
Greater/Lesser Scaup		526	
Green Heron		80	
Green-winged Teal	M	192	
Hairy Woodpecker		101	
Harlequin Duck	M	146	
hawk sp.		13	
Hermit Thrush		160	
Herring Gull		53140	X
Hooded Merganser	M	1000	
Hooded Warbler		4	
Horned Grebe	H	973	X
Horned Lark		686	
House Finch		1746	X
House Sparrow		3834	X
House Wren		175	
Iceland Gull		2	

TABLE 1A: SUMMARY SITE SPECIFIC AVIAN INFORMATION (RAW)

(BIRD CONSERVATION REGION 30 SPECIES SIGHTED BY MASS AUDUBON BIRD WATCHERS WITHIN BRISTOL COUNTY BETWEEN 2000-2010 PER MASS AUDUBON EBIRD DATA)

Species Name	Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)	Number of Mass Audubon Sightings Within Bristol County Between 2000-2010	Sighted Within New Bedford Harbor Between 2005-2008 By New Bedford Amateur Bird Watcher Dan Harper*
Indigo Bunting		36	
Killdeer	M	401	
Lapland Longspur		1	
Laughing Gull		641	
Least Bittern	M	1	
Least Flycatcher		52	
Least Sandpiper	M	1695	
Least Tern	H	2362	X
Lesser Black-backed Gull		7	
Lesser Scaup	H	1310	
Lesser Yellowlegs	M	236	
Lincoln's Sparrow		2	
Little Blue Heron	M	14	
Long-billed Dowitcher		2	
Long-tailed Duck	H	498	X
Magnolia Warbler		16	
Mallard	H	5634	X
Manx Shearwater	M	1	
Marsh Wren	H	17	
Merlin		35	
Monk Parakeet		21	
Mourning Dove		2587	
Mourning Warbler		0	
Mute Swan		2336	X
Nashville Warbler		7	
Nelson's Sparrow	M	13	
Northern Cardinal		2480	X
Northern Flicker	H	533	X
Northern Gannet	H	407	
Northern Harrier		186	
Northern Mockingbird		580	X
Northern Parula		19	
Northern Pintail	M	1508	
Northern Rough-winged Swallow		111	
Northern Saw-whet Owl		1	
Northern Shoveler		7	
Northern Shrike		2	
Northern Waterthrush		15	
Olive-sided Flycatcher		1	
Orange-crowned Warbler		10	
Orchard Oriole		28	
Osprey		1703	X
Ovenbird		218	
Palm Warbler		25	
Pectoral Sandpiper		50	

TABLE 1A: SUMMARY SITE SPECIFIC AVIAN INFORMATION (RAW)

(BIRD CONSERVATION REGION 30 SPECIES SIGHTED BY MASS AUDUBON BIRD WATCHERS WITHIN BRISTOL COUNTY BETWEEN 2000-2010 PER MASS AUDUBON EBIRD DATA)

Species Name	Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)	Number of Mass Audubon Sightings Within Bristol County Between 2000-2010	Sighted Within New Bedford Harbor Between 2005-2008 By New Bedford Amateur Bird Watcher Dan Harper*
peep sp.		106	X
Peregrine Falcon		32	X
Philadelphia Vireo		1	
Pied-billed Grebe		51	
Pileated Woodpecker		1	
Pine Siskin		1278	
Pine Warbler		144	
Piping Plover	HH	723	
Prairie Warbler	HH	48	
Purple Finch		92	
Purple Martin		22	
Purple Sandpiper	H	910	
Red Knot	HH	52	
Red-bellied Woodpecker		404	
Red-breasted Merganser	M	4552	X
Red-breasted Nuthatch		73	
Red-eyed Vireo		167	
Redhead		10	
Red-necked Grebe		8	
Red-shouldered Hawk		124	
Red-tailed Hawk		467	X
Red-throated Loon	HH	459	
Red-winged Blackbird		4847	X
Ring-billed Gull		21388	X
Ring-necked Duck		648	
Ring-necked Pheasant		3	
Rock Pigeon		2876	X
Roseate Tern	HH	2827	**
Rose-breasted Grosbeak		38	
Rough-legged Hawk		2	
Ruby-crowned Kinglet		61	
Ruby-throated Hummingbird		269	
Ruddy Duck	M	707	
Ruddy Turnstone	HH	987	
Ruffed Grouse		1	
Rusty Blackbird	H	6	
Saltmarsh Sparrow	HH	606	
Sanderling	HH	4299	
Savannah Sparrow		272	
Scarlet Tanager		58	
scoter sp.		497	
Seaside Sparrow	HH	143	
Sedge Wren	M	1	
Semipalmated Plover	M	2537	X
Semipalmated Sandpiper	H	1720	

TABLE 1A: SUMMARY SITE SPECIFIC AVIAN INFORMATION (RAW)

(BIRD CONSERVATION REGION 30 SPECIES SIGHTED BY MASS AUDUBON BIRD WATCHERS WITHIN BRISTOL COUNTY BETWEEN 2000-2010 PER MASS AUDUBON EBIRD DATA)

Species Name	Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)	Number of Mass Audubon Sightings Within Bristol County Between 2000-2010	Sighted Within New Bedford Harbor Between 2005-2008 By New Bedford Amateur Bird Watcher Dan Harper*
Sharp-shinned Hawk		76	X
Short-billed Dowitcher	H	250	
Short-billed/Long-billed Dowitcher		54	
Short-eared Owl		11	
Snow Bunting		288	
Snow Goose		2	
Snowy Egret	M	791	X
Solitary Sandpiper	H	17	
Song Sparrow		3605	X
Spotted Sandpiper	M	236	
Sterna sp.		20	
Stilt Sandpiper		1	
Surf Scoter	H	4147	
Surf/Black Scoter		111	
swallow sp.		263	
Swallow-tailed Kite		1	
Swamp Sparrow		226	
Tennessee Warbler		3	
Tree Swallow		16898	X
Tricolored Heron	M	7	
Tufted Duck		18	
Tufted Titmouse		2046	
Turkey Vulture		1132	
Veery		88	
Vesper Sparrow		2	
Virginia Rail		5	
warbler sp.		60	
Warbling Vireo		56	
Western Sandpiper	M	2	
Whimbrel	HH	50	
White-breasted Nuthatch		604	
White-crowned Sparrow		228	
White-eyed Vireo		76	
White-rumped Sandpiper	H	66	
White-throated Sparrow		1517	X
White-winged Scoter	H	2511	
Wild Turkey		131	
Willet	H	1349	
Willow Flycatcher	H	101	
Wilson's Phalarope	H	4	
Wilson's Snipe		157	
Wilson's Storm-Petrel		36	
Wilson's Warbler		2	
Winter Wren		71	
Wood Duck	M	165	X

TABLE 1A: SUMMARY SITE SPECIFIC AVIAN INFORMATION (RAW)

(BIRD CONSERVATION REGION 30 SPECIES SIGHTED BY MASS AUDUBON BIRD WATCHERS WITHIN BRISTOL COUNTY BETWEEN 2000-2010 PER MASS AUDUBON EBIRD DATA)

Species Name	Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)	Number of Mass Audubon Sightings Within Bristol County Between 2000-2010	Sighted Within New Bedford Harbor Between 2005-2008 By New Bedford Amateur Bird Watcher Dan Harper*
Wood Thrush	HH	157	
Worm-eating Warbler	H	2	
Yellow Warbler		1483	
Yellow-bellied Flycatcher		2	
Yellow-bellied Sapsucker		11	
Yellow-billed Cuckoo		32	
Yellow-breasted Chat		11	
Yellow-crowned Night-Heron	M	1	
Yellow-rumped Warbler		1394	X
Yellow-throated Vireo	H	3	

Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)

HH = Highest Priority

H = High Priority

M = Moderate Priority

Notes:

1). Mass Audubon bird sighting data compiled via archived data collected via eBird, an interactive computerized database that allows individual birdwatchers to report data online.

2). Bird Conservation Regions were formulated via the North American Bird Conservation Initiative, a forum of governmental agencies, private organizations, and bird initaives helping partners across the continent meet common bird conservation objectives. Priority Species for Bird Conservation Region 30 (which includes New Bedford Harbor) were produced by the Atlantic Coast Joint Venture, another partnership of federal, state, and private entities formulated to improve bird habitat conservation within the Atlantic Flyway, and includes the U.S. Fish and Wildlife Service among its membership and leadership.

* - Amateur bird watching results published on Web Log by Dan Harper at http://www.danielharper.org/blog/?page_id=454. From 2005 - 2008 Mr. Harper recorded bird sightings within New Bedford Harbor. At that time, Mr. Harper was the minister for the First Unitarian Church of New Bedford. Mr. Harper currently resides in Palo Alto, California.

** - Bird was not noted by Dan Harper within his blog; however, Bird Island (17 km from site) is known to be utilized as a breeding colony for the Roseate Tern.

TABLE 1B: SUMMARY SITE SPECIFIC AVIAN INFORMATION (FIRST SORT)

(BIRD CONSERVATION REGION 30 PRIORITY SPECIES SIGHTED WITHIN BRISTOL COUNTY BETWEEN 2000-2010 BY MASS AUDUBON BIRD WATCHERS)

Species Name	Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)	Number of Mass Audubon Sightings Within Bristol County Between 2000-2010	Sighted Within New Bedford Harbor Between 2005-2008 By New Bedford Amateur Bird Watcher Dan Harper*
American Bittern	M	6	
American Black Duck	HH	9793	X
American Golden-Plover	H	4	
American Oystercatcher	HH	347	X
American Wigeon	M	619	
American Woodcock	HH	15	
Bald Eagle	M	29	
Baltimore Oriole	H	342	X
Bay-breasted Warbler	H	3	
Black Scoter	H	6135	
Black Skimmer	M	2	
Black-and-white Warbler	H	53	
Black-bellied Plover	H	416	
Blackburnian Warbler	M	1	
Black-crowned Night-Heron	M	48	
Blue-winged Warbler	HH	148	
Brant	HH	2899	X
Broad-winged Hawk	H	25	
Brown Thrasher	H	58	X
Bufflehead	H	8219	X
Canada Goose	H	21380	X
Canada Warbler	M	5	
Canvasback	H	619	
Chimney Swift	H	245	X
Clapper Rail	H	2	
Common Eider	H	46554	X
Common Goldeneye	M	6862	X
Common Tern	M	4564	X
Dunlin	H	6103	
Eastern Kingbird	H	183	X
Eastern Towhee	H	583	
Field Sparrow	H	146	
Forster's Tern	H	15	
Gadwall	M	87	
Glossy Ibis	H	150	
Grasshopper Sparrow	M	5	
Gray Catbird	M	1790	X
Great Crested Flycatcher	H	181	X
Greater Scaup	H	3158	X
Greater Yellowlegs	H	593	
Green-winged Teal	M	192	
Harlequin Duck	M	146	
Hooded Merganser	M	1000	
Horned Grebe	H	973	X

TABLE 1B: SUMMARY SITE SPECIFIC AVIAN INFORMATION (FIRST SORT)

(BIRD CONSERVATION REGION 30 PRIORITY SPECIES SIGHTED WITHIN BRISTOL COUNTY BETWEEN 2000-2010 BY MASS AUDUBON BIRD WATCHERS)

Species Name	Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)	Number of Mass Audubon Sightings Within Bristol County Between 2000-2010	Sighted Within New Bedford Harbor Between 2005-2008 By New Bedford Amateur Bird Watcher Dan Harper*
Killdeer	M	401	
Least Bittern	M	1	
Least Sandpiper	M	1695	
Least Tern	H	2362	X
Lesser Scaup	H	1310	
Lesser Yellowlegs	M	236	
Little Blue Heron	M	14	
Long-tailed Duck	H	498	X
Mallard	H	5634	X
Manx Shearwater	M	1	
Marsh Wren	H	17	
Nelson's Sparrow	M	13	
Northern Flicker	H	533	X
Northern Gannet	H	407	
Northern Pintail	M	1508	
Piping Plover	HH	723	
Prairie Warbler	HH	48	
Purple Sandpiper	H	910	
Red Knot	HH	52	
Red-breasted Merganser	M	4552	X
Red-throated Loon	HH	459	
Roseate Tern	HH	2827	**
Ruddy Duck	M	707	
Ruddy Turnstone	HH	987	
Rusty Blackbird	H	6	
Saltmarsh Sparrow	HH	606	
Sanderling	HH	4299	
Seaside Sparrow	HH	143	
Sedge Wren	M	1	
Semipalmated Plover	M	2537	X
Semipalmated Sandpiper	H	1720	
Short-billed Dowitcher	H	250	
Snowy Egret	M	791	X
Solitary Sandpiper	H	17	
Spotted Sandpiper	M	236	
Surf Scoter	H	4147	
Tricolored Heron	M	7	
Western Sandpiper	M	2	
Whimbrel	HH	50	
White-rumped Sandpiper	H	66	
White-winged Scoter	H	2511	
Willet	H	1349	
Willow Flycatcher	H	101	
Wilson's Phalarope	H	4	

TABLE 1B: SUMMARY SITE SPECIFIC AVIAN INFORMATION (FIRST SORT)

(BIRD CONSERVATION REGION 30 PRIORITY SPECIES SIGHTED WITHIN BRISTOL COUNTY BETWEEN 2000-2010 BY MASS AUDUBON BIRD WATCHERS)

Species Name	Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)	Number of Mass Audubon Sightings Within Bristol County Between 2000-2010	Sighted Within New Bedford Harbor Between 2005-2008 By New Bedford Amateur Bird Watcher Dan Harper*
Wood Duck	M	165	X
Wood Thrush	HH	157	
Worm-eating Warbler	H	2	
Yellow-crowned Night-Heron	M	1	
Yellow-throated Vireo	H	3	

Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)
HH = Highest Priority
H = High Priority
M = Moderate Priority

Notes:
1). Mass Audubon bird sighting data compiled via archived data collected via eBird, an interactive computerized database that allows individual birdwatchers to report data online.
2). Bird Conservation Regions were formulated via the North American Bird Conservation Initiative, a forum of governmental agencies, private organizations, and bird initaives helping partners across the continent meet common bird conservation objectives. Priority Species for Bird Conservation Region 30 (which includes New Bedford Harbor) were produced by the Atlantic Coast Joint Venture, another partnership of federal, state, and private entities formulated to improve bird habitat conservation within the Atlantic Flyway, and includes the U.S. Fish and Wildlife Service among its membership and leadership.
* - Amateur bird watching results published on Web Log by Dan Harper at http://www.danielharper.org/blog/?page_id=454. Fror 2005 - 2008 Mr. Harper recorded bird sightings within New Bedford Harbor. At that time, Mr. Harper was the minister for the First Unitarian Church of New Bedford. Mr. Harper currently resides in Palo Alto, California.
** - Bird was not noted by Dan Harper within his blog; however, Bird Island (17 km from site) is known to be utilized as a breeding colony for the Roseate Tern.

TABLE 1C: SUMMARY SITE SPECIFIC AVIAN INFORMATION (SECOND SORT)

(BIRD CONSERVATION REGION 30 PRIORITY SPECIES SIGHTED WITHIN BRISTOL COUNTY BETWEEN 2000-2010 BY MASS AUDUBON BIRD WATCHERS AND ALSO SITED BY NEW BEDFORD BIRD WATCHER DAN HARPER IN NEW BEDFORD HARBOR BETWEEN 2005-2008)

Species Name	Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)	Number of Mass Audubon Sightings Within Bristol County Between 2000-2010	Sighted Within New Bedford Harbor Between 2005-2008 By New Bedford Amateur Bird Watcher Dan Harper*
American Black Duck	HH	9793	X
American Oystercatcher	HH	347	X
Baltimore Oriole	H	342	X
Brant	HH	2899	X
Brown Thrasher	H	58	X
Bufflehead	H	8219	X
Canada Goose	H	21380	X
Chimney Swift	H	245	X
Common Eider	H	46554	X
Common Goldeneye	M	6862	X
Common Tern	M	4564	X
Eastern Kingbird	H	183	X
Gray Catbird	M	1790	X
Great Crested Flycatcher	H	181	X
Greater Scaup	H	3158	X
Horned Grebe	H	973	X
Least Tern	H	2362	X
Long-tailed Duck	H	498	X
Mallard	H	5634	X
Northern Flicker	H	533	X
Red-breasted Merganser	M	4552	X
Roseate Tern	HH	2827	**
Semipalmated Plover	M	2537	X
Snowy Egret	M	791	X
Wood Duck	M	165	X

Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)

HH = Highest Priority

H = High Priority

M = Moderate Priority

Notes:

1). Mass Audubon bird sighting data compiled via archived data collected via eBird, an interactive computerized database that allows individual birdwatchers to report data online.

2). Bird Conservation Regions were formulated via the North American Bird Conservation Initiative, a forum of governmental agencies, private organizations, and bird initaives helping partners across the continent meet common bird conservation objectives. Priority Species for Bird Conservation Region 30 (which includes New Bedford Harbor) were produced by the Atlantic Coast Joint Venture, another partnership of federal, state, and private entities formulated to improve bird habitat conservation within the Atlantic Flyway, and includes the U.S. Fish and Wildlife Service among its membership and leadership.

* - Amateur bird watching results published on Web Log by Dan Harper at http://www.danielharper.org/blog/?page_id=454. From 2005 - 2008 Mr. Harper recorded bird sightings within New Bedford Harbor. At that time, Mr. Harper was the minister for the First Unitarian Church of New Bedford. Mr. Harper currently resides in Palo Alto, California.

** - Bird was not noted by Dan Harper within his blog; however, Bird Island (17 km from site) is known to be utilized as a breeding colony for the Roseate Tern.

TABLE 1D: SUMMARY SITE SPECIFIC AVIAN INFORMATION (FINAL SORT)

(BIRD CONSERVATION REGION 30 PRIORITY SPECIES SIGHTED WITHIN BRISTOL COUNTY BETWEEN 2000-2010 BY MASS AUDUBON BIRD WATCHERS AND ALSO SITED BY NEW BEDFORD BIRD WATCHER DAN HARPER IN NEW BEDFORD HARBOR BETWEEN 2005-2008 - BIRDS UNLIKELY TO BE AT SITE REMOVED)

Species Name	Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)	Number of Mass Audubon Sightings Within Bristol County Between 2000-2010	Sighted Within New Bedford Harbor Between 2005-2008 By New Bedford Amateur Bird Watcher Dan Harper*
American Black Duck	HH	9793	X
American Oystercatcher	HH	347	X
Brant	HH	2899	X
Bufflehead	H	8219	X
Canada Goose	H	21380	X
Common Eider	H	46554	X
Common Goldeneye	M	6862	X
Common Tern	M	4564	X
Greater Scaup	H	3158	X
Horned Grebe	H	973	X
Least Tern	H	2362	X
Long-tailed Duck	H	498	X
Mallard	H	5634	X
Red-breasted Merganser	M	4552	X
Roseate Tern	HH	2827	**
Semipalmated Plover	M	2537	X
Snowy Egret	M	791	X
Wood Duck	M	165	X

Species Prioritization for Bird Conservation Region 30 (Mid-Atlantic/Southern New England)

HH = Highest Priority

H = High Priority

M = Moderate Priority

Notes:

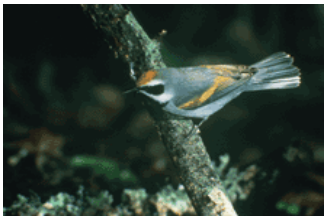
1). Mass Audubon bird sighting data compiled via archived data collected via eBird, an interactive computerized database that allows individual birdwatchers to report data online.

2). Bird Conservation Regions were formulated via the North American Bird Conservation Initiative, a forum of governmental agencies, private organizations, and bird initaives helping partners across the continent meet common bird conservation objectives. Priority Species for Bird Conservation Region 30 (which includes New Bedford Harbor) were produced by the Atlantic Coast Joint Venture, another partnership of federal, state, and private entities formulated to improve bird habitat conservation within the Atlantic Flyway, and includes the U.S. Fish and Wildlife Service among its membership and leadership.

3). This table has removed the following species, as, although they have been spotted within New Bedford Harbor, the specific habitat at th site is not ideal for nesting and/or feeding: Baltimore Oriole, Brown Thrasher, Chimney Swift, Eastern Kingbird, Grey Catbird, Great Crested Flycatcher, Northern Flicker.

* - Amateur bird watching results published on Web Log by Dan Harper at http://www.danielharper.org/blog/?page_id=454. From 2005 2008 Mr. Harper recorded bird sightings within New Bedford Harbor. At that time, Mr. Harper was the minister for the First Unitarian Church of New Bedford. Mr. Harper currently resides in Palo Alto, California.

** - Bird was not noted by Dan Harper within his blog; however, Bird Island (17 km from site) is known to be utilized as a breeding colony for the Roseate Tern.



nabci

Advancing integrated bird conservation in North America

Links to other NABCI efforts:

NABCI International

NABCI Mexico

NABCI Canada

Integrated bird conservation is about conserving birds:

- Across geopolitical boundaries
- Across taxonomic groups
- Across landscapes

It's about people working together to secure the future for North America's wild birds.

Welcome to the official Web site of the United States NABCI Committee.

The U.S. North American Bird Conservation Initiative (NABCI) Committee is a forum of government agencies, private organizations, and bird initiatives helping partners across the continent meet their common bird conservation objectives.

The Committee's strategy is to foster coordination and collaboration on key issues of concern, including coordinated bird monitoring, conservation design, private land conservation, international conservation, and institutional support in state and federal agencies for integrated bird conservation.

U.S. NABCI Committee January 2010 meeting summary

Next U.S. NABCI Committee meeting: August 2010 in Arlington, Virginia

U.S. NABCI Subcommittees:

- Policy and Legislative
- Monitoring and Database Management Team
- Private Lands
- Conservation Design
- Communications
- State of the Birds

Tri-national NABCI Committee is the international expression of NABCI and serves to increase cooperation and effectiveness of bird conservation efforts among the three countries.

News: NABCI and Association of Joint Venture Management Boards announce 2010 bird conservation award winners: Gary Myers, Kirk Nelson, and Charles Baxter. Read more here...

News: On March 11, Secretary of the Interior Ken Salazar released the 2010 State of the Birds Report, the first themed State of the Birds report which explores the vulnerability of birds and their habitats to climate changes across the major biomes of the United States.
For more information, visit:

State of the Birds Web site

News: Field Guide to the 2008 Farm Bill for Fish and Wildlife Conservation, a publication of U.S. NABCI and the Intermountain West Joint Venture, is now available! Version 1.1
You can also read the Farm Bill Guide online at www.nabci-us.org/fbguidehome.htm

The All-Bird Bulletin - News and information from the U.S. NABCI Committee

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Last updated January 2010

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Bird Conservation Regions (BCRs)

View an interactive BCR Map with BCR descriptions, contacts, and links to bird conservation plans.

or use Acrobat Reader or similar program to download the following documents:
Bird Conservation Region Map | Bird Conservation Region Descriptions

Don't have Adobe Acrobat Reader? Get it free online.To access ArcInfo files of the BCRs, click here.

What are Bird Conservation Regions? Bird Conservation Regions (BCRs) are ecologically distinct regions in North America with similar bird communities, habitats, and resource management issues. BCRs are a single application of the scale-flexible hierarchical framework of nested ecological units delineated by the Commission for Environmental Cooperation (CEC). The CEC framework comprises a hierarchy of 4 levels of ecoregions. At each spatial level, spatial resolution increases and ecoregions encompass areas that are progressively more similar in their biotic (e.g., plant and wildlife) and abiotic (e.g., soils, drainage patterns, temperature, and annual precipitation) characteristics. BCRs may be partitioned into smaller ecological units when finer scale conservation planning, implementation, and evaluation are necessary. Conversely, BCRs may be aggregated to facilitate conservation partnerships throughout the annual range of a group of species, recognizing that migratory species may use multiple BCRs throughout their annual life cycle. BCRs also facilitate domestic and international cooperation in bird conservation because these areas of relatively homogenous habitats and bird communities traverse state, provincial, and national borders.

How were BCRs developed? A mapping team comprised of members from United States, Mexico, and Canada assembled at the first international NABCI workshop held in Puebla, Mexico, in November 1998, to develop a consistent spatial framework for bird conservation in North America. After agreeing on general principles and considering numerous ecoregion delineations, they adopted CEC's hierarchical framework of nested

ecological units. The team's US members met in December of that year in Memphis, Tennessee, to apply the framework to the United States and developed a proposed map of BCRs. BCRs were created by aggregating CEC level II, III, and IV ecoregions in combinations that reflect current understanding of bird species distribution and life history requirements. The map was presented to and approved by the US NABCI Committee during its November 1999, meeting.The map is a dynamic tool. Its BCR boundaries will change over time as new scientific information becomes available. It is expected that the map will be updated every three years, with the next update occurring in November 2002.

What are the primary purposes of BCRs? The primary purposes of BCRs, as proposed by the mapping team in 1998 and approved in concept by the US Committee in 1999, are to:

- facilitate communication among the bird conservation initiatives;
- systematically and scientifically apportion the US into conservation units;
- facilitate a regional approach to bird conservation;
- promote new, expanded, or restructured partnerships; and
- identify overlapping or conflicting conservation priorities.

As integrated bird conservation progresses in North America, Bird Conservation Regions should ultimately function as the primary units within which biological foundation issues are resolved, the landscape configuration of sustainable habitats is designed, and priority projects originate.

- For more information on the ecological framework and the philosophy behind the development of BCRs, download the following document:
  A Proposed Framework for Delineating Ecologically-based Planning, Implementation, and Evaluation Units for Cooperative Bird Conservation in the US

- For more information on BCRs and their relationship to Joint Ventures, download the following document:
  BCRs and JVs: Evolving Roles for Bird Conservation Delivery

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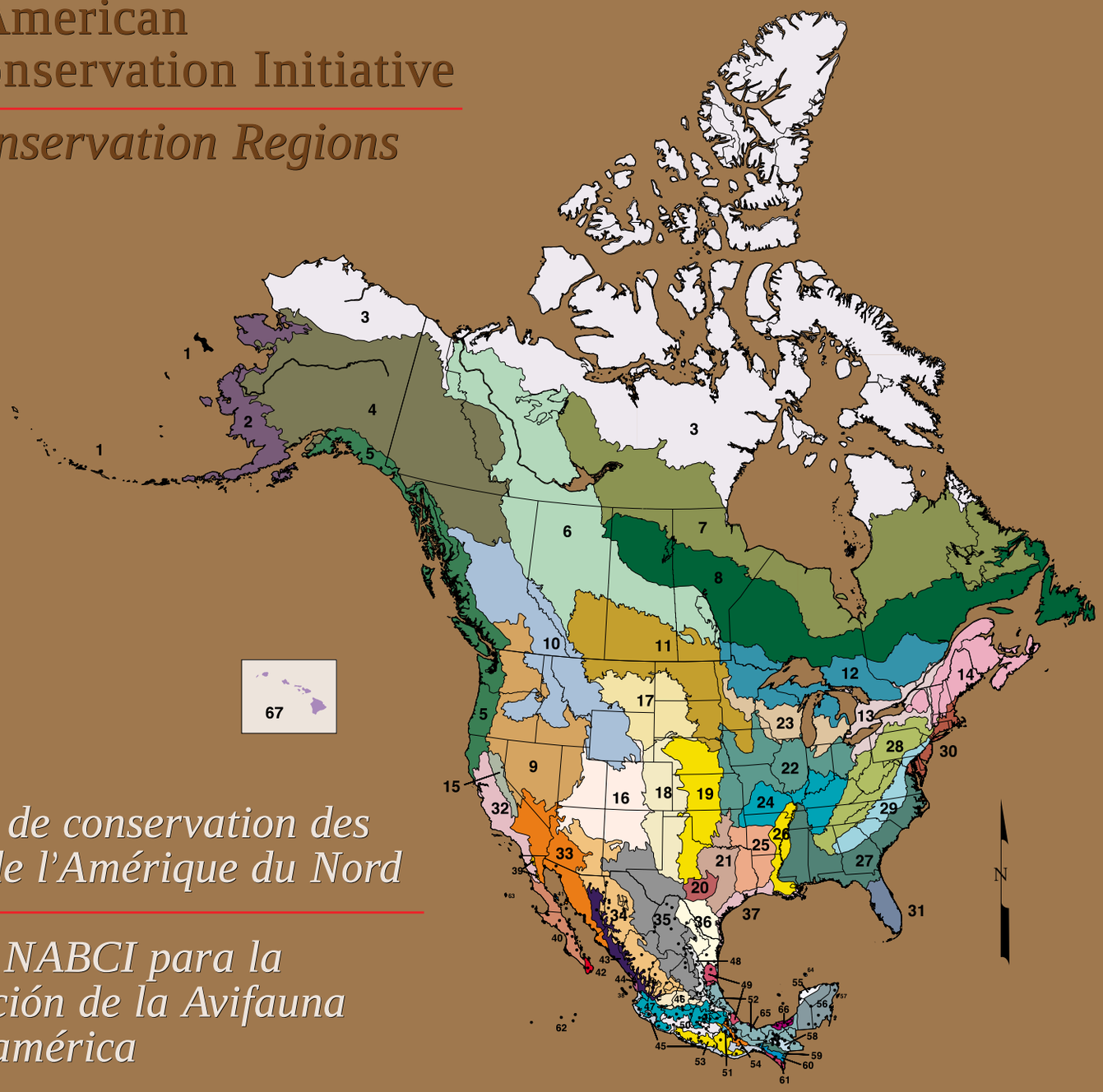
North American Bird Conservation Initiative

Bird Conservation Regions



Initiative de conservation des oiseaux de l'Amérique du Nord

Regiones NABCI para la conservación de la Avifauna de Norteamérica

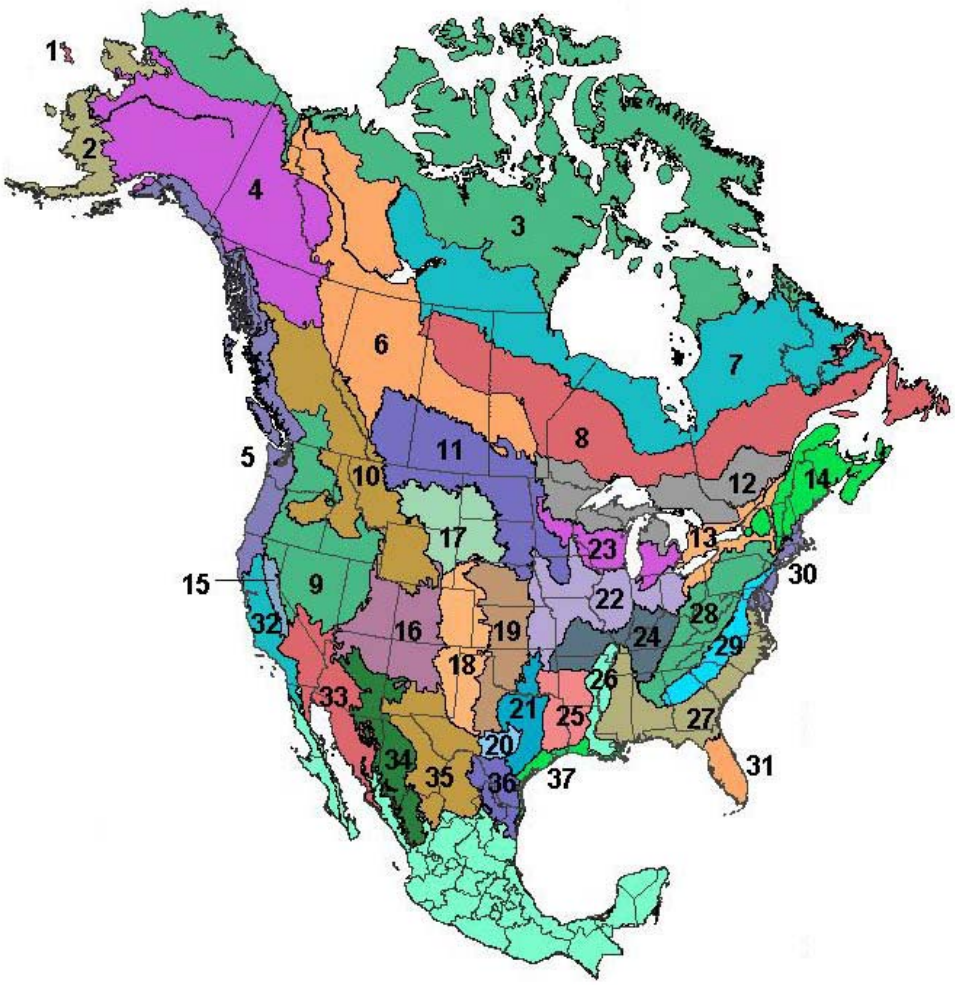
1. Aleutian/Bering Sea Islands
2. Western Alaska
3. Arctic Plains and Mountains
4. Northwestern Interior Forest
5. Northern Pacific Rainforest
6. Boreal Taiga Plains
7. Taiga Shield and Hudson Plains
8. Boreal Softwood Shield
9. Great Basin
10. Northern Rockies
11. Prairie Potholes
12. Boreal Hardwood Transition
13. Lower Great Lakes/St. Lawrence Plain
14. Atlantic Northern Forest
15. Sierra Nevada
16. Southern Rockies/Colorado Plateau
17. Badlands and Prairies
18. Shortgrass Prairie
19. Central Mixed-grass Prairie
20. Edwards Plateau
21. Oaks and Prairies
22. Eastern Tallgrass Prairie
23. Prairie Hardwood Transition
24. Central Hardwoods
25. West Gulf Coastal Plain/Ouachitas
26. Mississippi Alluvial Valley
27. Southeastern Coastal Plain
28. Appalachian Mountains
29. Piedmont
30. New England/Mid-Atlantic Coast
31. Peninsular Florida
32. Coastal California
33. Sonoran and Mohave Deserts
34. Sierra Madre Occidental
35. Chihuahuan Desert
36. Tamaulipan Brushlands
37. Gulf Coastal Prairie
38. Islas Marías
39. Sierras de Baja California
40. Desierto de Baja California
41. Islas del Golfo de California
42. Sierra y Planicies de El Cabo
43. Planicie Costera, Lomeríos y Cañones de Occidente
44. Marismas Nacionales
45. Planicie Costera y Lomeríos del Pacífico Sur
46. Sur del Altiplano Mexicano
47. Eje Neovolcánico Transversal
48. Sierra Madre Oriental
49. Planicie Costera y Lomeríos Secos del Golfo de México
50. Cuenca del Río Balsas
51. Valle de Tehuacán–Cuicatlán
52. Planicie Costera y Lomeríos Húmedos del Golfo de México
53. Sierra Madre del Sur
54. Sierra Norte de Puebla–Oaxaca
55. Planicie Noroccidental de Yucatán
56. Planicie de la Península de Yucatán
57. Isla Cozumel
58. Altos de Chiapas
59. Depresiones Intermontanas
60. Sierra Madre de Chiapas
61. Planicie Costera del Soconusco
62. Archipiélago de Revillagigedo
63. Isla Guadalupe
64. Arrecife Alacranes
65. Los Tuxtlas
66. Pantanos de Centla–Laguna de Términos
67. Hawaii

• Important Bird Area (displayed for Mexico only)

nabci

Bird Conservation Region 30

New England/Mid-Atlantic Coast



Note: Hawaii (not shown) is BCR 67

Description: This area has the densest human population of any region in the country. Much of what was formerly cleared for agriculture is now either in forest or in residential use. The highest priority birds are in coastal wetland and beach habitats, including the Saltmarsh Sharp-tailed Sparrow and Nelson's Sharp-tailed Sparrow, Seaside Sparrow, Piping Plover, American Oystercatcher, American Black Duck, and Black Rail. The region includes critical migration sites for Red Knot, Ruddy Turnstone, Sanderling, Semipalmated Sandpiper, and Dunlin. Most of the continental population of the endangered Roseate Tern nests on islands off the southern New England states. Other terns and gulls nest in large numbers, and large mixed colonies of herons, egrets, and

ibis may form on islands in the Delaware and Chesapeake Bay regions. Estuarine complexes and embayments created behind barrier beaches in this region are extremely important to wintering and migrating waterfowl, including approximately 65 percent of the total wintering American Black Duck population, along with large numbers of Greater Scaup, Tundra Swan, Gadwall, Brant, and Canvasback. Exploitation and pollution of Chesapeake Bay and other coastal zones, and the accompanying loss of submerged aquatic vegetation, have significantly reduced their value to waterfowl.

Bird Conservation Plans

Landbirds - Mid-Atlantic Coastal Plains, Southern New England
Shorebirds - Northern Atlantic
Waterbirds - Mid Atlantic/New England/Maritimes
Waterfowl - Atlantic Coast Joint Venture Waterfowl Implementation Plan
All Birds -New England/Mid-Atlantic Coast BCR

Implementation Plan,
Atlantic Coast Joint
Venture Strategic Plan

Joint Venture area:
Atlantic Coast

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International Site

Atlantic Coast Joint Venture

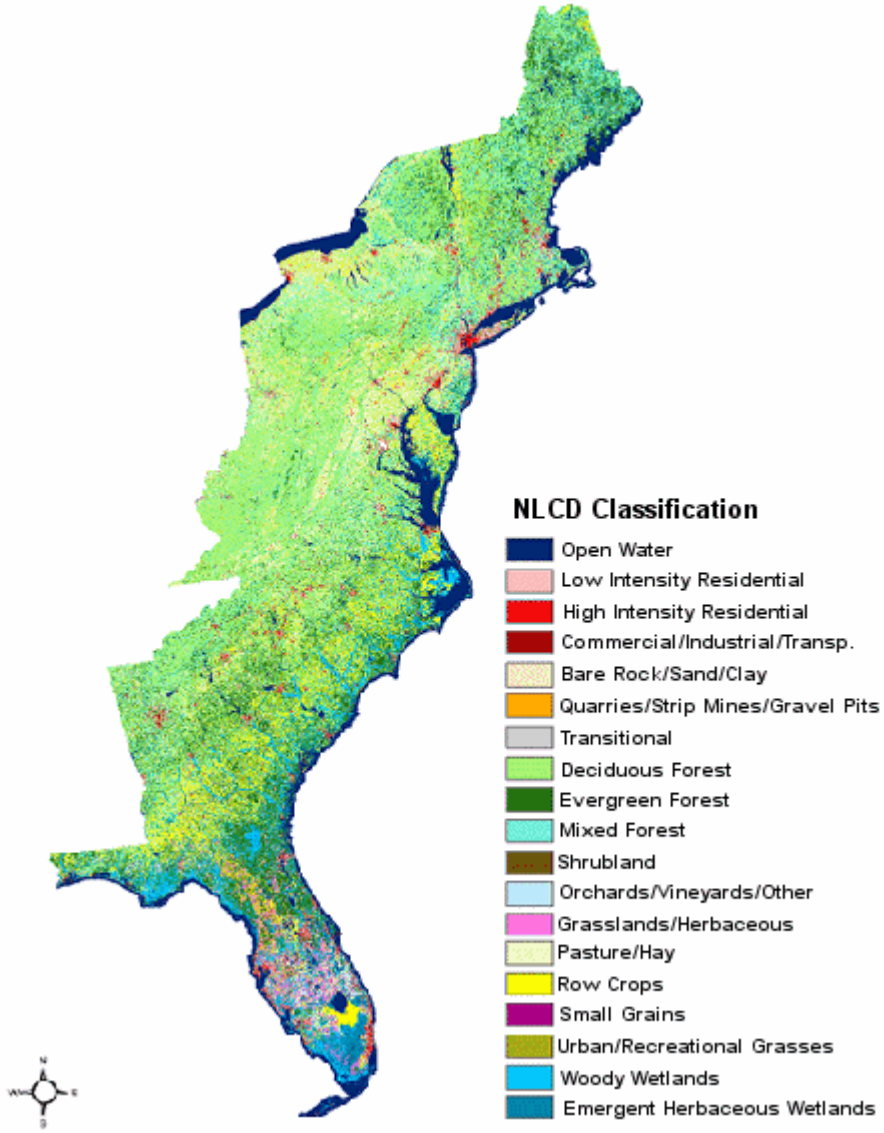
About Us

What is the Atlantic Coast Joint Venture?

The Atlantic Coast Joint Venture (ACJV) is a partnership focused on the conservation of habitat for native birds in the Atlantic Flyway of the United States from Maine south to Puerto Rico. The joint venture is a partnership of the 18 states and commonwealths and key federal and regional habitat conservation agencies and organizations in the joint venture area. The joint venture was originally formed as a regional partnership focused on the conservation of waterfowl and wetlands under the North American Waterfowl Management Plan in 1988 and has since broadened its focus to the conservation of habitats for all birds consistent with major national and continental bird conservation plans and the North American Bird Conservation Initiative.

This joint venture includes a total area of 283 million acres (442,000 square miles) representing 12% of the total area of the United States. It is the most densely populated region in the United States with a total of over 105 million people living in the area.

There is a tremendous diversity of ecosystems and habitats in the joint venture area from the boreal forests and rocky coastline at the northern reaches of the joint venture in Maine to the tropical mangrove swamps and coral reefs of Florida and Puerto Rico to the south and from the rugged peaks of the Appalachian Mountains in the west to the low-lying Atlantic Coastal Plain with its many coastal rivers, bays and estuaries forming the joint venture's eastern boundary. The Atlantic Ocean coastline extends for 2,069 miles from Maine to Florida with a combined shoreline of all tidal areas along the coast adding up to 28,673 miles. The variety of habitats in the joint venture supports a high abundance and diversity of bird species including 37 native species of waterfowl, 40 species of shorebirds, 72 species of colonially-nesting waterbirds (including pelagic species) and over 200 landbird species.



Landcover types within the joint venture boundary.

Mission Statement

The Atlantic Coast Joint Venture will provide a forum for federal, state, regional and local partners to coordinate and improve the effectiveness of bird habitat conservation planning, delivery and evaluation in the Atlantic Flyway.

ACJV Strategy

The objectives, strategies and measures of achievement for the ACJV can be grouped into three major components: *Biological Foundation, Conservation Coordination and Delivery, and Communication and Outreach*. Each of these three components is described in the ACJV Strategic Plan approved in July, 2004. The plan contains the goal(s) of each component, objectives and strategies are described for reaching each goal and overall and annual measures of achievement. The Plan was recently updated and revised in 2009.

Download the ACJV Strategic Plan *(2.67 MB Adobe pdf file)*

You will need Adobe Acrobat Reader software to open this document. If you do not have this software, you may obtain it free of charge by following the link above.

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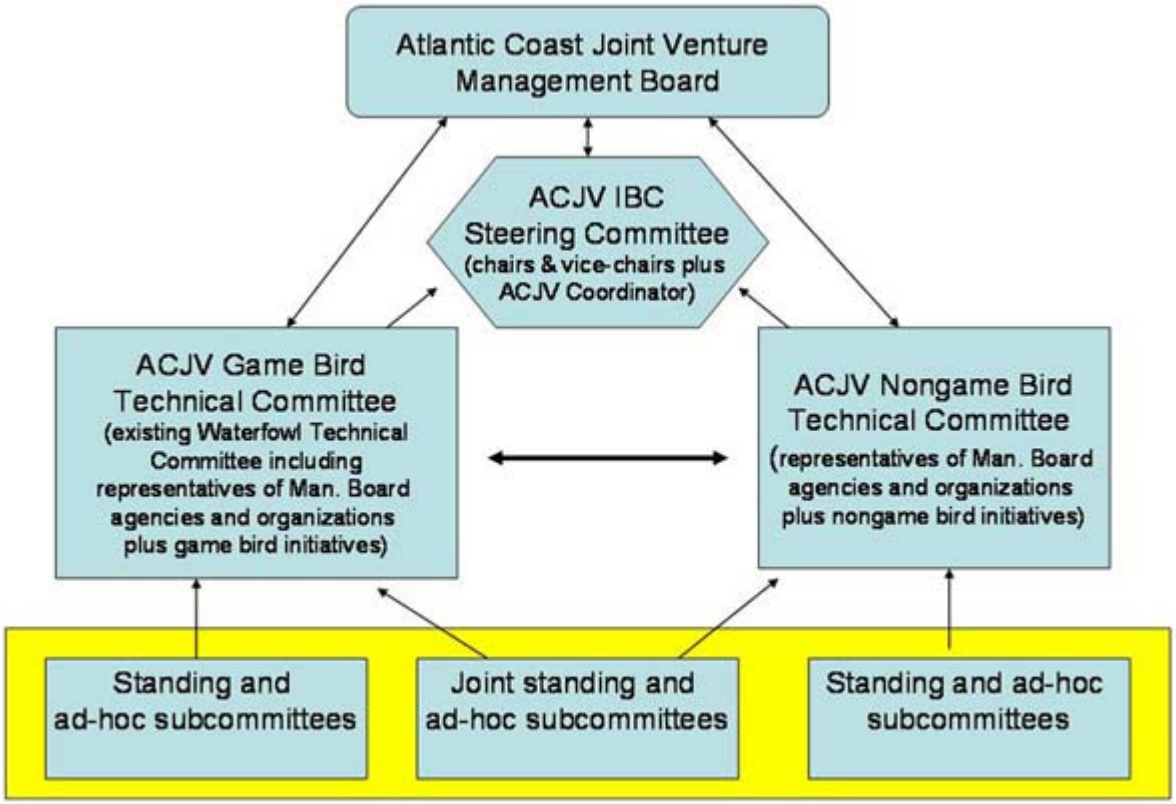
Atlantic Coast Joint Venture

Joint Venture Structure



Board and Committees—Management Board

The ACJV Management Board is comprised of representatives from the organizations that form the joint venture partnership. Their purpose is to provide overall leadership, guidance, resources and support to the joint venture partnership for the planning and delivery of bird habitat conservation in the joint venture area. Each member is responsible for ensuring that their member organization contributes to the overall goals of the ACJV.

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Game Bird Technical Committee

The ACJV Game Bird Technical Committee comprises staff members of joint venture member agencies and organizations appointed by their respective management board members and representatives of migratory game bird initiatives relevant to the ACJV area. ACJV staff serve as ex-officio members of this committee. The purpose of the ACJV Game Bird Technical Committee is to provide input, guidance and assistance on waterfowl and other game bird conservation in the joint venture based on the best available information to the management board and staff. This committee is responsible for the technical aspects of the planning and delivery of the North American Waterfowl Management Plan and other game bird plans in the joint venture area. Although the technical committee is focused primarily on waterfowl and other game bird science and delivery of conservation to benefit game birds, it is also aware of the efforts of the other bird conservation initiatives in order to make better informed decisions in delivering bird habitat conservation actions. The game bird technical committee will coordinate activities with the ACJV Nongame Bird Technical Committee, the Black Duck Joint Venture Technical Committee, and the Atlantic Flyway Migratory Game Bird Technical Section. This committee shall appoint standing and ad hoc subcommittees as needed to accomplish its objectives.

Nongame Bird Technical Committee

The ACJV Nongame Bird Technical Committee comprises staff members of joint venture member agencies and organizations appointed by their respective management board members and other representatives of the major continental, national and regional bird conservation initiatives in the joint venture area as appropriate. ACJV staff serve as ex-officio members of this committee. The Nongame Technical Committee recognizes and builds upon the existing infrastructure and responsibilities of continental and national bird initiatives including Partners in Flight, U.S. Shorebird Conservation Plan and Waterbird Conservation for the Americas. The purpose of the Nongame Bird Technical Committee is to provide guidance on integrating biological planning, conservation design, conservation delivery and evaluation among the major nongame bird conservation initiatives operating within the joint venture area and to compile and provide priority actions for consideration by the ACJV member agencies and organizations. The game bird technical committee will coordinate activities with the ACJV Game Bird Technical Committee and the Atlantic Flyway Migratory Nongame Bird Technical Section. This committee shall appoint standing and ad hoc subcommittees as needed to accomplish its objectives.

Waterfowl Technical Committee

The purpose of the Atlantic Coast Joint Venture Waterfowl Technical Committee (WTC) is to provide input and guidance to the management board and staff on waterfowl conservation in the joint venture based on the best information available. The WTC has the primary responsibility for translating the objectives of the North American Waterfowl Management Plan to the ACJV area and implementing projects to achieve those objectives.

Joint Venture Staff

The ACJV staff are employees of the U.S. Fish and Wildlife Service and coordinate the day to day activities of the joint venture partnership related to the biological foundation, conservation coordination and delivery and communication and outreach. The ACJV Coordinator has overall responsibility for achieving the goals of the joint venture, hiring and supervising joint venture staff, managing the budget, maintaining contacts with the joint venture management board and technical committees, seeking additional funding, and ensuring compliance with U.S. Fish and Wildlife Service policies. The Assistant Joint Venture and/or BCR coordinators are responsible for compiling the results of biological planning, maintaining partnerships, and coordinating the delivery of habitat conservation within specific regions of the joint venture (See map for these regions). The ACJV Science Coordinator has overall responsibility for the biological foundation of the joint venture including biological planning, conservation design, research, evaluation and information management. The ACJV GIS Analyst is responsible for developing and maintaining a GIS database for the ACJV. (This position is filled initially through an intra-agency agreement with USGS). The ACJV Communications/Outreach Coordinator coordinates all aspects of outreach and communications for the joint venture including accomplishment tracking and reporting, Web site development and maintenance, congressional outreach planning and developing specific outreach products for specific audiences, including Congress.

Contact the ACJV staff members.

BCR Steering Committees

Click here to see the

There are eight Bird Conservation Regions (BCRs) partially or wholly within the joint venture boundary. In each of these BCRs, the ACJV is or will be leading, supporting or facilitating integrated bird conservation planning by hosting workshops, writing conservation plans, developing GIS and other conservation tools and facilitating project development. In each of the BCRs where there are active planning efforts underway, a steering committee made up of a representative from each of the states in the BCR and other key partners is guiding this effort. These BCR steering committees

eight BCR regions in the ACJV.	provide guidance on developing and implementing bird conservation plans for the BCR.

State Working Groups

In some states within the ACJV, there are working groups of partners that have come together to plan and implement projects based on priorities in the bird conservation plans at the state level or the portion of a state within a BCR. These working groups can effectively step down regional goals to the state level and prioritize conservation actions within their states. Several states have recently formed bird conservation working groups to help compile information for the bird portion of the state Comprehensive Wildlife Conservation Strategy in their state. The joint venture supports and facilitates the formation of working groups in each state or commonwealth.

Focus Area Working Groups

In some ACJV focus areas or regions, there are working groups of partners that have come together to achieve the goals for that focus area or focus region. Examples include the Great Bay Resource Protection Partnership in New Hampshire, South Carolina Coastal Task Forces, St. Lawrence Valley Working Group in New York, Delaware Bay Partnership (New Jersey, Pennsylvania and Delaware) and Chesapeake Bay Waterfowl Working Group (Maryland, Delaware, Virginia and West Virginia). These partnerships can be particularly effective at pooling funds, resources and match to apply for grants. The Atlantic Coast Joint Venture supports the formation of these local partnerships and may be able to provide seed funds to assist in their development or coordination.

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This page was last updated on 07/26/2010 11:33:26

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Atlantic Coast Joint Venture

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From left to right: Kirsten Luke, Tim Jones, Melanie Steinkamp, Mitch Hartley, Debra Reynolds, Andrew Milliken, Craig Watson

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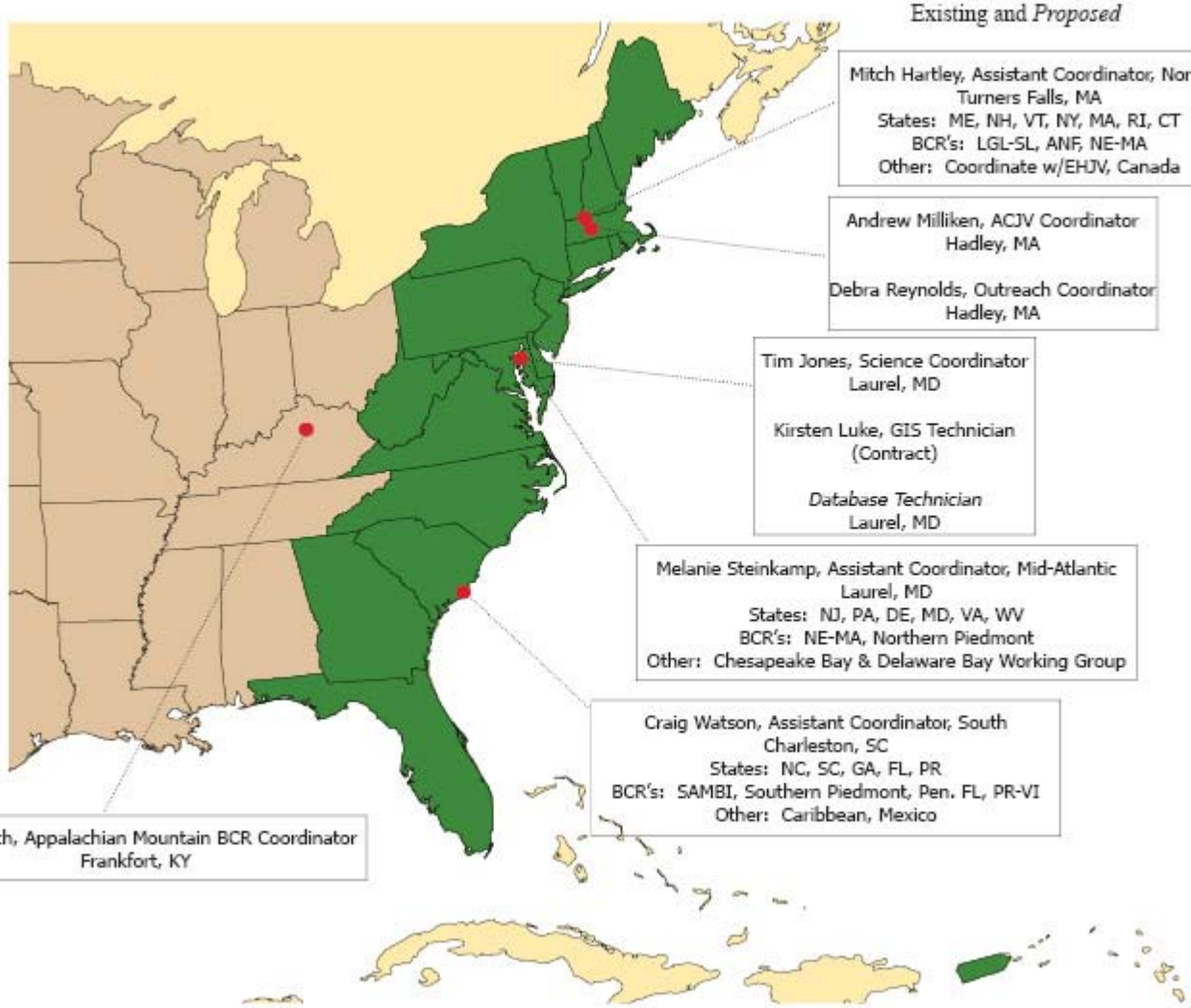
- Massachusetts Relay Service
- Maryland Relay
- Relay South Carolina
- Relay North Carolina

Atlantic Coast Joint Venture Staff

Existing and *Proposed*



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States: ME, NH, VT, NY, MA, RI, CT
BCR's: LGL-SL, ANF, NE-MA
Other: Coordinate w/EHJV, Canada

Andrew Milliken, ACJV Coordinator
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Melanie Steinkamp, Assistant Coordinator, Mid-Atlantic
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Craig Watson, Assistant Coordinator, South
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BCR's: SAMBI, Southern Piedmont, Pen. FL, PR-VI
Other: Caribbean, Mexico

Brian Smith, Appalachian Mountain BCR Coordinator
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This page was last updated on 11/12/2009 11:33:43

Priority Bird Species in Bird Conservation Regions partially or wholly within the Atlantic Coast Joint Venture

	BCR 13 (Lower Great Lakes/St. Lawrence Plain)	**BCR 14** (Atlantic Northern Forest)	**BCR 30** (Mid-Atlantic/Southern New England)	**BCR 27** (Southeastern Coastal Plain)	**BCR 28** (Appalachian Mountains)	**BCR 29** (Piedmont)	**BCR 31 (Peninsular Florida)**
Acadian Flycatcher				M	H	M	
American Avocet			M	H			H
American Bittern	H	M	M	H	M	M	H
American Black Duck	HH	HH	HH	HH	HH	M	
American Coot				HH		M	
American Kestrel (Southeast.)							HH
American Golden Plover	H	H	H	H			H
American Kestrel				H			
American Oystercatcher		M	HH	H			HH
American Redstart		H					
American White Pelican				H			M
American Wigeon			M	H			
American Woodcock	H	HH	HH	HH	HH	H	H
Anhinga							H
Antillean Nighthawk							H
Arctic Tern		H					
Atlantic Brant		M	HH				
Atlantic Puffin		M					
Audubon's Shearwater			H	HH			HH
Bachman's Sparrow			M	H	M	H	H
Bachman's Warbler				HH			HH
Bald Eagle		M	M	M	M		
Baltimore Oriole	M		H			M	
Band-rumped Storm-Petrel				H			
Bank Swallow	M	M					
Barn Owl				M			
Barn Swallow		M					
Barrows Goldeneye	H	HH					
Bay-breasted Warbler	M	HH	H				
Bermuda Petrel				HH			
Bewick's Wren						H	
Bewick's Wren, Appalachian population					HH		
Bicknell's Thrush		HH	H	H	M		H
Black Guillemot		H					
Black Rail			HH	H		M	H
Black Scoter		H	H	HH			
Black Skimmer				H			HH
Black Skimmer			M				
Black Tern	M			H			H
Black Vulture				M			
Black-and-white Warbler			H		M		
Black-backed Woodpecker		M					
Black-bellied Plover	M	H	H	M			M
Black-billed Cuckoo	H	M			H	M	
Black-necked Stilt							M
Blackburnian Warbler		M	M		M		
Black-capped Chickadee, Southern Blue Ridge population					M		
Black-capped Petrel				H			H
Black-crowned Night Heron	M	H	M	H			
Black-legged Kittiwake		M					
Blackpoll Warbler		M		M			
Black-throated Blue Warbler	M	H		M			M
Black-whiskered Vireo							H
Black-throated Green Warbler		M		HH			
Blue-winged Teal	M			H			
Blue-winged Warbler	H	H	HH		HH	M	
Bobolink	M	H		M			M
Bonaparte's Gull	M			M			M
Boreal Chickadee		H					
Boreal Owl		M					
Brant				HH			
Bridled Tern			H	H			
Broad-winged Hawk			H		M		
Brown Booby							H
Brown Creeper		M					
Brown Noddy							M
Brown Pelican				H			H
Brown Thrasher	H		H	H	M	M	
Brown-headed Nuthatch			M	H	H	HH	HH

Buff-breasted Sandpiper	H		H	HH	M	H	HH
Bufflehead			H				
Burrowing Owl				M			H
Canada Goose, resident population				MC			
Canada Goose, Atlantic Population	HH	H	HH	HH	H	H	
Canada Goose, North Atlantic Population			H				
Canada Warbler	M	HH	M		H		
Canvasback	H		H	HH			H
Cape May Warbler		H		M			M
Carolina Wren						M	
Cattle Egret				MC			MC
Cerulean Warbler	HH		M	HH	HH	M	
Chesnut-sided Warbler		H					
Chimney Swift	M	H	H	H	H	H	
Chuck-will's-widow				H	M	H	H
Clapper Rail			H	M			H
Coastal Plain Swamp Sparrow			M	M			
Common Eider		HH	H				
Common Goldeneye	HH	M	M	H			
Common Ground-Dove				HH			H
Common Loon	M	M		H			
Common Merganser	M						
Common Moorhen				H			
Common Nighthawk		H					H
Common Snipe			M				
Common Tern	H	H	M	HH			H
Connecticut Warbler				M			M
Cooper's Hawk				M			
Cory's Shearwater			M	H			
Crested Caracara							HH
Dickcissel						M	
Double-crested Cormorant				MC			M
Dunlin	M		H	H			H
Eastern Kingbird			H	H		M	
Eastern Meadowlark	M			H	M	M	H
Eastern Towhee			H	H	M	M	
Eastern Wood-Pewee		H		H	M	M	
Florida Scrub Jay							HH
Field Sparrow	H		H	H	H	M	M
Forster's Tern			H	M			M
Gadwall			M				
Glossy Ibis			H	H			H
Golden Eagle					H		
Golden-winged Warbler	HH		M		HH		
Grasshopper Sparrow	M		M	H	M	H	
Grasshopper Sparrow (floridanus)							HH
Gray Catbird			M				
Gray Jay		M					
Gray Kingbird							M
Great Black-backed Gull				MC			
Great Cormorant		HH					
Great Crested Flycatcher			H				
Great White Heron							HH
Great Egret				M			M
Greater Flamingo							H
Greater Scaup	H	M	H				
Greater Shearwater		HH	H	H			
Greater Snow Goose	M	MC		HH			
Greater Yellowlegs	M		H	M			M
Green-winged Teal			M				
Gull-billed Tern			HH	H			H
Harlequin Duck		HH	M				
Henslow's Sparrow	HH		M	HH	HH	M	HH
Herring Gull		H		MC			
Hooded Merganser			M			H	
Hooded Warbler				M	H		
Horned Grebe		M	H	H		M	H
Horned Lark		M					
Hudsonian Godwit	M	M	H				
Indigo Bunting				M	M	M	
Ipswich Savannah Sparrow		HH	M				

Ivory-billed Woodpecker				HH			HH
Kentucky Warbler			H	H	HH	H	
Killdeer		M	M				
King Rail	H		M	H	M	H	H
Kirtland's Warbler				HH			HH
Lark Sparrow					M		
Laughing Gull				MC			
Le Conte's Sparrow				H		M	H
Leach's Storm-Petrel		M					
Least Bittern	M		M	H		M	H
Least Sandpiper	M	M	M	H		M	H
Least Tern			H				H
Lesser Scaup	HH		H	HH			H
Lesser Yellowlegs			M	H		M	H
Limpkin				HH			HH
Little Blue Heron			M	H		M	H
Little Gull	H						
Loggerhead Shrike	M		M	HH	M	H	HH
Long-billed Curlew				HH			HH
Long-eared Owl		H					
Long-tailed Duck	HH	M	H				
Louisiana Waterthrush			H	M	H		
Mallard	M	MC	H	HH	M	M	
Magnificent Frigatebird							HH
Mangrove Cuckoo							H
Manx Shearwater			M	H			
Marbled Godwit	M		H	H			H
Marsh Wren			H	M			M
Masked Booby							H
Mississippi Kite				M			
Mottled Duck				M			HH
Nelson's Sharp-tailed Sparrow		HH	M	H			H
Northern Bobwhite	M		H	H	M	H	H
Northern Flicker	M	M	H	H	M	M	H
Northern Gannet		H	H	H			H
Northern Goshawk		M					
Northern Goshawk, Appalachian Population					H		
Northern Harrier	M	M		M			H
Northern Parula		M		M			
Northern Pintail	H		M	HH			H
Northern Saw-whet					M		
Olive-sided Flycatcher		H			M		
Orchard Oriole				M		M	
Osprey							M
Ovenbird		M					
Painted Bunting				HH		M	HH
Palm Warbler		M					
Pectoral Sandpiper	M			M			M
Peregrine Falcon		M		M	M		M
Pied-billed Grebe	M			H		M	M
Pine Grosbeak		M					
Pine Warbler				M		M	
Piping Plover	HH	HH	HH	HH		M	HH
Prairie Warbler (Florida)							HH
Prairie Warbler	M		HH	H	HH	HH	
Prothonotary Warbler	M		H	H	M	M	M
Purple Finch		H					
Purple Gallinule				HH			H
Purple Martin					M		
Purple Sandpiper		HH	H				
Purple Swamphen							MC
Razorbill		H	M	H			
Red Crossbill, Appalachian population					H		
Red Knot	M	H	HH	H			H
Red Phalarope		H	M	H			
Red-bellied Woodpecker				M			
Red-breasted Merganser			M				
Red-cockaded Woodpecker			M	HH	M	H	HH
Reddish Egret				M			HH
Redhead	M			HH			H
Red-headed Woodpecker	M		M	H	M	M	H
Red-necked Grebe		H					

Red-necked Phalarope		HH	M				
Red-shouldered Hawk				M			
Red-throated Loon		M	HH	H			H
Roseate Spoonbill							H
Roseate Tern			HH	H			HH
Rose-breasted Grosbeak	M	M					
Royal Tern			M	M			M
Ruddy Duck			M				
Ruddy Turnstone		H	HH	H			H
Ruffed Grouse		M			M	M	
Rusty Blackbird	M	H	H	H		H	H
Sacred Ibis							MC
Saltmarsh Sharp-tailed Sparrow			HH	HH			HH
Sanderling	M	M	HH	H			H
Sandhill Crane (FL subspecies)							M
Sandhill Crane				HH	M		M
Sandwich Tern			H	H			H
Seaside Sparrow (Atl. Coast races)							HH
Seaside Sparrow (Gulf Coast races)							H
Scarlet Tanager	M				M	M	
Seaside Sparrow (Cape Sable)							HH
Seaside Sparrow			HH	H			
Sedge Wren			M	M	M	M	M
Semipalmated Plover		M	M	M			M
Semipalmated Sandpiper	M	HH	H	H			H
Sharp-shinned Hawk						M	
Short-billed Dowitcher	H	H	H	H			H
Short-eared Owl	M	M		H	M	M	
Smooth-billed Ani							HH
Short-tailed Hawk							HH
Snail Kite							HH
Snowy Egret			M			M	M
Snowy Plover				HH			HH
Solitary Sandpiper	H		H	H	M		H
Sooty Shearwater							H
Sooty Tern							M
Song Sparrow	M			HH			
Sora			M			M	
Spotted Sandpiper			M	M			M
Stilt Sandpiper				H			H
Summer Tanager				M			
Surf Scoter		M	H				
Swainson's Warbler			M	H	H	M	
Swallow-tailed Kite				H			HH
Tricolored Heron			M	H			H
Tundra Swan	H		H	HH			
Upland Sandpiper	M	H	M	H	M	H	H
Veery		H					
Vesper Sparrow		M		H			H
Virginia Rail	M			HH		M	
Western Sandpiper			M	H	M	M	H
Whimbrel	M	H	HH	HH			H
Whip-poor-will		M	H		H	H	
White-breasted Nuthatch							HH
White Ibis				H			H
White-crowned Pigeon							H
White-eyed Vireo				M			
White-rumped Sandpiper			H				
White-tailed Kite							HH
White-tailed Tropicbird				H			
White-throated Sparrow				H		M	
White-winged Scoter	M		H	H			
Whooping Crane				HH	H	M	HH
Willet		M	H	H			
Willow Flycatcher	M		H	HH	M		
Wilson's Phalarope	M		H	H			H
Wilson's Plover			H	H			HH
Wilson's Snipe	M	M		H		M	
Wood Duck	H	M	M	HH		H	M
Wood Stork				HH		M	HH
Wood Thrush	H	HH	HH	H	HH	H	
Worm-eating Warbler	M		H	H	HH	M	
Yellow Rail	M	M		H			H
Yellow-bellied Flycatcher		M			M		

Yellow-bellied Sapsucker		H				M	
Yellow-bellied Sapsucker, Appalachian Population					H		
Yellow-billed Cuckoo				H			
Yellow-breasted Chat					M		
Yellow-crowned Night Heron			M	H			H
Yellow-throated Vireo			H	M	M	M	
Yellow-throated Warbler				M	M	M	

HH = Highest Priority
H = High Priority
M = Moderate Priority
MC = Management Concern (Overabundant species in need of management)

Rules For Species Prioritization

Priority	Criteria/Rule
HIGHEST	High BCR Concern and High BCR Responsibility and (High or Moderate Continental Concern)
HIGH	High Continental Concern and Moderate BCR Responsibility OR Moderate BCR Concern and High BCR Responsibility OR High BCR Concern and Moderate BCR Responsibility OR Non-breeding High Continental Concern species whose primary area of spring or fall migration overlaps the BCR
MODERATE	Moderate BCR Concern and Moderate BCR responsibility OR High Continental Concern and Low BCR Responsibility OR High BCR Concern and Low BCR Responsibility and Regionally Threatened Species (PIF Tier IIC) OR High BCR Responsibility and Low BCR Concern OR Sub-species of Regional Importance

Sources:
BCR 13, 14, 27, 30 based on approved BCR plans (http://www.acjv.org/bird_conservation_regions.htm)
BCR 29 based on ACJV and partner input, list prepared by Chuck Hunter, BCC list, list likely to change with additional input
BCR 28 based on Appalachian Mountains JV, ACJV staff and partner input, BCC list, list likely to change with additional input
BCR 31 based on list prepared by Chuck Hunter, BCC list, FNAI list, FFWCC list, FBCI partner input

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What is eBird?

Simple, yet powerful

eBird is an easy to use, interactive, computerized database that provides a simple way for you to keep track of the birds you see, anywhere, anytime. You can retrieve information on your bird observations—from your backyard to your neighborhood to your favorite bird-watching locations—any time you want. And you can also access the entire database to find out what other eBirders are reporting from across Massachusetts.

Perhaps the most exciting thing about eBird is that your records, combined with those of other observers, become a powerful tool for bird conservation by supplying scientifically useful data on species distribution and movement patterns in Massachusetts and across the continent.

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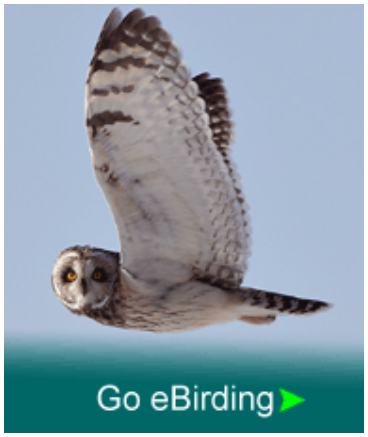

Good News for Massachusetts Birds!

Mass Audubon and the Cornell Lab of Ornithology are collaborating to promote the revision of a powerful new tool for protecting native birdlife with the release of eBird 2.0 at www.ebird.org, an updated version of the powerful Internet-based program currently used by thousands of birders. eBird is a free, user-friendly way for birders across North America to record, archive, and share their observations at any hour of the day. The data come to life via eBird's colorful new interactive maps. It is also an important tool for conservation, providing researchers with a comprehensive picture of the abundance and distribution of birds. Observations entered by birders will support the objectives of Mass Audubon's major bird conservation programs, including its Important Bird Area (IBA) program, biological inventories of our 30,000 acres of wildlife sanctuaries, and other new programs we are developing.

In addition to a completely new look and feel, eBird 2.0 has a streamlined data entry process and a suite of new output tools geared toward the interests of today's birders. On customized "My eBird" pages users can now view their life, state and county lists—all generated automatically as individual reports are entered.

There are two primary ways to search the data: by location and by species. For example, trip-planners can view a list of all the species recorded near their destination. Those interested in learning more about a particular species can view maps and charts showing seasonal distribution and frequency of reports. eBird allows participants to do more than just record sightings; it helps them understand how their observations fit into the big picture.

Mass Audubon and Cornell encourage citizen ornithologists to record species from their backyard, favorite Mass Audubon sanctuary, IBA, or other publicly accessible birding spot in Massachusetts in a user-friendly system. Massachusetts birders have thousands of checklists into eBird and the new improvements will enhance birders' ability to instantly retrieve and analyze not only their own data, but also that of all contributors to a particular list. Please help Mass Audubon and Cornell make Massachusetts's birdlife the most thoroughly documented state avifauna in eBird's national database.

Learn more!

Learn more about eBird, including how you can contribute:

- What is eBird?
- Who uses eBird?
- Why should I use eBird?
- How do I use eBird?
- Start eBirding now!

Short-eared Owl Photo © Jim Fenton

**Requires Adobe Acrobat Reader; click here for more information.*

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Yet Another Unitarian Universalist

Since 2005: progressive spirituality from a postmodern heretic and unashamed intellectual

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Birds of New Bedford harbor

From August, 2005, to September, 2008, including the following locales:
New Bedford's inner harbor from Rte. I-195 south, including water, islands, wetlands, and block or so inland;
Outer harbor as visible from hurricane barrier and Fort Phoenix state park;
Downtown neighborhood bounded by Spring St., County St., and U.S. 6.;
Fort Phoenix State Park in Fairhaven;
Riverside Cemetery in Fairhaven, including wetlands and open land to the harbor and Acushnet River.

Relative abundance, based on my limited observations and estimates:

- ab=abundant, 500-1,000 per day
- vc=very common, 100-499 per day
- com=common, 10-99 per day
- unc=uncommon, 1-9 per day
- rare, 1-10 per season
- no indication given for apparent strays, or if insufficient data

The List

Gaviiformes
Common Loon (unc winter, unc spring)
Podicipediformes
Horned Grebe (unc winter, unc spring)
Pelecaniformes
Double-crested Cormorant (summer, fall)
Ciconiiformes
Snowy Egret (summer)
Anseriformes
Mute Swan (unc winter)
Canada Goose (com fall, com winter)
Brant (com-vc winter, com spring)
Wood Duck (summer)
Mallard (com summer, fall, winter, spring)
American Black Duck (unc winter, unc spring)
Greater Scaup (com fall, com winter)
Common Eider (com winter, com spring)
Long-tailed Duck (com winter, com spring)
Common Goldeneye (com fall, com winter, unc spring)
Barrow's Goldeneye (rare winter)
Bufflehead (com fall, com-vc winter, com spring)
Red-breasted Merganser (com winter, com spring)
Common Merganser (unc fall, unc winter, unc spring)

Falconiformes
Osprey (fall)
Sharp-shinned Hawk (winter)
Cooper's Hawk (winter)
Northern Goshawk (winter)
Peregrine Falcon (winter)
Red-tailed Hawk (fall)
Charadriiformes
Semipalmated Plover (summer)
American Oystercatcher (summer)
Peeps (Calidris spp.) (summer)
Ring-billed Gull (vc-ab summer, fall, winter, spring)
Great Black-backed Gull (com summer, fall, winter, spring) nesting colony
Herring Gull (ab summer, fall, winter, spring) nesting colony
Bonaparte's Gull (com summer, fall)
Common Tern (summer)
Least Tern (summer)
Columbiformes
Rock Pigeon (ab summer, fall, winter, spring)
Apodiformes
Chimney Swift (spring, summer)
Coraciiformes
Belted Kingfisher (summer)
Piciformes
Northern Flicker (summer, unc winter)
Passeriformes
Great Crested Flycatcher (spring)
Tree Swallow (summer)
Eastern Kingbird (spring)
Blue Jay (spring, summer)
American Crow (com summer, fall, winter, spring)
Black-capped Chickadee (spring, summer)
Carolina Wren (spring)
American Robin (com winter, spring, summer, fall)
Gray Catbird (spring, summer)
Northern Mockingbird (spring, summer, fall)
Brown Thrasher (spring)
European Starling (ab summer, fall, winter, spring)
American Goldfinch (winter)
Cedar Waxwing (winter)
Yellow-rumped Warbler (winter)
Rufous-sided Towhee (spring)
Chipping Sparrow (com spring, summer)
Lark Sparrow (winter)
Song Sparrow (com-vc fall, winter, spring)
White-throated Sparrow (winter, spring)
Dark-eyed Junco (summer, fall)
Northern Cardinal (com winter, spring)
Red-winged Blackbird (fall, spring)
Baltimore Oriole (spring)
Common Grackle (spring)

House Finch (winter, spring, summer)
House Sparrow (vc fall, winter)

Note: Unfortunately, May is one of my busiest months at work and so I have missed most of the spring migration the past two years.

Where to bird

New Bedford harbor is primarily a marine industrial landscape, interspersed with dense residential development on the Fairhaven side, and a mixed urban setting on the New Bedford side. There are two urban green spaces on the Fairhaven side: Fort Phoenix State Park, and Riverside Cemetery. The heavy human development means we see lots of Rock Pigeons, House Sparrows, and European Starlings. Major points of interest for birders include the Herring Gull nesting colony on the rooftops of downtown New Bedford, and wintering ducks and waterfowl on the waters of the harbor. New Bedford harbor is probably not worth a trip for those living elsewhere, but it can provide interest if you're here anyway.

Summer: June 21 to September 20 — Summer is dominated by gulls, starlings, pigeons, and House Sparrows. Heavy recreational use by humans tends to keep birds away. Post-breeding dispersal and early fall migrants liven up late summer.

Fall: September 21 to December 20 — Beginning in October, ducks and other water birds beging to move into the area. By December, waterfowl have reached their highest concentrations, and the birding can sometimes be quite good.

Winter: December 21 to March 20 — Waterfowl continue on the harbor through March or April, with gradually decreasing numbers. Occasional raptors over the harbor. Early spring migrants may be seen at Fort Phoenix and Riverside Cemetery.

Spring: March 21 to June 20 — Spring migrants can be seen in Riverside Cemetery and at Fort Phoenix. Herring Gulls breed in late spring and early summer in the diffuse nesting colony on the roofs of downtown New Bedford (some nests visible from the roof of the Elm St. parking garage).

Best places to bird New Bedford harbor, roughly in order of interest:

- Pope's Island off Route 6, including the city park on south and the parking lot on north (best in winter; can see most of inner harbor). Also: Route 6 bridges across the harbor (from here, can see the parts of harbor not visible from Pope's Island; seals in winter)
- Fort Phoenix State Reservation including Fairhaven side of hurricane barrier (best in winter; good views of outer and inner harbor; small areas of wetlands and forests)
- New Bedford side of hurricane barrier including Palmer Island (best in winter; can see much of inner harbor as well as outer harbor; Palmer's Island sometimes shelters migrants)
- Riverside Cemetery, 274 Main St., Fairhaven and Marsh Island (year-round; Marsh Is. had wetlands, view of entire upper harbor)
- S end of Main St. in Fairhaven (this cove cannot be easily seen from other vantage points mentioned)
- End of State Pier in New Bedford (easily accessible from downtown, can see much of the inner harbor, seals and waterfowl close by in winter)
- Roof of Elm St. Parking Garage, downtown New Bedford (in June, watch Herring Gull nests on nearby rooftops)

3 Responses to "Birds of New Bedford harbor"

1. *Mary Anne McQuillan* says:
   January 8, 2007 at 6:19 pm

   Hi,
   Have you looked north from the Coggeshall St brige over the Acushnet River next to Nye Lubricants? There are usually birds along the marsh on the Fairhaven side. Also, there is a small park in Acushnet along the upper part of the "remediated" river north of where the Wood St. bridge crosses from NB to Acushnet.
   Fair Winds,
   Mary Anne

2. *Claire* says:
   March 4, 2007 at 10:35 am

   Not sure if you can comment but I was at Gull Island yesterday and noticed some rather large black birds. I think they may be cormorants but it seems this is not the time of year for them, according to your notes here. I didn't get a close look at them. Any ideas what they might be?

3. *Administrator* says:
   March 5, 2007 at 7:54 pm

   Claire — Along the South Coast, you could see both Great Cormorants and Double-Crested Cormorants during the winter, according to the standard reference "Birds of Massachusetts" by Richard Veit and Wayne R. Petersen (Mass Audubon, 1993). Also, both cormorants have been reported within 25 miles of New Bedford during the last two Christmas Bird Counts. The only thing the list above indicates is that I have not seen either cormorant in the small area I keep track of — that doesn't mean they're not here, it just means that I haven't seen them.

   Remember too that Gull Island is outside the area that I keep tabs on. And I would expect to see both cormorants along the coast during winter within a few miles of New Bedford harbor. Cormorants are pretty distinctive, so if you think you saw one, you probably did.

Leave a Reply

Name (required)

Mail (will not be published) (required)

Website

Comments may be held for moderation at any time. See comments policy. Please be patient.

Submit Comment

- Search for:

Search

- **Past posts**

July 2010

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

« Jun

- **New? Start here!**

Contents (archives, categories)

Index (tags)

Site map

2010 Summer road trip

6/29 UMinn Sacred Harp

7/3 Pioneer Valley All Day Singing

7/4 Preach at First Parish, Concord, Mass.

7/10-16 Ferry Beach RE Week

7/24 Jolly Mem. All Day Singing

•

Blogs | Online Periodicals

More blogs

Hover over link for a brief description.

- ## Academics & professionals

  - Forbidden Gospels
  - Useful Arts

- ## Books and authors

  - A Commonplace Book
  - Barbara Pym Society
  - Children's books
  - Indran Amirthanayagam
  - Read Roger
  - Will Shetterly

- ## Cultural creators

  - City Mama
  - En Mexico
  - Henry Mollicone
  - Renewable Music
  - Sartorialist
  - Writewrite

- ## Cultural detritus

  - Altered Barbie blog
  - Order of the Stick
  - Tallturtle
  - Tea Pages

- ## Cultural entrepreneurs

  - Condomania
  - Freelancer's Union blog
  - Jam by the spoonful
  - Ripe Life Coaching
  - Wordpress Foundation

- **Eco-stuff**
  - Better rail travel
  - BP oil spill coverage
  - Collective Roots
  - Fish Island
  - Transport Politic
- **Emergent | Congregational Change**
  - Brian McLaren
  - Seth's Blog
  - Ten Minutes or Less
- **Open source and alternative applications**
  - Books: Forgotten Books
  - Books: Internet Archive
  - Books: Project Gutenberg
  - Browser: Firefox
  - Calendar: 30 Boxes
  - Online docs: Zoho
  - Search: Clusty
- **Political**
  - Archdruid's Report
  - Faith in Public Life blog
  - Our Bodies, Our Blog
- **Religious education**
  - Phil's Little Blog
  - Religious Education in Palo Alto
- **Religious left**
  - Boy in the bands
  - Quaker Theology
  - Rabbi Michael
  - Rose Garden Yoga
  - Sermons in stones
  - Synablog
  - Wild Hunt

- ## Science & tech
  - Diaspora (Facebook sucks)
  - Inside Silicon Valley
  - Invasive species weblog
  - Nature magazine
- ## Sf
  - eI
  - Fluff the Plush Cthulhu
  - FOGcon
  - Locus
  - Making Light
  - Mundane sf
- ## Trad music
  - Bay Area Sacred Harp
  - Berkeley Sacred Harp Blog
  - BFX10 Early Music Festival
  - Chant Village
  - New England Folk Festival
  - Norumbega Harmony
  - Now shall my inward joys arise
- ## Unitarian Universalism
  - Carrots and ginger
  - Ironic Schmoozer
  - Ministrare
  - My sermons
  - Throw Yourself Like Seed
  - Truth to Power
  - UU blog aggregator
  - Video about UUism
  - What do UU's believe?

- ## On this blog

- ## Meta

  - Log in
  - Entries RSS
  - Comments RSS
  - WordPress.org

- **Articles | Info**

  - UU history timeline
  - All theology is local
  - What is a "post-Christian"?
  - Ecological theology
  - Folkish Songs for Worship
  - Archive of my sermons
  - Table of contents (categories, archives, etc.)
  - Index (tags)
- The Rhizosphere is a magical realm where all manner of amazing things happen.

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Entries (RSS) and Comments (RSS).

APPENDIX 22

Wetland Function-Value Evaluation Form

Total area of wetland 21.73 acres Human made? Yes Is wetland part of a wildlife corridor? No or a "habitat island"? No

Adjacent land use Industrial/Commercial Distance to nearest roadway or other development 400-500ft

Dominant wetland systems present E1UB, E2US, E2EM Contiguous undeveloped buffer zone present Yes

Is the wetland a separate hydraulic system? No If not, where does the wetland lie in the drainage basin? Coastline

How many tributaries contribute to the wetland? N/A Wildlife & vegetation diversity/abundance (see attached list)

Wetland I.D. _____

Latitude 41.622936 Longitude 70.915271

Prepared by: CHM Date _____

Wetland Impact:
Type Cap/Fill/Dredge Area 21.73 acres

Evaluation based on:
Office ✓ Field ✓

Corps manual wetland delineation completed? Y ✓ N _____

Function/Value	Suitability Y	Suitability N	Rationale (Reference #)*	Principal Function(s)/Value(s)	Comments
Groundwater Recharge/Discharge	✓		4, 7, 10, 15	✓	Wetland is a groundwater discharge location.
Floodflow Alteration	✓		6, 7, 8, 10		Wetland serves as flood storage.
Fish and Shellfish Habitat	✓		1, 2, 3, 4, 5, 6	✓	Evidence of shellfish; however, watercourse impaired.
Sediment/Toxicant Retention		✓	1, 2		Entire watercourse impaired.
Nutrient Removal		✓	5		Wetland does not act to remove nutrients.
Production Export		✓	6		Not significant export of production.
Sediment/Shoreline Stabilization	✓		1, 2, 7, 8, 9	✓	Wetland provides shoreline stabilization.
Wildlife Habitat	✓		4, 5, 6, 8, 17, 21	✓	Shellfish and avians present.
Recreation		✓	9, 12		Wetland not a valuable Recreation area.
Educational/Scientific Value		✓	11		Wetland has little scientific/educational value.
Uniqueness/Heritage		✓	1, 12, 13, 14		Wetland relatively unimportant to area/region.
Visual Quality/Aesthetics		✓	1, 2, 5, 12		Wetland is strewn with trash within port area.
ES Endangered Species Habitat	✓		N/A		Roseate Tern and Common Tern
Other					

Notes:

* Refer to backup list of numbered considerations.

APPENDIX 23

Commonwealth of Massachusetts

Division of Fisheries & Wildlife

Wayne F. MacCallum, *Director*

August 3, 2010

Chet H Myers, PE, LSP
Apex Companies, LLC
184 High Street, Suite 502
Boston, MA 02110

RE: South Terminal Extension
NHESP Tracking No. 10-28430

Dear Mr. Myers:

Thank you for contacting the Natural Heritage and Endangered Species Program ("NHESP") of the Massachusetts Division of Fisheries & Wildlife regarding state-listed rare species associated with the above referenced site. Based on the information provided, it appears that a portion of the project site is located within *Priority & Estimated Habitat* (PH 926/EH 755) as indicated in the *Massachusetts Natural Heritage Atlas* (13th Edition). Our database indicates that this area is mapped as foraging habitat for the Roseate Tern and Common Tern, state-listed as "Endangered" and "Special Concern," respectively. As acknowledged in your letter, the Roseate Tern is also Federally listed as "Endangered." These species are protected under the Massachusetts Endangered Species Act (MESA) (M.G.L. c. 131A) and its implementing regulations (321 CMR 10.00). State-listed wildlife are also protected under the state's Wetlands Protection Act (WPA) (M.G.L. c. 131, s. 40) and its implementing regulations (310 CMR 10.00). Fact sheets for most state-listed rare species can be found on our website (www.nhesp.org).

However, I understand that projects falling under the jurisdiction of the Comprehensive Environmental Response Compensation, and Liability Act (CERCLA) [42 u.s.c. sec. 9601 et seq. (1980)] are exempt from state review and permitting requirements although the EPA still applies the substantive standards of certain federal and state laws in its review of projects authorized under CERCLA. The NHESP cannot say with certainty whether this project would, or would not cause harm to foraging state and federally listed terns without seeing detailed project plans, but in your letter you requested preliminary comments from this office.

Based on a preliminary review of the information that has been provided and information that is currently contained in our database, it appears that the proposed dredging and terminal extension would only impact a small acreage of shallow-water feeding habitat for terns. Given the relatively small project footprint within mapped tern habitat, it does not appear that the project will result in any measurable harm to state-listed species, and our office would not require a "take" permit for the activity were the proposal to be in our permitting jurisdiction. However, an effort should be made to avoid the suspension of sediments and any potential sediment plume during dredging operations. Finally, given that this project will result in some unavoidable impacts to aquatic habitat, we encourage the project proponent to consider the implementation of a tern mitigation plan. For example, targeted tern foraging surveys and/or support for habitat management efforts would aid the conservation of state and federally listed terns in the Commonwealth. If you are interested in exploring mitigation options, please feel free to contact Carolyn Mostello, our Tern Project Leader, at (508) 389-6372.

Natural Heritage & Endangered Species Program
North Drive, Route 135, Westborough, MA 01581 **Tel:** (508) 389-6360 **Fax:** (508) 389-7891

This evaluation is based on the most recent information available in the Natural Heritage database, which is constantly being expanded and updated through ongoing research and inventory. If you have any questions regarding this letter please contact Emily Holt, Endangered Species Review Assistant, at (508) 389-6361.

Sincerely,

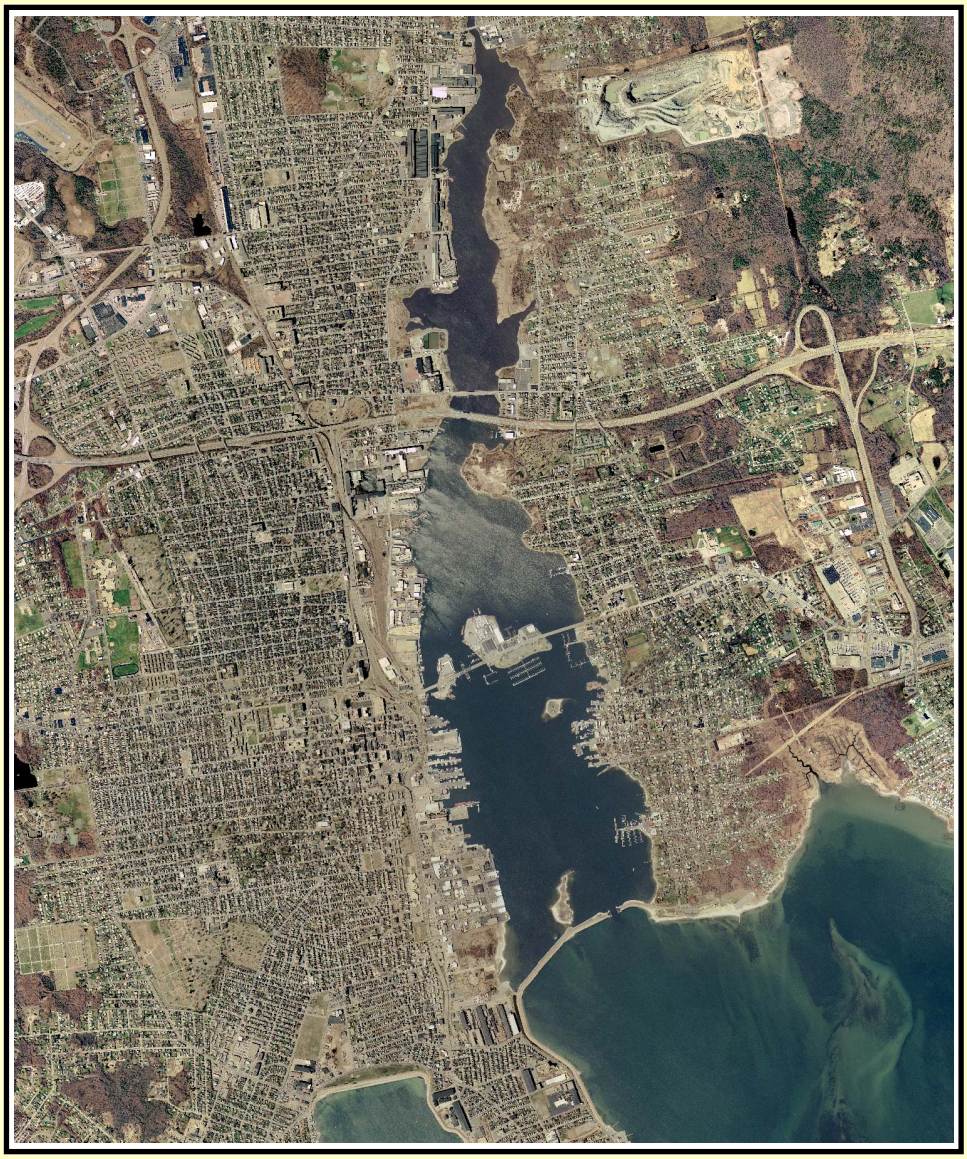
Thomas W. French

Thomas W. French, Ph.D.
Assistant Director

cc: Michael Amaral, USFWS

APPENDIX 24

Draft New Bedford Harbor Environment WETLANDS RESTORATION PLAN



Massachusetts Wetlands Restoration Program

Executive Office of Environmental Affairs

August 2002

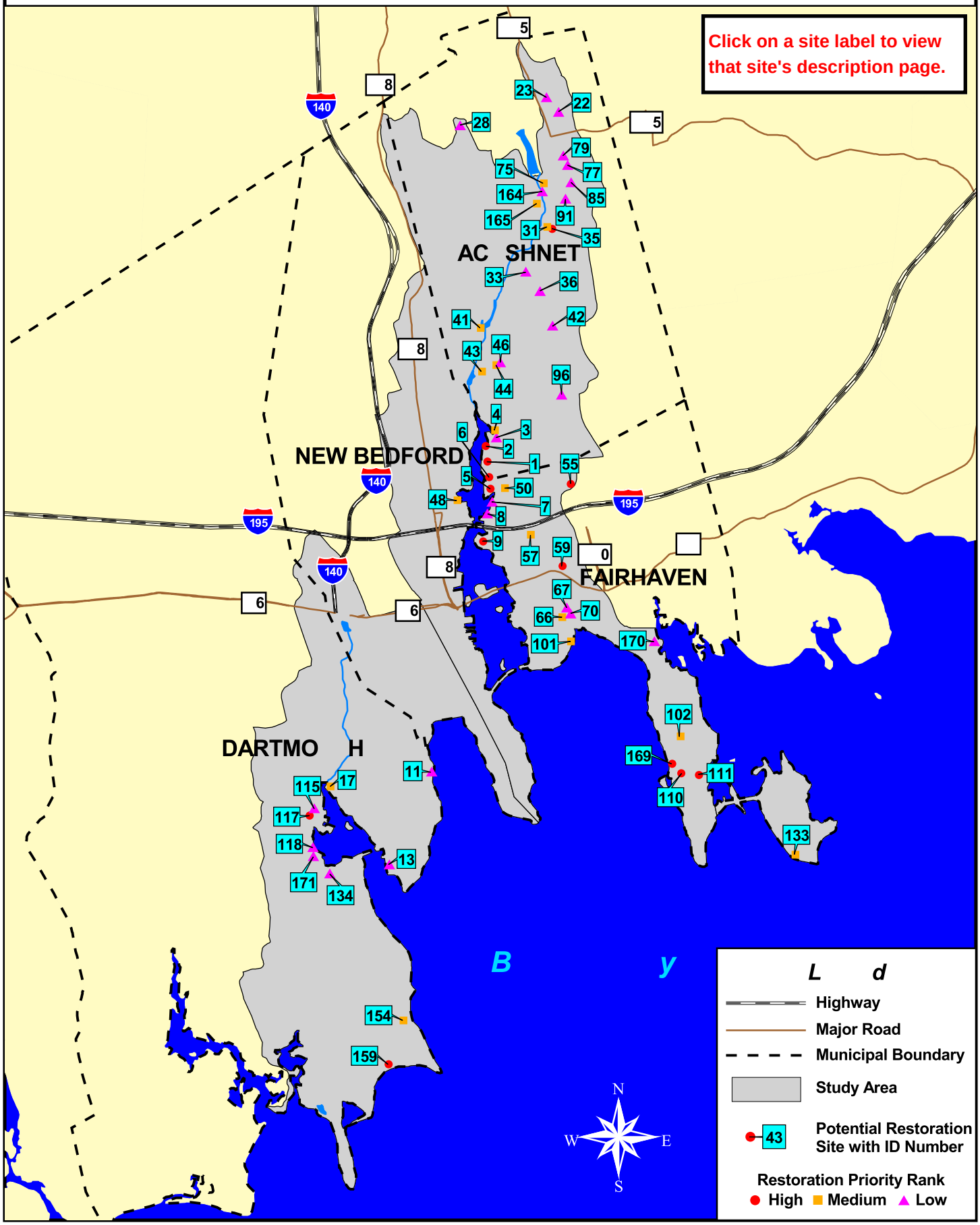
JANE SWIFT
Governor

BOB DURAND
Secretary

SHARON MCGREGOR
Assistant Secretary

CHRISTY FOOTE-SMITH
Director

New Bedford Harbor Environment
Potential Wetland Restoration Sites



Site	Priority Rank:	Town	Ownership:	Acres:	Wetland Type:
9	High	Fairhaven	Mixed	5+	Tidal

Impact Type
- [x] Filled
- [ ] Drained
- [ ] Impounded
- [x] Tidally Restricted
- [ ] Active Agriculture
- [ ] Channelized
- [ ] No Riparian Buffer
- [ ] Unknown

Site Attributes
- [ ] In NHESP Habitat
- [ ] In NHESP Biomap
- [x] In Flood Zone
- [x] In Open Space

This is an extremely degraded site located west of the Riverside Cemetery and directly abutting New Bedford Harbor. Research to date indicates that a majority of the site is privately owned and leased for the operation of two radio towers located on the southern portion. The town of Fairhaven also owns part of the site. GIS analysis and site observation indicate that the majority of this site is historically filled salt marsh. The fill ranges 2-6 feet above marsh grade. A small (0.5 ac.) area of marsh that remains along the northern perimeter appears to be severely tidally restricted and is dominated by Phragmites. Restoration actions may include removal of fill material and re-establishment of wetland grade, soils, hydrology, and vegetation. Restoration of proper tidal flow to the existing northern marsh should also be considered. The New Bedford Harbor Trustees and the Fairhaven / Acushnet Land Trust are exploring the purchase of this site for restoration purposes.

USGS Site Location Map

N

Zoom

3x

2x

1x

Aerial Photo Site Image

Site	Priority Rank:	Town	Ownership:	Acres:	Wetland Type:
48	Medium	New Bedford	Public	2?	Tidal

Impact Type
- [x] Filled
- [ ] Drained
- [ ] Impounded
- [ ] Tidally Restricted
- [ ] Active Agriculture
- [ ] Channelized
- [ ] No Riparian Buffer
- [ ] Unknown

Site Attributes
- [ ] In NHESP Habitat
- [ ] In NHESP Biomap
- [x] In Flood Zone
- [ ] In Open Space

This city-owned site directly abuts New Bedford Harbor and is known as Riverside Park. It appears to be an old industrial site that contains a recently demolished brick building. GIS analysis and site observation indicate that a portion of the site is historically filled salt marsh. The eastern shoreline of the site is fenced off with contamination warning signs. Research indicates that the EPA is planning to dredge and replace existing contaminated wetlands along the shoreline where a narrow fringe of salt marsh remains. Restoration actions may include removal of fill material and re-establishment of wetland grade, soils, hydrology, and vegetation. Salt marsh restoration should be considered during preparation of redevelopment plans. The Trustee Council has allocated $2M to assist the city with upland park improvements and will work with city planners to explore wetland restoration options.

USGS Site Location Map

N

Zoom

3x

2x

1x

Aerial Photo Site Image

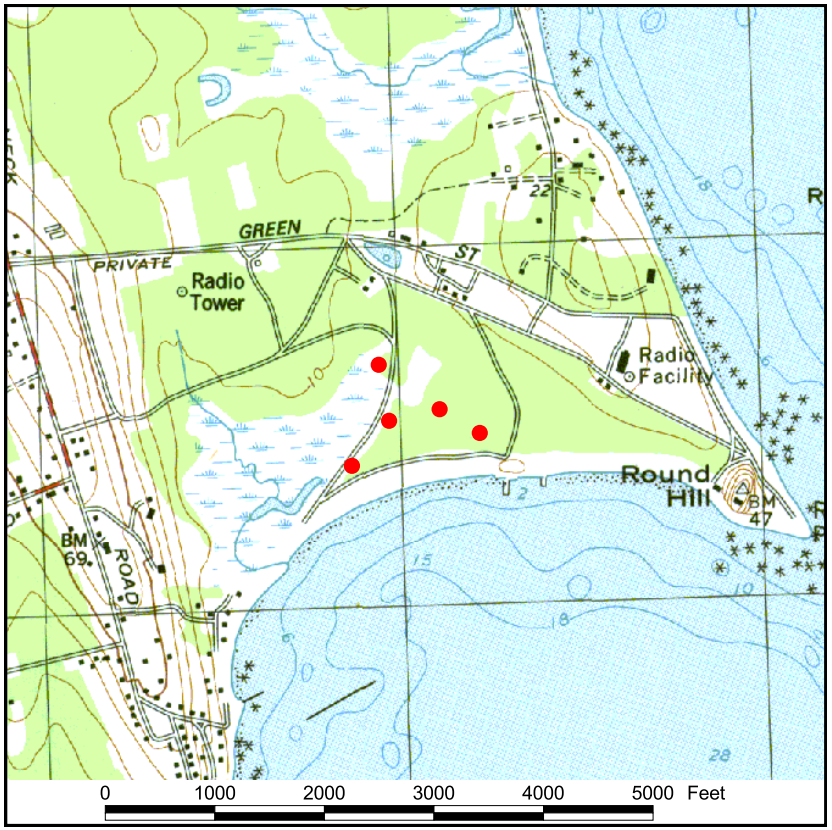
Site	Priority Rank:	Town	Ownership:	Acres:	Wetland Type:
159	High	Dartmouth	Public	10+	Tidal

Impact Type
- [x] Filled
- [ ] Drained
- [ ] Impounded
- [x] Tidally Restricted
- [ ] Active Agriculture
- [ ] Channelized
- [ ] No Riparian Buffer
- [ ] Unknown

Site Attributes
- [ ] In NHESP Habitat
- [ ] In NHESP Biomap
- [x] In Flood Zone
- [x] In Open Space

Site consists of a large, highly disturbed area that is part of the town-owned Round Hill Beach property. GIS analysis and site observation indicate that this area was historically a typical barrier beach-protected salt marsh system. Research to date suggests that back in the 1800s, the entire Round Hill peninsula was privately owned and extensively altered. It appears that the eastern half of the historic barrier beach and salt marsh system was filled in and cut off from tidal flow by construction of Ray Peck Drive (the public access road to the beach). An old wooden beam culvert is located beneath this road just before it intersects the beach parking lot, but it is unclear whether the culvert conveys any tidal flow to upgradient wetlands. Small areas of fragmented and degraded fresh marsh exist east of the road. Another potential salt marsh restoration area exists south of the sharp curve in the road, adjacent to the existing healthy salt marsh system. The majority of fill observed is 1-3 feet above wetland grade. Restoration actions may include removal of fill material and re-establishment of wetland grade, soils, hydrology, and vegetation, as well as placement of an appropriate culvert or bridge under Ray Peck Rd. to provide full tidal flushing to the restored salt marsh to the east. See Site Evaluation for further details.

USGS Site Location Map



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Zoom

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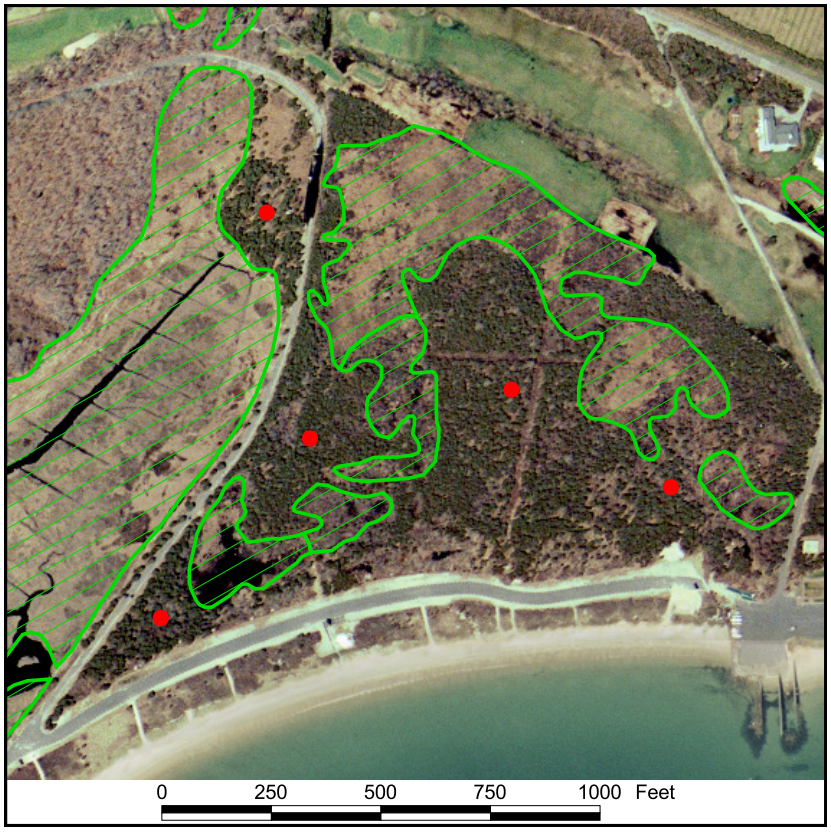
Aerial Photo Site Image



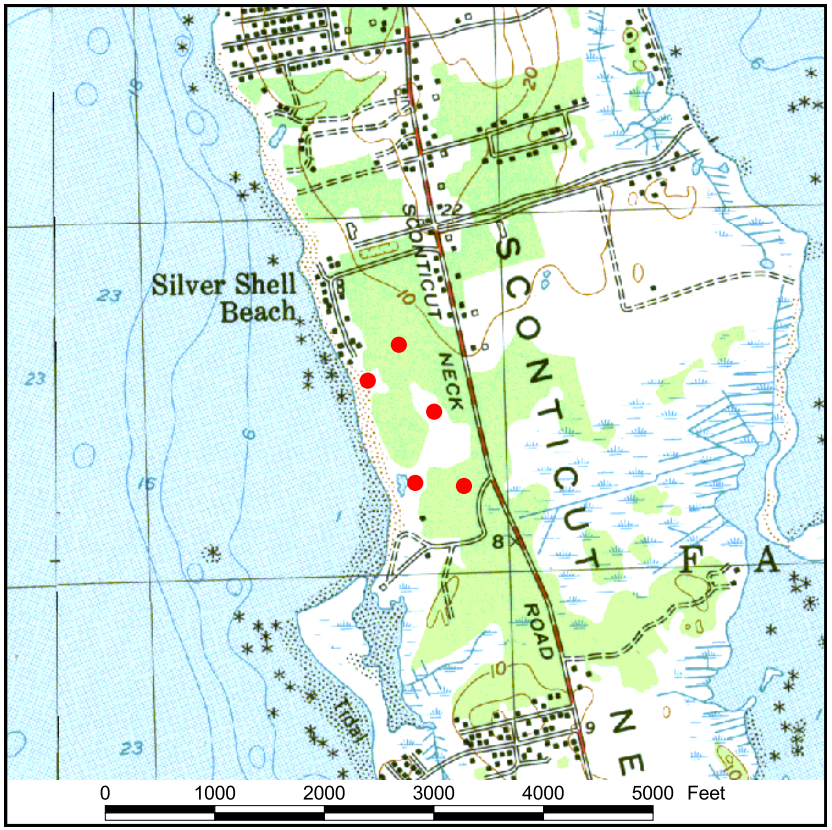
Site 169 **Priority Rank:** High **Town** Fairhaven **Ownership:** Private **Acres:** ~50 **Wetland Type:** Tidal

Impact Type
- [ ] Filled
- [ ] Drained
- [ ] Impounded
- [x] Tidally Restricted
- [ ] Active Agriculture
- [ ] Channelized
- [ ] No Riparian Buffer
- [ ] Unknown

Site Attributes
- [ ] In NHESP Habitat
- [x] In NHESP Biomap
- [x] In Flood Zone
- [ ] In Open Space

Site consists of a tidally influenced wetland system on the western shore of Sconticut Neck. GIS analysis and site observation indicate that this system may be tidally restricted by the natural dynamics of its outlet to the ocean (located just south of the end of Silver Shell Beach Drive). During the site visit, a long-time resident stated that mosquito control officials sometimes maintain the tidal opening, but it is often clogged with sand and gravel, thus restricting tidal flow and impounding freshwater within the wetland. The wetland observed is dominated by Phragmites and had a large standing pool of water upstream of the outlet opening. It appeared that only the highest portion of the tide would flow into the wetland. This site should be further evaluated for restoration options which may include more frequent maintenance of the outlet, application of Open Marsh Water Management, and/or the installation of an outlet structure to ensure full and consistent tidal flushing.

USGS Site Location Map



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Zoom

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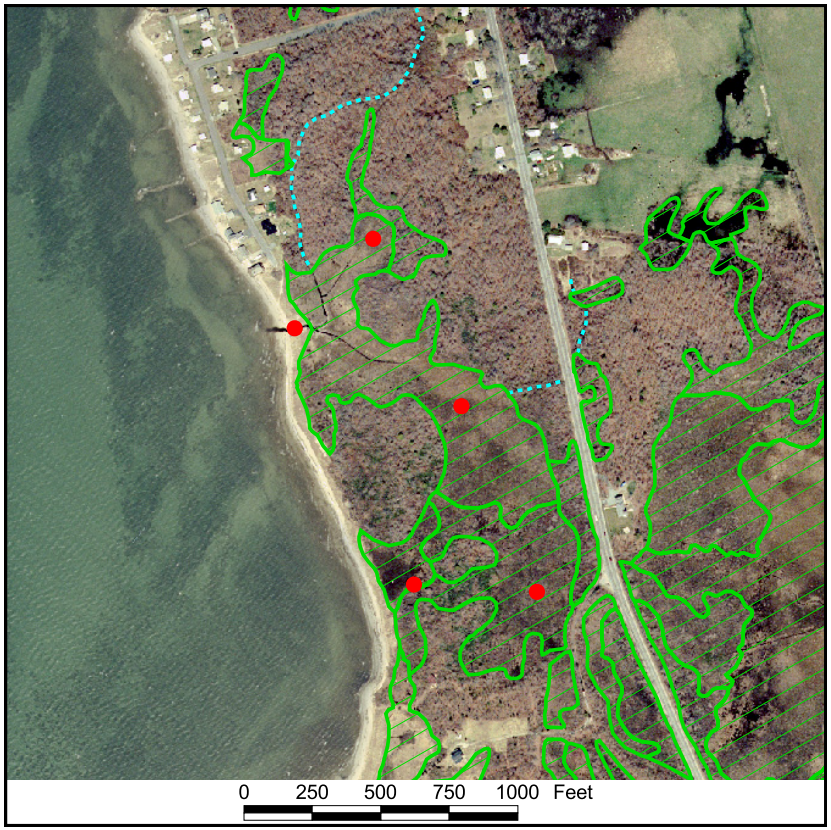
Aerial Photo Site Image



ROUND HILL BEACH / MEADOWS SHORE, DARTMOUTH, MASSACHUSETTS POTENTIAL WETLAND RESTORATION SITE #159

Overview

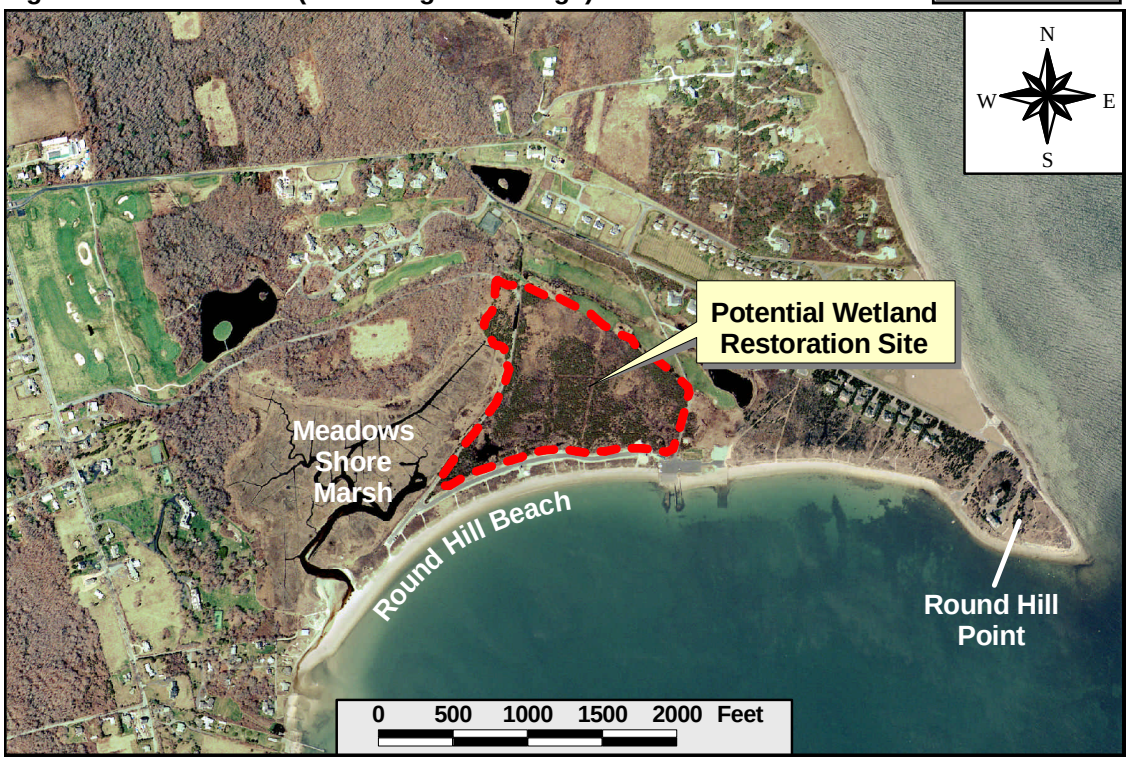
The Round Hill Beach / Meadows Shore potential wetland restoration site consists of a highly disturbed (former) coastal wetland system protected by a barrier beach along the southern shore of the town of Dartmouth, just west of Round Hill Point (Figure 1). The site is situated within a larger town-owned beach and park property and contains up to (or possibly more than) 24 acres of historically filled salt marsh. Historic documents, including an 1893 USGS map, confirm that the areas of forested upland and degraded freshwater wetlands east of Ray Peck Drive and north of Round Hill Beach were once coastal salt marsh associated with the barrier beach and dune system that is still present today. Research to date indicates that this entire wetland area was filled in during the early 1900s to create a private airport and runway system with associated buildings and infrastructure.

Table 1: General Site Information	
Town:	Dartmouth
Location:	North of Round Hill Beach, south of Round Hill Condominiums, and east of the Meadows Shore salt marsh
Ownership:	Town of Dartmouth
Contacts:	**Property:** Dartmouth Park Department **Restoration Activities:** Dartmouth Park Department and Conservation Commission **Local Environmental Groups:** Dartmouth Natural Resources Trust, Lloyd Center for Environmental Studies **Site History:** Round Hill Associates, Bristol County Mosquito Control

This site presents a superb - and quite rare – opportunity to restore a large area of contiguous, historically filled salt marsh and barrier beach coastal ecosystem that is publicly owned and remains vacant of permanent structures. Through the removal of fill material, re-creation of salt marsh plain, and excavation of historic tidal channels, this project could significantly enlarge this valuable tidal system and greatly enhance the many natural functions and values that it provides within the greater New Bedford Harbor environment. These functions and values include flood protection, pollutant attenuation, and coastal ecosystem fish and wildlife habitat. A restoration project at this site would also provide valuable stewardship and educational opportunities due to its highly visible public location.

Figure 1: Site Location (click image to enlarge)

Previous View



Site Description

The landscape surrounding this site is occupied by the Round Hill Condominiums and Round Hill Golf Course to the north and east, Round Hill Beach to the south, and Ray Peck Drive and Meadows Shore marsh to the west (Figure 1). Just west of the site, the existing Meadows Shore marsh appears to have been left largely untouched by historic human alterations (except for a filled area in the northeast corner) and is dominated by native salt marsh vegetation. The potential wetland restoration site includes all areas of historically filled salt marsh. It presently contains a mix of secondary successional upland vegetation surrounding areas of degraded seasonal freshwater wetlands. Sections below provide more information on the site's soils, hydrology, and vegetation.

Vegetation: The site's wooded upland areas consist of mid-successional species such as Eastern Red Cedar (*Juniperus virginiana)* that are quite uniform across the upland areas of the site. The freshwater wetlands located within the site are dominated by Purple Loosestrife (*Lythrum salicaria*, an invasive species), which is an indicator of degraded wetland conditions (Photograph 1).

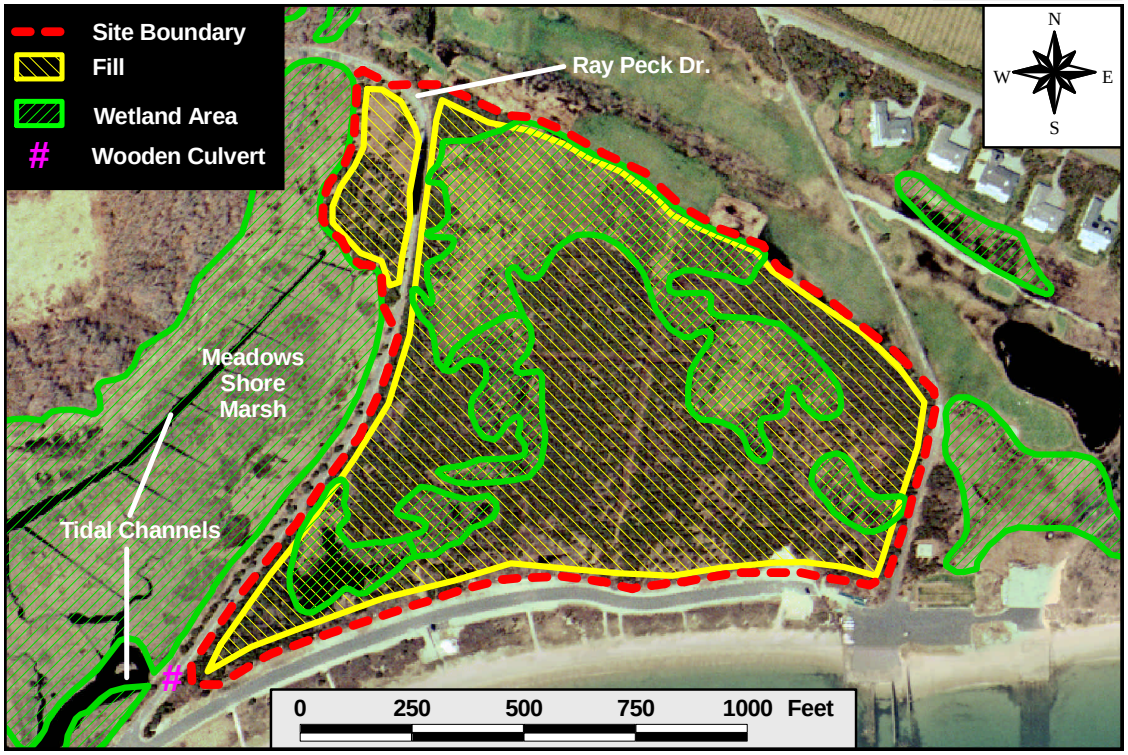
Photograph 1: View of degraded wetland area within site (foreground) - upland area shown in background

Soils: Soil samples (20 cm deep) taken from within the wetlands of this site revealed minimal development of organics with less than 1 cm of humus underlain by a sandy, mineral soil. Soil mottling indicated hydric conditions. Soils in the surrounding upland areas were extremely sandy and well drained.

Hydrology: The main tidal channel within the marsh west of the site terminates at an old wooden culvert (4 ft. by 8 ft.) beneath Ray Peck Drive. The culvert does not appear to convey tidal flow to the site (Figure 2, Photograph 2). Salinities within the tidal channel at Meadows Shore marsh were between 24 and 22 ppt. There was no standing water present in the wetland areas east of Ray Peck Drive during July 2002.

Figure 2: Site Details (click image to enlarge)

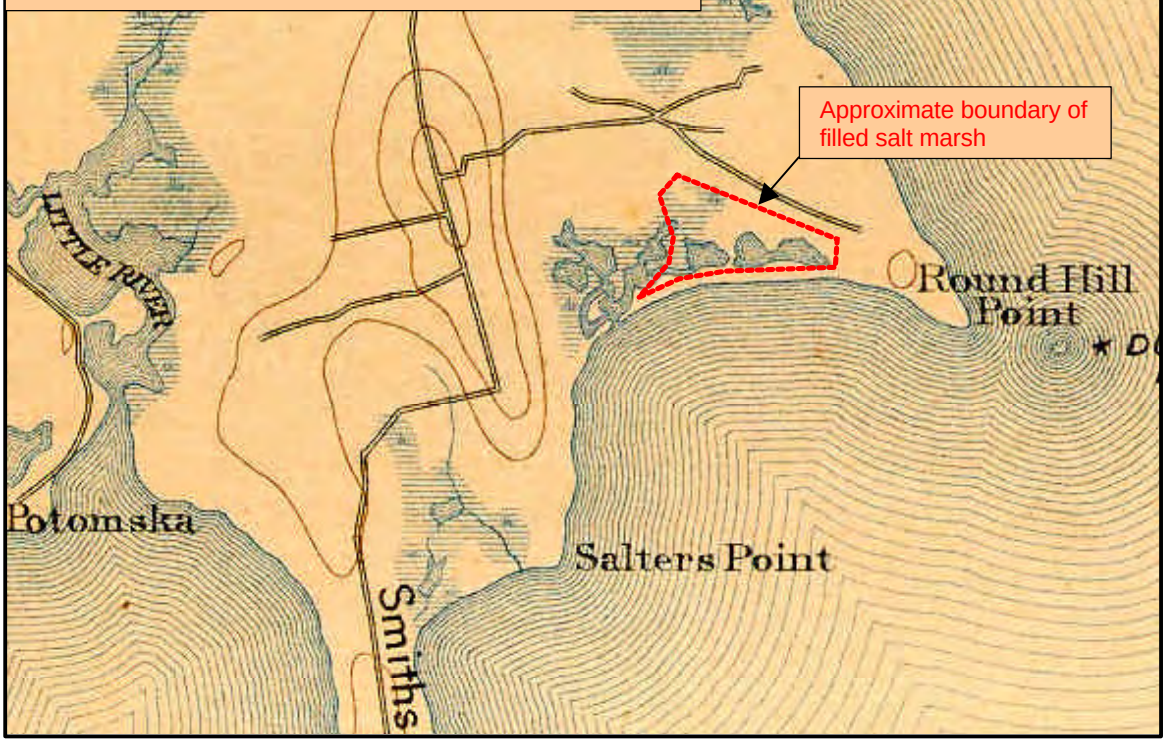
Previous View



Sources of Degradation

Past human activity has significantly altered this historic coastal wetland site. Historic maps, including an 1893 USGS Topographic map (Figure 3) and a tracing of an 1856 Town of Dartmouth map, confirm that this site was coastal wetland prior to at least the late 1800's. A 1928 aerial photograph of this site, provided by the Lloyd Center for Environmental Studies (Dartmouth, MA), depicts this site "shortly after filling of the northern third of the marsh and dredging of the inlet". Under private ownership, farm facilities, dwellings, airplane and blimp hangers, an aviation school, runways, M.I.T research facilities, and a series of pumping stations and catch basins were constructed on this filled site between 1928 and 1937. Information obtained from the Bristol County Mosquito Control indicates mosquito control activities, including ditching, took place on this site as far back as 1959. Today, only remnants such as concrete foundations, catch basin structures, and the non-functioning wooden culvert beneath Ray Peck Drive remain, with approximately 4 to 8 ft. of fill material throughout the site.

Figure 3: 1893 USGS Map of Round Hill Beach Area



Photograph 2: View of wooden culvert at end of tidal creek in Meadows Shore marsh

Photograph 3: Remnant structure on upland fill.

Restoration Recommendations

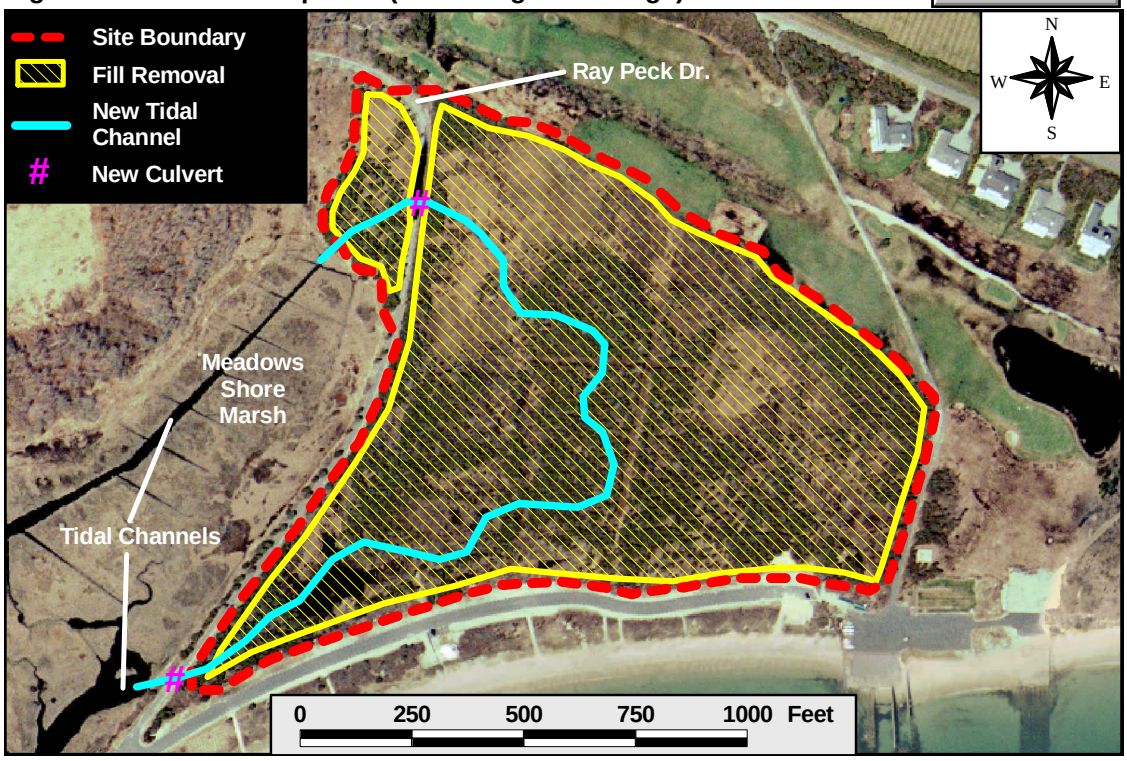
The main focus of this project will be the removal of significant amounts of fill material to restore coastal salt marsh. The access road (Ray Peck Drive) which separates the existing Meadows Shore marsh from this site must remain intact as it provides public access to the Round Hill Beach area. Therefore, a tidal connection at either the non-functioning wooden culvert or other location will need to be constructed to provide tidal flushing to restored wetland areas east of the road (Figure 4). Under current conditions, restoration of tidal flow alone would not restore salt marsh habitat because the elevation of fill and degraded wetlands east of Ray Peck Drive is much higher than the Meadows Shore marsh. Removal of fill material and re-grading to proper marsh elevations will be required. Possible restoration actions may include:

- Removal of all fill from historic wetlands east of Ray Peck Drive as well as the smaller filled wetland in the northeast corner of Meadows Shore marsh; and re-grading to proper salt marsh elevation
- Re-location and piling of a portion of the fill within the site to create a habitat island (an option that would reduce the costs of off-site hauling and disposal)
- Replacement of the old wooden culvert beneath Ray Peck Drive to restore full tidal flushing to newly restored salt marsh
- Installation of a second culvert further north beneath Ray Peck Drive to improve flushing of newly restored salt marsh and northern reaches of the Meadows Shore salt marsh
- Excavation of tidal channels to aid in tidal flushing and create coastal open-water habitat associated with the newly restored salt marsh
- Re-planting of newly created marsh plain to aid in marsh establishment

The image below depicts the location and extent of features discussed in the various restoration alternatives. MWRP would be happy to discuss these alternatives in greater detail with those who are interested in this potential restoration site.

Figure 4: Restoration Options (click image to enlarge)

Previous View



Anticipated Permits / Regulatory Issues

A number of permits and regulatory reviews are anticipated for this project (Table 3). Additional permits and review may be required depending on the source of funding and final scope of work. This site is not under a Wetlands Restriction Order, Conservation Restriction Order, and is not located within an Area of Critical Environmental Concern. Therefore, this project would not require the associated additional regulatory review.

Table 3: Description Of Anticipated Permits and Regulatory Review

REGULATION:	POTENTIAL THRESHOLD:	ACTION:	PERMIT:
Wetlands Protection Act, MGL c.131, s.40 and 310 CMR 10.00 & local by-laws	Any project that will dredge, fill, alter, or remove any wetland resource area	File a Notice of Intent (NOI) with Cons. Commission and DEP	Order of Conditions
Federal Clean Water Act, Section 404	All projects involving discharge of fill or dredged materials to the Waters of the US, including wetlands	File for a federal permit from the US Army Corps of Engineers	Programmatic General Permit for Massachusetts
Massachusetts 401 Water Quality Certification Program, MGL c. 21, ss 26-53, and 314 CMR 9.00	Discharge of dredged or fill material, dredging and dredged material disposal activities in waters of the US within the Commonwealth which require federal licenses or permits.	File for 401 Water Quality Certification with the MA DEP	MA DEP 401 Water Quality Certificate
Massachusetts Environmental Policy Act, MGL Ch. 30, ss. 61-61H and 310 CMR 11.00	Alteration of 5,000 sq. ft. or more of bordering or isolated vegetated wetlands	File an Environmental Notification Form (ENF), an EIR may be required for wetland conversion	Massachusetts Environmental Policy Act Certificate
Chapter 91, Waterfront Protection Act, MGL c. 91	The placement of fill or structures (such as culverts), or the alteration of existing licensed structures in flowed or filled tidelands	File for a license to place a structure, in this case a culvert, in the tidal channel	DEP Waterways Program Chapter 91 Liscense
Coastal Zone Consistency Review	Any coastal project that requires a federal license, is implemented by a federal agency, or gets federal funding	File an application with the Massachusetts Coastal Zone Management Office	CZM Consistency Statement

Cost Estimates

Project costs will vary depending on the restoration options chosen. Removal of one-half of the fill, wetland plantings, installation of one culvert, and creation of a tidal channel is estimated to cost approximately **$3,063,000**. Removal of all fill areas, wetland plantings, installation of two culverts, and creation of a tidal channel is estimated to cost approximately **$6,086,000**. Note that these estimates assume that hazardous materials will not be encountered. *Costs estimated using RS Means, *Site Work & Landscape Cost Data*, 2002.

Planning & Permitting:
Topographic Survey w/ major features and vegetation zones @ $2,675.00* / acre x 24 acres = $64,200.00
Permitting, including permit applications and permit plans is estimated @ $40,000.00
Total: $104,200.00

Construction:
Excavation @ $4.44*/cu yd, Hauling @ $9.90*/cu. yd., and Dewatering @ $9.65 /cu. yd. = $23.99 / cu. yd.

24 ac. fill @ 232,318 cu. yds = $5,573,308.82
Plantings + labor @ $0.75/pot (18in. grid) x 24 ac. = 459,976 plants = $344,982.00

Excavation of Tidal Channel @ 2000 cu. yds. = $47,980.00
Pre-cast 4 ft. by 8 ft. Concrete Culvert @ $200.00 / linear ft. x 40 ft. x 2 culverts = $16,000.00

Other Information

- An historic map depicting 1937 engineering plans for Edward H. R. Green's estate is available through the M. I. T. archives
- Additional historic information may be available through Bristol County Mosquito Control and the Round Hill Associates
- This site is near listed Priority / Estimated Habitat for the Piping Plover (*Charadrius melodus*), a threatened species listed by the MA Natural Heritage and Endangered Species Program; it is also listed as a threatened species under the Federal Endangered Species Act.

APPENDIX 25

New Bedford Harbor
Navigational Dredge – Phase III, Part A

State Enhanced Remedy – Performance Standards

I MADEP 401 Water Quality Program Standards:

1. Anti-degradation provisions of the Massachusetts Surface Water Quality Standards protect all waters, including wetlands. The Contractor shall take all steps necessary to assure that the proposed activities will be conducted in a manner, which will avoid violations of said standards.

2. Prior to the start of in-water work, the SER Project Manager (SER PM) shall be notified of any proposed change(s) in plans that may affect waters or wetlands.

3. As proposed, silt-curtains and absorbent booms shall be deployed to enclose the area being dredged. The contractor's plan for deployment of the silt curtains/absorbent booms shall be submitted to the SER PM for review prior to the start of in-water work. Should the deployment of silt-curtains prove not feasible or be unsuccessful, the SER PM will be notified prior to any dredging without silt curtains.

4. Water Quality Monitoring:

    a. **When the dredging operation is contained within a silt-curtained area,** the following water-quality monitoring program shall be carried out daily for the first three days of dredging and once a week thereafter:
        i. A reference location shall be established outside of and approximately 200-feet from the silt-curtained area and a monitoring location shall be established outside of and within 15-feet of the silt-curtain.
        ii. Turbidity shall be measured, using an optical backscatter sensor, at both the reference and monitoring locations, at established depths: near the water's surface, at the mid-point of the water column and near the bottom. The three values obtained shall be averaged, such that a single, representative turbidity value is calculated for the monitoring site and a single, representative value is calculated for the reference site.
        iii. Turbidity shall be measured at both the monitoring and reference site prior to the start of dredging, and once every two hours during dredging.
        iv. An exceedance of the project turbidity standard shall be attributed to project activities when the average turbidity at the monitoring site exceeds the average reference site turbidity plus the permissible turbidity increase, as outlined in the following table:

Reference Site Turbidity (NTUs)	Permissible Turbidity Increase
<10	Reference plus 20 NTUs
11-20	Reference plus 15 NTUs
>21	Reference plus 30% of reference

v. If, in two consecutive monitoring events, the average turbidity at the monitoring site exceeds the average turbidity at the reference site by more than the permissible turbidity increase, then water samples, composited over the entire water column, from both the monitoring and reference sites shall be collected and submitted for analysis of Total Suspended Solids, dissolved PCBs, arsenic, cadmium, copper, chromium, lead, mercury, nickel, and zinc. When samples are submitted to the laboratory, a 36-hour turn-round time shall be requested. Additionally, the Proponent, or their contractor, shall take operational action(s) designed to limit such exceedences, such as increasing the dredge cycle time, inspection and any necessary repair, of the silt curtains, deployment of an additional row of silt curtains or other mitigation measures. Turbidity monitoring shall continue on the schedule outlined in Section 6.a.iii, until compliance is reestablished.

vi. If compliance can not be reestablished within 48 hours, dredging shall cease and Department and any other interested local, state, or federal agency staff, in consultation with the Proponent, their contractors and/or consultants shall review the operational actions undertaken, the results of the analyses of the water samples and evaluate the biological significance of the available data and determine the requirements for additional mitigation, if any.

b. **Should the deployment of silt-curtains prove not possible or be unsuccessful,** the following water-quality monitoring program shall be carried out daily for the first three days of dredging and twice a week thereafter:

i. A reference location shall be established approximately 200-feet up-current from the dredge and a monitoring location shall be established 200-feet down-current from the dredge.

ii. Turbidity shall be measured, using an optical backscatter sensor, at both the reference location and the monitoring location, at established depths: near the water's surface, at the mid-point of the water column and near the bottom. The three depth values obtained shall be averaged, such that a single, representative turbidity value is calculated for the reference location and a single, representative turbidity value is calculated for the monitoring location.

iii. Turbidity shall be measured at both the reference location and at the edge of the mixing zone prior to the start of dredging, and once every two hours of dredging.

iv. An exceedance of the project turbidity standard shall be attributed to project activities when the average turbidity at the edge of the mixing zone exceeds the reference site turbidity plus the permissible turbidity increase, as outlined in the following table:

Reference Site Turbidity (NTUs)	Permissible Turbidity Increase
<10	Reference plus 20 NTUs
11-20	Reference plus 15 NTUs
21-30	Reference plus 10 NTUs
>31	Reference plus 30% of reference

v. If, in two consecutive monitoring events, the average turbidity at the edge of the mixing zone exceeds the average turbidity at the reference site plus the permissible turbidity increase, then water samples, composited over the entire water column, from both the reference location and the edge of the mixing zone shall be collected and submitted for analysis of Total Suspended Solids, dissolved PCBs, arsenic, cadmium, copper, chromium, lead, mercury, nickel, and zinc. When samples are submitted to the laboratory, a 36-hour turn-round time shall be requested. Additionally, the Proponent, or their contractor, shall take operational action(s) designed to limit such exceedences, such as increasing the dredge cycle time, inspection and any necessary repair, of the silt curtains, deployment of an additional row of silt curtains or other mitigation measures. Turbidity monitoring shall continue on the schedule outlined in Section 6.b.iii, until compliance is reestablished.

vi. If compliance cannot be reestablished within 48 hours, dredging shall cease and the Department and any other interested local, state or federal agency staff, in consultation with the Proponent, their contracts and/or consultants shall review the operational actions undertaken, the results of the analyses of the water samples and evaluate the biological significance of the available data and determine the requirements for additional mitigation, if any.

5. As proposed, dredging of contaminated, silty sediment shall be done using a closed, environmental, clamshell bucket. Where pilings or other debris are found to interfere with environmental bucket closure or equipment operation, a conventional clamshell bucket may be used to extract the pilings/debris. Sediment removal during such activity shall be minimized to the greatest extent practicable. Should dredging with the environmental bucket become unfeasible or unsuccessful, the SER PM must be notified prior to any contaminated sediment dredging not using the environmental bucket, and the contractor must also continue to meet the project water quality standard performance standards.

6. Water discharged from the barge shall be appreciably free of suspended sediment and meet the water quality criteria established in Section 4 (above). Any free liquid

flowing from the barge in the harbor shall be passed through a sand media filter or equivalent filtration system (which must be approved by the project Resident Engineer) prior to discharge.

7. Diesel-powered equipment shall be fitted with after-engine emissions controls such as oxidation catalysts or particulate filters.

8. Within 30 days of the completion of the initial dredging, a bathymetric, survey of the dredge footprint, depicting post-dredge conditions, shall be sent to the MADEP SER Project Manager.

9. Disposal of any volume of dredged material at any location in tidal waters is subject to approval by the Department and the Massachusetts Coastal Zone Management office.

II <u>MADEP Chapter 91 Waterways Standards:</u>

1. Acceptance of these Waterways Conditions shall constitute an agreement by the Proponent to conform to all terms and conditions herein.

2. All subsequent maintenance dredging and transportation and disposal of this dredge material, during the term of this Project shall conform to all standards and conditions applied to the original dredging operation performed under this Project.

3. After completion of the work authorized, the Proponent shall furnish to the Department a suitable plan showing the depths at mean low water over the area dredged. Dredging under this Project shall be conducted so as to cause no unnecessary obstruction of the free passage of vessels, and care shall be taken to cause no shoaling. If, however, any shoaling is caused, the Proponent shall at his/her expense, remove the shoal areas. The Proponent shall pay all costs of supervision, and if at any time the Department deems necessary a survey or surveys of the area dredged, the Proponent shall pay all costs associated with such work.

4. The Proponent shall assume and pay all claims and demands arising in any manner from the work authorized herein, and shall save harmless and indemnify the Commonwealth of Massachusetts, its officers, employees, and agents from all claims, audits, damages, costs, and expenses incurred by reason thereof.

5. The Proponent shall, at least three days prior to the commencement of any dredging in tide water, give written notice to the Department of the time, location, and amount of the proposed work.

<u>Special Waterways Conditions</u>

1. Dredge material shall be transported to suitable disposal facilities; unregulated dumping of dredge materials is not permitted.

2. The Proponent shall develop and implement a Navigation Plan to address and mitigate temporary impacts to navigation during dredging activities.

3. The Proponent shall provide and maintain in good working order appropriate United States Coast Guard (USCG) approved navigation aids to assist mariners in avoiding work areas as required by the USCG.

4. The Proponent shall maintain vehicular access to water-dependent users throughout construction activities.

5. The Proponent shall remove and properly dispose of all temporary structures no later than three (3) months after completion of the dewatering and amendment of the sediments. Temporary structures are defined as berms and dikes; lime silo; dewatering tanks, erosion and sediment control systems, pipes, and siltation curtains.

6. Modification to this Project: the SER PM, may review on an individual basis, modifications to construction activities and/or temporary structures which represent and insignificant deviation from original specifications, in terms of configuration, materials or other relevant design or fabrication parameters as determined by DEP within all areas of construction. Such review shall be in accordance with the following procedure:
    a. The Proponent shall submit a written request describing the proposed modifications to the work accompanied by plans, for prior review of the DEP. The DEP will consider comments submitted within ten (10) days of the DEP's receipt of the request. The DEP will send any significant modifications to the Resource Agencies for review and comment and to identify any future Performance Standards, if necessary. EPA will also have the opportunity to make a consistency determination if the change is significant, as necessary. The DEP will notify the Resource Agencies of any minor modifications.

7. After completion of the work authorized the Proponent shall furnish the Department a suitable plan showing the depths at mean low water over the areas dredged within 90 days of completion if each phase of the dredging.

APPENDIX 26

David Westcott, AICP

Chief Planner

TECHNICAL EXPERTISE

- Environmental Impacts
- Wetland Scientist
- Permitting Specialist
- Dredging and Port Studies
- Marine Impact Evaluations

PROJECT ASSIGNMENT
Impacts on Essential Fish Habitat

YEARS OF EXPERIENCE
Maguire: Since 1978
Total: Since 1976

EDUCATION
BS/1976/Resource Development
MCP/1979/Community Plan Development

PROFESSIONAL REGISTRATIONS
American Institute
Certified Planner AICP 4614
NATIONAL, 1983
Health & Safety for Hazardous Waste
NEW ENGLAND, 1991

PROFESSIONAL ASSOCIATIONS
American Planning Association,
RI Assoc. of Wetland Scientists

PUBLICATIONS
"A Plan for the Newport Waterfront" University of Rhode Island Marine Bulletin 35 URI Marine Advisory Service, 1979.

PROFESSIONAL PROFILE

Mr. Westcott combines the skills of a professional planner with those of a biologist and natural resource specialist. He is experienced in the delineation and mapping of wetlands, and evaluating impacts of public and private infrastructure projects on wetlands, freshwater and marine resources and at developing mitigation plans for minimizing such impacts.

REPRESENTATIVE PROJECTS: Marine Environmental Impact Evaluations

Rhode Island Region Long-Term Dredged Material Disposal Site Evaluation and Environmental Impact Statement: Assisted the U.S. Army Corps of Engineers to identify and designate an offshore site for marine disposal of dredged material from Rhode Island and southeastern Massachusetts.

Dredged Material Management Plan for Massachusetts Designated Port Areas: Project Manager for this project to identify potential disposal sites for dredged sediments unsuitable for unconfined open water disposal from designated port areas in Gloucester, Salem, Fall River and New Bedford

Buzzards Bay Disposal Site Final Environmental Impact Report: Supervised staff conducting environmental studies in support of the designation of an historic disposal site to accept disposal of uncontaminated sediments from dredging projects on the south shore of Massachusetts.

New Bedford/Fairhaven Harbor Final Environmental Impact Report (FEIR): Supervised preparation of the Final EIR and the final screening analysis to determine the preferred alternative site for confined aquatic disposal (CAD) for contaminated dredged material.

Supplemental Draft EIS on Siting of Treatment Facilities for Boston Harbor, MA: EIS evaluating alternative sites for treatment and Disposal facilities which led to decision to site facilities on Deer Island in Boston.

Central Artery / Third Harbor Tunnel Contract C09A Dredging: Environmental lead for major components of the interchange between I-90 and I-93 in and around the Fort Point Channel area of Boston. Evaluated impacts of various design alternatives on Fort Point Channel including physical, chemical and hydrologic impacts of required dredge and fill for highway construction. Obtained all required permits for dredging, filling, and interchange construction.

Water Transportation Facilities, Boston Harbor, MA: Evaluation of alternatives to provide ferry access for materials, equipment and supplies needed for construction of facilities on Deer and Nut Islands as part of the Boston Harbor Cleanup. Evaluated alternative sites for marine terminals throughout Boston Harbor in a comprehensive study. This study led to selection of Quincy Shipyard as the principal marine terminal for equipment and supplies. Recommendations were also used to develop a network of terminals for transport of up to 1,200 workers per day to the islands by ferry.

Oak Bluffs Harbor, Oak Bluffs, MA: Planning, evaluation of environmental impacts and permitting for replacement of the harbor bulkhead in Oak Bluffs Harbor. This was a new steel sheet pile bulkhead with a concrete pedestrian walkway, which replaced an existing deteriorated wooden bulkhead. The bulkhead provides the principal berthing space for pleasure craft using the harbor during the summer.

Oak Bluffs Ferry Terminal Expansion, Martha's Vineyard, MA; Evaluated environmental impacts or proposed new ferry terminal including a reoriented ferry berth, new transfer bridge, berthing dolphins and fender systems, a high-speed pedestrian ferry berth, new vehicle staging area, ADA-accessible walkway for passenger loading/unloading, and terminal building improvements. Prepared all permit applications in support of terminal expansion.

Edgartown Harbor, Edgartown, MA: Planning, evaluation of impacts, and permitting support for the replacement of a section of harbor bulkhead in Edgartown, MA. This project replaced a deteriorating bulkhead and associated structures, which supported the only boat fueling facilities in Edgartown and the principal landing location for the local conch fishery.

Woods Hole, Falmouth, MA: Evaluated the chemical, physical and biological impacts of discharge of treated and untreated wastewater to Woods Hole in Falmouth, MA.

Cape Cod Canal, Sandwich, MA: Evaluated tidal flushing of Cape Cod Canal and impacts of discharge of treated wastewater via an outfall diffuser into the canal.

Jones River Estuary, Kingston, MA: Developed tidal model of estuary, modeled tidal flow and evaluated physical, chemical and biological impacts of land application of wastewater on adjacent uplands, salt marsh and the estuary.

Plymouth Harbor, Plymouth, MA: Conducted studies of tidal mixing in the harbor, including metering and dye and drogue studies; and evaluated physical, chemical, and biological impacts of an existing discharge and proposed discharges of treated wastewater at four locations within the harbor.

Harbor Dredging Plan, Providence, RI: Conducted investigations of the characteristics of sediment and evaluations of the impacts of dredging Providence Inner Harbor to a uniform depth of -15' Mean High Water. This work was conducted in support of permit applications and plans for reconstruction of riverwalks and development of a new boat basin in the inner harbor.

River Relocation Project, Providence, RI: Planning and permitting for the relocation of the tidally influenced Woonasquatucket, Moshassuck and Providence Rivers in the

heart of the City of Providence. This project included evaluation of the impacts of dredging, reconstruction of river walls and the construction of new riverwalks. Prepared all permit applications for river relocation and proposed new construction.

U.S. Coast Guard, Permitting for Vessel Haul-out Facility, Honolulu, HI: Project Planner responsible for permitting of pile supported reinforced concrete piers, relieving platform, and shoreside improvements utilized for the mooring of Coast Guard rescue vessels and for the removal of the same via a marine haul-out.

U.S. Coast Guard, Permitting for Wharf Reconstruction, Woods Hole, MA – Project Planner responsible for permitting for reconstruction of USCG wharf in Woods Hole, including replacement of pile supported wharf sections with permanent bulkhead and fill.

Enighed Pond Marine Terminal, St. John, USVI conducted special studies on the marine environment within Enighed Pond and Turner Bay including material transport models, wetland loss mitigation plans, coral loss mitigation plans, alternative site analysis, dredged material disposal plans, and conceptual design plans to support an application before the U.S. Army Corps of Engineers for construction of new port facilities in St. John.

South Quay Port Facility, East Providence, Rhode Island: Evaluated environmental impacts of dredge and fill activities associated with development of a 25 acre container port and general cargo port facility and prepared all applications for zoning approval and permit applications.

Merrimack River, Masschusetts: Biological Assessment of the impacts of renewal of NPDES discharge permits throughout the Merrimack River basin on populations of short-nosed sturgeon (*Acipenser brevirostrum*) in the river basin.

Jennifer Ann James

Wetland Biologist/Environmental Scientist

TECHNICAL EXPERTISE

- Wetlands, regulatory and environmental issues
- Wetland delineation and evaluation
- Benthic surveys
- Natural resource habitat assessment
- Permitting
- Environmental management/ land management plans
- Flora and fauna surveys

PROJECT ASSIGNMENT
Environmental Scientist

YEARS OF EXPERIENCE
Maguire: Since 2005
Total: Since 2001

EDUCATION
BS/2001/Wildlife Biology/ University of Rhode Island
MS/2010/Wetland Biology/ University of Rhode Island (in progress)

PROFESSIONAL TRAINING
OSHA 40-Hour HazWhopper
Wildlife Certification
Hunter Safety Course

PROFESSIONAL REGISTRATIONS
RI Soil Evaluator D-4081
Wildlife Society Member
Society of Wetland Scientists
New England
Invasive Plant Group

PROFESSIONAL PROFILE

Ms. James is a wetland biologist and an environmental scientist skilled at managing individual and team projects related to wetlands, regulatory and environmental issues. Her experience includes wetland delineation and evaluation, natural resource habitat assessment, benthic surveys and analysis and permitting for major infrastructure design projects. Initial projects have involved field-related activities from soil and groundwater sampling to environmental management planning. Recently she has conducted a number of regulatory-required assessments including wetland delineation, permitting, environmental assessments, terrestrial and benthic habitat analysis and environmental management plans for state / federal agencies.

REPRESENTATIVE PROJECTS

Environmental Assessment Report and wetland delineation, Anguilla Landfill, St. Croix USVI: As part of the closure of the Anguilla Landfill a Coastal Zone Management permit was submitted this included an environmental assessment report (EAR). As part of the EAR a terrestrial resource review, wetland resource delineation and analysis, benthic survey and impact analysis for the project were preformed. Additional services include the overall impact of the project on the island and the coastal resources, water quality management and extensive mitigation efforts on the neighboring salt ponds, mangrove wetlands and Caribbean Sea.

Environmental Assessment Report and Natural Resource Survey, Diageo Distillery, St. Croix USVI: As part of the construction of a new distillery for Captain Morgan Rum a Major Tier 1 Coastal Zone Management permit was submitted this included an environmental assessment report (EAR). As part of the EAR are a terrestrial resource review, wetland resource delineation and analysis, benthic survey, endangered species review and impact analysis were performed. Due to the location of this project an extensive archaeological review was necessary and coordination with the Virgin Island State Preservation Officer was required.

Environmental Assessment Report and Natural Resource Survey, Bovoni Landfill, St. Thomas USVI: As part of the closure of the Bovoni Landfill a terrestrial resource study including endangered species mitigation (terrestrial and marine), CZM Permits and over five acres of wetland mitigation was conducted in accordance with EPA and Army Corps of Engineers. Additional permits included stormwater pollution prevention plans and air permits for the operation of the gas flare.

Permitting, Oak Bluffs Ferry Terminal/Pier, Martha's Vineyard, MA: Drafted permits for new construction of the Steamship Authority pier in Oak Bluffs that was being extended over the ocean and thus had potential impacts on endangered species. The permitting required a Notice of Intent, Essential Fish Habitat Assessments, Stormwater Management Policy, and Chapter 91 License.

Feasibility Study, MA Maritime Academy, Buzzard's Bay, MA: Prepared initial permit review and initial review of essential fish habitat which would be affected by maintenance dredging and instillation of new docks at the MMA. Additional review of what impacts these structures would have on other endangered species and eel grass. In addition to permit and endangered species review, the academy wanted more information about different types of aquaculture practices which could be used as part of this project.

Phase I Site Investigation and Wetland Permit Consulting, Cross Mills Fire Department, Charlestown, RI: This Phase I Environmental Assessment determined the potential for any hazardous materials or oil release and outlined potential problems building a new fire station within 50 feet of freshwater wetlands and under CRMC regulations.

Wetland Delineation and Permitting for Nickerson State Park, Brewster, MA: Delineated freshwater wetlands throughout a 1,900-acre State Park. Prepared Eastern Box Turtle work plan for Natural Heritage for the *Protection of the Endangered Eastern Box Turtle*. Prepared a Notice of Intent (NOI) for the local Conservation Commission and for MADEP, and attended public meetings. Coordinated and permitted a sewer replacement and electrical line replacement project for the Park with Massachusetts Historical, MADEP, the local Conservation Commission, and the Natural Heritage and Endangered Species Program.

Wetland Delineation and NOI Submittal, North Adams, MA: Delineated Freshwater vegetated wetlands for municipal road reconstruction. All permits were submitted and prepared for MADEP and the local conservation commission. **Wetland Delineation, Pearl Street Sewer Connection, Gardner, MA:** Delineated bordering freshwater wetlands for a section of road approximately five miles long.

Permitting and Wetland Delineation, WBDC Sewer Construction, Shrewsbury, MA: Delineated freshwater wetlands and prepared a NOI for the WBDC to construct a cross-county sewer line which connected to an undeveloped parcel. Prepared all documents and attended public meetings for the Conservation Commission.

Permitting and Wetlands Delineation, Gorton Pond, Warwick, RI: Delineated freshwater vegetated wetlands containing state endangered species. Prepared a preliminary determination on behalf of Warwick for the Rhode Island Department of Environmental Management (RIDEM).

Wetland Delineation for Road Construction, Hubbardston, MA: Delineated bordering vegetated wetlands for approximately one-and-a-half miles of road for a municipal road reconstruction project.

Permitting Terminal License, St. Croix Renaissance Group (SCRG), St. Croix, U.S. Virgin Islands (USVI): Prepared a terminal license application for EPA for a large-scale oil storage and oil transfer facility in the USVI. Follow-up documentation for a U.S. Coast Guard submittal was also prepared.

Public Perception, RI WINDS, RI: Reviewed public documents concerning the use of

wind power for New England. Authored document defining public perception of large public works projects in Southern Massachusetts and all of Rhode Island. Documents created for the Energy Council of Rhode Island and the Governor of Rhode Island.

Wetland Delineation and NOI Submittal, Robins Road, Westborough, MA: Delineated freshwater vegetated wetlands and an ACOE (area of critical environmental concern) for municipal road reconstruction. All permits were submitted and prepared for MADEP and the local Conservation Commission.

Permitting/Wetland Delineation, Private Owner, Lincoln RI: Delineated freshwater vegetated wetlands and prepared permit deliverables for a private owner to expand on current building. Deliverables were prepared for RIDEM.

Permitting/Wetland Delineation, CVS Corporation, Smithfield, RI: Delineated freshwater vegetated wetlands and prepared permitting associated with parking lot expansion for RIDEM.

Coastal Resources Management Council (CRMC) Assent Application, Conanicut Yacht Club, Jamestown, RI: Created supporting documentation for the repairs to an existing seawall in accordance with CRMC regulations and concerns. Also permitted additional docks and building repair work to be done within the coastal zone.

Environmental Assessment, Togus, ME: Field surveying done to asses the ecological communities and the potential effects of development on a local National Guard Base. Completed inventory of flora and fauna.

Permitting and Delineation, Dexter Road, East Providence, RI: Delineated coastal vegetated wetlands and also inland vegetated wetlands. Also delineated areas of critical concern. Prepared permitting for RIDEM.

Wetland Delineation and Permitting, Parker Pond, Gardner, MA: Delineated wetland boundaries for the replacement of sewer lines running under land under water. Also drafted permits for borings and pipe-bursting activities.

Environmental Management Plan, Stone's Ranch Military Base, East Lyme CT: Created an environmental improvement and habitat management plan for the Connecticut U.S. Army National Guard. Plan was to be implemented and utilized by the entire base for any future development and maintenance of natural communities on the base. Created plan for over 1,800 acres of land. Incorporated plans for invasive species management, land-use trends, wildlife and fisheries habitat improvement, timber harvest, and rare species management.

ADDITIONAL EXPERIENCE

Small Mammal Surveying: Surveyed different state-owned management areas for the purpose of cataloging species and abundance present in different areas of Rhode Island.

Freshwater Fish Population Surveying: Surveyed different freshwater lakes, ponds and streams throughout Rhode Island for the purpose of cataloging species and abundance in difference areas of Rhode Island for the Department of Environmental Management.

Osprey Population Study: Responsible for all Osprey-related data collected for the State of Rhode Island. Required field work to conduct visual observations of nesting sites and dynamics of the species. Published annual newsletter stating the yearly finds and other general Osprey information.

Apex Companies, LLC

Ron Jarman, Ph.D

Senior Environmental Manager

Education

Ph.D Environmental Engineering
University of Oklahoma
1984

MS. Environmental Science
1976

BS. Biology
Oklahoma State University
1965

Organizations

Air and Waste Management Association (Chapter Board of Directors)

National Association of Environmental Professionals

Environmental Federation of Oklahoma (Board of Directors)

Society of Petroleum Engineers (Board of Directors-Local Section)

Training and Certifications

OSHA 40-Hour Health and Safety Training

OSHA 10-Hour Construction Safety Training

First Aid and CPR

Years of experience
48 Years

Dr. Jarman has more than 48 years of experience in the environmental field. He has provided professional consulting services on environmental matters to industrial, commercial and governmental clients throughout the United States. He has worked extensively in matters involving fish population and natural resource damages, environmental regulatory interpretation, Corps of Engineering permits, wetlands mitigation, risk evaluation, threatened and endangered species, negotiation support, the acquisition of environmental permits, closure of hazardous waste sites, and site characterization.

Dr. Jarman has vast experience at designing field studies to quantify injury for the purpose of compiling information on site-specific chemical, physical, and biological conditions. He is adept at evaluating the basis and technical merit of natural resource injury claims and developing wetland mitigation programs. He has provided expert witness testimony for cases involving regulatory compliance, impact evaluations and site cleanups. Examples of his experience include the following specific projects

Experience
Fisheries Assessments and Population Analysis

- Negotiation Support, Habitat Analysis and Mitigation Planning Resulting from Development of a Large Recreational Lake. Included Cost Assessment of Multiple Mitigation Options. CABO Development Incorporated.
- Fish Kill Assessment, Habitat Analysis and Mitigation Planning of Fourmile Creek, Fish Kill Impacts. Proactive Program to Avoid Natural Resource Damage Claims. Magellan Midstream Partners, LLC.
- Fishery Impact, Habitat Assessment, Expert Witness and Technical Support for Defendant Relating to Fish Kill Involving Endangered Species on Canadian River, Confidential Client.
- Fish Population, Habitat Analysis and Impacts Assessment from Heavy Metals Contribution, Lead Smelter Facility, Confidential Client.
- Fish Population, Habitat Assessment and Impacts Development for Review of CERCLA-induced Endangerment Assessment for NPL Site, ARCO Coal Co.
- Recreational Usage and Fish Habitat Impact Studies for Floreffe Diesel Fuel Spill on Ohio River, Kirkpatrick & Lockhart (representing Ashland Diesel Fuel Co.).
- Ecological Risk Assessment to Evaluate Chronic Impacts to the Ohio and Monongahela Rivers from the Release of Diesel Fuel, Kirkpatrick & Lockhart (representing Ashland Diesel Fuel Co.).
- Fish Kill Assessment, Habitat Evaluation, Threatened and Endangered Species Impacts and Valuation, Natural Resource Damage Assessment, Pipeline Failure and Ammonia Release, Magellan Pipeline Partners, LLC.

- Development of Aquatic Ecoregions in the Midcontinent, including Watershed Groupings, Stream Composition and Stream Habitat Assessment, Water Resources Board.
- Development of Stream Assessment Technology in Support of the Development of Water Quality Standards, Water Resources Board.
- Fish Kill Assessment, Habitat Analysis and Mitigation Planning of Crystal Creek, Fish Kill Impacts. Proactive Program to Avoid Natural Resource Damage Claims. Magellan Midstream Partners, LLC.
- Fish Population, Habitat Assessment, Stream Characterization on Six Streams. Confidential Client, Confidential Locations.

Natural Resource Damage Assessment

- Wetlands Mitigation and Site Restoration Program Development, Planning, and Negotiation Support for the Responsible Party in Response to Natural Resources Trustees Demands for Compensation from Damage Related to Ammonia Release. Magellan Pipeline Partners.
- Natural Resource Damage Support for Responsible Parties to Negotiate Solution with Natural Resources Trustees to Long Term Smelter Impacts on Receiving Streams, Confidential Clients.
- Wetlands Mitigation Program as a Result of the Development of a World Class Shooting Range. Provided Negotiation support, Cost Analysis, Program Development and Implementation under Corps of Engineers Supervision. United Stated Shooting Sports Association.
- Evaluation, Negotiation Support, Program Development, Implementation Oversight and Monitoring of a Mitigation Program for Loss of Aquatic Resources from Commercial Construction, Trammell Crow Development Corporation.
- Natural Resource Damage Assessment, Verdigris River Oil Spill, Farmland Industries, Inc.
- Fish Kill Assessment and Valuation, Natural Resource Damage Assessment, Pipeline Damage and Unleaded Gasoline Release, Midwest, Confidential Client, Confidential Location.
- Expert Witness for the Defendant on Karr, et al vs. The GHK Company et al regarding Surface Water and Natural Resource Impacts from Gas Well Drilling Activities, Pushmataha and Latimer Counties, (2003)
- Surface Water Observation Analysis, Section 404 Permitting Planning and Pre-construction Notification, Cement Manufacturing Facility, Confidential Client, Confidential Location (Technical Support).
- Gasoline Spill and Fish Kill Evaluation on Mill Creek, Santa Fe-Southern Pacific, Inc., Salem, OR
- Expert Witness for the Defendant on Honnoll vs. The GHK Company et al regarding Surface Water and Natural Resource Impacts from Gas Well Drilling Activities.
- Expert Witness for the Defendant in Anna Karr vs. State Attorney General's Office regarding Surface Water Impacts from Wastewater Treatment Facility (2001).

LITIGATION SUPPORT

- Expert Witness Testimony for the Plaintiff in the State vs. Kerr-McGee Corporation et al. (1976)
- Congressional Testimony - Testimony before the Subcommittee on Commerce, Transportation, and Tourism of the Committee on Energy and Commerce, U.S. House of Representatives regarding "Tar Creek Implementation of Superfund" (1982).
- Congressional Testimony - Testimony before the Subcommittee of the Committee on Government Operations, U.S. House of Representatives regarding a "Review of Hazardous Waste Cleanup and Disposal Efforts at Tinker Air Force Base" (1984).
- Expert Witness for the Defendant in United States of America vs. Pennzoil Exploration and Production Company (1991).
- Expert Witness for the Plaintiff in a lawsuit between a Confidential Natural Gas Pipeline and Distribution Company and a Valve Manufacturing Company regarding the Occurrence of PCBs as a Result of Valve Usage and Maintenance (1995).
- Deposition and Expert Witness Testimony, Gray vs. Oil Transport Company for Newcombe & Redman, regarding the impact of a chemical fire and it's residual impacts to soil (1997).
- Expert Witness for the Defendant in Anna Karr vs. Attorney General's Office regarding Surface Water Impacts from Wastewater Treatment Facility (2001).
- Expert Witness for the Defendant in BNSF Railroad Company vs. The Charles B. Grant Trust , et al regarding the Hydrocarbon Impacts from Historical Materials on the Property Boundary (2004).
- Expert Witness and Technical Support for the Defendants Claiming Eutrophication of Major Northeastern Reservoir, Joyce Paul & McDaniel.
- Expert Witness for the Defendants in Claims of Natural Resource Damages From Exploration & Production Sites, Hartzog Conger.

- Expert Witness and Technical Support for the Defendants in Claims of Natural Resource Damages from Poultry Production. Confidential Client, Confidential Location.
- Expert Witness and Technical Support for the Plaintiffs Regarding Processing and Shipping of Nuclear Regulated Materials. Doerner, Saunders, Daniel & Anderson.

THREATENED & ENDANGERED SPECIES

- Multiple Endangered Species Evaluations – multiple sites, multiple locations.
- Helium Construction Project, Duke Energy Field Services.
- Threatened & Endangered Species Review for Stormwater Permit, Pipeline, GPM Gas Services Company, Multiple Locations.
- Endangered Species Evaluation, Thunderbird Power Project, Triad Design Group.
- Endangered Species Evaluation (Salamander) Impacts from Pipeline Construction in Urban Area. Oneok , Inc.
- Threatened and Endangered Species Review Related to 120 Mile Long Corridor Pipeline Construction. Oneok, Inc.
- Threatened and Endangered Species Review Related to 16 Mile Long Corridor Pipeline Construction. Oneok, Inc.

WATER RESOURCES

- Natural Resources Damage Assessment, Verdigris River/Oolagah Reservoir, Farmland Industries, Inc.
- PCB Investigation and Public Involvement & Education Program, Fort Gibson Lake Watershed
- Surface Water Observation Analysis, Cement Manufacturing Facility, Confidential Client, Confidential Location.
- Administration and Direction of the Water Quality Division of the Oklahoma Water Resources Board, Including Planning, Budgeting, Cost Control, Personnel Management, and Communicating and Coordinating with all Levels of Public Citizens, Industrial, Municipal, and Governmental Personnel and Officials.
- Clean Water Act, Section 208, Water Quality Planning, State Department of Health.
- Nutrient Reduction Study, Illinois River Task Force, Illinois River Basin.
- Member, Governor Nigh's Illinois River Task Force.
- Research Related to Fish Culture, Pond Construction, Pond Management, Fish Feeding, Fish Food Processing, Disease Control, Weed Control, Water Chemistry, Composition of Fish Flesh, & Biological Properties of Warm Water Fish Ponds.
- Evaluation of Draft Environmental Impact Statement (DEIS) for Proposed Airport, Kirkland and Ellis, Denver, CO.
- Water Resource Planning for 700,000 acres Water Resources in the Midcon, Department of Wildlife Conservation.

REGULATORY COMPLIANCE

- Request Variance from Water Quality Standards, Pulp and Paper Mill, Weyerhaeuser Corporation.
- Environmental Permitting, Ice Plants, Southland Corp.
- Regulatory Support for Planning and Implementation of Riverbank Stabilization Project, Refinery Site, Sun Corporation.
- RCRA Regulatory Review, Brick Kiln, First Miss Gold, NE
- Regulatory Compliance Evaluation of Wastewater Treatment System for Refinery, National Cooperative Refining Corporation.
- Regulatory Assessment/Water Quality Issues Assessment, Cypress AMAX Mining Co.
- Administrative Order on Consent, Steel Manufacturing Facility, Sheffield Steel Corp.
- Environmental Permitting, New 750 MW Gas-Fired Power Generating Facility, Cogentrix Northeast.
- Stormwater Permit Evaluation, Helium Construction Project, Duke Energy Field Services.
- Site Specific Criteria Modification Request, Texaco Refining and Marketing, Inc.
- Site Specific Criteria Modification Request, Total Petroleum Corp.

HAZARDOUS/SOLID WASTE MANAGEMENT

- Preparation of Final Work Plan for Mercury Remediation, Natural Gas Pipeline Control Facility, Vastar Resources, Inc.
- Mercury-Contaminated Soil Remediation, Natural Gas Pipeline Control Facility, Vastar Resources, Inc.

- Development of RCRA Closure Plans and Oversight of Closure, Boat Motors/Stern Drives Manufacturing Facility, MerCruiser.
- Heavy Metals Discharge Assessment, Reclaimed Mining Zone, CLIMAX Molybdenum Company.
- Contaminated Soil Removal Action, Colorado Interstate Gas Company.
- Evaluation of Waste Oil Migration, Industrial Disposal Pit, Columbian Chemicals Company.
- RCRA Refinery Clean Closure and Certification.
- PCB Management Program, Energy Coatings Corp.
- PCB Characterization for 36 Sites, Gas Transmission Company, Texas Eastern Pipeline Company, Multiple Locations in the Southeastern U.S.
- PCB Contamination Assessment for Gas Pipeline, Williston Basin Interstate Gas Company/Montana-Dakota Utilities, Multiple Locations in Four-State Area.
- RCRA Pond Closures, National Cooperative Refining Corporation.
- Installation of RCRA Monitor Well System, MerCruiser Corporation.
- PCB Contamination Assistance, Natural Gas Pipeline & Distribution System, Colorado Interstate Gas company.
- Evaluation of Disposal Practices, Questar Corp.
- RCRA Waste Removal, Warehouse Facility, Talley Corp.
- Acid Mine Water Impacts Reduction Program, Tar Creek RI/FS.
- Field Studies Direction, Tar Creek Superfund Site Ranking Studies.
- Mercury Assessment Program Involving 76 Manometer Sites, Natural Gas Pipeline, Vastar Resources, Inc.
- Environmental Contaminant Characterization, Electrical Substation, Western Area Power Administration.
- Characterization for Decommissioning of Foundry, Western Area Power Administration.
- Site Decommissioning of Former Manufacturing Facility, Weyerhaeuser Company.
- Emergency Evaluation and Remediation Recommendations for Diesel Fuel Spill, Yellow Freight Trucking, Inc.
- Assessment of Potential for Fluids Migration and Recommendations for Repair to Failed Liner, Tailings Impoundment.
- Soil, Sediment, Water and Benthic Sample Collection and Analysis Plan Implementation, Verdigris River Oil Spill, Farmland Industries, Inc.
- Site Investigation/Soil Remediation Treatment, Gas Compressor Stations & Gas Plants, Mobil Business Resources Corporation, Multiple Locations.
- Phytoremediation Design, Regulatory Interaction, Construction Oversight, and Closure Documentation, Fertilizer Manufacturer, Terra Nitrogen.

ENVIRONMENTAL ASSESSMENTS/AUDITS

- Fatal Flaw Analysis for Proposed New Facility, Tamko Roofing Products, Inc.
- Expanded Phase I Environmental Site Assessment, Used Oil Refinery, Inland Resources, Inc., Salt Lake City.
- Environmental Assessments, Two (2) Tank-cleaning Facilities, All Waste Tank Cleaning, Ontario, Canada.
- Environmental Assessments, Two (2) Office Buildings, Citicorp, Inc.
- Environmental Assessments, Twelve (12) Oil Field Service Yards, Confidential Client, Multiple Sites.
- Environmental Assessments, Twelve (12) Oil and Gas Properties, Cominion Oil Company, Multiple Sites.
- Phase II Sampling Program Development, GE Capital.
- Environmental Assessment, Microchip Manufacturing Facility, Hamilton Standard.
- Phase II Sampling, Microchip Manufacturing Facility, Hamilton Standard.
- Environmental Assessment, Office Building, LaSalle Partners, Inc.
- Environmental Assessment, Asphalt Refinery, Koch Oil Co.
- Environmental Assessment, Two (2) Oil Fields comprising over 30,000 acres, Mercury Exploration.
- Environmental Assessment, Printing Facility, ROMO Companies, Inc.
- Environmental Assessment, 6,000 acre Property, Confidential Client.
- Environmental Assessment, Natural Gas Collection & Processing Facility, Sidley & Austin.
- Environmental Assessment, Oil Refinery, Union Bank, Southeast WY.

- Multidisciplinary Site Assessment of Greenfield Site (Air Quality, Wetlands, Natural & Cultural Resources) - Fatal Flaw Analysis, Weyerhaeuser Corporation, Confidential Location.
- Environmental Assessment for Plant Siting at 26 Potential Sites in 3-State Area, Confidential Client.
- Site Assessment of Fueling Facility, Stapleton Airport, Continental Airlines, Inc.
- Site Assessment of Electronics Manufacturing Site, Lowrance Corporation.

MISCELLANEOUS

- Groundwater Remediation Evaluation, Nuclear Fuel Processing Facility, Sequoyah Fuels Corp.
- Closure of Two (2) RCRA Hazardous Waste Management Units, Frontier Refining Inc.
- Construction Coordination for Tar Creek Remedial Program.
- Asbestos Abatement Program, Williston Basin Interstate Gas Company.
- Stormwater Permitting, Mining Facility, CO Aggregate.
- Stormwater Permitting of Construction Project, Texaco Refining and Marketing, Inc.
- Installation Restoration Program, Tinker Air Force Base Technical Review Committee, Water Resources Board.

Apex Companies, LLC

Mary C. Murray, PWS

Senior Environmental Scientist

Education

MS. Environmental Science
John Hopkins University
1996

BS. Biology
Old Dominion University
1990

Associations

Soil and Water Conservation District Supervisor
Board Treasurer
Associate

International School Board of Directors, Environmental Advisor

Training and certifications

OSHA 40-Hour Health and Safety Training

Professional Wetland Scientist, 2000, (PWS #1292)

Certified for Aquatic Insect Collection for Mitigation Monitoring Projects

Field Studies in Tropical Marine Biology, GWU, San Salvador Bahama Field Station

Years of experience
17 Years

Ms. Murray has over 17 years of experience in natural resources assessment and management of environmental permitting and compliance projects for capital improvement and water resources projects for both public and private sector clients. This experience includes all aspects of Section 404 and 401 Clean Water Act (CWA) permitting and NEPA/SEPA Environmental Assessment (EA) Documentation preparations including Agency coordination for approval of Record of Decision and Finding of No Significant Impact for numerous infrastructure projects.

Ms. Murray has extensive experience in environmental permitting for projects in politically sensitive locations under Federal, State, and Local regulations. Ms. Murray previously served as the Water Quality Program Administrator a City Storm Water Division and Engineering and Property Management. Ms. Murray's experience with permitting and NEPA/SEPA compliance includes capital improvements infrastructure projects such as highways, transit, neighborhood improvements, potable waterline extensions, gravity and force main sanitary sewer extensions, and storm water systems.

Ms. Murray has technical knowledge of Environmental Assessment Documentation required for FERC 3rd Party EAs associated with LNG terminal projects and LNG pipelines and WWTP Feasibility Studies for evaluation and analysis of potential environmental impacts for Natural Resources, Threatened and Endanger Aquatic Species, Water Quality, Wetlands, Floodplains, and Essential Fish Habitat Assessment.

Experience

FERC 3rd Party EA preparation for Cassotte Landing LNG Terminal and Various Pipelines

Ms. Murray prepare NEPA FERC 3rd Party EA documentation including sections related to Natural Resources, Water Quality, Floodplains, Wetlands, and Fisheries to evaluate environmental impacts associates with a Marine Terminal project and for various pipeline extensions for LNG pipelines. Reviewed technical reports and prepared third party EA comments and documentation required to support the Finding of No Significant Impacts for FERC. Documentation included Essential Fish Habitat Assessment and determination of impacts, avoidance and minimization and mitigation measures.

Environmental Permitting and NEPA/SEPA EA Documentation. Water Quality Program Administrator. Duties included providing environmental permitting for all capital improvement projects for a major City Engineering and Property Management Department. Managed all aspects of Section 404/401 Clean Water Act permitting and mitigation and NEPA/SEPA EA documentation to ensure compliance with Federal, State, and Local regulations. Worked closely with regulatory agencies to negotiate permit applications and obtain SEPA EA approvals and Findings of No Significant Impacts.

Rocky River Outfall - Clean Water Act Permitting and SEPA EA for 33,000 lf gravity main utility corridor. Provided field reconnaissance and wetland delineation along 33,000 linear foot utility corridor along South Prong and unnamed tributaries to Rocky River. Prepared Section 404/401 CWA permits for Nationwide Permit No. 12 and SEPA EA approvals. Project involved inter basin transfer issues and negotiations with State Historic Preservation Office regarding impacts to National Register Historic Property bisected by utility corridor.

Regional Waste Water Treatment Plant Expansion Feasibility Study. Provided environmental permitting feasibility study for expansion of wastewater treatment plant discharge to Lake Wylie. Environmental issues were evaluated for feasibility according to Federal, State, and Local regulatory permitting related to projects alternatives including combined operation between two wastewater treatment facilities on opposite sides of Lake Wylie and under separate County jurisdictions.

Regency Centers Storm Water Compliance. Coordinated Storm Water Management Facilities Inventory Inspections, Regulatory Review Summaries, and Identified Maintenance Recommendations and Budgets to prioritize 50 sites throughout eastern U.S. for storm water compliance. Worked with project team to complete reporting for client within short turn around (30-day) deadline and achieve consistency with similar projects occurring simultaneously throughout the Eastern United States.

Colonial Pipeline Corporation, Clean Water Act Permitting. Provides project regulatory review for Colonial Pipeline Corporation Maintenance Projects. Identifies permitting needs, budgets, and schedules for multiple sites throughout the Eastern United States. Coordinated field efforts, prepares permits, and provides regulatory agency coordination to ensure project regulatory timelines are met.

- Duke Energy, Marshall Steam Station, 17-acre Constructed Treatment Wetland for FGD Scrubber
- Charlotte Storm Water Services BMP Design Manual Development
- Mt. Holly - CMU Long Creek Regional Wastewater Treatment System Expansion Feasibility Study
- Town of Mooresville, Presbyterian Pump Station and Sewer Outfall SEPA – EA
- Town of Mooresville, Mt. Mourne Sewer Outfall SEPA-EA
- Cassote Landing LPG Terminal and Pipeline FERC – EA
- Central Midland Council of Governments Stream and Wetland Mitigation Bank
- CWA Permitting for Wake Forest Watershed Improvements Project on-line Water Quality BMPs
- Willora Lake Wetland Restoration and Water Quality Pond Retrofit

Served as a stakeholder for large City project involving the mapping of the water-supply watersheds for implementation of their Local Water Supply Watershed Ordinance. Participated in Wetland Restoration Program initiatives including the Lower Catawba Local Watershed Plan, and the Lower Rocky River/Yadkin Local Watershed Plan. Lead CSWS contact person for development of MOU between WRP, MSWS, and CSWS for implementation and design of WRP Mitigation Projects – major municipality. Participated as a stakeholder in multiple components of the Beaverdam Creek Watershed Study and Partnership as well as other Water Quality program initiatives.

Designed and implemented two local stream habitat restoration projects for compensatory mitigation. Performed geomorphic field assessments and supported preparation of preliminary designs for large scale wetland and stream restoration projects for Fed-ex facility, large Steele Facility, and other local development projects. Provided inspection and monitoring for stream restoration, wetland, and BMP projects.

Supported major municipality in the development of planting guidance and specifications for the restoration of right-of-way along newly installed utility corridors as an approved use within the designated County Surface Water Improvement and Management Buffers. The planting guidance and specifications serve to enhance water quality protection along utility corridors.

Groundwater Quality Investigation and Risk Assessment at a 22,000-acre facility with high-density un-exploded ordinance at the Camp Edwards Army National Guard Facility. Prepared work plans and field sampling plans for storm water sampling, groundwater, surface water and sediment sampling at ponds and swamps, and soil sampling at areas of concern.

Army National Guard, Storm Water Pollution Prevention Plans (SWPPPs), Team Member responsible for conducting interviews, performing site assessments, preparing maps and drawings to illustrate storm water flow patterns, conducting illicit discharge studies, training site personnel on storm water sample collection, preparing SWPPPs for numerous (25) Armories and other facilities for compliance with NPDES General Permit NCD08000.

Prepared a Piedmont Prairie Restoration and Management Plan for the Anne Springs Close Greenway located in Fort Mill, South Carolina. Co-authored a Mecklenburg County publication (1996) related to Best management Practices (BMPs) for Watershed Protection Basins. This booklet is a selection and planting guide for aquatic and wetland plants of the Piedmont region. It contains guidance materials for littoral shelf plantings for watershed protection basins. Assisted in drafting revisions to the Land Development Standards Manual specifications for Wet Pond BMPs for Engineering & Building Standards Department, Land Development Services.

Served as Quality Assurance/Quality Control Chemist working with the National Contract Laboratory Program's (CLP) Sample Management Office of the EPA and worked with a team of chemists on data validation projects and analytical methods development for the Engineering and Analysis Division of the EPA. Performed data validation, contract compliance screening, and QA/QC for both inorganic and organic sample analysis.

TABLE 7 - NEW BEDFORD HARBOR DREDGE - PHASE III

Water Quality Monitoring - Turbidity Measurements

June 12, 2008 -- August 25, 2009

Date	Time of Up Current	Average of Up Current	Time of Down Current	Average of Down Current	Difference (Down Current - Up Current)	Time of Disposal Location	Average of Disposal Location	Project Title	Project and/or Location
06/13/08	11:15	0.00	10:45	0.00	0.00	-	-	TOP of CAD II	TOP of CAD II
06/14/08	7:20	0.00	8:25	0.23	0.23	-	-	TOP of CAD II	TOP of CAD II
06/14/08	10:15	0.90	10:35	2.00	1.10	-	-	TOP of CAD II	TOP of CAD II
06/14/08	12:40	0.00	12:50	1.00	1.00	-	-	TOP of CAD II	TOP of CAD II
06/14/08	16:30	2.03	16:55	1.17	-0.87	-	-	TOP of CAD II	TOP of CAD II
06/16/08	16:45	14.63	16:30	0.00	-14.63	17:00	1.29	TOP of CAD II	CAD I (Disposal Only)
06/19/08	8:00	6.07	8:30	2.17	-3.90	-	-	TOP of CAD II	TOP of CAD II
06/19/08	12:00	23.43	12:30	4.23	-19.20	12:05	1.77	TOP of CAD II	CAD I (Disposal Only)
06/24/08	7:50	0.07	8:00	0.20	0.13	-	-	TOP of CAD II	TOP of CAD II
06/24/08	10:00	0.57	10:10	0.23	-0.33	-	-	TOP of CAD II	TOP of CAD II
06/26/08	10:05	1.67	10:10	0.47	-1.20	-	-	TOP of CAD II	TOP of CAD II
06/26/08	11:50	0.67	11:55	3.17	2.50	-	-	TOP of CAD II	TOP of CAD II
06/26/08	18:00	0.00	18:05	6.60	6.60	-	-	TOP of CAD II	TOP of CAD II
06/26/08	16:00	0.00	16:07	5.10	5.10	-	-	TOP of CAD II	TOP of CAD II
06/30/08	7:00	0.00	7:10	0.27	0.27	-	-	TOP of CAD II	TOP of CAD II
06/30/08	16:10	4.33	16:05	0.23	-4.10	-	-	TOP of CAD II	TOP of CAD II
06/30/08	14:25	2.87	14:20	2.73	-0.13	-	-	TOP of CAD II	TOP of CAD II
06/30/08	12:15	6.87	12:20	2.10	-4.77	-	-	TOP of CAD II	TOP of CAD II
06/30/08	10:00	0.63	10:04	1.70	1.07	-	-	TOP of CAD II	TOP of CAD II
07/03/08	15:40	4.17	15:55	6.13	1.97	-	-	TOP of CAD II	TOP of CAD II
07/03/08	13:30	5.50	13:35	4.93	-0.57	-	-	TOP of CAD II	TOP of CAD II
07/03/08	12:20	1.77	12:40	3.60	1.83	12:30	20.97	TOP of CAD II	CAD I (Disposal Only)
07/03/08	10:40	0.00	10:45	4.50	4.50	-	-	TOP of CAD II	TOP of CAD II
07/03/08	8:40	15.03	8:45	6.00	-9.03	-	-	TOP of CAD II	TOP of CAD II
07/03/08	6:46	0.83	6:55	0.97	0.13	6:50	6.77	TOP of CAD II	CAD I (Disposal Only)
07/08/08	12:00	0.30	12:10	1.53	1.23	12:25	7.17	TOP of CAD II	CAD I (Disposal Only)
07/08/08	10:05	14.33	10:23	7.60	-6.73	-	-	TOP of CAD II	TOP of CAD II
07/08/08	7:40	0.93	7:45	0.87	-0.07	-	-	TOP of CAD II	TOP of CAD II
07/08/08	7:05	3.10	7:25	2.10	-1.00	7:32	19.13	TOP of CAD II	CAD I (Disposal Only)
07/31/08	7:10	0.40	7:20	0.20	-0.20	-	-	Steamship	Steamship
07/31/08	9:10	8.86	9:25	0.10	-8.76	-	-	Steamship	Steamship
07/31/08	11:10	1.15	11:17	0.00	-1.15	-	-	Steamship	Steamship
07/31/08	14:18	0.30	14:25	5.26	4.96	-	-	Steamship	Steamship
07/31/08	16:45	2.43	16:35	0.43	-2.00	-	-	Steamship	Steamship
08/04/08	12:00	2.53	12:35	0.53	-2.00	12:25	-	Steamship	CAD I (Disposal Only)
08/05/08	7:40	0.26	7:50	0.00	-0.26	-	-	Steamship	Steamship
08/05/08	9:40	1.33	9:50	1.63	0.30	-	-	Steamship	Steamship

TABLE 7 - NEW BEDFORD HARBOR DREDGE - PHASE III

Water Quality Monitoring - Turbidity Measurements

June 12, 2008 -- August 25, 2009

Date	Time of Up Current	Average of Up Current	Time of Down Current	Average of Down Current	Difference (Down Current - Up Current)	Time of Disposal Location	Average of Disposal Location	Project Title	Project and/or Location
08/05/08	12:00	22.40	12:10	2.53	-19.87	-	-	Steamship	Steamship
08/05/08	14:05	1.17	14:20	16.20	15.03	-	-	Steamship	Steamship
08/05/08	16:46	2.53	16:55	0.66	-1.87	16:45	-	Steamship	CAD I (Disposal Only)
08/07/08	10:00	0.00	10:30	0.00	0.00	-	-	Steamship	Steamship
08/07/08	11:45	0.03	12:00	0.83	0.80	-	-	Steamship	Steamship
08/07/08	14:20	0.00	14:30	0.93	0.93	-	-	Steamship	Steamship
08/07/08	15:30	0.00	15:55	6.70	6.70	0.65	-	Steamship	CAD I (Disposal Only)
08/07/08	17:15	0.00	17:25	0.00	0.00	-	-	Steamship	Steamship
08/08/08	7:15	0.00	7:25	0.00	0.00	-	-	Steamship	Steamship
08/08/08	13:30	0.16	13:40	11.07	10.91	-	-	Steamship	Steamship
08/08/08	15:45	0.30	16:01	0.93	0.63		-	Steamship	Steamship
08/11/08	8:50	4.00	8:40	0.00	-4.00	-	-	Steamship	Steamship
08/11/08	16:30	1.23	16:50	2.00	0.77	-	-	Steamship	Steamship
08/12/08	11:20	0.00	11:30	1.40	1.40	-	-	Steamship	Steamship
08/12/08	13:40	0.00	13:30	2.93	2.93	-	-	Steamship	Steamship
08/12/08	15:30	0.00	15:40	4.26	4.26	-	-	Steamship	Steamship
08/18/08	8:30	0.00	8:40	0.96	0.96	-	-	Steamship	Steamship
08/18/08	10:30	8.53	10:44	0.00	-8.53			Steamship	Steamship
08/18/08	12:30	5.93	12:40	2.97	-2.96	-	-	Steamship	Steamship
08/18/08	15:28	5.90	15:32	2.70	-3.20			Steamship	Steamship
08/18/08	17:34	0.83	17:40	2.97	2.14		-	Steamship	Steamship
08/21/08	9:50	1.03	10:15	0.13	-0.90	-	-	Steamship	Steamship
08/21/08	12:45	3.90	12:50	0.00	-3.90	-	-	Steamship	Steamship
08/21/08	14:59	5.53	14:50	0.63	-4.90	-	-	Steamship	Steamship
08/21/08	17:22	5.60	17:26	0.83	-4.77	-	-	Steamship	Steamship
08/21/08	16:04	2.20	17:04	2.86	0.66	16:00	-	Steamship	CAD I (Disposal Only)
08/26/08	7:00	4.10	7:10	0.50	-3.60	-	-	Steamship	Steamship
08/26/08	8:55	0.30	9:02	18.47	18.17	-	-	Steamship	Steamship
08/26/08	11:05	4.97	11:15	5.43	0.46	-	-	Steamship	Steamship
08/26/08	13:00	2.77	13:12	9.73	6.96	-	-	Steamship	Steamship
08/28/08	7:30	3.77	7:40	3.37	-0.40	-	-	Steamship	Steamship
08/28/08	9:30	5.10	9:35	6.30	1.20	-	-	Steamship	Steamship
08/28/08	11:40	2.67	11:35	6.27	3.60	-	-	Steamship	Steamship
08/28/08	15:35	10.10	15:28	6.50	-3.60	-	-	Steamship	Steamship
08/28/08	8:50	24.10	8:57	9.63	-14.47	-	-	Steamship	Steamship
09/03/08	9:00	1.03	9:11	6.57	5.54	-	-	Steamship	Steamship
09/03/08	11:25	1.00	11:32	16.13	15.13	-	-	Steamship	Steamship

TABLE 7 - NEW BEDFORD HARBOR DREDGE - PHASE III

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June 12, 2008 -- August 25, 2009

Date	Time of Up Current	Average of Up Current	Time of Down Current	Average of Down Current	Difference (Down Current - Up Current)	Time of Disposal Location	Average of Disposal Location	Project Title	Project and/or Location
09/03/08	13:52	1.47	13:44	1.27	-0.20	-	-	Steamship	Steamship
08/27/08	13:47	2.83	13:40	8.57	5.74	N/A*[2]	N/A*[2]	BOC II	BOC II
08/27/08	15:42	2.10	15:35	4.23	2.13	N/A*[2]	N/A*[2]	BOC II	BOC II
08/27/08	17:30	2.23	17:42	3.16	0.93	N/A*[2]	N/A*[2]	BOC II	BOC II
08/28/08	8:00	1.90	8:10	1.53	-0.37	N/A*[2]	N/A*[2]	BOC II	BOC II
08/28/08	10:30	4.23	10:24	3.17	-1.06	N/A*[2]	N/A*[2]	BOC II	BOC II
08/28/08	12:22	3.73	12:27	2.23	-1.50	N/A*[2]	N/A*[2]	BOC II	BOC II
08/28/08	14:45	9.00	14:50	1.83	-7.17	N/A*[2]	N/A*[2]	BOC II	BOC II
08/28/08	16:40	1.60	16:50	4.13	2.53	N/A*[2]	N/A*[2]	BOC II	BOC II
09/03/08	8:10	3.33	8:05	19.23	15.90	N/A*[2]	N/A*[2]	BOC II	BOC II
09/03/08	10:54	4.10	11:02	1.93	-2.17	N/A*[2]	N/A*[2]	BOC II	BOC II
09/03/08	13:05	1.63	13:17	9.13	7.50	N/A*[2]	N/A*[2]	BOC II	BOC II
09/11/08	8:22	1.63	8:49	4.67	3.04	N/A*[2]	N/A*[2]	BOC II	BOC II
09/11/08	10:40	1.67	10:32	1.63	-0.04	N/A*[2]	N/A*[2]	BOC II	BOC II
09/11/08	13:00	1.30	13:05	1.73	0.43	N/A*[2]	N/A*[2]	BOC II	BOC II
09/11/08	16:42	2.33	17:00	3.80	1.47	N/A*[2]	N/A*[2]	BOC II	BOC II
09/16/08	9:50	1.50	10:00	2.37	0.87	N/A*[2]	N/A*[2]	BOC II	BOC II
09/16/08	11:50	3.50	11:56	1.67	-1.83	N/A*[2]	N/A*[2]	BOC II	BOC II
09/16/08	14:41	10.20	14:30	3.60	-6.60	N/A*[2]	N/A*[2]	BOC II	BOC II
09/16/08	16:20	5.33	16:16	4.73	-0.60	N/A*[2]	N/A*[2]	BOC II	BOC II
09/18/08	11:40	1.13	11:50	2.10	0.97	N/A*[2]	N/A*[2]	BOC II	BOC II
09/18/08	15:36	3.20	15:45	3.57	0.37	N/A*[2]	N/A*[2]	BOC II	BOC II
03/23/09	*[1]	1.45	*[1]	1.85	0.40	-	N/A*[3]	PH III PART B	NBRF
03/25/09	11:25	1.10	12:25	3.59	2.49	12:15	N/A*[3]	PH III PART B	NBRF (Disposal Only)
03/27/09	12:20	0.40	12:30	0.30	-0.10	12:14	N/A*[3]	PH III PART B	NBRF (Disposal Only)
04/05/09	11:40	1.55	13:00	1.73	0.18	11:55	N/A*[3]	PH III PART B	NBRF (Disposal Only)
04/08/09	13:20	2.94	13:35	2.43	-0.51	13:25	N/A*[3]	PH III PART B	NBRF (Disposal Only)
04/10/09	14:15	1.10	14:50	1.33	0.23	14:25	N/A*[3]	PH III PART B	NBRF (Disposal Only)
04/13/09	14:20	1.04	14:45	1.75	0.71	-	N/A*[3]	PH III PART B	NBRF
04/14/09	17:00	3.63	17:30	2.39	-1.24	17:15	N/A*[3]	PH III PART B	NBRF (Disposal Only)
04/21/09	10:14	2.21	11:00	5.05	2.84	10:50	N/A*[3]	PH III PART A	Gifford St.
04/22/09	8:15	1.70	8:28	4.07	2.37	8:20	N/A*[3]	PH III PART A	Gifford St.
04/22/09	13:50	1.60	14:10	2.17	0.57	-	N/A*[3]	PH III PART A	Gifford St.

TABLE 7 - NEW BEDFORD HARBOR DREDGE - PHASE III

Water Quality Monitoring - Turbidity Measurements

June 12, 2008 -- August 25, 2009

Date	Time of Up Current	Average of Up Current	Time of Down Current	Average of Down Current	Difference (Down Current - Up Current)	Time of Disposal Location	Average of Disposal Location	Project Title	Project and/or Location
04/23/09	* [1]	1.83	* [1]	2.00	0.17	7:35	N/A*[3]	PH III PART A	Gifford St., South Terminal
04/24/09	8:35	1.43	9:35	1.73	0.30	9:25	N/A*[3]	PH III PART A	CAD II (Disposal only)
04/26/09	12:25	0.85	13:05	1.37	0.52	12:45	N/A*[3]	PH III PART A	Gifford St., South Terminal
05/04/09	11:30	3.02	* [1]	1.22	-1.80	11:45	N/A*[3]	PH III PART A	CAD II (Disposal only)
05/06/09	11:45	1.70	12:00	1.80	0.10	11:50	N/A*[3]	PH III PART A	CAD II (Disposal only)
05/06/09	16:45	2.50	16:58	14.30	11.80	-	N/A*[3]	PH III PART A	Gifford St.
05/07/09	15:00	13.00	15:20	2.73	-10.27	-	N/A*[3]	PH III PART A	South Terminal
05/13/09	13:30	1.37	13:50	1.47	0.10	13:36	N/A*[3]	PH III PART A	CAD II (Disposal only)
05/14/09	8:20	0.60	8:45	2.27	1.67	8:35	N/A*[3]	PH III PART A	CAD II (Disposal only)
05/16/09	12:30	2.09	13:25	0.61	-1.48	-	N/A*[3]	PH III PART A	Union Wharf
05/20/09	14:00	21.60	14:20	3.19	-18.41	-	N/A*[3]	PH III PART A	Gifford St.
05/22/09	8:00	0.81	8:15	0.29	-0.52	8:05	N/A*[3]	PH III PART A	CAD II (Disposal only)
05/28/09	10:13	1.09	10:25	1.85	0.76	-	N/A*[3]	PH III PART A	Linberg Marine
05/28/09	14:00	1.06	14:45	1.71	0.65	14:20	N/A*[3]	PH III PART A	CAD II (Disposal only)
06/04/09	14:35	1.60	14:52	3.53	1.93	-	N/A*[3]	PH III PART A	Linberg Marine
06/04/09	16:20	1.90	16:55	3.13	1.23	16:35	N/A*[3]	PH III PART A	CAD II (Disposal only)
06/06/09	14:05	1.47	14:30	3.76	2.29	-	N/A*[3]	PH III PART A	Linberg Marine
06/14/09	8:40	3.07	9:15	3.17	0.10	8:50	N/A*[3]	PH III PART A	CAD II (Disposal only)
06/17/09	15:25	2.99	15:40	4.05	1.06	-	N/A*[3]	PH III PART A	WA-S
06/18/09	8:30	0.87	9:00	1.30	0.43	8:45	N/A*[3]	PH III PART A	CAD II (Disposal only)
06/22/09	11:15	1.66	11:35	1.04	-0.62	-	N/A*[3]	PH III PART A	ONWF
06/24/09	10:10	4.54	10:25	0.46	-4.08	-	N/A*[3]	PH III PART A	Gifford St.
07/01/09	14:40	2.88	15:17	3.83	0.95	-	N/A*[3]	PH III PART A	Gifford St.
07/02/09	16:45	2.28	17:15	5.23	2.95	-	N/A*[3]	PH III PART A	Gifford St.
07/08/09	11:55	1.93	12:15	1.83	-0.10	-	N/A*[3]	PH III PART A	NL
07/08/09	14:33	3.60	14:40	18.00	14.40	14:35	N/A*[3]	PH III PART A	CAD II (Disposal only)
07/10/09	9:30	0.73	10:15	1.05	0.32	-	N/A*[3]	PH III PART A	Packer Marine

TABLE 7 - NEW BEDFORD HARBOR DREDGE - PHASE III

Water Quality Monitoring - Turbidity Measurements

June 12, 2008 -- August 25, 2009

Date	Time of Up Current	Average of Up Current	Time of Down Current	Average of Down Current	Difference (Down Current - Up Current)	Time of Disposal Location	Average of Disposal Location	Project Title	Project and/or Location
07/15/09	13:58	1.97	14:05	5.57	3.60	-	N/A*3	PH III PART A	Gifford St.
07/17/09	13:48	2.13	14:05	1.59	-0.54	-	N/A*3	PH III PART A	WA-S
07/22/09	13:35	2.59	14:00	3.63	1.04	-	N/A*3	PH III PART A	South Terminal
07/23/09	15:30	4.22	15:40	2.70	-1.52	-	N/A*3	PH III PART A	South Terminal
07/28/09	8:55	4.62	9:10	4.35	-0.27	-	N/A*3	PH III PART A	South Terminal
08/12/09	13:40	2.90	14:10	4.51	1.61	-	N/A*3	PH III PART A	Gifford St.
08/13/09	17:48	1.90	18:05	2.60	0.70	-	N/A*3	PH III PART A	South Terminal
08/17/09	10:10	0.77	10:25	2.07	1.30	-	N/A*3	PH III PART A	Packer Marine
08/20/09	14:25	2.28	14:45	2.79	0.51	-	N/A*3	PH III PART A	Packer Marine
08/25/09	16:46	5.62	17:00	3.23	-2.39	-	N/A*3	PH III PART A	South Terminal

Comments:

- Denotes a non-disposal event

*1 Time field left blank on original field sheet/log-book

*2 Bottom of CAD disposal events were off shore and water quality montitoring was not completed

*3 PH III Part A and Part B Dredging were completed with a silt curtain around CAD II therefore no disposal location readings were taken (up-current and down-current measurements were taken outside the silt curtain.

Technical Memorandum

Date: December 15, 2009

To: Robert Leitch, PE, USACE North Atlantic Division New England District (NAE)

From: Paul Dragos, Battelle

Subject: Turbidity Monitoring and Plume Sampling Results for City Dredge Disposal at the New Bedford Harbor CAD Cell # 2

This Technical Memorandum presents a summary of the turbidity monitoring results for the surveys conducted at the navigational dredging Confined Aquatic Disposal (CAD) cell # 2 in New Bedford, Massachusetts (Figure 1). The turbidity sampling was conducted during disposal of navigational dredged material by the City of New Bedford into the CAD cell on April 14, May 20, 21, & 27, and July 8 of 2009. Dredged material released into the CAD cell during monitoring operations was dredged from the channel north of the Coggeshall Street Bridge, the Niemiec Boat Yard, the Packer Pier, and the Gifford Street Boat Ramp.

Figure 1. Portion of New Bedford Harbor Showing the Location of the City CAD Cell.

Background

The City of New Bedford was engaged in Phase III of the Harbor Maintenance Dredge Program performing maintenance dredging at various locations in New Bedford Harbor during the spring and summer of 2009. The City dredging was not part of the on-going EPA Superfund remedial dredging project. A number of dredge areas were included in Phase III infrastructure improvements at numerous piers and wharves that serve the fishing, ferry, tourism, and shipping industries. The dredged material was disposed into CAD cell # 2 located north of Popes Island. During the months of disposal operations, the CAD cell was surrounded by a silt curtain made of a porous fabric which was suspended from the water surface and hung to the harbor bottom. The curtain was intended to contain any suspended sediment plumes resulting from disposal of dredged material into the CAD cell. The curtain consisted of 6 or 8 separate sections of fabric. One section acted as a gate which was opened and closed to allow the barge and tug to enter and exit the cell.

Objective

The objective of this effort was to conduct shipboard, real-time tracking of suspended sediment plumes resulting from disposal operations in and around the CAD cell. The presence, extent, and concentration of suspended sediments were determined for plumes both inside and outside the silt curtain. The data obtained during this effort consisted of the following:

- water current velocity from continuous Acoustic Doppler Current Profiler (ADCP) measurements;
- turbidity and suspended sediment concentration derived from continuous ADCP measurements of acoustic backscatter;
- turbidity and total suspended solids (TSS) from whole water samples at plume and reference stations; and
- toxicity from whole water samples collected at plume and reference stations.

Methods

Details on the survey/sampling methods can be found in the project Field Sampling Plan (Battelle, 2009).

The study design incorporated broad scale monitoring of sediment plumes using a ship-mounted ADCP to collect continuous turbidity measurements combined with discrete location water column sampling for post-survey analysis of turbidity, TSS, and toxicity. The ADCP measurements were made as the survey vessels ran a series of transects within and outside (primarily down-current) of the CAD cell from immediately after the time of release until any plume had dissipated (approximately 1 to 1½ hours). The *in situ* ADCP backscatter data was compared to laboratory derived TSS and turbidity data from whole water samples to post-calibrate the instrument and to provide an independent measure of particulate concentration.

Velocity Survey

During the first day of the study and prior to dredged material disposal, a velocity survey was performed to delineate the current structures in the survey area over a tidal cycle. The velocity survey was conducted using one RD Instruments 1200kHz Workhorse Mariner ADCP mounted over the side of the 24 ft vessel *Sea Quest* (Figure 2). The ADCP measured current velocity every 1-2 seconds at 0.5 m vertical intervals throughout the water column while the vessel was underway. A series of harbor transects were occupied once every hour over a complete tidal cycle to determine the three-dimensional current structure throughout the survey area between Popes Island and the Route 195 bridge. The position and real-time current data were collected and displayed on the data collection laptop in real-time

(Figure 3). The tracklines were run 13 times over a period of approximately 13 hours. Current velocity data were processed on shore immediately after the survey and graphical outputs of each hourly run were developed for use by the survey crews during the plume tracking surveys.

Figure 2. ADCP Mounted in Operational Position Over the Side of the *Sea Quest* with the Acoustic Transducers Just Below the Water Surface.

Plume Tracking Surveys

Plume tracking was conducted using two RD Instruments 1200kHz Workhorse Mariner ADCPs mounted on two separate vessels, the *Gale Force* and the *Sea Quest*. The ADCP was used to measure current velocity and acoustic backscatter intensity in decibels (db) every 1-2 seconds at 0.33 m vertical intervals throughout the water column while the vessels were underway. The acoustic backscatter intensity is a function of the suspended sediment concentration in the water column. As the vessels ran transects across the survey area, the ADCP mapped out vertical slices of suspended sediment concentration along those transects. The ADCP concurrently measured velocity of the tidal currents (speed and direction) which was used to aid plume tracking. The ADCP measurements were recorded and displayed in real-time (Figure 3).

Transect locations were determined on-the-fly to maximize the plume coverage in response to plume dynamics. The general procedure during each disposal event was as follows:

1. Prior to beginning of sampling, each boat used the ADCP to monitor current direction and speed and confirm currents determined during the velocity survey. The boat locations were adjusted thereafter to be down-current of the dredged material release point.

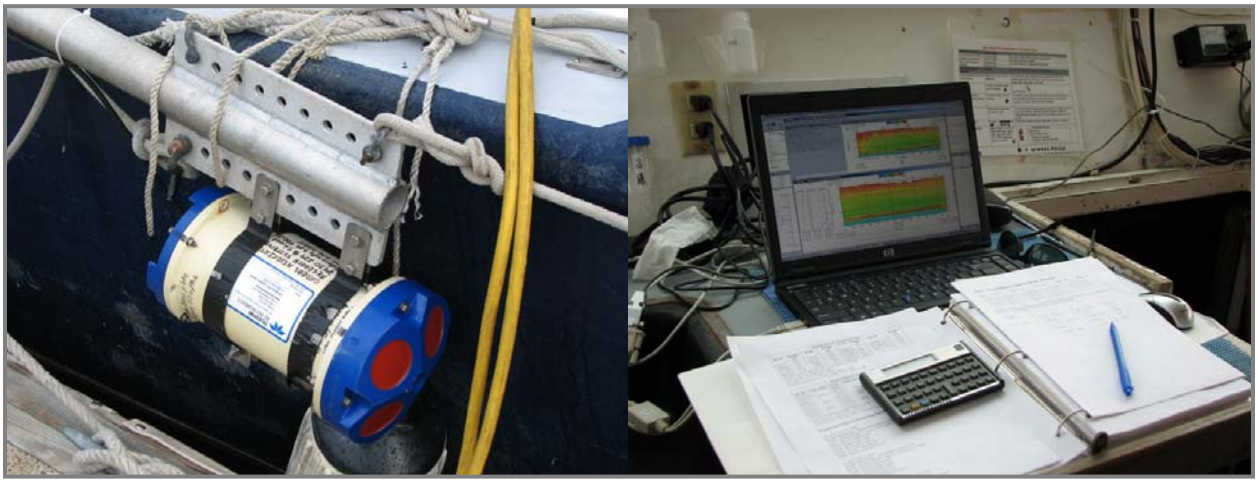

Figure 3. RD Instruments 1200khz Workhorse Mariner ADCP Mounted Over the Side of the Vessel and ADCP Real-Time Display / Data Collection Laptop.

2. Prior to release of the dredged material into the CAD cell, each boat collected whole water samples at mid-depth and near-bottom reference stations along with ADCP backscatter data. During the May 20 disposal event, an additional whole water sample was collected at mid-depth at the up-current reference station for toxicity analysis.
3. Immediately after the release (Figure 4), and for the next 1-1½ hours the *Sea Quest* ran east-west and north-south transects, at the discretion of the Chief Scientist, throughout the CAD cell until the plume was no longer significantly above background.
4. Immediately after the release, and for the next 1-1½ hours the *Gale Force* ran transects outside the CAD cell running east-west, north-south, and along the outside of the curtain, at the discretion of the Chief Scientist.
5. In the CAD cell, whole water samples were collected in the plume centroid and at two other locations within the plume (lateral stations). It was up to the discretion of the Chief Scientist to determine during which transect(s) and how long after release the samples were taken but samples were generally taken while the plume signal was still strong, in most cases during the second transect and again when the plume concentration was more moderate. During the May 20 disposal event, an additional whole water sample was collected at mid-depth in the plume centroid for toxicity analysis.
6. Outside the CAD cell, an attempt was made to collect whole water samples in any plume observed (three stations at two depths) at the discretion of the Chief Scientist. During the May 20 disposal event, an additional whole water sample was collected for toxicity analysis.

Real-time demarcation of the plume with ADCP provided the information needed to select sampling locations and depths. Each vessel collected TSS and turbidity samples from near-bottom (approximately 1 m above the bottom) and mid-depth at three plume stations and two reference stations (summarized in Table 1). Whole water samples were collected with Niskin bottles on hand lines. Three toxicity samples were also collected during the first of the disposal monitoring surveys: one from the plume centroid; one outside the silt curtain; and one at an up-current reference station unimpacted by dredging activities.

Laboratory TSS and Turbidity Testing Methods

The whole water samples collected during the survey were analyzed by Alpha Analytical Laboratory for TSS using U.S. EPA Method 2540 D. A well-mixed sample was filtered through a standard glass fiber filter (GF/F) and the residual retained on the filter was dried and weighed. For each batch of 20 or fewer samples, a laboratory method blank, duplicate, and laboratory control sample (LCS) was processed and analyzed with the field samples[1]. Results are reported on a dry-weight basis.

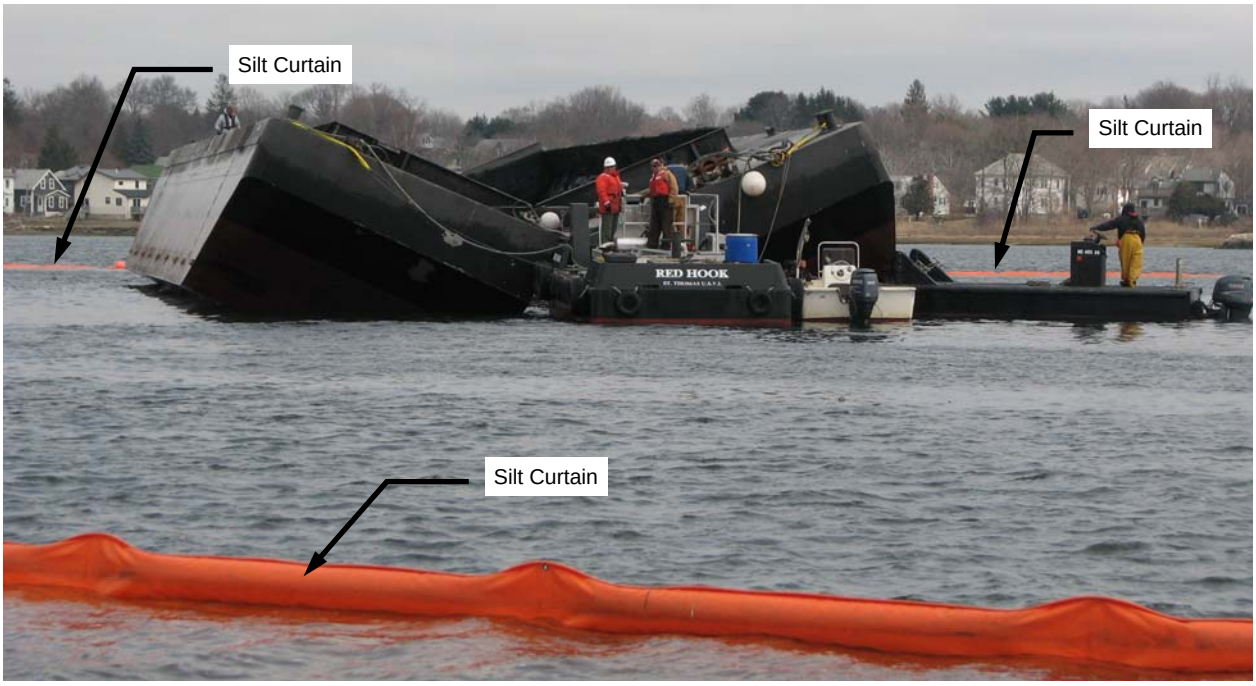

Figure 4. Split Hull Scow Immediately after Placement of Dredged Material into the CAD Cell.

Table 1. Sampling During Each Disposal Event by Each Survey Vessel.

Station	Parameters	Depth	Number of Water Samples	Comments
Turbidity and TSS Samples				
Plume Centroid Station	Turbidity, TSS	Near-bottom and mid-depth	2	Add 5% duplicate sample for QC
Plume Lateral Stations (2)	Turbidity, TSS	Near-bottom and mid-depth	4	
Reference Stations ≥1500 ft up- and down current (2)	Turbidity, TSS	Near-bottom and mid-depth	4	
Toxicity Samples (1 disposal event only)				
Plume Centroid Station	Toxicity	Mid-depth	1	
Plume Station outside Silt Curtain	Toxicity	Mid-depth	1	
Reference Station ≥1500 ft up or down current	Toxicity	Mid-depth	1	

[1] One exception to this QC procedure occurred during analysis of the April 14, 2009 samples when no laboratory duplicate was analyzed.

The whole water samples collected during the survey were also analyzed by Alpha Analytical Laboratory for turbidity using U.S. EPA Method 180.1. A well-mixed sample was analyzed for turbidity using a nephelometer to compare the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension. Results are reported in nephelometric turbidity units (NTU).

Toxicity Testing Methods

Acute and chronic (sub-lethal) exposure screening assays were performed on discrete water samples to evaluate the potential toxicity of the water samples. Assay design included a laboratory control treatment, a site reference sample, and two site samples collected during disposal of dredged material. Samples were evaluated "As Received" without dilutions. Testing was based on programs and protocols developed by the U.S. EPA (2002) primarily designed to provide standard approaches for the evaluation of toxicological effects of discharges on aquatic organisms, and for the analysis of water samples. Testing included the following assays: modified 2 day acute and 7 day chronic assays conducted with the mysid shrimp, *Americamysis bahia*, and the red macro alga, *Champia parvula*, and 60 minute chronic fertilization assays conducted with the purple sea urchin, *Arbacia punctulata*. All mysid and urchin fertilization assays and the acute survival portion of the algal assays were conducted by EnviroSystems, Inc. (ESI) located in Hampton, New Hampshire. Additionally, the acute and chronic algal assays were also conducted by Aquatox Testing & Consulting, Inc. of Guelph, Ontario, Canada in order to provide data in the event that the assay conducted by ESI failed to meet the target endpoints.

Statistical analysis of acute and chronic exposure data was completed using CETIS (Comprehensive Environmental Toxicity Information System) software. The program computes acute and chronic exposure endpoints based on U.S. EPA decision tree guidelines specified in individual test methods. For chronic exposure endpoints statistical significance was accepted at $\propto < 0.05$.

As part of the toxicity testing laboratory quality control program, standard reference toxicant assays are conducted on a regular basis for each test species to provide relative health and response data while allowing for comparison with historic data sets.

ADCP Calibration

Data were collected to calibrate the acoustic ADCP instruments to TSS and turbidity correcting for site-specific factors including particle size distribution, particle type, and particle surface roughness. At whole water sampling stations, Niskin bottles were lowered over the side of the vessel to collect discrete water samples. Simultaneously, the ADCP collected acoustic backscatter data. Turbidity and TSS from water samples at a given depth and time were compared with acoustic backscatter from ADCP at the same depth and time. The sample volumes for turbidity/TSS and backscatter are not the same which, in a turbulent, heterogeneous suspended sediment plume introduces some bias to the calibration. However, the method has been commonly used with good results in many field studies with a range of current velocities, sediment types, and sediment grain size distributions (see the review paper by Poerbandono and Mayerle, 2004).

ADCPs were calibrated for turbidity and TSS against water samples analyzed in the laboratory. All samples available from both boats during all disposal monitoring surveys were used in the calibrations. The ADCP is primarily designed and used to quantify current velocity by measuring the Doppler frequency shift in the acoustic backscatter signal. The acoustic backscatter intensity is measured and recorded but processed no further by the ADCP because only the frequency shift is used to calculate velocity and the frequency shift is independent of the backscatter intensity. The backscatter intensity,

however, is dependent on the suspended sediment concentration, but in order to calibrate backscatter to suspended sediment concentration, losses due to acoustic beam spreading and acoustic absorption by water must be accounted for in the backscatter signal. Based on the energy of acoustic intensity, Deines (1999) simplified the active sonar equation from underwater acoustic theory for the broadband ADCP:

$$10\log_{10}(SSC) = C_k + K_C E + 10\log_{10}(R^2) + 2\alpha_w R$$

where SSC is suspended sediment concentration, R is the range along the beam to the scatterer, α_w is the attenuation coefficient due to water absorption (primarily dependent on the frequency and provided by the instrument manufacturer), and E is the acoustic echo strength (in instrument counts). The last two terms in the equation represent the effects of acoustic beam spreading and acoustic absorption by water, respectively. C_k and K_C are constants that cannot be measured directly. Least squares regression analysis was used to estimate the best values for the constants C_k and K_C (Figure 5). The estimated values for C_k and K_C are -30.68 mg/L and 0.4371 mg/L/dB, respectively and are within the range suggested by Poerbandono and Mayerle (2004). The error on C_k with 95% confidence is ± 6.76 mg/L. Assuming a linear relationship between turbidity and suspended sediment concentration (Figure 6), an equation of the same form was used for calibration of the ADCP to turbidity (Figure 7). The estimated values for C_k and K_C for turbidity are -34.76 NTU and 0.4351 NTU/dB, and the error on C_k with 95% confidence is ± 6.68 NTU.

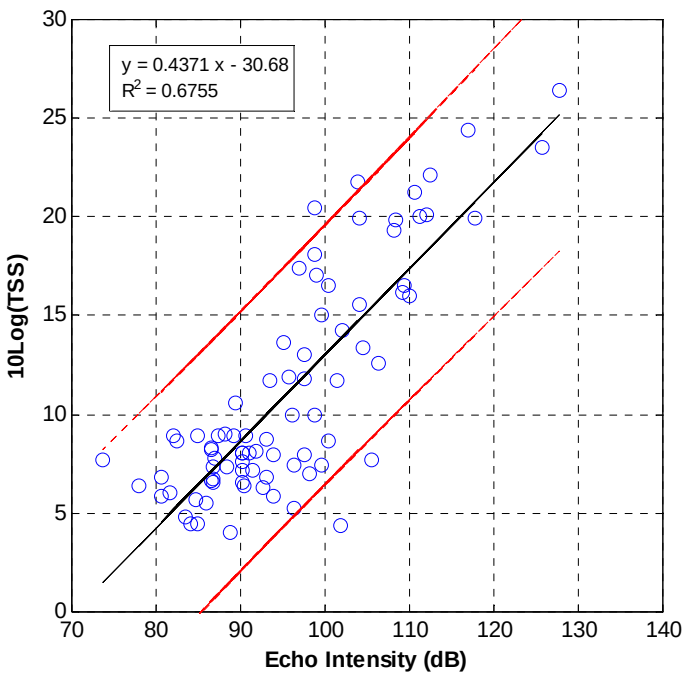

Figure 5. Least Squares Regression Analysis of Total Suspended Solids (TSS) from Whole Water Samples Analyzed in the Laboratory versus ADCP Echo Intensity in Decibels (dB).
Red Lines Indicate the Regression 95% Confidence Interval.

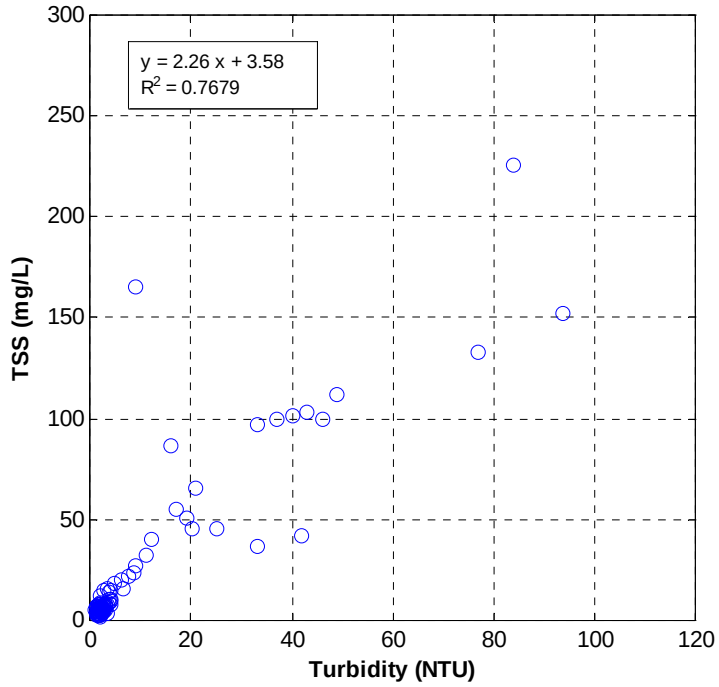

Figure 6. Least Squares Regression Analysis of TSS versus Turbidity from Whole Water Samples Analyzed in the Laboratory.

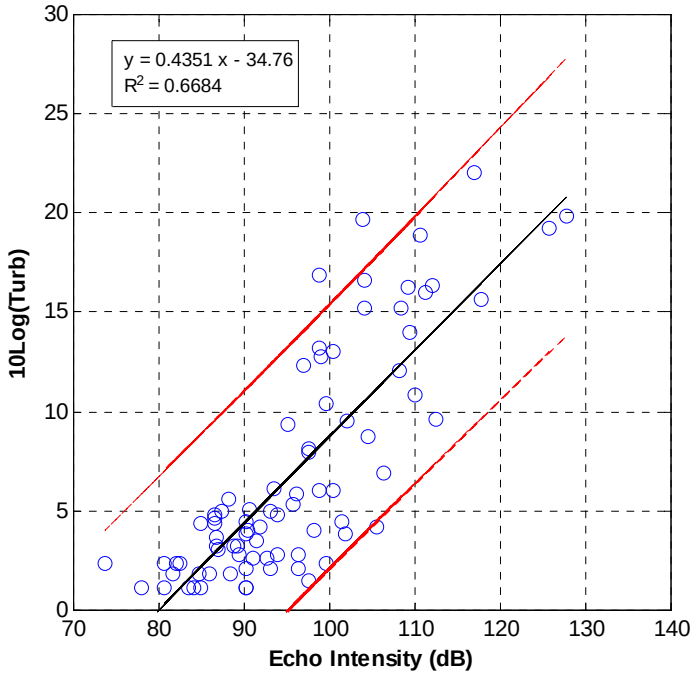

Figure 7. Least Squares Regression Analysis of Turbidity from Whole Water Samples Analyzed in the Laboratory versus ADCP Echo Intensity in Decibels (dB).
Red Lines Indicate the Regression 95% Confidence Interval.

Results

Velocity Survey

Tidal currents dominate the movement of water in New Bedford Harbor and thereby the movement of any suspended sediment in the water column. There exists, however, a generally weak inflow of fresh water from the Acushnet River at the north. This fresh water inflow results in a weak estuarine circulation which is superimposed on the stronger tidal flow. The estuarine circulation is the density driven movement of fresher surface water down the estuary simultaneous with the movement of saltier bottom water up the estuary. In New Bedford Harbor, the combined effect of the tides and the estuarine circulation is vertical shear in the water column velocity, in which the ebb currents are stronger near-surface and flood currents are stronger near-bottom. The Acushnet freshwater inflow varies seasonally and is significantly weaker than the tides except occasionally during large spring freshet events, which did not occur during this study.

A velocity survey was performed on March 27, 2009 using ADCP to delineate the current structure in detail in the survey area between Popes Island and the Route 195 bridge. The results of the velocity survey were used during the plume tracking surveys to provide *a priori* estimates of plume movement. Appendix A presents the results of that survey as a series of hourly velocity vectors along the harbor transects over a complete tidal cycle for the near-surface and mid-depth locations. Peak near-surface tidal flows were generally less that 35 cm/s (0.7 kts) in the immediate vicinity of the CAD cell and less than 55 cm/s (1.1 kts) in the navigation channel. The mid-depth tidal flows were slightly weaker that the near-surface flows with the strongest less that 30 cm/s (0.6 kts) near the CAD cell and less than 50 cm/s (1.0 kts) in the navigation channel. The configuration of the harbor results in a flow which diverges around Popes Island just below the CAD cell. During the ebb tide (southward flow) the currents diverge near Popes Island with most of the flow moving southwestward following the navigation channel and some moving southeastward around Popes Island to the east. During the flood tide (northward flow) the pattern reverses.

Current velocities inside the curtained CAD cell were too weak to measure accurately with ADCP at speeds less than 2 cm/s.

Turbidity and Suspended Sediment Results

Turbidity and TSS results from laboratory analysis of whole water samples collected at reference and plume stations during the plume tracking surveys are summarized in Appendix B. The data passed all laboratory quality control criteria. The relative percent differences (RPD) in field duplicate turbidity and TSS were acceptable; average RPD for turbidity was 22% and average RPD for TSS was 53%. This is typical given the small values being measured at reference stations (where small absolute differences can result in large RPDs) and the heterogeneous nature of the plume sampled at plume stations. The turbidity and TSS results presented in Appendix B are discussed throughout the rest of this technical memo.

Toxicity Testing Results

Toxicity results from the acute and chronic (sub-lethal) exposure assays performed on site water samples collected during disposal activities are summarized in Table 2. Results are presented for the test endpoints: survival, growth, development and reproduction. Results for test endpoints for each sample were statistically compared to those from both the event-specific site reference sample and the laboratory control sample. Assay results for the laboratory control sample met the minimum test acceptability criteria for the acute and chronic exposure assays, indicating the test was in control and that healthy test organisms were used. Assay results for the site water samples collected on May 20, 2009 during disposal activities at the City's CAD cell showed no significant reduction in endpoints for any of the test species

between the reference and CAD sampling sites (Table 2). There were no measurable acute or sub-lethal impacts from exposure of the test species, *A. punctalata*, *A. bahia*, and *C. parvula*, to water collected during disposal activities.

Table 2. Summary of Toxicity Test Results, May 20, 2009 Water Samples

Sample	Time After Release (min)	Turbidity from ADCP (NTU)	Toxicity Results					
			Sea Urchin (*A. punctulata*)	Mysid (*A. bahia*)			Red alga (*C. parvula*)	
			mean fertilization (%)	48-hr mean survival (%)	7-day mean survival (%)	7-day mean biomass (mg/mysid)	48-hr mean survival (%)	7-day mean reproduction (cystocarp/ plant)
Lab Control	na	na	97.1	100	84.4	0.431	100	34.0
Site Reference	na	< 2	93.5[1]	100	82.5	0.462	100	34.0
Outside silt curtain	49	~12	95.0[1]	100	97.5	0.519	100	34.1
Inside silt curtain	20	~70	94.1[1]	97.5	87.5	0.435	100	34.7
Acceptance Criteria (for Lab Control)			> 70	≥ 90	≥ 80	>0.2	no necrosis	≥ 10

[1] Assay result significantly different compared to the laboratory control sample.

Disposal Plume Turbidity and Suspended Sediment

Background Turbidity

Prior to beginning each disposal sampling event, each boat collected reference samples at two stations (Figure 1) at two depths (mid-depth and near-bottom) at least 1500 ft from the CAD cell and away from any other dredge activity. The turbidity and TSS measured in the laboratory from whole water samples are presented in Appendix B. The reference levels were low and consistent across the study area. The mean background turbidity was 2.1 NTU and the mean background TSS was 5.7 mg/L. With the exception of one profile in the channel south of the CAD cell the background turbidity was approximately 1 – 3.2 NTU and the background TSS was approximately 2 – 12 mg/L.

Plume Measurements

Five disposal plumes were monitored in and around the CAD cell on five different days. In the series of figures presented in Appendix C, suspended sediment measurements collected during the plume surveys using ADCP are presented. For each disposal event, a series of 5 to 7 figures show water column observations made pre-release and at various times after releases. Included in each figure are three panels presenting the locations of measurements and vertical contours of observed turbidity inside and outside the CAD cell silt curtain. The location panel shows the CAD cell boundaries, the approximate location of the dredge barge at the time of release, and the locations of both the inner and outer boat transects at the time of the measurements as indicated. The two vertical contour panels present the calibrated turbidity in NTU and TSS in mg/L along each vessel transect. The contours are labeled and oriented west to east (or east to west) based on the end points of the transect. In the following sections, TSS values in mg/L are referenced alongside corresponding turbidity values.

Disposal Plume April 14, 2009

On April 14, 2009, a disposal plume was surveyed during a dredged material release from a split hull barge at the New Bedford Harbor CAD cell. The material placed into the CAD cell was from City dredging operations north of the Coggeshall Street Bridge. The release took place at 16:47 hours and monitoring was carried out during the approximately 1 hour period of weak northerly currents that

followed (published low tide for the day was 16:59). The currents outside the cell were weak and variable (< 10 cm/s) with a slight northward component particularly on the west of the cell in the navigation channel. Currents inside the silt curtain were too weak to measure at speeds less than 2 cm/s. In the presence of little current to transport and disperse the suspended sediment, the disposal plume stayed close to the point of release, transported primarily by its own momentum.

Part 1 of Appendix C documents the suspended sediment plume observed in the water column after the release. In it, a series of five figures are presented showing the results from five sets of concurrent inner and outer transects selected at intervals over a period of approximately 45 minutes until the plume dissipated. Figure 1-1 presents background conditions before the release showing two transects run just inside and outside the silt curtain on the north side of the CAD cell. Water column turbidity was observed at background levels during both transects, although an offset bottom echo is visible in the inner transect which should not be confused with any water column turbidity[2]. By 8 to 11 minutes after release (Figure 1-2), the disposal plume was observed at approximately 25 NTU (62 mg/L) inside the silt curtain north of the point of release. Seen in the outer turbidity profile, there was a very weak turbidity signal, just above background (< 5 NTU; 12 mg/L), visible leaking from one of the seam slits in the silt curtain. By 19 to 22 and 27 to 39 minutes after release (Figures 1-3 and 1-4), the inner boat was measuring turbidity at approximately 15 NTU (38 mg/L) near bottom and the outer boat could find no trace of the plume. By 40 to 44 minutes after release (Figure 1-5), the plume had settled and water column turbidity had returned to background levels.

Disposal Plume May 20, 2009

On May 20, 2009, a disposal plume was surveyed during a dredged material release from a hopper barge. The material placed into the CAD cell was dredged during City dredging operations at the Niemiec Boat Yard just north of Popes Island. The barge hoppers were opened at 07:50 hours, however, some of the dredged material did not fall readily through the hopper doors. An excavator was used to shovel material out of some hopper bins and to dump water into the bins to wash away the material that was adhering to the sides.

The currents in the harbor were at ebb during the approximately 90 minute monitoring period (published high tide was 04:51). Outside the cell currents were as strong as 30 cm/s to the south on the west side of the cell and 15 cm/s to the south on the east side. Currents inside the silt curtain were too weak to measure at speeds less than 2 cm/s.

Part 2 of Appendix C documents the turbidity and TSS observations at the CAD cell on May 20th. In it, a series of seven figures are presented with the results of seven sets of concurrent inner and outer transects selected at intervals over a period of approximately 90 minutes until the plume dissipated. Figure 2-1 presents background conditions before the release. Inside and outside the silt curtain, turbidity was < 2 NTU and TSS was <5 mg/L. Figure 2-2 presents turbidity observed 3 to 6 minutes after release where a very strong plume signal can be seen inside the silt curtain, near-bottom, south of the barge with turbidity as high as 70 NTU (175 mg/L)[3]. Outside the silt curtain to the south, a filament of slightly elevated turbidity (< 5 NTU; <12 mg/L) was visible near the curtain gate. Between 10 and 24 minutes after release (Figures 2-3 and 2-4) the plume spread within the cell and the concentration remained high (70 NTU; 175 mg/L)[3]. The use of the excavator to liberate the dredged material stuck in the hopper bins probably contributed to the elevated turbidity in the cell. Outside the silt curtain there was no evidence of

[2] Bottom echoes occasionally appear reflected in the water column as a result of surface acoustic reflections or software inability to correctly identify sharp depth changes. However, these 'bright lines' are not easily confused with water column plumes because of their linear nature.

[3] A uniform color scale was used in all figures unless otherwise noted. These peak values are offscale on the figure.

the plume at that time, suggesting that the previously seen filament of the plume near the gate was short lived. By 39 minutes after release (Figure 2-5), turbidity within the CAD cell was reduced to approximately 30 NTU (75 mg/L) near bottom and by 55 minutes after release (Figure 2-6) it was further reduced to 20 NTU (50 mg/L). During both these intervals some evidence of elevated turbidity was seen just outside the CAD cell, probably emanating from seam slits in the silt curtain or possibly caused by some low-level turbidity seepage through the curtain itself. Even so, the highest turbidity observed outside was approximately 12 NTU (30 mg/L). Finally after 84 minutes (Figure 2-7), turbidity within the CAD cell was approaching background at 10 NTU (25 mg/L).

Disposal Plume May 21, 2009

On May 21, 2009, a disposal plume was surveyed during a dredged material release from a hopper barge. The material placed into the CAD cell was dredged during City dredging operations at the Gifford Street Boat Ramp, located just north of the hurricane barrier. The barge hoppers were opened at 08:18 hours and no excavator was necessary to help release the material. The currents in the harbor were at ebb during the approximately 1 hour monitoring period (published high tide was 05:48). Outside the cell, currents were as strong as 30 cm/s to the south on the west side of the cell and 15 cm/s to the south on the east side. Currents inside the silt curtain were too weak to measure at less than 2 cm/s.

Part 3 of Appendix C documents the turbidity and TSS observations at the CAD cell on May 21th. Figure 3-1 presents background conditions before the release. Inside and outside the silt curtain, turbidity was < 2 NTU and TSS was <5 mg/L. Figure 3-2 presents turbidity observed 1 to 6 minutes after release; a very strong plume signal was present near-bottom inside the silt curtain (65 NTU; 136 mg/L)[3]. Outside the silt curtain there was no evidence of the plume. Between 5 and 9 minutes after release (Figure 3-3), the plume concentration remained high at approximately 50 NTU (125 mg/L) near-bottom as well as higher in the water column near the center of the cell. During this time interval, elevated turbidity was seen outside the CAD cell at concentrations as high as 20 NTU (50 mg/L). These were the highest values observed outside the cell during any of the surveys. They are probably the result of some of the plume escaping when the gate was opened to allow the tug and barge to exit. By 18 minutes after release (Figure 3-4), turbidity inside the CAD cell had dissipated to approximately 25 NTU (62 mg/L), by 39 minutes after release (Figure 3-5) it had dissipated to 15 NTU (38 mg/L), and by 51 minutes after release (Figure 3-6) it had further dissipated in size if not in concentration (15 NTU; 38 mg/L). Outside the silt curtain there was no evidence of the plume at these times. Finally, after 57 minutes (Figure 3-7) turbidity within the CAD cell was observed just above background at approximately 8 NTU (20 mg/L).

Disposal Plume May 27, 2009

On May 27, 2009, a disposal plume was surveyed during release of dredged material from the City dredging project at the Niemiec Boat Yard. The dredged material was released from a hopper barge although an excavator was used to help push some of the material out of some of the hopper bins. The barge hoppers were opened at 08:16. The currents in the harbor were at flood during the approximately 70 minute monitoring period (published low tide was 04:37). Outside the cell currents were 20-25 cm/s to the north on the west side of the cell and weak and variable to 10 cm/s northward on the east side. Currents inside the silt curtain were less than 2 cm/s.

Part 4 of Appendix C documents the turbidity and TSS observations at the CAD cell on May 27th. Figure 4-1 presents background conditions before the barge entered the CAD cell. Inside and outside the silt curtain, turbidity was < 2 NTU and TSS was <5 mg/L. Figure 4-2 presents turbidity observed 3 to 6 minutes after release; a very strong plume signal was present near-bottom inside the silt curtain (110 NTU; 260 mg/L)[3]. Note the change in the turbidity scale used in this figure and the next. Outside the silt curtain there was no evidence of the plume. Between 5 and 9 minutes after release (Figure 4-3), the plume concentration remained high at approximately 100 NTU (247 mg/L) near-bottom. Again there was

no evidence of the plume outside the silt curtain. By 31 minutes after release (Figure 4-4), turbidity inside the CAD cell had dissipated to approximately 25 NTU (62 mg/L) and by 50 and 54 minutes after release (Figure 4-5 and 4-6) it had further dissipated to 15 NTU (38 mg/L). Outside the silt curtain there was no evidence of the plume. Finally, after 63 minutes (Figure 4-7) turbidity within the CAD cell was nearing background at approximately 13 NTU (32 mg/L).

Disposal Plume July 8, 2009

On July 8, 2009, a disposal plume was surveyed during a dredged material release from a hopper barge. The material placed into the CAD cell was dredged during City dredging operations at the Packer Pier, located on the New Bedford Harbor shoreline between the Route 6 and Route 195 bridges. The silt curtain gate was left open during the dump and the survey; the silt curtain being no longer required at this time of year under the conditions of the dredging permit. The barge hoppers were opened at 12:04 and no excavator was necessary to help release the material. The barge had been on a mooring in the CAD cell since the previous afternoon and it was not moved out of the CAD cell after release. In addition, two other barges were moored in the cell alongside the dredged material barge. As a result, the inner survey boat did not have access to the center area of the CAD cell. The currents in the harbor were at ebb during the approximately 1 hour monitoring period (published high tide was 09:20). Outside the cell, currents were 20-25 cm/s to the south on the west side of the cell and 10-20 cm/s to the south on the east side. Currents inside the silt curtain were less than 2 cm/s.

Part 5 of Appendix C documents the turbidity and TSS observations at the CAD cell on July 8th. Figure 5-1 presents background conditions before the release. Inside and outside the silt curtain, turbidity was < 2 NTU and TSS was <5 mg/L. Figure 5-2 presents turbidity observed 1 to 4 minutes after release; a strong plume signal was present inside the silt curtain near-bottom at 45 NTU (112 mg/L) extending to near the surface at 18 NTU (45 mg/L). Outside the silt curtain there was no evidence of the plume. Between 9 and 16 minutes after release (Figure 5-3), the plume had nearly dissipated inside the cell except for a relatively high concentration (20 NTU; 50 mg/L) within 1 m of the bottom. No plume was observed outside the cell at this time. The transects performed 15, 26, and 46 minutes after release (Figures 5-4 through 5-6) all observed low turbidity concentrations (<20 NTU; <50 mg/L) inside the cell and no turbidity above background outside the cell. Finally, after 58 minutes (Figure 5-7), turbidity within the CAD cell was just above background at approximately 6 NTU (15 mg/L).

That no evidence of the plume was observed outside the open curtain gate seemed at first surprising, but there were factors that kept the plume contained despite the open gate. First, the plume dissipated quickly and after the first few minutes it was limited to the lower ¼ of the water column within the excavated part of the cell where it was confined by the shoulder slope; and second, the gate was located on the west side of the cell where the tidal current in large part simply passed by the gate without flowing into or out of the cell.

Summary

A number of general observations can be made and conclusions drawn based on an overview of the results from the five CAD cell disposal plume surveys performed during this study, including:

- Water column plumes created during disposal of dredged material into the CAD cell were nearly completely contained within the CAD cell silt curtain.
- Inside the silt curtain, turbidities were observed as high as 110 NTU with TSS concentrations as high as 260 mg/L.

- Outside the silt curtain, the highest turbidities observed were only 20 NTU with TSS concentration of 50 mg/L and then only within close proximity to the cell in small filaments of plume which appear to have escaped the silt curtain at one of its seams.
- The presence of the silt curtain nearly eliminated any tidal current within the CAD cell; currents inside the cell were less than 2 cm/s and too weak to measure.
- Within the CAD cell, the bulk of the turbidity plumes were limited to the lower half of the water column, down within the excavated cell, with the highest values usually within 1 or 2 meters of the bottom.
- All the plumes dissipated to near background levels within 1 to 1-1½ hours.
- During near slack tide conditions the disposal plumes largely pooled beneath the barge within the cell but during flood or ebb tides some of the plume collected against the inside of the silt curtain on the north or south side, respectively.
- There were no significant reductions in endpoints for any of the toxicity test species, indicating that there were no measurable acute or sub-lethal impacts to marine organisms from exposure to the plume samples collected.

Literature Cited

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Deines, K. L. 1999. Backscatter Estimation using Broadband Acoustic Doppler Current Profilers. Proceedings IEEE 6th Working Conference on Current Measurement. 249-253.

US EPA. 2002. Methods for Measuring the Acute Toxicity of Effluents to Freshwater and Marine Organisms. Fourth Edition. EPA-821-R-02-012.

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APPENDIX A

New Bedford Harbor Tidal Velocity Structure
Measured with ADCP
March 27, 2009

Part 1: Near-Surface Tidal Velocity

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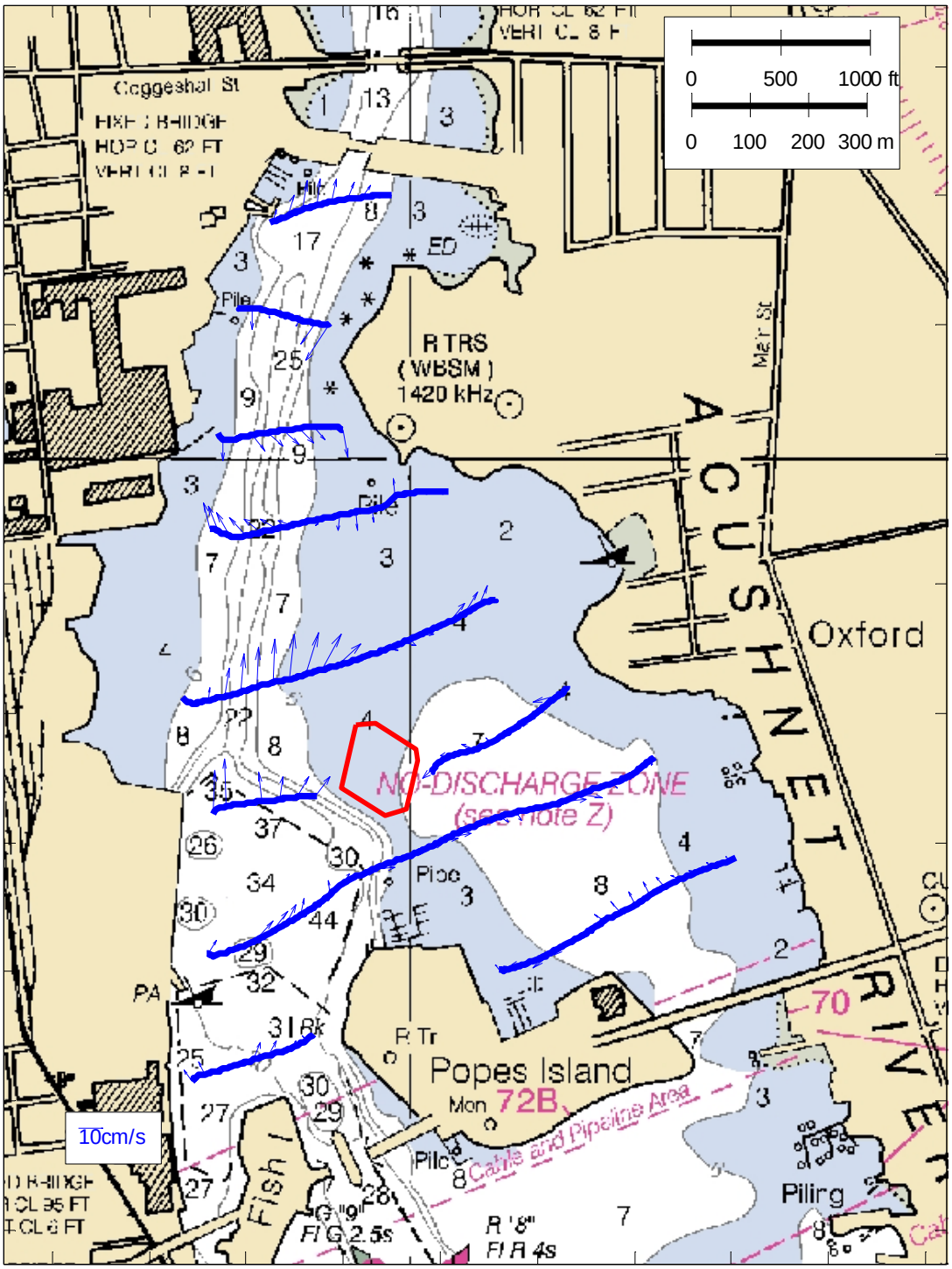
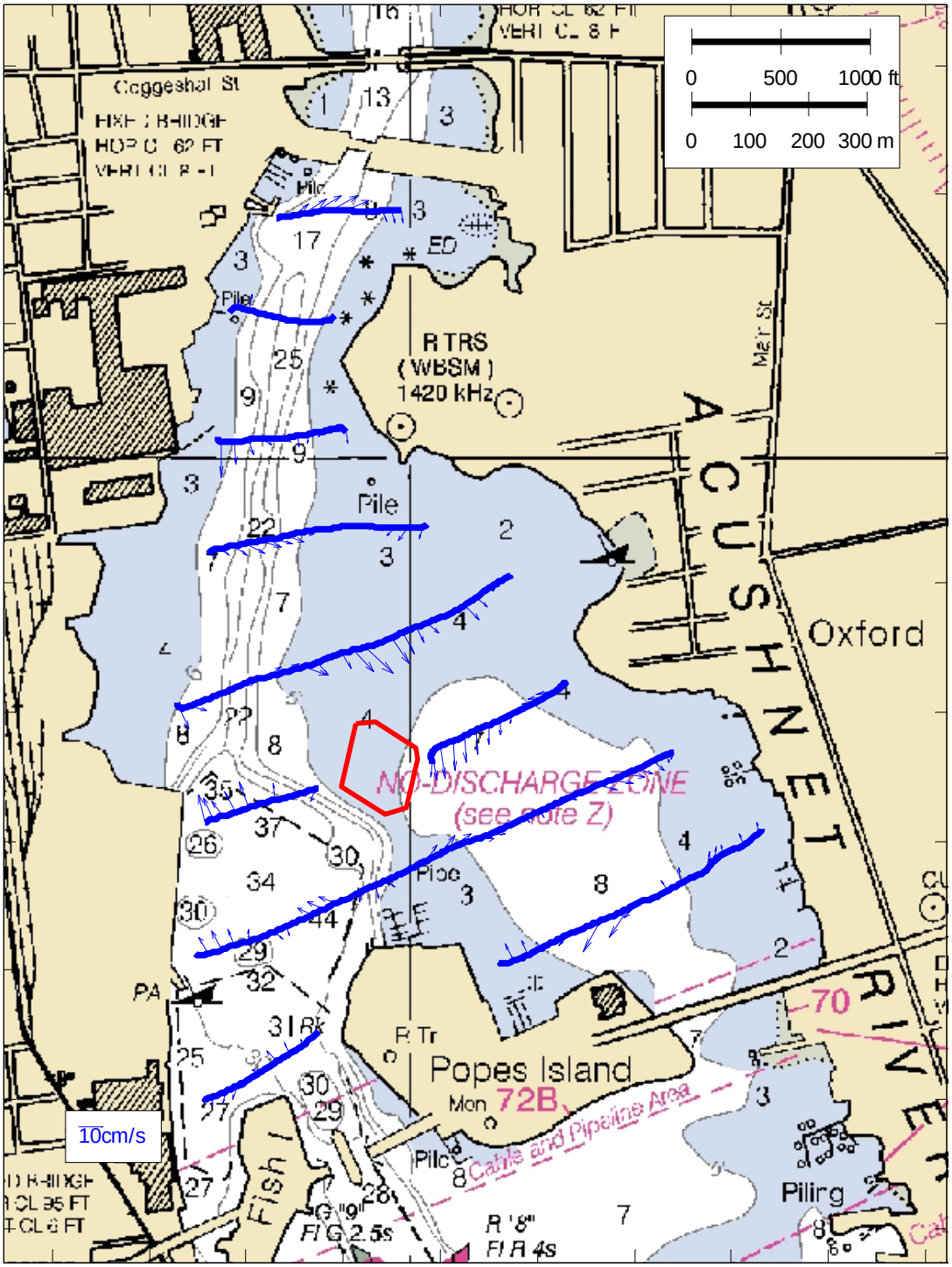
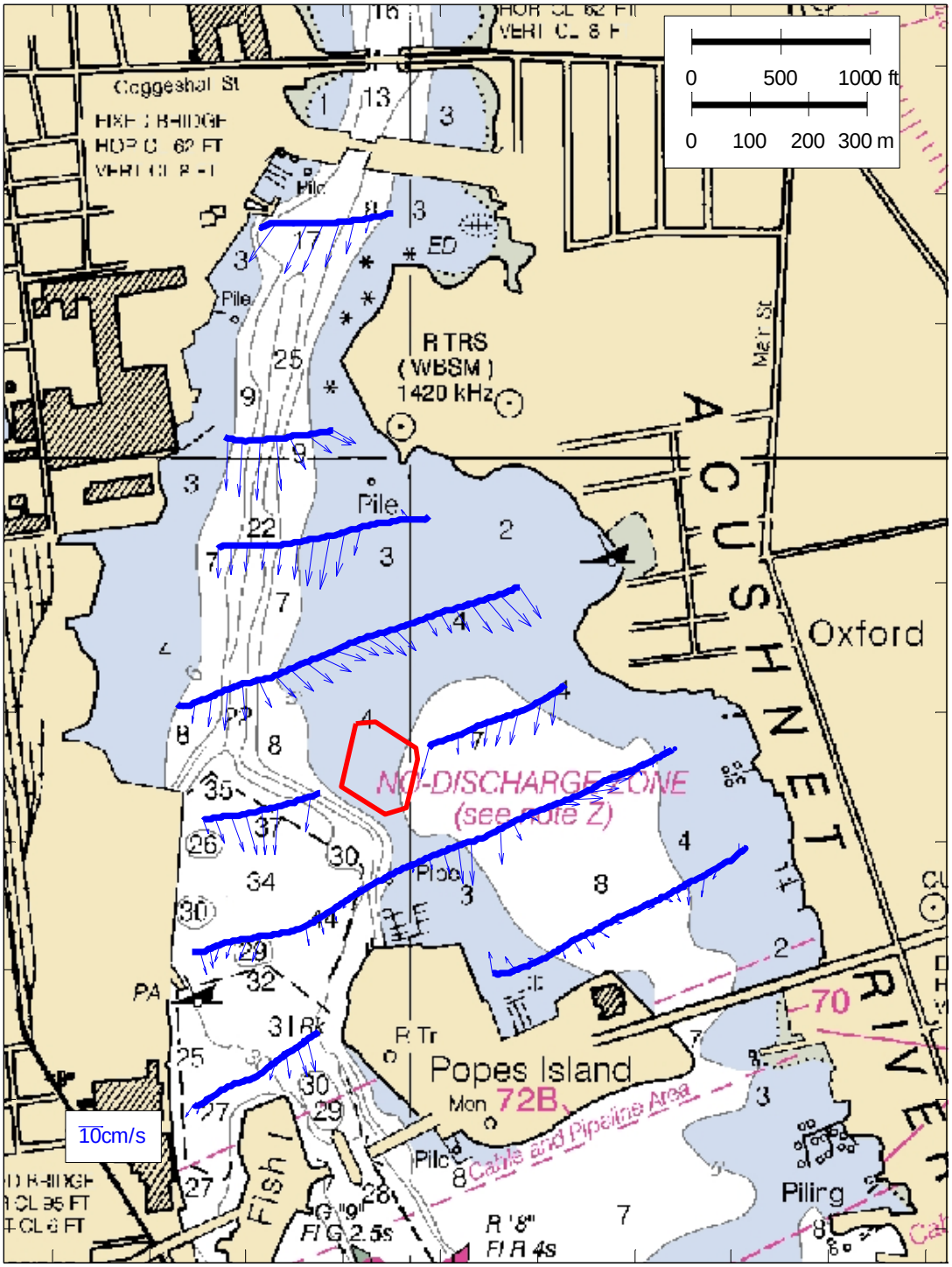
2 HOURS BEFORE HIGH SLACK - Depth 1.21m



1 HOUR BEFORE HIGH SLACK - Depth 1.21m



HIGH SLACK - Depth 1.21m



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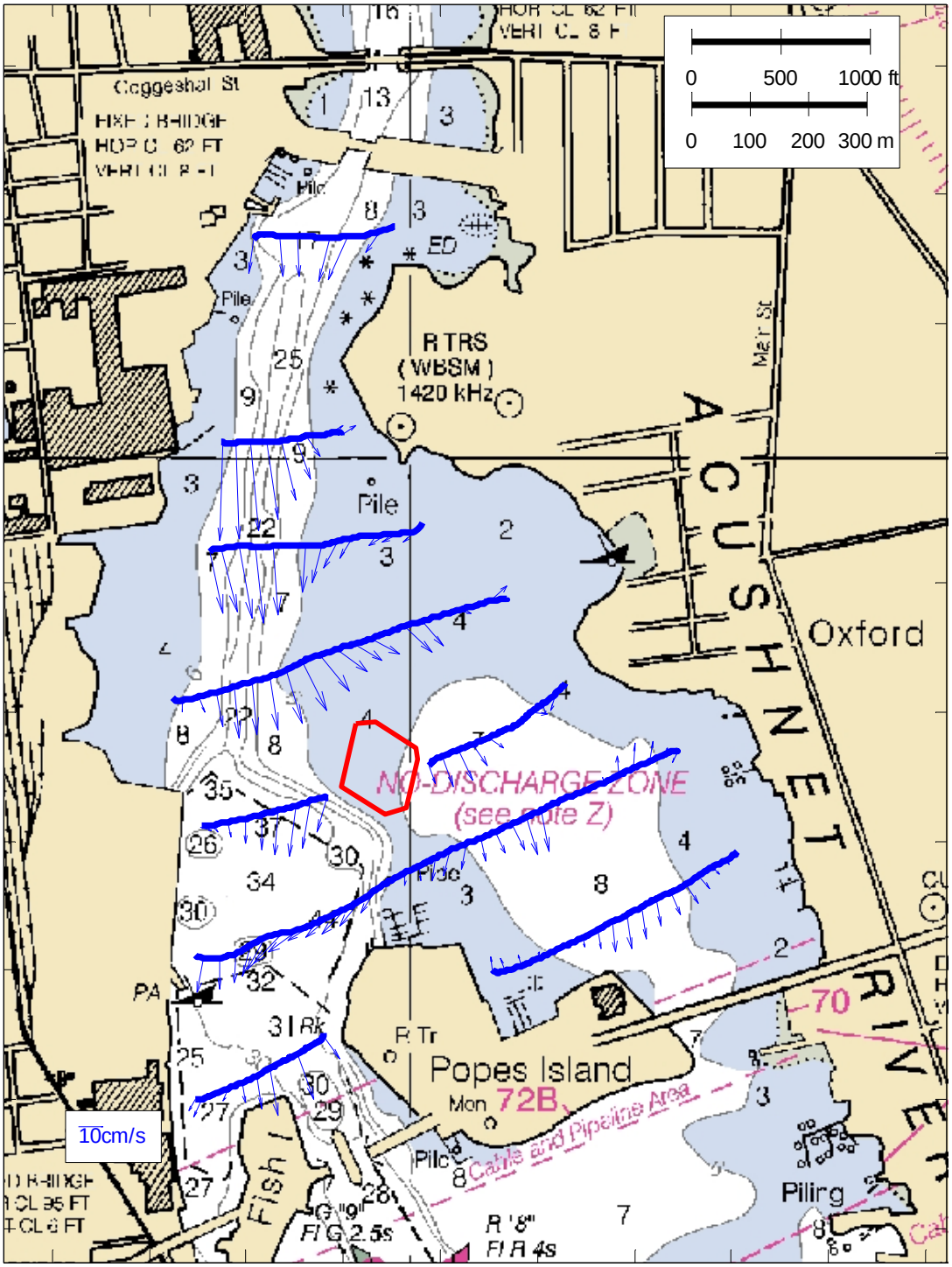
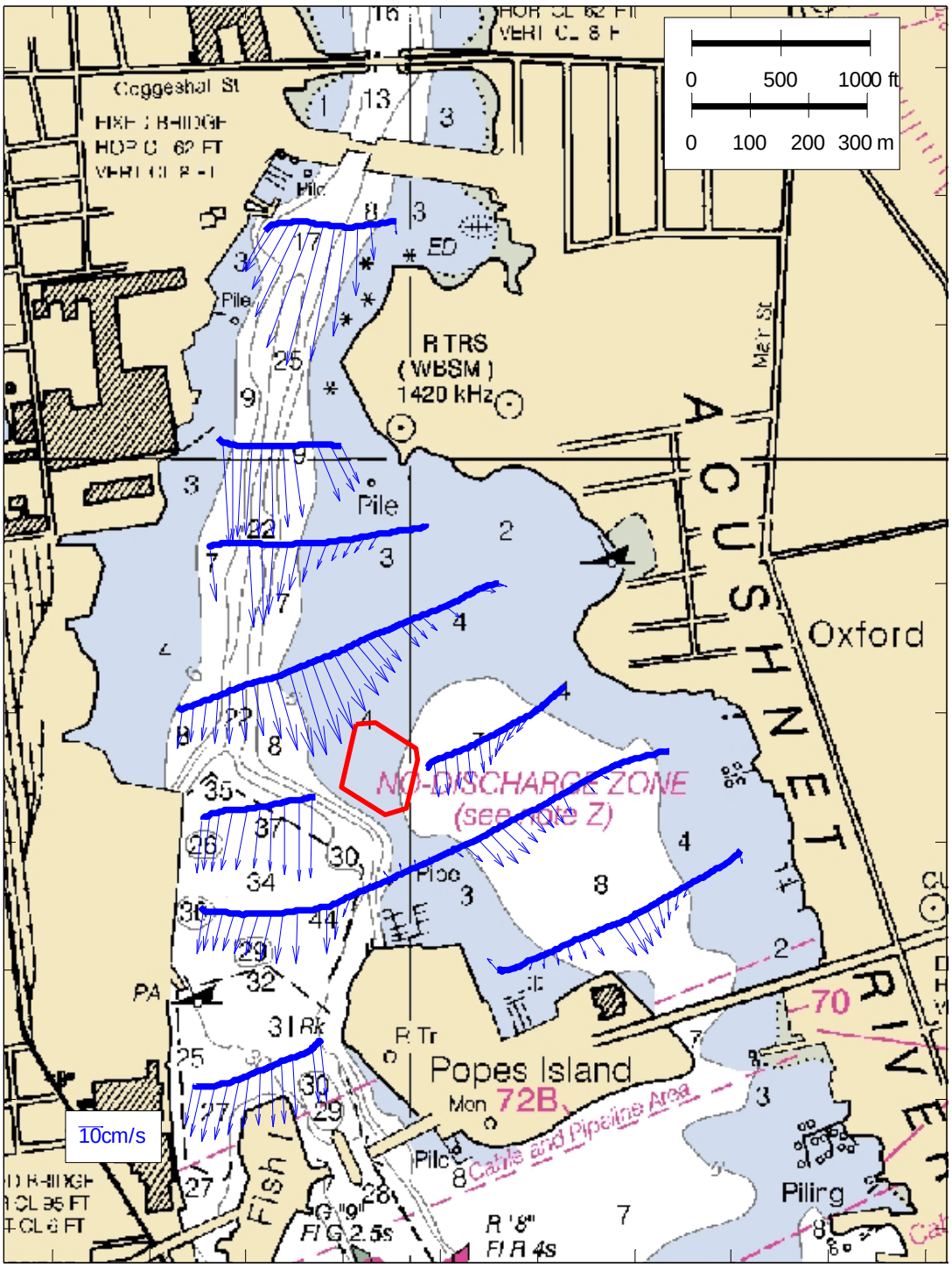
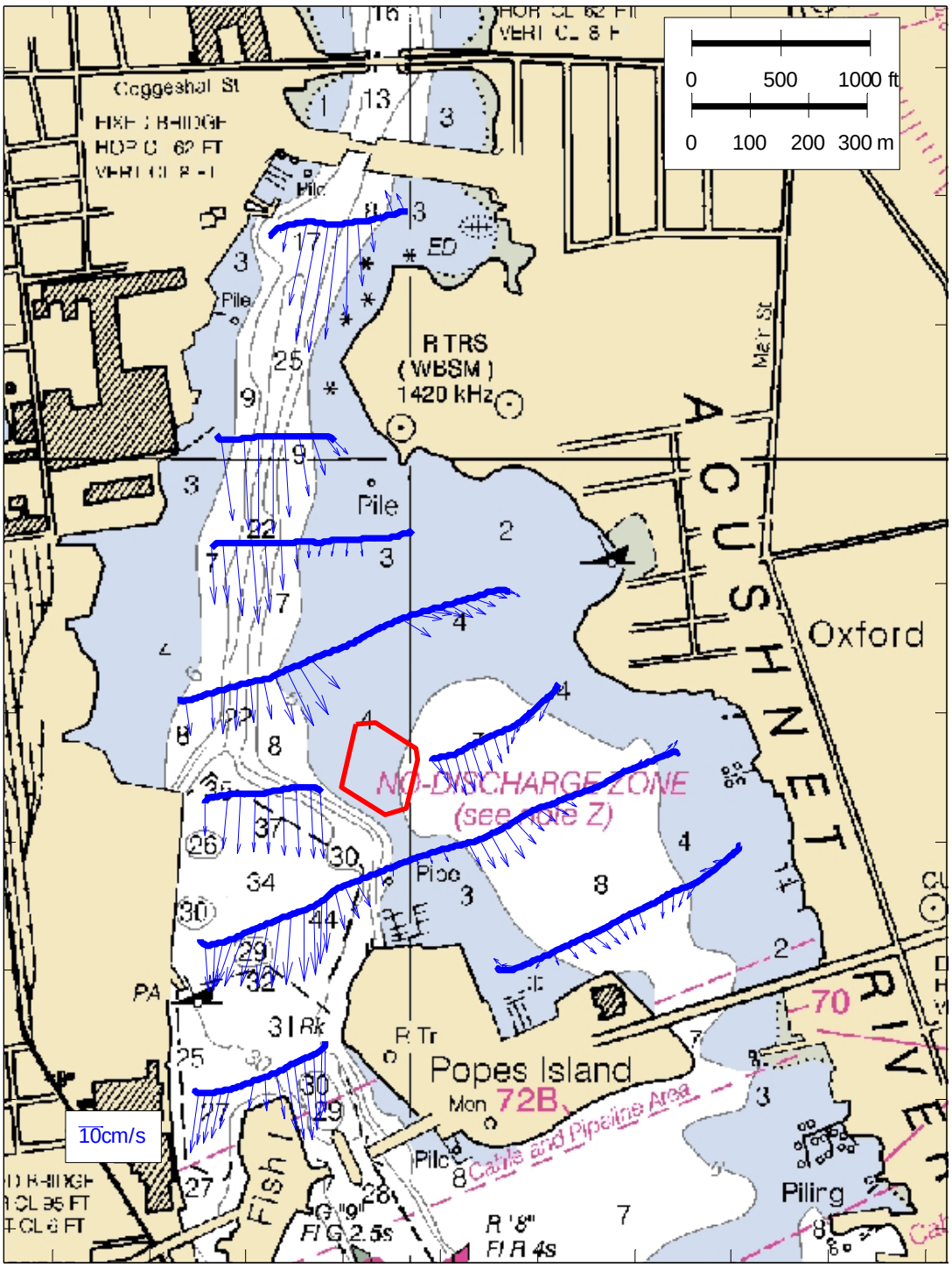


2 HOURS AFTER HIGH SLACK - Depth 1.23m



3 HOURS AFTER HIGH SLACK - Depth 1.24m



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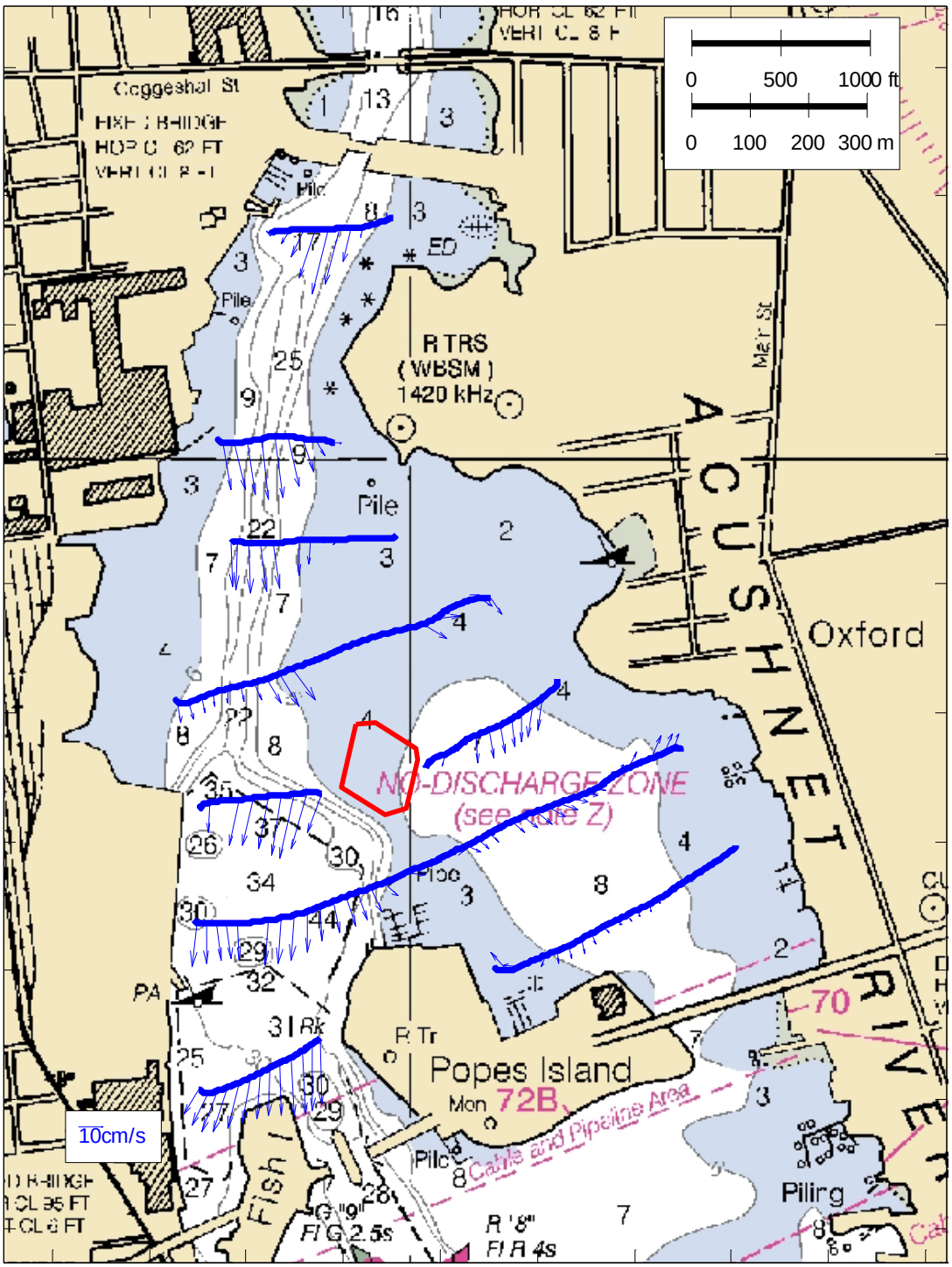
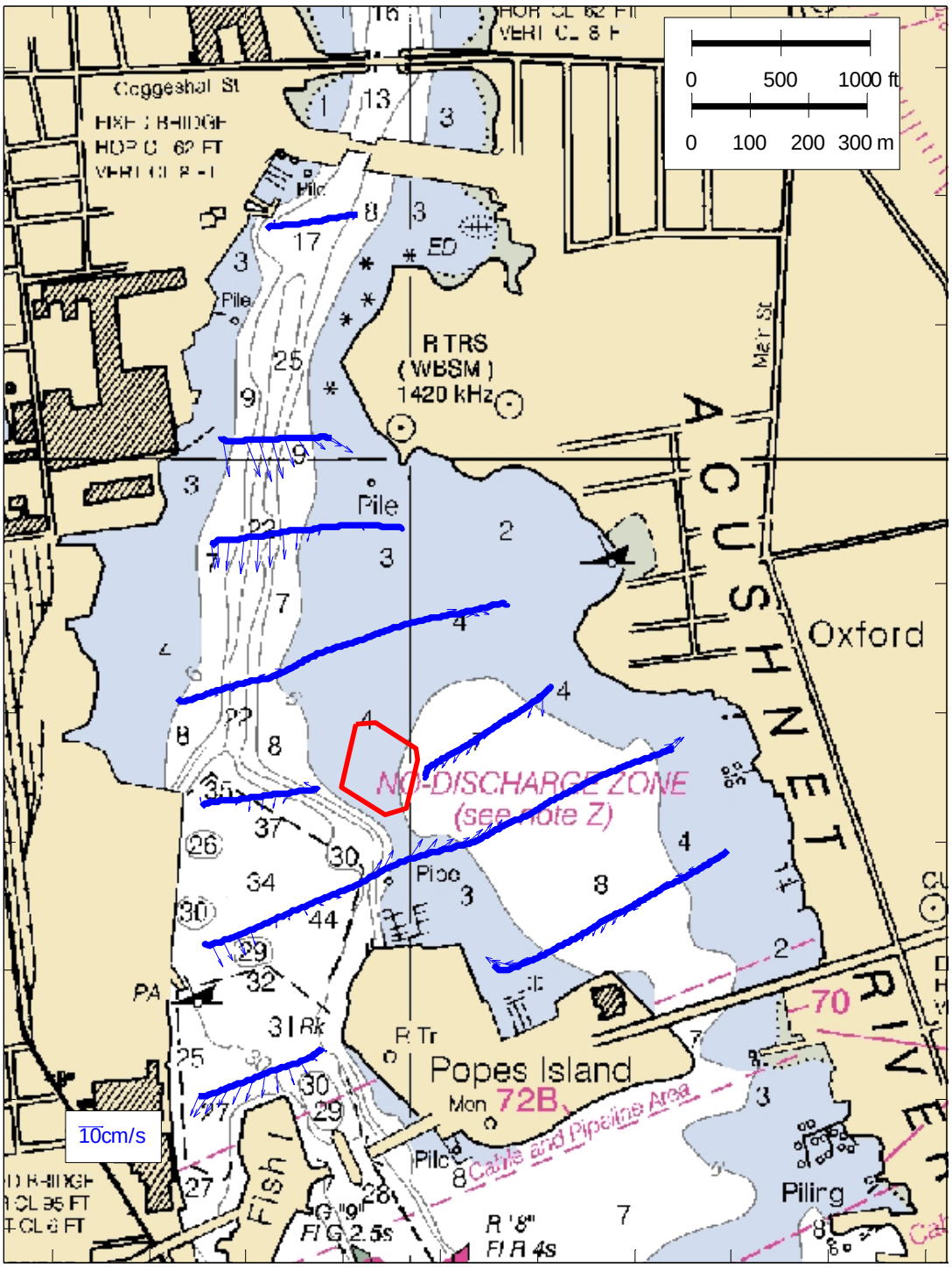
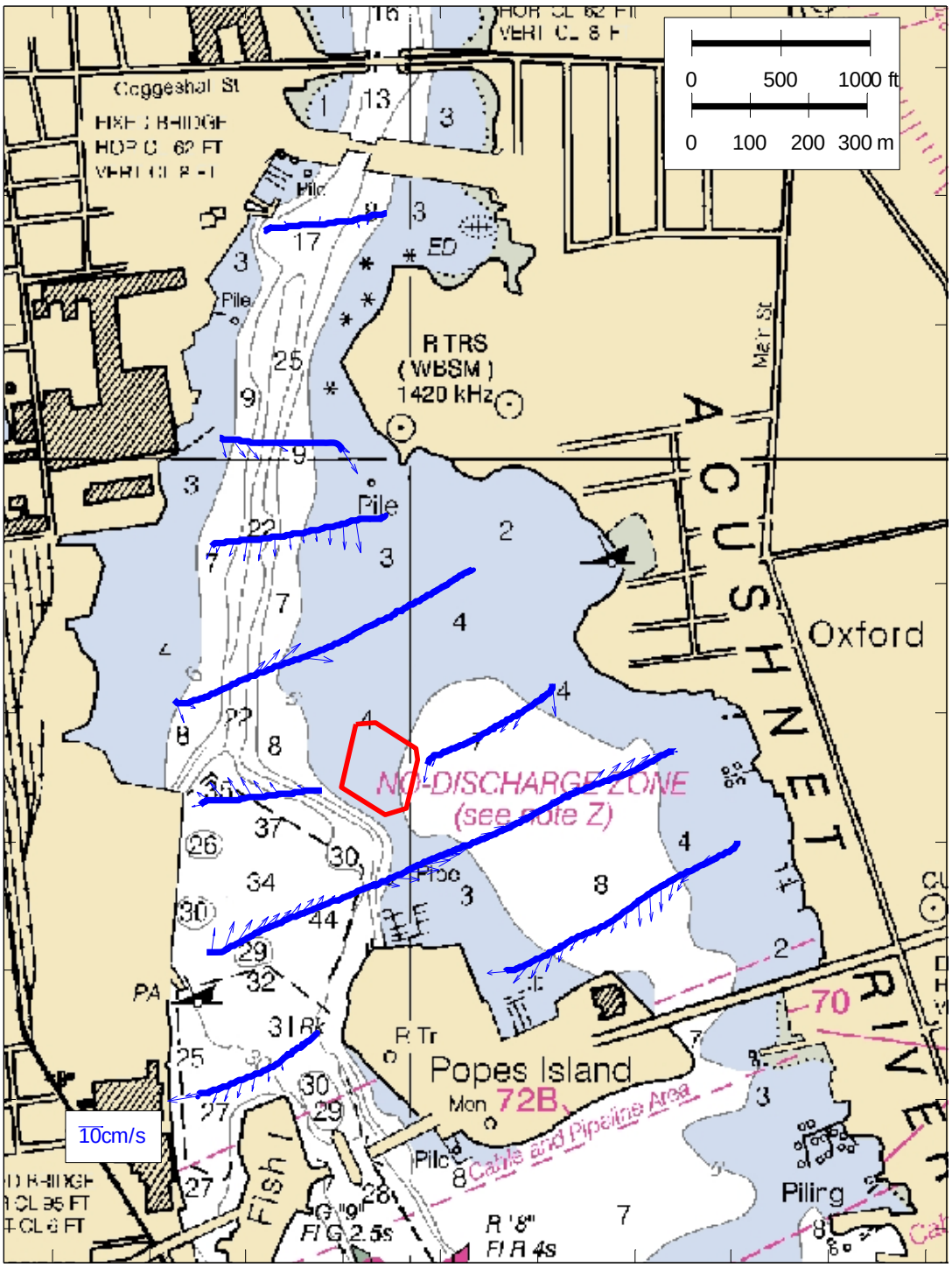


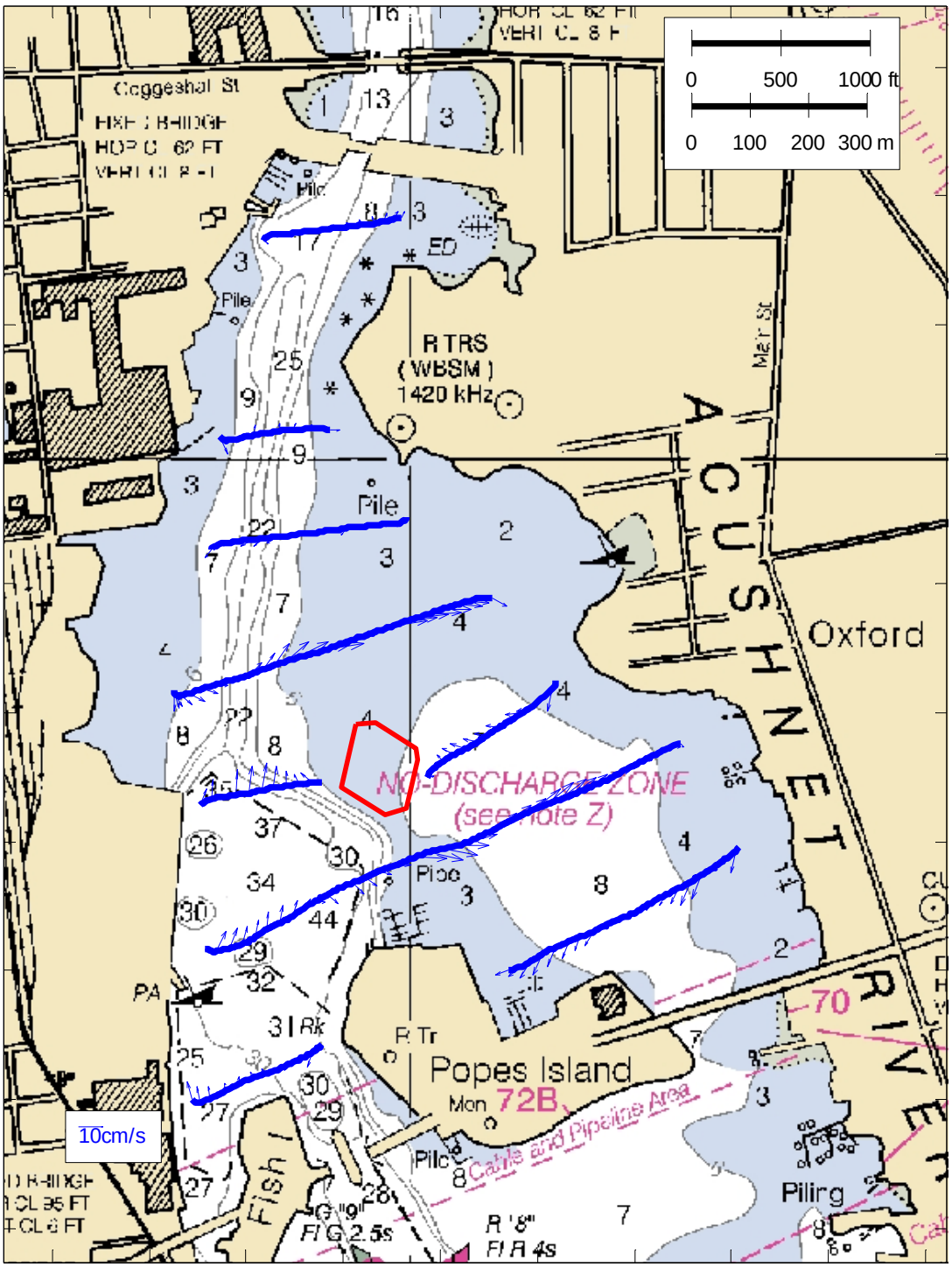
5 HOURS AFTER HIGH SLACK - Depth 1.24m



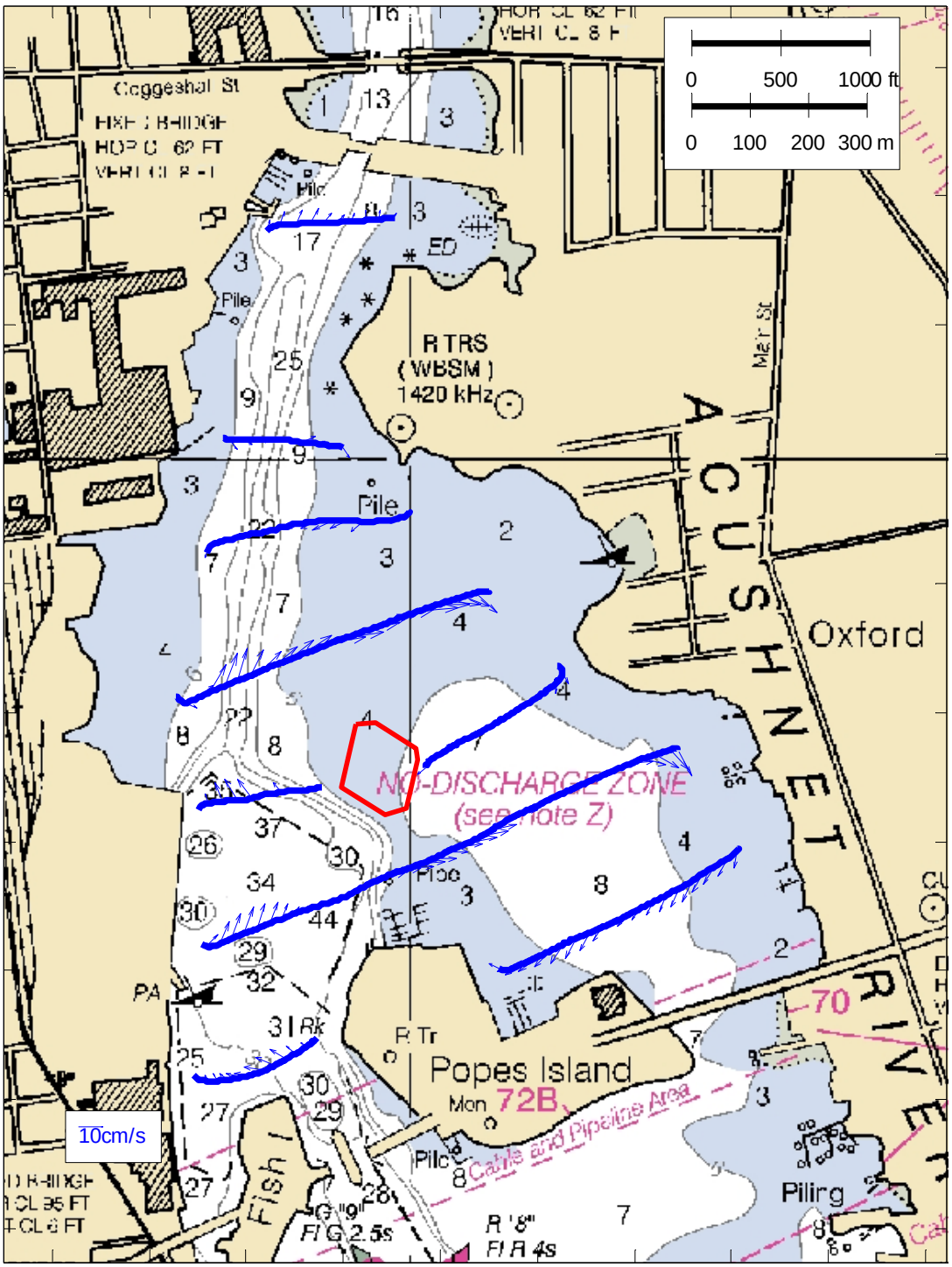
0.5 HOURS AFTER LOW SLACK - Depth 1.24m



1.5 HOURS AFTER LOW SLACK - Depth 1.24m



2.5 HOURS AFTER LOW SLACK - Depth 1.24m



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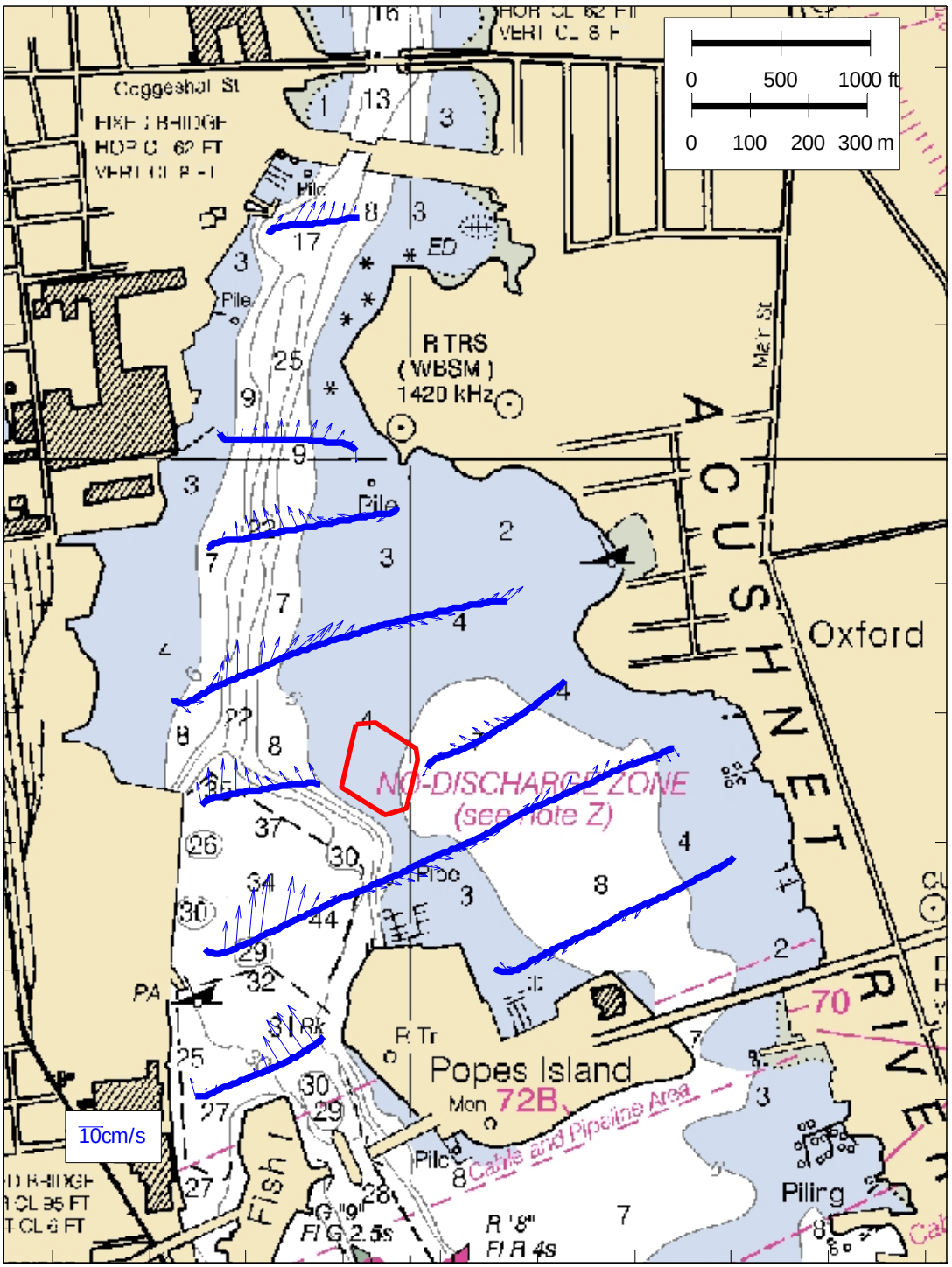
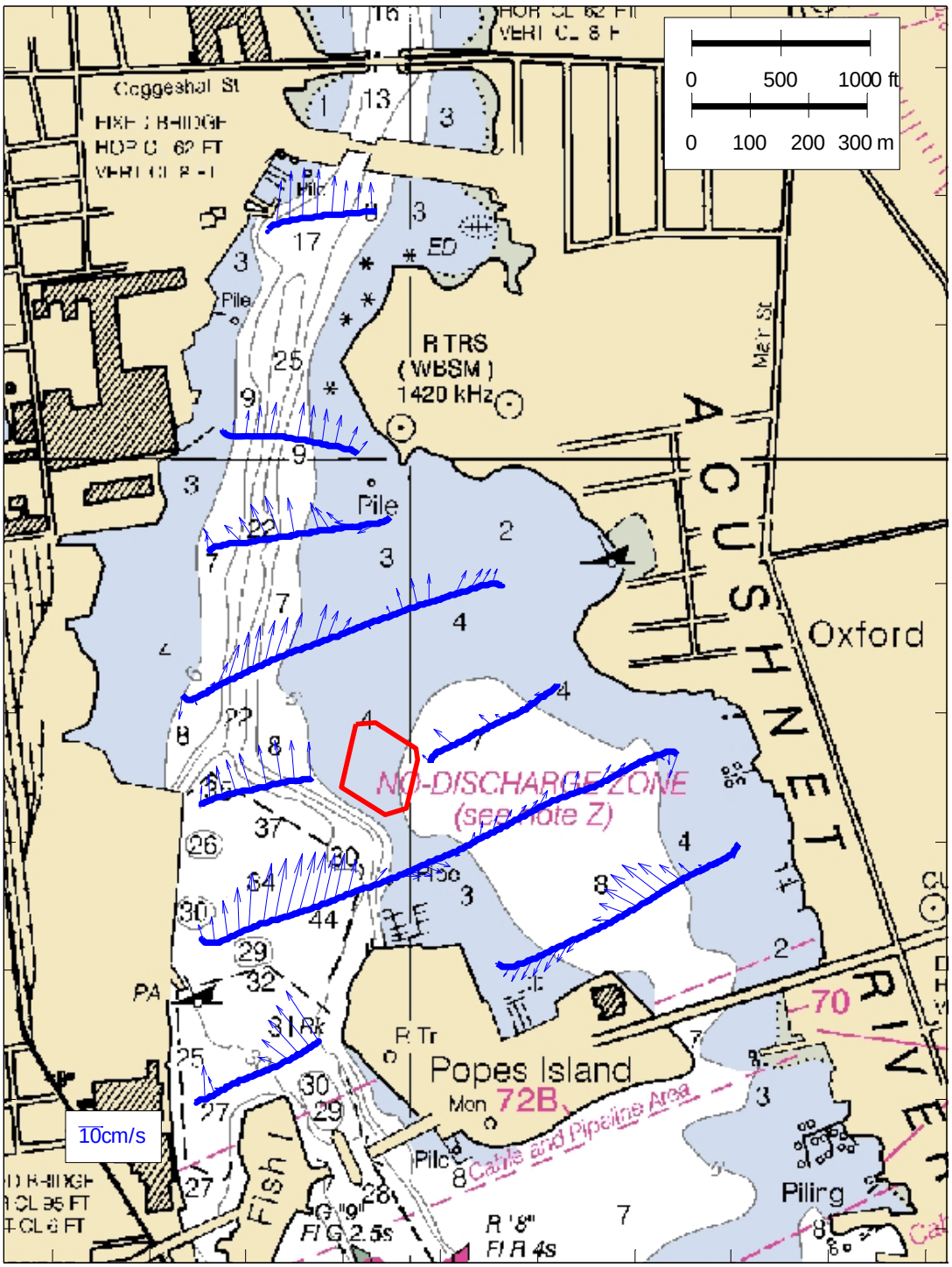


4.5 HOURS AFTER LOW SLACK - Depth 1.24m



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Part 2: Mid-Depth Tidal Velocity

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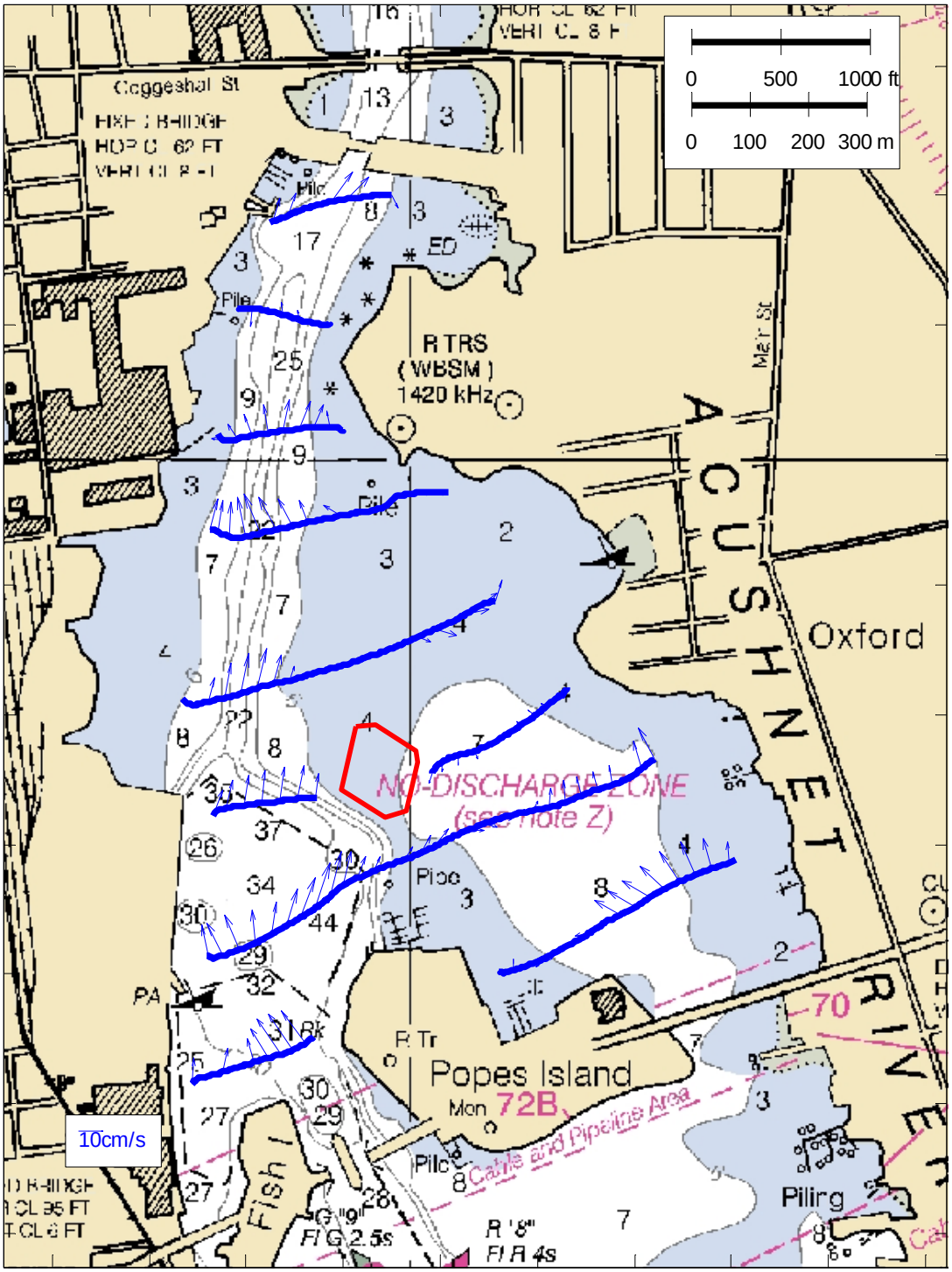
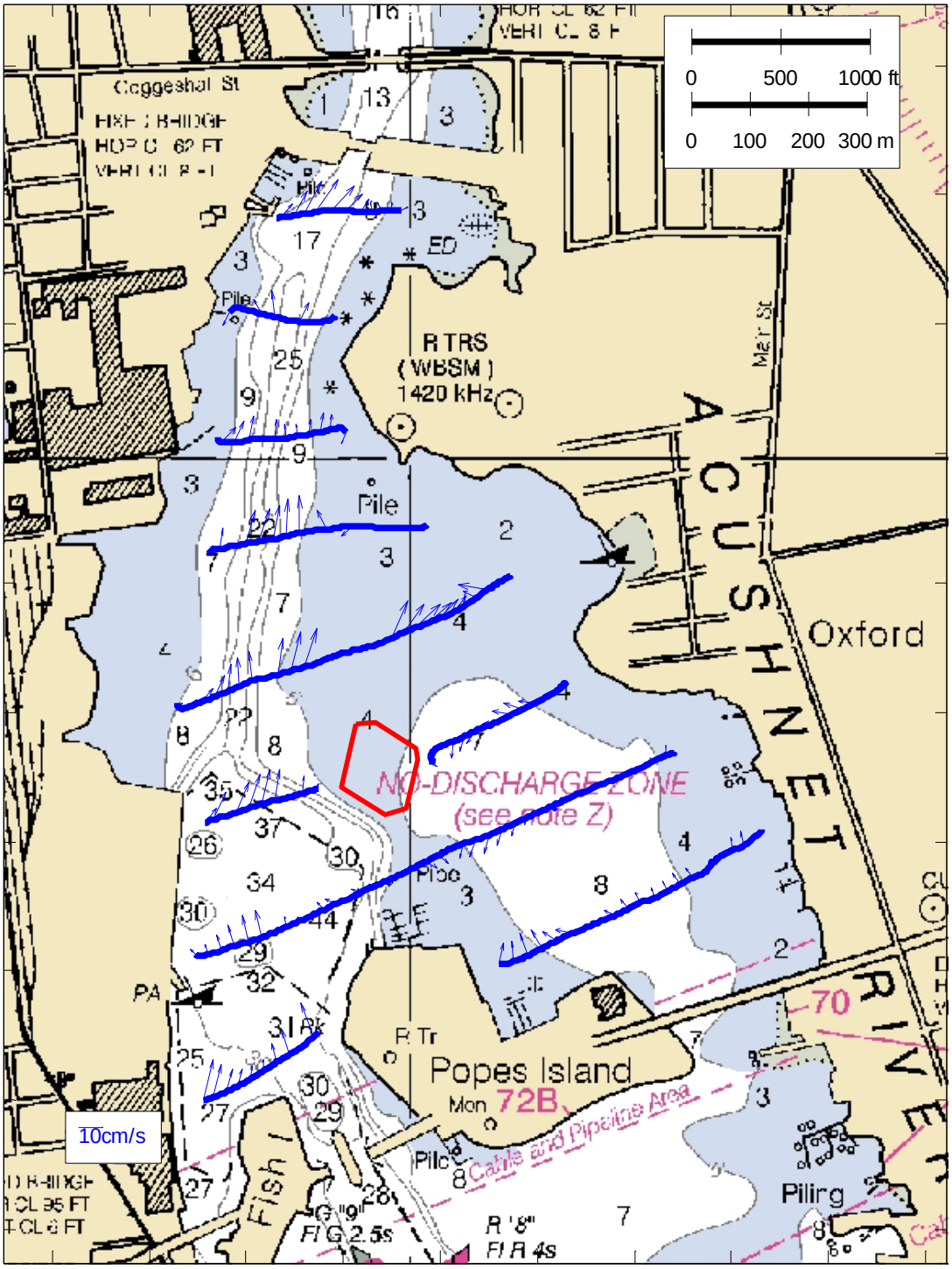
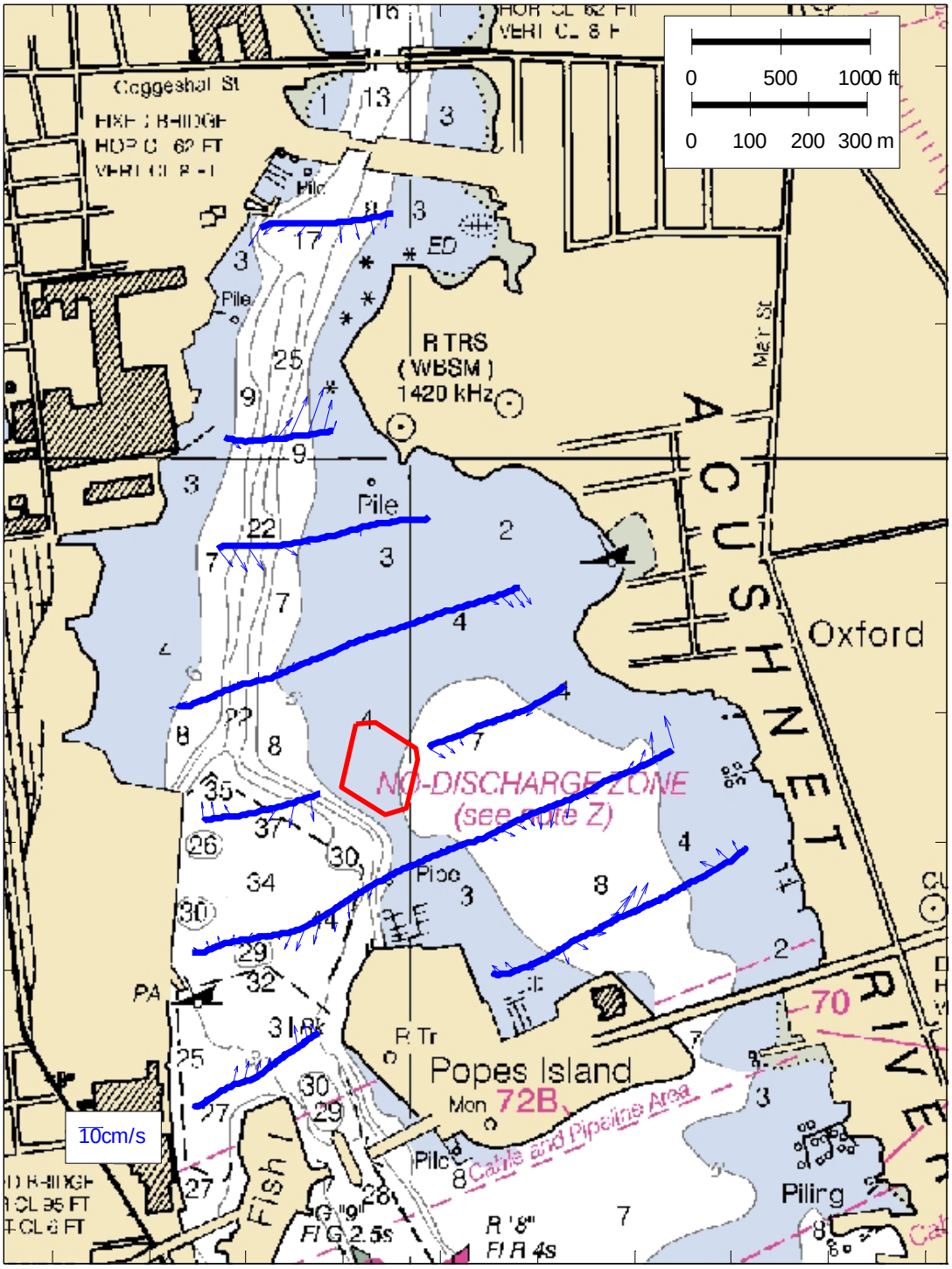
2 HOURS BEFORE HIGH SLACK - Depth 2.21m



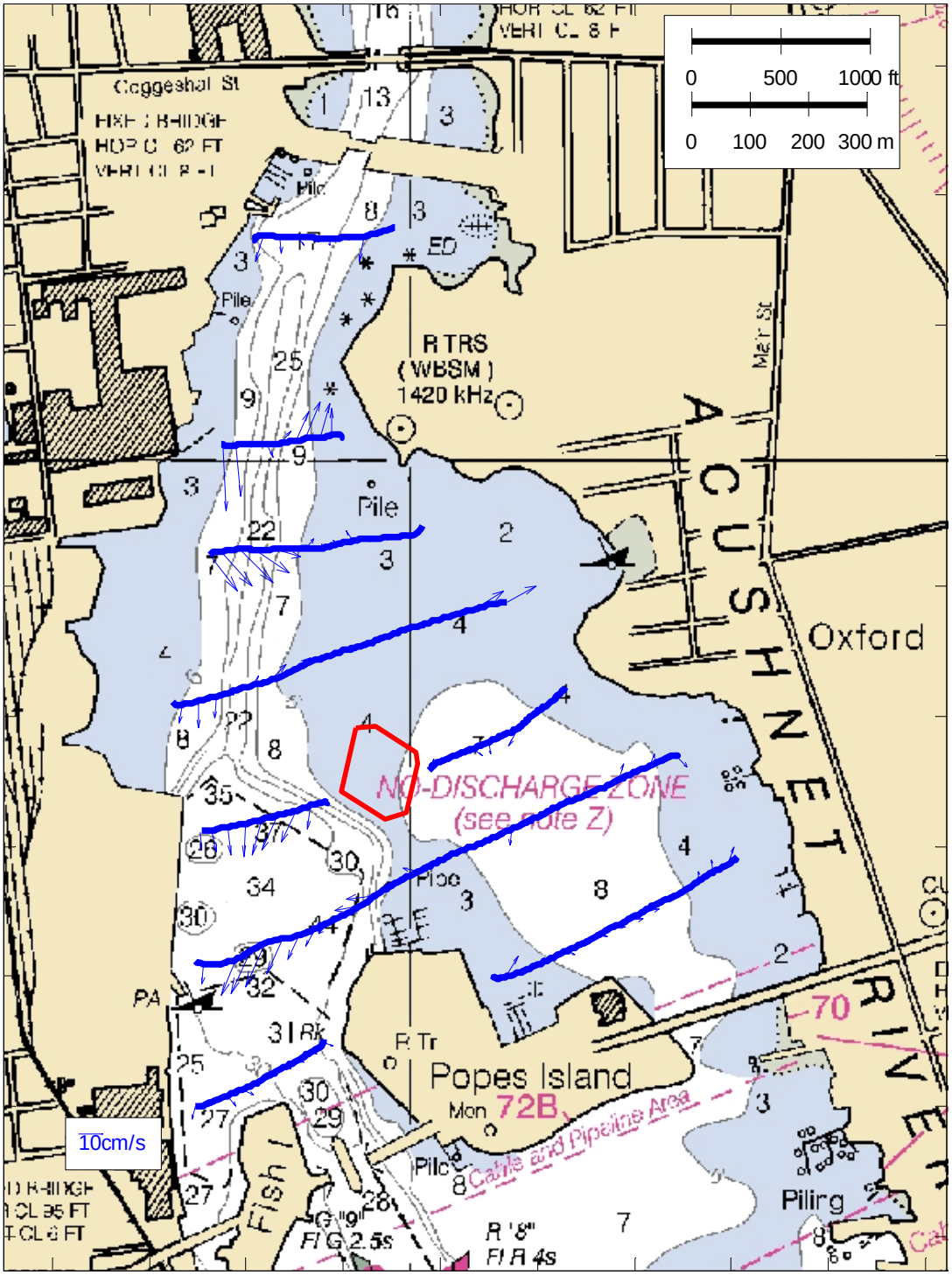
1 HOUR BEFORE HIGH SLACK - Depth 2.21m



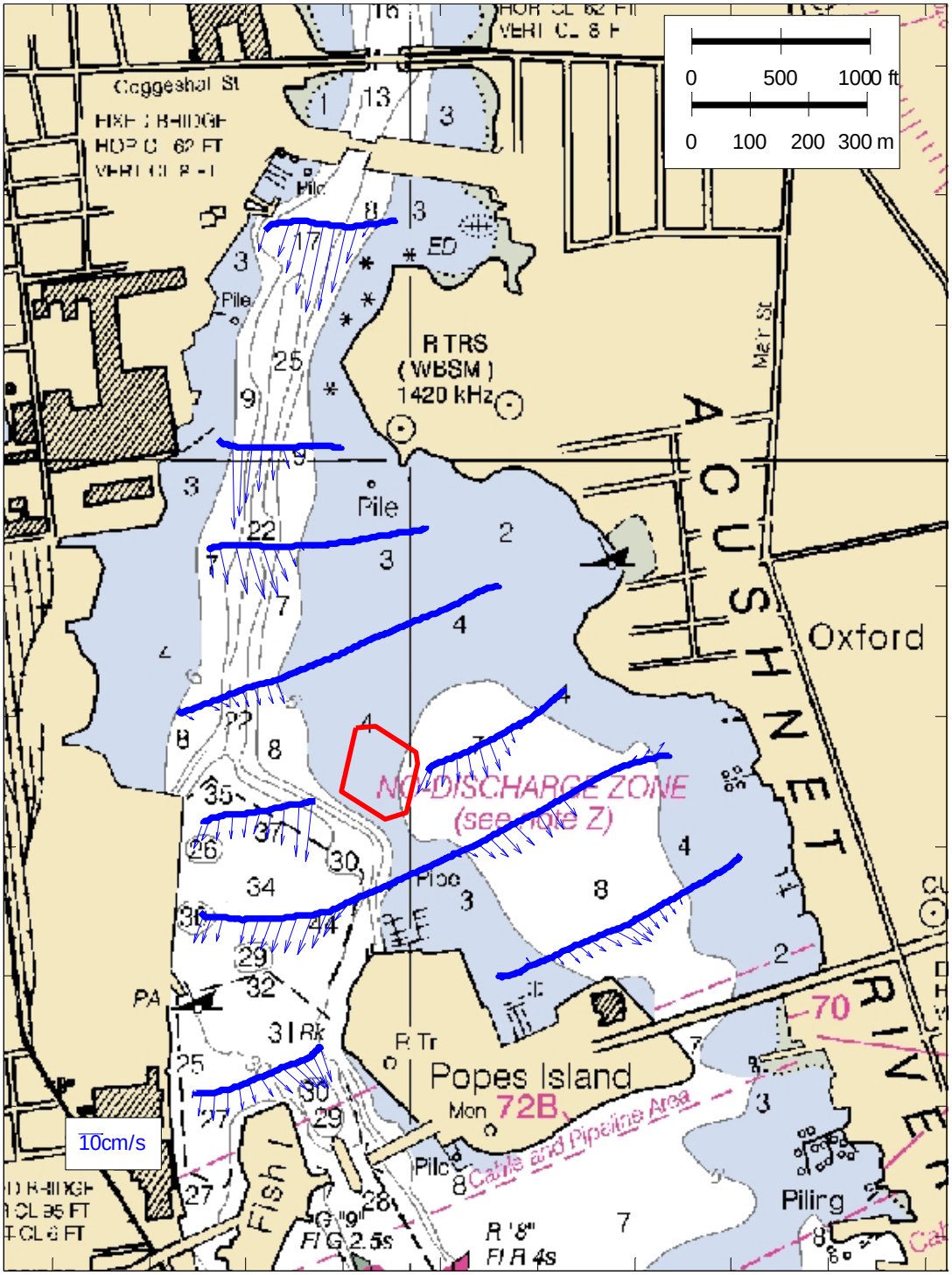
HIGH SLACK - Depth 2.21m



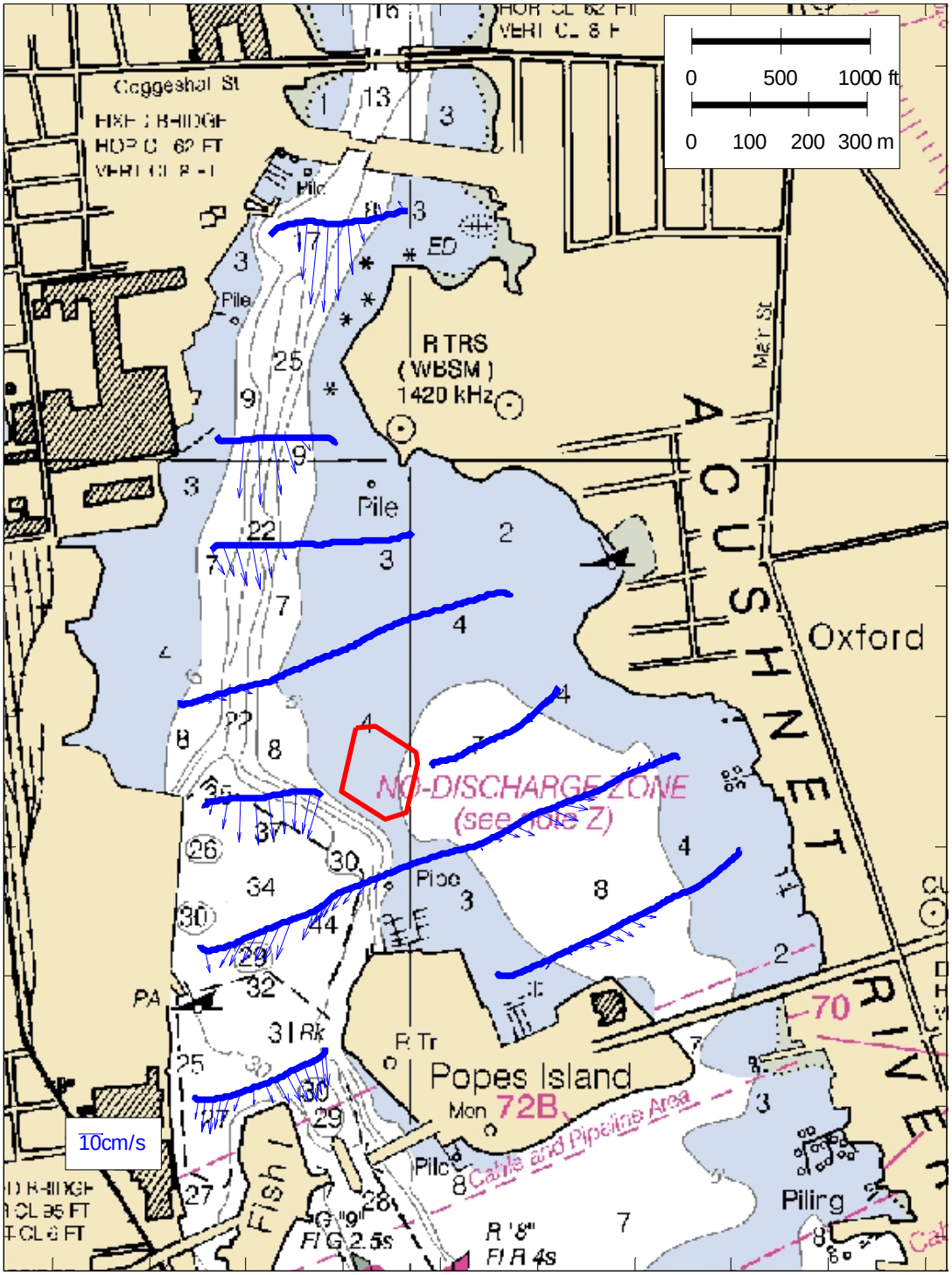
1 HOUR AFTER HIGH SLACK - Depth 2.21m



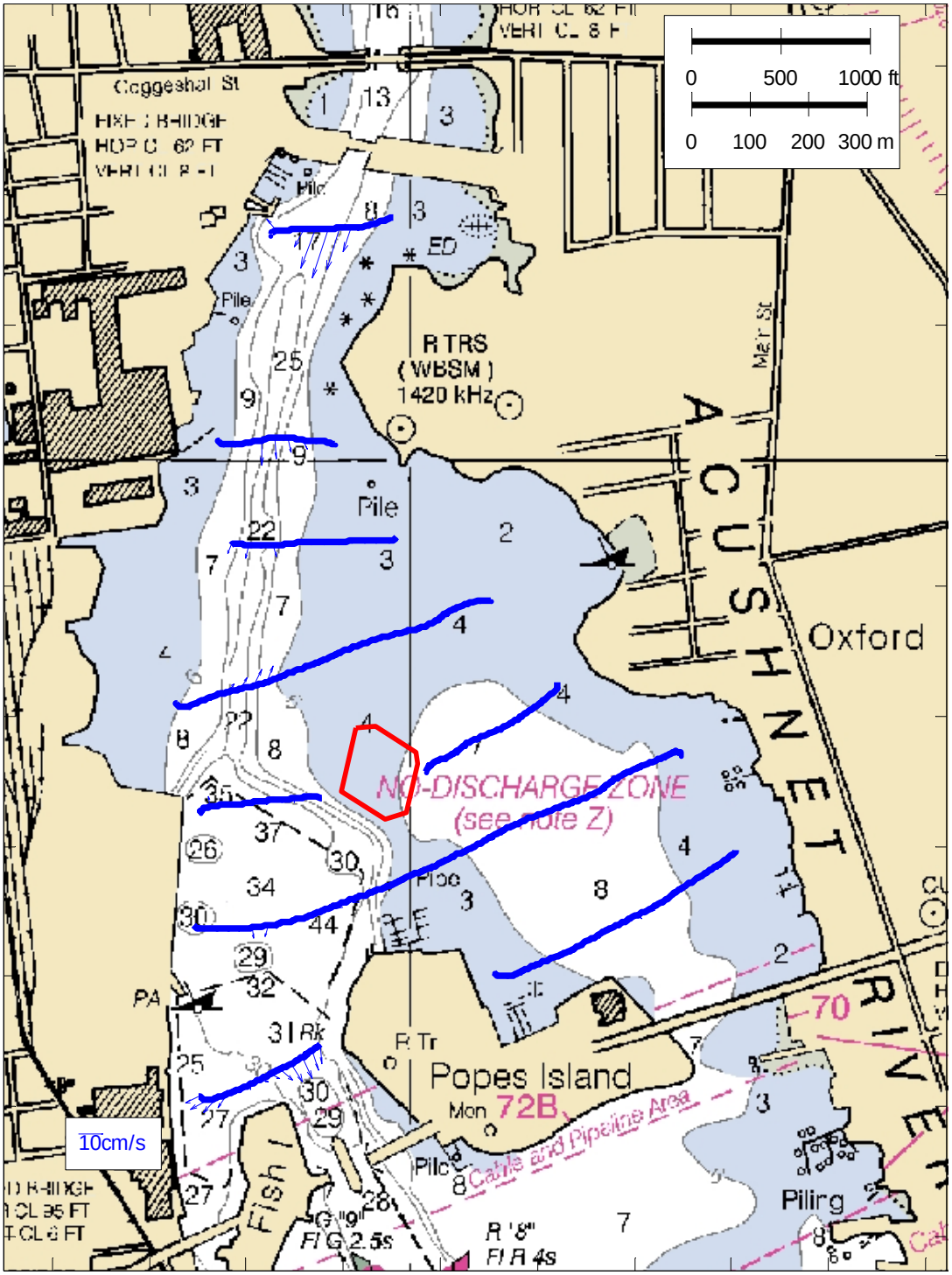
2 HOURS AFTER HIGH SLACK - Depth 2.23m



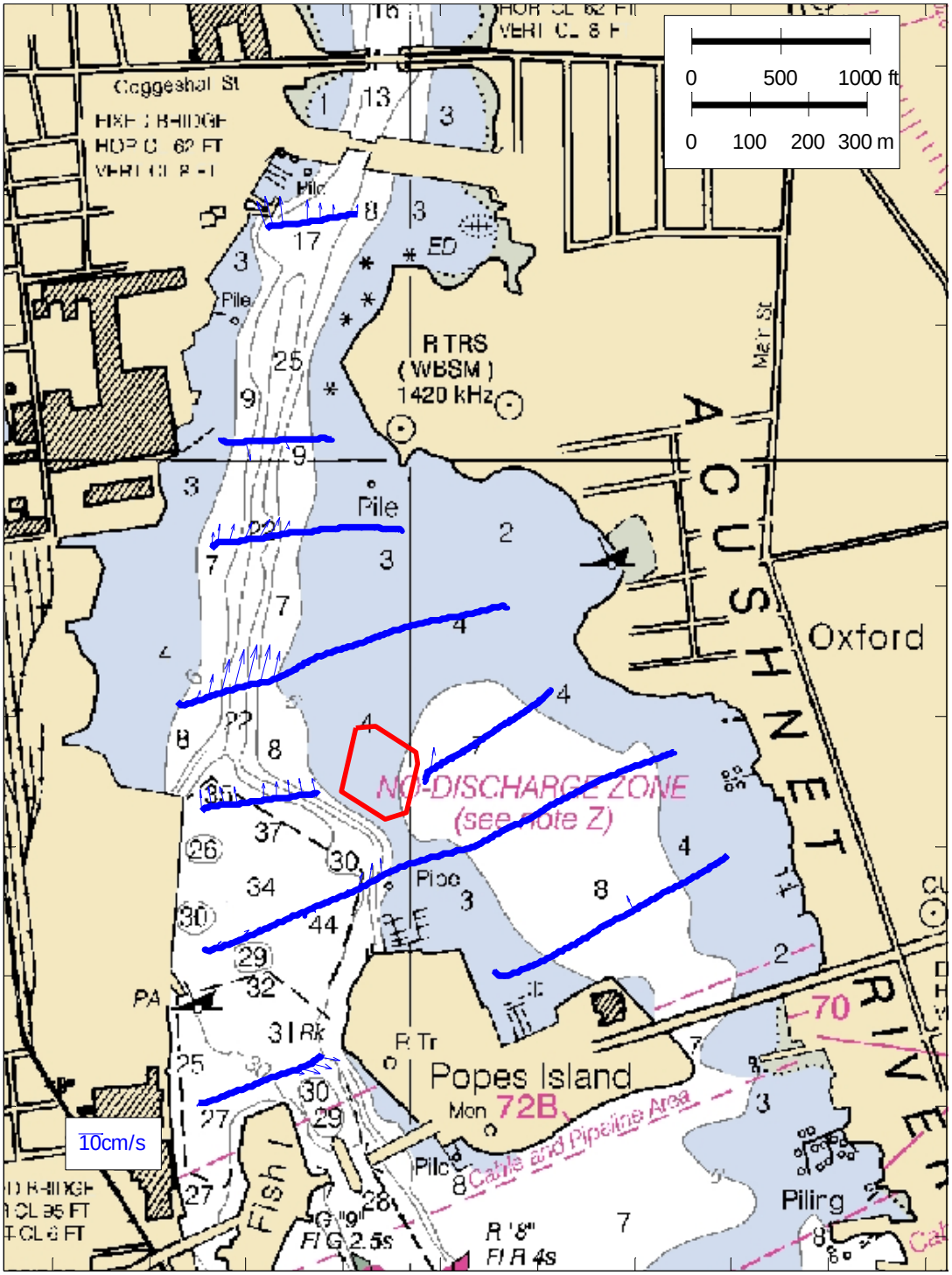
3 HOURS AFTER HIGH SLACK - Depth 2.24m



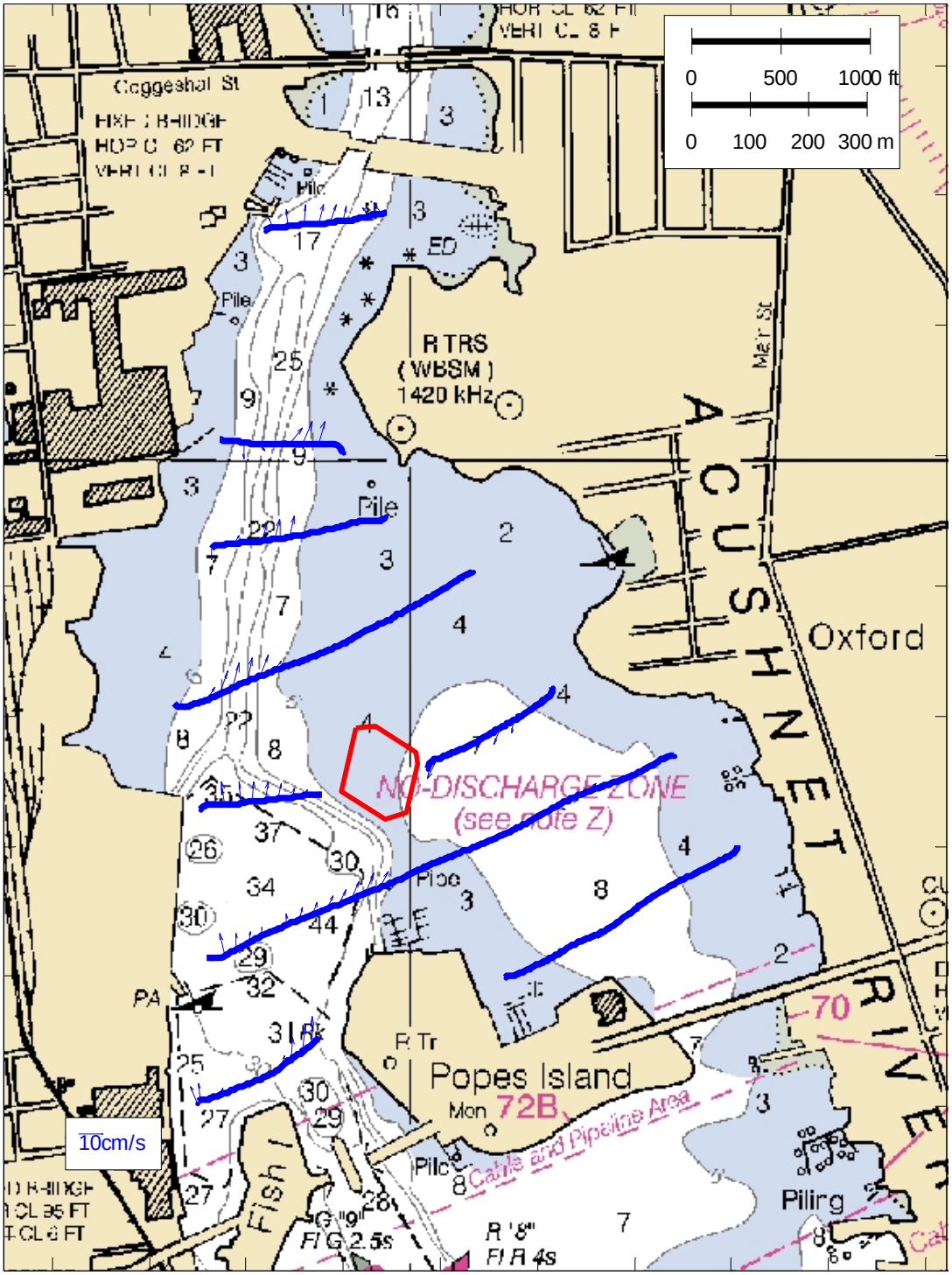
4 HOURS AFTER HIGH SLACK - Depth 2.24m



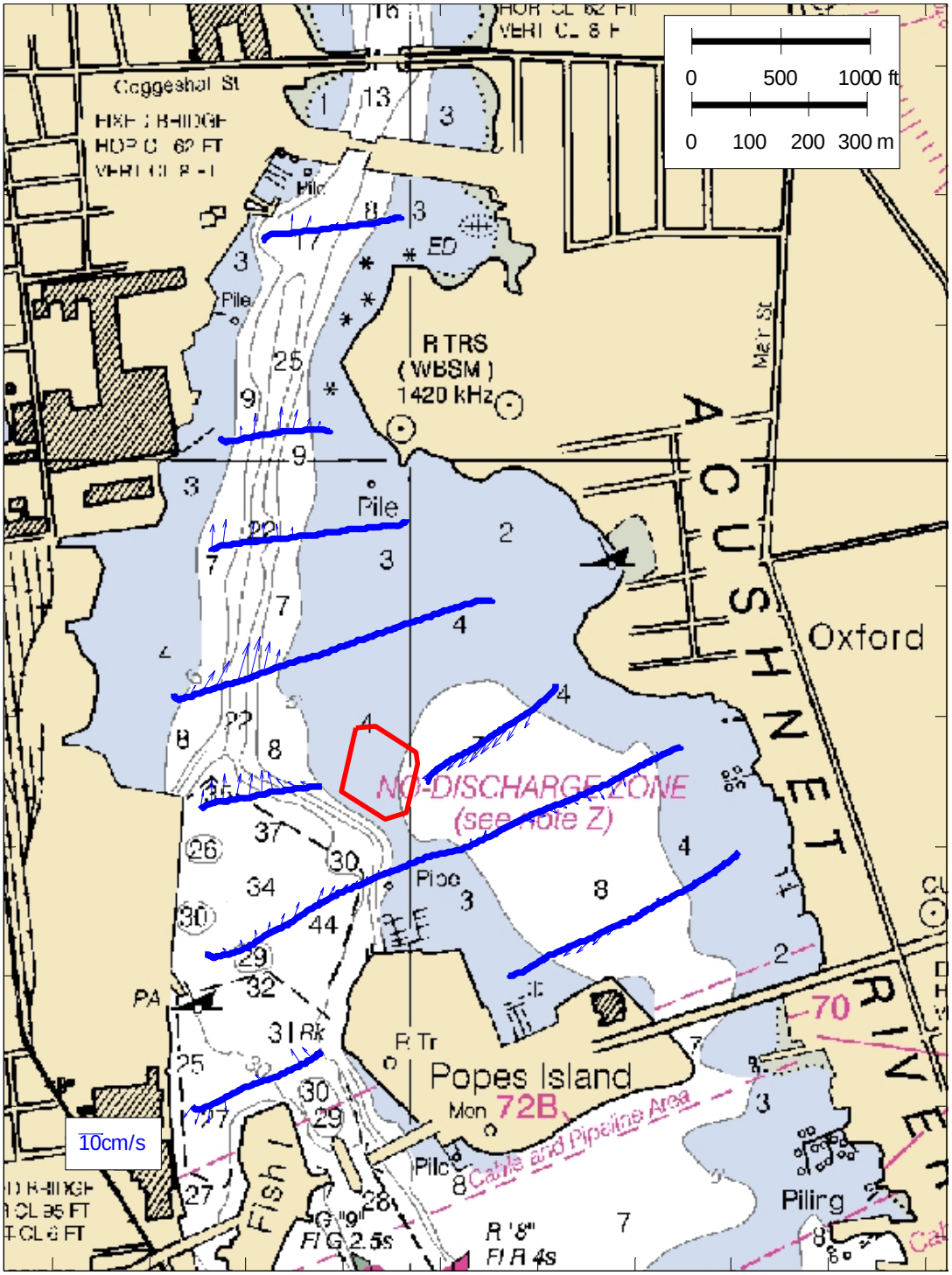
5 HOURS AFTER HIGH SLACK - Depth 2.24m



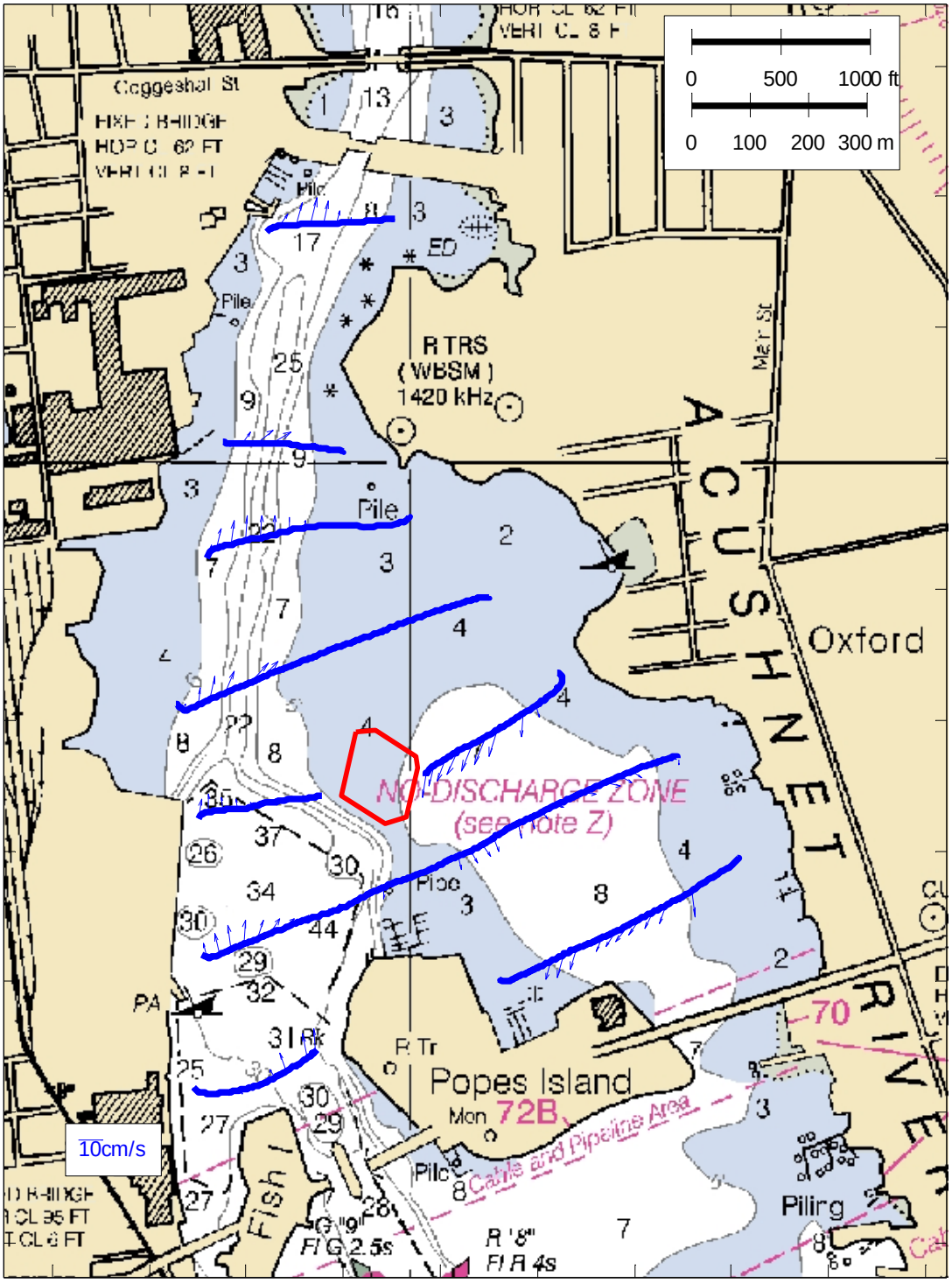
0.5 HOURS AFTER LOW SLACK - Depth 2.24m



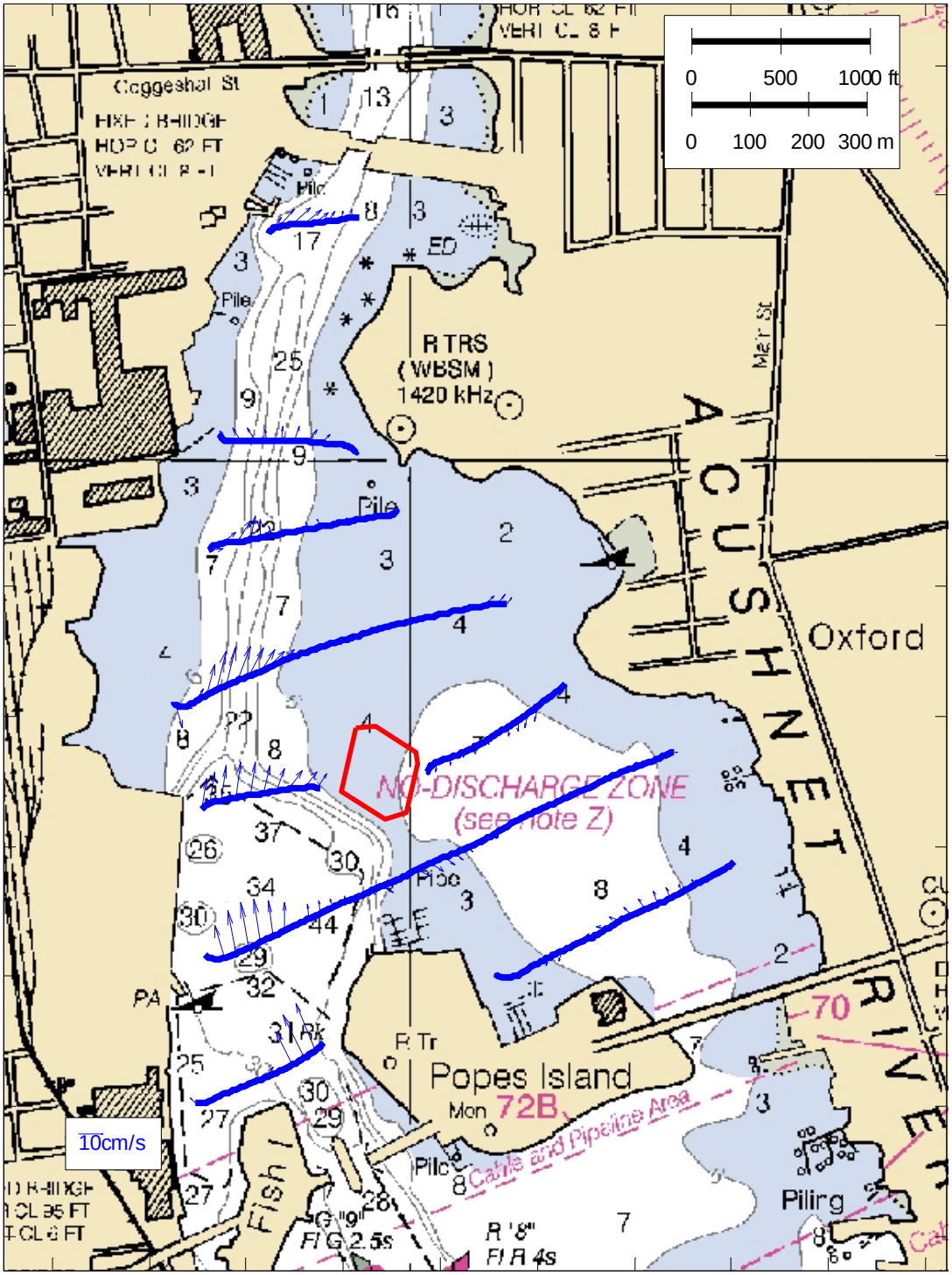
1.5 HOURS AFTER LOW SLACK - Depth 2.24m



2.5 HOURS AFTER LOW SLACK - Depth 2.24m



3.5 HOURS AFTER LOW SLACK - Depth 2.24m



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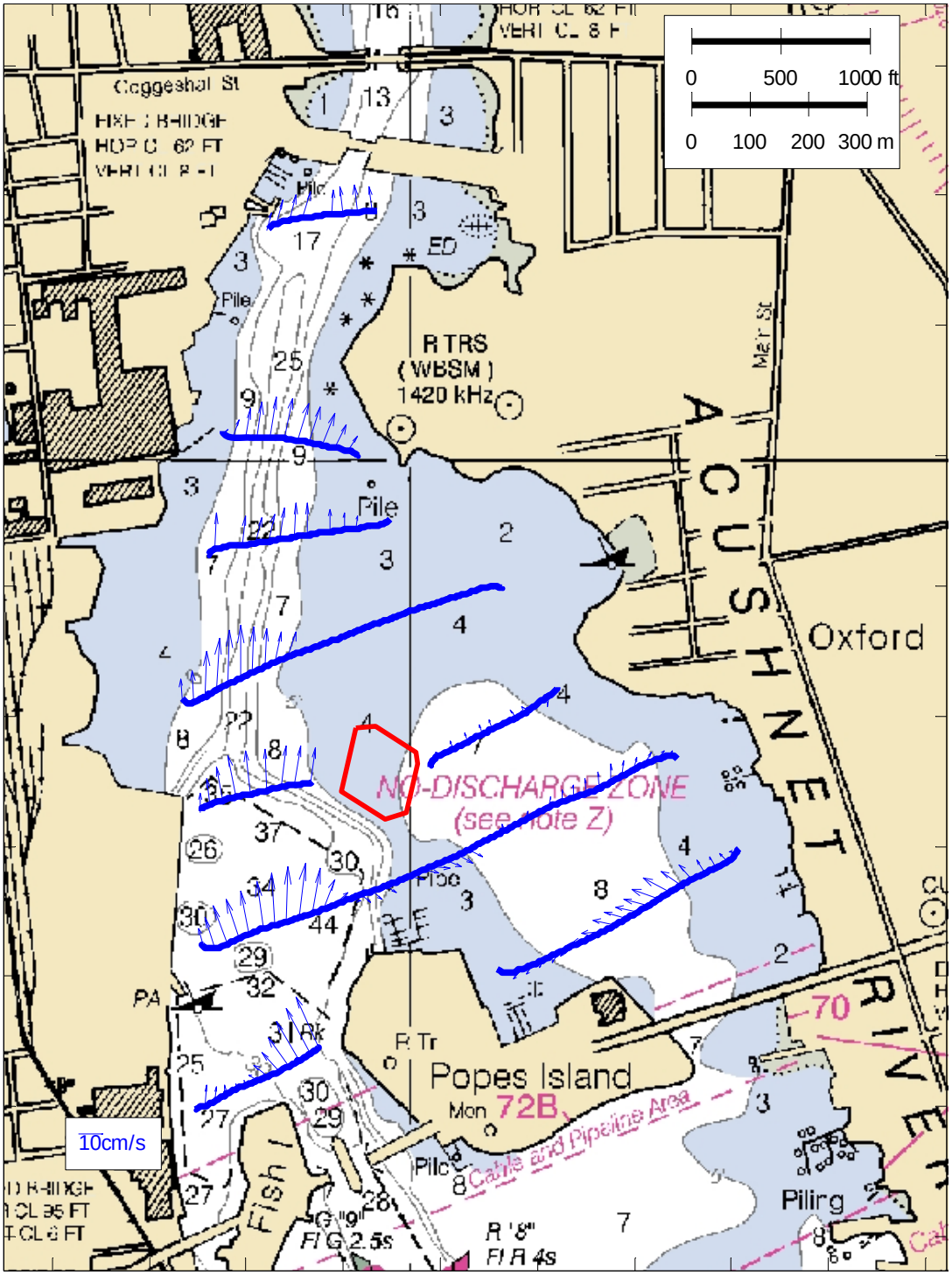

APPENDIX B

New Bedford Harbor
Laboratory Turbidity and TSS Results
April 14, May 20, 21, 27, and July 8, 2009

Date	Time	Depth (ft)	Turbidity (NTU)	TSS (mg/L)	Station ID	Station Type	ADCP File Name
Event (NB1) Date: April 14, 2009							
Sea Quest – inside silt curtain							
4/14/2009	16:00	5	1.3	4.3	1460	North Reference	NB09A034.mat
4/14/2009	16:00	10	1.3	2.8	1460	North Reference	NB09A034.mat
4/14/2009	16:14	15	4.1	14.8	1461	South Reference	NB09A034.mat
4/14/2009	16:14	30	4.9	18.2	1461	South Reference	NB09A034.mat
4/14/2009	17:07	15	7.5	21.7	S019	Plume Lateral	NB09A035.mat
4/14/2009	17:07	30	25	44.9	S019	Plume Lateral	NB09A035.mat
4/14/2009	17:22	15	1.9	5.5	S020	Plume Lateral	NB09A036.mat
4/14/2009	17:22	30	94	152	S020	Plume Lateral	NB09A036.mat
4/14/2009	17:40	4	1.5	4	S021	Plume Centroid	NB09A036.mat
4/14/2009	17:40	8	1.5	3.5	S021	Plume Centroid	NB09A036.mat
Gale Force – outside silt curtain							
4/14/2009	15:55	9	3	4.6	17	North Reference	NB09B014.mat
4/14/2009	15:55	18	1.9	11.5	17	North Reference	NB09B014.mat
4/14/2009	16:17	4	1.7	5.8	18	South Reference	NB09B015.mat
4/14/2009	16:17	9	1.3	2.8	18	South Reference	NB09B015.mat
4/14/2009	17:01	4	1.3	3	19	Plume Centroid	NB09B018.mat
4/14/2009	17:01	8	1.5	3.7	19	Plume Centroid	NB09B018.mat
4/14/2009	17:05	4	1.3	3.8	20	Plume Lateral	NB09B018.mat
4/14/2009	17:05	2	1.6	2.5	20	Plume Lateral	NB09B019.mat
4/14/2009	17:10	4	1.2	3	21	Plume Lateral	NB09B019.mat
4/14/2009	17:10	2	0.95	4.8	21	Plume Lateral	NB09B019.mat
4/14/2009	17:12	2	1.3	2.2	22	Dup	NB09B019.mat
Event (NB2) Date: May 20, 2009							
Sea Quest – inside silt curtain							
5/20/2009	7:40	5	1.7	7.8	1460	North Reference	NB09A043.mat

Date	Time	Depth (ft)	Turbidity (NTU)	TSS (mg/L)	Station ID	Station Type	ADCP File Name
5/20/2009	7:40	9	2.1	7.7	1460	North Reference	NB09A043.mat
5/20/2009	8:10	15	17	54.8	S023	Plume Centroid	NB09A045.mat
5/20/2009	8:10	30	84	226	S023	Plume Centroid	NB09A045.mat
5/20/2009	8:25	10	3.4	15.3	S025	Plume Lateral	NB09A047.mat
5/20/2009	8:25	18	33	97.1	S025	Plume Lateral	NB09A047.mat
5/20/2009	8:38	15	20	45.1	S026	Plume Lateral	NB09A049.mat
5/20/2009	8:38	30	43	103	S026	Plume Lateral	NB09A049.mat
5/20/2009	9:45	12	1.8	6.3	S027	South Reference	NB09A054.mat
5/20/2009	9:45	25	1.3	6.3	S027	South Reference	NB09A054.mat
Gale Force – outside silt curtain							
5/20/2009	7:43	9	2.2	5.2	26	North Reference	NB09B023.mat
5/20/2009	7:43	17	2.1	2.5	26	North Reference	NB09B023.mat
5/20/2009	8:24	5	1.8	5.7	28	Plume Lateral	NB09B025.mat
5/20/2009	8:24	3	1.9	3.7	28	Plume Lateral	NB09B025.mat
5/20/2009	8:27	6	2	1.8	29	Plume Lateral	NB09B025.mat
5/20/2009	8:27	3	1.6	3.5	29	Plume Lateral	NB09B025.mat
5/20/2009	8:31	5	2.4	5.8	30	Plume Centroid	NB09B025.mat
5/20/2009	8:31	10	1.9	6.5	30	Plume Centroid	NB09B025.mat
5/20/2009	9:42	3	1.7	2.5	32	South Reference	NB09B025.mat
5/20/2009	9:42	3	1.6	1.8	32	South Reference	NB09B025.mat
5/20/2009	9:42	6	1.6	6.3	32	South Reference	NB09B025.mat
Event (NB3) Date: May 21, 2009							
Sea Quest – inside silt curtain							
5/21/2009	7:03	5	1.7	7.3	S028	North Reference	NB09A057.mat
5/21/2009	7:03	8	2	6	S028	North Reference	NB09A057.mat
5/21/2009	7:19	15	1.3	6.3	S029	South Reference	NB09A058.mat
5/21/2009	7:19	28	1.6	4.5	S029	South Reference	NB09A058.mat
5/21/2009	8:27	16	37	99.5	S031	Plume Centroid	NB09A062.mat

Date	Time	Depth (ft)	Turbidity (NTU)	TSS (mg/L)	Station ID	Station Type	ADCP File Name
5/21/2009	8:27	30	160	278	S031	Plume Centroid	NB09A062.mat
5/21/2009	8:40	15	8.9	26.8	S032	Plume Lateral	NB09A064.mat
5/21/2009	8:40	26	77	133	S032	Plume Lateral	NB09A064.mat
5/21/2009	8:52	13	4	10	S033	Plume Lateral	NB09A065.mat
5/21/2009	8:52	25	46	99.7	S033	Plume Lateral	NB09A065.mat
Gale Force – outside silt curtain							
5/21/2009	7:01	10	2	5.2	34	North Reference	NB09B029.mat
5/21/2009	7:01	20	2	8.7	34	North Reference	NB09B029.mat
5/21/2009	7:15	9	1.8	4.2	36	South Reference	NB09B029.mat
5/21/2009	7:15	5	1.5	5.4	36	South Reference	NB09B029.mat
5/21/2009	8:31	9	6.2	20	38	Plume Lateral	NB09B031.mat
5/21/2009	8:31	18	11	31.8	38	Plume Lateral	NB09B031.mat
5/21/2009	8:31	9	6.5	15.2	38	Plume Lateral-dup	NB09B031.mat
5/21/2009	8:36	15	1.6	4.8	39	Plume Lateral	NB09B031.mat
5/21/2009	8:36	30	1.4	6.5	39	Plume Lateral	NB09B031.mat
5/21/2009	8:45	15	4	7.3	40	Plume Centroid	NB09B031.mat
5/21/2009	8:45	30	1.7	5.5	40	Plume Centroid	NB09B031.mat
Event (NB4) Date: May 27, 2009							
Sea Quest – inside silt curtain							
5/27/2009	7:17	5	2.5	4.3	S034	North Reference	NB09A073.mat
5/27/2009	7:17	8	2.6	6.5	S034	North Reference	NB09A073.mat
5/27/2009	7:34	12	2.4	2.7	S035	South Reference	NB09A074.mat
5/27/2009	7:34	24	1.6	3.3	S035	South Reference	NB09A074.mat
5/27/2009	8:25	8	2.6	5.8	S036	Plume Centroid	NB09A078.mat
5/27/2009	8:25	18	97	442	S036	Plume Centroid	NB09A078.mat
5/27/2009	8:43	16	16	86.5	S038	Plume Lateral	NB09A080.mat
5/27/2009	8:43	30	9.1	165	S038	Plume Lateral	NB09A080.mat
5/27/2009	9:01	15	42	41.8	S039	Plume Lateral	NB09A082.mat

Date	Time	Depth (ft)	Turbidity (NTU)	TSS (mg/L)	Station ID	Station Type	ADCP File Name
5/27/2009	9:01	30	40	101	S039	Plume Lateral	NB09A082.mat
Gale Force – outside silt curtain							
5/27/2009	7:15	13	2.2	4.2	42	North Reference	NB09B037.mat
5/27/2009	7:15	7	3.2	3	42	North Reference	NB09B037.mat
5/27/2009	7:15	7	2.6	6.3	42	North Reference-dup	NB09B037.mat
5/27/2009	7:34	4	2.1	1.7	44	South Reference	NB09B037.mat
5/27/2009	7:34	8	1.8	1.6	44	South Reference	NB09B037.mat
5/27/2009	8:33	4	3.2	7.8	45	Plume Lateral	NB09B041.mat
5/27/2009	8:33	8	19	50.6	45	Plume Lateral	NB09B041.mat
5/27/2009	8:42	8	2.8	14.7	47	Plume Centroid	NB09B041.mat
5/27/2009	8:42	4	2.5	5	47	Plume Centroid	NB09B041.mat
5/27/2009	8:56	3	3.9	9	48	Plume Lateral	NB09B041.mat
5/27/2009	8:56	7	3.8	13.7	48	Plume Lateral	NB09B041.mat
Event (NB5) Date: July 8, 2009							
Sea Quest – inside silt curtain							
7/8/2009	11:35	5	2.7	7.7	S040	North Reference	NB09A096.mat
7/8/2009	11:35	10	2.8	5.2	S040	North Reference	NB09A096.mat
7/8/2009	11:44	12	1.9	3.8	S041	South Reference	NB09A097.mat
7/8/2009	11:44	25	1.4	6.2	S041	South Reference	NB09A097.mat
7/8/2009	12:12	10	49	112	S042	Plume Centroid	NB09A100.mat
7/8/2009	12:12	20	12	39.8	S042	Plume Centroid	NB09A100.mat
7/8/2009	12:25	12	3.8	10	S043	Plume Lateral	NB09A102.mat
7/8/2009	12:25	25	21	65.3	S043	Plume Lateral	NB09A102.mat
7/8/2009	12:38	11	8.6	23	S044	Plume Lateral	NB09A104.mat
7/8/2009	12:38	20	33	36	S044	Plume Lateral	NB09A104.mat
Gale Force – outside silt curtain							
7/8/2009	11:29	6	2.7	6.6	55	North Reference	NB09B051.mat
7/8/2009	11:29	12	3.1	7.5	55	North Reference	NB09B051.mat

Date	Time	Depth (ft)	Turbidity (NTU)	TSS (mg/L)	Station ID	Station Type	ADCP File Name
7/8/2009	11:41	5	1.7	4.8	56	South Reference	NB09B052.mat
7/8/2009	11:41	9	2.1	4.7	56	South Reference	NB09B052.mat
7/8/2009	12:39	8	3.6	8	57	Plume Centroid	NB09B055.mat
7/8/2009	12:39	16	3	6.2	57	Plume Centroid	NB09B055.mat
7/8/2009	12:42	4	3.1	7.7	58	Plume Lateral	NB09B055.mat
7/8/2009	12:42	7	2.9	6.8	58	Plume Lateral	NB09B055.mat
7/8/2009	12:47	6	2.4	5.7	59	Plume Lateral	NB09B055.mat
7/8/2009	12:47	11	2.3	4.5	59	Plume Lateral	NB09B055.mat
7/8/2009	12:47	11	2.3	5.4	59	Plume Lateral-dup	NB09B055.mat

APPENDIX C

New Bedford Harbor
Observations of Turbidity
Measured with ADCP
April 14, May 20, 21, 27, and July 8, 2009

Part 1: Turbidity Survey April 14, 2009

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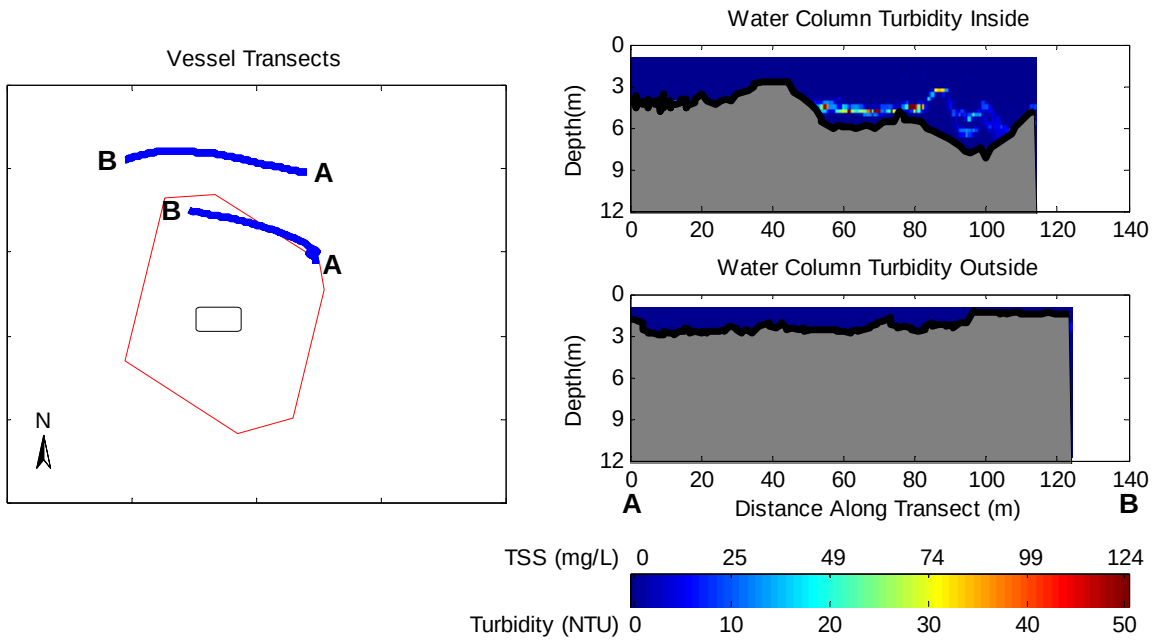

Figure 1-1. Observations Before Release During April 14, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

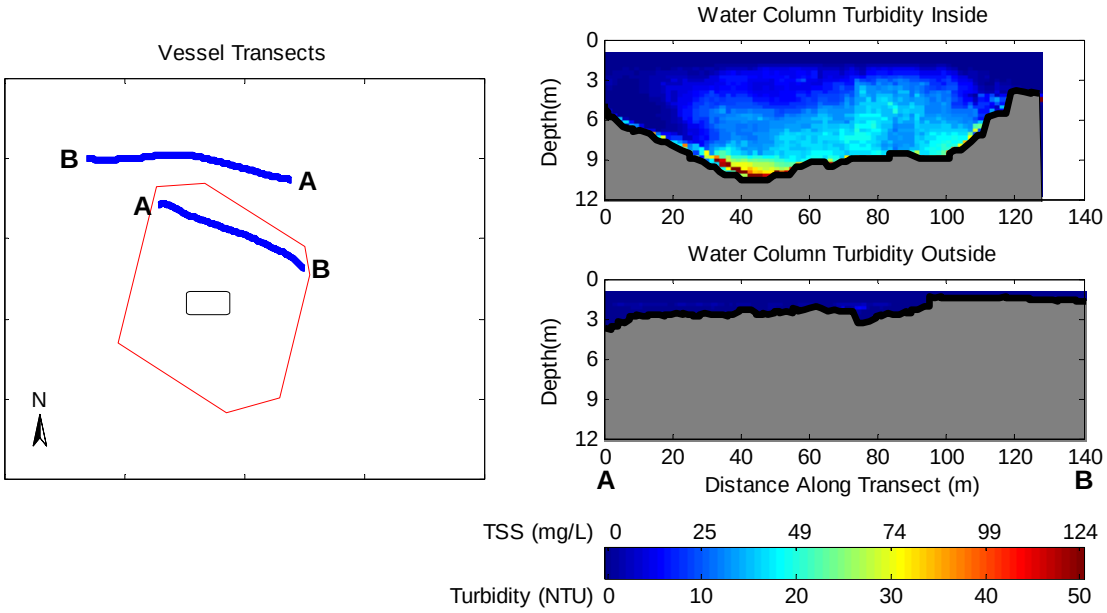

Figure 1-2. Observations from 8 to 11 Minutes after Release During April 14, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

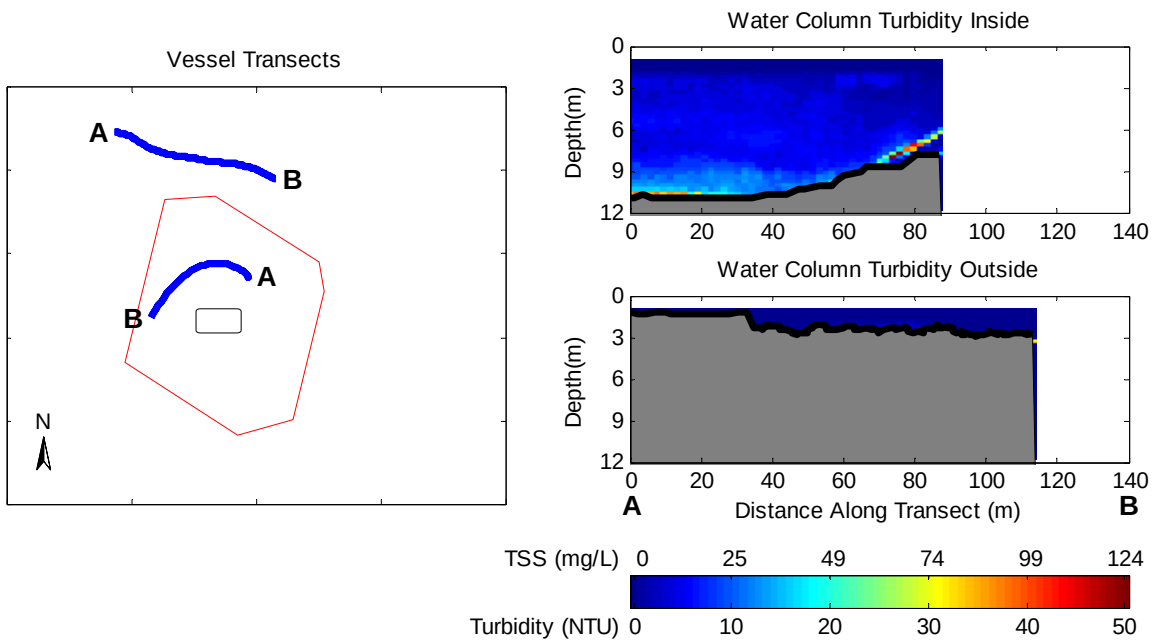

Figure 1-3. Observations from 19 to 22 Minutes after Release During April 14, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

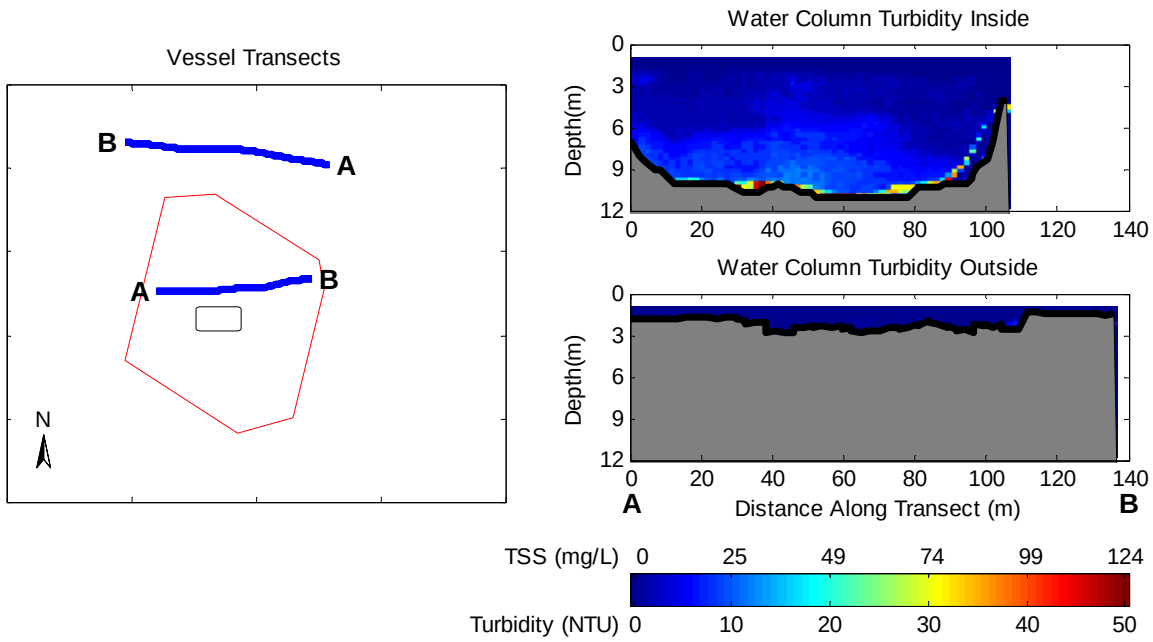

Figure 1-4. Observations from 27 to 39 Minutes after Release During April 14, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

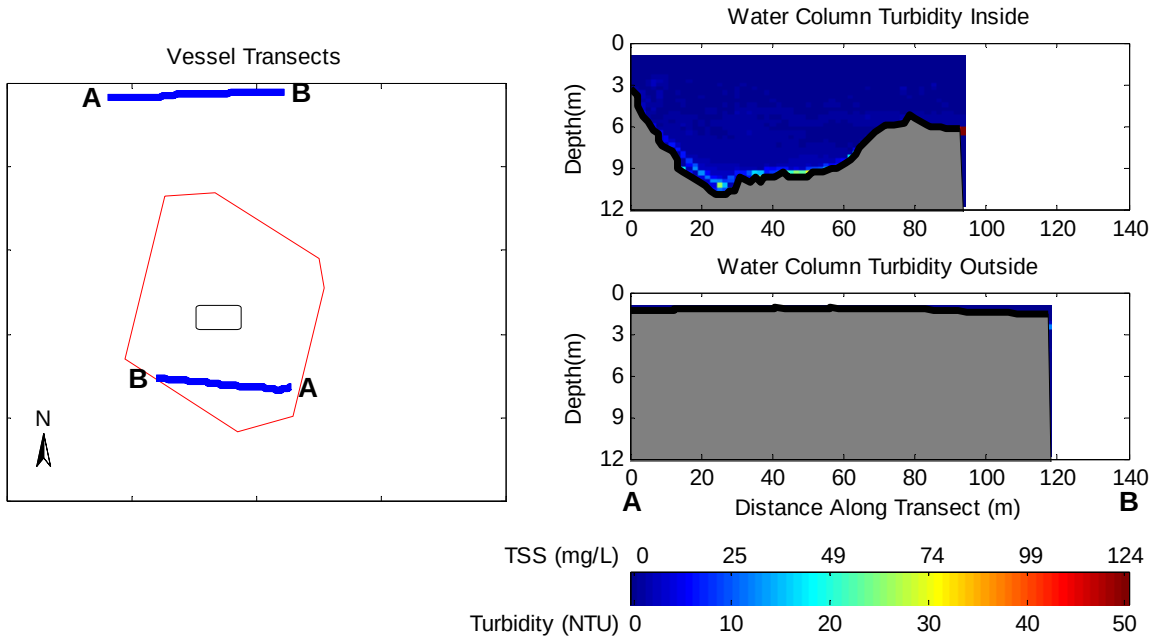

Figure 1-5. Observations from 40 to 44 Minutes after Release During April 14, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

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Part 2: Turbidity Survey May 20, 2009

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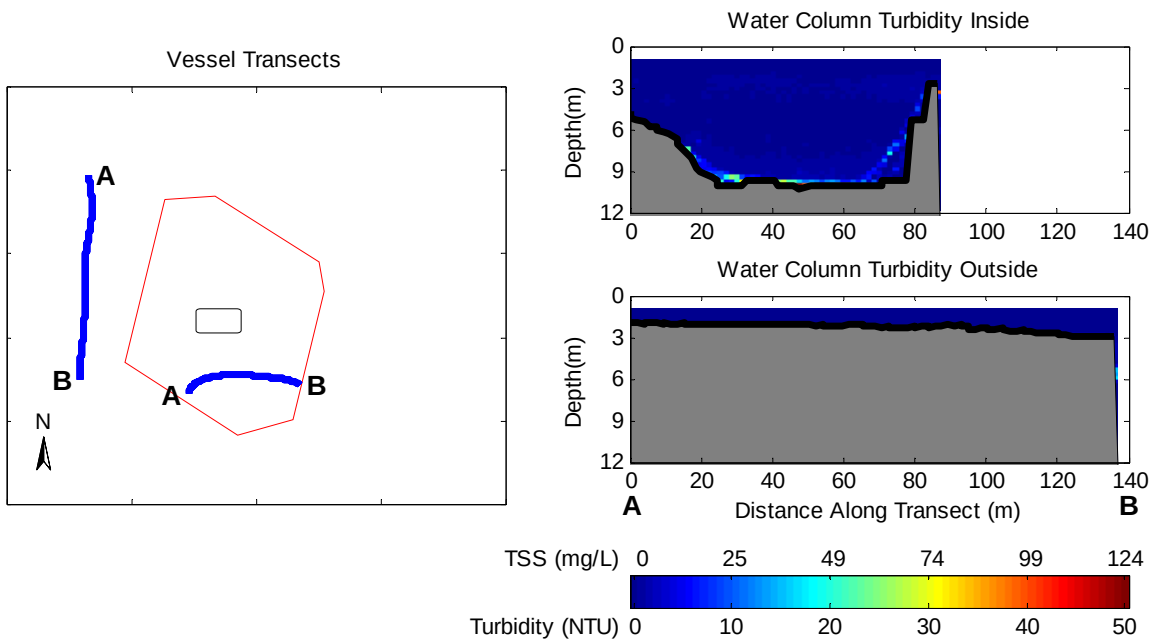

Figure 2-1. Observations Before Release During May 20, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

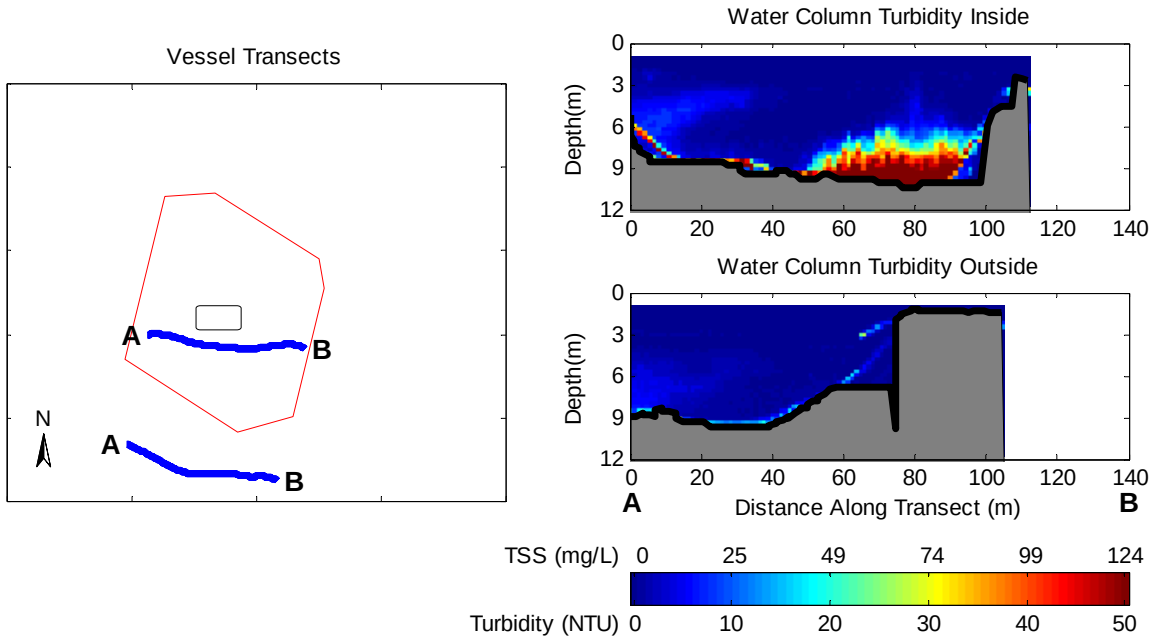

Figure 2-2. Observations from 3 to 6 Minutes after Release During May 20, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

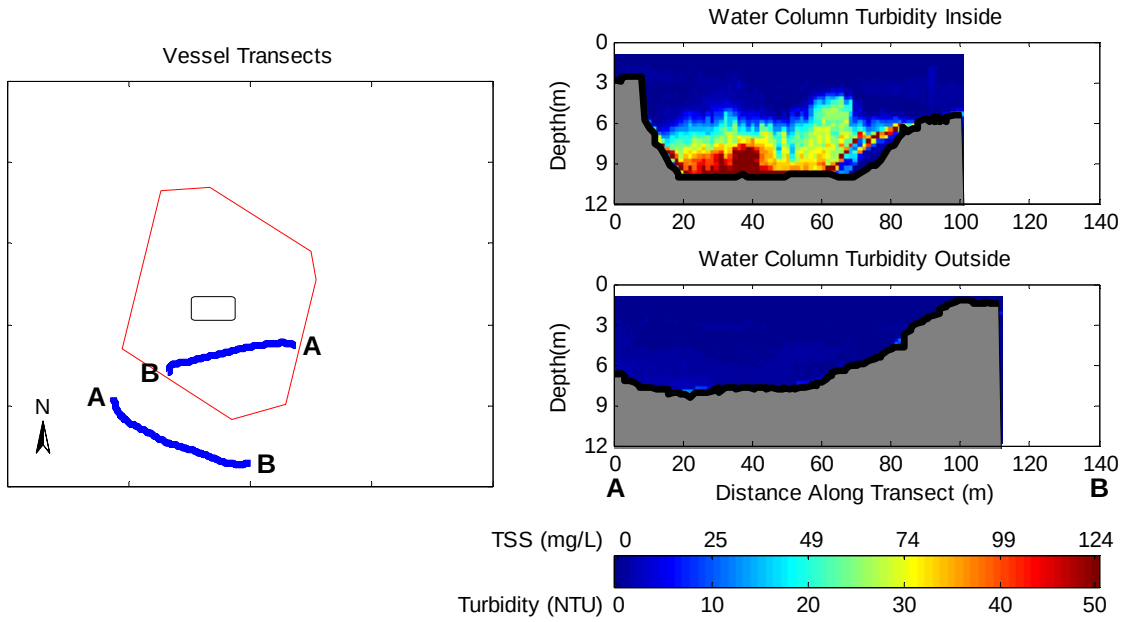

Figure 2-3. Observations from 10 to 12 Minutes after Release During May 20, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

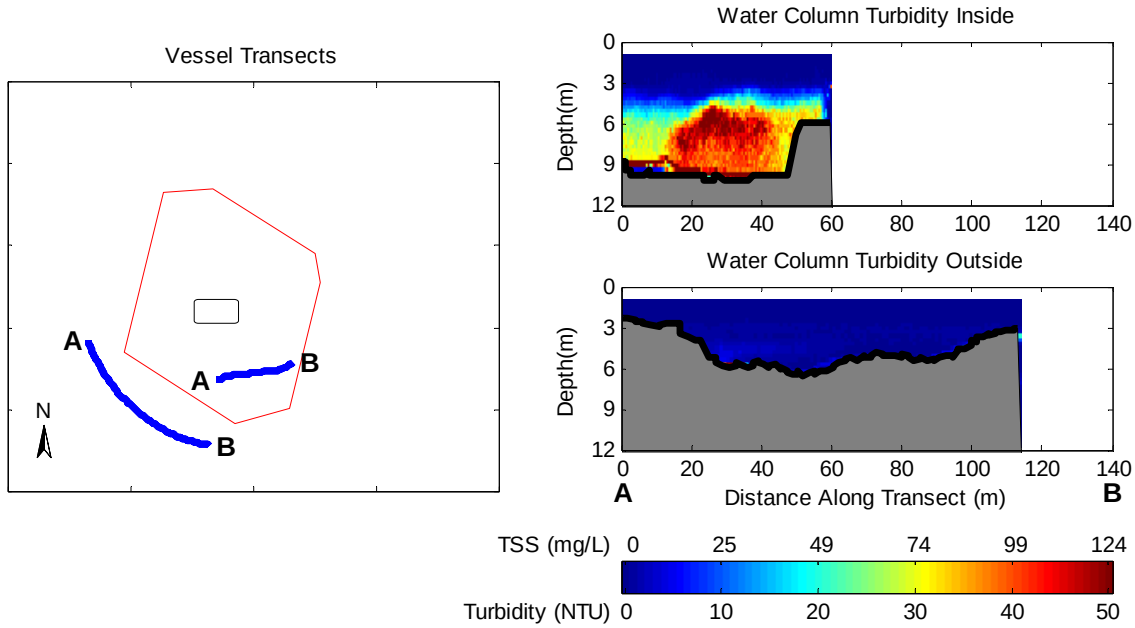

Figure 2-4. Observations from 18 to 24 Minutes after Release During May 20, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

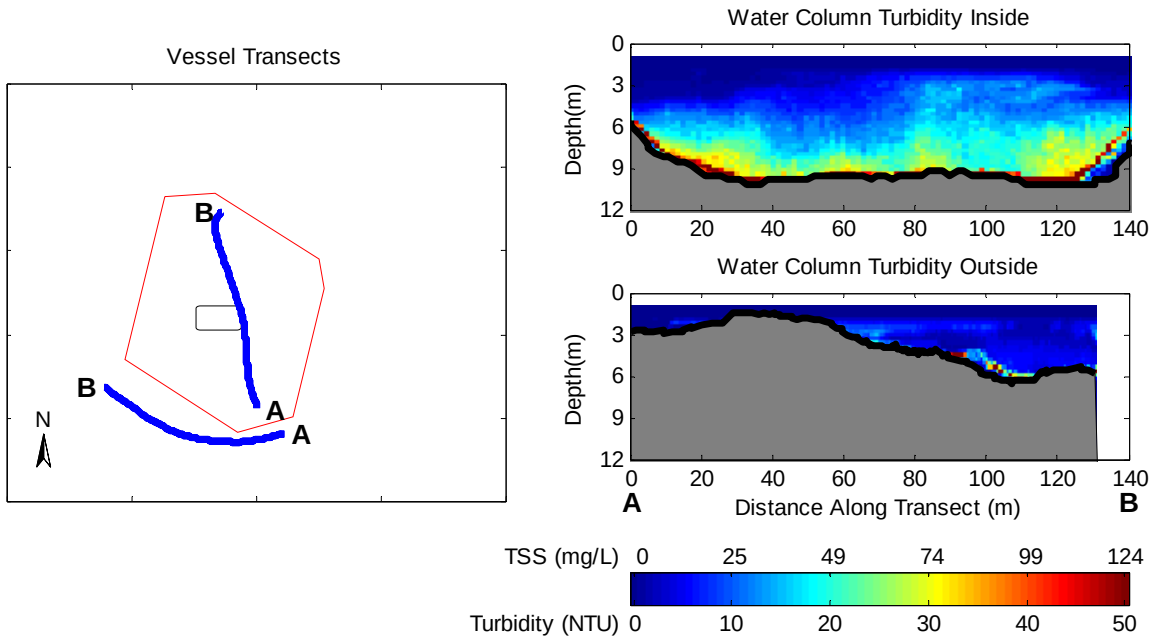

Figure 2-5. Observations from 39 to 43 Minutes after Release During May 20, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

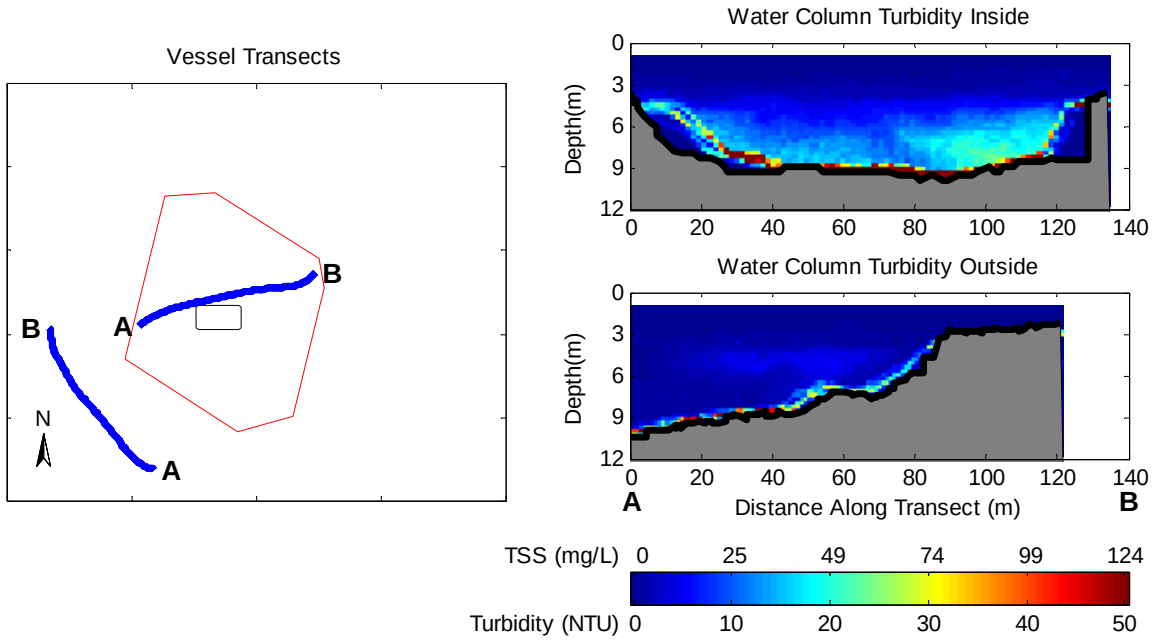

Figure 2-6. Observations from 55 to 57 Minutes after Release During May 20, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

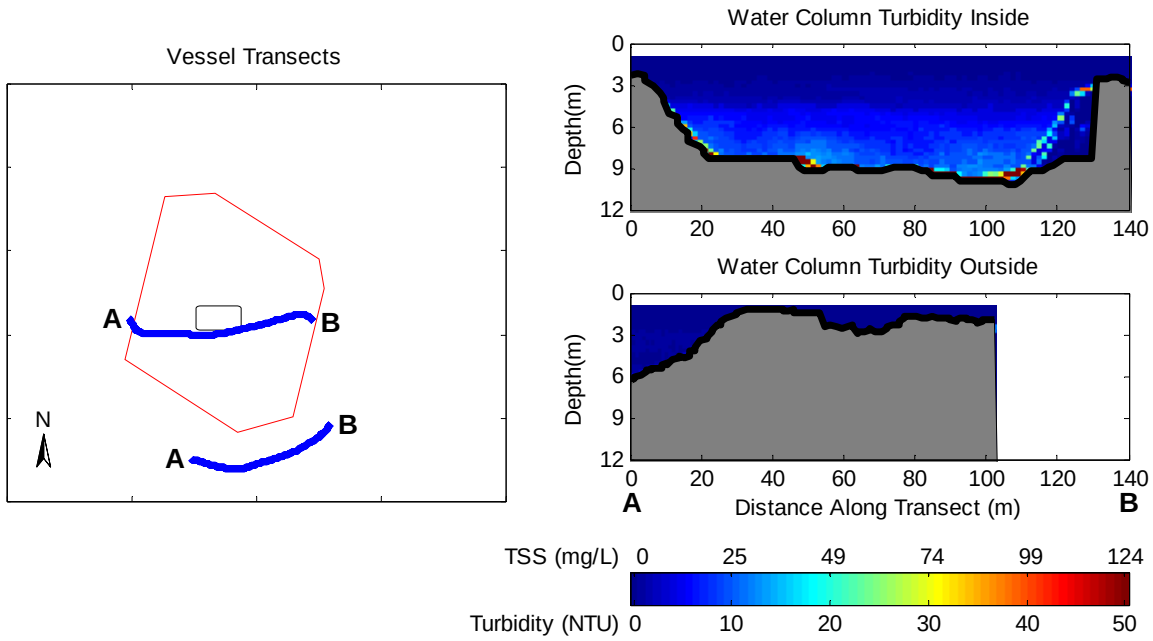

Figure 2-7. Observations from 84 to 87 Minutes after Release During May 20, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

Part 3: Turbidity Survey May 21, 2009

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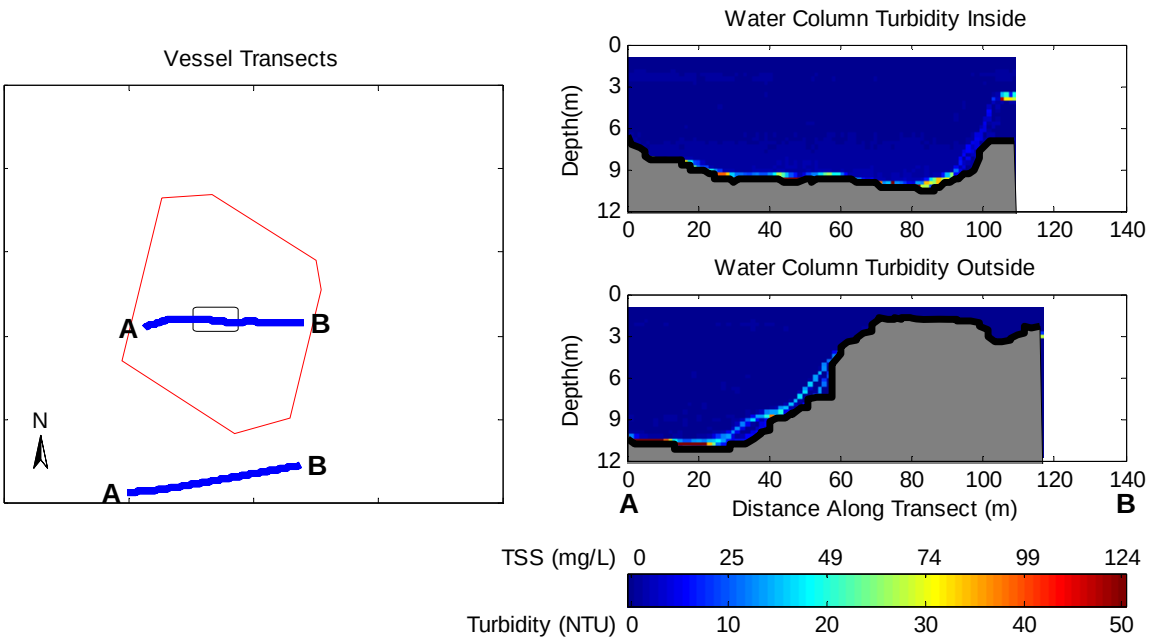

Figure 3-1. Observations Before Release During May 21, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

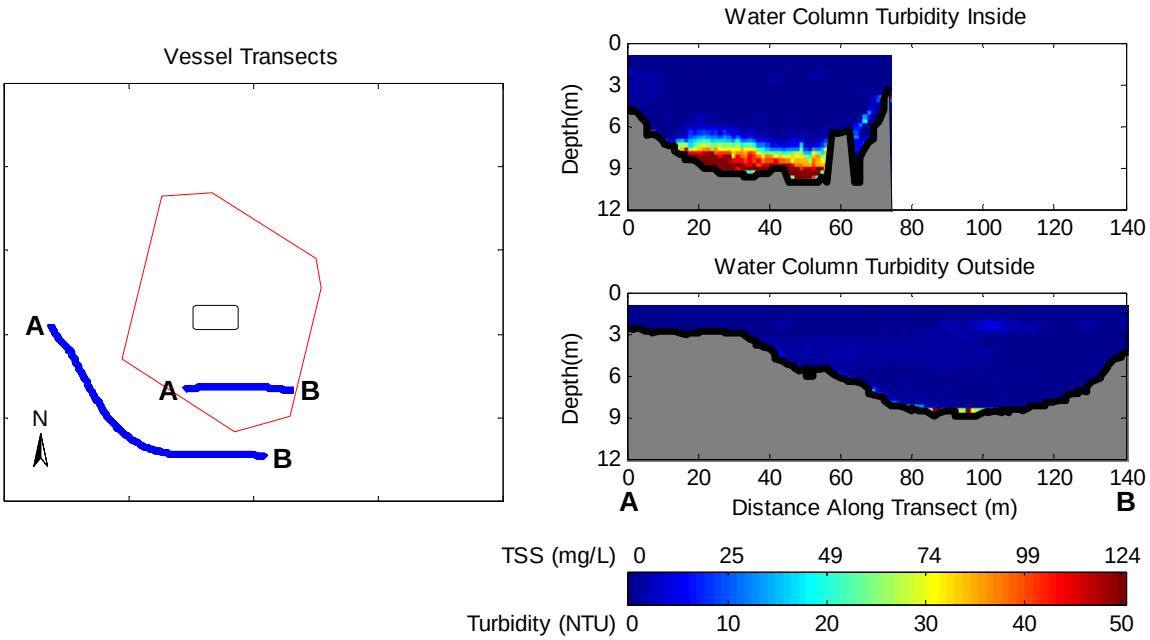

Figure 3-2. Observations from 1 to 6 Minutes after Release During May 21, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

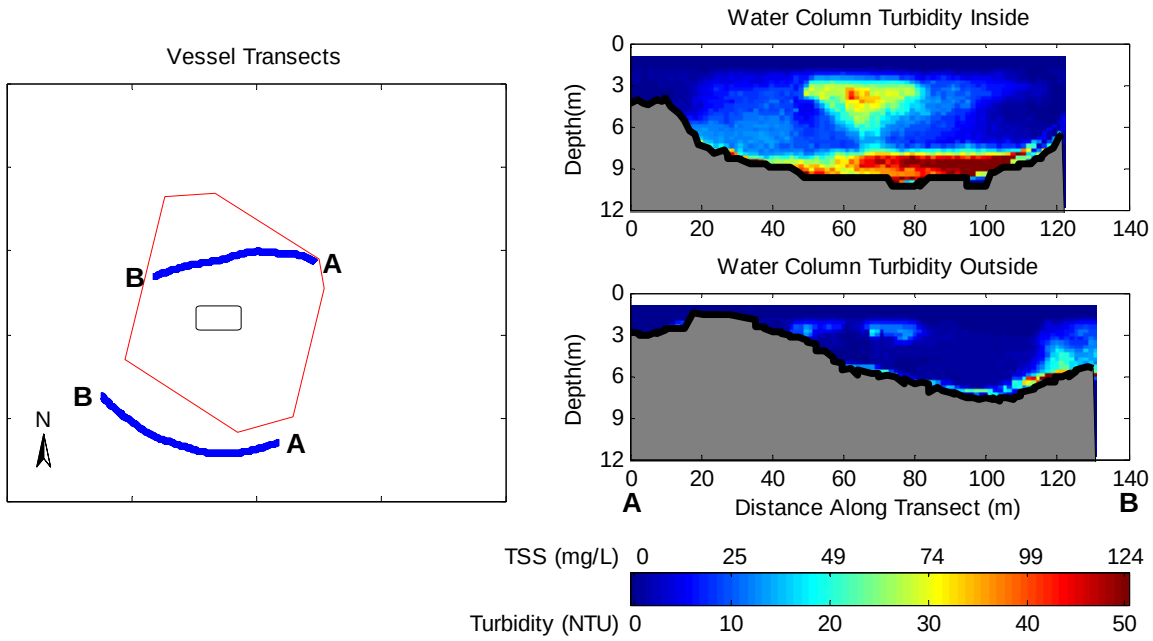

Figure 3-3. Observations from 5 to 9 Minutes after Release During May 21, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

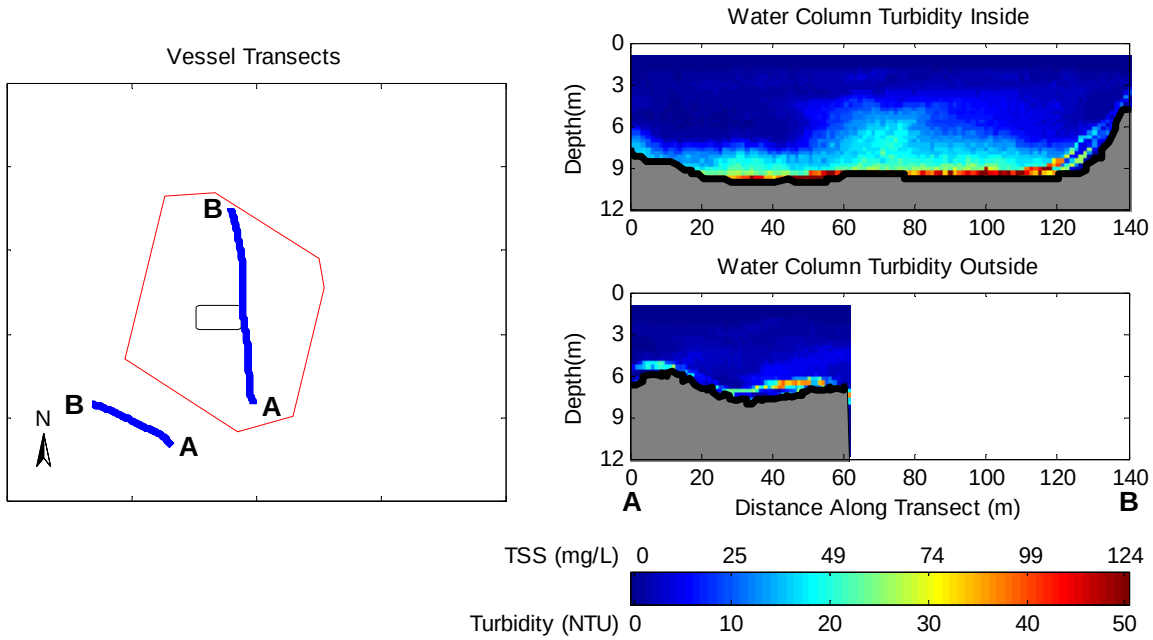

Figure 3-4. Observations from 18 to 21 Minutes after Release During May 21, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

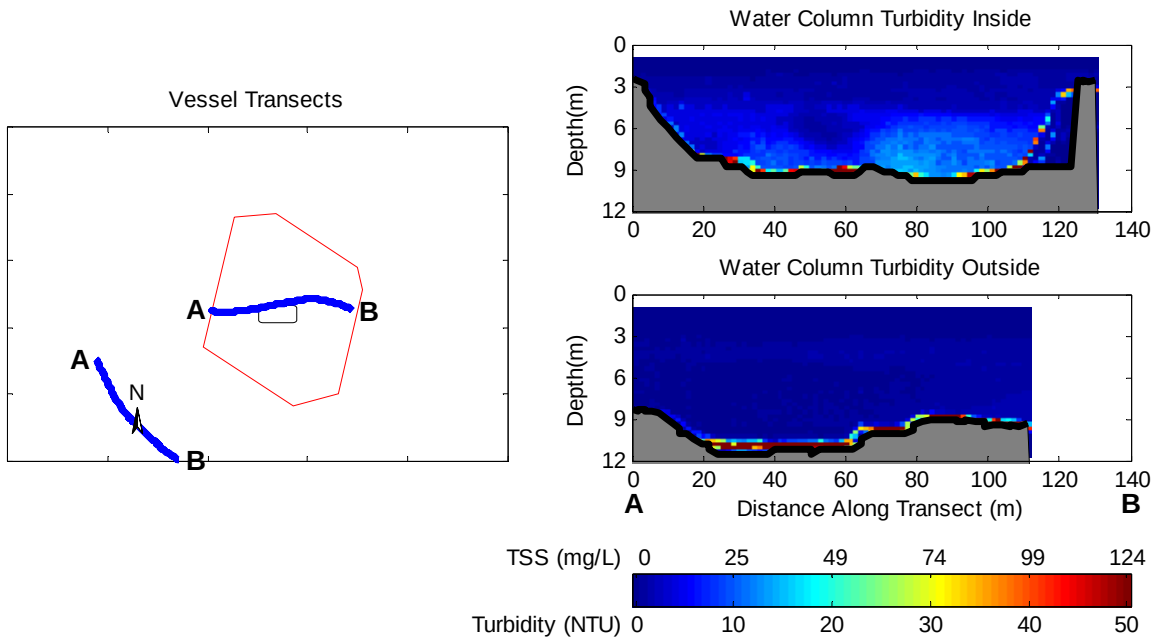

Figure 3-5. Observations from 39 to 42 Minutes after Release During May 21, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

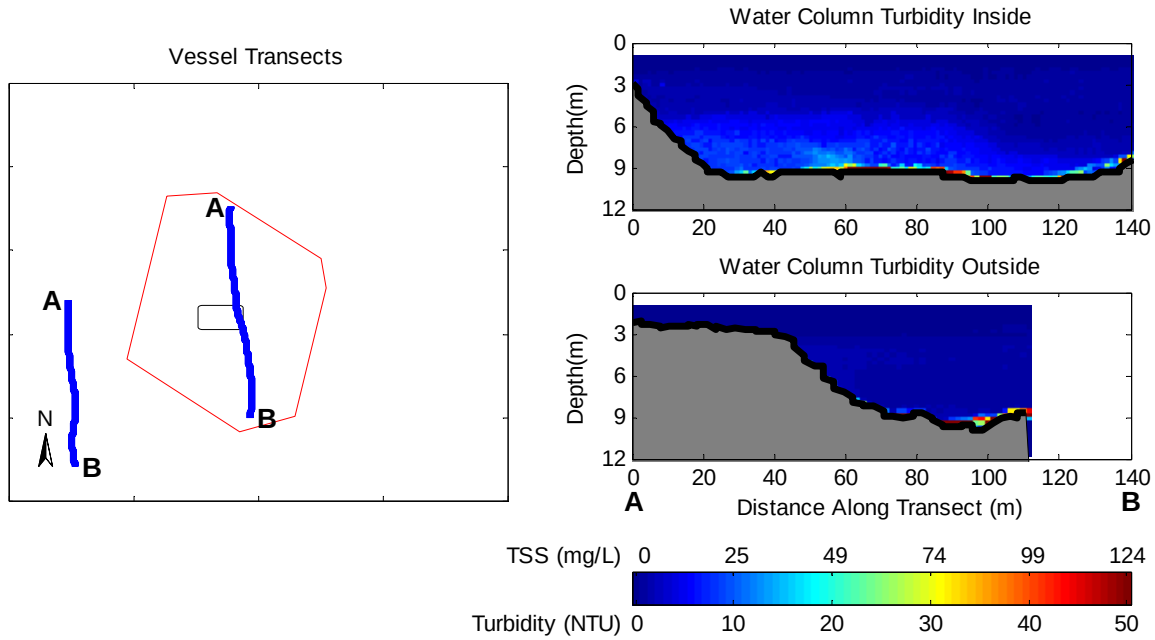

Figure 3-6. Observations from 51 to 54 Minutes after Release During May 21, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

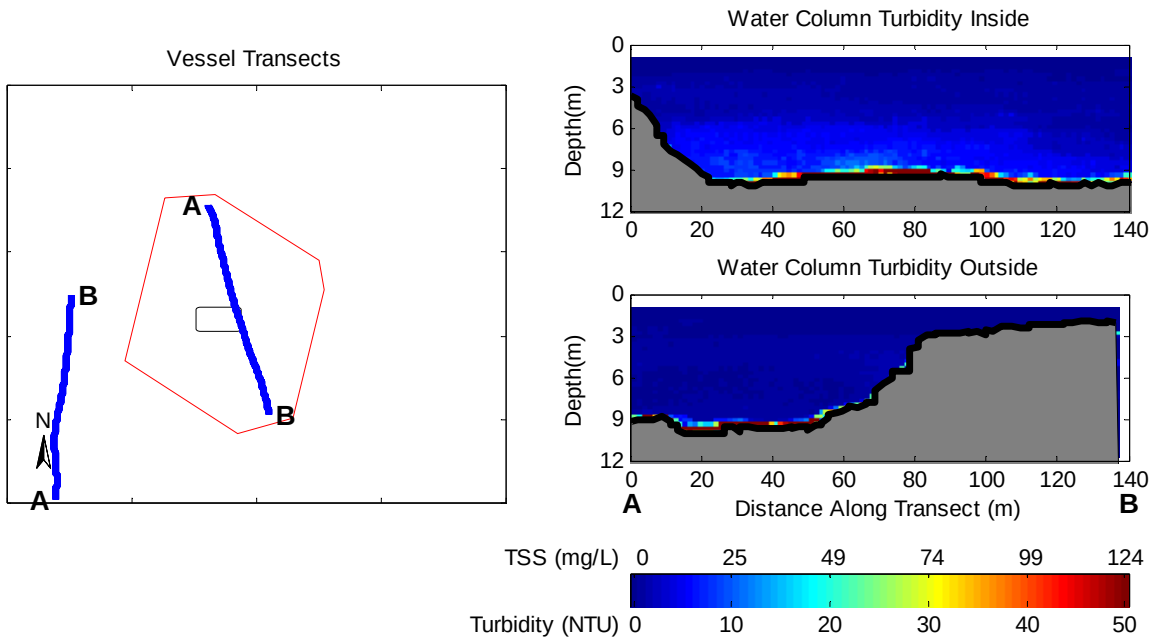

Figure 3-7. Observations from 57 to 59 Minutes after Release During May 21, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

Part 4: Turbidity Survey May 27, 2009

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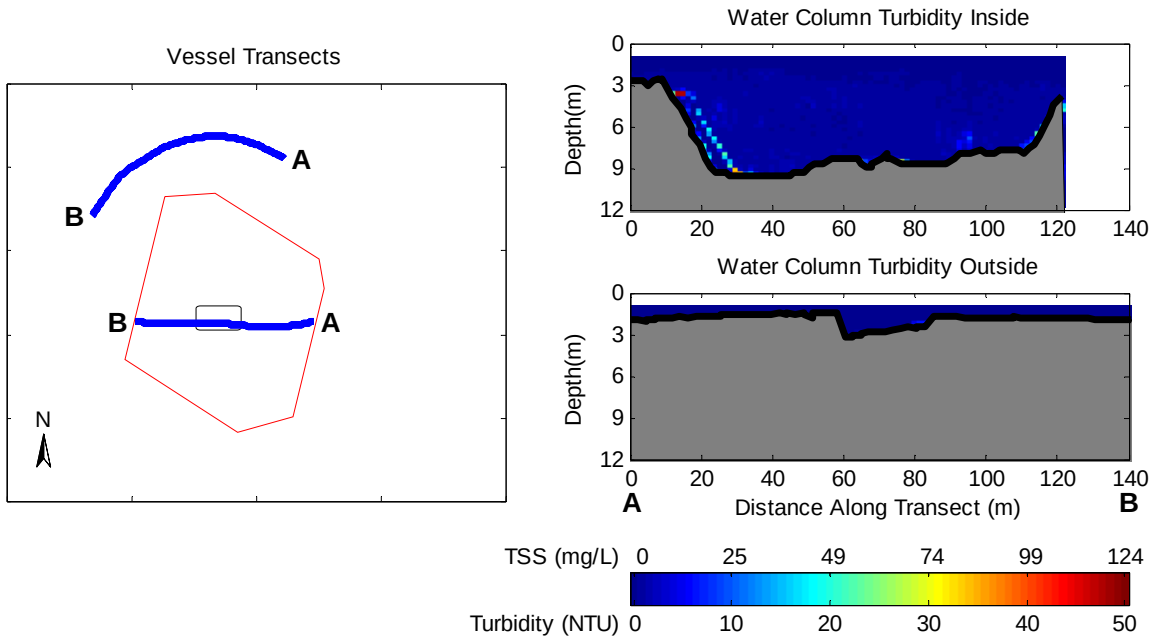

Figure 4-1. Observations Before Release During May 27, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

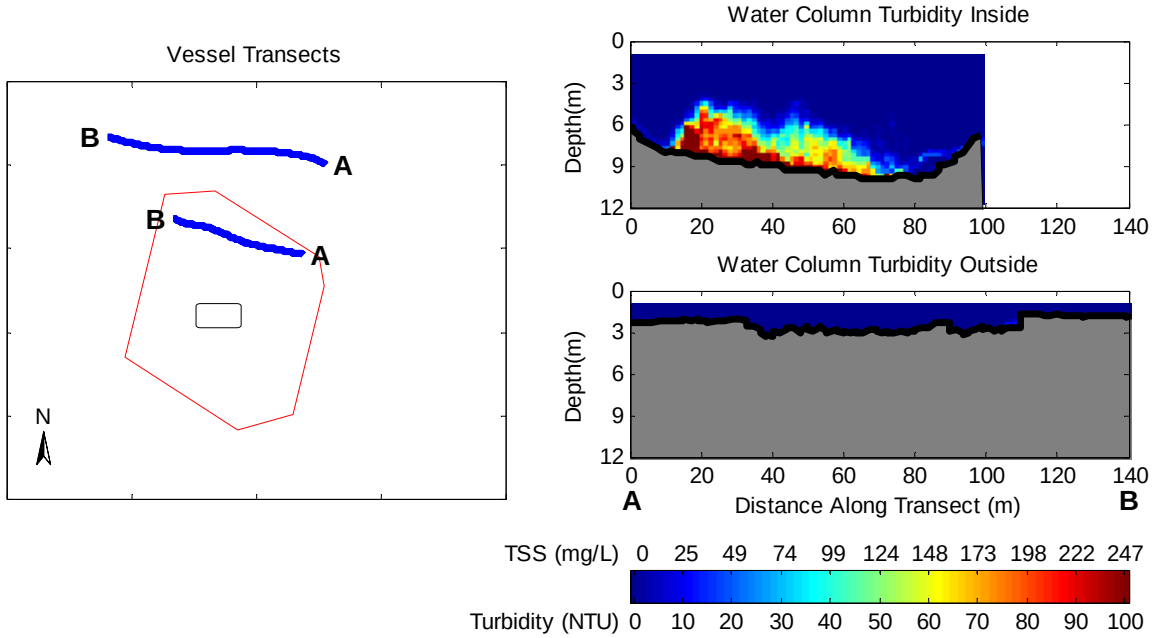

Figure 4-2. Observations from 3 to 6 Minutes after Release During May 27, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect. Note change in turbidity scale.

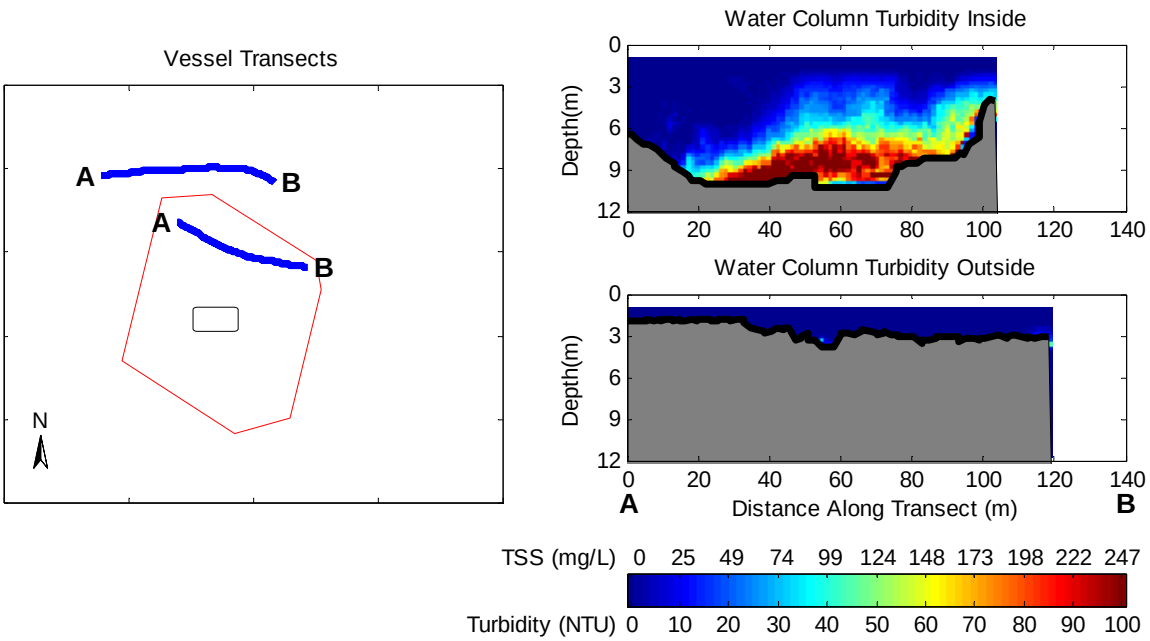

Figure 4-3. Observations from 5 to 9 Minutes after Release During May 27, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect. Note change in turbidity scale.

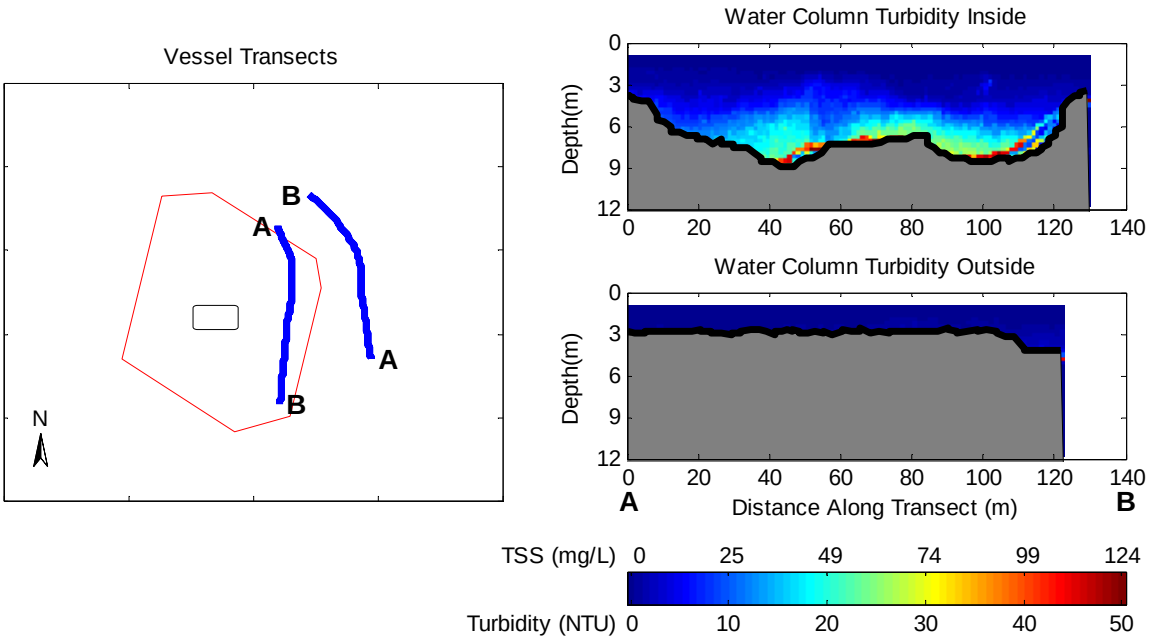

Figure 4-4. Observations from 31 to 34 Minutes after Release During May 27, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

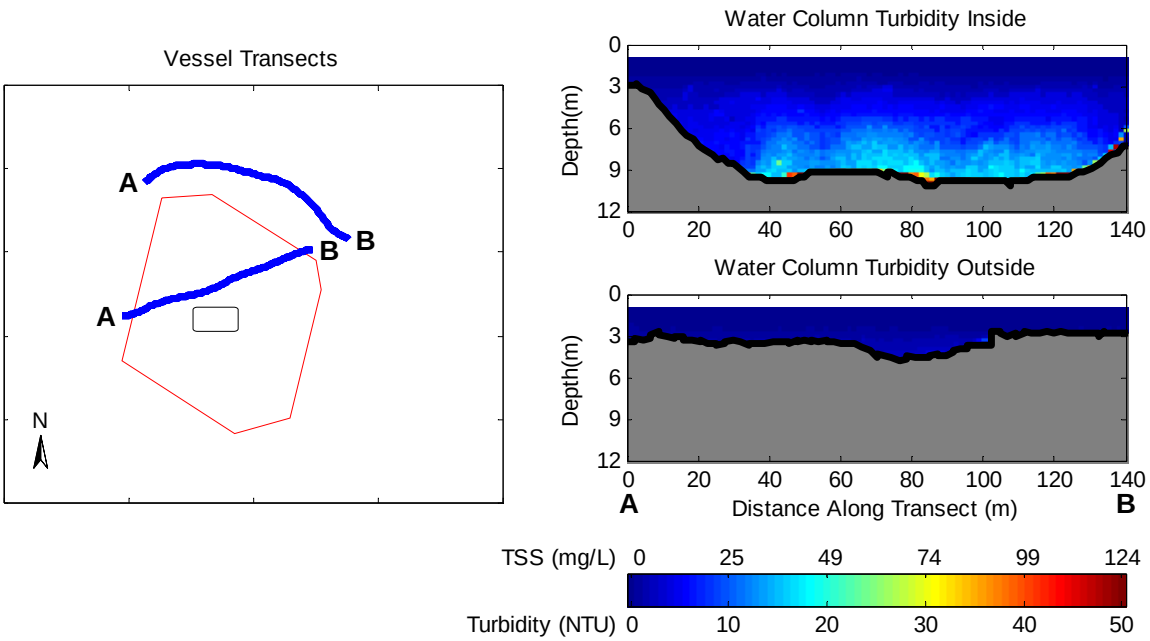

Figure 4-5. Observations from 50 to 53 Minutes after Release During May 27, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

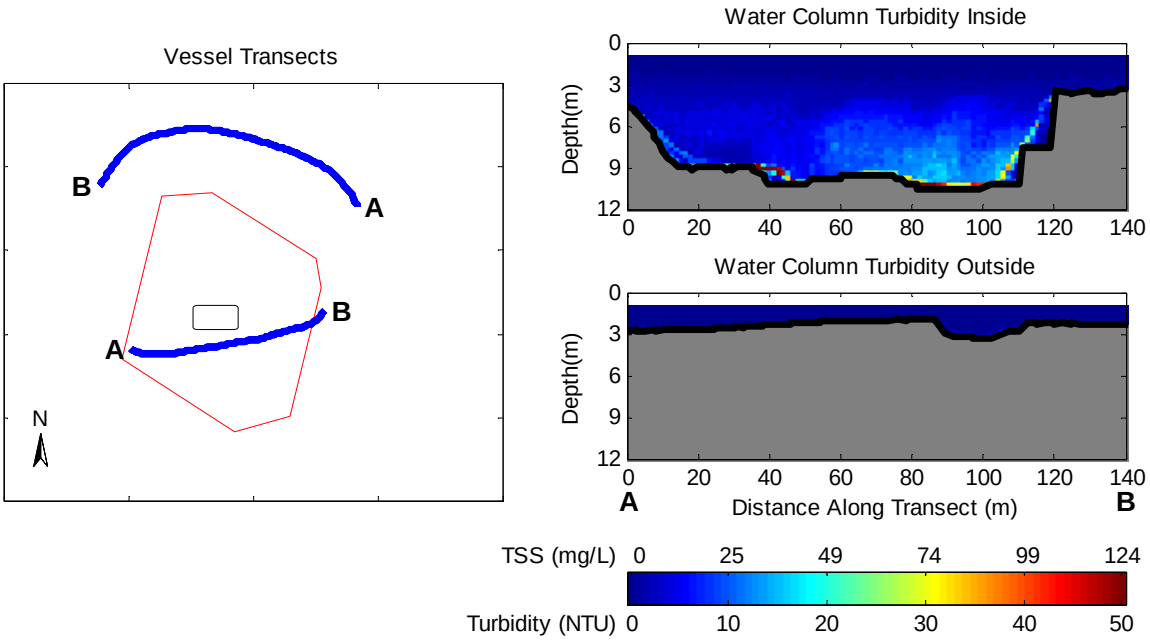

Figure 4-6. Observations from 54 to 57 Minutes after Release During May 27, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

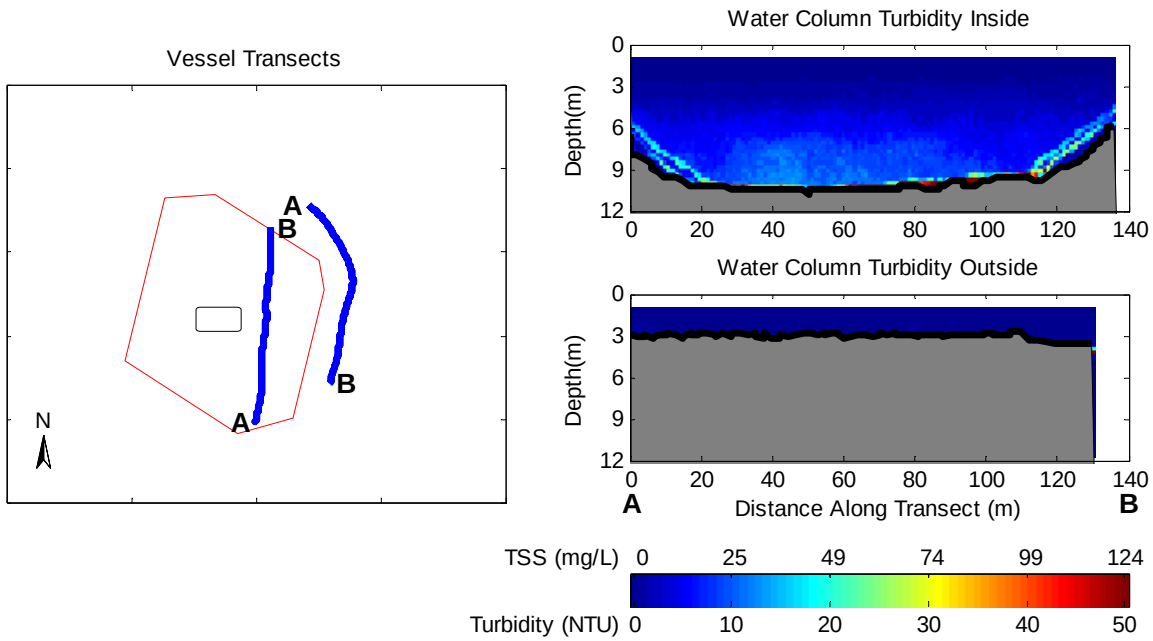

Figure 4-7. Observations from 63 to 67 Minutes after Release During May 27, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

Part 5: Turbidity Survey July 8, 2009

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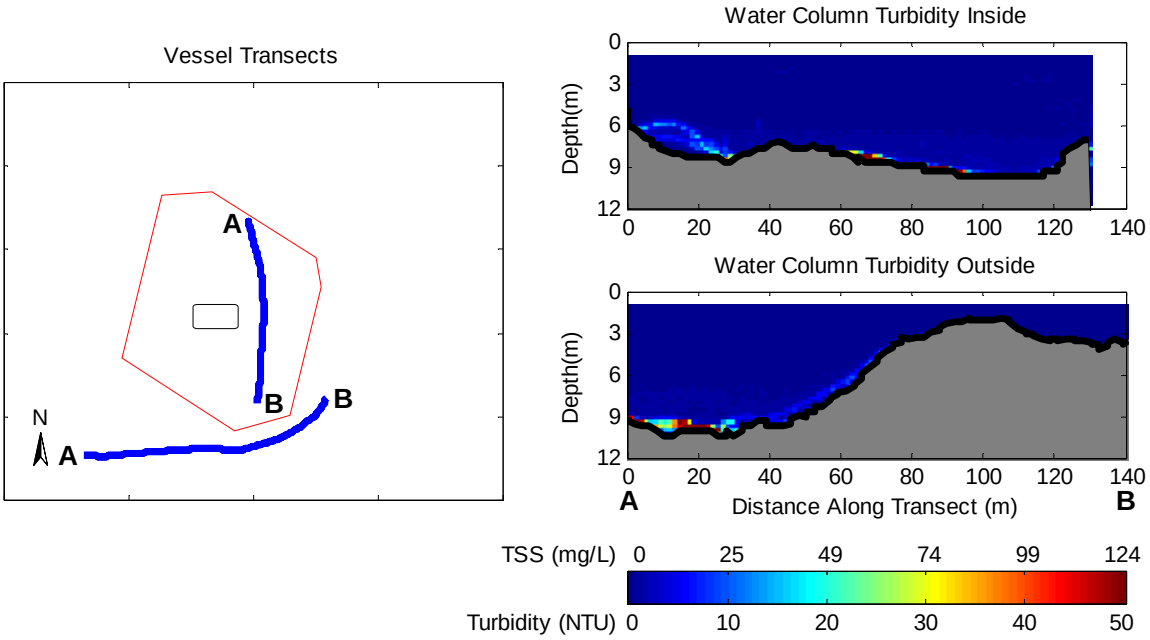

Figure 5-1. Observations Before Release During July 8, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

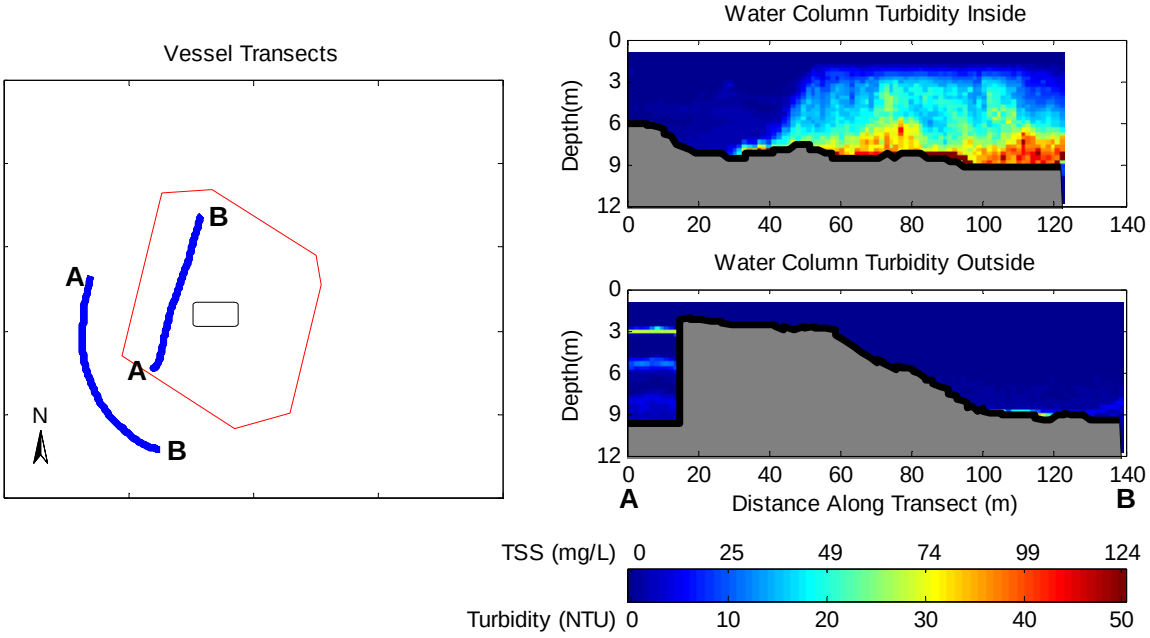

Figure 5-2. Observations from 1 to 4 Minutes after Release During July 8, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

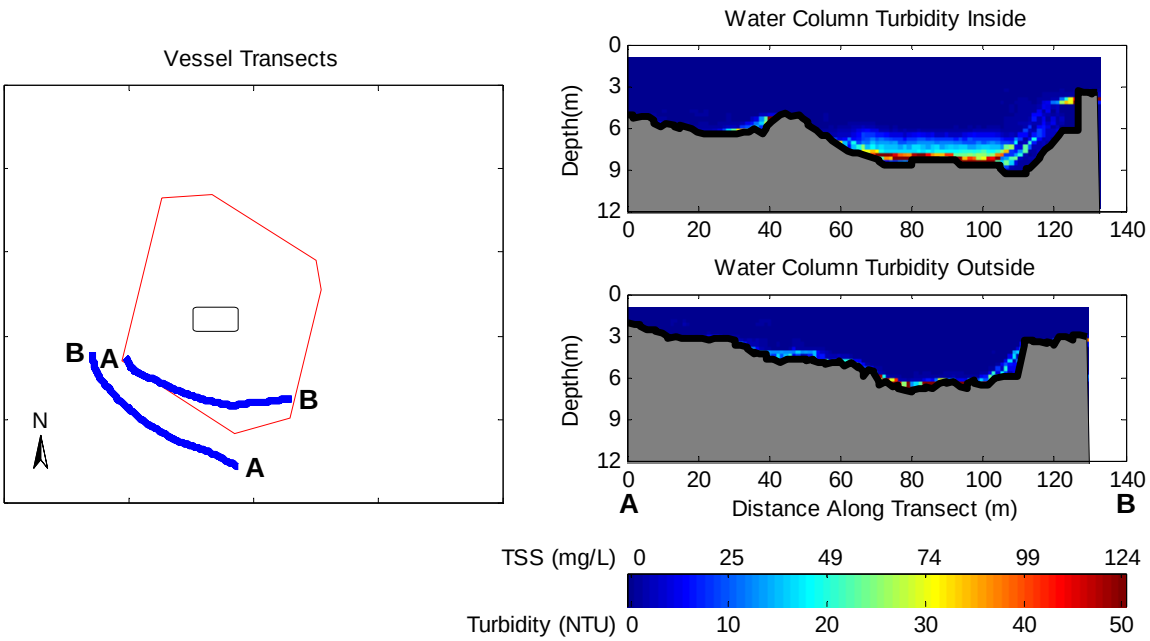

Figure 5-3. Observations from 9 to 16 Minutes after Release During July 8, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

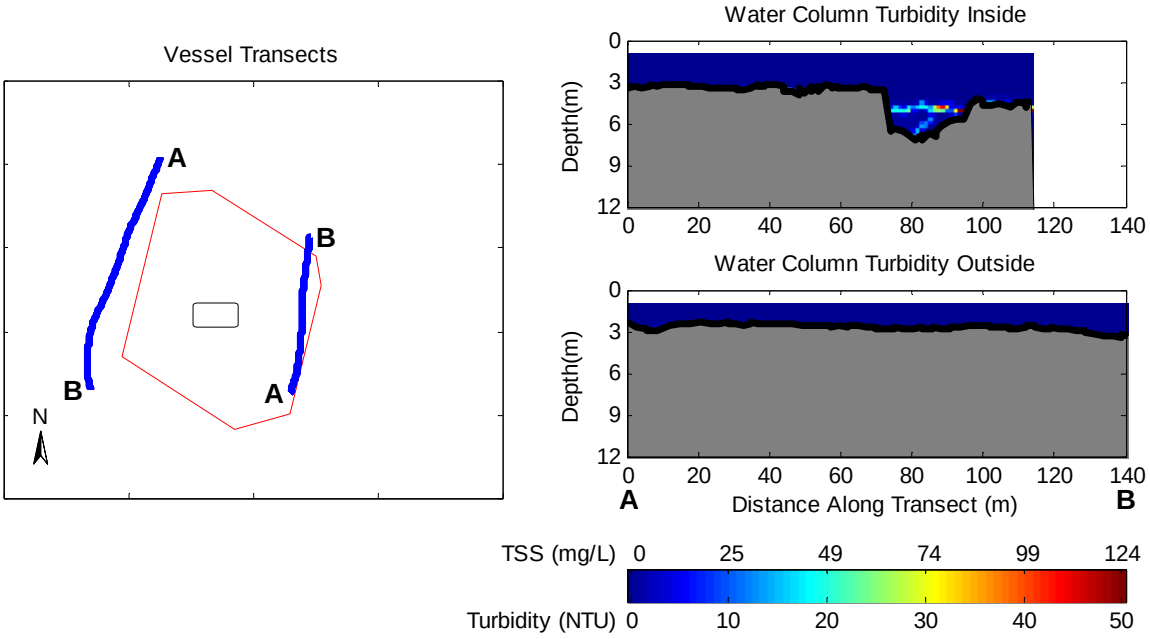

Figure 5-4. Observations from 15 to 18 Minutes after Release During July 8, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

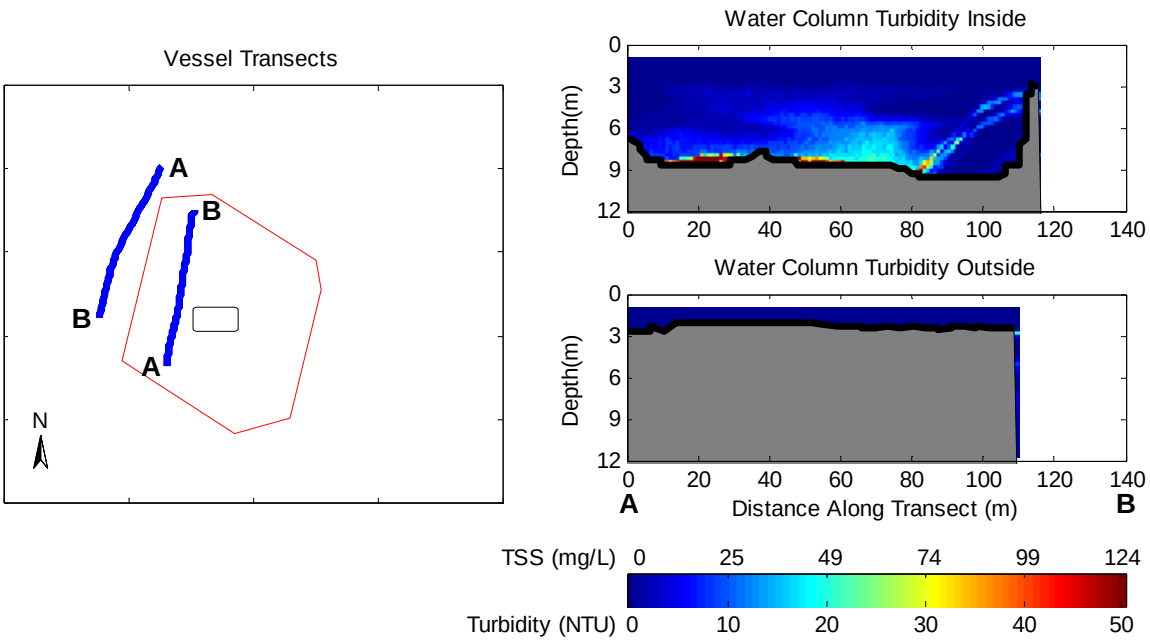

Figure 5-5. Observations from 26 to 29 Minutes after Release During July 8, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

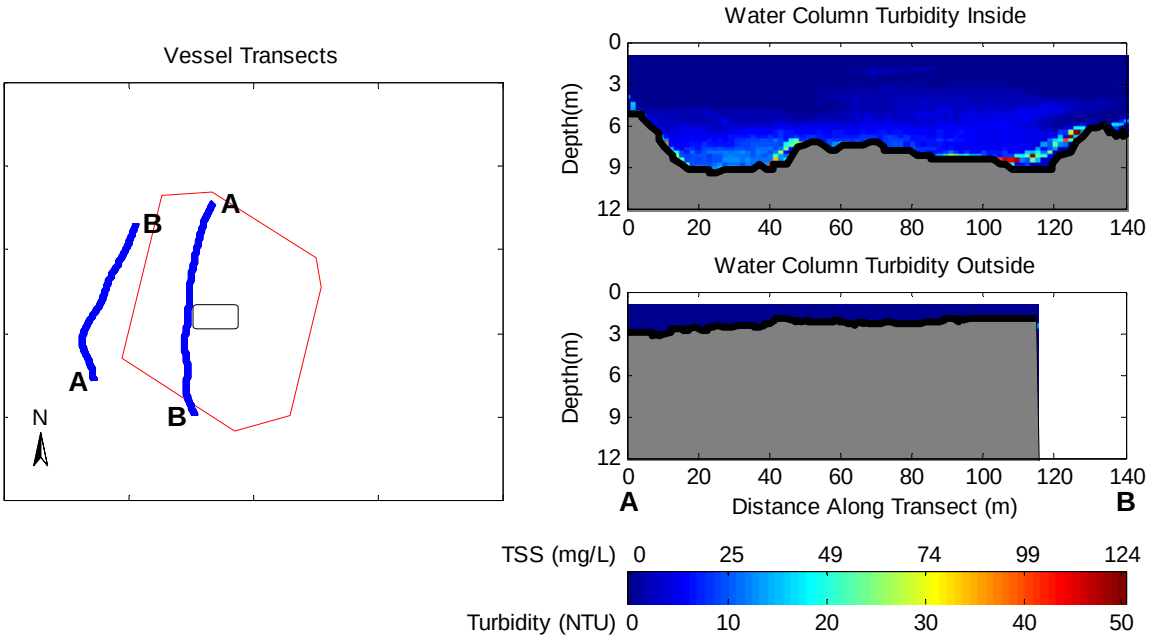

Figure 5-6. Observations from 46 to 49 Minutes after Release During July 8, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

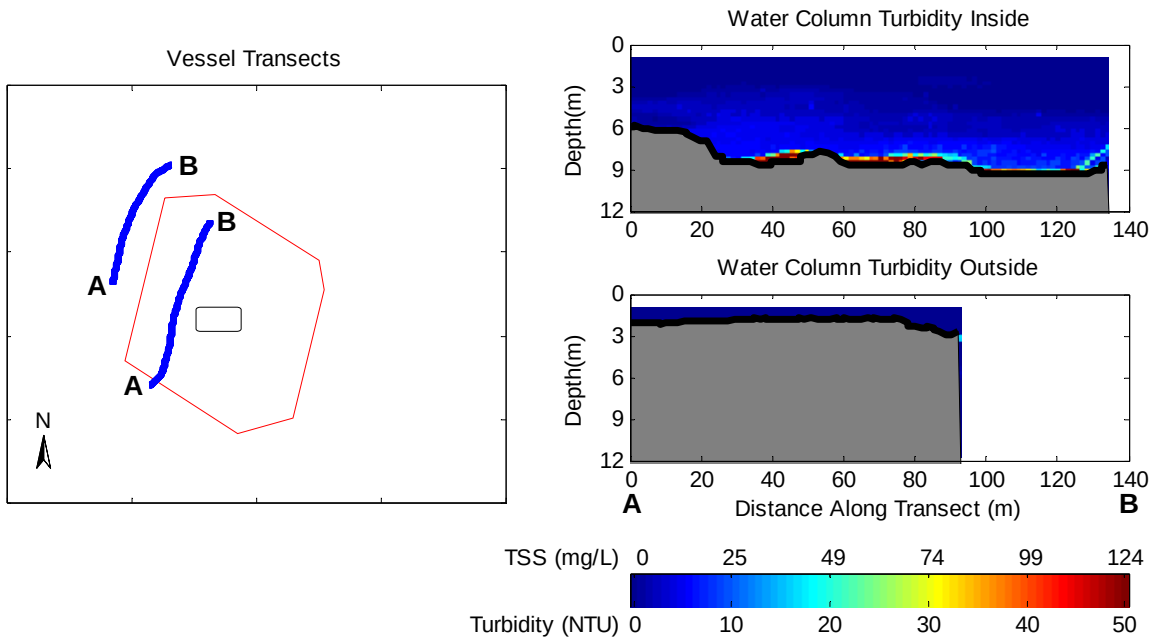

Figure 5-7. Observations from 58 to 61 Minutes after Release During July 8, 2009 Disposal into the New Bedford Harbor CAD Cell. The left panel shows concurrent inner and outer vessel transects. The right panel shows vertical slices of calibrated turbidity and TSS measured with ADCP along each vessel transect.

Atlantic Bluefin Tuna (*Thunnus thynnus*)

***Essential Fish Habitat for Atlantic Bluefin Tuna*:**

- **Spawning, eggs and larvae:** In pelagic and near coastal surface waters from the North Carolina/South Carolina border at 33.5□ N, south to Cape Canaveral, FL from 15 miles from shore to the 200 m isobath; all waters from offshore Cape Canaveral at 28.25□ N south around peninsular Florida to the U.S./Mexico border from 15 miles from shore to the EEZ boundary.

- **Juveniles/Subadults (<145 cm TL):** All inshore and pelagic surface waters warmer than 12□ C of the Gulf of Maine and Cape Cod Bay, MA from Cape Ann, MA (~42.75□ N) east to 69.75□ W (including waters of the Great South Channel west of 69.75□ W), continuing south to and including Nantucket Shoals at 70.5□ W to off Cape Hatteras, NC (approximately 35.5□ N), in pelagic surface waters warmer than 12□ C, between the 25 and 200 m isobaths; also in the Florida Straits, from 27□ N south around peninsular Florida to 81□ W in surface waters from the 200 m isobath to the EEZ boundary.

- **Adults (>145 cm TL):** In pelagic waters of the Gulf of Maine from the 50 m isobath to the EEZ boundary, including the Great South Channel, then south of Georges Bank to 39□ N from the 50 m isobath to the EEZ boundary; also, south of 39□ N, from the 50 m isobath to the 2,000 m isobath to offshore Cape Lookout, NC at 34.5□ N. In pelagic waters from offshore Daytona Beach, FL (29.5□ N) south to Key West (82□ W) from the 100 m isobath to the EEZ boundary; in the Gulf of Mexico from offshore Terrebonne Parish, LA (90□ W) to offshore Galveston, TX (95□ W) from the 200 m isobath to the EEZ boundary.

Summary of Essential Fish Habitat (EFH) and General Habitat Parameters for Federally Managed Species

Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
American plaice	Eggs	GOME, GB and estuaries from Passamaquoddy Bay to Saco Bay, ME and from Mass. Bay to Cape Cod Bay, MA	<12	(32)	30 - 90	All year in GOME Dec - June on GB Peaks April & May both	Surface waters	
	Larvae	GOME, GB, Southern NE and estuaries from Passamaquoddy Bay to Saco Bay, ME and from Mass Bay to Cape Cod Bay, MA	<14	(32)	30-130	Between January and August, with peaks in April and May	Surface Waters	
	Juveniles	GOME and estuaries from Passamaquoddy Bay to Saco Bay, ME and from Mass Bay to Cape Cod Bay, MA	<17	(32)	45-150		Bottom habitats with fine-grained sediments or substrate of sand or gravel	(Strong concentrations inside and around 100m isobath in Western GOME; Major Prey: echinoderms, arthropods, annelids)
	Adults	GOME, GB and estuaries from Passamaquoddy Bay to Saco Bay, ME and from Mass Bay to Cape Cod Bay, MA	<17	(34-20)	45-175		Bottom habitats with fine-grained sediments or a substrate of sand or gravel	
	Spawning Adults	GOME, GB and estuaries from Passamaquoddy Bay to Saco Bay, ME and from Mass Bay to Cape Cod Bay, MA	<14	(32)	<90	March through June	Bottom habitats of all substrate types	
Atlantic cod	Eggs	GOME, GB, eastern portion of continental shelf off southern NE and following estuaries: Englishman/ Machias Bay to Blue Hill Bay; Sheepscot R., Casco Bay, Saco Bay, Great Bay, Mass Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay	<12	32 - 33 (10 - 35)	<110	Begins in fall, peaks in winter and spring	Surface Waters	
	Larvae	GOME, GB, eastern portion of continental shelf off southern NE and following estuaries: Passamaquoddy Bay to Penobscot Bay; Sheepscot R., Casco Bay, Saco Bay, Great Bay, Mass Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay	<10	32 - 33	30-70	Spring	Pelagic waters	
	Juveniles	GOME, GB, eastern portion of continental shelf off southern NE and following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay	<20	30 - 35	25 - 75		Bottom habitats with a substrate of cobble or gravel	HAPC - An area approximate of 300sq. nautical miles along the northern edge of GB and the Hague line containing gravel cobble substrate.
	Adults	GOME, GB, southern NE, middle Atlantic south to Delaware Bay and following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay	<10	(29 - 34)	10-150		Bottom habitats with a substrate of rocks, pebbles, or gravel	(Major prey: fish crustaceans, decapods, amphipods)

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Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
	Spawning Adults	GOME, GB, southern NE, middle Atlantic south to Delaware Bay and following estuaries: Englishman/ Machias Bay to Blue Hill Bay; Sheepscot R., Mass Bay, Boston Harbor, Cape Cod Bay, MA	<10	(10 - 35)	10-150	spawn during fall, winter, and early spring	Bottom habitats with a substrate of smooth sand, rocks, pebbles, or gravel	
Atlantic halibut	Eggs	GOME, GB	4 - 7	<35	<700	Between late fall and early spring, peak Nov and Dec.	Pelagic waters to the sea floor	
	Larvae	GOME, GB		30 - 35			Surface waters	
	Juveniles	GOME, GB	>2		20 - 60		Bottom habitats with a substrate of sand, gravel, or clay	
	Adults	GOME, GB	<13.6	30.4-35.3	100-700		Bottom habitats with a substrate of sand, gravel, or clay	(Major prey: crustaceans, fish, cod, squid)
	Spawning Adults	GOME, GB	<7	<35	<700	Between late fall and early spring, peaks in Nov. and Dec.	Bottom habitats with a substrate of soft mud, clay, sand, or gravel; rough or rocky bottom locations along slopes of the outer banks	
Atlantic herring	Eggs	GOME, GB and following estuaries: Englishman/ Machias Bay, Casco Bay,& Cape Cod Bay	<15	32 - 33	20 - 80	July through November	Bottom habitats with a substrate of gravel, sand, cobble, shell fragments & aquatic macrophytes. .	Eggs adhere to bottom forming extensive beds. Eggs most often found in areas of well-mixed water, with tidal currents between 1.5 and 3.0 knots (Egg beds can range from 4500 to 10,000 Km^2 on GB. Eggs susceptible to suffocation from high densities and siltation)
	Larvae	GOME, GB, Southern NE and following estuaries: Passamaquoddy Bay to Cape Cod Bay, Narragansett Bay, & Hudson R./ Raritan Bay	<16	32	50 - 90	Between August and April, peaks from Sept. - Nov.	Pelagic waters	
	Juveniles	GOME, GB, Southern NE and Middle Atlantic south to Cape Hatteras and following estuaries: Passamaquoddy Bay to Cape Cod Bay; Buzzards Bay to Long Island Sound; Gardiners Bay to Delaware Bay	<10	26 - 32	15-135		Pelagic waters and bottom habitats	
	Adults	GOME, GB, southern NE and middle Atlantic south to Cape Hatteras and following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Cape Cod Bay; Buzzards Bay to Long Island Sound; Gardiners Bay to Delaware Bay; & Chesapeake Bay	<10	>28	20-130		Pelagic waters and bottom habitats	(major prey: zooplankton)
	Spawning Adults	GOME, GB, southern NE and middle Atlantic south to Delaware Bay and Englishman/ Machias Bay Estuary	<15	32 - 33	20 - 80	July through November	Bottom habitats with a substrate of gravel, sand, cobble and shell fragments, also on aquatic macrophytes	Herring eggs are spawned in areas of well-mixed water, with tidal currents between 1.5 and 3.0 knots

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Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Atlantic salmon	Eggs	Rivers from CT to Maine: Connecticut, Pawcatuck, Merrimack, Cocheco, Saco, Androscoggin, Presumpscot, Kennebec, Sheepscot, Ducktrap, Union, Penobscot, Narraguagus, Machias, East Machias, Pleasant, St. Croix, Denny's, Passagassawaukeag Aroostook, Lamprey, Boyden, Orland Rivers, and the Turk, Hobart & Patten Streams; and the following estuaries for juveniles and adults: Passamaquoddy Bay to Muscongus Bay; Casco Bay to Wells Harbor; Mass Bay, Long Island Sound, Gardiners Bay to Great South Bay. All aquatic habitats in the watersheds of the above listed rivers, including all tributaries to the extent that they are currently or were historically accessible for salmon migration.	<10	Fresh water	30-31 cm	Between October and April	Bottom habitats with a gravel or cobble riffle (redd) above or below a pool in rivers	need clean well-oxygenated freshwater
	Larvae		<10	Fresh water		Between March and June for alevins/fry	Bottom habitats with a gravel or cobble riffle (redd) above or below a pool in rivers	
	Juveniles		<25	Fresh water to Oceanic	10- 61 cm		Bottom habitats of shallow gravel/cobble riffles interspersed with deeper riffles and pools in rivers and estuaries Water velocities between 30 - 92cm/sec	As they grow, parr transform into smolts. Atlantic salmon smolts require access downstream to the ocean. Upon entering the ocean, post-smolts become pelagic and range from Long Island Sound north to the Labrador Sea.
	Adults		<22.8	Fresh water to Oceanic			Oceanic adult Atlantic salmon are primarily pelagic and range from waters of the continental shelf off southern NE north throughout the GOME Dissolved oxygen above 5ppm for migratory pathway.	HAPC - Eleven rivers in Maine includes: St. Croix, Denny's, East Machias, Machias, Pleasant, Turk stream, Narraguagus, Penobscot, Ducktrap, Sheepscot, and Kennebec River.
	Spawning Adults		<10	Fresh water	30- 61 cm	October and November	Bottom habitats with a gravel or cobble riffle (redd) above or below a pool in rivers	Water velocity around 61cm per second
Atlantic sea scallop	Eggs	GOME, GB, southern NE and middle Atlantic south to Virginia-North Carolina border and following estuaries: Passamaquoddy Bay to Sheepscot R.; Casco Bay, Mass Bay, and Cape Cod Bay	<17			May through October Peaks in May and June in middle Atlantic area, and in Sept. and Oct. on GB and GOME	Bottom habitats	Eggs remain on sea floor until they develop into the first free-swimming larval stage.
	Larvae	GOME, GB, southern NE and middle Atlantic south to Virginia-North Carolina border and following estuaries: Passamaquoddy Bay to Sheepscot R.; Casco Bay, Mass Bay, and Cape Cod Bay	<18	16.9 - 30			Pelagic waters and bottom habitats with a substrate of gravelly sand, shell fragments, pebbles, or on various red algae, hydroids, amphipod tubes and bryozoans	
	Juveniles	GOME, GB, southern NE and middle Atlantic south to Virginia-North Carolina border and following estuaries: Passamaquoddy Bay to Sheepscot R.; Casco Bay, Great Bay, Mass Bay, and Cape Cod Bay	<15		18-110		Bottom habitats with a substrate of cobble, shells, and silt	(prey: filter feeders on phytoplankton; preferred substrates are associated with low concentrations of inorganics for optimal feeding)
	Adults	GOME, GB, southern NE and middle Atlantic south to Virginia-North Carolina border and following estuaries: Passamaquoddy Bay to Sheepscot R.; Casco Bay, Great Bay, Mass Bay, and Cape Cod Bay	<21	>16.5	18-110		Bottom habitats with a substrate of cobble, shells, coarse/gravelly sand, and sand	

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Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
	Spawning Adults	GOME, GB, southern NE and middle Atlantic south to Virginia-North Carolina border and following estuaries: Passamaquoddy Bay to Sheepscot R.; Casco Bay, Mass Bay, and Cape Cod Bay	<16	>16.5	18-110	May through October, peaks in May and June in middle Atlantic area, and in Sept. and Oct. on GB and in GOME	Bottom habitats with a substrate of cobble, shells, coarse/gravelly sand, and sand	
Haddock	Eggs	GB southwest to Nantucket Shoals and coastal areas of GOME and the following estuaries: Great Bay, Mass Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay	<10	34 - 36	50 - 90	March to May, peak in April	Surface waters	
	Larvae	GB southwest to the middle Atlantic south to Delaware Bay and the following estuaries: Great Bay, Mass Bay, Boston Harbor, Cape Cod Bay, Buzzards Bay, and Narragansett Bay	<14	34 - 36	30 - 90	January to July, peak in April and May	Surface waters	
	Juveniles	GB, GOME, middle Atlantic south to Delaware Bay	<11	31.5 - 34	35-100		Bottom habitats with a substrate of pebble gravel	
	Adults	GB and eastern side of Nantucket Shoals, throughout GOME, *additional area of Nantucket Shoals, and Great South Channel	<7	31.5 - 35	40-150		Bottom habitats with a substrate of broken ground, pebbles, smooth hard sand, and smooth areas between rocky patches	*additional area more accurately reflects historic patterns of distribution and abundance
	Spawning Adults	GB, Nantucket Shoals, Great South Channel, throughout GOME	<6	31.5 - 34	40-150	January to June	Bottom habitats with a substrate of pebble gravel or gravelly sand	
Monkfish (Goose-fish)	Eggs	GOME, GB, southern NE, middle Atlantic south to Cape Hatteras, North Carolina	<18		15- 1000	March to September	Surface waters	(eggs contained in long mucus veils that float near or at the surface)
	Larvae	GOME, GB, southern NE, middle Atlantic south to Cape Hatteras, North Carolina	15		25-1000	March to September	Pelagic waters	
	Juveniles	Outer continental shelf in the middle Atlantic, mid-shelf off southern NE, all areas of GOME	<13	29.9-36.7	25-200		Bottom habitats with substrates of a sand-shell mix, algae covered rocks, hard sand, pebbly gravel, or mud	
	Adults	Outer continental shelf in the middle Atlantic, mid-shelf off southern NE, outer perimeter of GB, all areas of GOME	<15	29.9-36.7	25-200		Bottom habitats with substrates of a sand-shell mix, algae covered rocks, hard sand, pebbly gravel, or mud	(Major prey: fish, shrimp, squid, crustaceans, mollusks)
	Spawning Adults	Outer continental shelf in the middle Atlantic, mid-shelf off southern NE, outer perimeter of GB, all areas of GOME	<13	29.9-36.7	25-200	February to August	Bottom habitats with substrates of a sand-shell mix, algae covered rocks, hard sand, pebbly gravel, or mud	
Ocean pout	Eggs	GOME, GB, southern NE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay and Cape Cod Bay	<10	32-34	<50	Late fall and winter	Bottom habitats, generally hard bottom sheltered nests, holes, or crevices where they are guarded by parents	(eggs are laid in gelatinous masses and take 2-3 months to develop

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Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
	Larvae	GOME, GB, southern NE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay and Cape Cod Bay	<10	>25	<50	Late fall to spring	Bottom habitats in close proximity to hard bottom nesting areas	
	Juveniles	GOME, GB, southern NE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay, Boston Harbor and Cape Cod Bay	<14	>25	<80		Bottom habitats, often smooth bottom near rocks or algae	
	Adults	GOME, GB, southern NE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay, Boston Harbor and Cape Cod Bay	<15	32 - 34	<110		Bottom habitats. (Dig depressions in soft sediments which are then used by other species)	(major prey: mollusks, crustaceans, echinoderms, sand dollars)
	Spawning Adults	GOME, GB, southern NE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Mass Bay, and Cape Cod Bay	<10	32 - 34	<50	Late summer to early winter, peaks in Sept. and October	Bottom habitats with a hard bottom substrate, including artificial reefs and shipwrecks	(internal fertilization)
Offshore hake	Eggs	Outer continental shelf of GB and southern NE south to Cape Hatteras, North Carolina	<20		<1250	Observed all year and primarily collected at depths from 110 - 270m	Pelagic waters	
	Larvae	Outer continental shelf of GB and southern NE south to Chesapeake Bay	<19		<1250	Observed all year and primarily collected at depths from 70 - 130m	Pelagic waters	
	Juveniles	Outer continental shelf of GB and southern NE south to Cape Hatteras, NC	<12		170- 350		Bottom habitats	
	Adults	Outer continental shelf of GB and southern NE south to Cape Hatteras, NC	<12		150 - 380		Bottom habitats	(major prey: fish - cannibalistic, shrimp, other crustaceans)
	Spawning Adults	Outer continental shelf of GB and southern NE south to the Middle Atlantic Bight	<12		330 - 550	Spawn all throughout the year	Bottom habitats	
Pollock	Eggs	GOME, GB and the following estuaries: Great Bay to Boston Harbor	<17	32 - 32.8	30-270	October to June, peaks in November to February	Pelagic waters	
	Larvae	GOME, GB and the following estuaries: Passamaquoddy Bay, Sheepscot R., Great Bay to Cape Cod Bay	<17		10-250	September to July, peaks from Dec. to February	Pelagic waters	(migrate inshore as they grow)
	Juveniles	GOME, GB and the following estuaries: Passamaquoddy Bay to Saco Bay; Great Bay to Waquoit Bay; Long Island Sound, Great South Bay	<18	29 - 32	0 - 250		Bottom habitats with aquatic vegetation or a substrate of sand, mud or rocks	(Intertidal zone may be important nursery area. Juveniles present in shallow intertidal zone at all tide stages throughout summer. Subtidal marsh creeks such as Little Egg Harbor, NJ are also seasonally important as nursery)

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Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
	Adults	GOME, GB, southern NE, and middle Atlantic south to New Jersey and the following estuaries: Passamaquoddy Bay, Damariscotta R., Mass Bay, Cape Cod Bay, Long Island Sound	<14	31 - 34	15-365		Hard bottom habitats including artificial reefs	(major prey: crustaceans, fish, mollusks)
	Spawning Adults	GOME, southern NE, and middle Atlantic south to New Jersey includes Mass Bay	<8	32 - 32.8	15-365	September to April, peaks December to February	Bottom habitats with a substrate of hard, stony, or rocky bottom includes artificial reefs	
Red hake	Eggs	GOME, GB, continental shelf off southern NE, and middle Atlantic south to Cape Hatteras	<10	< 25		May to November, peaks in June and July	Surface waters of inner continental shelf	
	Larvae	GOME, GB, continental shelf off southern NE, and middle Atlantic south to Cape Hatteras and following estuaries: Sheepscot R., Mass Bay to Cape Cod Bay; Buzzards Bay, Narragansett Bay & Hudson R./ Raritan Bay	<19	>0.5	<200	May to December, peaks in Sept. and October	Surface waters	(newly settled larvae need shelter, including live sea scallps, also use floating or mid-water objects for shelter)
	Juveniles	GOME, GB, continental shelf off southern NE, and middle Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Saco Bay; Great Bay, Mass Bay to Cape Cod Bay; Buzzards Bay to Conn. R.; Hudson R./ Raritan Bay, & Chesapeake Bay	<16	31 - 33	<100		Bottom habitats with substrate of shell fragments, including areas with an abundance of live scallops	
	Adults	GOME, GB, continental shelf off southern NE, and middle Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Saco Bay; Great Bay, Mass Bay to Cape Cod Bay; Buzzards Bay to Conn. R.; Hudson R./ Raritan, Delaware Bay, & Chesapeake Bay	<12	33 - 34	10-130		Bottom habitats in depressions with a substrate of sand and mud	(major prey: fish and crustaceans)
	Spawning Adults	GOME, southern edge of GB, continental shelf off southern NE, and middle Atlantic south to Cape Hatteras and following estuaries: Sheepscott R., Mass Bay, Cape Cod Bay, Buzzards Bay, & Narragansett Bay	<10	>25	<100	May to November, peaks in June and July	Bottom habitats in depressions with a substrate of sand and mud	
Redfish	Eggs	No EFH identification or description for this life history stage						Redfish are ovoviviparous (live bearers)
	Larvae	GOME, southern GB	<15		50-270	March to October, peak in August	Pelagic waters	
	Juveniles	GOME, southern edge of GB	<13	31 - 34	25-400		Bottom habitats with a substrate of silt, mud, or hard bottom	
	Adults	GOME, southern edge of GB	<13	31 - 34	50-350		Bottom habitats with a substrate of silt, mud, or hard bottom	
	Spawning Adults	GOME, southern edge of GB	<13	31 - 34	5 -350	April to August	Bottom habitats with a substrate of silt, mud, or hard bottom	copulation occurs between Oct-Jan. Fertilization is delayed until Feb-Apr

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White hake	Eggs	GOME, GB, southern NE and the following estuaries: Great Bay to Cape Cod Bay				August to September	Surface waters	
	Larvae	GOME, southern edge of GB, southern NE to middle Atlantic and the following estuaries: Mass Bay, to Cape Cod Bay				May - mid-Atlantic area Aug. & Sept. - GOME, GB area	Pelagic waters	
	Juveniles	GOME, southern edge of GB, southern NE to middle Atlantic and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Cape Cod Bay	<19		5 - 225	May-Sep - pelagic	Pelagic stage - pelagic waters; Dermersal stage - Bottom habitat with seagrass beds or substrate of mud or fine-grained sand	
	Adults	GOME, southern edge of GB, southern NE to middle Atlantic and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Cape Cod Bay	<14		5 - 325		Bottom habitats with substrate of mud or fine-grained sand	(major prey: small fish, shrimp and other crustaceans)
	Spawning Adults	GOME, southern edge of GB, southern NE to middle Atlantic	<14		5 - 325	April to May - southern part of range; August - Sept.- northern part of range	Bottom habitats with substrate of mud or fine-grained sand in deep water.	
Whiting (Silver hake)	Eggs	GOME, GB, continental shelf off southern NE, middle Atlantic south to Cape Hatteras and the following estuaries: Merrimack R. to Cape Cod Bay	<20		50-150	All year, peaks June to October	Surface waters	
	Larvae	GOME, GB, continental shelf off southern NE, middle Atlantic south to Cape Hatteras and the following estuaries: Mass Bay to Cape Cod Bay	<20		50-130	All year, peaks July to September	Surface waters	
	Juveniles	GOME, GB, continental shelf off southern NE, middle Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Casco Bay, Mass Bay to Cape Cod Bay	<21	>20	20-270		Bottom habitats of all substrate types	
	Adults	GOME, GB, continental shelf off southern NE, middle Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Casco Bay, Mass Bay to Cape Cod Bay	<22		30-325		Bottom habitats of all substrate types	
	Spawning Adults	GOME, GB, continental shelf off southern NE, middle Atlantic south to Cape Hatteras and the following estuaries: Mass Bay and Cape Cod Bay	<13		30-325		Bottom habitats of all substrate types	
Window-pane flounder	Eggs	GOME, GB, southern NE, middle Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Delaware Inland Bays	<20		<70	February to November, peaks May and October in middle Atlantic July - August on GB	Surface waters	

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Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
	Larvae	GOME, GB, southern NE, middle Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Delaware Inland Bays	<20		<70	February to November, peaks May and October in middle Atlantic July - August on GB	Pelagic waters	
	Juveniles	GOME, GB, southern NE, middle Atlantic south to Cape Hatteras and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Chesapeake Bay	<25	5.5 - 36	1 - 100		Bottom habitats with substrate of mud or fine grained sand	
	Adults	GOME, GB, southern NE, middle Atlantic south to Virginia - NC border and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Chesapeake Bay	<26.8	5.5 - 36	1 - 75		Bottom habitats with substrate of mud or fine grained sand	(major prey: polychaetes, small crustaceans, mysids, small fish)
	Spawning Adults	GOME, GB, southern NE, middle Atlantic south to Virginia -NC border and the following estuaries: Passamaquoddy Bay to Great Bay; Mass Bay to Delaware Inland Bays	<21	5.5 - 36	1 - 75	February - December, peak in May in middle Atlantic	Bottom habitats with substrate of mud or fine grained sand	
Winter flounder	Eggs	GB, inshore areas of GOME, southern NE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Delaware Inland Bays	<10	10 - 30	<5	February to June, peak in April on GB	Bottom habitats with a substrate of sand, muddy sand, mud, and gravel	* On GB, eggs are generally found in water temp < 8EC, and < 90m deep.
	Larvae	GB, inshore areas of GOME, southern NE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Delaware Inland Bays	<15	4 - 30	<6	March to July, peaks in April and May on GB	Pelagic and bottom waters	* On GB, larvae are generally found in water temp < 8EC, and < 90m deep.
	Juveniles (age 1+)	GB, inshore areas of GOME, southern NE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Chincoteague Bay	<25	10 - 30	1 - 50		Bottom habitats with a substrate of mud or fine grained sand	* Young-of-year exist where water temp <28, depths 0.1 - 10m, salinities 5 - 33 (major prey: amphipods, copepods, polychaetes, bivalve siphons)
	Adults	GB, inshore areas of GOME, southern NE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Chincoteague Bay	<25	15 - 33	1 - 100		Bottom habitats including estuaries with substrate of mud, sand, gravel	(major prey: amphipods, polychaetes, bivalve siphons, crustaceans)
	Spawning Adults	GB, inshore areas of GOME, southern NE, middle Atlantic south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Delaware Inland Bays	<15	5.5 - 36	<6*	February to June	Bottom habitats including estuaries with substrate of mud, sand, gravel	*except on GB where they spawn as deep as 80m
Witch flounder	Eggs	GOME, GB, continental shelf off southern NE, middle Atlantic south to Cape Hatteras	<13	High	Deep	March to October	Surface waters	
	Larvae	GOME, GB, continental shelf off southern NE, middle Atlantic south to Cape Hatteras	<13	High	Deep	March to November, peaks in May - July	Surface waters to 250m	

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Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
	Juveniles	GOME, outer continental shelf from GB south to Cape Hatteras	<13	34 - 36	50-450 to 1500m		Bottom habitats with fine-grained substrate	(the upper slope is nursery area; major prey: crustaceans, polychaetes, mollusks)
	Adults	GOME, outer continental shelf from GB south to Chesapeake Bay	<13	32 - 36	25-300		Bottom habitats with fine-grained substrate	(major prey: polychaetes, echinoderms, crustaceans, mollusks, squid)
	Spawning Adults	GOME, outer continental shelf from GB south to Chesapeake Bay	<15	32 - 36	25-360	March to November, peaks in May-August	Bottom habitats with fine-grained substrate	
Yellowtail flounder	Eggs	GB, Mass Bay, Cape Cod Bay, southern NE continental shelf south to Delaware Bay and the following estuaries: Passamaquoddy Bay to Saco Bay; Great Bay to Cape Cod Bay	<15	32.4 - 33.5	30 - 90	Mid-March to July, peaks in April to June in southern NE	Surface waters	
	Larvae	GB, Mass Bay, Cape Cod Bay, southern NE continental shelf, middle Atlantic south to Chesapeake Bay and the following estuaries: Passamaquoddy Bay to Cape Cod Bay	<17	32.4 - 33.5	10 - 90	March to April in New York bight; May to July in south NE and southeastern GB	Surface waters	(largely an oceanic nursery)
	Juveniles	GB, GOME, southern NE continental shelf south to Delaware Bay and the following estuaries: Sheepscot R., Casco Bay, Mass Bay to Cape Cod Bay	<15	32.4 - 33.5	20 - 50		Bottom habitats with substrate of sand or sand and mud	
	Adults	GB, GOME, southern NE continental shelf south to Delaware Bay and the following estuaries: Sheepscot R., Casco Bay, Mass Bay to Cape Cod Bay	<15	32.4 -33.5	20 - 50		Bottom habitats with substrate of sand or sand and mud	(major prey: annelids, arthropods, mollusks)
	Spawning Adults	GB, GOME, southern NE continental shelf south to Delaware Bay and the following estuaries: Mass Bay to Cape Cod Bay	<17	32.4 - 33.5	10-125		Bottom habitats with substrate of sand or sand and mud	
Atlantic mackerel	Eggs	Continental Shelf from Maine through Cape Hatteras, NC also includes estuaries from Great Bay to Cape Cod Bay; Buzzards Bay to Long Island Sound; Gardiners Bay and Great South Bay	5-23	(18 - >30)	0 - 15		Pelagic waters	(peak spawning in salinities >30ppt)
	Larvae	Continental Shelf from GOME through Cape Hatteras, NC also includes estuaries from Great Bay to Cape Cod Bay; Narragansett Bay to Long Island Sound; Gardiners Bay and Great South Bay	6-22	(>30)	10-130		Pelagic waters	
	Juveniles	Continental Shelf from GOME through Cape Hatteras, NC also includes estuaries from Passamaquoddy Bay; Penobscot Bay to Saco Bay; Great Bay; Mass Bay to Cape Cod Bay; Narragansett Bay, Long Island Bay; Gardiners Bay to Hudson R./ Raritan Bay	4 - 22	(>25)	0 - 320		Pelagic waters	

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Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
	Adults	Continental Shelf from GOME through Cape Hatteras, NC also includes estuaries from Passamaquoddy Bay to Saco Bay; Mass Bay to Long Island Bay; Gardiners Bay to Hudson R./ Raritan Bay	4 - 16	(>25)	0 - 380		Pelagic waters	(opportunistic feeding: can filter feed or select individual prey. Major prey: crustaceans, pelagic mullosks, polychaetes, squid, fish)
Black sea bass	Eggs	Continental Shelf and estuaries from southern NE to North Carolina, also includes Buzzards Bay			0 - 200	May to October	Water column of coastal Mid-Atlantic Bight and Buzzards Bay	
	Larvae	Pelagic waters over Continental Shelf from GOME to Cape Hatteras, NC, also includes Buzzards Bay	(11-26)	(30 - 35)	(<100)	(May - Nov, peak Jun - Jul)	Habitats for transforming (to juveniles) larvae are near coastal areas and into marine parts of estuaries between Virginia and NY. When larvae become demersal, found on structured inshore habitat such as sponge beds.	
	Juveniles	Demersal waters over Continental Shelf from GOME to Cape Hatteras, NC, also includes estuaries from Buzzards Bay to Long Island Sound; Gardiners Bay, Barnegat Bay to Chesapeake Bay; Tangier/ Pocomoke Sound and James River	>6	>18	(1 - 38)	Found in coastal areas (Apr - Dec , peak Jun - Nov) between VA and MA, but winter offshore from NJ and south; Estuaries in summer and spring	Rough bottom, shellfish and eelgrass beds, man-made structures in sandy-shelly areas, offshore clam beds and shell patches may be used during wintering	(YOY use salt marsh edges and channels; high habitat fidelity)
	Adults	Demersal waters over Continental Shelf from GOME to Cape Hatteras, NC, also includes estuaries: Buzzards Bay, Narragansett Bay, Gardiners Bay, Great South Bay, Barnegat Bay to Chesapeake Bay; Tangier/ Pocomoke Sound and James River	>6	(>20)	(20- 50)	Wintering adults (Nov. to April) offshore, south of NY to NC Inshore, estuaries from May to October	Structured habitats (natural & man-made) sand and shell substrates preferred	(spawn in coastal bays but not estuaries; change sex to males with growth; prey: benthic and near bottom inverts, small fish, squid)
Bluefish	Eggs	North of Cape Hatteras, found over Continental Shelf from Montauk Point, NY south to Cape Hatteras, South of Cape Hatteras, found over Continental Shelf through Key West, Florida	>18	>31ppt	Mid-shelf depths	April to August	Pelagic waters	*No EFH designation inshore
	Larvae	North of Cape Hatteras, found over Continental Shelf from Montauk Point, NY south to Cape Hatteras, South of Cape Hatteras, found over Continental Shelf through Key West, Florida, the slope sea and Gulf Stream between latitudes 29N and 40N; includes the following estuaries: Narragansett Bay	>18	>30ppt	>15	April to September	Pelagic waters	No EFH designation inshore for larvae

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Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
	Juveniles	North of Cape Hatteras, found over Continental Shelf from Nantucket Island, MA south to Cape Hatteras,South of Cape Hatteras, found over Continental Shelf through Key West, Florida, the slope sea and Gulf Stream between latitudes 29N and 40N also includes estuaries between Penobscot Bay to Great Bay; Mass Bay to James R.; Albemarie Sound to St. Johns River, FL	(19-24)	(23 - 36) freshwater zone in Albemarie Sound		North Atlantic estuaries from June to October Mid-Atlantic estuaries from May to October South Atlantic estuaries from March to December	Pelagic waters	(use estuaries as nursery areas; can intrude into areas with salinities as low as 3 ppt)
	Adults	North of Cape Hatteras, found over Continental Shelf from Cape Cod Bay, MA south to Cape Hatteras,South of Cape Hatteras, found over Continental Shelf through Key West, Florida also includes estuaries between Penobscot Bay to Great Bay; Mass Bay to James R.; Albemarie Sound to Pamilco/ Pungo R., Bougue Sound, Cape Fear R., St. Helena Sound, Broad R., St. Johns R., & Indian R.	(14-16)	>25ppt		North Atlantic estuaries from June to October Mid-Atlantic estuaries from April to October South Atlantic estuaries from May to January	Pelagic waters	Highly migratory (major prey: fish)
Butterfish	Eggs	Over Continental shelf from GOME through Cape Hatteras, NC,also in estuaries from Mass Bay to Long Island Sound; Gardiners Bay, Great South Bay, and Chesapeake Bay	11 - 17	(25 - 33)	0-1829	(spring and summer)	Pelagic waters	
	Larvae	Over Continental shelf from GOME through Cape Hatteras, NC,also in estuaries from Boston Harbor, Waquoit Bay to Long Island Sound; Gardiners Bay to Hudson R./ Raritan Bay; Delaware Bay and Chesapeake Bay	9 - 19	(6.4 - 37)	10-1829	(summer and fall)	Pelagic waters	
	Juveniles	Over Continental shelf from GOME through Cape Hatteras, NC also in estuaries from Mass Bay, Cape Cod Bay to Delaware Inland Bays; Chesapeake Bay, York R. and James R.	3 - 28	(3 - 37)	10-365 (most <120)	(winter - shelf spring to fall - estuaries)	Pelagic waters (larger individuals found over sandy and muddy substrates)	(pelagic schooling - smaller individuals associated with floating objects including jellyfish)
	Adults	Over Continental shelf from GOME through Cape Hatteras, NC,also in estuaries from Mass Bay, Cape Cod Bay to Hudson R./ Raritan Bay; Delaware Bay and Inland Bays; York R. and James R.	3 - 28	(4 - 26)	10-365 (most <120)	(winter - shelf summer to fall - estuaries)	Pelagic waters (schools form over sandy, sandy-silt and muddy substrates)	(common in inshore areas and surf zone; prey: planktonic, thaliacians, squid, copepods)
Illex squid	Juveniles	Over Continental shelf from GOME through Cape Hatteras, NC	2 -23		0 - 182	(carried northward by Gulf Stream)	Pelagic waters	
	Adults	Over Continental shelf from GOME through Cape Hatteras, NC	4 - 19		0 -182	(late fall - offshore, spawn Dec- Mar)	Pelagic waters	(prey: fish, crustaceans, squid; die after spwaning)
Loligo	Eggs***	Over Continental shelf from GOME through Cape Hatteras, NC	(>8)	(30 - 32)	(<50)	(May - spawned, hatch in Jul)	(Demersal egg masses are commonly found on sandy/mud bottom, usually attached to rocks/boulders, pilings or algae such as fucus, ulva, laminaria, porphyra)	*** EFH is not currently designated for this life stage (Eggs are demersal, enclosed in gelatinous capsule containing up to 200 eggs. Laid in masses of hundreds of capsules from different females)

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Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
	Juveniles	Over Continental shelf from GOME through Cape Hatteras, NC	4 - 27	(31 - 34)	0 - 213	spring - fall - inshore winter - offshore	Pelagic waters	(inhabit upper 10m at depth of 50 - 100m on continental shelf)
	Adults	Over Continental shelf from GOME through Cape Hatteras, NC	4 - 28		0 - 305	(Mar - Oct - inshore; winter - offshore)	Pelagic waters	(prey: fish, crustaceans)
Ocean quahog	Juveniles	Eastern edge of GB and GOME throughout the Atlantic EEZ	<18	(>25)	8-245		Throughout substrate to a depth of 3ft within federal waters, occurs progressively further offshore between Cape Cod and Cape Hatteras	(medium to fine grained sands, sandy mud, silty sand)
	Adults	Eastern edge of GB and GOME throughout the Atlantic EEZ	<18	(>25)	8 -245	(spawn May-Dec with several peaks)	Throughout substrate to a depth of 3ft within federal waters, occurs progressively further offshore between Cape Cod and Cape Hatteras	(medium to fine grained sands, sandy mud, silty sand; earliest age of maturity 7 yrs, avg 13 yrs; suspension feeders on phytoplankton)
Scup	Eggs	Southern NE to coastal Virginia includes the following estuaries: Waquoit Bay to Long Island Sound; Gardiners Bay, Hudson R./ Raritan Bay	13 - 23	>15	(<30)	May - August	Pelagic waters in estuaries	
	Larvae	Southern NE to coastal Virginia includes the following estuaries: Waquoit Bay to Long Island Sound; Gardiners Bay, Hudson R./ Raritan Bay	13 - 23	>15	(<20)	May - September	Pelagic waters in estuaries	
	Juveniles	The Continental Shelf from GOME to Cape Hatteras, NC includes the following estuaries: Mass Bay, Cape Cod Bay to Long Island Sound; Gardiners Bay to Delaware Inland Bays; & Chesapeake Bay	>7	>15	(0 - 38)	Spring and summer in estuaries and bays	Dermersal waters north of Cape Hatteras and Inshore on various sands, mud, mussel, and eelgrass bed type substrates	
	Adults	The Continental Shelf from GOME to Cape Hatteras, NC includes the following estuaries: Cape Cod Bay to Long Island Sound; Gardiners Bay to Hudson R./ Raritan Bay; Delaware Bay & Inland Bays; & Chesapeake Bay	>7	>15	(2 -185)	Wintering adults (November - April) are usually offshore, south of NY to NC	Dermersal waters north of Cape Hatteras and Inshore estuaries (various substrate types)	(spawn < 30m during inshore migration - May - Aug; prey: small benthic inverts)
Spiny Dogfish	Juveniles	GOME through Cape Hatteras, NC across the Continental Shelf; Continental Shelf waters South of Cape Hatteras, NC through Florida; also includes estuaries from Passamaquaddy Bay to Saco Bay; Mass Bay & Cape Cod Bay	3 - 28		10-390		Continental Shelf waters and estuaries	
	Adults	GOME through Cape Hatteras, NC across the Continental Shelf;Continental Shelf waters South of Cape Hatteras, NC through Florida; also includes estuaries from Passamaquaddy Bay to Saco Bay; Mass Bay & Cape Cod Bay	3 - 28	(30 - 32)	10-450		Continental Shelf waters and estuaries	(major prey: crabs, eels, small fish)

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Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
Summer flounder	Eggs	Over Continental Shelf from GOME to Cape Hatteras, NC; South of Cape Hatteras to Florida			30-70 fall; 110 winter; 9-30 spring	October to May	Pelagic waters , heaviest concentrations within 9miles of shore off NJ and NY	
	Larvae	Over Continental Shelf from GOME to Cape Hatteras, NC; South of Cape Hatteras to Florida; also includes estuaries from Waquoit Bay to Narragansett Bay; Hudson River/ Raritan Bay; Barnegat Bay, Chesapeake Bay, Rappahannock R., York R., James R., Albemarie Sound, Pamlico Sound, Neuse R. to Indian R.	(9 - 12)	(23-33) Fresh in Hudson R. Raritan Bay area	10-70	mid-Atlantic Bight from Sept. to Feb.; Southern part from Nov. to May at depths 9-30m	Pelagic waters, larvae most abundant 19 - 83km from shore; Southern areas 12 - 52 miles from shore	(high use of tidal creeks and creek mouths)
	Juveniles	Over Continental Shelf from GOME to Cape Hatteras, NC; South of Cape Hatteras to Florida; also includes estuaries from Waquoit Bay to James R.; Albemarie Sound to Indian R.	>11	10 -30 Fresh in Narrag. Bay, Albem/ Pamlico Sound, & St. Johns R.	(0.5-5) in estuary		Demersal waters, muddy substrate but prefer mostly sand; found in the lower estuaries in flats, channels, salt marsh creeks, and eelgrass beds	HAPC - All native species of macroalgae, seagrasses and freshwater and tidal macrophytes in any size bed as well as loose aggregations, within adult and juvenile EFH. (Major prey: mysid shrimp)
	Adults	Over Continental Shelf from GOME to Cape Hatteras, NC; South of Cape Hatteras to Florida; also includes estuaries from Buzzards Bay, Narragansett Bay, Conn. R. to James R.; Albemarie Sound to Broad R.; St. Johns R., & Indian R.		Fresh in Albemarie Sound, Pamlico Sound, & St. Johns R.	(0 - 25)	Inhabit shallow coastal and estuarine waters during warmer months and move offshore on outer Continental Shelf at depths of 150m in colder months	Demersal waters and estuaries	HAPC - All native species of macroalgae, seagrasses and freshwater and tidal macrophytes in any size bed as well as loose aggregations, within adult and juvenile EFH. (Major prey: fish, shrimp, squid, polychaetes)
Surf clams	Juveniles	Eastern edge of GB and the GOME throughout Atlantic EEZ	(2-30)		0 -60 , low density beyond 38		Throughout substrate to a depth of three feet within federal waters. (Burrow in med. To coarse sand and gravel substrates. Also found in silty to fine sand, not in mud)	
	Adults	Eastern edge of GB and the GOME throughout Atlantic EEZ	(2-30)		0 -60 , low density beyond 38	(spawn-summer to fall at 19 - 30 ºC)	Throughout substrate to a depth of three feet within federal waters	
Tilefish	Eggs	US Canadian Boundary to VA/NC boundary (shelf break; GB to Cape Hatteras)	8 - 19	(34 - 36)	76-365	(Serial spawning March - November; peaks April - October)	Water column	
	Larvae	US Canadian Boundary to VA/NC boundary Outer continental shelf; (GB to Cape Hatteras)	8 - 19	(33 - 35)	76-365	(Feb - Oct; peaks July - Oct)	Water column	

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Species	Life Stage	Geographic Area	Temp (EC)	Salinity (‰)	Depth (m)	Seasonal Occurrence	Habitat Description	Comments
	Juveniles	US Canadian Boundary to VA/NC boundary (shelf break, submarine canyon walls and flanks; GB to Cape Hatteras)	8 - 18	(33 - 36)	76-365	(All year; may leave GB in winter)	Rough bottom, small burrows, and sheltered areas. (Substrate - rocky, stiff clay, human debris)	(Tilefish are shelter-seeking and habitat limited). HAPC is substrate between the 76 and 365m isobath, from U.S. / Canadian Boundary to the Virginia / North Carolina boundary within statistical areas 616 and 537 (intersection of isobaths east of Cape May, NJ and south of Provincetown, MA)
	Adults	US Canadian Boundary to VA/NC boundary (shelf break, submarine canyon walls and flanks; GB to Cape Hatteras)	8 - 18	(33 - 36)	76-365	(All year; may leave GB in winter)	Rough bottom, small burrows, and sheltered areas. (Substrate - rocky exposed ledges, stiff clay)	HAPC is substrate between the 250 and 1200 ft isobath, from U.S. / Canadian Boundary to the Virginia / North Carolina boundary within statistical areas 616 and 537 (intersection of isobaths east of Cape May, NJ and south of Provincetown, MA) (prey: crustaceans, fish, decapods, benthic epifauna)
Red drum	Larvae	Along the Atlantic coast from Virginia through the Florida Keys	2 - 33	Low salinity	<50		Estuarine wetlands especially important Flooded saltmarshes, brackish marsh, tidal creeks, mangrove fringe, seagrasses	Red drum are euryhaline
	Juveniles	Along the Atlantic coast from Virginia through the Florida Keys	2 - 33	20 - 40	<50	Found throughout Chesapeake Bay from Sept. - Nov.	Utilize shallow backwaters of estuaries as nursery areas and remain till they move to deeper water portions of the estuary associated with river mouths, oyster bars and front beaches	Red drum are eurythermal and larger juveniles and Adults more susceptible to effects of winter cold waves than small fish
	Adults	Along the Atlantic coast from Virginia through the Florida Keys	2 - 33	20 - 40	<50	Found in Chesapeake in Spring and Fall and also along Eastern Shore of VA	Concentrate around inlets, shoals, capes along the Atlantic coast - Shallow bay bottoms or oyster reef substrate preferred. Also nearshore artificial reefs.	HAPCs for red drum include all coastal inlets, all state-designated nursery habitats of particular importance to red drum (NC - all Primary and Secondary Nursery Areas), SAV extremely important, barrier islands in NC, SC, GA, FL and passes between barrier islands into estuaries
Spanish mackerel		South Atlantic and Mid-Atlantic Bights	>20	>30			Sandy shoals of capes and offshore bars, high profile rock bottoms and barrier island ocean side waters from surf zone to shelf break but from the Gulf Stream shoreward;	All coastal inlets
Cobia		South Atlantic and Mid-Atlantic Bights	>20	>25			Sandy shoals of capes and offshore bars, high profile rock bottoms and barrier island ocean side waters from surf zone to shelf break but from the Gulf Stream shoreward; high salinity bays, estuaries, seagrass habitat.	All coastal inlets
King mackerel		South Atlantic and Mid-Atlantic Bights	>20	>30			Sandy shoals of capes and offshore bars, high profile rock bottoms and barrier island ocean side waters from surf zone to shelf break but from the Gulf Stream shoreward;	All coastal inlets
Golden crab		Chesapeake Bay to the south through the Florida Straight (and into Gulf of Mexico)			290-570	(Gulf Stream EFH because it helps to disperse golden crab larvae)	Flat foraminifera ooze, distinct mounds of dead coral, ripple habitat, dunes, black pebble habitat, low outcrop, and soft bioturbated habitat	

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Coastal Migratory Pelagics

King Mackerel (*Scomberomorus cavalla*)

Spanish Mackerel (*Scomberomorus maculatus*)

Cobia (*Rachycentron canadum*)

Essential Fish Habitat (EFH) for Coastal Migratory Pelagics:

Essential fish habitat for coastal migratory pelagic species includes sandy shoals of capes and offshore bars, high profile rocky bottom and barrier island ocean-side waters, from the surf to the shelf break zone, but from the Gulf Stream shoreward, including *Sargassum.* In addition, all coastal inlets, all state-designated nursery habitats of particular importance to coastal migratory pelagics.

For cobia, essential fish habitat also includes high salinity bays, estuaries, and seagrass habitat. In addition the Gulf Stream is an essential fish habitat because it provides a mechanism to disperse coastal migratory pelagic larvae.

For king, Spanish mackerel and cobia, essential fish habitat occurs in the South Atlantic and Mid-Atlantic Bights.

Sandbar shark (*Carcharhinus plumbeus*)

***Essential Fish Habitat (EFH) for Sandbar Shark*:**

- **Neonates/early juveniles (90 cm):** Shallow coastal areas to the 25 m isobath from Montauk, Long Island, NY at 72□ W, south to Cape Canaveral, FL at 80.5□ W(all year); nursery areas in shallow coastal waters from Great Bay, NJ to Cape Canaveral, FL, especially Delaware and Chesapeake Bays (seasonal-summer); also shallow coastal waters to up to a depth of 50 m on the west coast of Florida and the Florida Keys from Key Largo at 80.5□ W north to south of Cape San Blas, FL at 85.25□ W. Typical parameters: salinity-greater than 22 ppt; temperatures-greater than 21□ C.

- **Late juveniles/subadults (91 to 179 cm):** Offshore southern New England and Long Island, all waters, coastal and pelagic, north of 40□ N and west of 70□ W; also, south of 40□ N at Barnegat Inlet, NJ, to Cape Canaveral, FL (27.5□ N), shallow coastal areas to the 25 m isobath; also, in the winter, from 39□ N to 36□ N, in the Mid-Atlantic Bight, at the shelf break, benthic areas between the 100 and 200 m isobaths; also, on the west coast of Florida, from shallow coastal waters to the 50 m isobath, from Florida Bay and the Keys at Key Largo north to Cape San Blas, FL at 85.5□ W.

- **Adults (180 cm):** On the east coast of the United States, shallow coastal areas from the coast to the 50 m isobath from Nantucket, MA, south to Miami, FL; also, shallow coastal areas from the coast to the 100 m isobath around peninsular Florida to the Florida panhandle at 85.5□ W, near Cape San Blas, FL including the Keys and saline portions of Florida Bay.

□ **Habitat Areas of Particular Concern:** Important nursery and pupping grounds have been identified in shallow areas and the mouth of Great Bay, NJ, lower and middle Delaware Bay, lower Chesapeake Bay, MD and near the Outer Banks, NC, in areas of Pamlico Sound adjacent to Hatteras and Ocracoke Islands and offshore those islands.

NOAA Technical Memorandum NMFS-NE-122

Essential Fish Habitat Source Document:

Fishery-Independent Surveys, Data Sources, and Methods

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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120. **Marine Mammal Research Program of the Northeast Fisheries Science Center during 1990-95.** By Janeen M. Quintal and Tim D. Smith. September 1999. v + 28 p., 4 tables, 4 app. NTIS Access. No. PB2000-100809.

NOAA Technical Memorandum NMFS-NE-122

This series represents a secondary level of scientifiic publishing. All issues employ thorough internal scientific review; some issues employ external scientific review. Reviews are -- by design -- transparent collegial reviews, not anonymous peer reviews. All issues may be cited in formal scientific communications.

Essential Fish Habitat Source Document:

Fishery-Independent Surveys, Data Sources, and Methods

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Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

---

[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, CHIEF
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INTRODUCTION

This report describes the methods used to collect various data which have been utilized in the Northeast Fisheries Science Center Essential Fish Habitat (EFH) Source Documents to describe the life history and habitat characteristics of federally-managed species within the northeastern United States. These documents employ data which were collected in surveys by the Northeast Fisheries Science Center (NEFSC) and several New England and Middle Atlantic states, as well as other agencies. This report summarizes data collection methods for the food habits database, egg and larval surveys (presented north to south), and juvenile and adult surveys (NEFSC surveys, then other surveys north to south).

Geographic locations discussed in the EFH source documents are presented in Figures 1-4 (respectively, northeast U.S. and contiguous Canadian waters; larger scale of coastal New England and Georges Bank to Bay of Fundy; more northern Canadian waters; and South Atlantic Bight).

NEFSC FOOD HABITS DATABASE

Feeding ecology data are available from samples collected by the Food Web Dynamics Program during NEFSC Bottom Trawl Surveys from 1973-1990. This database contains over 123,000 stomach samples from 174 species of fish and squid. Diet summaries of species collected during the surveys were analyzed separately for the 1973-1980 and 1981-1990 time periods due to differences in stomach analyses and data processing.

During 1973-1980, stomach samples were preserved and processed in the laboratory. Prey weights were recorded to the nearest 0.01 g. During 1981-1990, stomach samples were processed at sea, and prey volumes were visually estimated to the nearest 0.1 cc. For prey without calcareous shells, there is an approximately 1:1 relationship between prey weight (mg) and volume (ml); for shelled prey, the weight:volume ratio exceeds unity (Steimle *et al*. 1994). The differences in prey identification and prey measurements make comparisons between 1973-1980 and 1981-1990 data difficult. Invertebrate prey were identified more accurately, and to lower taxonomic levels, in the laboratory-processed samples (1973-1980). In contrast, fish prey were more accurately identified to species, while most invertebrates were identified only to higher taxonomic levels, in the field-processed samples (1981-1990). Consequently, comparisons between the two periods are biased by differences in the level of identification.

EGG AND LARVAL SURVEYS

NEFSC MARMAP SURVEYS

The NEFSC Marine Resources Monitoring, Assessment and Prediction program (MARMAP) sampled fish eggs and larvae on monthly to bimonthly surveys from Cape Hatteras, NC, to Cape Sable, NS, from 1977 through 1987 (Sibunka and Silverman 1984, 1989). Sampling concentrated on the continental shelf, in depths ≥ 8 m, but stations as deep as 2,476 m were sampled. A total of 81 surveys were made. Dates and numbers of tows for each survey for which data are available are listed in Tables 1 and 2 for eggs and larvae, respectively. Less data are available for eggs than for larvae because egg samples from 1977 and two later cruises (cruises 1-11 and 51-52 in Table 2) were destroyed in a fire. Overall sampling effort (all surveys combined) for eggs and larvae is shown in Figure 5. Sampling effort by month (all years combined) is shown in Figures 6 and 7.

Sampling was conducted with 61 cm diameter "bongo" plankton samplers with 0.333 and 0.555 mm mesh nets; they were fished to a maximum depth of 200 m, or to within 5 m of the seabed. Towing wire was paid out at 50 m/min and retrieved at 20 m/min. Vessel speed was adjusted between 1 and 2 knots to maintain a 45° angle in the tow wire. Digital flowmeters were used to determine volumes of water filtered. Catches were multiplied by a "haul factor" for conversion to densities per 10 m^2 of sea surface, where:

$$\text{Haul factor} = \frac{\text{maximum sampling depth}}{\text{(net mouth area) x (flowmeter revolutions) x (flowmeter calibration)}}$$

Depths were determined with an electronic meter block; a mechanical time depth recorder was also used beginning in 1982. Surface temperatures were measured with a stem thermometer in a bucket sample. Subsurface temperatures were measured with reversing thermometers on a string of Niskin water samplers set at specific water depths, and with expendable bathythermographs (XBTs). Beginning in 1987, hydrographic measurements were made using a Seabird conductivity, temperature, and depth (CTD) instrument.

SOUTH ATLANTIC BIGHT MARMAP

From 1973-1980, the South Carolina Marine Resources Research Institute conducted ichthyoplankton surveys throughout the South Atlantic Bight (SAB) (Powles and Stender 1976; Collins and Stender 1987). The studies were sponsored by the National Marine

Fisheries Service (NMFS) MARMAP Program Office. A total of 1,163 samples were taken from Cape Hatteras, NC to Cape Canaveral, FL, in depths ranging from 9-3,490 m. Locations of all collections are shown in Figure 8.

Two types of gear were used for neuston collections: a 1.0 x 0.5 m neuston net with 505 micron mesh, and a 2.0 x 1.0 m net with 947 micron mesh. Both nets were towed half-submerged. Samples were also taken with a bongo frame with 0.6 m diameter nets (333 and 505 micron mesh; only the latter samples were sorted for ichthyoplankton). All bongo tows were double oblique from 0 to ≤ 200 m depths. A total of 533 neuston tows and 500 bongo tows were taken over the duration of the study. Samples were preserved at sea and sorted in the laboratory under dissecting microscopes. No data were available for distribution/abundance of eggs. Larval abundance data were converted to numbers per 10 m^2 via the same calculations used for NEFSC MARMAP data.

JUVENILE AND ADULT SURVEYS

NEFSC BOTTOM TRAWL SURVEYS

Seasonal distributions of adult and juvenile fish were determined from the NEFSC bottom-trawl survey catch data. Surveys have been conducted in the fall since 1963 and in the spring since 1968; seasonal surveys have also been conducted in summer and winter on an intermittent basis (Table 3a-d). Temporal coverage of the surveys has changed through time; e.g., recent fall cruises have tended to occur earlier in the year (Figure 9). The general pattern of spring and fall surveys is typically south to north, beginning in central to southern portions of the Middle Atlantic Bight, followed by southern New England-Nantucket Shoals, Georges Bank, and finally the Gulf of Maine and Scotian Shelf. Trawl stations were selected in a stratified random design that provides unbiased estimates of fish availability to the trawl gear in relation to the distribution of species. Strata were defined based on water depth, latitude, and historical fishing patterns. Within each stratum, stations were assigned randomly for each survey; the number of stations allotted to a stratum was in proportion to its area. A minimum of two stations was assigned to small strata for the calculation of means and variances. Station allotments were approximately one station per 200 n mi^2.

The surveys were conducted in depths from 27 m to 366 m; however, greater depths were occasionally sampled in canyons along the continental shelf break. At each station, the total catch was sorted by species, and the catch of each species was weighed (to the nearest 0.1 kg) and measured (to the nearest cm); very large catches were subsampled. Geographic location, depth, and hydrographic data were also collected at each station. A complete description and evaluation of the bottom trawl survey program, including routine sampling protocols, can be found in Grosslein (1969), Azarovitz (1981), and Northeast Fisheries Science Center (1988). Geographic coverage of the NEFSC bottom-trawl surveys by season is shown in Figure 10.

Efforts have been made to maintain a standard trawl time series for over three decades. However, changes to the vessels, trawls, and trawl doors have been inevitable. To examine the effects of these changes to the survey, a series of gear comparison experiments was conducted; the data used in the EFH source documents reflects a standardization of these data.

Vessels

Three vessels have been used throughout the time series to conduct the surveys: the NOAA *R/V Albatross IV*, the *R/V Delaware II*, and the *R/V Atlantic Twin* (Table 3). The *Albatross IV* has been the primary vessel used in the survey with the *Delaware II* used during periods when the *Albatross IV* was unavailable. A series of vessel comparison cruises was conducted during 1981-1982 and 1986-1988 to evaluate the relative catchability of these vessels and to calculate fishing power (vessel conversion) coefficients (Table 4) (Byrne and Forrester 1991a).

During 1972-1975, the *R/V Atlantic Twin* was used to conduct inshore surveys primarily in the southern New England-Middle Atlantic area. There are no data available to examine the relative catchability of this vessel in comparison to the *Albatross IV*; therefore, the catch data from these surveys were not adjusted.

Trawls

Offshore surveys (depths greater than 27 m) conducted in the fall have used a #36 Yankee bottom trawl rigged with 41 cm rollers and a 1.25 cm (stretched mesh) cod end and towed at 1.8 m/s (= 6.5 km/h or approximately 3.7 kn) for 30 minutes at each station throughout the time series (see Table 3). The #36 Yankee trawl was also used during the 1968-1972 and 1982-1996 offshore spring surveys, but was replaced by a larger, high-opening #41 Yankee trawl during 1973-1981 in an effort to increase the fishing power for pelagic species.

Inshore surveys (depths less than 27 m) during 1972-1975 on the *R/V Atlantic Twin* were conducted with a modified 3/4 #36 Yankee trawl; all others used a standard #36 Yankee trawl. During 1976-1981, the #36 and #41 trawls were used inshore in the fall and spring, respectively. Surveys conducted in the summer used a #36 Yankee trawl throughout the series. A variety of trawls have been used during winter surveys including the #36 trawl (1964-1966, 1981), the #41 trawl (1972 and

1978), and a #36 trawl fitted with a chain sweep covered by rubber disks and 30 fathom ground cables designed to be more efficient in monitoring flounders (1992-1997).

An analysis of the differential catchability of the #36 and #41 Yankee trawls was conducted during gear comparison cruises in 1973-1975 and the calculation of trawl gear conversion coefficients for those nets (Table 4) was made by Sissenwine and Bowman (1978). No other trawl conversion factors are available.

Trawl Doors

During 1963-1984, the standard trawl doors used during the surveys were oval, wood/steel combination doors manufactured by the A.S. Bergens Mekaniske Versteder Co. (BMV) of Norway. These doors were used with both the #36 and #41 Yankee trawls with minimal modifications during this period. However, production of these doors ceased in 1983 and all-steel polyvalent doors manufactured by the Euronete Co. of Portugal were chosen to replace the BMV doors. In 1985, the polyvalent doors were placed in service as the standard survey door. An analysis of the differential catchability of the trawl doors was conducted using data collected from cruises in 1984, 1986-1987, and 1990-1991 and the calculation of trawl door conversion coefficients (Table 4) was made by Byrne and Forrester (1991b). To the extent possible, bottom trawl survey data were adjusted to reflect the following standard gear configuration:

vessel: *R/V Albatross IV*
trawl: #36 Yankee
trawl doors: Polyvalent.

Table 4 contains conversion coefficients for those species that had significantly different catch rates (in numbers) at the 0.05 level for each of the major gear changes in the survey. Catch data (in numbers) from each of the surveys were adjusted using these conversion factors on a station-by-station basis to provide a standardized set of data. Adjusted catches by species and survey were separated into juveniles and adults utilizing estimated lengths at 50% maturity (L_{50}) [O'Brien *et al.* (1993) for all species except the following: Marques da Silva (1993) (spiny dogfish); Almeida *et al.* (1995) (goosefish); and Hendrickson *et al.* (1996) (northern shortfin squid)]. The L_{50} values used were those calculated for females averaged over stock areas. The smallest adult lengths are the L_{50} values rounded to the nearest whole cm (Table 4). Total numbers-at-length data for each life stage were summed by station and plots of relative abundance by station generated for the spring and fall time series. Due to the variability in area covered and gears used during winter and summer surveys, distribution maps are presented as dot plots of presence/absence for each life stage.

NEFSC SEA SCALLOP SURVEYS

Sea scallop surveys by the NEFSC began in 1975 and have been conducted annually since 1977 (Table 5). Consistency of sampling dates and methods is greatest for the period 1982-1997, so this is the period for which data are presented. The surveys were designed to monitor the distribution, abundance, and recruitment patterns of the sea scallop resource in US offshore waters from Cape Hatteras, NC to Georges Bank (Figure 11). Sampling stations were selected using a stratified random design where strata were defined based on water depth and latitude. Within each stratum, stations were assigned randomly; the number of stations allotted to a stratum was proportional to its area. In selected strata in which commercial fishing activity or known concentrations of sea scallops were present, additional stations were randomly assigned prior to the survey to increase the precision of the abundance estimates for those strata.

The primary vessel used to conduct the survey throughout the series was the *R/V Albatross IV*; however, the *R/V Delaware II* (1978 only), *R/V Chapman* (1989 only), and *R/V Oregon II* (1989-1993) were also used during the series. Since 1979, the surveys have used a 2.44 m (8 ft) wide commercial sea scallop dredge with a 5.1 cm (2 in) ring bag and a 3.8 cm (1.5 in) mesh liner. The dredge was towed at 3.5 kn (~6.1 km/h) for 15 min at each station throughout the time series (Table 5).

The 1975 survey was conducted using transect sampling. Prior to 1979, a 3.05 m (10 ft) unlined dredge and different sampling strata were used. Data collected during these surveys have been standardized to the current gear configuration and stratification scheme [see Serchuk *et al.* (1982) for details]. In 1989, the sampling strata set was revised and strata with consistently low catch levels were eliminated (Wigley and Serchuk 1996). This resulted in slightly reduced spatial coverage, but increased precision in abundance estimates. Data from all prior surveys were post-stratified to conform to the current stratification scheme.

At each station, the total catch was sorted into biological and trash components. Live scallops collected at each station were counted and shell height measurements taken by 5 mm intervals. The bycatch of selected species was also enumerated and measured to the nearest centimeter and trash was measured by volume. Geographic location, depth, and hydrographic data were also collected at each station. A description of the survey program, including routine sampling protocols, can be found in Serchuk and Smolowitz (1980), Serchuk *et al.* (1979), Serchuk et al. (1982), and Wigley and Serchuk (1996). Total numbers-at-length data were summed by

station and plots of sea scallop abundance by station were generated for the time series.

NEFSC ATLANTIC SURFCLAM/ OCEAN QUAHOG SURVEYS

The NEFSC conducted a total of 23 surveys during 1965-1997 to monitor and evaluate the distribution, abundance, and size composition of Atlantic surfclam and ocean quahog populations off the northeast coast between Cape Hatteras, NC and the Scotian Shelf. The survey was initially designed to monitor the surfclam population; however, as the ocean quahog industry grew, the survey was expanded to monitor that species as well. Prior to 1976, the surveys were conducted intermittently; annual surveys were conducted during 1976-1984, and at least every third year since 1986 (Table 6). Overall geographic coverage of all surveys combined is shown in Figure 12. During the earliest years of the survey, sampling stations were selected based on a grid-type design with stations spaced at approximate 10 nm intervals along latitude-longitude or LORAN lines. In 1978, the station selection method was modified to a stratified random design with strata defined primarily by depth and bottom type (the pre-1978 data have been post-stratified to conform to the stratified random design). Within each stratum, stations were assigned randomly; the number of stations allotted to a stratum was proportional to its area. In selected strata in which either commercial fishing activity or clam concentrations were known to occur, additional stations were randomly assigned prior to the survey to increase the precision of the abundance estimates in those strata.

The primary vessel used throughout the time series was the *R/V Delaware II*; however, the *R/V Albatross IV* (1966 and 1969) and *R/V Undaunted* (1965 only) were also used. Changes to the survey gear have included modifications to the dredge pump type, dredge width, and mesh size (Table 6). Since limited comparative gear testing occurred prior to some of the changes, and multiple changes were made sometimes simultaneously, it is difficult to calculate standardization coefficients from the survey data. The major change to the survey gear was the conversion from a 122 cm (48 in) width dredge with a surface supplied pump to a 152 cm (60 in) dredge with an electrohydraulic submersible pump in 1979 (Smolowitz and Nulk 1982). There are no data available to evaluate the effect of these changes to the gear. In addition to the pump and width changes, the mesh opening of the dredge changed from 1.91 cm to 5.08 cm over a period of three years (1978-1980). Limited data are available to evaluate effects of the changes in mesh on ocean quahog collections, but no data are available to evaluate effects of the changes on surfclam catch. No major changes have been made to the survey gear or methods since 1980, with the exception of a change in the vessel winch and the addition of a grate on the front of the dredge during the onboard wash of the catch (possibly increasing the retention of small clams) in 1997.

The dredge was towed at 1.5 knots (~2.6 km/h) for 5 min at each station throughout the time series (Table 6). At each station, the catch was sorted to species, and subsamples of surfclam and ocean quahog were measured to determine the size distribution of the catch. The total meat weight of the clams collected at each station was computed from length-weight equations (Murawski and Serchuk 1989; Northeast Fisheries Science Center 1998). Geographic location, depth, and hydrographic data were also collected at each station. A description of the survey program, including routine sampling protocols, can be found in Murawski (1981), Murawski and Serchuk (1989), Smolowitz and Nulk (1982), and Northeast Fisheries Science Center (1996).

During the 1997 survey, the performance of the survey gear was evaluated with bottom contact sensors, angle indicator (to determine when the dredge was fishing), pressure and depth sensors, GPS to determine ship speed and location, and video. The results indicated that the efficiency of the dredge gear was similar in 1997 to that in 1992 and different than in 1994. A complete description of this analysis is available in Northeast Fisheries Science Center (1998).

MASSACHUSETTS BOTTOM TRAWL SURVEYS

The Massachusetts Division of Marine Fisheries (MA-DMF) has conducted a series of standardized bottom trawl surveys in Massachusetts and adjacent coastal waters, including all of Buzzards Bay, Nantucket Sound and Cape Cod Bay, and the southwestern Gulf of Maine, during the spring and fall since 1978 (Table 7a, b). The surveys were designed to determine factors affecting the distribution and abundance of a broad suite of finfish and invertebrate species. The stations sampled are included in distribution/abundance figure in each source document. Trawl stations were selected using a stratified random design and sampling protocols were identical to those followed during NEFSC surveys. Sampling density was one station per 19 n. mi^2. At each station, the total catch was sorted by species, and the catch of each species weighed (to the nearest 0.1 kg) and measured (to the nearest cm). Geographic location, depth, and hydrographic data were also collected at each station. A complete description and evaluation of the bottom trawl survey program, including routine sampling protocols, can be found in Howe *et al.* (1997).

Two vessels have been used to conduct the surveys; the *R/V Francis Elizabeth* during 1978-1981, and the NOAA *R/V Gloria Michelle* from 1982 to the present. Vessel comparison experiments were not conducted to

evaluate the relative catchability of these ships, so the data have not been standardized. The surveys used a 3/4 North Atlantic-type two seam (Whiting) trawl rigged with a 9-cm rubber disc chain sweep and 1.25 cm (stretched mesh) cod end towed at 2.5 kn (~4.4 km/h) for 20 min at each station throughout the time series (Table 7a, b). Stations were occupied during daylight hours only. Catch data (in numbers) were divided into juveniles and adults by species using the methods described for the NEFSC survey data.

RHODE ISLAND NARRAGANSETT BAY TRAWL SURVEYS

A monthly bottom trawl survey of 12 fixed stations in and just outside Narragansett Bay (Figure 13) by the Rhode Island Division of Fish and Wildlife began in January 1990 (Lynch 1998). A 13th station was added in 1992. The 12.8 m R/V *Thomas J. Wright* was used for sampling. Tows were made with a 3/4 scale high rise otter trawl with 11.9 m headrope, 16.5 m footrope, and mesh sizes (stretch) 10.2 cm below gore on wing, 11.4 cm at top of net above gore, 6.4 cm at top of belly, 5.1 cm at bottom of belly, 2.5 cm codend, and 0.95 cm codend liner. Trawl doors were wooden, 0.6 x 1.2 m, and located 14 m ahead of the wings. Tows were 20 min at 2.5 kn (~4.4 km/h). Catches were sorted by species. Numbers, lengths (nearest cm) and total weight were recorded for all species. Data presented are means of the three monthly tows per station per season for seven years of sampling (1990-1996). Depth and surface and bottom water temperature were recorded at all stations.

CONNECTICUT LONG ISLAND SOUND TRAWL SURVEYS

This survey by the Connecticut Department of Environmental Protection covered Long Island Sound waters in both CT and NY, from longitude 72°03' to 73°39', in depths of 5-46 m (Connecticut Department of Environmental Protection 1997). The data which are utilized in the source documents are from 1992 through 1997 sampling, and have been divided into spring and fall sampling periods. Typically, spring sampling consisted of 40 sites sampled monthly during April-June, and fall sampling was 40 sites/month in September and October. In 1992 there was no April sampling, and in 1993 and 1994 another 40 site cruise was added in November. Overall sampling effort for spring and fall sampling is shown in Figure 14.

The sampling design was stratified random. The study area was divided into 1.85 x 3.7 km (1 x 2 nautical mile) strata based on depth and bottom type. Sites were selected randomly from within each stratum, with the number of sites based on stratum size (minimum two sites per stratum). All samples were taken from the 15.2 m R/V *John Dempsey*. Sampling was done with a Wilcox 14 m high-rise otter trawl with 9.1 m headrope, 14.0 m footrope, 102 mm mesh trawl body and 51 mm mesh cod end. Trawl doors were steel "V" type, 1.2 m long x 0.8 m high, weighing 91 kg. Tows were 30 minutes at 3.5 kn (~6.1 km/h). Catches were sorted by species, all finfish and squid were counted, and total weight per species was determined with a model 8100 Doran scale. Subsamples (minimum 30 individuals) of squid and selected finfish species were measured to the centimeter (lengths rounded down). Measurements were made only on catches from selected tows (e.g., the first 3 tows of the day), and were not made on catches in all months of all years. Therefore, available length data from 1992-1997 was augmented with earlier data. Histograms showing seasonal length frequencies represent lengths typically encountered in spring and fall based on both a subset of 1992-1997 catches and on earlier data. Temperature and salinity were measured 1 m below the surface and 0.5 m above bottom, using a YSI model 33 S-C-T meter, before each tow.

NEFSC HUDSON-RARITAN TRAWL SURVEY

This survey used the same basic stratified random sampling design as the NEFSC bottom trawl survey. The lower Hudson-Raritan Estuary was divided into six non-channel and three channel strata, which in turn were divided into 217 blocks (Figure 15). Detailed stratum/block information is provided in Wilk *et al.* (1996); statistical descriptions of stratified random sampling design can be found in Grosslein (1969), Azarovitz (1981), and Northeast Fisheries Science Center (1988). The NOAA *R/V Gloria Michelle* was used for all sampling. Due to the vessel's draft, only waters ≥ 3 m deep were sampled.

The data utilized in the source documents are based on monthly sampling from January 1992 through June 1997 (Figure 16), with the exception that no sampling was conducted in May or September. When possible, 40 blocks were sampled per month. The seasonal data are presented as averages of catches in spring (March-April), summer (June-August), fall (October-November), and winter (December-February) (Figure 16). Fish and large invertebrates were collected using an otter trawl with 8.5 m (28 ft) headrope, 10.4 m (34 ft) footrope, 102 mm (4 in) mesh trawl body, and 35 mm (1.375 in) mesh cod end liner. Trawl doors weighed 36.3 kg (80 lb). Tows were 10 min at ~3.7 km/hr (2 kn). Loran C coordinates and/or GPS positions, latitude, longitude, depth, and time were recorded at the beginning and end of each tow.

All specimens of each species caught were

collectively weighed to the nearest 0.1 kg and individually measured to the nearest whole cm as follows. Fish from the snout to the end of the middle caudal ray (i.e., either fork or total length depending on species); bivalves across the widest point of the shell; and squid from the anterior margin to the posterior end of the dorsal mantle. Where large catches required subsampling, an expansion factor (weight of total catch/weight of subsample) was applied to the number and length frequency of the total catch. Catch data was separated into juveniles and adults using the same methods as described above for NEFSC survey data.

Hydrographic data were taken while drifting at each station using a Hydrolab Surveyor 3 Display Logger and H_2O Multiprobe fitted with sensors for depth, temperature, salinity and dissolved oxygen (the latter was not measured before 1993). The instrument was calibrated before each cruise. Bottom water observations were taken at the end of each trawl station.

SEAMAP-SA BOTTOM TRAWL SURVEYS

The Southeast Area Monitoring and Assessment Program-South Atlantic (SEAMAP-SA) is an NMFS-sponsored survey conducted by the South Carolina Department of Natural Resources, Marine Resources Division (SCMRD). Data were available from trawl surveys of coastal habitats between Cape Hatteras and Cape Canaveral beginning in 1986, but data presented in the source documents are for only 1990 through 1996, when sampling was most consistent (Webster *et al.* 1990; Beatty and Boylan 1997; SEAMAP-SA/SCMRD 1997). Collections were made at randomly selected sites in predefined strata. During 1990-1996 the survey included 24 strata, each of which was divided into an inshore (4.6-9.1 m depth) and offshore (9.1-18.2 m) stratum, for a total of 48 strata (Figure 4). The number of stations allotted to a stratum was in proportion to its area, although in 1990-1996 proportionally more samples were taken in the inshore than the offshore strata.

The 22.9 m R/V *Lady Lisa* was used for sampling. Trawls used were paired 22.9 m mongoose-type Falcon trawls, with 91.4 m three-lead bridles attached to pairs of 3.0 m x 1.0 m wooden chain doors. Headropes were 22.0 m and footropes 22.9 m. Trawl bodies were constructed of #15 twine and had 45 mm stretch mesh. Cod ends were #30 twine with 39 mm stretch mesh. A tickler chain was attached to each door. Tows were 20 minutes long. Fish collected were counted, measured to the nearest cm, and weighed by species to the nearest gram (except for very large catches, which were subsampled). Catch-per-tow was defined as the combined catch from both paired nets. Surface and bottom temperature, salinity and sampling depth were recorded at each station.

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Table 1. Dates and number of tows for each NEFSC MARMAP fish egg survey, 1978-1987.

Survey	***No. Tows***	***Start Date***	***End Date***		***Survey***	***No. Tows***	***Start Date***	***End Date***
12	155	10/06/78	11/11/78		46	160	09/14/83	11/09/83
13	72	11/16/78	11/29/78		47	149	11/16/83	12/19/83
14	102	02/25/79	03/14/79		48	159	01/10/84	02/08/84
15	102	04/01/79	05/07/79		49	151	03/02/84	04/25/84
16	170	05/06/79	05/29/79		50	177	05/09/84	06/02/84
17	123	06/17/79	07/13/79		53	106	07/10/84	07/30/84
18	145	08/11/79	09/02/79		54	119	07/25/84	08/30/84
19	158	10/04/79	10/28/79		55	158	09/17/84	11/03/84
20	102	11/15/79	12/20/79		56	144	11/01/84	12/05/84
21	170	02/20/80	04/04/80		57	125	01/08/85	02/06/85
22	175	04/16/80	05/12/80		58	120	02/27/85	04/12/85
23	148	05/23/80	06/29/80		59	130	04/02/85	04/22/85
24	153	07/16/80	08/09/80		60	134	05/09/85	05/30/85
25	174	09/26/80	10/29/80		61	150	07/17/85	08/29/85
26	137	11/19/80	12/21/80		62	173	08/30/85	09/22/85
27	151	02/18/81	03/24/81		63	140	09/10/85	11/15/85
28	99	03/19/81	04/08/81		64	179	11/07/85	12/12/85
29	143	03/19/81	05/12/81		65	173	01/10/86	02/12/86
30	143	05/21/81	06/17/81		66	145	03/04/86	04/27/86
31	78	06/27/81	07/19/81		67	161	05/08/86	06/06/86
32	94	08/04/81	09/02/81		68	105	06/17/86	07/17/86
33	169	09/17/81	11/08/81		69	116	07/29/86	08/29/86
34	88	11/18/81	12/21/81		70	155	08/27/86	09/24/86
35	145	02/14/82	03/23/82		71	147	09/14/86	11/06/86
36	166	03/11/82	05/08/82		72	159	11/05/86	12/11/86
37	132	05/18/82	06/11/82		73	132	01/07/87	02/08/87
38	123	07/13/82	08/07/82		74	152	03/24/87	04/28/87
39	149	09/15/82	11/09/82		75	91	04/13/87	04/22/87
40	152	11/17/82	12/20/82		76	193	05/07/87	06/07/87
41	148	01/18/83	03/01/83		77	129	05/31/87	06/30/87
42	139	03/09/83	05/01/83		78	155	07/07/87	08/10/87
43	170	05/26/83	06/21/83		79	179	08/19/87	09/20/87
44	116	07/27/83	08/30/83		80	144	09/11/87	10/30/87
45	62	08/16/83	09/04/83		81	124	11/04/87	12/10/87

Table 2. Dates and number of tows for each NEFSC MARMAP larval fish survey, 1977-1987.

Survey	***No. Tows***	***Start Date***	***End Date***		***Survey***	***No. Tows***	***Start Date***	***End Date***
1	183	02/13/77	04/08/77		41	153	01/18/83	03/01/83
2	189	03/04/77	04/22/77		42	139	03/09/83	05/01/83
3	189	04/14/77	05/13/77		43	176	05/26/83	06/21/83
4	205	05/18/77	06/22/77		44	117	07/27/83	08/30/83
5	160	07/30/77	08/30/77		45	62	08/16/83	09/04/83
6	142	10/18/77	11/09/77		46	165	09/14/83	11/09/83
7	90	11/13/77	12/13/77		47	151	11/16/83	12/19/83
8	166	02/16/78	03/17/78		48	160	01/10/84	02/08/84
9	172	04/18/78	05/23/78		49	156	03/02/84	04/25/84
10	148	06/24/78	07/16/78		50	178	05/09/84	06/02/84
11	152	08/12/78	09/04/78		51	41	06/17/84	06/24/84
12	155	10/06/78	11/11/78		52	68	07/04/84	07/18/84
13	74	11/16/78	11/29/78		53	107	07/10/84	07/30/84
14	102	02/25/79	03/14/79		54	119	07/25/84	08/30/84
15	106	04/01/79	05/07/79		55	158	09/17/84	11/03/84
16	170	05/06/79	05/29/79		56	144	11/01/84	12/05/84
17	123	06/17/79	07/13/79		57	125	01/08/85	02/06/85
18	146	08/11/79	09/02/79		58	120	02/27/85	04/12/85
19	160	10/04/79	10/28/79		59	130	04/02/85	04/22/85
20	103	11/15/79	12/20/79		60	134	05/09/85	05/30/85
21	171	02/20/80	04/04/80		61	150	07/17/85	08/29/85
22	175	04/16/80	05/12/80		62	173	08/30/85	09/22/85
23	148	05/23/80	06/29/80		63	140	09/10/85	11/15/85
24	153	07/16/80	08/09/80		64	179	11/07/85	12/12/85
25	174	09/26/80	10/29/80		65	173	01/10/86	02/12/86
26	137	11/19/80	12/21/80		66	145	03/04/86	04/27/86
27	152	02/18/81	03/24/81		67	161	05/08/86	06/06/86
28	99	03/19/81	04/08/81		68	105	06/17/86	07/17/86
29	144	03/19/81	05/12/81		69	116	07/29/86	08/29/86
30	145	05/21/81	06/17/81		70	155	08/27/86	09/24/86
31	78	06/27/81	07/19/81		71	147	09/14/86	11/06/86
32	96	08/04/81	09/02/81		72	159	11/05/86	12/11/86
33	169	09/17/81	11/08/81		73	133	01/07/87	02/08/87
34	88	11/18/81	12/21/81		74	151	03/24/87	04/28/87
35	145	02/14/82	03/23/82		75	90	04/13/87	04/22/87
36	166	03/11/82	05/08/82		76	193	05/07/87	06/07/87
37	132	05/18/82	06/11/82		77	129	05/31/87	06/30/87
38	124	07/13/82	08/07/82		78	155	07/07/87	08/10/87
39	151	09/15/82	11/09/82		79	179	08/19/87	09/20/87
40	152	11/17/82	12/20/82		80	144	09/11/87	10/30/87
					81	124	11/04/87	12/10/87

Table 3a. NMFS NEFSC bottom trawl surveys conducted during the spring, 1968-1997.

Year	***Vessel***	***Start Date***	***End Date***	***No. of Stations***	***Trawl Gear***	***Study Area***
1968	Albatross IV	4-Mar-68	8-Apr-68	251	36 Yankee	Scotian Shelf - Cape Hatteras
1969	Albatross IV	5-Mar-69	10 Apr 69	257	36 Yankee	Scotian Shelf - Cape Hatteras
1970	Albatross IV	13-Mar-70	30-Apr-70	279	36 Yankee	Scotian Shelf - Cape Hatteras
1971	Albatross IV	9-Mar-71	5-May-71	339	36 Yankee	Scotian Shelf - Cape Hatteras
1972	Albatross IV	8-Mar-72	28-Apr-72	303	36 Yankee	Gulf of Maine - Cape Hatteras
1973	Alb IV & AT	19-Mar-73	4-Jun-73	480	41 & 3/4 Yankee[1]	Scotian Shelf - Cape Hatteras
1974	Alb IV & AT	12-Mar-74	5-May-74	272	41 & 3/4 Yankee[1]	Scotian Shelf - So. Atlantic Bight
1975	Alb IV & AT	14-Mar-75	12-May-75	303	41 & 3/4 Yankee[1]	Scotian Shelf - Cape Hatteras
1976	Alb IV & De II	3-Mar-76	8-May-76	374	41 Yankee	Scotian Shelf - Cape Hatteras
1977	Alb IV & De II	19-Mar-77	20-May-77	351	41 Yankee	Scotian Shelf - Cape Hatteras
1978	Albatross IV	20-Mar-78	26-May-78	388	41 Yankee	Scotian Shelf - Cape Hatteras
1979	Alb IV & De II	20-Mar-79	12-May-79	470	41 Yankee	Scotian Shelf - Cape Hatteras
1980	Alb IV & De II	16-Mar-80	16-May-80	434	41 Yankee	Scotian Shelf - Cape Fear
1981	Delaware II	17-Mar-81	22-May-81	362	41 Yankee	Scotian Shelf - Cape Fear
1982	Delaware II	8-Mar-82	8-May-82	379	36 Yankee	Scotian Shelf - Cape Fear
1983	Albatross IV	7-Mar-83	6-May-83	375	36 Yankee	Gulf of Maine - Cape Fear
1984	Albatross IV	29-Feb-84	27-Apr-84	374	36 Yankee	Scotian Shelf - Cape Fear
1985	Albatross IV	25-Feb-85	13-Apr-85	362	36 Yankee	Gulf of Maine - Cape Fear
1986	Albatross IV	3-Mar-86	27-Apr-86	361	36 Yankee	Gulf of Maine - Cape Hatteras
1987	Alb IV & De II	23-Mar-87	5-May-87	334	36 Yankee	Gulf of Maine - Cape Hatteras
1988	Albatross IV	5-Mar-88	21-Apr-88	314	36 Yankee	Gulf of Maine - Cape Hatteras
1989	Delaware II	27-Feb-89	13-Apr-89	291	36 Yankee	Gulf of Maine - Cape Hatteras
1990	Delaware II	5-Mar-90	18-Apr-90	311	36 Yankee	Gulf of Maine - Cape Hatteras
1991	Delaware II	5-Mar-91	19-Apr-91	324	36 Yankee	Gulf of Maine - Cape Hatteras
1992	Albatross IV	2-Mar-92	16-Apr-92	307	36 Yankee	Gulf of Maine - Cape Hatteras
1993	Albatross IV	8-Mar-93	30-Apr-93	319	36 Yankee	Gulf of Maine - Cape Hatteras
1994	Delaware II	28-Feb-94	27-Apr-94	326	36 Yankee	Gulf of Maine - Cape Hatteras
1995	Albatross IV	7-Mar-95	27-Apr-95	325	36 Yankee	Gulf of Maine - Cape Hatteras
1996	Albatross IV	6-Mar-96	29-Apr-96	335	36 Yankee	Gulf of Maine - Cape Hatteras
1997	Albatross IV	3-Mar-97	23-Apr-97	327	36 Yankee	Gulf of Maine - Cape Hatteras

[1] #41 Yankee used by the Albatross IV; 3/4 Yankee used by the R/V Atlantic Twin.

Table 3b. NMFS NEFSC bottom trawl surveys conducted during the fall, 1963-1996.

Year	***Vessel***	***Start Date***	***End Date***	***No. of Stations***	***Trawl Gear***	***Study Area***
1963	Albatross IV	13-Nov-63	16-Dec-63	182	36 Yankee	Scotian Shelf - Hudson Canyon
1964	Albatross IV	22-Oct-64	25-Nov-64	183	36 Yankee	Scotian Shelf - Hudson Canyon
1965	Albatross IV	6-Oct-65	9-Nov-65	190	36 Yankee	Scotian Shelf - Hudson Canyon
1966	Albatross IV	12-Oct-66	13-Nov-66	189	36 Yankee	Scotian Shelf - Hudson Canyon
1967	Albatross IV	17-Oct-67	10-Dec-67	263	36 Yankee	Scotian Shelf - Cape Hatteras
1968	Albatross IV	10-Oct-68	26-Nov-68	266	36 Yankee	Scotian Shelf - Cape Hatteras
1969	Albatross IV	8-Oct-69	23-Nov-69	267	36 Yankee	Scotian Shelf - Cape Hatteras
1970	Alb IV & De II	3-Sep-70	21-Nov-70	295	36 Yankee	Scotian Shelf - Cape Hatteras
1971	Albatross IV	29-Sep-71	19-Nov-71	296	36 Yankee	Scotian Shelf - Cape Hatteras
1972	Alb & De & AT	28-Sep-72	5-Dec-72	455	36 & 3/4 Yankee[2]	Scotian Shelf - So. Atlantic Bight
1973	Alb & De & AT	26-Sep-73	20-Nov-73	417	36 & 3/4 Yankee[2]	Scotian Shelf - Cape Hatteras
1974	Alb IV & De II	23-Sep-74	10-Nov-74	371	36 Yankee	Scotian Shelf - Cape Hatteras
1975	Alb IV & De II	15-Oct-75	7-Nov-75	387	36 Yankee	Cape Cod - Cape Hatteras
1976	Albatross IV	28-Sep-76	23-Nov-76	340	36 Yankee	Scotian Shelf - Cape Hatteras
1977	Delaware II	26-Sep-77	15-Dec-77	402	36 Yankee	Scotian Shelf - Cape Hatteras
1978	Delaware II	6-Sep-78	22-Nov-78	533	36 Yankee	Scotian Shelf - Cape Hatteras
1979	Alb IV & De II	12-Sep-79	19-Nov-79	565	36 Yankee	Scotian Shelf - Cape Fear
1980	Delaware II	17-Sep-80	21-Nov-80	388	36 Yankee	Scotian Shelf - Cape Fear
1981	Alb IV & De II	15-Sep-81	13-Nov-81	376	36 Yankee	Scotian Shelf - Cape Fear
1982	Albatross IV	13-Sep-82	12-Nov-82	374	36 Yankee	Scotian Shelf - Cape Fear
1983	Albatross IV	12-Sep-83	10-Nov-83	366	36 Yankee	Scotian Shelf - Cape Fear
1984	Albatross IV	10-Sep-84	9-Nov-84	339	36 Yankee	Gulf of Maine - Cape Hatteras
1985	Alb IV & De II	9-Sep-85	16-Nov-85	340	36 Yankee	Scotian Shelf - Cape Hatteras
1986	Alb IV & De II	13-Sep-86	6-Nov-86	352	36 Yankee	Gulf of Maine - Cape Hatteras
1987	Albatross IV	10-Sep-87	6-Nov-87	316	36 Yankee	Gulf of Maine - Cape Hatteras
1988	Albatross IV	12-Sep-88	28-Oct-88	307	36 Yankee	Gulf of Maine - Cape Hatteras
1989	Delaware II	11-Sep-89	2-Nov-89	320	36 Yankee	Gulf of Maine - Cape Hatteras
1990	Delaware II	11-Sep-90	26-Oct-90	332	36 Yankee	Gulf of Maine - Cape Hatteras
1991	Delaware II	9-Sep-91	25-Oct-91	327	36 Yankee	Scotian Shelf - Cape Hatteras
1992	Albatross IV	8-Sep-92	28-Oct-92	324	36 Yankee	Gulf of Maine - Cape Hatteras
1993	Delaware II	7-Sep-93	27-Oct-93	325	36 Yankee	Gulf of Maine - Cape Hatteras
1994	Albatross IV	6-Sep-94	27-Oct-94	331	36 Yankee	Gulf of Maine - Cape Hatteras
1995	Albatross IV	5-Sep-95	27-Oct-95	326	36 Yankee	Gulf of Maine - Cape Hatteras
1996	Albatross IV	9-Sep-96	31-Oct-96	320	36 Yankee	Gulf of Maine - Cape Hatteras

[2] #36 Yankee used by the Albatross IV and Delaware II; 3/4 Yankee used by the R/V Atlantic Twin.

Table 3c. NMFS NEFSC bottom trawl surveys conducted during the summer 1963-1995.

Year	***Vessel***	***Start Date***	***End Date***	***No. of Stations***	***Trawl Gear***	***Study Area***
1963	Albatross IV	18-Jul-63	19-Aug-63	181	36 Yankee	Scotian Shelf - Hudson Canyon
1964	Albatross IV	27-Jul-64	22-Aug-64	176	36 Yankee	Scotian Shelf - Hudson Canyon
1965	Albatross IV	7-Jul-65	10-Aug-65	358	36 Yankee	Scotian Shelf - Hudson Canyon
1969	Albatross IV	14-Jul-69	16-Aug-69	257	36 Yankee	Scotian Shelf - Cape Hatteras
1977	Delaware II	27-Jul-77	31-Aug-77	291	36 Yankee	Gulf of Maine - Cape Hatteras
1978	Alb IV & De II	25-Jul-78	11-Aug-78	302	36 Yankee	Gulf of Maine - Cape Hatteras
1979	Alb IV & De II	25-Jul-79	31-Aug-79	272	36 Yankee	Gulf of Maine - Cape Fear
1980	Alb IV & De II	11-Jul-80	22-Aug-80	297	36 Yankee	Gulf of Maine - Cape Fear
1991	Delaware II	22-Jul-91	2-Aug-91	6	36 Yankee	Gulf of Maine
1993	Delaware II	20-Jul-93	6-Aug-93	70	36 Yankee	Gulf of Maine
1994	Albatross IV	26-Jul-94	5-Aug-94	28	36 Yankee	Gulf of Maine
1995	Albatross IV	14-Aug-95	25-Aug-95	38	36 Yankee	Gulf of Maine

Table 3d. NMFS NEFSC bottom trawl surveys conducted during the winter 1964-1997.

Year	***Vessel***	***Start Date***	***End Date***	***No. of Stations***	***Trawl Gear***	***Study Area***
1964	Albatross IV	16-Jan-64	15-Feb-64	194	36 Yankee	Scotian Shelf - Hudson Canyon
1965	Albatross IV	1-Feb-65	2-Mar-65	177	36 Yankee	Scotian Shelf - Hudson Canyon
1966	Albatross IV	18-Jan-66	23-Feb-66	187	36 Yankee	Scotian Shelf - Hudson Canyon
1972	Albatross IV	23-Feb-72	3-Mar-72	56	41 Yankee	northeast Georges Bank
1978	Albatross IV	18-Jan-78	27-Jan-78	174	41 Yankee	Nantucket Sound-Delaware Bay
1981	Delaware II	6-Jan-81	28-Jan-81	86	36 Yankee	southern New England – Mid-Atlantic Bight
1992	Delaware II	25-Feb-92	6-Mar-92	129	Mod. 36 Yankee[3]	Georges Bank - Cape Hatteras
1993	Albatross IV	3-Feb-93	27-Feb-93	122	Mod. 36 Yankee[3]	Georges Bank - Cape Hatteras
1994	Delaware II	31-Jan-94	23-Feb-94	92	Mod. 36 Yankee[3]	Georges Bank - Cape Hatteras
1995	Albatross IV	7-Feb-95	3-Mar-95	144	Mod. 36 Yankee[3]	Georges Bank - Cape Hatteras
1996	Albatross IV	5-Feb-96	29-Feb-96	129	Mod. 36 Yankee[3]	Gulf of Maine - Cape Hatteras
1997	Albatross IV	3-Feb-97	27-Feb-97	121	Mod. 36 Yankee[3]	Georges Bank - Cape Hatteras

[3] #36 Yankee trawl equipped with a rubber disk covered chain sweep and 30 fathom ground cables.

Table 4. Species-specific conversion factors, and lengths (L, in cm) at which both males and females are considered adults for EFH purposes, from NEFSC bottom trawl survey cruises conducted since 1963.

Common Name	***Scientific Name***	***Conversion Factors (numbers)[1]***			
		Trawls	**Doors**	**Vessels**	**L**
Atlantic cod	*Gadus morhua*	-	1.56	0.79	35
Haddock	*Melanogrammus aeglefinus*	-	1.49	0.82	32
Pollock	*Pollachius virens*	-	2.21	-	39
Redfish	*Sebastes* spp.	-	-	-	22
Goosefish	*Lophius americanus*	0.408	-	0.83	43
Ocean pout	*Macrozoarces americanus*	-	-	0.70	29
Silver hake	*Merluccius bilinearis*	0.424	-	-	23
Red hake	*Urophycis chuss*	-	1.31	-	26
White hake	*Urophycis tenuis*	-	-	-	35
Witch flounder	*Glyptocephalus cynoglossus*	-	-	-	30
American plaice	*Hippoglossoides platessoides*	-	-	0.82	27
Yellowtail flounder	*Limanda ferruginea*	0.568	1.22	0.85	26
Winter flounder	*Pseudopleuronectes americanus*	0.495	1.46	-	27
Windowpane	*Scophthalmus aquosus*	0.599	1.54	0.82	22
Sea scallop	*Placopecten magellanicus*	-	1.39	1.22	
Atlantic herring	*Clupea harengus*	-	-	0.59	25
Atlantic salmon	*Salmo salar*	-	-	-	
Bluefish	*Pomatomus saltatrix*	-	-	-	
Longfin inshore squid	*Loligo pealeii*	-	-	0.83	16
Northern shortfin squid	*Illex illecebrosus*	-	-	0.78	20
Atlantic mackerel	*Scomber scombrus*	-	-	-	26
Butterfish	*Peprilus triacanthus*	-	-	-	12
Summer flounder	*Paralichthys dentatus*	0.813	-	-	28
Scup	*Stenotomus chrysops*	-	-	-	15
Black sea bass	*Centropristis striata*	-	-	-	19
Spiny dogfish	*Squalus acanthias*	0.714	-	0.79	83[2]
Atlantic surfclam	*Spisula solidissima*	-	-	-	
Ocean quahog	*Arctica islandica*	-	-	-	4.9

[1]Conversion Factors to NEFSC Survey standard configuration:
Trawls: #41 Yankee to #36 Yankee - Spring 1973-1981 only
Doors: BMV to Polyvalent - Spring 1985 to present
Vessels: Delaware II to Albatross IV - Various, some during same survey

[2]Females are considered adults at 83 cm, males at 60 cm.

Table 5. NMFS NEFSC sea scallop surveys conducted during 1982-1997.

Year	***Season***	***Vessel***	***Start Date***	***End Date***	***No. of Stations***	***Study Area***
1982	Summer	Albatross IV	1-Jun-82	11-Jun-82	439	Mid Atlantic Bight - Cape Hatteras
1982	Summer	Albatross IV	12-Jul-82	6-Aug-82	205	Gulf of Maine - Mid Atlantic Bight
1983	Summer	Albatross IV	26-Jul-83	2-Sep-83	615	Georges Bank - Cape Hatteras
1984	Summer	Albatross IV	24-Jul-84	31-Aug-84	699	Georges Bank - Cape Hatteras
1985	Summer	Albatross IV	22-Jul-85	31-Aug-85	573	Georges Bank - Cape Hatteras
1986	Summer	Albatross IV	29-Jul-86	29-Aug-86	504	Georges Bank - Cape Hatteras
1987	Summer	Albatross IV	6-Jul-87	13-Aug-87	641	Georges Bank - Cape Hatteras
1988	Summer	Albatross IV	7-Jul-88	10-Aug-88	619	Georges Bank - Mid Atlantic Bight
1989	Summer	Alb/CH/OR	9-Jun-89	9-Aug-89	435	Georges Bank - Mid Atlantic Bight
1990	Summer	Oregon II	26-Jul-90	20-Aug-90	469	Georges Bank - Cape Hatteras
1991	Summer	Oregon II	28-Jul-91	21-Aug-91	437	Georges Bank - Cape Hatteras
1992	Summer	Oregon II	1-Aug-92	22-Aug-92	420	Georges Bank - Cape Hatteras
1993	Summer	Oregon II	31-Jul-93	25-Aug-93	446	Georges Bank - Cape Hatteras
1994	Summer	Albatross IV	22-Jun-94	18-Jul-94	482	Georges Bank - Cape Hatteras
1995	Summer	Albatross IV	19-Jun-95	30-Jun-95	247	Mid Atlantic Bight - Cape Hatteras
1995	Summer	Albatross IV	25-Jul-95	6-Aug-95	314	Long Island
1996	Summer	Albatross IV	29-Jul-96	26-Aug-96	453	Georges Bank - Cape Hatteras
1997	Summer	Albatross IV	21-Jul-97	17-Aug-97	496	Georges Bank - Cape Hatteras

Table 6. NMFS NEFSC Atlantic surfclam and ocean quahog surveys conducted during 1965-1997.

Year	***Season***	***Vessel***	***Start Date***	***End Date***	***Stations***	***Dredge Pump Type***	***Dredge Width (cm)***	***Size (cm)***	***Study Area***
1965	Spring	Undaunted	11-May-65	25-Jun-65	374	Surface	76	5.1	Montauk Pt. - Cape Hatteras
1965	Autumn	Undaunted	22-Oct-65	21-Nov-65	217	Surface	76	5.1	Montauk Pt. - Oregon Inlet
1966	Summer	Albatross IV	14-Aug-66	31-Aug-66	483	Surface	76	5.1	Montauk Pt. - False Cape
1969	Summer	Albatross IV	20-Jun-69	3-Jul-69	562	Surface	76	5.1	Gloucester - False Cape
1970	Summer	Delaware II	17-Jul-70	24-Aug-70	596	Surface	122	3.0	Nantucket Shoals - Delmarva
1974	Summer	Delaware II	5-Aug-74	10-Aug-74	141	Surface	76	5.1	New Jersey - Virginia
1976	Spring	Delaware II	6-Apr-76	13-May-76	217	Surface	122	3.0	Long Island - North Carolina
1977	Winter	Delaware II	26-Jan-77	17-Mar-76	280	Surface	122	3.0	Nantucket Shoals - Chesapeake Bay
1978	Winter	Delaware II	5-Jan-78	11-Feb-78	346	Surface	122	1.9	Gulf of Maine - Cape Hatteras
1978	Autumn	Delaware II	2-Dec-78	21-Dec-78	163	Surface	122	1.9	So. New England - Chesapeake Bay
1979	Winter	Delaware II	4-Jan-79	1-Feb-79	139	Submerse	152	2.5	Cape Cod - Cape Hatteras
1980	Winter	Delaware II	3-Jan-80	10-Feb-80	229	Submerse	152	5.1	So. New England - Mid Atlantic Bight
1980	Summer	Delaware II	15-Aug-80	12-Sep-80	199	Submerse	152	5.1	Scotian Shelf - Mid Atlantic Bight
1981	Summer	Delaware II	3-Aug-81	11-Sep-81	518	Submerse	152	5.1	Scotian Shelf - Chesapeake Bay
1982	Summer	Delaware II	22-Jul-82	3-Sep-82	394	Submerse	152	5.1	Georges Bank - Virginia
1983	Summer	Delaware II	15-Aug-83	28-Sep-83	396	Submerse	152	5.1	Scotian Shelf - Cape Hatteras
1984	Summer	Delaware II	9-Jul-84	1-Aug-84	448	Submerse	152	5.1	Georges Bank - Cape Hatteras
1986	Summer	Delaware II	17-Jun-86	18-Jul-86	334	Submerse	152	5.1	Georges Bank - Cape Hatteras
1989	Summer	Delaware II	26-Jun-89	21-Jul-89	361	Submerse	152	5.1	Georges Bank - Cape Hatteras
1992	Summer	Delaware II	8-Jun-92	13-Jul-92	484	Submerse	152	5.1	Gulf of Maine - Cape Hatteras
1994	Summer	Delaware II	18-Jul-94	24-Aug-94	538	Submerse	152	5.1	Georges Bank - Cape Hatteras
1997	Summer	Delaware II	8-Jun-97	14-Jul-97	472	Submerse	152	5.1	Georges Bank - Cape Hatteras

Table 7a. State of Massachusetts Division of Marine Fisheries bottom trawl surveys conducted during the spring, 1978-1997.

Year	***Vessel***	***Start Date***	***End Date***	***No. of Stations***	***Trawl Gear***	***Study Area***
1978	Francis Elizabeth	12-May-78	11-Jun-78	95	3/4 Whiting	Massachusetts State Waters
1979	Francis Elizabeth	30-Apr-79	27-May-79	100	3/4 Whiting	Massachusetts State Waters
1980	Francis Elizabeth	5-May-80	24-May-80	98	3/4 Whiting	Massachusetts State Waters
1981	Francis Elizabeth	6-May-81	21-May-81	97	3/4 Whiting	Massachusetts State Waters
1982	Gloria Michelle	4-May-82	21-May-82	95	3/4 Whiting	Massachusetts State Waters
1983	Gloria Michelle	9-May-83	25-May-83	96	3/4 Whiting	Massachusetts State Waters
1984	Gloria Michelle	7-May-84	22-May-84	99	3/4 Whiting	Massachusetts State Waters
1985	Gloria Michelle	6-May-85	22-May-85	94	3/4 Whiting	Massachusetts State Waters
1986	Gloria Michelle	4-May-86	17-May-86	96	3/4 Whiting	Massachusetts State Waters
1987	Gloria Michelle	4-May-87	19-May-87	97	3/4 Whiting	Massachusetts State Waters
1988	Gloria Michelle	9-May-88	25-May-88	92	3/4 Whiting	Massachusetts State Waters
1989	Gloria Michelle	8-May-89	24-May-89	97	3/4 Whiting	Massachusetts State Waters
1990	Gloria Michelle	7-May-90	23-May-90	95	3/4 Whiting	Massachusetts State Waters
1991	Gloria Michelle	7-May-91	22-May-91	98	3/4 Whiting	Massachusetts State Waters
1992	Gloria Michelle	5-May-92	20-May-92	92	3/4 Whiting	Massachusetts State Waters
1993	Gloria Michelle	5-May-93	19-May-93	88	3/4 Whiting	Massachusetts State Waters
1994	Gloria Michelle	10-May-94	25-May-94	88	3/4 Whiting	Massachusetts State Waters
1995	Gloria Michelle	9-May-95	24-May-95	98	3/4 Whiting	Massachusetts State Waters
1996	Gloria Michelle	7-May-96	22-May-96	101	3/4 Whiting	Massachusetts State Waters
1997	Gloria Michelle	6-May-97	21-May-97	98	3/4 Whiting	Massachusetts State Waters

Table 7b. State of Massachusetts Division of Marine Fisheries bottom trawl surveys conducted during the fall, 1978-1996.

Year	***Vessel***	***Start Date***	***End Date***	***No. of Stations***	***Trawl Gear***	***Study Area***
1978	Francis Elizabeth	5-Sep-78	2-Oct-78	95	3/4 Whiting	Massachusetts State Waters
1979	Francis Elizabeth	11-Sep-79	4-Oct-79	99	3/4 Whiting	Massachusetts State Waters
1980	Francis Elizabeth	8-Oct-80	29-Oct-80	97	3/4 Whiting	Massachusetts State Waters
1981	Francis Elizabeth	14-Oct-81	5-Nov-81	95	3/4 Whiting	Massachusetts State Waters
1982	Gloria Michelle	8-Sep-82	27-Sep-82	94	3/4 Whiting	Massachusetts State Waters
1983	Gloria Michelle	7-Sep-83	24-Sep-83	90	3/4 Whiting	Massachusetts State Waters
1984	Gloria Michelle	10-Sep-84	27-Sep-84	94	3/4 Whiting	Massachusetts State Waters
1985	Gloria Michelle	3-Sep-85	19-Sep-85	94	3/4 Whiting	Massachusetts State Waters
1986	Gloria Michelle	8-Sep-86	27-Sep-86	96	3/4 Whiting	Massachusetts State Waters
1987	Gloria Michelle	8-Sep-87	27-Sep-87	92	3/4 Whiting	Massachusetts State Waters
1988	Gloria Michelle	6-Sep-88	22-Sep-88	91	3/4 Whiting	Massachusetts State Waters
1989	Gloria Michelle	6-Sep-89	20-Sep-89	86	3/4 Whiting	Massachusetts State Waters
1990	Gloria Michelle	4-Sep-90	19-Sep-90	90	3/4 Whiting	Massachusetts State Waters
1991	Gloria Michelle	4-Sep-91	19-Sep-91	89	3/4 Whiting	Massachusetts State Waters
1992	Gloria Michelle	9-Sep-92	24-Sep-92	81	3/4 Whiting	Massachusetts State Waters
1993	Gloria Michelle	8-Sep-93	23-Sep-93	84	3/4 Whiting	Massachusetts State Waters
1994	Gloria Michelle	7-Sep-94	22-Sep-94	98	3/4 Whiting	Massachusetts State Waters
1995	Gloria Michelle	6-Sep-95	21-Sep-95	98	3/4 Whiting	Massachusetts State Waters
1996	Gloria Michelle	4-Sep-96	19-Sep-96	97	3/4 Whiting	Massachusetts State Waters

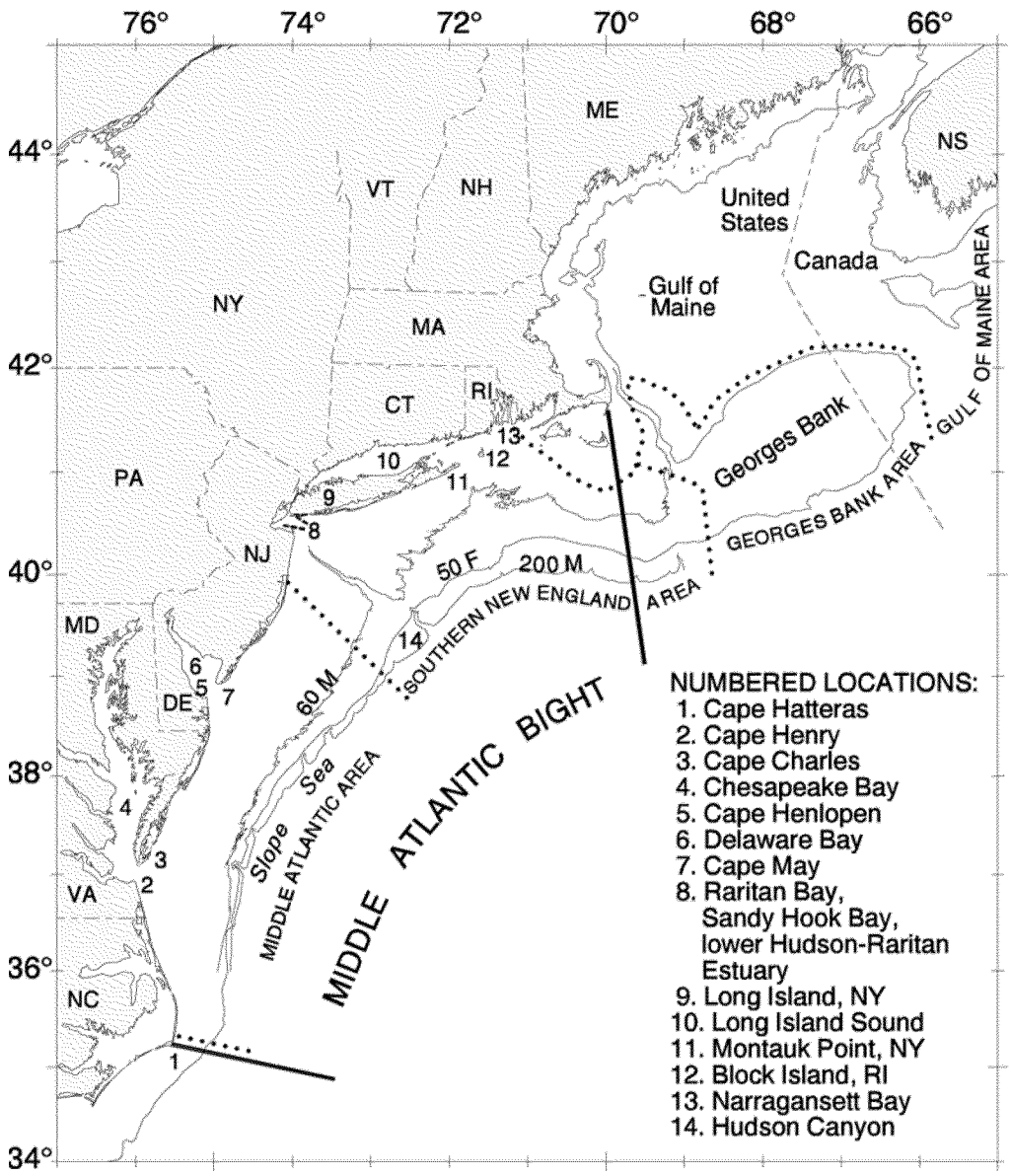


Figure 1. Geographic locations - northeast U.S. and contiguous Canadian waters.

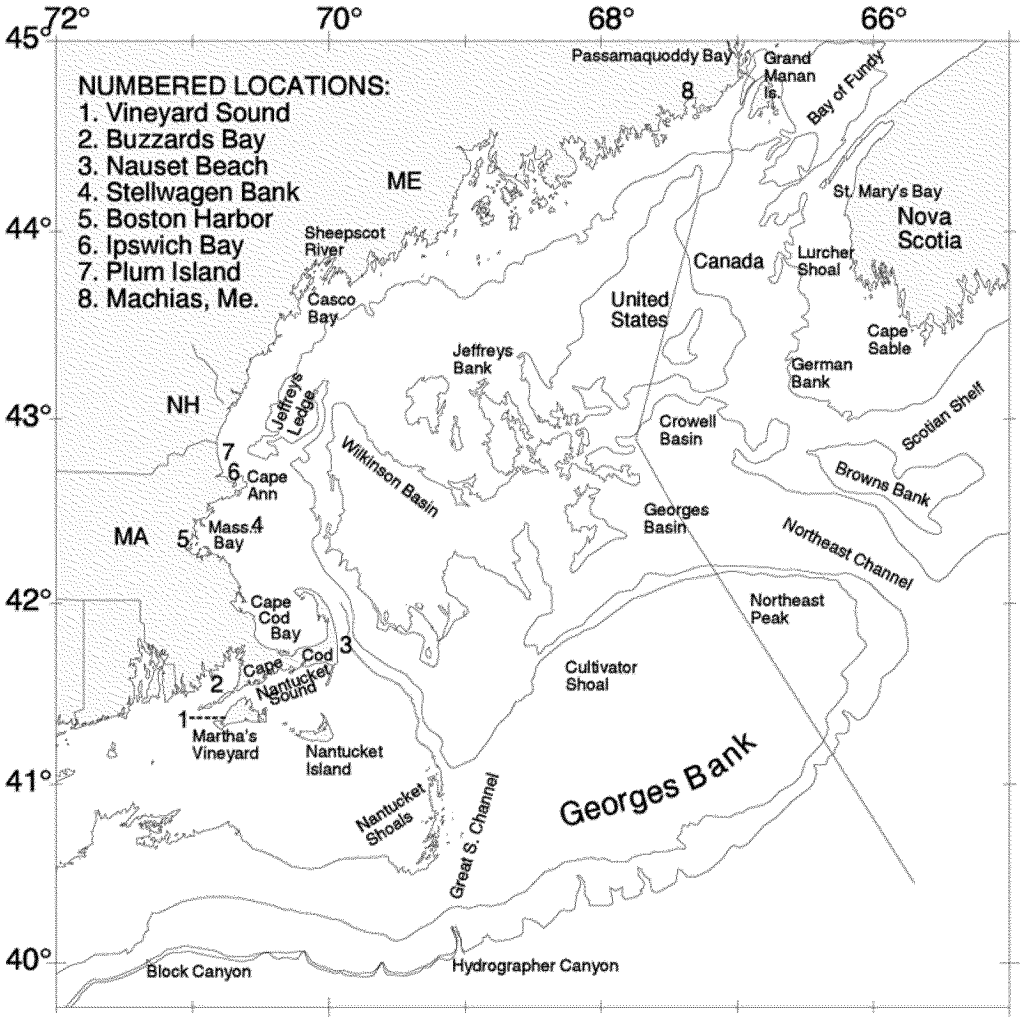


Figure 2. Geographic locations – coastal New England and Georges Bank to Bay of Fundy.

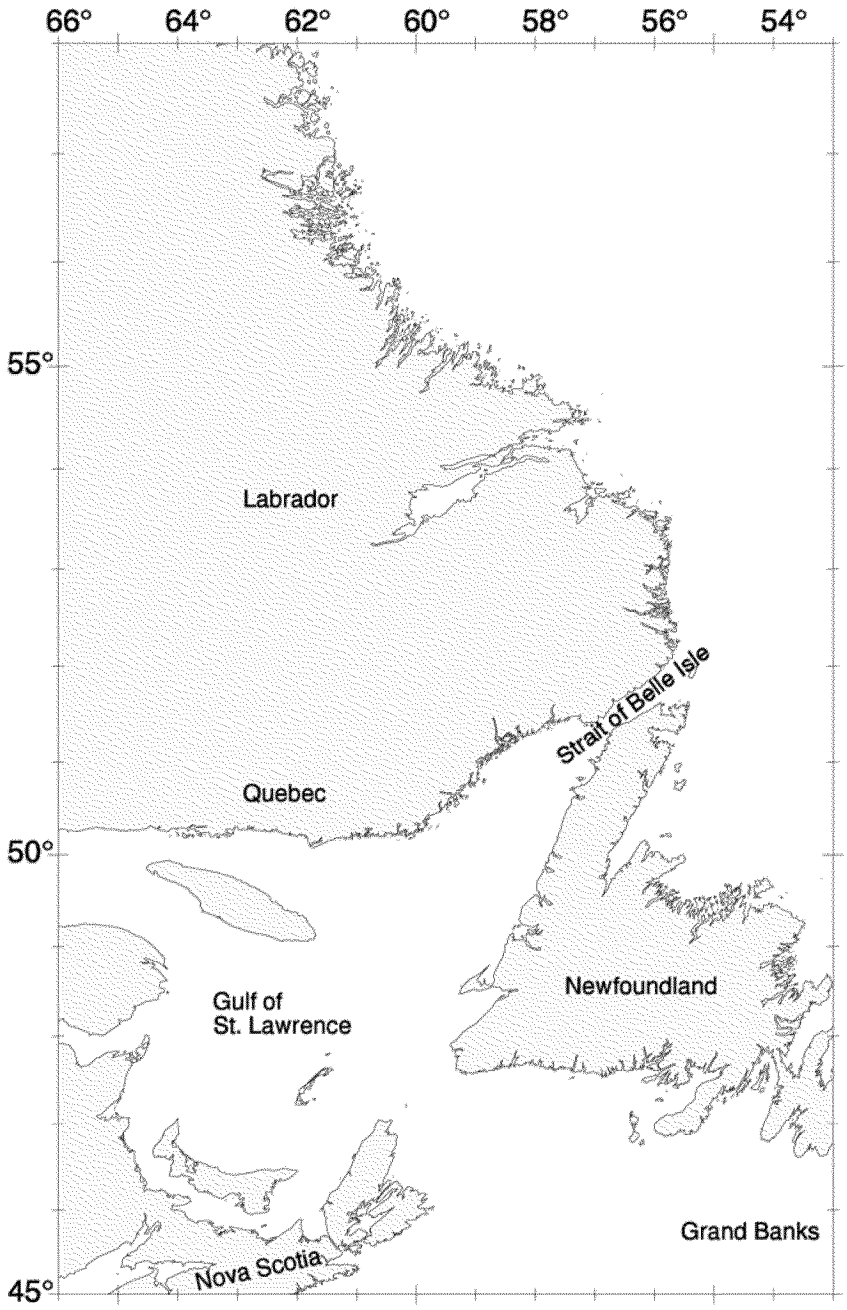


Figure 3. Geographic locations - Canadian waters from Nova Scotia north.

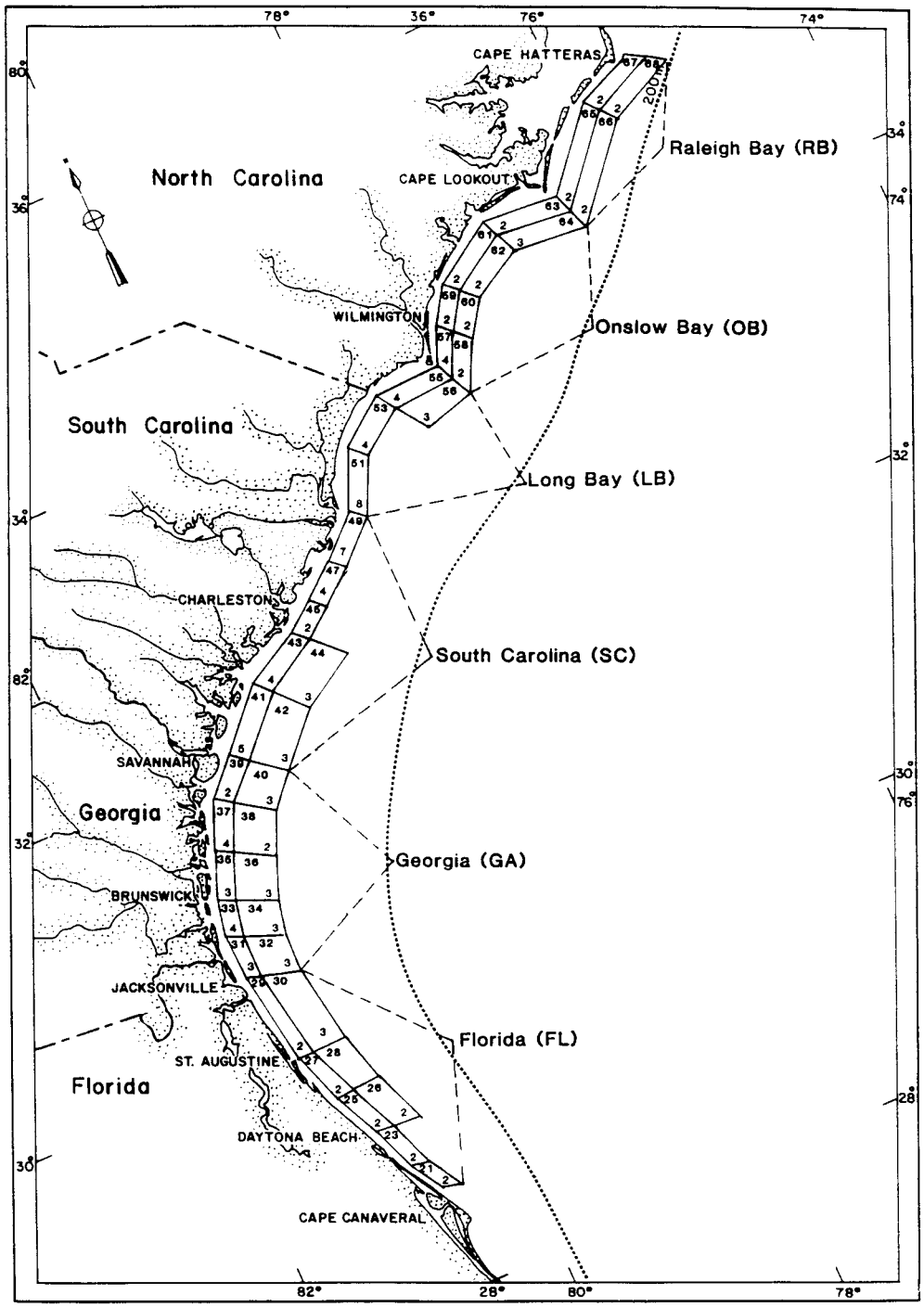


Figure 4. Geographic locations - South Atlantic Bight. Strata sampled in SEAMAP-SA shallow water trawl survey are also shown. Stratum number is shown in the upper left of each stratum, and the number of trawl sites within each stratum is shown in the lower right. Strata are not drawn to scale (from Webster *et al.* 1990).

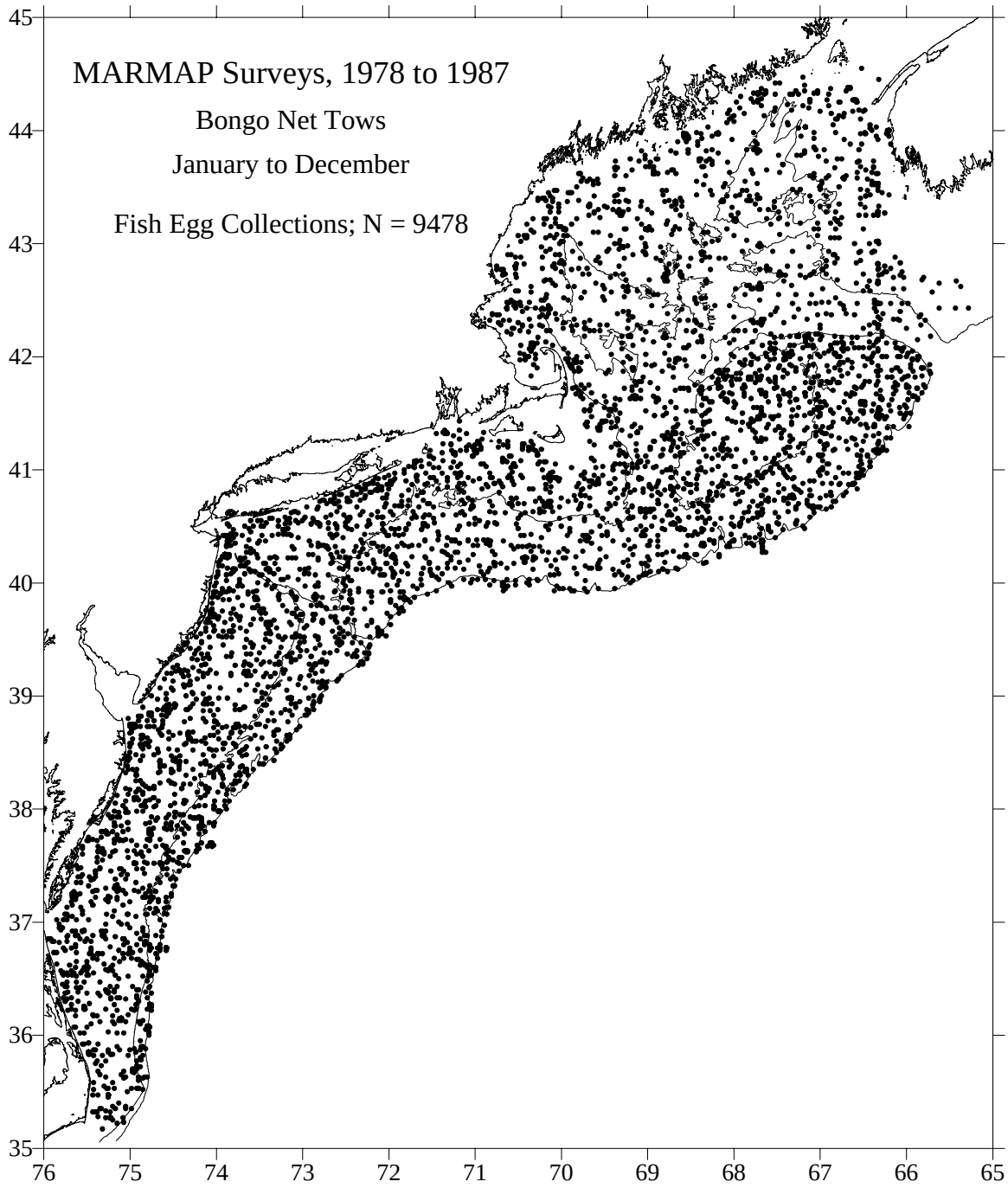
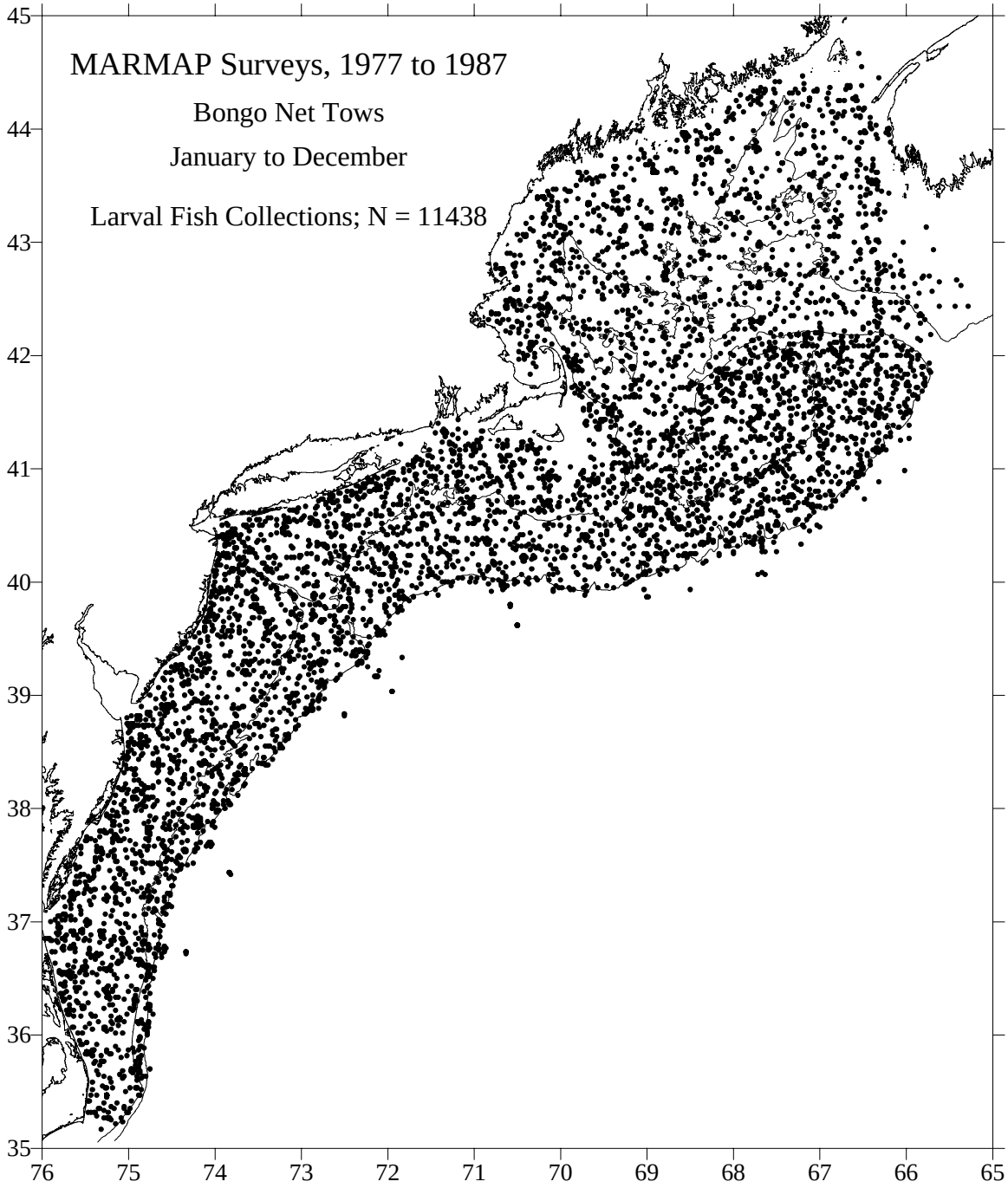


Figure 5. Distribution of all tows for ichthyoplankton eggs and larvae (all surveys combined) during NEFSC MARMAP surveys.



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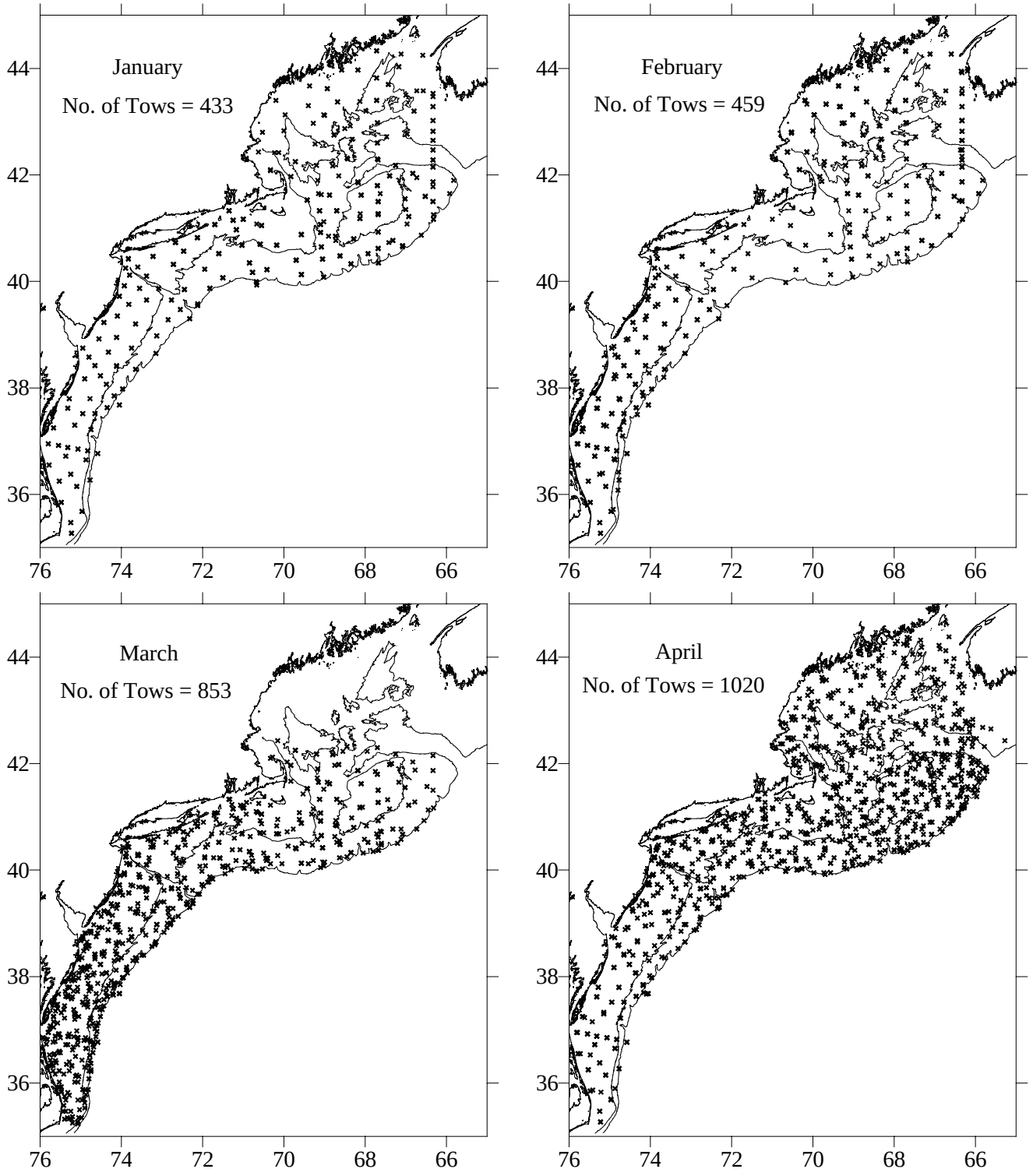
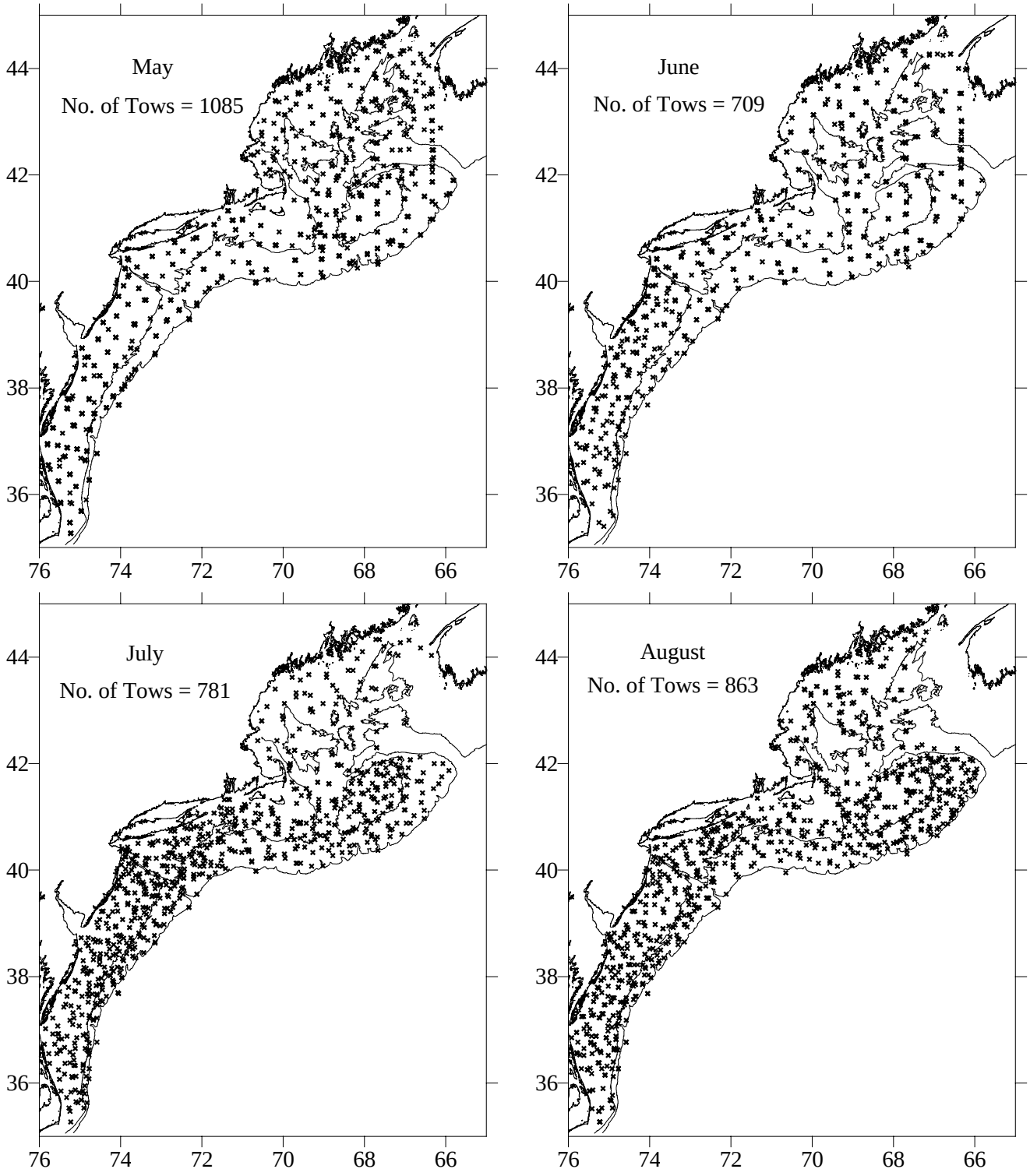


Figure 6. Distribution of all tows for ichthyoplankton eggs by month (all years combined) during NEFSC MARMAP surveys.



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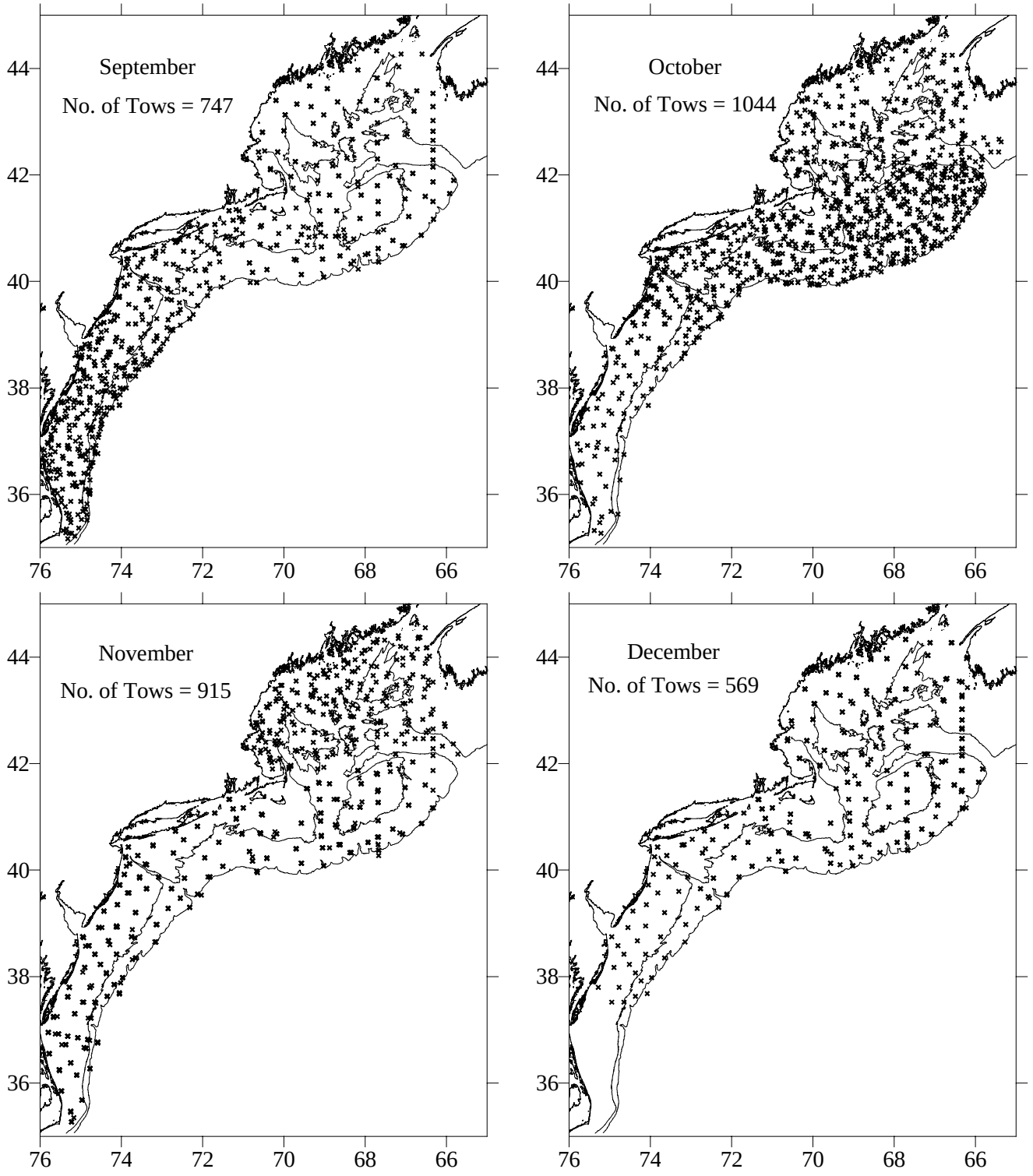


Figure 6. cont'd.

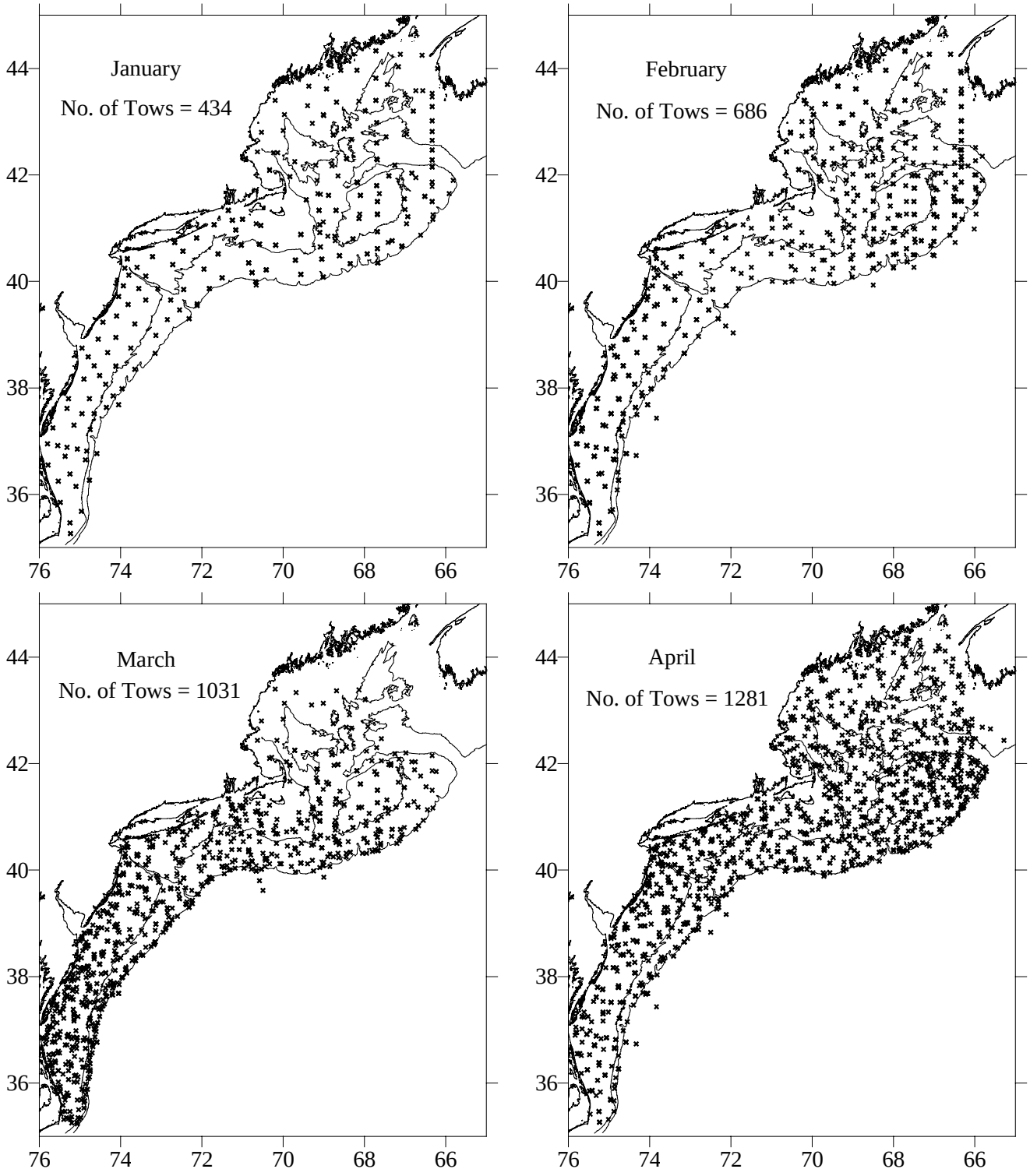
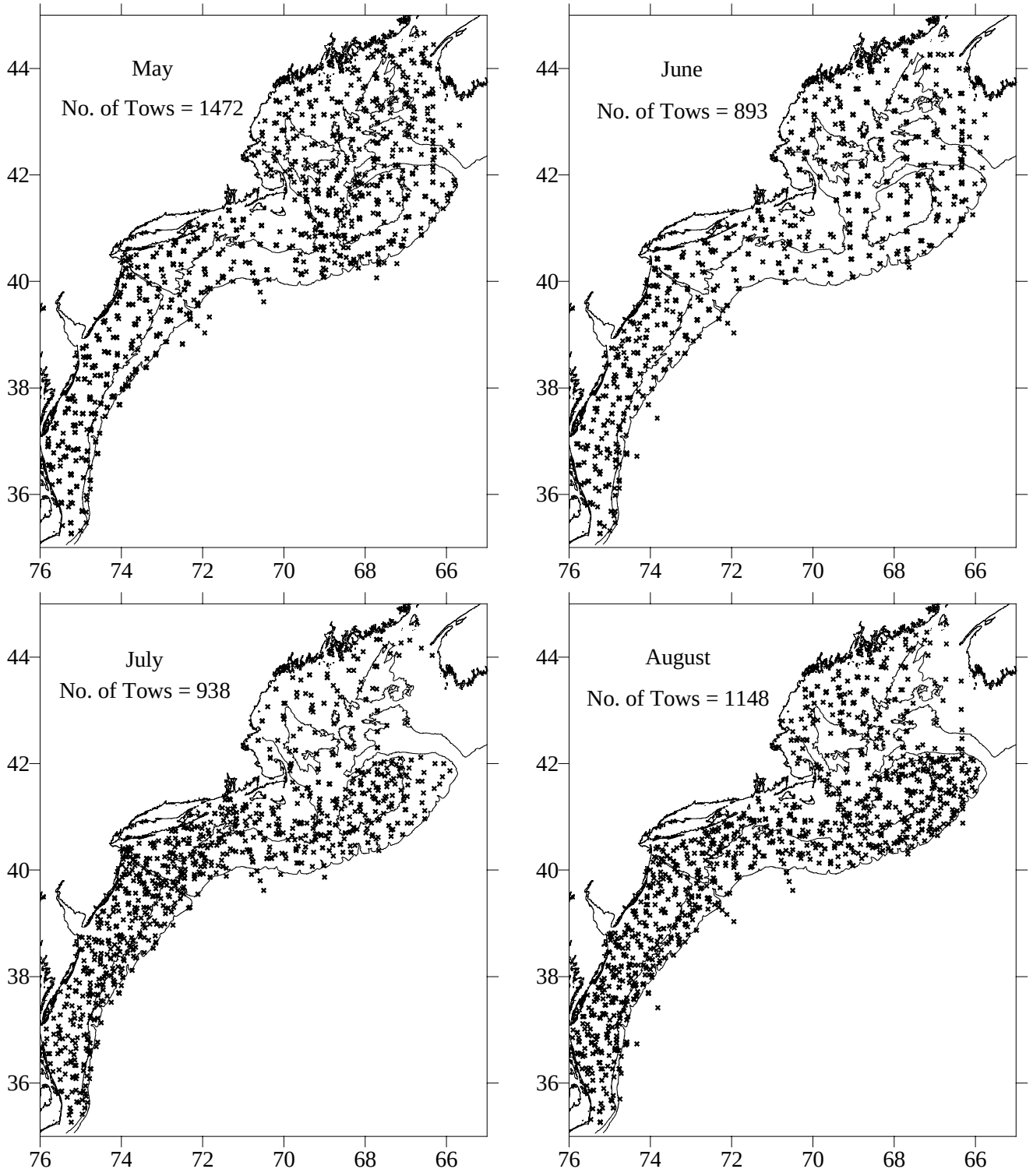


Figure 7. Distribution of all tows made by month for ichthyoplankton larvae during NEFSC MARMAP surveys (all years combined).



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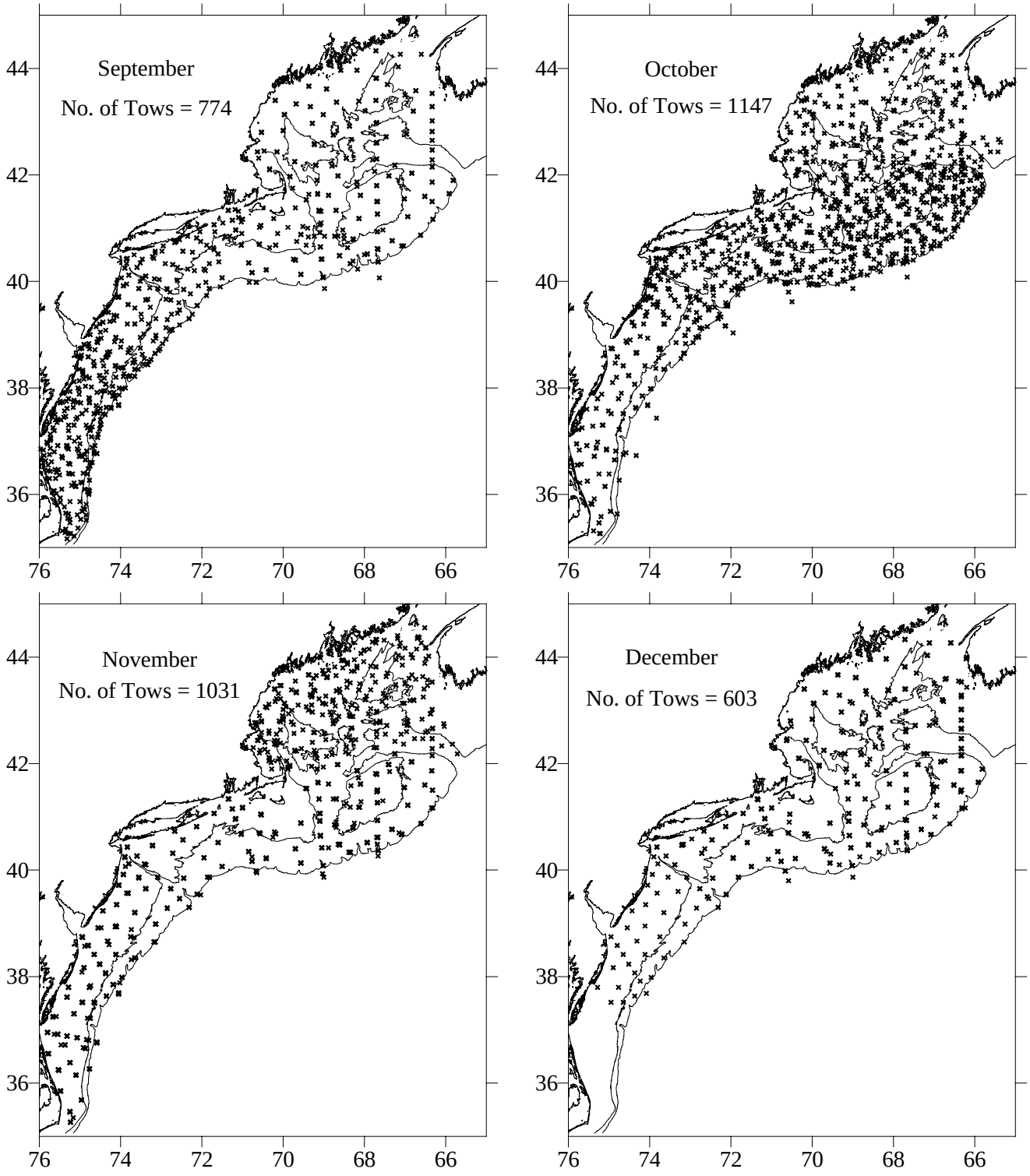

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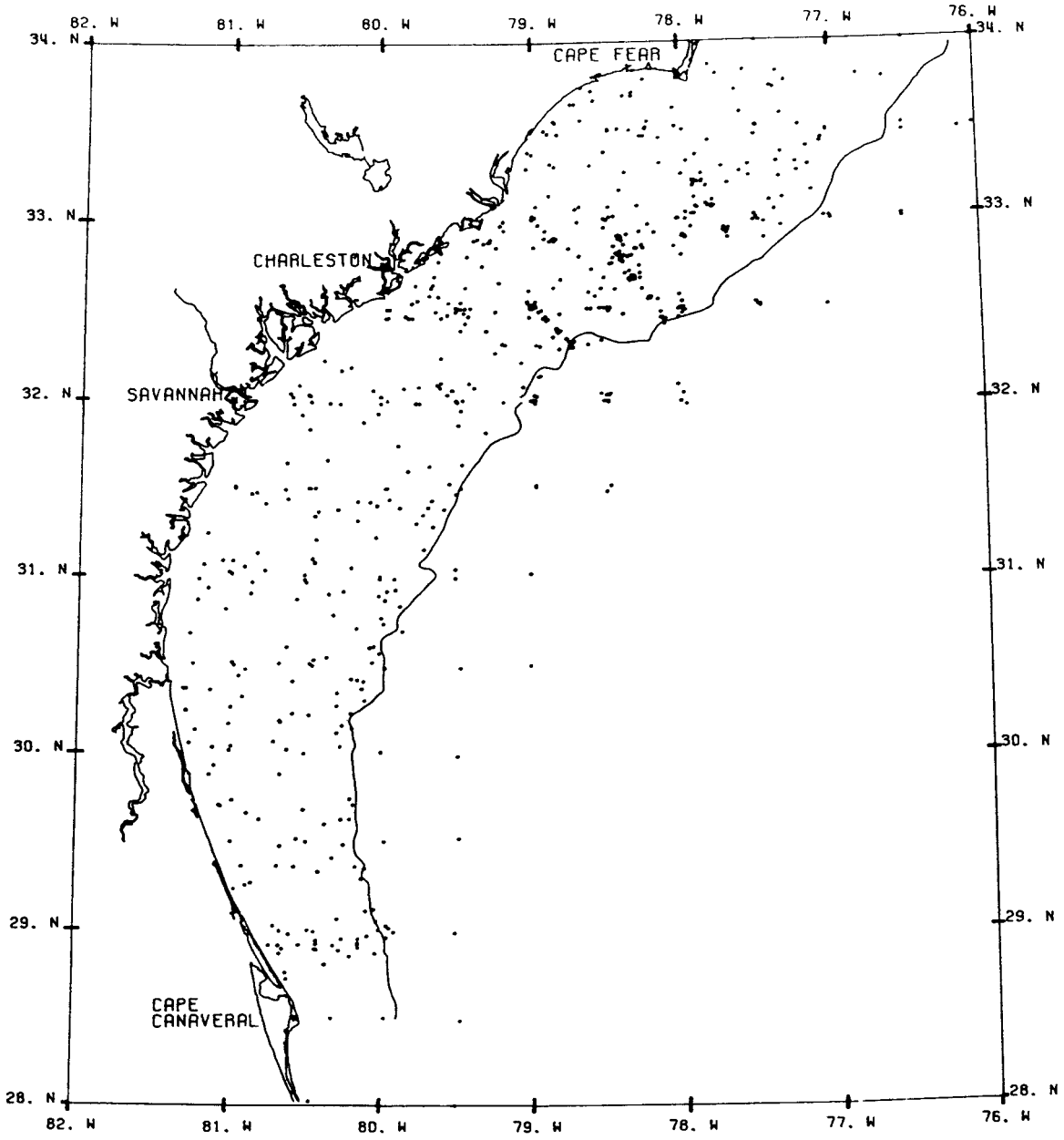


Figure 8. Distribution of all tows conducted during the South Atlantic Bight MARMAP surveys (from Collins and Stender 1987).

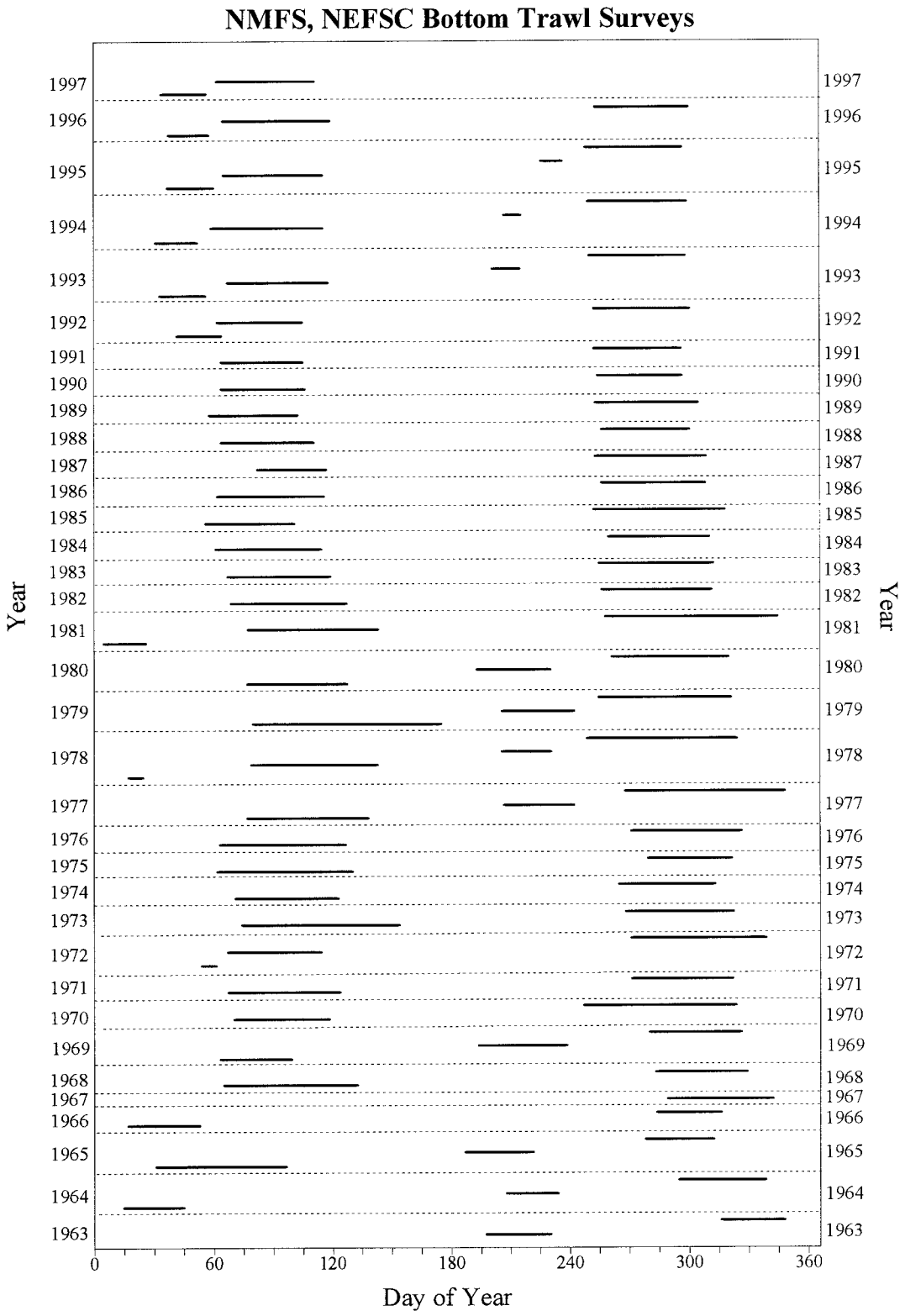


Figure 9. Temporal distribution of NEFSC bottom trawl surveys, 1963-1997.

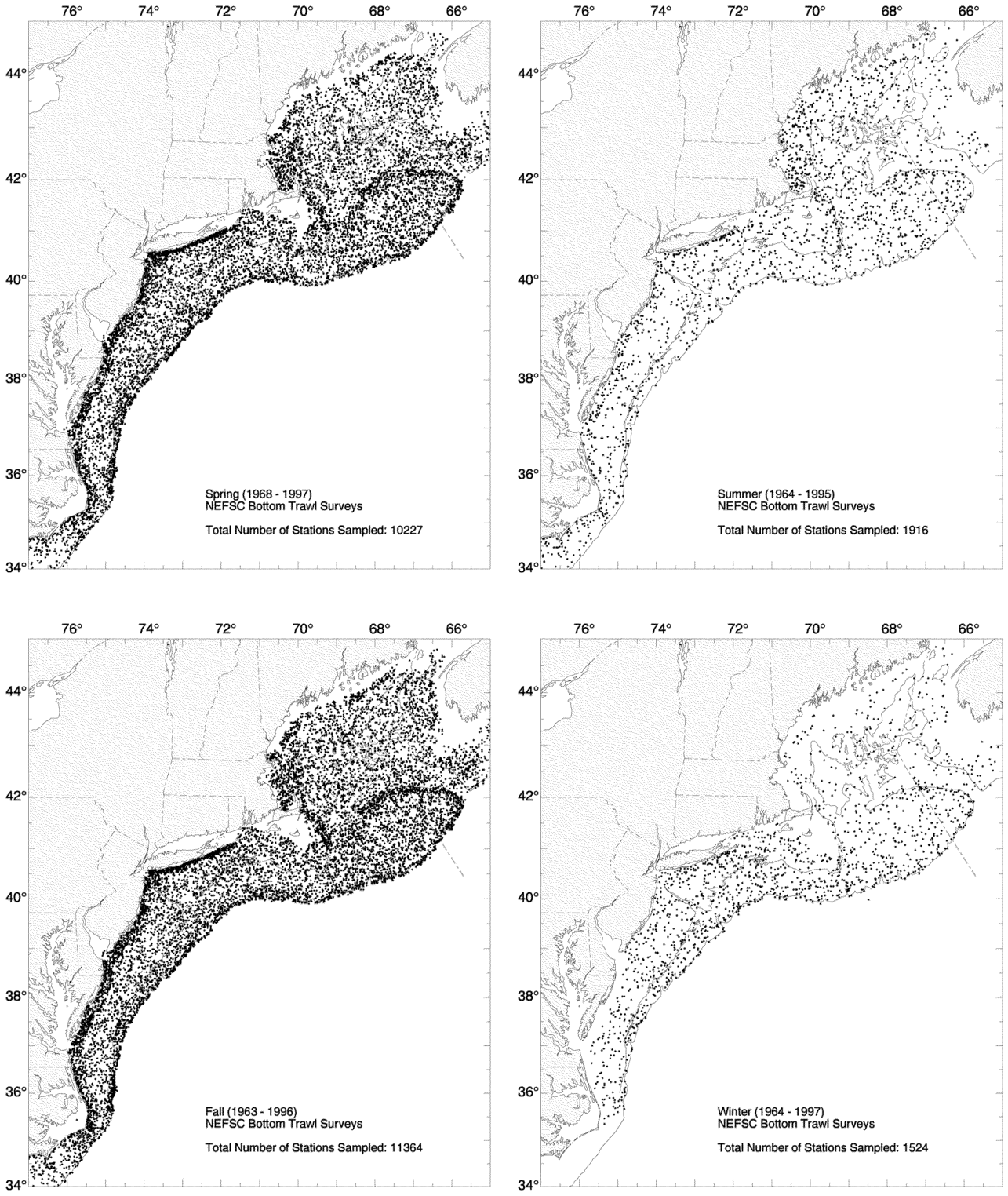


Figure 10. Distribution of NEFSC bottom trawl survey tows by season.

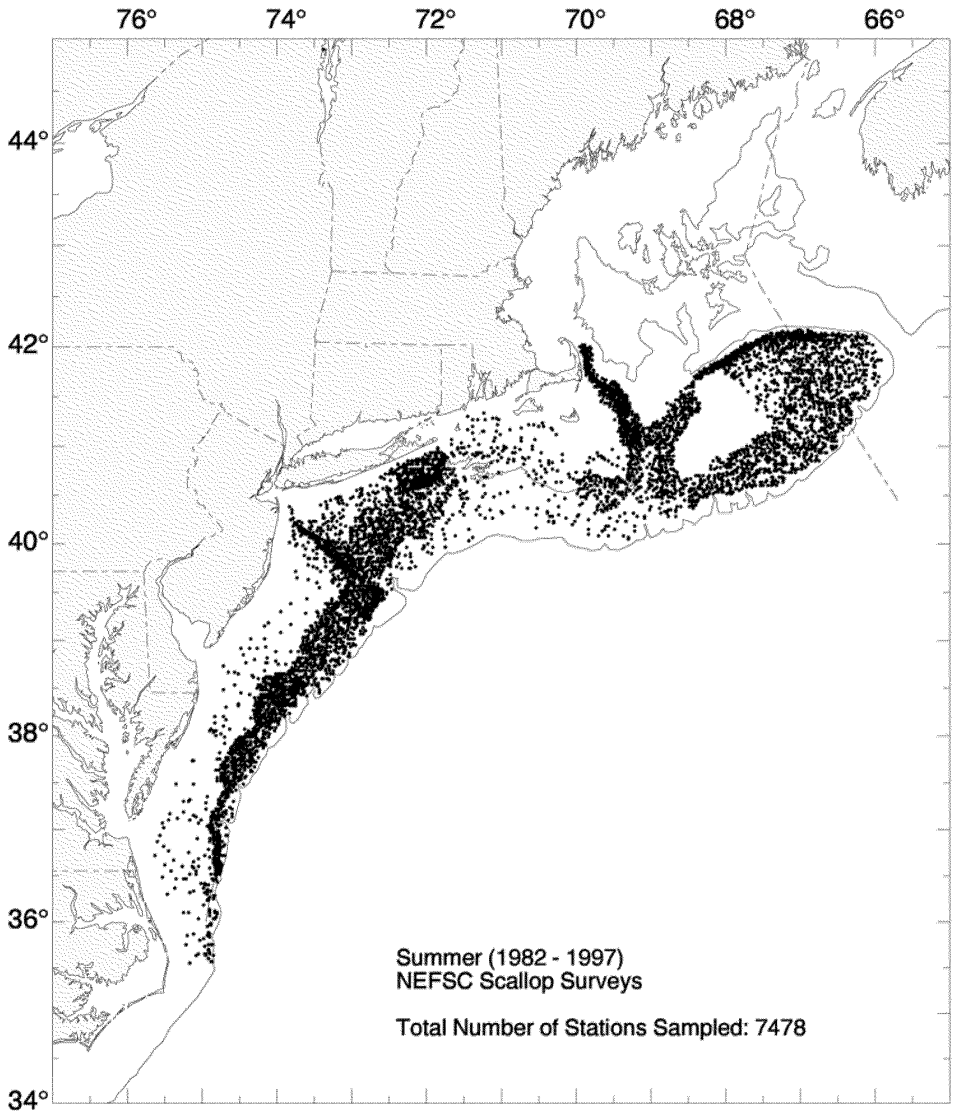


Figure 11. Distribution of all NEFSC sea scallop tows, summer 1982-1997.

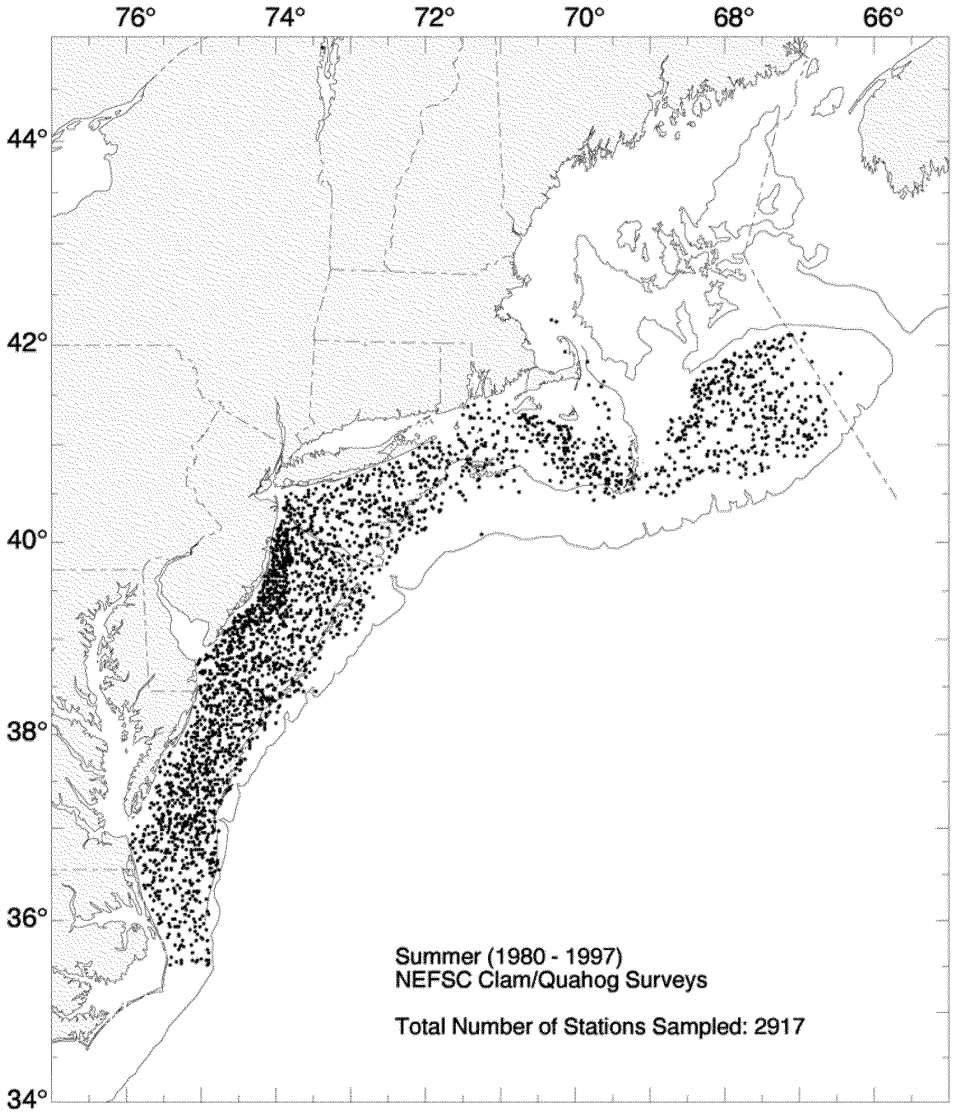


Figure 12. Distribution of all NEFSC Atlantic surfclam/ocean quahog tows, summer 1980-1997.

Rhode Island Division of Fish and Wildlife
Trawl Survey of Narragansett Bay 1990 - 1996

Standard Stations

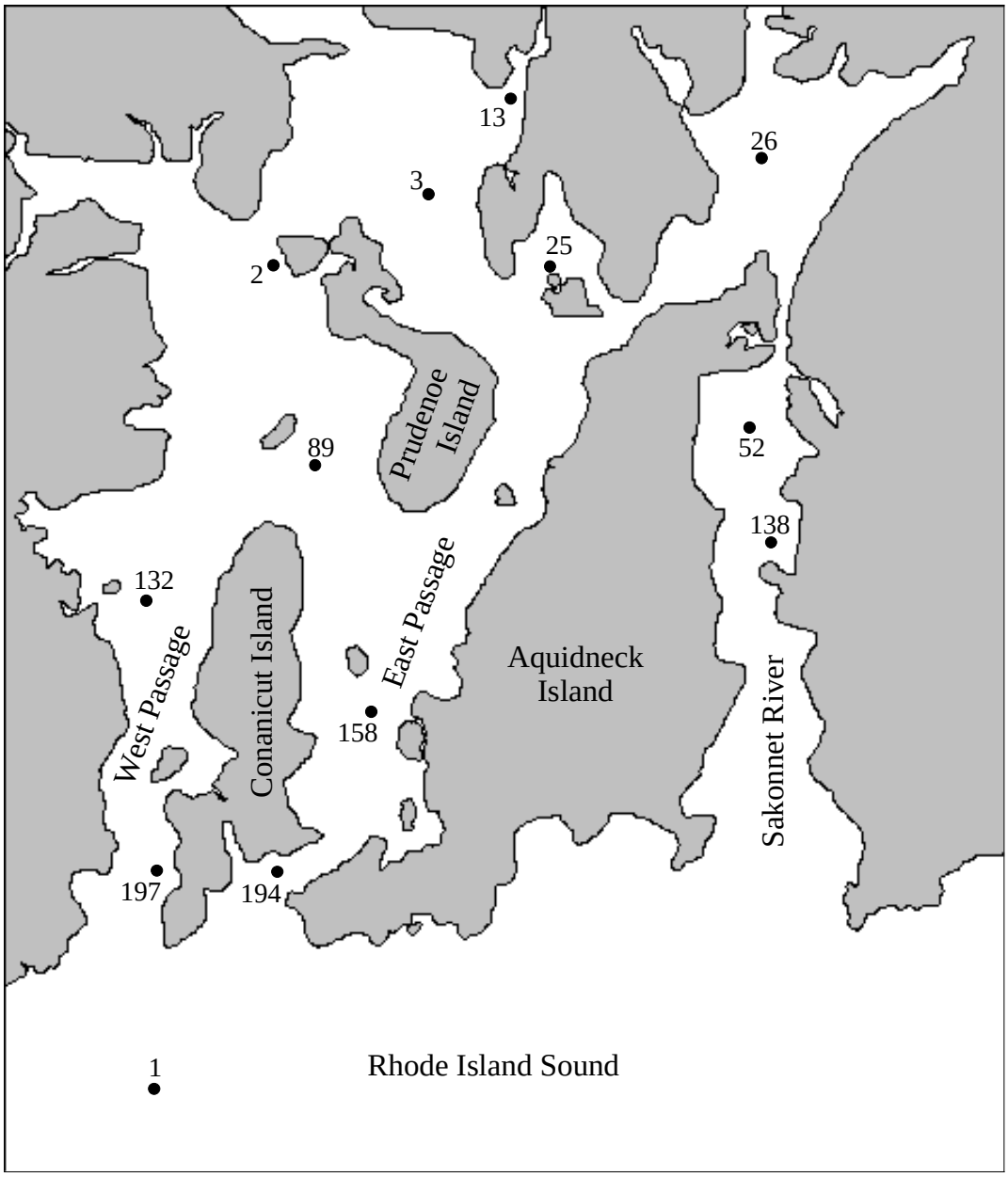


Figure 13. Stations sampled in Rhode Island's Narragansett Bay/Coastal trawl survey.

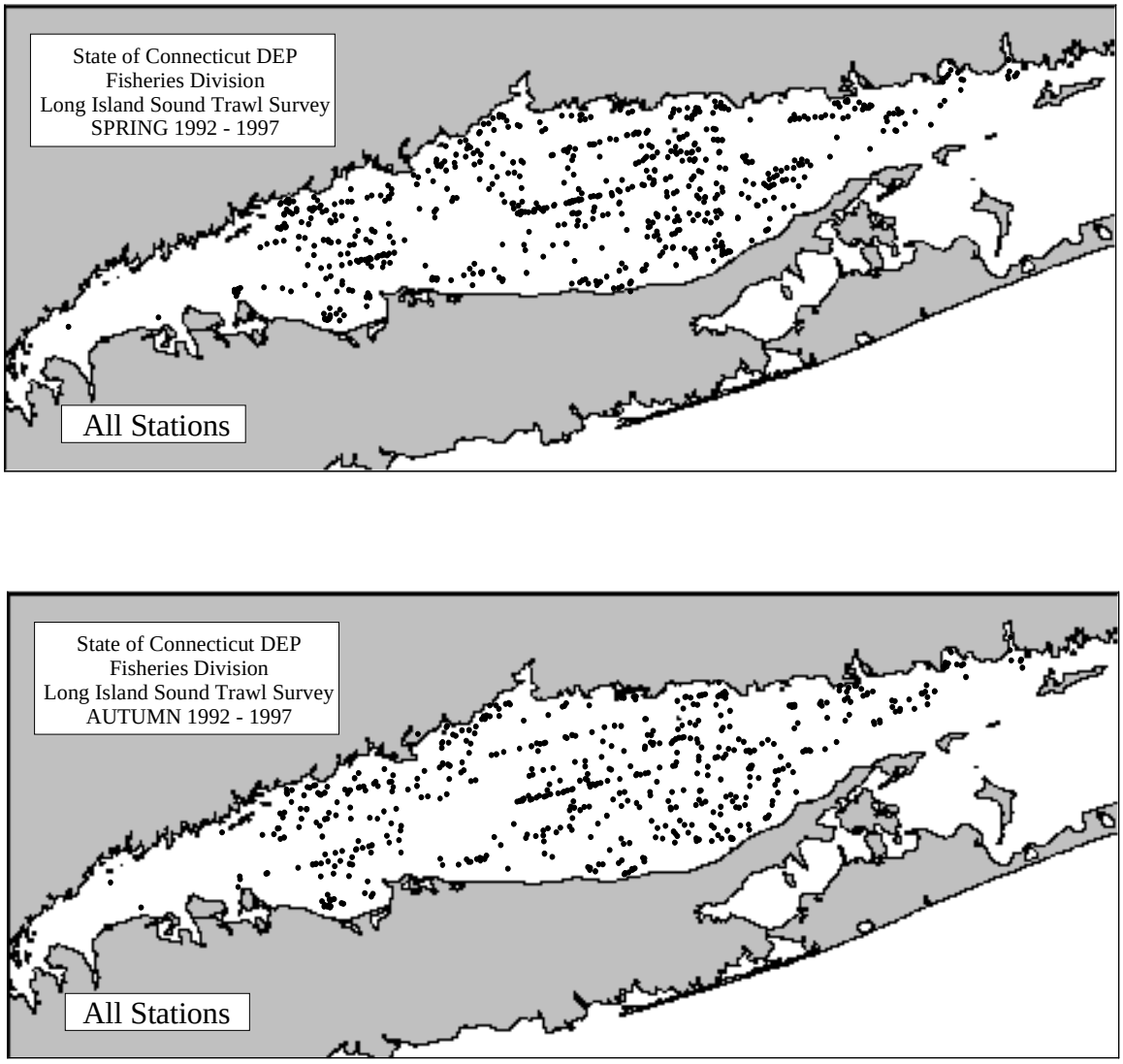


Figure 14. Distribution of all tows made during the Long Island Sound trawl survey in spring and autumn, 1992-1997.

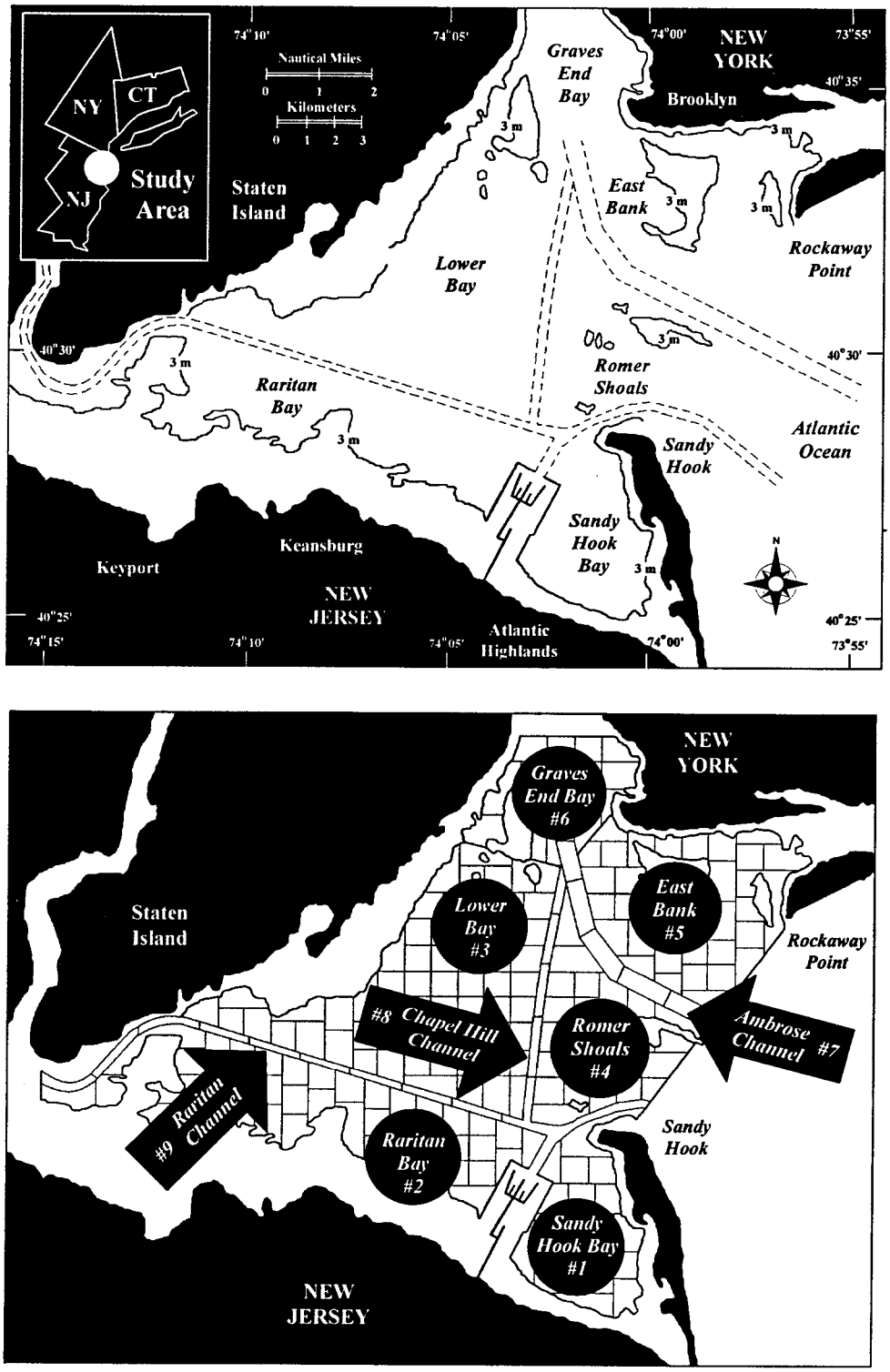


Figure 15. Lower Hudson-Raritan Estuary bottom trawl surveys. Upper map shows the survey area, and the lower map shows the area divided into 9 strata and 217 sampling blocks.

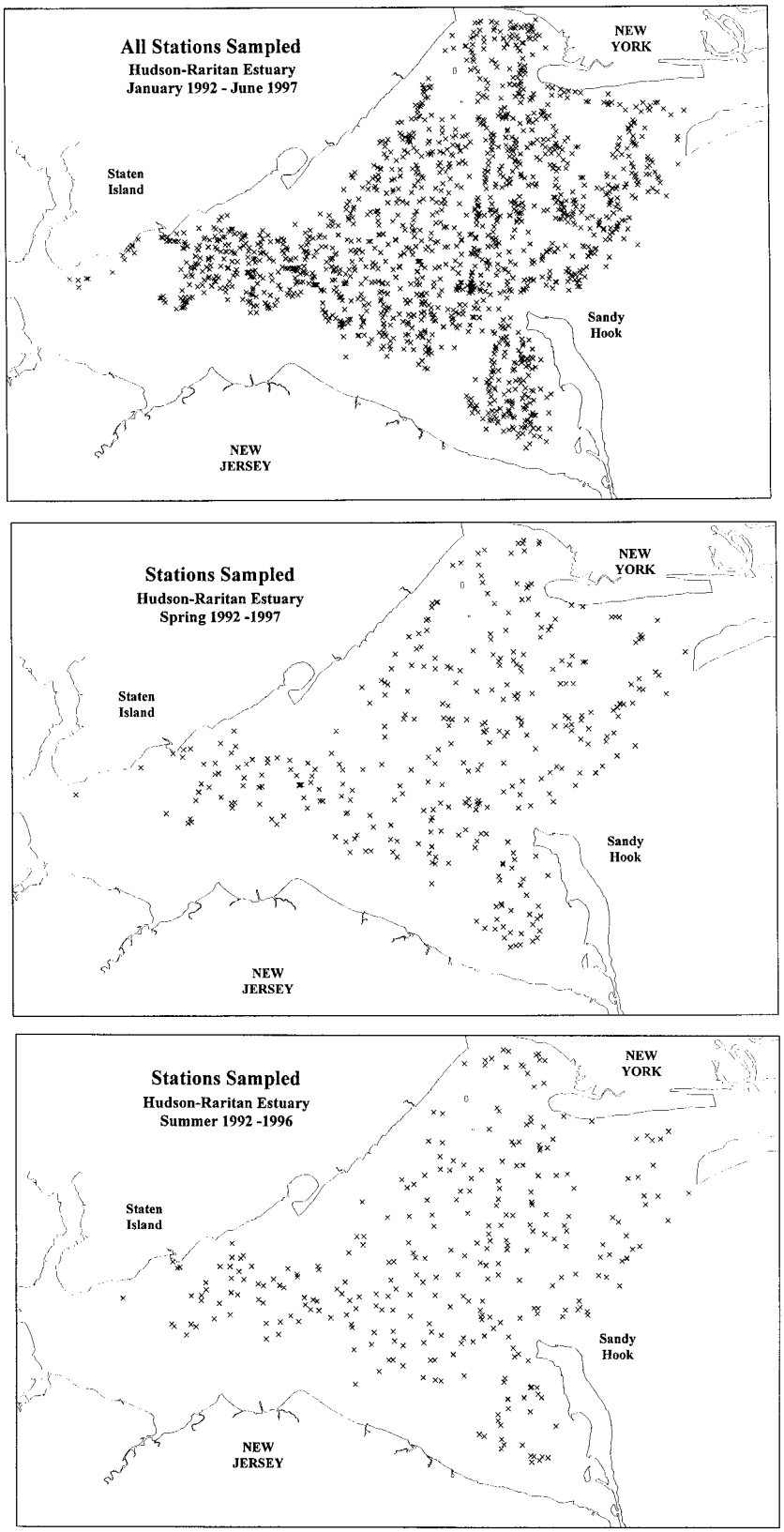
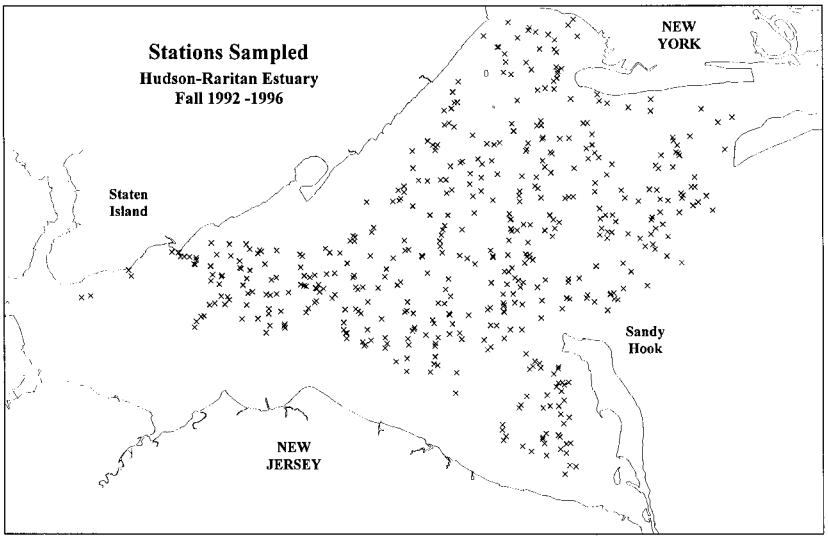


Figure 16. Distribution of Hudson-Raritan bottom trawl survey tows, January 1992 to June 1997.



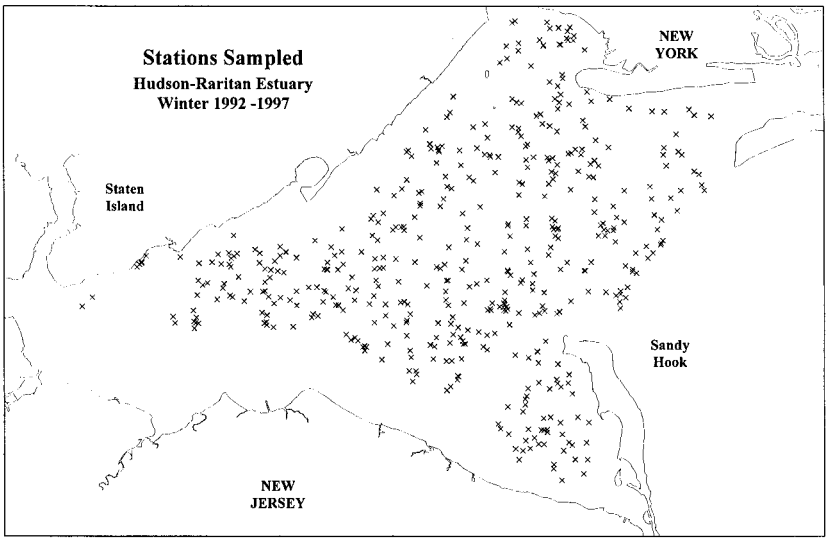


Figure 16. cont'd.

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This series represents a secondary level of scientific publishing in the National Marine Fisheries Service (NMFS). For all issues, the series employs thorough internal scientific review, but not necessarily external scientific review. For most issues, the series employs rigorous technical and copy editing. Manuscripts that may warrant a primary level of scientific publishing should be initially submitted to one of NMFS's primary series (*i.e., Fishery Bulletin, NOAA Technical Report NMFS,* or *Marine Fisheries Review*).

Identical, or fundamentally identical, manuscripts should not be concurrently submitted to this and any other publication series. Manuscripts which have been rejected by any primary series strictly because of geographic or temporal limitations may be submitted to this series.

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The ethics of scientific research and scientific publishing are a serious matter. All manuscripts submitted to this series are expected to adhere -- at a minimum -- to the ethical guidelines contained in Chapter 1 ("Ethical Conduct in Authorship and Publication") of the *CBE Style Manual*, fifth edition (Chicago, IL: Council of Biology Editors). Copies of the manual are available at virtually all scientific libraries.

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Organization: Manuscripts must have an abstract, table of contents, and -- if applicable -- lists of tables, figures, and acronyms. As much as possible, use traditional scientific manuscript organization for sections: "Introduction," "Study Area," "Methods & Materials," "Results," "Discussion" and/or "Conclusions," "Acknowledgments," and "References Cited."

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For spelling of scientific and common names of fishes, mollusks, and decapod crustaceans from the United States and Canada, use *Special Publications* No. 20 (fishes), 26 (mollusks), and 17 (decapod crustaceans) of the American Fisheries Society (Bethesda, MD). For spelling of scientific and common names of marine mammals, use *Special Publication* No. 4 of the Society for Marine Mammalogy (Lawrence, KS). For spelling in general, use the most recent edition of *Webster's Third New International Dictionary of the English Language Unabridged* (Springfield, MA: G.&C. Merriam).

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STANDARD MAIL A

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific ournals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series includes: data reports of long-term or large area studies; synthesis reports for major resources or habitats; annual reports of assessment or monitoring programs; documentary reports of oceanographic conditions or phenomena; manuals describing field and lab techniques; literature surveys of major resource or habitat topics; findings of task forces or working groups; summary reports of scientific or technical workshops; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing. Limited free copies are available from authors or the NEFSC. Issues are also available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series includes: data reports on field and lab observations or experiments; progress reports on continuing experiments, monitoring, and assessments; background papers for scientific or technical workshops; and simple bibliographies. Issues receive internal scientific review but no technical or copy editing. No subscriptions. Free distribution of single copies.

Fishermen's Report **and** ***The Shark Tagger*** -- The ***Fishermen's Report*** (FR) is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of the FR; copies are available through free subscription. ***The Shark Tagger*** (TST) is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of the TST; copies are available only to participants in the tagging program.

To obtain a copy of a technical memorandum or a reference document, or to subscribe to the fishermen's report, write: Research Communications Unit, Northeast Fisheries Science Center, 166 Water St., Woods Hole, MA 02543-1026. An annual list of NEFSC publications and reports is available upon request at the above address. Any use of trade names in any NEFSC publication or report does not imply endorsement.

NOAA Technical Memorandum NMFS-NE-123

Essential Fish Habitat Source Document:

American Plaice, *Hippoglossoides platessoides*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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NOAA Technical Memorandum NMFS-NE-123

This series represents a secondary level of scientifiic publishing. All issues employ thorough internal scientific review; some issues employ external scientific review. Reviews are -- by design -- transparent collegial reviews, not anonymous peer reviews. All issues may be cited in formal scientific communications.

Essential Fish Habitat Source Document:

American Plaice, *Hippoglossoides platessoides*, Life History and Habitat Characteristics

Donna L. Johnson, Peter L. Berrien, Wallace W. Morse, and Joseph J. Vitaliano

National Marine Fisheries Serv., James J. Howard Marine Sciences Lab., 74 Magruder Rd., Highlands, NJ 07732

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Woods Hole, Massachusetts

September 1999

Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

---

[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, CHIEF
ECOSYSTEMS PROCESSES DIVISION
NORTHEAST FISHERIES SCIENCE CENTER

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INTRODUCTION

The American plaice, *Hippoglossoides platessoides*, is an arctic-boreal pleuronectid flatfish that inhabits both sides of the North Atlantic (Figure 1). In Europe, it is known as the long rough dab and occurs from Iceland and Spitzbergen south to the North Sea, the western Baltic, and as far south as the English Channel. In the western Atlantic, it is common from the outer coast of Labrador, south from Hamilton Inlet, Newfoundland, on the Grand Banks, in the Gulf of St. Lawrence, west and south to Cape Cod (Figure 2; Bigelow and Schroeder 1953; Smith *et al.* 1975). It occurs as far south as Montauk Point, NY.

In Canadian waters, American plaice have been exploited since the start of the otter trawl fishery in 1947. It is one of four major species contributing to the Newfoundland and Labrador fisheries and is the most abundant flatfish species in the northwest Atlantic (Bowering and Brodie 1991). In U.S. waters, the fishery for American plaice started to develop around 1975 in the Gulf of Maine as the abundance of other commercially desirable flatfish, such as yellowtail flounder, winter flounder, and summer flounder, began to decrease (Sullivan 1981). Prior to 1973, the primary use of American plaice caught on Georges Bank was for bait (Lange and Lux 1978).

LIFE HISTORY

EGGS

American plaice spawn buoyant eggs which lack oil globules. The eggs have a characteristically large, transparent perivitelline space, which is formed from water entering between the egg and its membrane (Bigelow and Schroeder 1953). The average diameter of an egg is 2.5 mm (range 1.38-3.2 mm). Eggs incubate from 11 to 14 days at 3.9^{o}C (Bigelow and Schroeder 1953). During development, the embryo is covered with a scattered pigment.

In the northwest Atlantic, plaice eggs have been collected during all months of the year (Berrien and Sibunka 1999). In the Gulf of Maine and on the Scotian Shelf, egg abundance peaks in early April and May (Smith *et al.* 1975; Neilson *et al.* 1988).

LARVAE

American plaice larvae hatch at 2.4 mm SL (Fahay 1983) and development of five clusters or groups of pigment begins at 4-6 mm (Klein-MacPhee, in prep.). Yolk absorption is complete about 5 days after hatching when the larva is 6.2-7.5 mm long. Transformation of the larva and migration of the left eye begins when the larva is approximately 20 mm. Although the duration of the transformation process varies with temperature, it is usually complete when the larva is 30-40 mm (Colton and Marak 1969).

Sullivan (1981) found that larval plaice were transported by currents southwest along the coast; some were retained in the Gulf of Maine while others were transported to Georges Bank. Changes in circulation patterns also lead to large numbers of pelagic larvae being transported off Georges Bank (Colton and Temple 1961; Sullivan 1981). Larval plaice that drift into the slope water zone along the southern edge of Georges Bank are susceptible to transport in a northeasterly direction away from Georges Bank and the continental shelf. Differences in temperature between the coastal and slope water zones could affect the transported larvae by subjecting them to thermal stress. Plaice larvae were found in relatively shallow waters on Georges Bank, in Massachusetts Bay, and along coastal Maine (Smith *et al.* 1975).

JUVENILES

The body shape continues to change, flattening and increasing in depth from side to side. As the migration of the left eye across the top of the head to the right side reaches completion, descent towards the bottom begins (Huntsman 1918). Pigment patterns become more abundant and develop on the right side of the body while the left side remains unpigmented. Growth during the first year is greater in warmer, southern climates. Juveniles can reach 7.6 cm by winter.

ADULTS

The body of the adult plaice is broad with a sharp noise and wide gaping mouth. Adults obtain average lengths between 27-66 cm TL. It is the only Gulf of Maine flounder that is right-handed with a large mouth, round tail, and straight lateral line with a slight arch over the pectoral fin (Bigelow and Schroeder 1953).

REPRODUCTION

American plaice is a bottom spawner and the eggs drift into the upper water column after they are released (Colton and Temple 1961). Spawning begins north of Cape Cod in March and continues through the middle of June (Bigelow and Schroeder 1953; Smith *et al.* 1975). Spawning occurs at depths < 90 m and spawning adults migrate from deeper depths into shoaler grounds before spawning (Bigelow and Schroeder 1953).

Ichthyoplankton collections made in Cape Cod Bay revealed that plaice eggs were present from January through July, and larvae were present from January

through August (Scherer 1984). Early stage eggs were collected on the northern perimeter of the Bay suggesting that it was a spawning site. The southern distribution of late-stage eggs suggested displacement by counter-clockwise drift patterns in the Bay. It is believed that the American plaice eggs may have been spawned outside of Cape Cod Bay and drifted into the Bay by prevailing currents. The eggs could have drifted as much as 49.0 km from their original spawning location (Scherer 1984). Smith *et al.* (1975) determined from the low larval occurrence and the prevailing circulation patterns off southern New England that spawning had occurred along the southern edge of Georges Bank and that the larvae were subsequently transported by currents into the Middle Atlantic Bight.

MATURITY

The median age at maturity for females in the Gulf of Maine is 3.6 years (O'Brien *et al*. 1993). Growth rates are higher and maturity is reached earlier in the southern areas (Scotian Shelf, Gulf of Maine) than in the north. The lowest growth rates occurred in St. Mary's Bay while the fastest growth rates occurred in the Gulf of Maine (Table 1). Powles (1965) noted that slower growth rates were observed in deeper waters. Differences also occurred between gender and after four years of age, females grew faster than males and both sexes grew faster in southern regions.

Water temperatures control spawning in American plaice resulting in varied times and locations in the northwest Atlantic (Bowering and Brodie 1991). They can thrive in temperatures ranging from -0.5 to 13.0^{o}C (Bigelow and Schroeder 1953; Bowering and Brodie 1991). Water temperatures from 1.7 to 7.7°C represent conditions where highest development occurs.

Areas of maximum spawning occur in the western Gulf of Maine and over southeastern Georges Bank; optimum spawning temperatures range between 3-6°C. These bottom water temperatures exist throughout much of the spawning period within the 100 m isobath from Cape Cod to New Jersey (Colton 1972). Outside this southern boundary, temperatures are too high for survival rather than too high for reproduction (Colton 1972).

FOOD HABITS

American plaice larvae feed on plankton, diatoms, and copepods. Prior to settling, juveniles feed on small crustaceans, polychaetes, and cumaceans (Bigelow and Schroeder 1953). Feeding competition exists between young plaice and cod (Powles 1965). Diets of adults are primarily echinoderms, chiefly sand dollars, sea urchins, and brittle stars (Huntsman 1918; Pitt 1973; Sullivan 1981). The brittle star, *Ophiura sarsi*, makes up 65% of the plaice diet at some locations in the Gulf of Maine (Klein-MacPhee, in prep.). The diets of plaice collected during Northeast Fisheries Science Center (NEFSC) bottom trawl surveys were dominated by echinoderms, arthropods, annelids, and mollusks (Figure 3) [see Reid *et al.* (1999) for a discussion of methods].

Plaice are opportunistic feeders and flexible in their dietary habits, and will take whatever is most abundant or accessible (Langton and Bowman 1981; Macdonald and Green 1986; Langton and Watling 1990; Keats 1991; Zamarro 1992; Klemetsen 1993; Ntiba and Harding 1993; Martell and McClelland 1994; Packer *et al*. 1994; Berestovskiy 1995). The stomach contents of plaice from western Nova Scotia, Gulf of Maine, Georges Bank, and southern New England are generally similar (Powles 1965; Minet 1973; Pitt 1973; Langton and Bowman 1981) although the specific prey consumed can vary geographically.

In southern New England, plaice consume large quantities of amphipods, shrimp (*Crangon*), polychaetes, and bivalves (Klein-MacPhee, in prep.). On Georges Bank, their diet consists primarily of sand dollars, brittle stars, bivalves, pandalid shrimp, and polychaetes (Bigelow and Schroeder 1953). In Sheepscot Bay, Maine, polychaetes, mysids, amphipods, sand shrimp (*Crangon septemspinosa*), and Atlantic herring are important prey (Langton and Watling 1990; Packer and Langton, in prep.). Offshore in the Gulf of Maine, the brittle star *Ophiura sarsi* is one of the dominant epifaunal taxa (Watling *et al*. 1988) and is the primary prey of plaice; crustaceans (euphausiids and pandalid shrimp), bivalve mollusks (*Yoldia* spp., *Chlamys islandica*, *Cerastoderma pinnulatum*), and tube-dwelling polychaetes are of secondary importance (Langton and Bowman 1981; Bowman and Michaels 1984; Packer *et al*. 1994). In Passamaquoddy Bay, Canada, amphipods, mysids, euphausiids, polychaetes, bivalve mollusks and Atlantic herring are the major prey of plaice (Tyler 1971, 1972; Macdonald and Green 1986; Macdonald and Waiwood, 1987).

American plaice can undergo a size-related shift in their diets. Smaller (< 25-30 cm) individuals feed predominately on mysids, amphipods, polychaetes, small brittle stars, and some mollusks. Larger individuals (> 25-30 cm) feed primarily on fish, brittle stars and other echinoderms, and bivalve mollusks (Huntsman 1918; Powles 1965; Pitt 1973; Langton and Bowman 1981; Bowman and Michaels 1984; Martell and McClelland 1994). Bowman and Michaels (1984) report that polychaetes are especially important prey of plaice < 20 cm and note that the largest fish feed mostly on echinoderms. In Sheepscot Bay, Maine, mysids generally decreased in importance with increasing predator size and polychaetes appeared to increase (Packer and Langton, in prep.).

There is little or no feeding during January and February. This is followed by a rapid increase of feeding

in May, which continues through September (Powles 1965). The highest feeding rates occur during the summer enabling high-energy production for metabolic use and gonad maturation (MacKinnon 1972).

PREDATION

Plaice ≤ 35 cm are frequently preyed on by cod and other bottom feeding species (Powles 1965; Bowman and Michaels 1984). Adults are consumed by Greenland sharks (Bigelow and Schroeder 1953), goosefish, and spiny dogfish. Plaice larvae are commonly consumed by redfish (Klein-MacPhee, in prep.). Along the Scotian Shelf and in the Gulf of St. Lawrence, grey seals are the primary predators of plaice (Benoit and Bowen 1990).

MIGRATION

In U.S. and Canadian waters, American plaice is regarded as a sedentary species migrating only for spawning and feeding (Pitt 1969; Colton 1972; Bowering and Brodie 1991).

STOCK STRUCTURE

American plaice is managed as one stock under the Multispecies Fishery Management Plan of the New England Fishery Management Council (NEFMC 1993). The principal gear used to harvest it is the otter trawl; recreational and foreign catches are insignificant. Since the mid-1970s, landings from the Gulf of Maine have exceeded those from Georges Bank. In 1993 the catch in the Gulf of Maine was more than twice as large as the catch from Georges Bank (O'Brien 1995).

HABITAT CHARACTERISTICS

The habitat characteristics of American plaice are summarized by life history stage in Table 2. Data from the following surveys were used to determine habitat characteristics: (1) National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC) Marine Monitoring Assessment and Prediction (MARMAP) ichthyoplankton survey, (2) NMFS, NEFSC bottom trawl survey, (3) Massachusetts Division of Marine Fisheries (MDMF) bottom trawl survey, and (4) the NEFSC Food Habits Investigation. A description of survey methods and materials is found in Reid *et al.* (1999).

EGGS

Plaice eggs were collected at temperatures ranging from about 1-12°C (Figure 4). During February through April, most eggs were collected at 2-6°C. During May to July the majority of eggs were found at 5-8°C. From August to December, eggs were found at higher temperatures, with most eggs found at 9-11°C.

Eggs were found over depths ranging from 10-180 m, with the majority occurring between 50-90 m.

LARVAE

Plaice larvae were captured at temperatures ranging from 4-14°C (Figure 5). Larvae were most abundant at 6-8°C from March through June and 10-12°C during July and August.

Larvae were found over depths ranging from 30-210 m, with most occurring at 50-90 m except for August, where about 45% also occurred at 130 m.

JUVENILES

In the Northeast Fisheries Science Center spring bottom trawl survey, juvenile American plaice were found in large numbers at temperatures ranging from 4-6°C with an overall range of 2-10°C (Figure 6). During autumn, large catches were made in areas with temperatures of 6-11°C. They occurred at depths ranging from 15-200 m in the spring and 50-275 m in the autumn. The majority occurred at shallower depths of 50-100 m during the spring to slightly deeper areas of 100-175 m during the autumn.

In the Massachusetts Division of Marine Fisheries bottom trawl survey, juvenile plaice were collected at temperatures ranging from 2-12°C during the spring and 5-17°C during the autumn (Figure 7). They were most abundant at 4-6°C in the spring and 7-10°C in the autumn. In the spring, they were found over depths ranging from 10-80 m, with the majority occurring between 45-60 m. During autumn they were found from 20-80 m with the majority again occurring between 45-60 m.

ADULTS

The geographic boundaries of American plaice distribution appear to be defined by warm summer and fall temperatures. Since the early 1940s, coastal warming and cooling trends have been observed in waters between Cape Sable and Long Island (Colton 1972). These trends are related to changes of subsurface water. Cold years are defined as years when coastal water from Labrador displaces slope water. Warm years occur when there is a low ratio of coastal to central Atlantic water and slope

water borders the 200 m isobath.

Huntsman (1918) noted that the maturity of plaice varied as much as 11 years and depended on the water temperatures. The highest temperature, 10°C, for Passamaquoddy Bay and the Cape Cod region had the shortest time of development to maturity (3-5 years). The lowest temperature recorded was 0°C for Newfoundland (Bay of Islands) and plaice had the longest development time (10-13 years) (Huntsman 1918; Bigelow and Schroeder 1953). On the Scotian Shelf, American plaice ranged between 0-13°C with preferences between 1-4°C (Scott 1982a).

Dow (1977) found that water temperatures influence the abundance of American plaice in a study of climatic effects on relative abundance and availability. There were significant positive correlations between the annual catch of fish off the Maine coast and mean annual surface temperatures. These results imply that temperature is a limiting factor in the abundance of American plaice.

On the Scotian Shelf American plaice range between 27-366 m, with preferences between 55-128 m (Scott 1982a). United States research vessel surveys and commercial catch statistics confirm similar movement and depth preferences in the Gulf of Maine (Colton 1972). Plaice normally occur in waters 25-180 m deep, however they have been captured at depths > 800 m (Iglesia *et al.* 1996). They are also found in shoal waters when temperatures are severely cold (Bigelow and Schroeder 1953). In the Gulf of Maine, plaice occur at depths of 15-200 m, more frequently at 30-50 m (Klein-MacPhee, in prep.). With the exception of witch flounder, plaice is considered the most abundant of all flatfish in the Gulf of Maine at depths between 54-90 m (Klein-MacPhee, in prep.). They are also widespread on Georges Bank in 27-366 m of water.

American plaice occur at mean salinities of 20-22 ppt in Hamilton Inlet, Labrador (Backus 1957), 30 ppt or lower in Baltic areas, 32.8 ppt in the Gulf of Maine, and 34 ppt in offshore Atlantic waters (Bigelow and Schroeder 1953).

During a study of fishes of the Scotian Shelf, Scott (1982a) found American plaice had salinity preferences between 31-34 ppt; highest abundance occurred at 33 ppt. Of the 31 species studied by Scott (1982a), American plaice displayed the widest salinity, depth, and temperature ranges.

American plaice are frequently found on fine sand or gravel bottoms (Scott and Scott 1988; Bowering and Brodie 1991). On the Scotian Shelf, plaice were most abundant on sand and gravel substrates (Scott 1982b). They were found in lesser numbers on sand, silt, and clay and were rare on Scotian Shelf drift (a mixed substrate). In eastern Newfoundland, plaice were frequently collected where sandy substrates bordered areas of bedrock. It is believed that their occurrence near bedrock is because bedrock is the preferred habitat of an important prey, green sea urchins, *Strongylocentrotus droebachiensis* (Keats 1991). In some areas, their distribution has been correlated with mud substrates (Walsh 1996; Packer and Langton, in prep.).

In the Northeast Fisheries Science Center spring bottom trawl survey, adults appeared to have similar temperature preferences to juveniles with most found at temperatures from 4-6°C with an overall range of 1-12°C (Figure 6). In autumn, plaice were also mostly found at temperatures of 4-6°C. American plaice were collected at 15-300 m deep in the spring and autumn; they were most abundant between 50-175 m.

In the Massachusetts Division of Marine Fisheries bottom trawl survey, adults had similar temperature preferences to juveniles (Figure 7). Adult plaice were collected at temperatures from 2-9°C during spring surveys and 5-14°C during autumn. Most were found between 4-6°C in the spring and 7-10°C in the autumn. Adults in both spring and autumn were found over depths ranging from 20-80 m, with most occurring at 45-75 m.

GEOGRAPHICAL DISTRIBUTION

American plaice occur on both sides of the North Atlantic. On the western side of the Atlantic, it is common from the outer coast of Labrador, Newfoundland, the Grand Banks, and the Gulf of St. Lawrence west and south to Cape Cod; its southern limit is Montauk Point, NY (Figure 2; Bigelow and Schroeder 1953; Smith *et al.* 1975). It also occurs in North Atlantic estuaries and rivers where it ranges from highly abundant to rare (Jury *et al.* 1994; Table 3).

EGGS

The NEFSC MARMAP ichthyoplankton survey (1978-1987) captured eggs throughout the year (Figure 8). During February and March, eggs were collected on Stellwagen Bank, off Cape Ann, on Jeffreys Ledge, along coastal Maine, and on Georges Bank. During April and May, the highest egg concentrations occurred in the mixed waters and eastern edge of Georges Bank and along the coastal areas off eastern Massachusetts, the Gulf of Maine, southwest Nova Scotia, and Browns Bank. From June through December, eggs were collected almost exclusively along the coastal areas of in the Gulf of Maine; some eggs were collected on Georges Bank and the Scotian Shelf.

LARVAE

Larvae were first captured in the NEFSC MARMAP ichthyoplankton survey (1977-1987) in small numbers during March on the southeastern flank of Georges Bank (Figure 9). By April, numbers increased throughout

Georges Bank and larval distributions spread towards the Great South Channel and onto Nantucket Shoals. Peak abundance occurred during May from Georges Bank as far south as Delaware. The highest May abundance occurred around Cape Cod Bay and along the 60 m contour on Georges Bank. Larval abundance decreased dramatically in June and continued to decline in August.

JUVENILES

In the NEFSC bottom trawl survey, juvenile American plaice occurred from coastal Maine north towards the Bay of Fundy, west to the Scotian Shelf and Georges Bank, and south from Cape Cod, the Great South Channel, and Georges Bank (Figure 10). During winter, juveniles were caught at scattered locations throughout the Gulf of Maine. Juveniles were present in only a few locations along the Great South Channel and the northeast sector of Georges Bank. In the spring, juveniles were abundant between Cape Cod and Cape Ann, out to Stellwagen Bank, and onto Jeffreys Ledge. Juveniles were captured in lower numbers throughout the Gulf of Maine. In the summer, juveniles were found in the inshore and coastal areas of Maine, the Gulf of Maine, along its western perimeter, and within Cape Cod Bay. By autumn the center of abundance was located between Cape Cod and Cape Ann, and along the western part of the Gulf of Maine; a few juveniles were collected on Georges Bank and the northeast sector of the Middle Atlantic Bight. Dense pockets were found within various basins, the northern end of the Great South Channel, and along the 100 m contour.

In the Massachusetts Division of Marine Fisheries bottom trawl survey, juvenile American plaice were abundant around Cape Ann and in Cape Cod Bay during spring and autumn (Figure 11).

ADULTS

In the NEFSC bottom trawl survey, adult American plaice were scattered throughout the Gulf of Maine, the Great South Channel, Georges Bank and Browns Bank in the winter (Figure 10). Their distribution was similar in spring. Larger catches occurred along the Maine coast, Jeffreys Ledge, and Stellwagen Bank. In the summer and autumn, adults appeared to leave Georges Bank. Many were present along the Gulf of Maine, its western perimeter, and within Cape Cod Bay. Those that remained on Georges Bank occurred only on the outer edges of the bank away from the 60 m shoal areas and the eastern edge of the Middle Atlantic Bight. During autumn, large catches occurred within various basins, the northern end of the Great South Channel, and along the 100 m contour.

In the Massachusetts Division of Marine Fisheries bottom trawl survey, American plaice adults occurred in significant numbers around Cape Ann during the spring and autumn (Figure 11).

STATUS OF THE STOCKS

The Gulf of Maine accounts for approximately 72% of the American plaice landings since 1976. The remaining U.S. catch originates mainly on Georges Bank; < 1% of the catch is taken from western Nova Scotia, southern New England, and the Middle Atlantic Bight (Sullivan 1981).

From 1963 through 1974, catches from Georges Bank averaged 2,706 metric tons (mt) or 69% of the U.S. catch (Figure 12). From 1975 to 1979, landings from Georges Bank nearly tripled (O'Brien *et al.* 1992) while catches in the Gulf of Maine increased from 1,507 to 8,835 mt. Landings declined in 1986 and continued to drop through 1990 when landings reached an historic low of 637 mt on Georges Bank. Subsequent increases in landings are probably due to improved recruitment, an increase in spawning stock biomass, and an increase in fishing effort as opposed to an increase in abundance (Sullivan 1981; O'Brien *et al.* 1992). The spawning stock biomass dropped from 41,400 mt in 1980-1982 to 7,700 mt in 1987-1989. By 1991, the presence of the strong 1987 year class raised biomass to 13,400 mt.

Low population indices for the Gulf of Maine and Georges Bank occurred in 1991-1992, but they increased dramatically in 1993 due to the 1989 and 1990 year classes (O'Brien 1995). In 1995, it was estimated that the American plaice stock would remain overexploited due to low abundance, increased fishing effort, and increased discard mortality (O'Brien 1995). In a recent report to Congress from the Secretary of Commerce (National Marine Fisheries Service 1997), the American plaice stock within the jurisdiction of the New England Fisheries Management Council was classified as "overfished."

The distribution of American plaice was compared between years of low abundance (1985-1989) and high abundance (1976-1981) (Figure 13). When the population was at low levels, juveniles and adults were infrequently caught during spring trawl surveys in the Gulf of Maine and on Georges Bank. Larger catches were only encountered from Cape Cod to Cape Ann. Strong recruitment occurred from 1976 to 1981. Large catches of juveniles and adults occurred in coastal Gulf of Maine and there were scattered catches along Browns Bank and Georges Bank. Adults were caught more frequently in the shoal waters (60 m) of Georges Bank, while the juveniles were caught more frequently along the northern edge of Georges Bank.

RESEARCH NEEDS

- Determination of how depth, temperature, and bottom type control the spatial and temporal distribution of plaice; this is especially important for U.S. populations where little research has been conducted.
- Confirmation of vertical migration and seasonal distribution patterns of early life stages.
- Age and growth determination based on otolith microstructure.
- The strength of habitat dependency and/or interaction for juveniles and adults.
- Determination of adult migration patterns (i.e., tagging studies).

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Table 1. The age (A) and length (L) at which 50% of the female American plaice, *Hippoglossoides platessoides*, are mature in the northwest Atlantic.

Area	**A_{50}** (yrs)	**L_{50}** (cm)	**Year**	**Source**
Labrador	8.11	45.84	1978-1988	Bowering and Brodie (1991)
Northern Grand Bank	13.98	42.14	1961-1965	Pitt (1975)
Northern Grand Bank	10.57	40.36	1969-1972	Pitt (1975)
St. Mary's Bay, Newfoundland	15.20	54.00	1964	Pitt (1966)
Flemish Cap	7.80	40.00	1964	Pitt (1966)
Southeastern Grand Bank	8.79	41.45	1971	Pitt (1975)
St. Pierre Bank	9.48	48.26	1978-1988	Bowering and Brodie (1991)
Scotian Shelf	6.00	31.00	1970-1974	Beacham (1983)
Scotian Shelf	4.70	30.80	1975-1979	Beacham (1983)
Nova Scotia to Cape Hatteras	- -	33.60	1979	Morse (1979)
Atl. Coast of N. Am. (77' - 42')	8.00	30.00	1991	Miller *et al.* (1991)
Gulf of Maine	3.80	29.70	1980	Sullivan (1981)
Gulf of Maine	3.60	26.80	1986-1990	O'Brien *et al.* (1993)

Table 2. Summary of life history and habitat characteristics for American plaice, *Hippoglossoides platessoides.* (NTS = NMFS Trawl Survey; MITS = Massachusetts Inshore Trawl Survey).

Life Stage	Size Range	Time of Year Distribution	Habitat/Location	Substrate	Temperature
Spawning Adults [1]		March - mid June, (peak spawning April-May)	American plaice in general occur along the continental shelf from southern Labrador to Montauk Pt. NY. Within Massachusetts Bay, coastal Gulf of Maine, and shelf.		March to June 2.7-4.4°C
Eggs [2]	1.5 to 3.0 mm	Gulf of Maine: Jan - Dec Georges Bank: Jan - June, Dec.	Pelagic, within the 100 m contour, along the coast of Maine, Massachusetts, inshore and shoal waters of Georges Bank. Nursery area = shelf.		Range 1-12°C (most 4-8°C)
Larvae [3]	4 to 6 mm at hatching; 5.1 to 16.4 mm	March - August (peak = May)	Pelagic, within the 100 m contour, along the coast of Maine, Massachusetts, inshore and shoal waters of Georges Bank. Nursery area = shelf.		Range 4-14°C (most 5-10°C)
Juveniles [4]	18 to 34 mm at metamorphosis; 3 cm to < 27cm (Trawl Surveys)	January – December	Latitude range (77°, 42°) Strong concentrations inside and around the 100m isobath in western Gulf of Maine during the spring and autumn surveys. Scattered abundance in deeper waters of western and central Gulf of Maine and the northern sector of Georges Bank.	Fine sand and gravel.	NTS Spring 2-10°C (most 4-6°C); Autumn 4-15°C (most 6-11°C); MITS Spring 2-12°C (most 4-6°C); Autumn 5-17°C (most 7-10°C)
Adults [5]	≥ 27 cm to 66 cm (Trawl Surveys); max size = 81 cm	January - December	Both sides of the North Atlantic, latitude range (77°, 42°) boreal.	Fine sand and gravel.	NTS Spring 1-12°C (most 4 to 6°C); Autumn 3-11°C (most 4-6°C); MITS Spring 2-9°C (most 4-6°C); Autumn 5-14°C (most 7-10°C). 1.7-7.7°C highest development; -1.5°C lower temperature limit; 10-13°C upper temperature limit

[1] Bigelow and Schroeder 1953, Sullivan 1981, Miller *et al.* 1991
[2] Sullivan 1981, Fahay 1983, Miller *et al.* 1991
[3] Smith *et al.* 1975, Sullivan 1981
[4] Sullivan 1981, Miller *et al.* 1991, Wigley and Gabriel 1991
[5] Miller *et al.* 1991

Table 2. cont'd.

Life Stage	Salinity	Bottom Depth	Estuarine Use	Notes
Spawning Adults [1]	32.8 ppt March-April, Gulf of Maine	< 90 m	Inshore and shoal areas, largely an oceanic nursery (see Table 3)	Spawning adults migrate from greater depths into shoaler grounds before spawning.
Eggs [2]	32.8 ppt March-April, Gulf of Maine	Pelagic 10-325 m (most 30-90 m)	Inshore and shoal areas, largely an oceanic nursery (see Table 3)	Spherical with smooth shell. Only Pleuronectid known to have a very wide perivitelline space, no oil globule. 11-14 day incubation duration.
Larvae [3]	32.8 ppt March-April, Gulf of Maine	30-210 m (most 50-90 m)	Inshore and shoal areas, largely an oceanic nursery (see Table 3)	Transformation occurs between 18-34 mm (usually > 25 mm SL).
Juveniles [4]	32.8 ppt March-April Gulf of Maine	Pelagic-shallow shelf (36-713 m); NTS Spring 15-200 m (most 50-100 m); Autumn 50-275 m (most 100-170 m); MITS Spring 10-80 m (most 45-60 m); Autumn 20-80 m (most 45-60 m)	Inshore and shoal areas, largely an oceanic nursery (see Table 3)	Larval - juvenile migration = pelagic to shallow shelf.
Adults [5]	32.8 ppt March-April Gulf of Maine; 30 ppt Baltic, 34 ppt open Atlantic, 20-22 ppt Hamilton Inlet, Labrador	NTS Spring 15-275 m (most 50-175 m); Autumn 25-300 m (most 50-175 m); MITS Spring 5-80 m (most 45-75 m); Autumn 20-80 m (most 45-55, 70 m)	Inshore and shoal areas, largely an oceanic nursery (see Table 3)	

[1] Bigelow and Schroeder 1953, Sullivan 1981, Miller *et al.* 1991
[2] Sullivan 1981, Fahay 1983, Miller *et al.* 1991
[3] Smith *et al.* 1975, Sullivan 1981
[4] Sullivan 1981, Miller *et al.* 1991, Wigley and Gabriel 1991
[5] Miller *et al.* 1991

Table 3. Distribution and relative abundance of American plaice in North Atlantic estuaries and rivers by life history stage (from Jury *et al.* 1994). (*** = Highly Certain; ** = Moderately Certain; * = Reasonable Inference).

Estuaries and Rivers	Life Stage	Distribution and Relative Abundance		Months of Occurrence	Data Reliability
		Mixing	Seawater		
Passamaquoddy Bay	**A**dults (A)		Common	March - Nov	**
	Spawning adults (S)		Common	March - May	**
	Juveniles (J)	Common	Common	March - Nov	*
	Larvae (L)		Common	April - June	**
	Eggs (E)		Common	March - May	**
Englishman / Machias Bay	**A**		Common	March - Nov	*
	S		Common	March - May	*
	J	Common	Common	March - Nov	*
	L		Common	April - June	*
	E		Common	March - May	*
Narraguagus Bay	**A**		Common	March - Nov	*
	S		Common	March - May	*
	J	Common	Common	March - Nov	*
	L		Common	April - June	*
	E		Common	March - May	*
Blue Hill Bay	**A**		Common	March - Nov	*
	S		Common	March - May	*
	J	Common	Common	March - Nov	*
	L		Common	April - June	*
	E		Common	March - May	*
Penobscot Bay	**A**		Common	March - Nov	**
	S		Common	March - May	**
	J	Common	Common	March - Nov	**
	L		Common	April - June	**
	E		Common	March - May	**
Muscongus Bay	**A**		Abundant	March - Nov	**
	S		Common	March - May	*
	J	Common	Highly Abundant	March - Nov	*
	L	Rare	Common	April - June	*
	E		Common	March - May	*
Damariscotta River	**A**		Abundant	March - Nov	**
	S		Common	March - May	**
	J	Common	Highly Abundant	March - Nov	*
	L	Rare	Common	April - June	*
	E		Common	March - May	**
Sheepscot River	**A**		Abundant	March - Nov	***
	S		Common	March - May	***
	J	Common	Highly Abundant	March - Nov	***
	L	Rare	Common	April - June	***
	E		Common	March - May	**
Kennebec / Androscoggin Rivers	**A**		Abundant	March - Nov	**
	S		Common	March - May	*
	J	Common	Highly Abundant	March - Nov	*
	L	Rare	Common	April - June	*
	E		Common	March - May	*
Casco Bay	**A**		Abundant	March - Nov	*
	S		Common	March - May	*
	J	Common	Highly Abundant	March - Nov	*
	L	Rare	Common	April - June	*
	E		Common	March - May	*

Table 3. cont'd.

Estuaries and Rivers	Life Stage	Distribution and Relative Abundance		Months of Occurrence	Data Reliability
		Mixing	Seawater		
Saco Bay	**A**		Abundant	March. - Nov.	*
	S		Common	March - May	*
	J	Common	Highly Abundant	March. - Nov.	*
	L	Rare	Common	April - June	*
	E		Common	March - May	*
Wells Harbor	**A**				*
	S				**
	J		Rare	June - Oct.	*
	L		Rare	April - June	*
	E		Rare	March - May	*
Great Bay	**A**		Rare	March - Nov.	*
	S				**
	J		Rare	March - Nov.	*
	L		Rare	April - July	*
	E		Rare	March - June	*
Merrimack River	**A**				*
	S				**
	J	Rare		March - Sept.	*
	L	Rare		April - July	*
	E	Rare		March - June	*
Massachusetts Bay	**A**		Highly Abundant	Jan. - Dec.	***
	S		Highly Abundant	Feb. - June	**
	J		Highly Abundant	Jan. - Dec.	***
	L		Abundant	March - July	*
	E		Abundant	Feb. - June	*
Boston Harbor	**A**		Abundant	Jan. - Dec.	**
	S		Common	Feb. - June	*
	J		Abundant	Jan. - Dec.	*
	L	Rare	Common	March - July	*
	E	Rare	Common	Feb. - June	*
Cape Cod Bay	**A**		Abundant	Jan. - Dec.	**
	S		Highly Abundant	Feb. - May	**
	J		Highly Abundant	Jan. - Dec.	**
	L	Rare	Highly Abundant	March - July	**
	E	Rare	Highly Abundant	Feb. - July	**

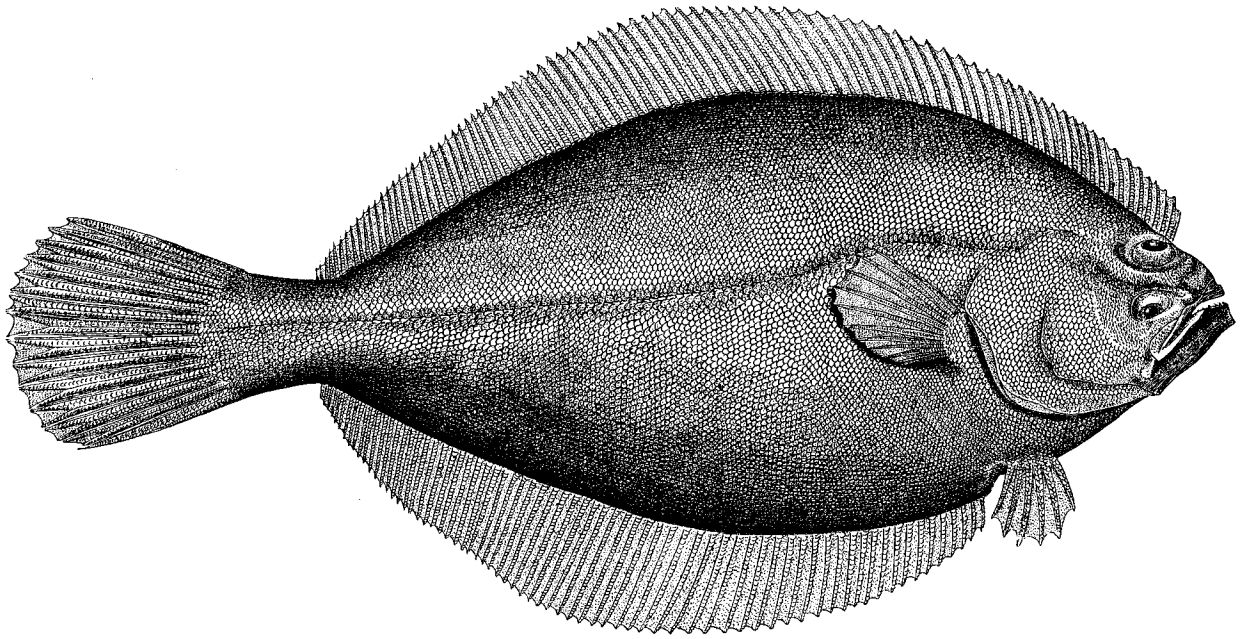


Figure 1. The American plaice, *Hippoglossoides platessoides* (Fabricius 1780) (from Goode 1884).

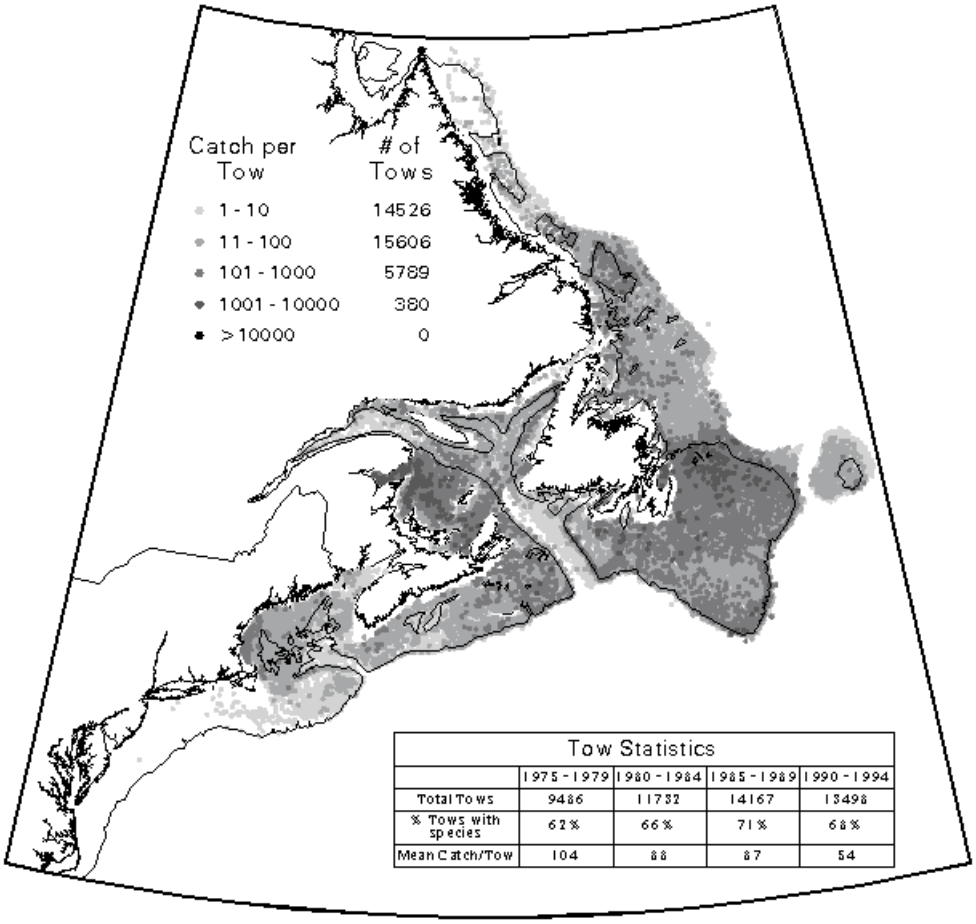


Figure 2. Distribution and abundance of American plaice from Newfoundland to Cape Hatteras based on research trawl surveys conducted by Canada (DFO) and the United States (NMFS) from 1975-1994 (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

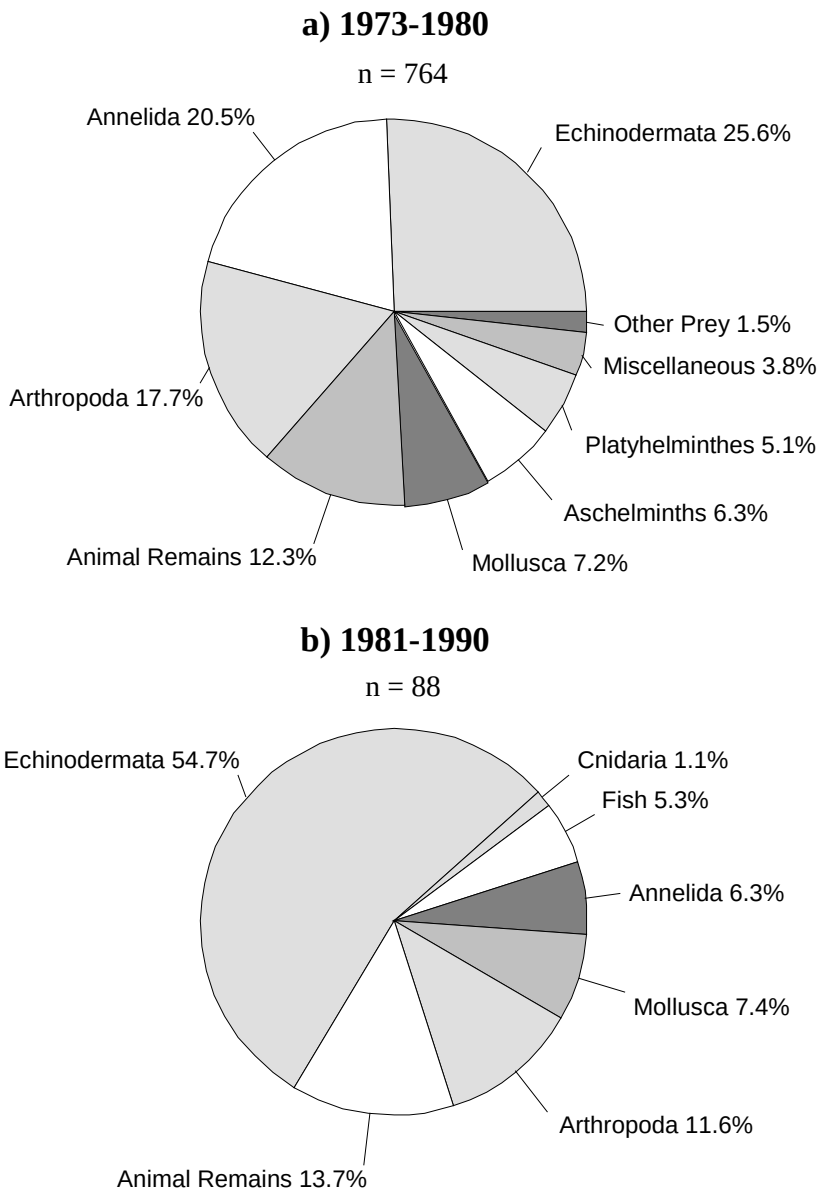


Figure 3. Abundance (percent occurrence) of the major prey items in the diet of American plaice based on NEFSC trawl survey data on food habitats during 1973-1980 and 1981-1990. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details]. The category "animal remains" refers to unidentifiable animal matter.

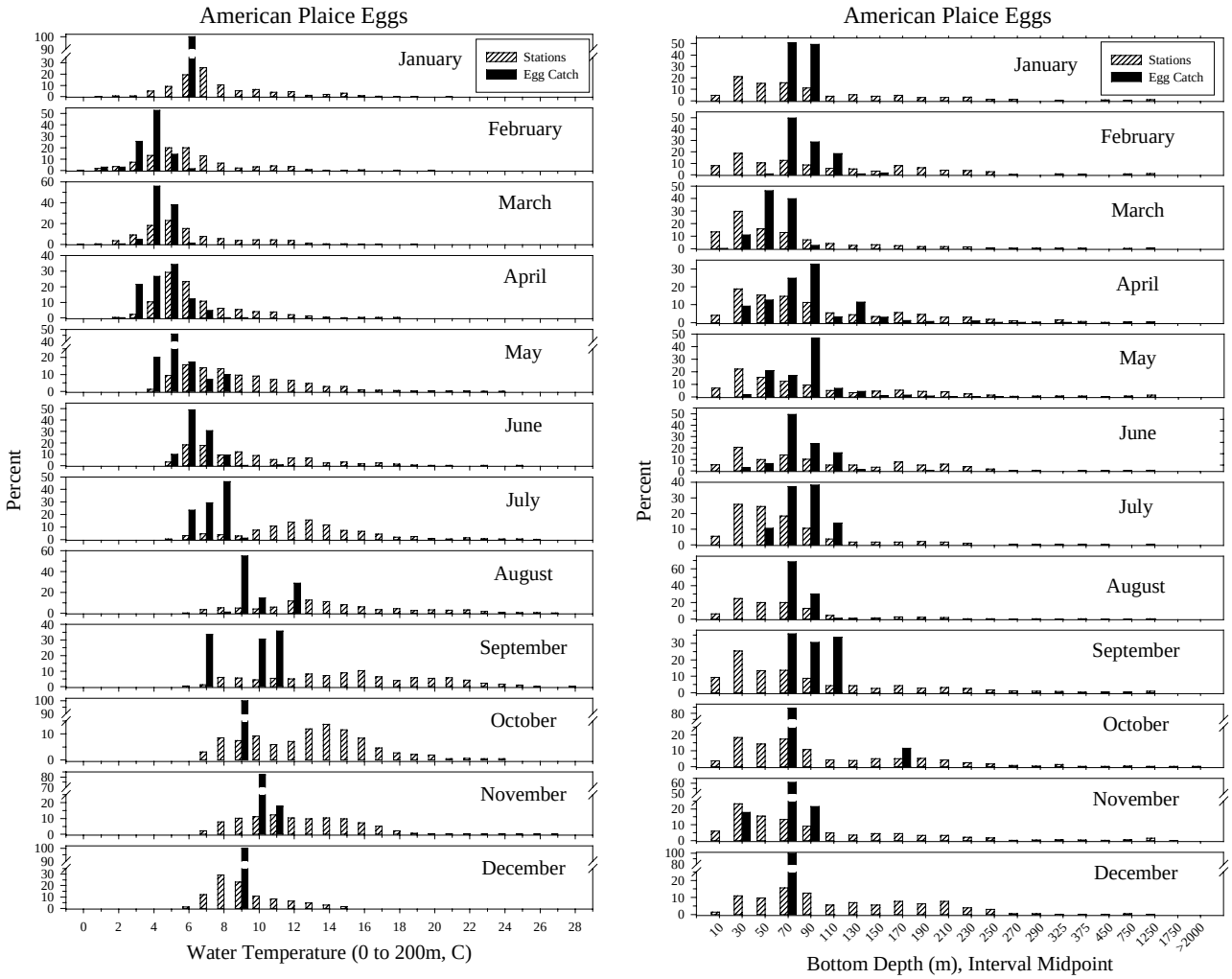


Figure 4. Mean water column temperature (to a maximum of 200 m) and bottom depth associated with collections of American plaice eggs during MARMAP ichthyoplankton surveys, 1978-1987. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

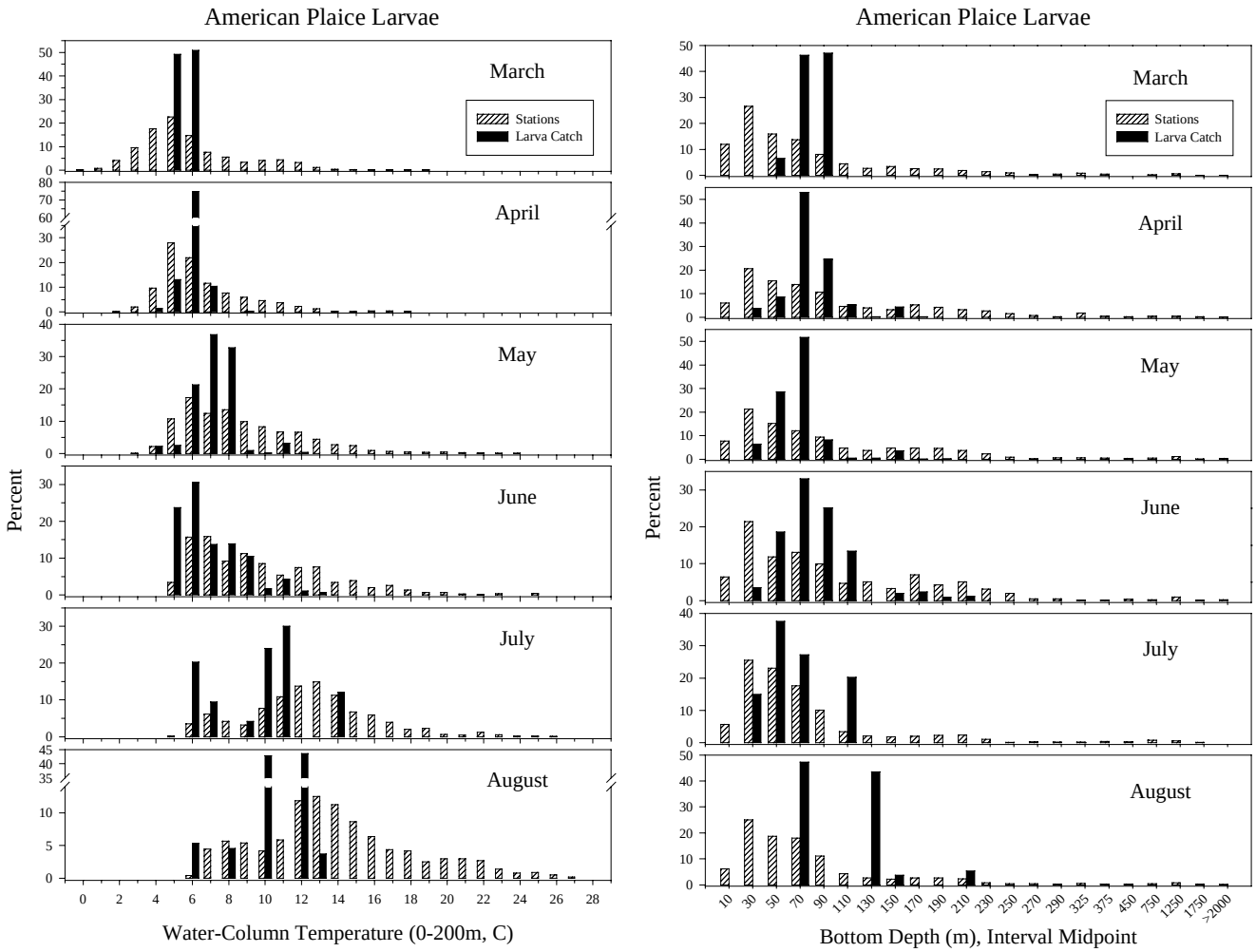


Figure 5. Mean water column temperature (to a maximum of 200 m) and bottom depth associated with collections of American plaice larvae during MARMAP ichthyoplankton surveys, 1977-1987. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

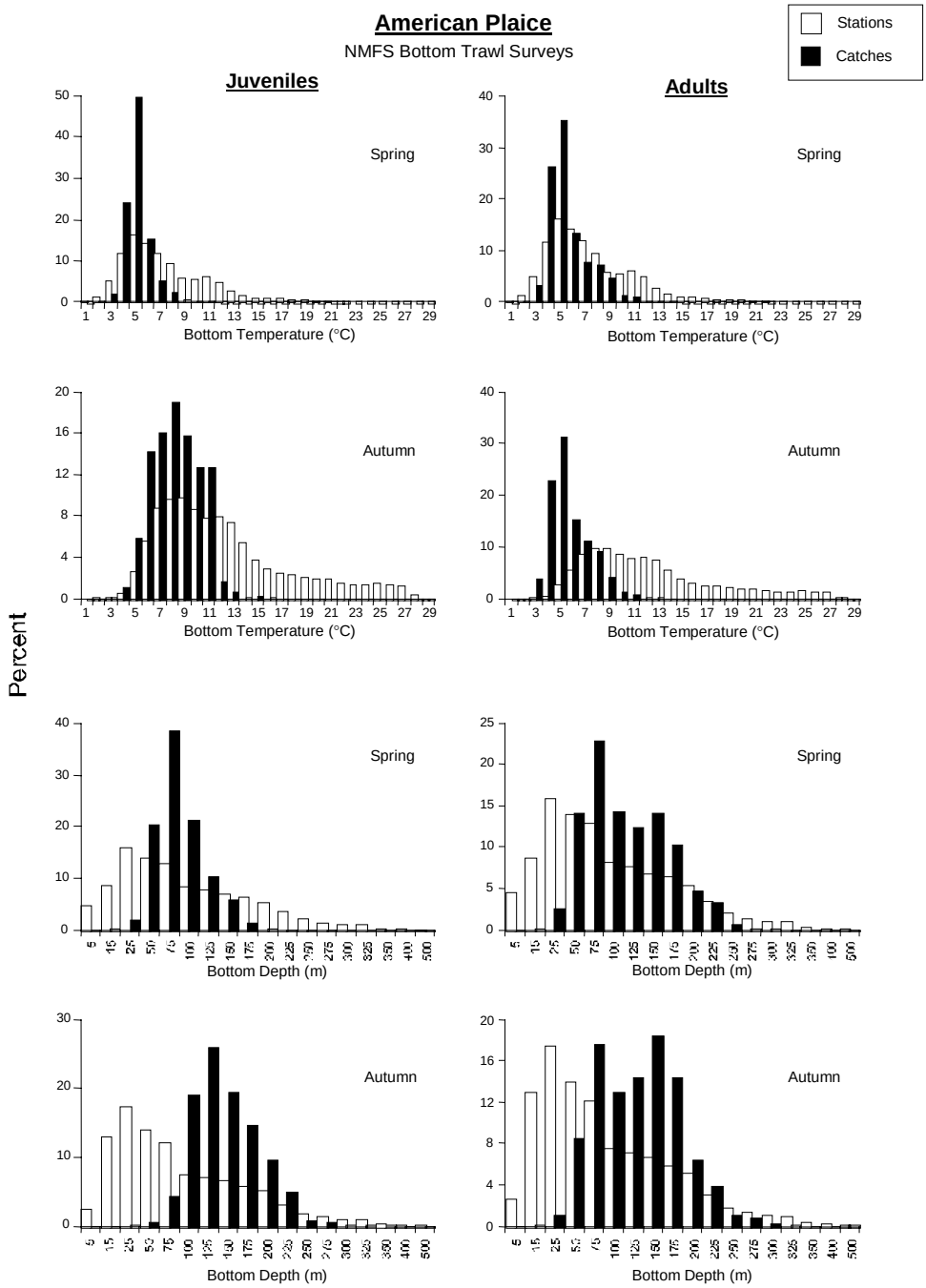


Figure 6. Distribution of juvenile and adult American plaice in relation to bottom temperature and depth based on spring (1968-1997) and autumn (1963-1996) NEFSC bottom trawl surveys. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

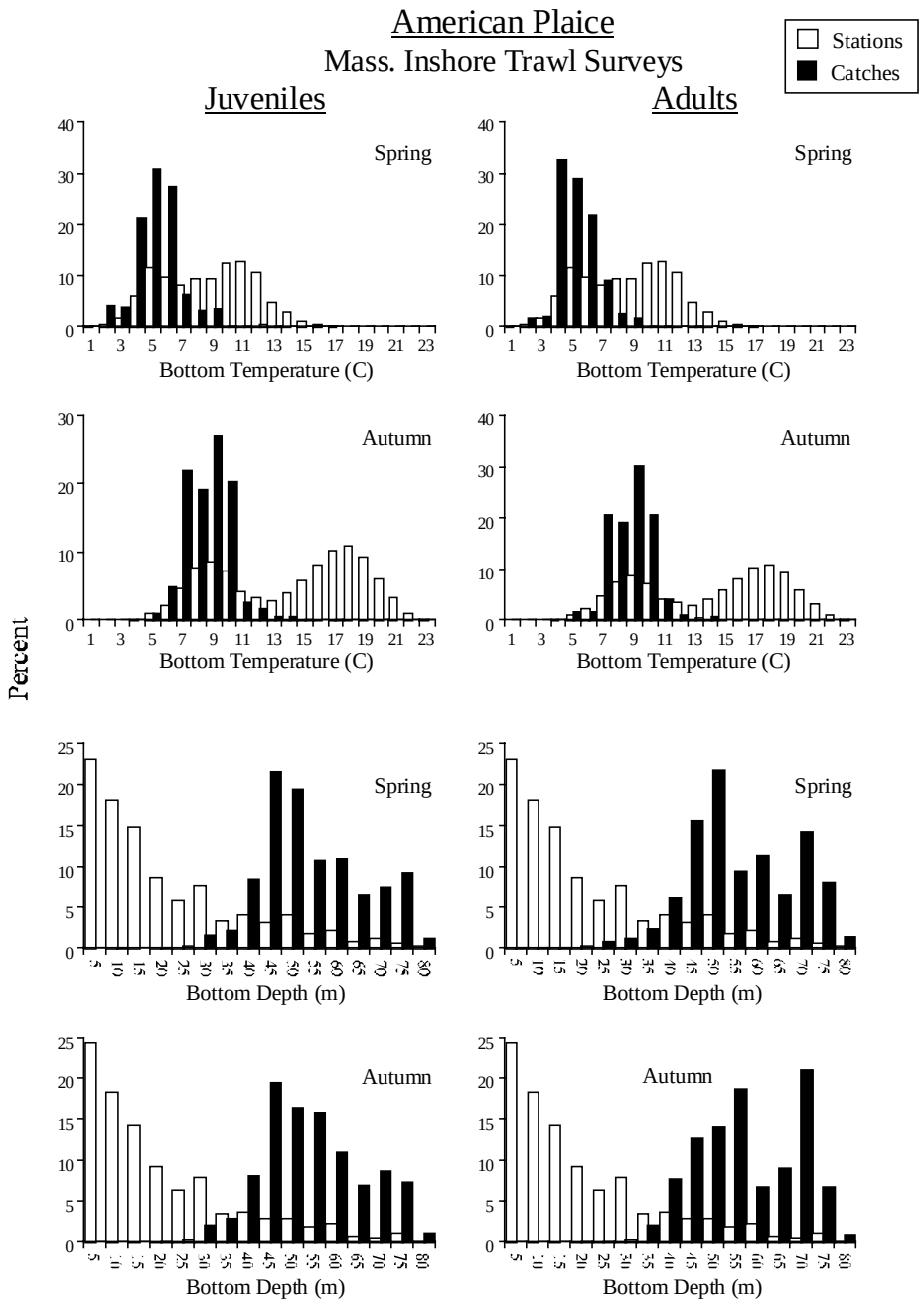


Figure 7. Distribution of juvenile and adult American plaice in relation to bottom temperature and depth based on spring and autumn Massachusetts inshore bottom trawl surveys, 1978-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

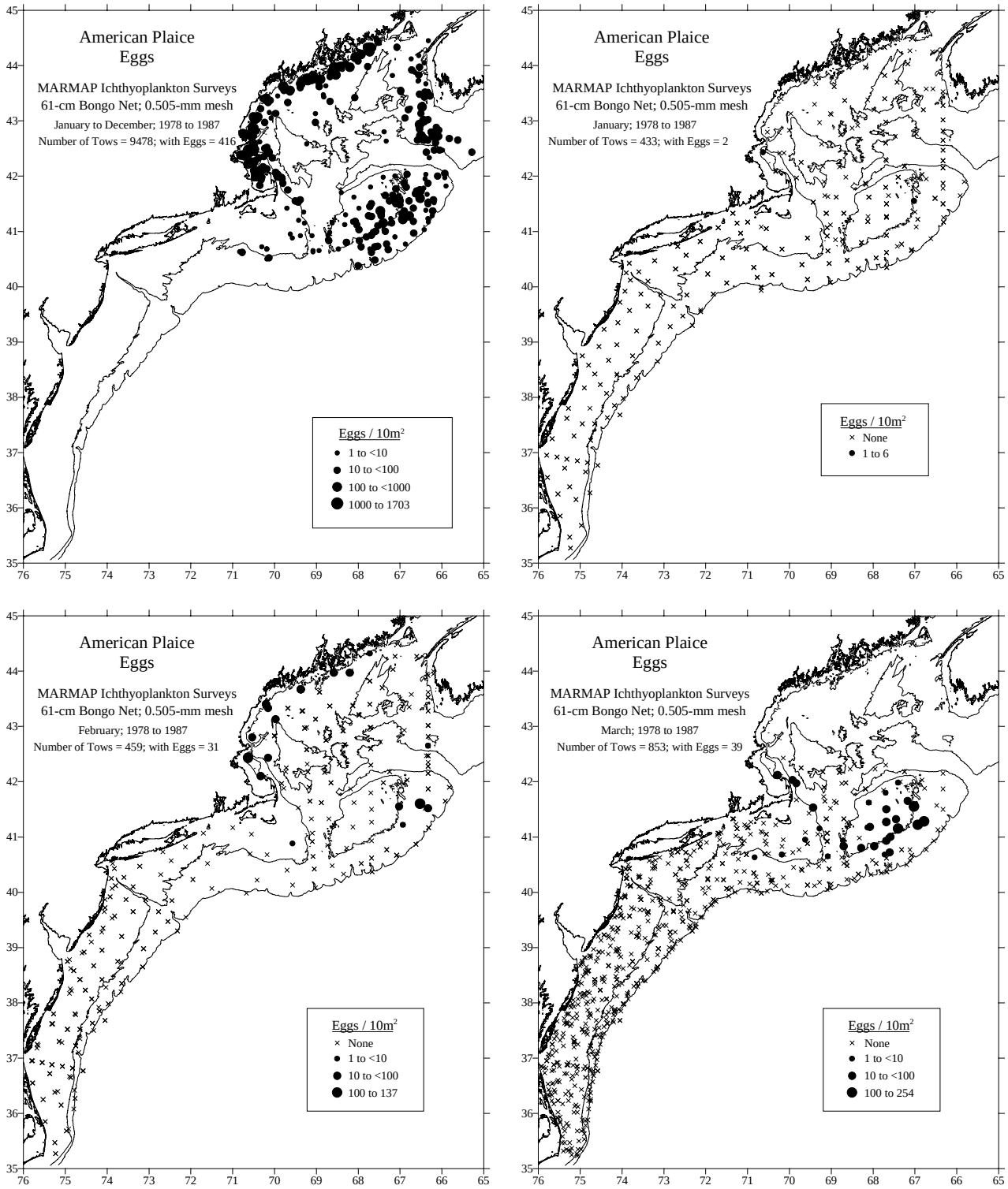
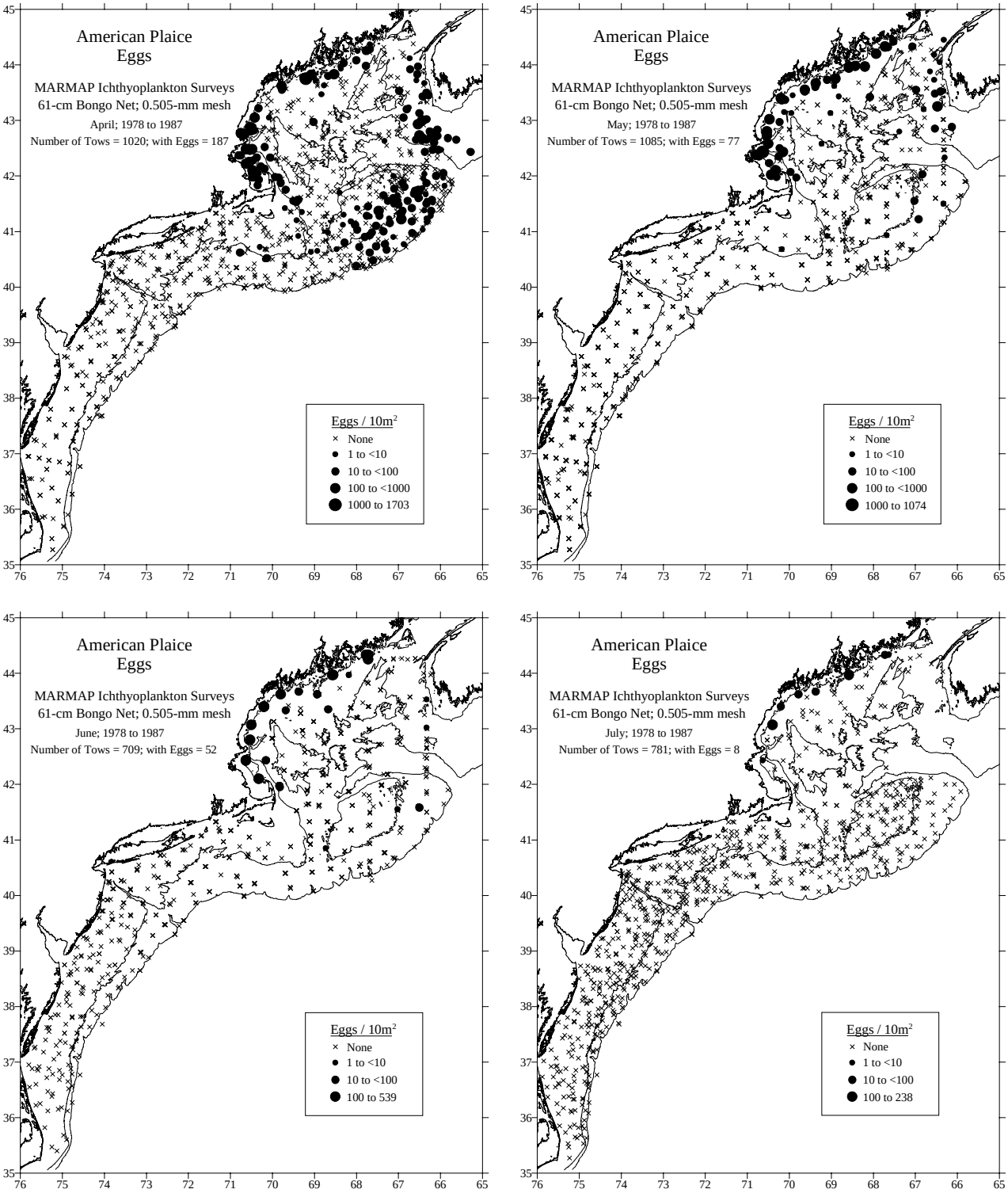


Figure 8. Distribution and abundance of American plaice eggs during MARMAP ichthyoplankton surveys, January to December, 1978-1987.



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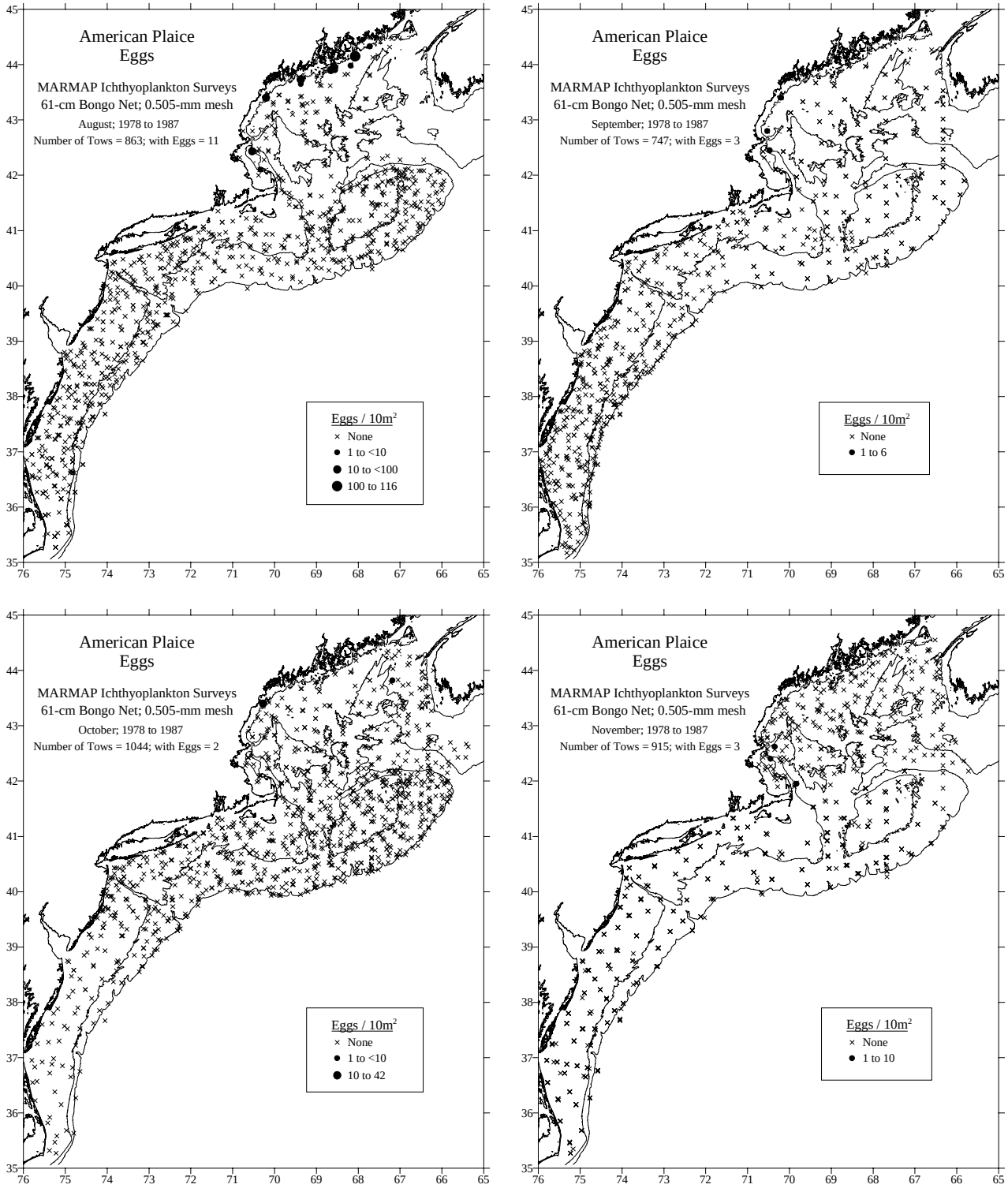

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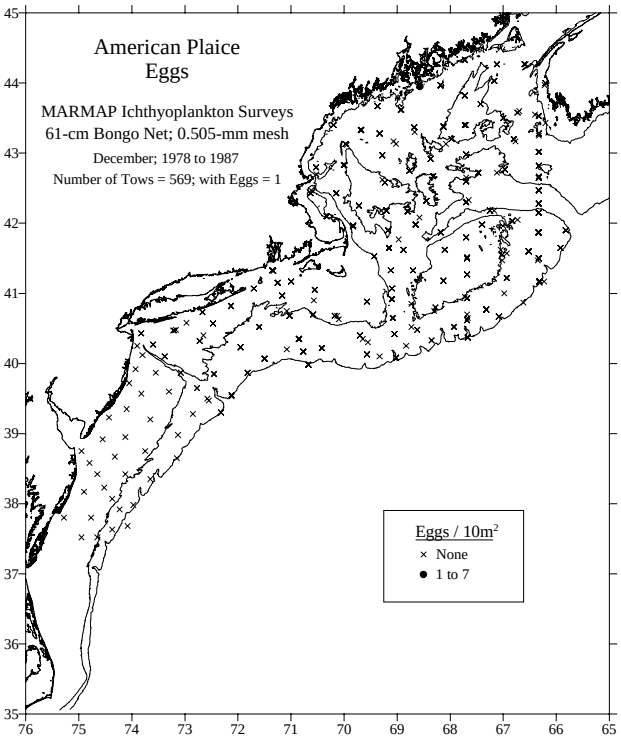

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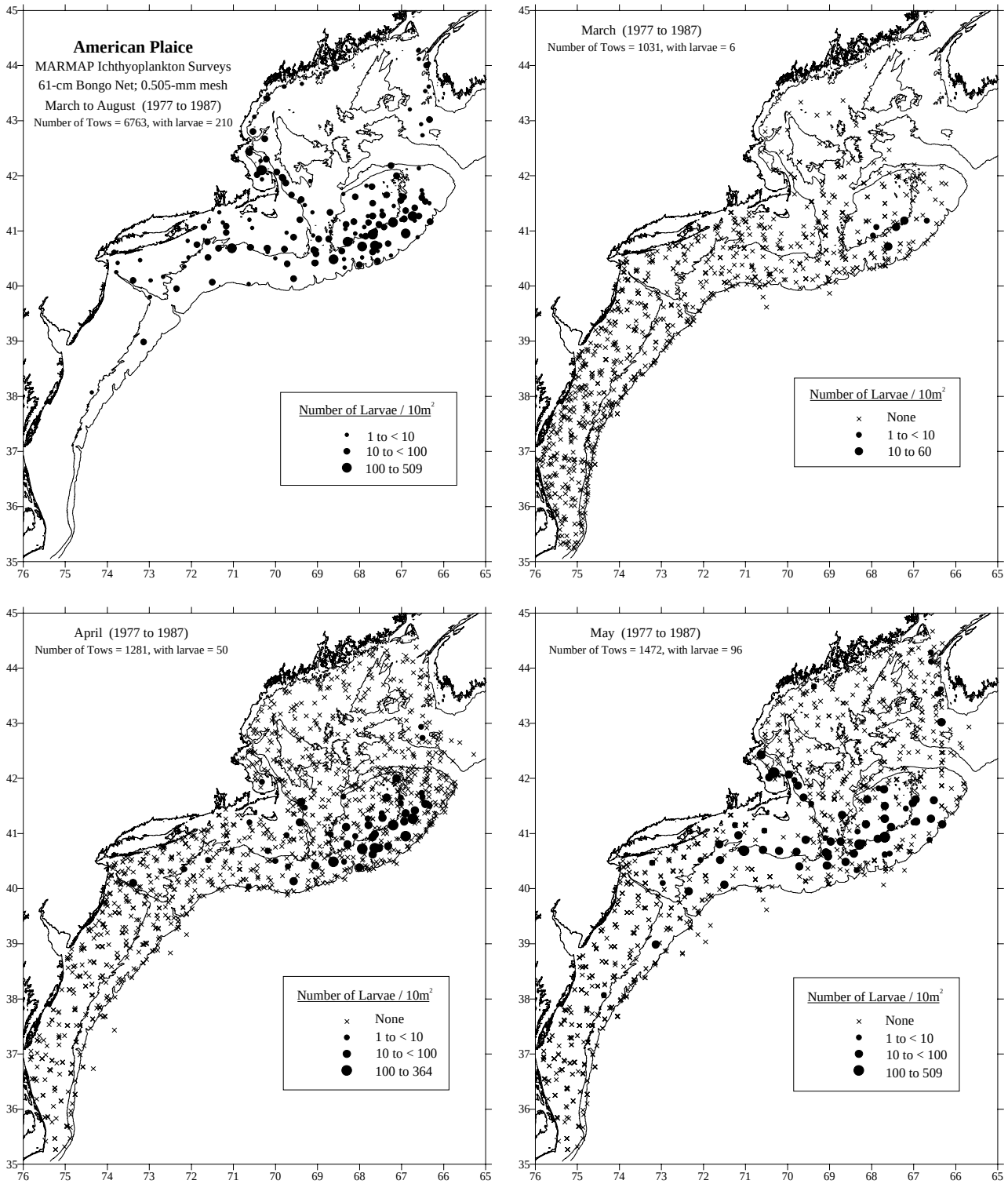
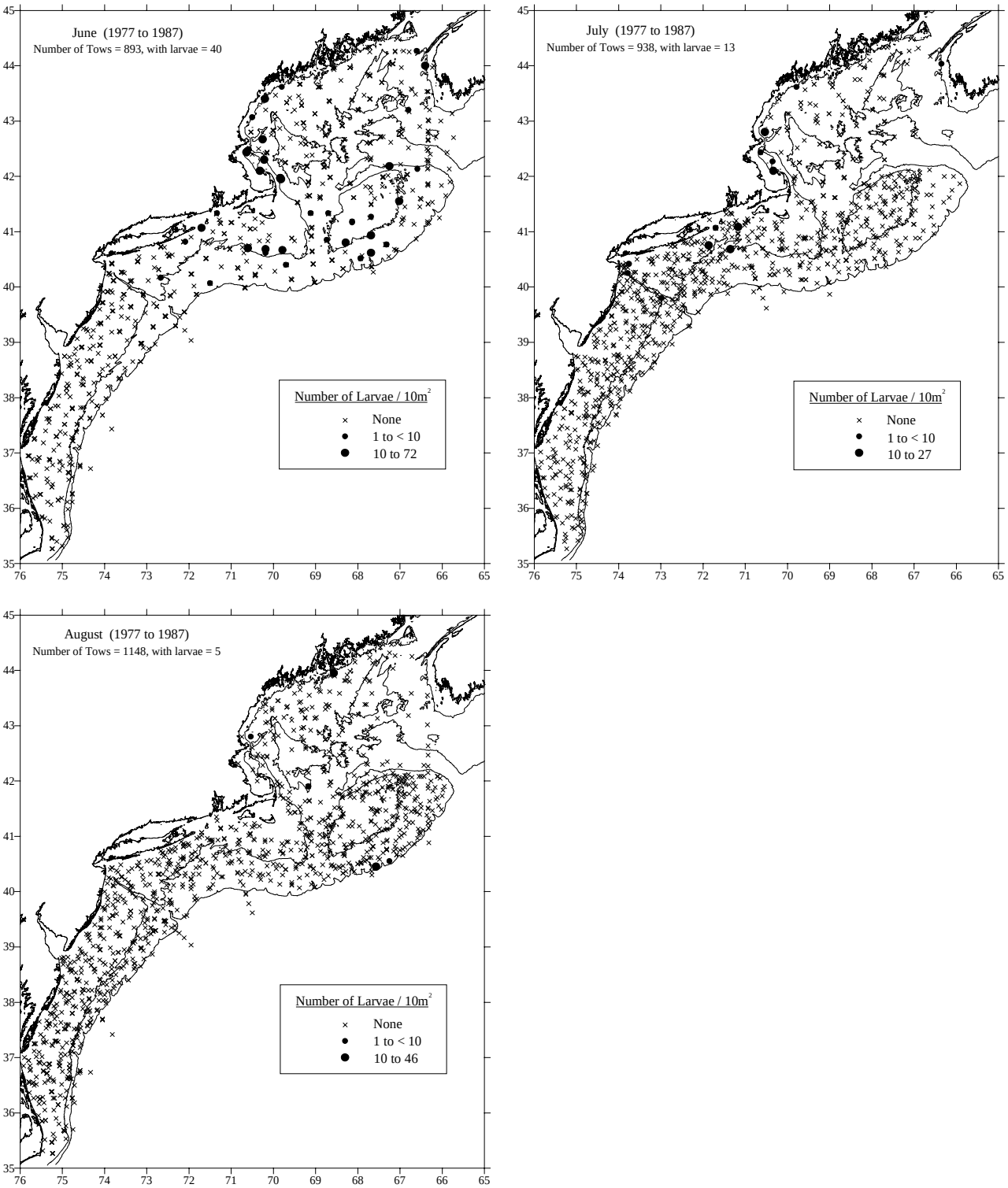


Figure 9. Distribution and abundance of American plaice larvae during MARMAP ichthyoplankton surveys, March to August, 1977-1987.



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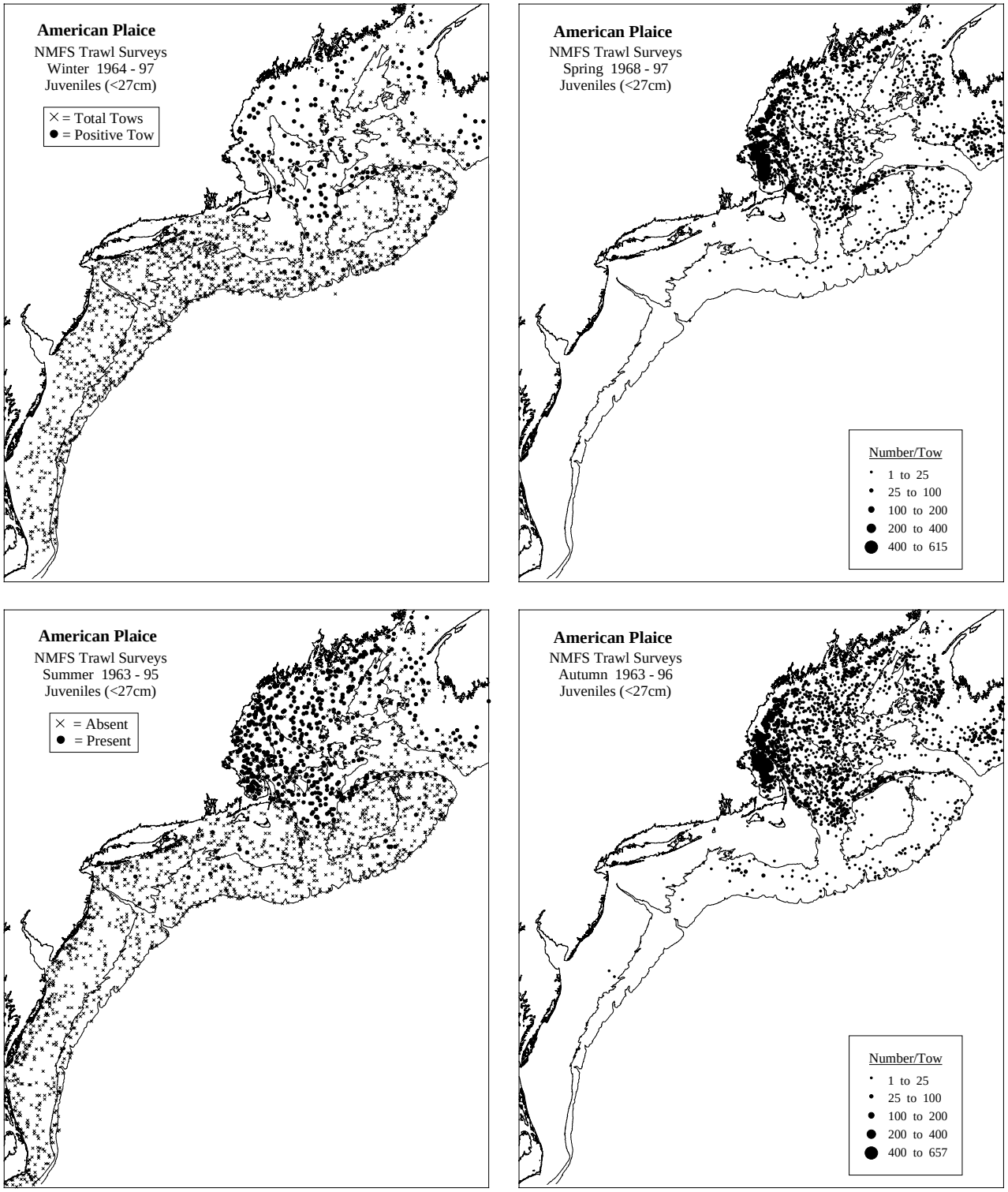

Figure 10. Distribution and abundance of juvenile and adult American plaice from winter (1964-1997), spring (1968-1997), summer (1963-1995), and autumn (1963-1996) NEFSC bottom trawl surveys. Densities are represented by dot size in spring and autumn plots, while only presence and absence are represented in winter and summer plots [see Reid *et al*. (1999) for details].

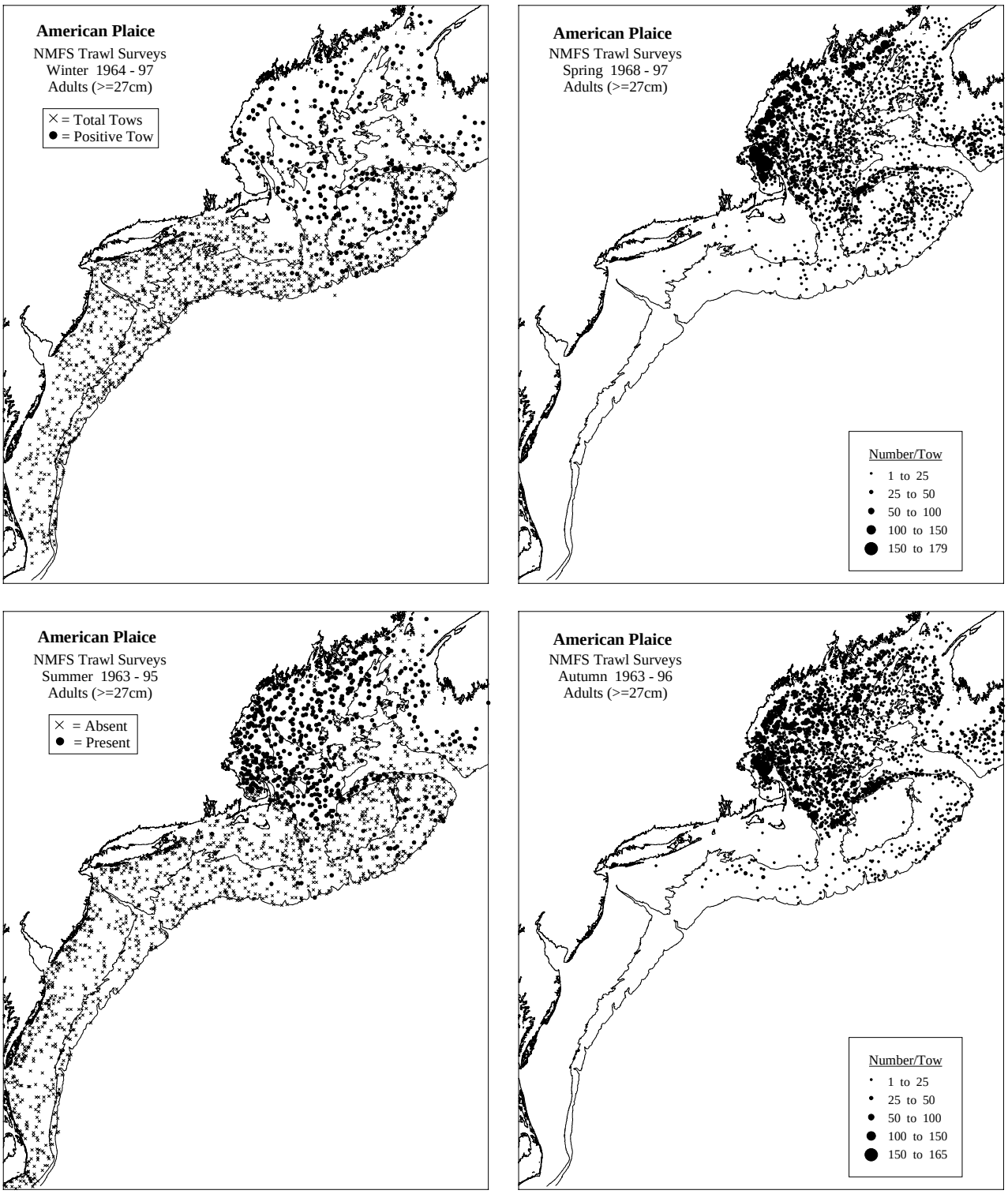

Figure 10. cont'd.

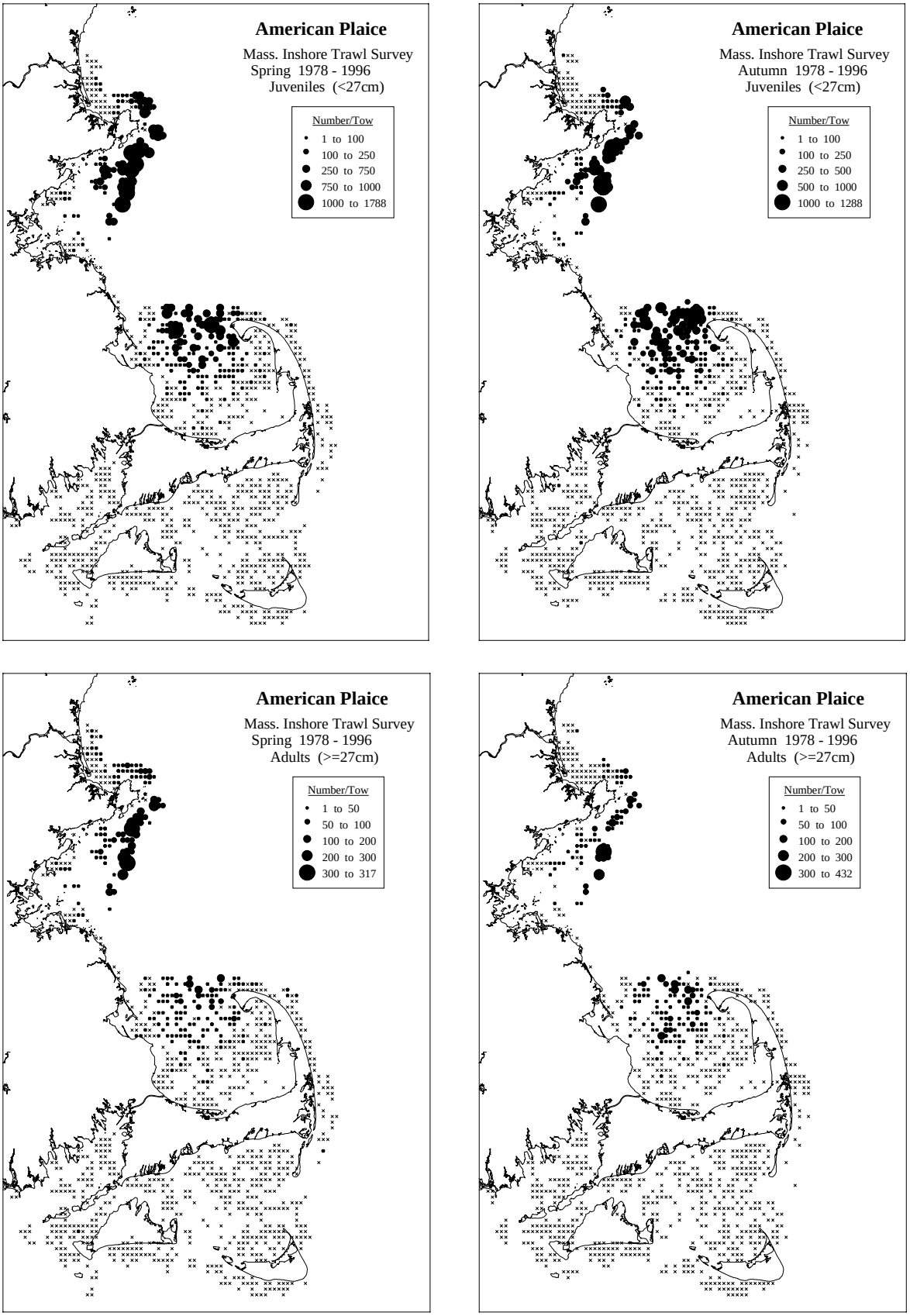

Figure 11. Distribution and abundance of juvenile and adult American plaice from the Massachusetts inshore bottom trawl surveys, 1978-1996.

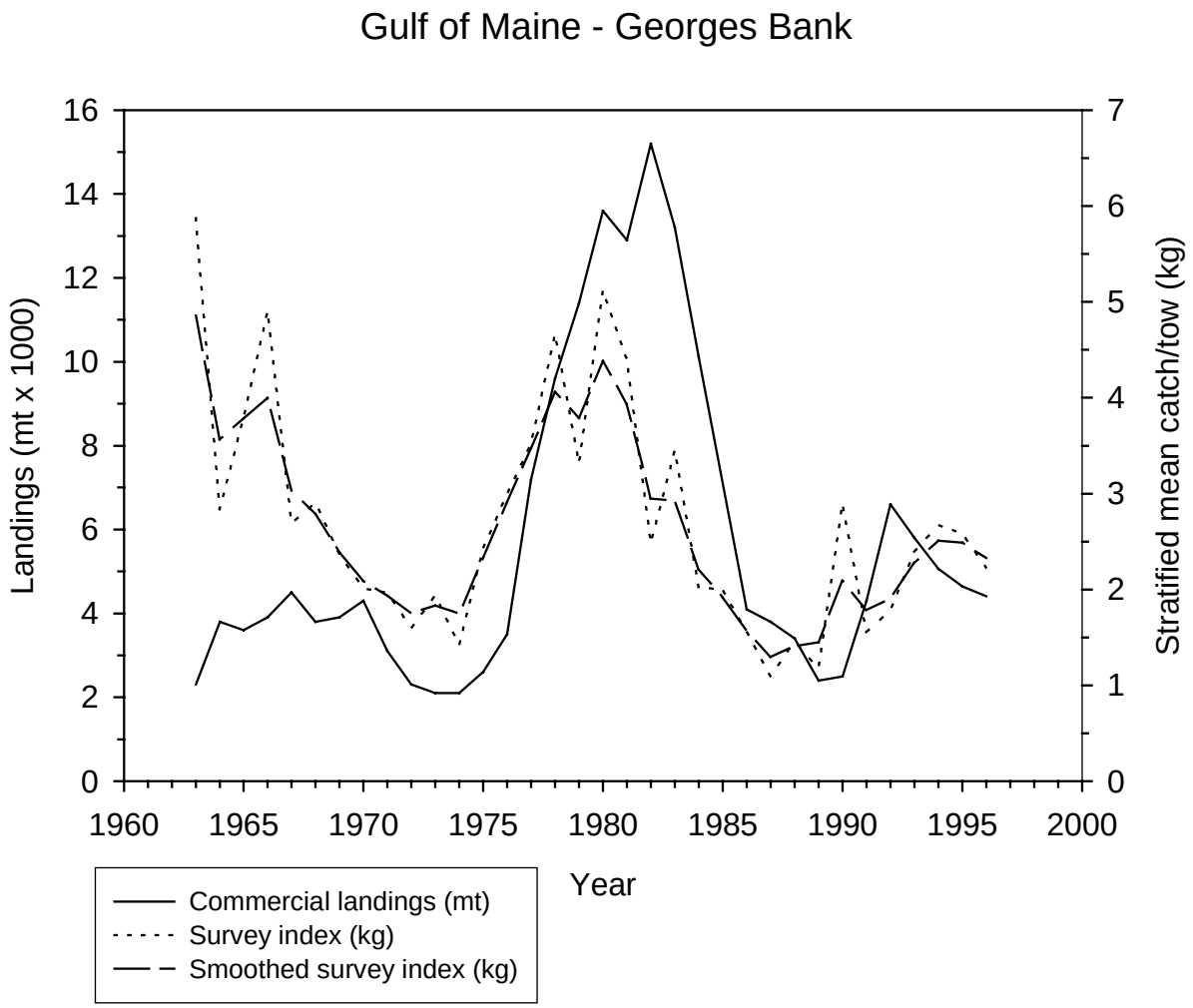

Figure 12. Commercial landings and survey indices for American plaice from the Gulf of Maine-Georges Bank region, 1963-1996.

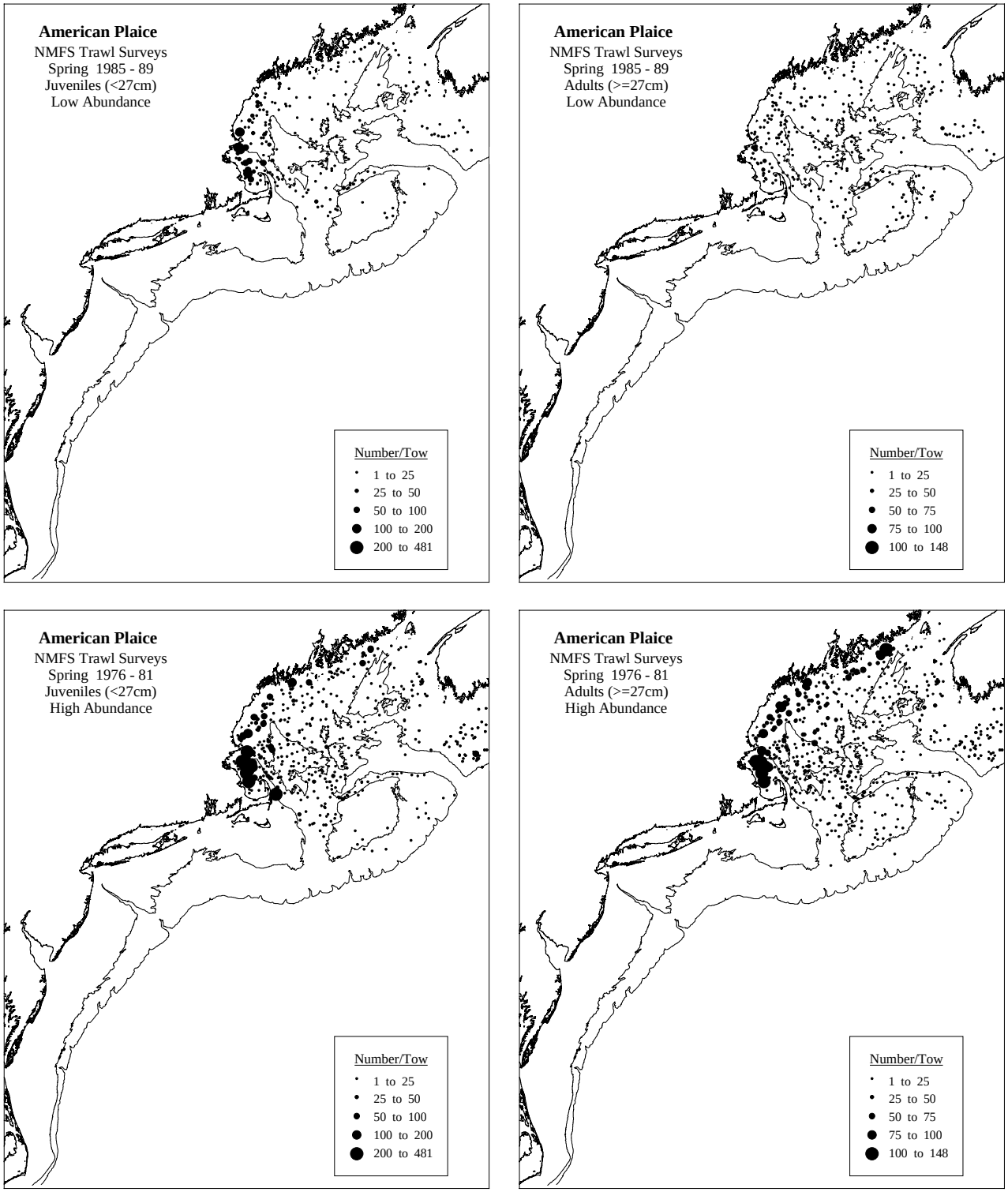

Figure 13. Distribution and abundance of juvenile and adult American plaice during a period of low abundance (1985-1989) and a period of high abundance (1976-1981), from spring NEFSC bottom trawl surveys.

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STANDARD MAIL A

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific ournals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

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Fishermen's Report **and** ***The Shark Tagger*** -- The ***Fishermen's Report*** (FR) is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of the FR; copies are available through free subscription. ***The Shark Tagger*** (TST) is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of the TST; copies are available only to participants in the tagging program.

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NOAA Technical Memorandum NMFS-NE-124

Essential Fish Habitat Source Document:

Atlantic Cod, *Gadus morhua*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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NOAA Technical Memorandum NMFS-NE-124

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Essential Fish Habitat Source Document:

Atlantic Cod, *Gadus morhua*, Life History and Habitat Characteristics

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September 1999

Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

---

[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, CHIEF
ECOSYSTEMS PROCESSES DIVISION
NORTHEAST FISHERIES SCIENCE CENTER

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INTRODUCTION

The Atlantic cod (Figure 1) is distributed in the northwest Atlantic Ocean from Greenland to Cape Hatteras, North Carolina. Within the overall distribution, densities are highest off Newfoundland, in the Gulf of St. Lawrence and on the Scotian Shelf, while in U.S. waters, densities are highest on Georges Bank and the western Gulf of Maine. Atlantic cod are managed as two stocks in American waters: (1) Gulf of Maine and (2) Georges Bank and southward (Mayo 1995). Little interchange occurs between the two. It occurs from nearshore areas to depths exceeding 400 m (rarely). The greatest concentrations off the northeast coast of the U.S. are on rough bottoms in waters between 10 and 150 m and at temperatures between 0 and 10°C.

A regular pattern of migrations, associated with reproduction and seasonal temperature change, has been observed in the Newfoundland stock (Rose 1993). Here, huge schools of cod leave wintering areas in deep oceanic waters and follow tongues of deep, relatively warm, oceanic waters ("highways") across the shelf to summer feeding areas nearshore. They then move northward along the Newfoundland coast in late summer, and eventually return to wintering areas. Spawning occurs in dense concentrations (> 1 fish/m^3) as they begin this mass movement, with multiple pairs of spawning fish observed in "columns" above the mass. As this huge mass of fish migrates inshore, it periodically encounters important prey aggregations (e.g., capelin and shrimp) and disperses. The mass is led by the largest size class (or "scouts") and the smallest fish are found at the rear. The author postulates that the youngest learn the route from the oldest, and that loss of the largest fish (through fishery pressure directed at them) could result in changes in this migration pattern. Similar changes have been observed in Norwegian herring stocks, but observations of such migrations are lacking in the two U.S. stocks. Off New England, Atlantic cod typically move into coastal waters during the fall and then retreat into deeper waters during spring. Another seasonal movement occurs in the Great South Channel area where they move southwesterly during autumn, spend the winter in southern New England and the Mid-Atlantic coast, and then return in the spring.

Atlantic cod attain ages of 20 years, although most enter fisheries at ages 2-5. They can grow to lengths of 130 cm and weights of 25-35 kg and average 26 cm by the end of their first year. Median age at sexual maturity is 1.7-2.3 years at lengths between 32 and 41 cm (O'Brien *et al.* 1993). Fecundity is high and a large female may produce between 3 and 9 million eggs. Spawning occurs near bottom during winter and early spring, usually in water temperatures between 5 and 7°C. Eggs are pelagic and drift for 2-3 weeks before hatching. The larvae are also pelagic until they reach 4-6 cm in about 3 months, whence they descend to the bottom. Further details of the life history of Atlantic cod are summarized in the Final EIS for Amendment 5 (NEFMC 1993) for the multispecies complex, and certain data are updated in Amendment 7, Vol. 1 of the Multispecies FMP (NEFMC 1996). Generalizations contained in those summaries suffice to describe most biological and life history traits of cod occurring off the northeastern coast of the U.S. The present document examines dietary requirements and expands somewhat on spawning patterns, distributions and habitat characteristics of four life history stages (eggs, larvae, juveniles, adults).

LIFE HISTORY

EGGS

Atlantic cod eggs are pelagic, buoyant, spherical and transparent. Their diameter ranges from 1.2-1.7 mm. The chorion is smooth (unsculptured) and the yolk is homogeneous. There are no oil globules and the perivitelline space is narrow (Fahay 1983; Markle and Frost 1985). Hatching occurs after 8 to 60 days in varying temperatures (Hardy 1978) and averages 2-3 weeks in average spring conditions (Lough *et al.* 1989). Temperature, more than season, also exerts the most influence on egg and hatchling sizes (Miller *et al.* 1995).

LARVAE AND PELAGIC-JUVENILES

Larvae hatch at sizes between 3.3 and 5.7 mm, with pigmented eyes, but unformed mouth parts. The body is long and tapering and the vent opens laterally on the finfold, rather than at its margin. The preanus length is < 50% of the total length. Characteristic pigment includes pairs of bars on the dorsal and ventral edges of the body and individual melanophores under the notochord tip. Pollock (*Pollachius virens*) larvae are similar, but have five primary caudal rays on the superior hypural; Atlantic cod larvae have four (Fahay 1983). Some studies have found increased growth rates with warmer temperatures (e.g., Laurence 1978); others have correlated enhanced growth with concentrations of zooplankton prey (Suthers *et al.* 1989). Several studies have described developing larvae drifting in a clockwise pattern around Georges Bank with high concentrations over the southern flank between 50 and 100 m (e.g., Lough *et al.* 1989). Larvae occur from near-surface to depths of 75 m, and larvae move deeper with growth (Hardy 1978).

JUVENILES

Transformation to the juvenile stage occurs at sizes greater than 20 mm, when all fin rays are formed (Fahay 1983). Descent from the water column to bottom habitats occurs at sizes of 2.5-6 cm (Fahay 1983; Lough *et al.*

1989) or < 7 cm (Bailey 1975). Most remain on the bottom after this descent, and there is no evidence of a subsequent, diel, vertical migration (Bailey 1975). Coloration during this initial descent mimics the substrate, reducing predation (Lough *et al.* 1989). After descent to the bottom, juveniles are most dense in the following areas: off Cape Ann, MA, Massachusetts Bay, Vineyard Sound, Nantucket Shoals, and the Northeast Peak of Georges Bank (present report).

ADULTS

Adults are heavy-bodied and have a large head, blunt snout and a distinct barbel under the lower jaw tip. Color varies, but usually includes many small spots and a pale lateral line. Color can change depending on bottom habitats. There are three distinct dorsal fins and two distinct anal fins. Vertebrae number 50-59 and fin ray counts are: D_1: 13-16; D_2: 19-24; D_3: 18-21; A_1: 20-24; A_2: 17-22. Size averages 2.3-3.6 kg and the largest recorded was 95.9 kg (Scott and Scott 1988). They tend to move in schools, usually on the bottom, although they may also occur in the water column.

REPRODUCTION

Both size and age at maturity have declined in recent decades, likely in response to the fishery harvesting older and larger fish, or to a general decline in stock biomass due to intense exploitation. In a Scotian Shelf study (Beacham 1983), the median age at maturity declined about 50% between 1959 (when age at 50% maturity was 5.4 years in males, 6.3 years in females) and 1979 (when age at 50% maturity was 2.8 years in both sexes). Median lengths at maturity declined from 51 to 39 cm in males, 54 to 42 cm in females. This "smaller and younger at maturity" trend continued between 1972 and 1995 in all zones between Georges Bank and Labrador (Trippel *et al.* 1997). Presently, in U.S. waters, sexual maturity is reached at ages between 1.7 and 2.3 years (median) and lengths between 32 and 41 cm (average) (O'Brien *et al.* 1993). Age and length at 50% maturity for Georges Bank and Gulf of Maine stocks are shown in Table 1. In preparing the distribution maps for this report, a size of 35 cm was used as the division between juveniles and adults, based on data in Table 1 and Morse (1979).

On Georges Bank, an analysis of the Marine Resources Monitoring, Assessment and Prediction (MARMAP) data set indicates that 60% of spawning occurs between February 23 and April 6, based on the abundance of Stage III eggs, back-calculated to spawning date. Ninety percent occurs between mid-November and mid-May, with a median date of mid-March (Page *et al.* 1998; Colton *et al.* 1979). Spawning begins along the southern flank of Georges Bank and progresses toward the north and west. It ends latest in the year on the eastern side of the bank. Egg distributions indicate that the most intense spawning activity occurs on the Northeast Peak of Georges Bank (Page *et al.* 1998). The results of the present compilation of egg distributions indicate that most spawning occurs not only on the Northeast Peak of Georges Bank, but also around the perimeter of the Gulf of Maine, and over the inner half of the continental shelf off southern New England. It occurs year-round, with a peak in winter and spring. Peak spawning is related to environmental conditions. It is delayed until spring when winters are severe and peaks in winter when they are mild (Smith *et al.* 1979; Smith *et al.* 1981). Spawning peaks in April on Browns Bank (Hurley and Campana 1989). Reproduction also occurs in nearshore areas, such as Beverly-Salem Harbor, MA, where eggs are found November through July (with a peak in April) at temperatures between -2 and 20°C (Elliott *et al.* 1979).

FOOD HABITS

The Atlantic cod has a varied diet. Reported food items vary by life history stage and study area (Table 2). During Northeast Fisheries Science Center (NEFSC) bottom trawl surveys, the most frequently observed food items were invertebrates, with fishes comprising only a minor component (Figure 2; Table 3). In another study, leading fish (also known as "scouts") at the head of migrating shoals were larger, were more successful in feeding on preferred prey (fishes and pelagic invertebrates), and had a more varied diet than those following, which tended to feed mostly on benthic invertebrates (Deblois and Rose 1996). Although cannibalism is not often reported to occur in this species, recent studies suggest the importance of habitat segregation of Age 1 cod from older year classes in order to avoid it (Gotceitas *et al.* 1995, in prep.).

PREDATION

Yolk sac larvae are vulnerable to zooplankton predators including *Aurelia*, *Thysanoessa* and *Euchaeta* (Bailey 1984). Adults, because of their large size, have few enemies other than large sharks. Young stages, however, are preyed upon by spiny dogfish, winter skate, silver hake, sea raven, squid (northern shortfin), Atlantic halibut, fourspot flounder and adult cod.

MIGRATIONS

In the middle part of their range, cod are non-migratory in the strictest sense, only undertaking minor seasonal movements in reaction to changing temperatures. At the extremes of their range, however, cod migrate

annually (see Introduction). In the extreme northern region (east coast of Labrador) cod are only present during summer and early fall. In the Middle Atlantic Bight as far south as Chesapeake Bay, cod only occur during winter and spring and retreat north and east to Nantucket Shoals as shallow waters in the southern part of the Bight exceed 20°C (Heyerdahl and Livingstone 1982).

STOCK STRUCTURE

Several stocks have been recognized in Canadian and U.S. waters. In U.S. waters three (or four) stocks occur: (1) in the Gulf of Maine, north of Provincetown; (2) on Georges Bank; (3) in southern New England, south and west of Nantucket Shoals; and (4) along the Middle Atlantic Bight, although the latter three intermingle. In U.S. waters, cod are managed as two stocks, the Gulf of Maine, and the Georges Bank and southward stocks (Mayo 1995).

HABITAT CHARACTERISTICS

The results of a literature review directed at habitat requirements of four life history stages of Atlantic cod are presented in Appendix 1 and a synthesis of those data are presented in Table 4. These tables include data from U.S. (and certain non-U.S.) western Atlantic stocks, but excludes data from the eastern Atlantic. Data from Canadian waters were included only if the results could reasonably be applied to U.S. stocks. Specifics of some Canadian studies (e.g., distribution relative to temperatures within a distinct region) were not included since they have little applicability to U.S. waters.

In general, young stages of Atlantic cod tend to have restricted distributions near major spawning centers. With increasing age, they tend to be more widely distributed and occur in deeper, colder and more saline water (Tremblay and Sinclair 1985).

EGGS

An analysis of nearly 50 years of trawl data in Canadian waters concluded that spawning rarely occurs beyond the continental shelf, but rather occurs near where eggs and larvae are likely to be retained (Hutchings *et al.* 1993). These authors concluded that inshore spawning populations contribute more to recruitment than those farther offshore. In MARMAP sampling between 1979 and 1987, eggs were collected from virtually all depths sampled, but primarily from depths < 100 m (Berrien and Sibunka 1999). Many reports describe eggs occurring in the upper 10 m of the water column, although spring rainfalls can lower the salinity and they will then sink to lower depths. Although eggs are collected in a wide range of temperatures and salinities, several studies have found optimum conditions for incubation, hatching and development, depending on study site (Table 4). The present compilation of collections indicates that most eggs are found in water column temperatures of 4-8°C (winter, spring, summer) or 7-14°C (fall). A lab study found that egg mortality was independent of temperature, but that mortality increased at lower salinities within the range 26-36 ppt (Laurence and Rogers 1976).

LARVAE AND PELAGIC-JUVENILES

Several studies have found increased recruitment success when dispersion of larvae from spawning areas by currents is reduced (Table 4; Cong *et al.* 1996). Although larvae have been collected from a wide range of temperatures, most are found in temperatures < 8°C, although growth rates may be enhanced in warmer temperatures (e.g., Lawrence 1978) and one study found no increased mortality when larvae were exposed to higher temperatures (Iversend and Danielssen 1984). Larvae can survive undercooling to -1.8^{o}C but if in direct contact with ice they froze at -1.36^{o}C (Valerio *et al.* 1992). When larvae are 3-8 days old, they are positively phototactic and are reported to occur from the surface to 75 m depths, moving deeper in the water column as they grow older (Hardy 1978).

JUVENILES

Juveniles may tolerate a wider range of temperatures than adults (Table 4; and Bigelow and Schroeder 1953). Several studies have stressed the importance of cobble substrates over finer grained bottoms after settlement (e.g., Bigelow and Schroeder 1953; Colton 1978), and some of these studies have related this preference to avoidance of predation by older year classes of cod (e.g., Gotceitas and Brown 1993 and others). Nearshore nurseries (including grass beds) may be significantly more important to survival of juveniles than offshore habitats (see Table 4).

ADULTS

Adult cod are typically found on or near bottom along rocky slopes and ledges. They prefer depths between 40 and 130 m, but are sometimes found in midwater. Cod rarely occur deeper than 200 m. Larger individuals remain closer to the bottom in deeper water, and many move to offshore banks during summer (Hardy 1978; Cohen *et al.* 1990). Several studies have ascertained a preference by adult cod for coarse sediments over finer mud and silt (Table 4; Scott 1982b). They engage in diel vertical migrations, where they make forays off the bottom

and into the water column at night (several studies; e.g., Beamish 1966). Cod can occur in temperatures from near freezing to 20°C, and are usually found in temperatures < 10°C, except during fall when they can occur in warmer temperatures. Larger fish are generally found in colder waters (Cohen *et al.* 1990).

GEOGRAPHICAL DISTRIBUTION

Atlantic cod in the northwest Atlantic are distributed from Cape Chidley, Labrador to Cape Henry, VA (Figure 3). The areas of highest abundance are in Canadian waters and include the eastern coast of Labrador south of Cape Harrison, off eastern Newfoundland, the Flemish Cap, the Grand Bank, the Gulf of St. Lawrence, and the Scotian Shelf.

The estuarine occurrences of early life history stages between Maine and the Chesapeake Bay are shown in Table 5. These are expressed as relative abundance characterizations, based on the observations of biologists working in each of the systems listed, but they are not quantitative measurements and should be considered as presence or absence value only. Despite these limitations, it is apparent that no early life history stages are commonly collected south of Buzzards Bay, and north of there they are uncommon in systems comprised mostly of low salinity zones.

EGGS

During MARMAP sampling between the Gulf of Maine and Cape Hatteras, 1978-1987, eggs were distributed throughout the study area, with centers of abundance in western Gulf of Maine, Georges Bank and southern New England waters (Berrien and Sibunka 1999). Although they occurred year-round, densities were much lower during August and September. Maximum average densities of eggs occurred during March on Georges Bank. A downward trend in abundance was observed between 1979 and 1987 in this study area (Berrien and Sibunka 1999). Monthly distribution maps presented here (Figure 4) pertain to the same MARMAP collections. In general, eggs were most dense on the Northeast Peak of Georges Bank and around the perimeter of the Gulf of Maine, as well as lower densities in southern New England waters (Figure 4). Monthly densities reached a peak in March-April, declined through the summer, and began to increase again in the fall. Note the relative lack of sampling in the Gulf of Maine during March, when densities might be expected to be high.

Eggs usually occurred at temperatures between 4 and 8°C, although they also occurred at warmer temperatures, especially during the fall (Figure 5). Most eggs occurred over depths of 60-110 m, although they occurred in shallower waters during the winter (Figure 5).

There is no information on this life history stage from state surveys.

LARVAE AND PELAGIC-JUVENILES

Larvae also occurred in MARMAP samples year-round. They were most abundant in March-May over Georges Bank and southern New England (Figure 6), although sampling was light during March in the Gulf of Maine. Few larvae were collected between August and October. Most larvae were collected in temperatures between 4 and 10°C and over depths of 30-70 m (Figure 7).

There is no information on this life history stage from state surveys.

JUVENILES

The distribution of juveniles (< 35 cm) closely matches that of spawning activity, with centers of abundance on Georges Bank and the western part of the Gulf of Maine (Figure 8). [Also see the distribution of immature Atlantic cod, < 37 cm, resulting from NEFSC bottom trawl survey cruises, 1968-1986 in Wigley and Gabriel (1991)]. During spring trawl surveys, densities are highest in the area north and south of Cape Ann, Massachusetts. During summer (presence or absence data only) juveniles are mostly found along the western shore of Gulf of Maine, but also occur on the Northeast Peak of Georges Bank and on Browns Bank. Fall densities are highest in the areas of Massachusetts Bay, Nantucket Shoals and the Northeast Peak of Georges Bank. Winter distributions (presence or absence data only) are similar. During spring, juveniles are mostly found in temperatures of 4-7°C and depths of 25-75 m, while during fall, they occur mostly between 7 and 12°C, but in the same depths (Figure 9).

Juvenile cod (< 35 cm) occur in nearshore waters of Massachusetts during spring and fall (Figure 10). In the spring they are most dense around Cape Ann and the tip of Cape Cod, with scattered occurrences in Massachusetts Bay and Nantucket Sound. In the fall they occur densely around Cape Ann and throughout Cape Cod Bay, but are not found in Nantucket Sound. During spring surveys, their occurrences relative to temperature and depth closely match those sampled, but during fall surveys, they tend to occur at the coolest and deepest sampling stations (Figure 11).

In a trawl survey of Narragansett Bay undertaken by the Rhode Island Division of Fish and Wildlife, 1990-1996, very few juvenile cod were collected. They were collected in winter, spring and summer at stations with bottom temperatures between 5 and 22°C and depths of 10-110 ft. Too few were collected to draw conclusions regarding temperature or depth preferences.

See below for cod occurrences in Long Island Sound, and Hudson-Raritan Estuary/Sandy Hook Bay.

ADULTS

Spring densities of cod adults closely match those of the fall, with additional collections made throughout the central part of the Middle Atlantic Bight (Figure 8). Temperature and depth preferences are similar to those of juveniles except that the depth range of adults is greater than juveniles during the fall (Figure 9). During summer (presence or absence data only) adult cod are found throughout the Gulf of Maine and on Georges and Browns Banks (Figure 8). Fall densities are highest in the western part of Gulf of Maine, Nantucket Shoals and on the Northeast Peak of Georges Bank. Winter occurrences (presence or absence data only) are scattered over Georges Bank and southern New England with fewer occurrences in the western part of Gulf of Maine.

Adults occur more frequently in spring surveys than in fall surveys in nearshore Massachusetts. During the spring, they occur abundantly around Cape Ann, the tip of Cape Cod, and the western part of Cape Cod Bay (Figure 10). A few adults are found during fall surveys, and these are restricted to the Cape Ann and Cape Cod tip areas. Adults occur in the coolest stations sampled during spring and fall, occur at all depths sampled during spring, but only in the deepest stations sampled during fall (Figure 11).

Only one adult cod was collected in a survey of Narragansett Bay by the Rhode Island Division of Fish and Wildlife, 1990-1996. Cod do not regularly occur in Long Island Sound. In a survey of that body of water by the State of Connecticut, 1992-1997, only three (unmeasured) cod were collected, all near the eastern end of the sound, during the spring, at temperatures of 9-10°C. A NEFSC trawl survey of the Hudson-Raritan Estuary/Sandy Hook Bay, 1992-1997, only collected two cod, both during winter (D. McMillan, National Marine Fisheries Service, Highlands, NJ, personal communication).

STATUS OF THE STOCKS

Combined commercial landings of the Gulf of Maine and Georges Bank stocks of cod are presently at their lowest level in 25 years (Mayo 1995 and Figure 12). Annual landings from the Gulf of Maine stock averaged 5,500 tons from 1960-1975; 12,000 tons from 1976-1985. A record high 18,000 tons was landed in 1991, but landings have declined since (Murawski *et al.* 1997). The relatively strong 1987 year-class no longer dominates catches, and recent landings are mostly comprised of weaker year classes deriving from 1988-1991 (Mayo 1995). The most recent year-classes have been among the weakest recorded. The Gulf of Maine stock is markedly depressed and remains overexploited.

Annual U.S. landings from the Georges Bank stock increased from 10,800 tons in 1960 to 40,000 tons in 1980, then declined to 18,000 in 1986 and 9,800 in 1994. Canadian landings from the same stock peaked at 14,300 tons in 1990, but have declined sharply since. The stock is currently dominated by the 1990 year-class. Subsequent year-classes have been much weaker and older fish are almost non-existent in this stock. This stock is presently at very low abundances, compared to historical levels (Murawski *et al.* 1997).

Based on landings (Gulf of Maine stock) or combined landings and estimates of spawning stock biomass (Georges Bank stock), 1979-1982 was selected as a period of relatively high abundance for cod, and 1993-1996 as a period of low abundance. The distributions of juveniles and adults during spring bottom trawl surveys were then plotted (Figure 13). Juveniles were relatively less dense in all areas where they occurred during the low-abundance period and are absent from certain areas (e.g., Long Island, Nantucket Shoals, Browns Bank) where they occurred during high-abundance periods. Distributions of adults during the two periods were similar. During the low-abundance period, densities were obviously lower throughout their range, and they did not occur in certain regions sampled (e.g., Browns Bank, much of southern New England) where they occurred during high-abundance periods.

RESEARCH NEEDS

Our knowledge of habitat requirements of Atlantic cod is scant beyond the distribution and relative abundance levels (EFH tiers 1 and 2). Scientists have only recently begun to investigate the early settlement stage and its associated substrate preferences (Lough *et al.* 1989) and the importance of certain bottom habitat types to the survival of young-of-the-year (e.g., Tupper and Boutilier 1995). Associated with these studies are those equating bottom habitats with the avoidance of predation, including cannibalism (e.g., Gotceitas *et al.* 1995, in prep.) or the importance of habitat segregation between year classes (e.g., Fraser *et al.* 1996). These kinds of studies are essential to improving our understanding of the importance of habitat at tiers 3 and 4 (effects of habitat variables on growth and/or survival).

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Table 1. Age and length at 50% maturity for two stocks of Atlantic cod, *Gadus morhua*. Data are from Mayo (1995). Similar results were obtained in a Canadian study for zones near U.S. waters (Trippel *et al.* 1997).

	Georges Bank	**Georges Bank**	**Gulf of Maine**	**Gulf of Maine**
	Males	Females	Males	Females
Age at 50% Maturity	1.9 years	1.7 years	2.3 years	2.1 years
Length at 50% Maturity	41 cm	39 cm	36 cm	32 cm

Table 2. Food habits of Atlantic cod, *Gadus morhua*.

Source	Study Area and Food Habits
	LARVAE
Marak 1960	Georges Bank, Gulf of Maine: Larvae eat most abundant prey. 4-18 mm eat mostly larval copepods; 18+ mm eat mostly adult copepods.
Bainbridge and McKay 1968	Greenland: Larvae (3-10 mm) mostly eat nauplii and copepodites of the copepods *Calanus* and *Temora*. Also euphausiids.
McLaren and Avendano 1995	Scotian Shelf (Western Bank): Larvae predominant prey: 2 species of the copepod *Pseudocalanus*.
	JUVENILES AND ADULTS
Bowman 1975	Gulf of Maine: Primary item: herring. Also redfish, mackerel, cod, and red and rock crabs.
Hacunda 1981	Central Maine coast ; Crustaceans most important, especially amphipods, *Unciola, Leptocheirus*, and decapods *Crangon, Cancer*.
Langton 1982	Northwest Atlantic: Initially crustaceans, switch to fishes with growth. Overlaps with white hake (*Urophycis tenuis*) and, at smaller sizes, with haddock (*Melanogrammus aeglefinus*).
Bigelow and Schroeder 1953	Gulf of Maine: Mollusks most important. Also other invertebrates.
Langton and Bowman 1980	Gulf of Maine: Diet by weight (%): Pisces 69.5; Clupeidae 23.3; Crustacea 26.1; other decapods 14.1; Mollusca 0.7; Echinodermata 0.4.
Tyler 1972	Passamaquoddy Bay: Winter - *Meganyctiphones, Mysis, Pandalus*; summer - *Meganyctiphones, Clupea, Pandalus.*
Keats *et al.* 1987	Conception Bay, Newfoundland: < 12.5 cm ate mostly small zooplankton; > 12.5 cm ate mostly benthic organisms, in areas with thick macroalgal cover. Latter not used as food source, however.
Whitehead *et al.* 1986	Northeastern Atlantic: Diet variable: (fishes) herring, capelin, haddock, codling; (invertebrates) euphausiids, hyperiids, amphipods, polychaetes.
Kohler and Fitzgerald 1969	Gulf of St. Lawrence, offshore Nova Scotian Banks: Small cod ate mostly crustaceans, switch to fish diet as they grow. Species taken depends on relative abundance of prey. Herring most important in GOSL, sand lance on Nova Scotian Banks. Some seasonal variation within areas and by depth.
Casas and Paz 1994	Flemish Cap: Invertebrates (crustaceans and polychaetes) dominant in juvenile diets; adults consume mostly fish, mainly redfish (*Sebastes* sp.).
Casas et al 1991	Flemish Cap: Hyperiid amphipods main item in juvenile cod; as size increases, shift to fish as food item. Most important fish prey juvenile redfish (*Sebastes* sp.). Rate of cannibalism very low.
Keats and Steele 1992	Newfoundland (eastern): Juveniles (Age 0 and 1) feed mostly during daylight and most prey was planktonic.
Witman and Sebens 1992	Gulf of Maine: Cod fed heavily on tethered brittle stars in this experiment.
Robichaud *et al.* 1991	Cape Breton I., Nova Scotia: Cod fed on snow crabs (*Chionecetes* sp.) and toad crabs (*Hyas* spp.), with the latter selected somewhat more often.
Methven and Piatt 1989	Newfoundland: Capelin very important diet item. When abundance is high, occurrences in cod stomachs high; when abundance low, occurrences in cod stomachs low.
Lilly and Parsons 1991	Northeast Newfoundland: Northern shrimp (*Pandalus borealis*) identified as important food item of cod throughout shrimp's range.
Minet and Perodou 1978	SW Newfoundland and NE Gulf of St. Lawrence: Capelin and crustaceans most important components. In some areas, larger cod ate more herring, redfish and plaice.

Table 3. Minor diet items of Atlantic cod (*Gadus morhua*) based on NEFSC Food Habits Study during bottom trawl surveys. Listed below are items occurring at 1-5 percent frequency. See Figure 1 for items occurring more frequently.

1973-1980: Diet Item	**Percent Frequency**	**1981-1990: Diet Item**	**Percent Frequency**
Polychaeta	4.70	Euphausiidae	4.68
Unciola irrorata	4.70	Decapoda (shrimp)	3.92
Eualus pusiolus	4.50	Paguridae	3.77
Trematoda	4.35	Ophiuroidea	3.64
Pagurus acadianus	3.49	*Cancer* sp.	3.24
Gastropoda	3.24	Bivalvia	2.81
Decapoda (crab)	3.03	*Cancer irroratus*	2.54
Ophiopholis aculeata	2.98	Gastropoda	2.26
Pandalidae	2.88	*Merluccius bilinearis*	2.26
Pandalus montagui	2.53	Gammaridea	2.11
Ammodytes sp.	2.53	Crustacea	1.63
Caprellidae	2.43	Mollusca	1.63
Cancridae	2.43	*Cancer borealis*	1.61
Decapoda	2.38	Isopoda	1.61
Paguridae	2.33	*Crangon septemspinosa*	1.56
Cephalapoda	2.22	Rock	1.45
Lysianassidae	2.18	Aphroditidae	1.44
Cancer borealis	2.18	Pectinidae	1.15
Ophiuroidea	2.12		
Aphroditidae	2.07		
Pagurus sp.	2.07		
Sand	2.07		
Aeginna longicornis	1.97		
Holothuroidea	1.87		
Pontogeneia inermis	1.82		
Cirolanidae	1.82		
Hyas sp.	1.72		
Axius serratus	1.52		
Bivalvia	1.52		
Politolana polita	1.47		
Pectinidae	1.47		
Pandalus borealis	1.32		
Neomysis americana	1.32		
Calanoida	1.32		
Gastropoda operculum	1.32		
Copepoda	1.26		
Anonyx sarsi	1.16		
Crangonidae	1.11		
Mollusca	1.11		
Clupeidae	1.11		
Syrrhoe crenulata	1.01		
Euphausiidae	1.01		

Table 4. Summary of life history and habitat parameters for Atlantic cod, *Gadus morhua*. Based on data contained in Appendix 1, Table of Habitat Parameters.

Life History Stage	Spatial and Temporal Distribution	Temperature	Salinity	Depth/ Substrate/ Vegetation	Diel/ Light/ Vertical	Predator/ Prey
Eggs [1]	Pelagic. Bays, harbors, offshore banks. Begins fall, peaks winter and spring.	Most 2.0-8.5°C for incubation. 12.0°C upper limit. Mortality independent of temp.	Most 32-33 ppt. Eggs sink in spring freshets. Inverse relationship with mortality, 26-36 ppt.	Usually < 70 m	Near surface unless salinities low. Eggs in poor condition may sink.	--
Larvae [2]	Pelagic. Most over Georges Bank, perimeter of Gulf of Maine, southern New England, continental shelf. Densest in spring.	Most 4-8°C (winter-spring), 7-12°C (summer-fall).	Most 32-33 ppt.	NA	Youngest from surface to 75 m. Move deeper with age. Migrate vertically in reaction to light.	Growth strongly correlated with zooplankton volume. Yolk sac larvae vulnerable to zooplankton predators.
Juveniles [3]	Mostly in shoal waters, coastal or offshore banks, summer. Deeper water winter.	6-20°C. More tolerant of extremes than adults. Temp. preferences differ winter-summer.	30-35 ppt.	'Cobble' preferred over finer grains. Uses vegetation for predator avoidance. Survival may be enhanced in structurally complex habitats.	Some changes in vertical distribution, day/night (see Appendix 1).	Avoid predation by seeking refuge in structured habitats.
Adults [4]	Seasonal migrations except in Gulf of Maine. Most dense Massachusetts Bay, NE Georges Bank, Nantucket Shoals.	Generally < 10°C. Varies seasonally.	Wide range of oceanic salinities. Mortality < 2.3 ppt.	Rocky, pebbly, gravelly. Avoid finer sediments.	Usually on bottom during day, may move up into water column at night.	Varied diet. Predation by large sharks, spiny dogfish, and, as juveniles, older cod.

[1] Bonnet 1939, Bigelow and Schroeder 1953, Laurence and Rogers 1976, Hardy 1978
[2] Rau 1974, Hardy 1978, Bailey 1984, Suthers *et al.* 1989
[3] Bigelow and Schroeder 1953, Hardy 1978, MacDonald *et al.* 1984, Clark and Green 1990, Gotceitas and Brown 1993
[4] Bigelow and Schroeder 1953, Beamish 1966, Odense *et al.* 1966, Hardy 1978, Scott 1982b, Cohen *et al.* 1990

Table 5. Distribution of life history stages of Atlantic cod (*Gadus morhua*) in representative estuaries between Maine and Chesapeake Bay. Occurrences are not quantitative and may be based on a single, or very few, specimens. Estimates of relative abundance after Jury *et al*. (1994), Stone *et al.* (1994).

Estuary	Eggs	Larvae	Juveniles	Adults
Passamaquoddy Bay	None	Common	Common	Common
Englishman, Machias Bays	Common	Common	Abundant	Common
Narraguagus Bay	Common	Common	Abundant	Common
Blue Hill Bay	Common	Common	Abundant	Common
Penobscot Bay	None	Common	Common	Common
Muscongus Bay	Rare	Rare	Common	Common
Damariscotta Bay	Rare	Rare	Common	Common
Sheepscot River	Abundant	Abundant	Common	Abundant
Kennebec/Androscoggin Rivers	None	None	Common	Common
Casco Bay	Common	Common	Common	Common
Saco Bay	Common	Common	Common	Common
Wells Harbor	Rare	Rare	Rare	None
Great Bay	Common	Common	Rare	Rare
Merrimack River	Rare	Rare	Rare	Rare
Massachusetts Bay	Common	Common	Common	Common
Boston Harbor	Common	Common	Common	Common
Cape Cod Bay	Common	Common	Common	Common
Waquoit Bay	Rare	Rare	Rare	None
Buzzards Bay	Common	Common	Common	Common
Narragansett Bay	Rare	Rare	Rare	Rare
Long Island Sound	Rare	Rare	Rare	Rare
Connecticut River	None	None	None	None
Gardiners Bay	Rare	Rare	Rare	Rare
Great South Bay	None	None	None	None
Hudson River/Raritan Bay	None	Rare	None	None
Barnegat Bay to Chesapeake Bay	None	None	None	None

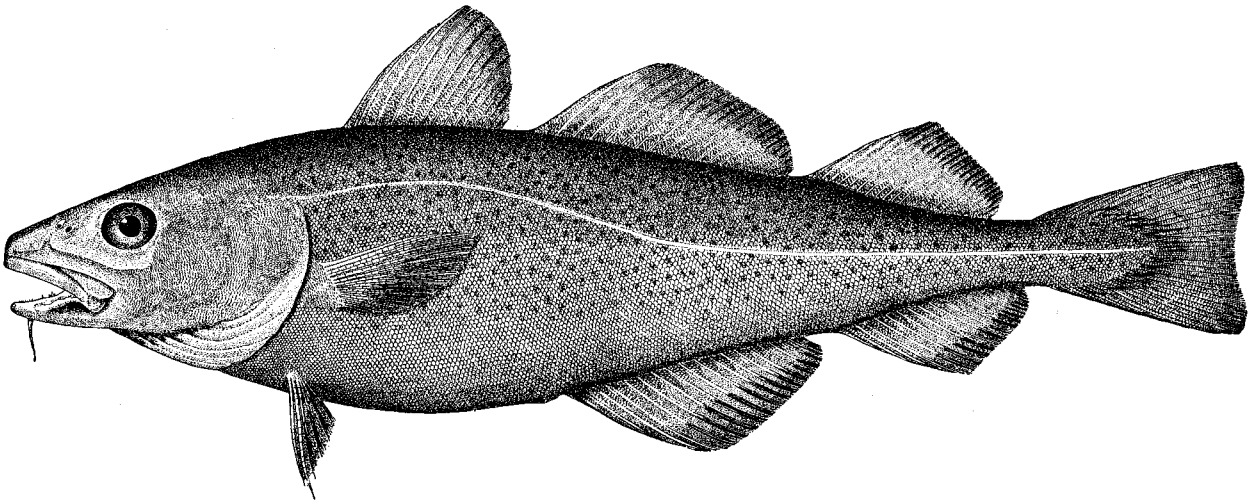


Figure 1. The Atlantic cod, *Gadus morhua* (from Goode 1884).

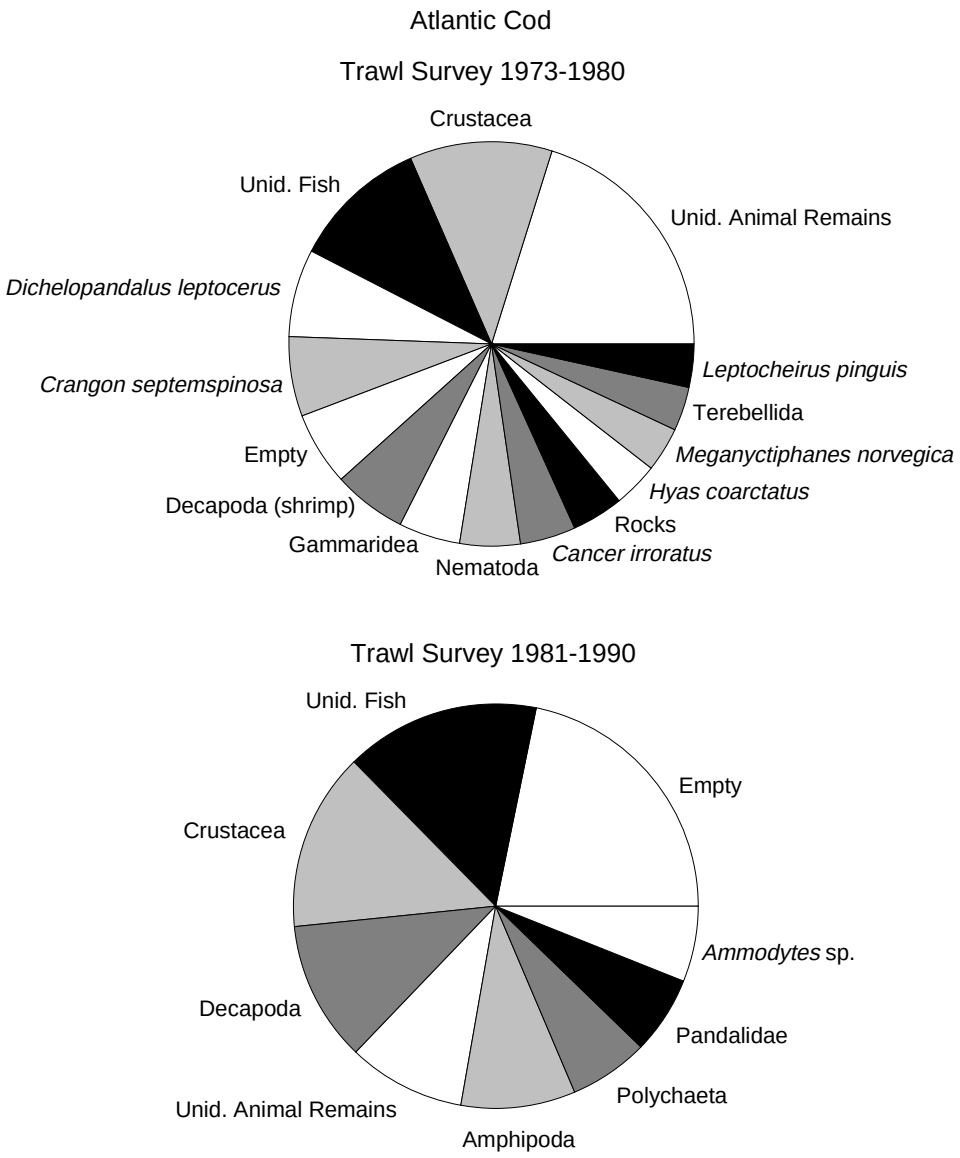


Figure 2. Abundance of the major prey items in the diet of Atlantic cod, based on NEFSC bottom trawl survey data on food habits collected during 1973-1980 and 1981-1990. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details]. All other diet items less than 5 percent frequency are listed in Table 3. The category "animal remains" refers to unidentifiable animal matter.

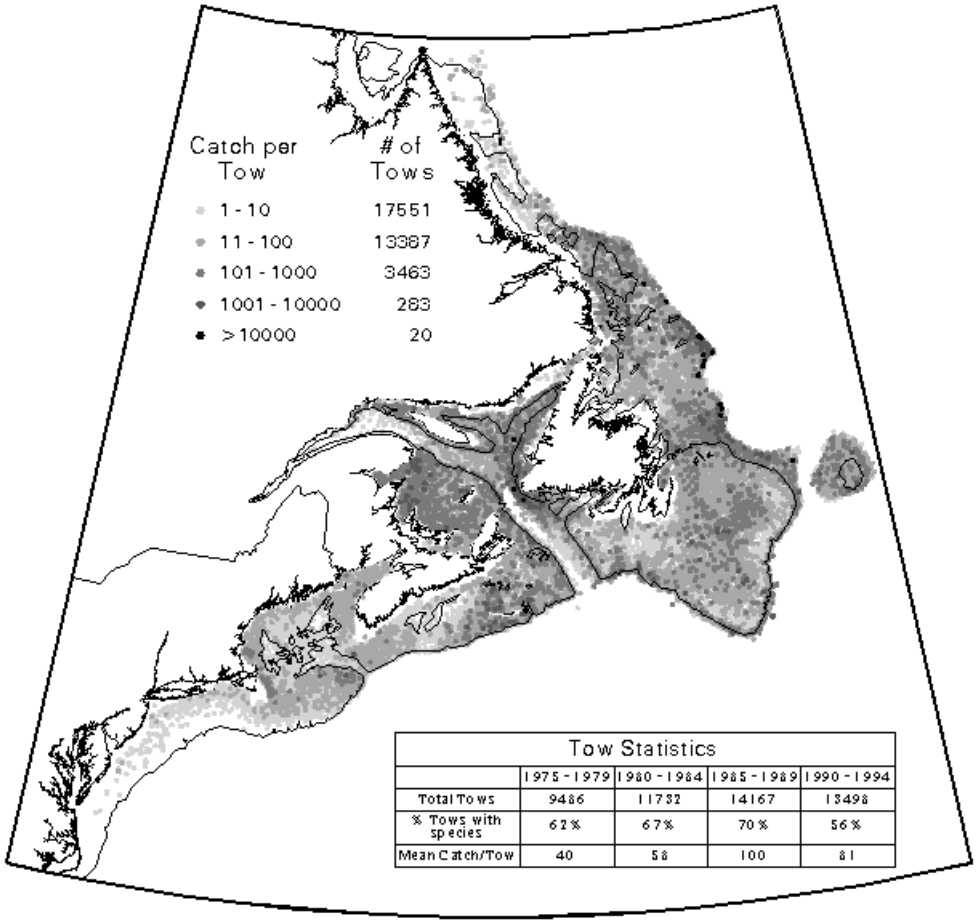


Figure 3. Distribution and abundance of Atlantic cod from Newfoundland to Cape Hatteras based on research trawl surveys conducted by Canada (DFO) and the United States (NMFS) from 1975-1994 (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

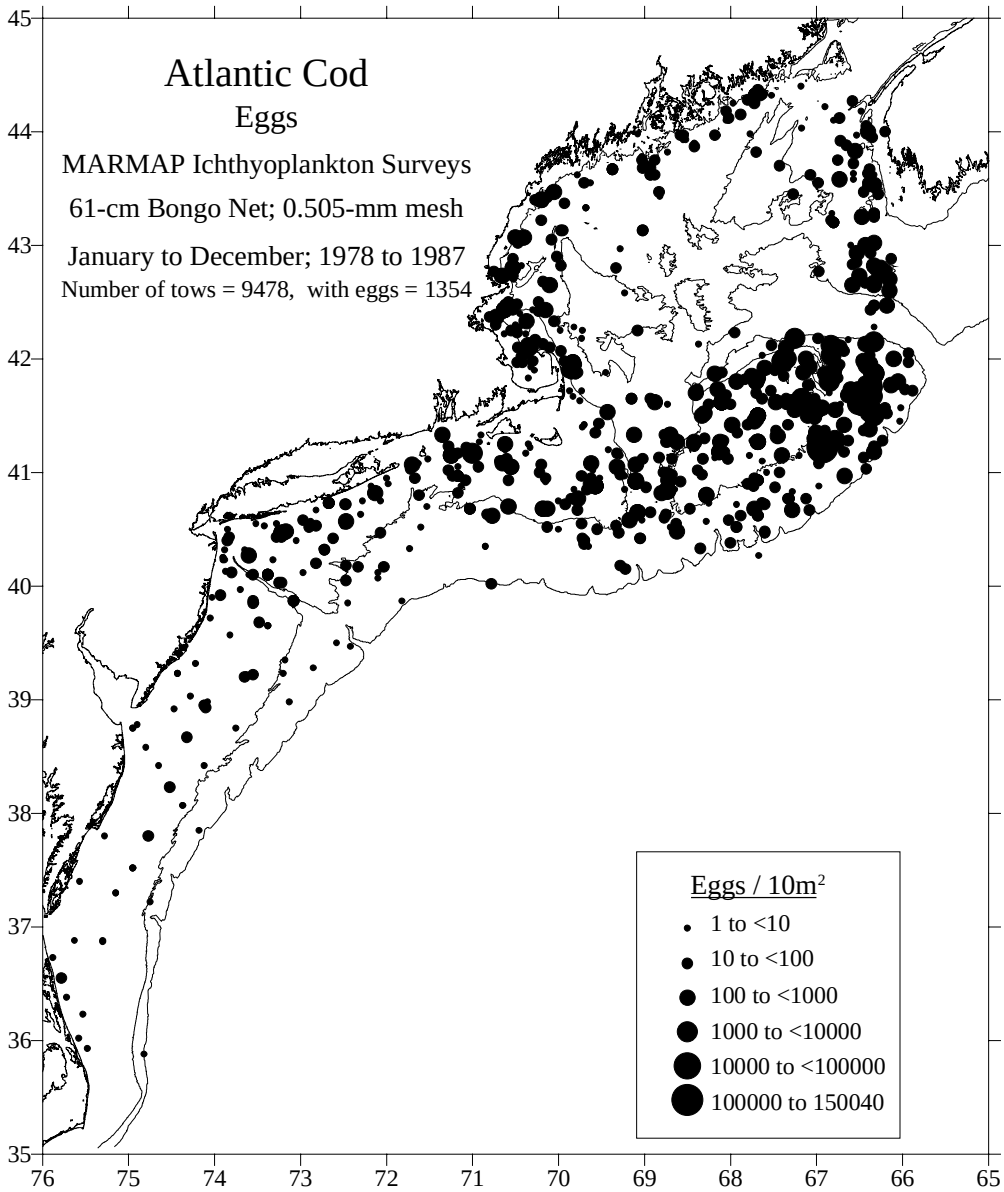
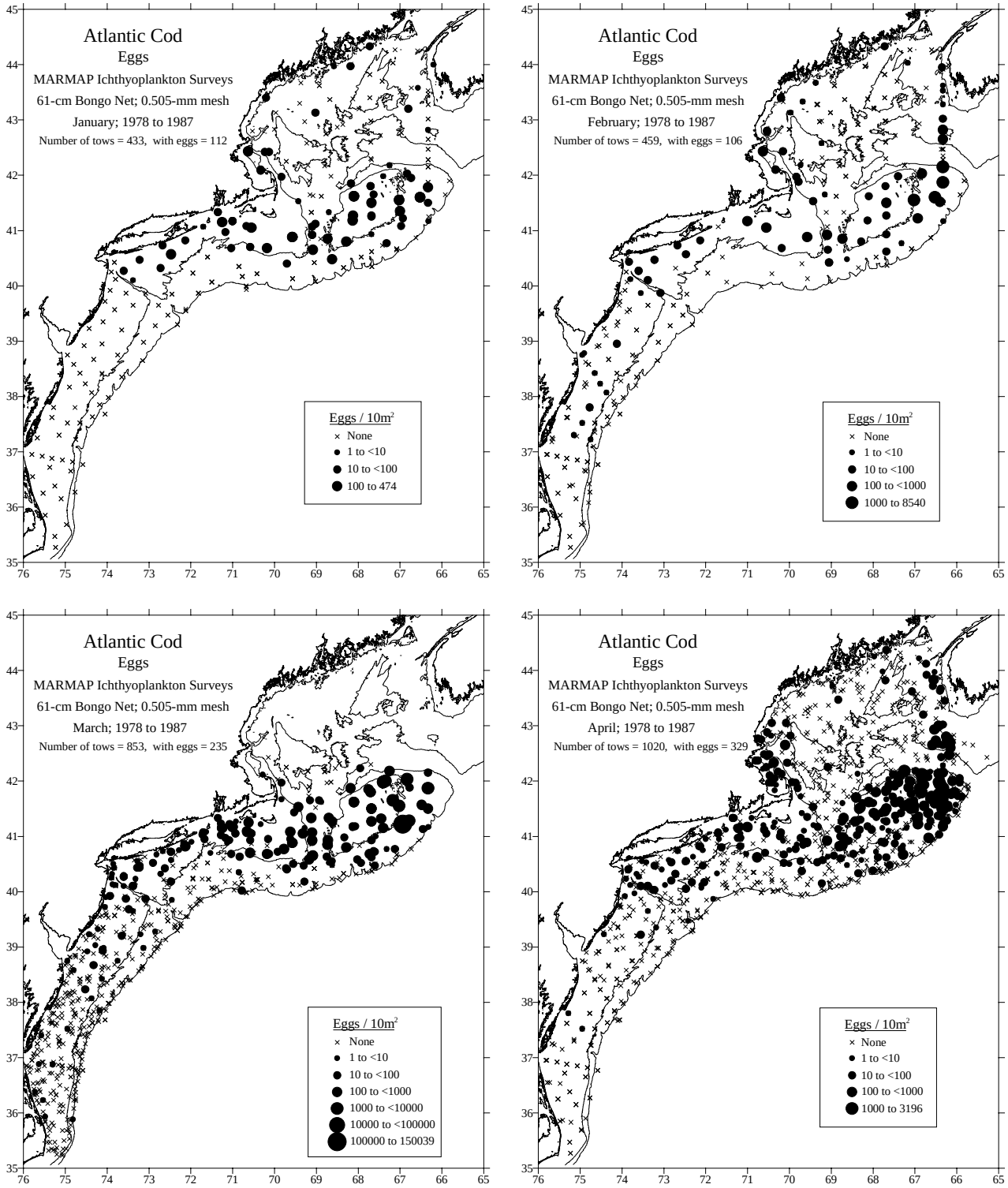


Figure 4. Distribution and abundance of Atlantic cod eggs collected during NEFSC MARMAP ichthyoplankton surveys, January to December, 1978-1987 [see Reid *et al.* (1999) for details]. Abundance is represented by dot size, and sampling effort is indicated by small x.



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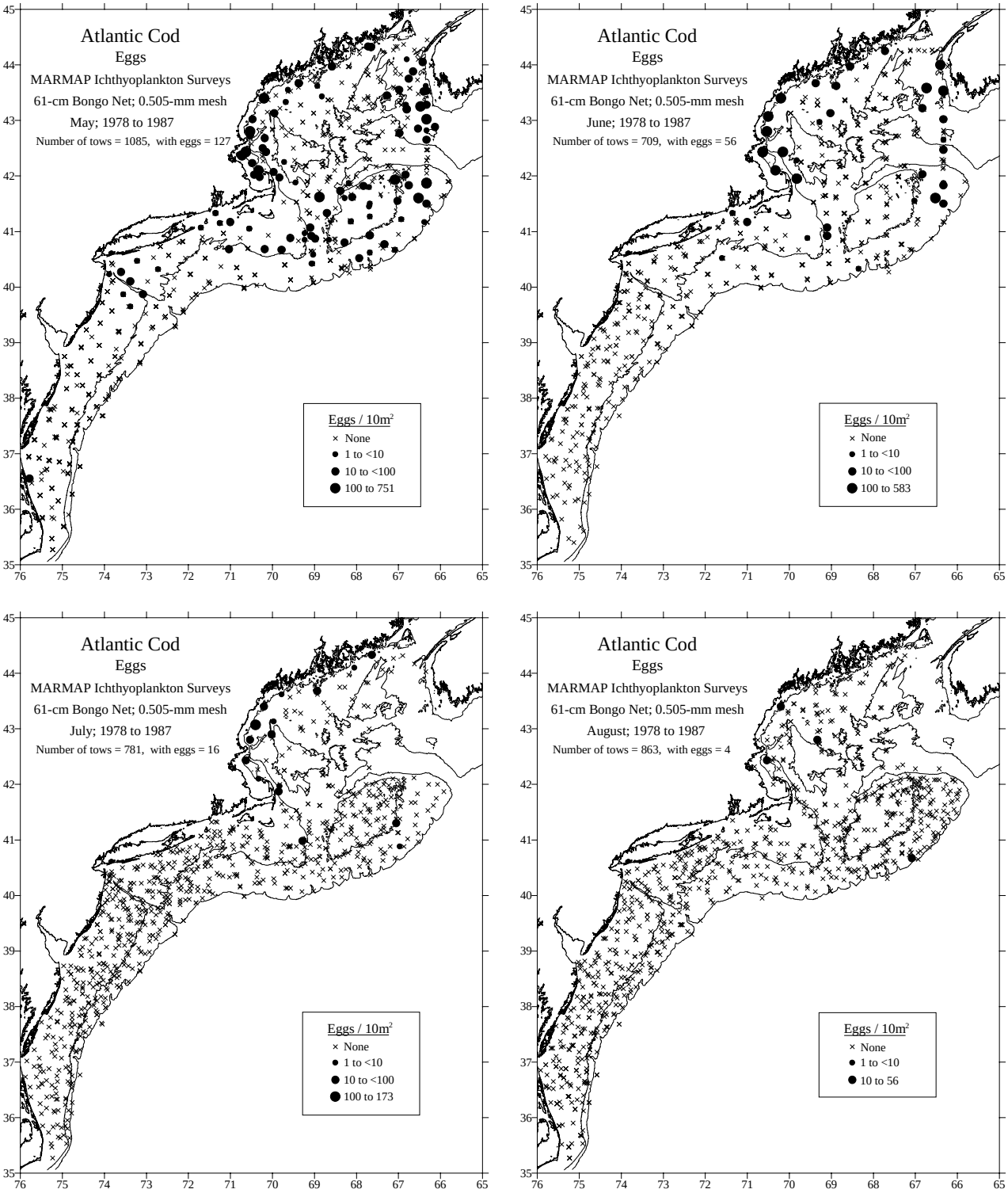

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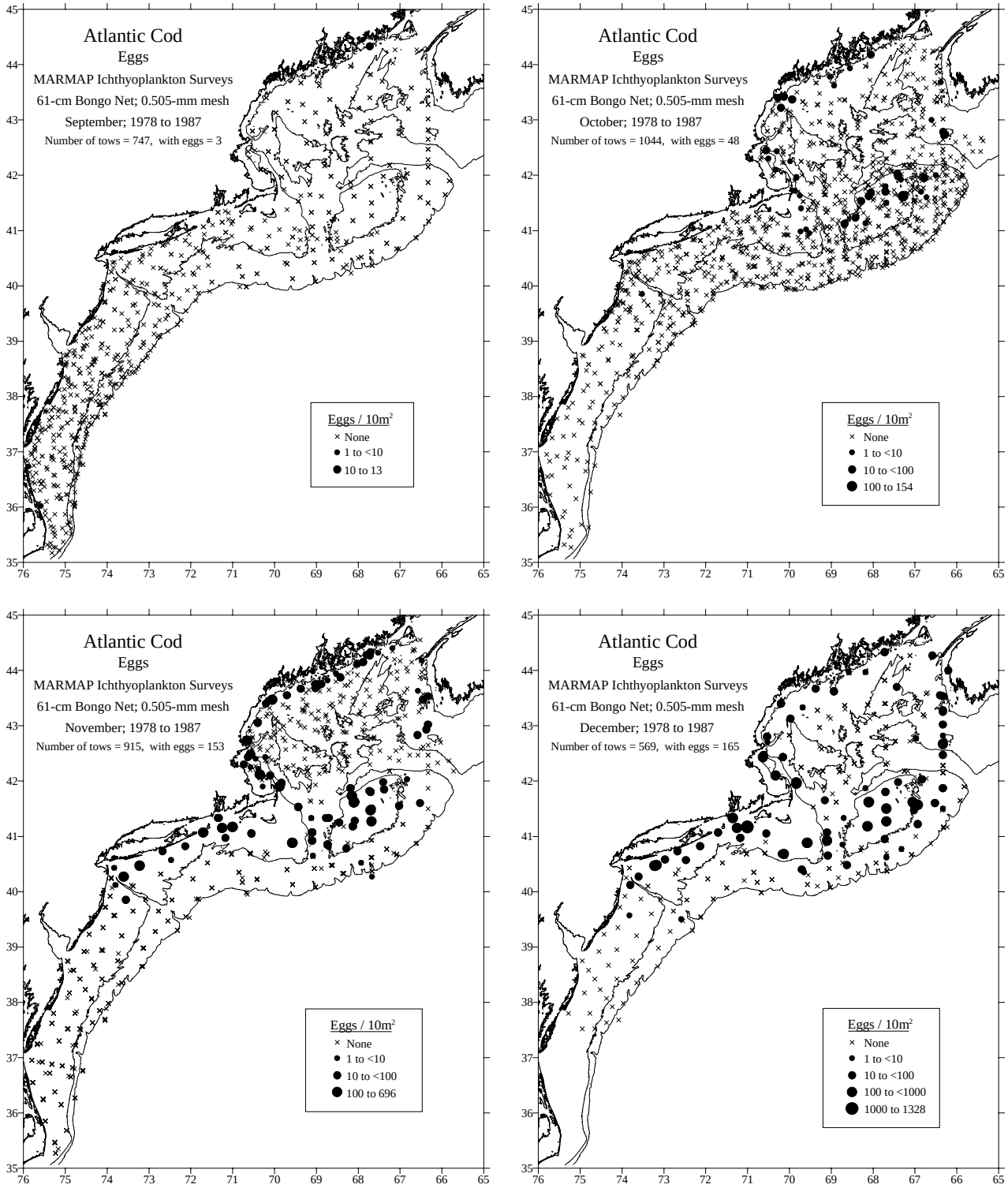

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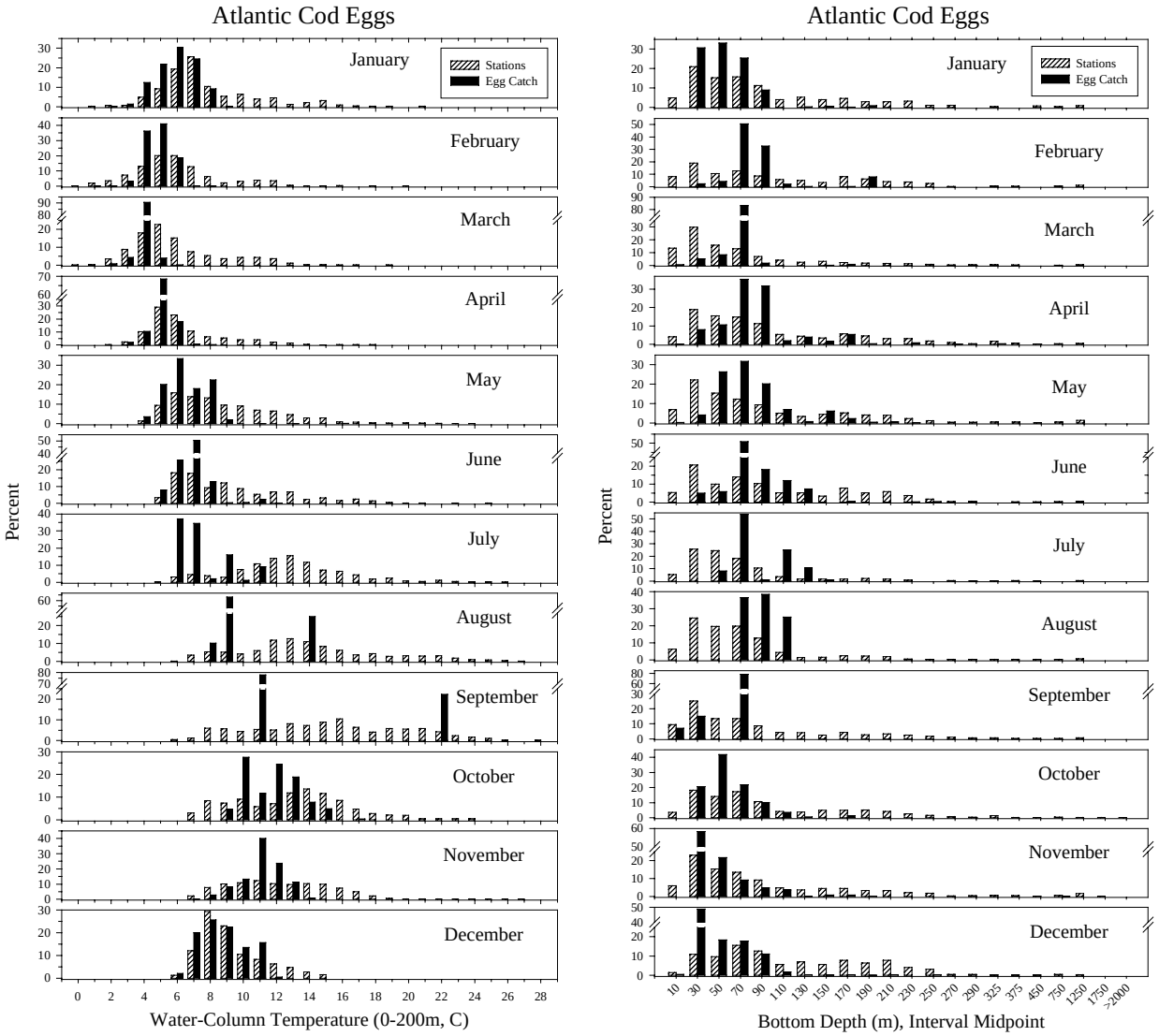


Figure 5. Mean water column temperature and bottom depth associated with collections of Atlantic cod eggs during NEFSC MARMAP ichthyoplankton surveys (1978-1987) by month for all years combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

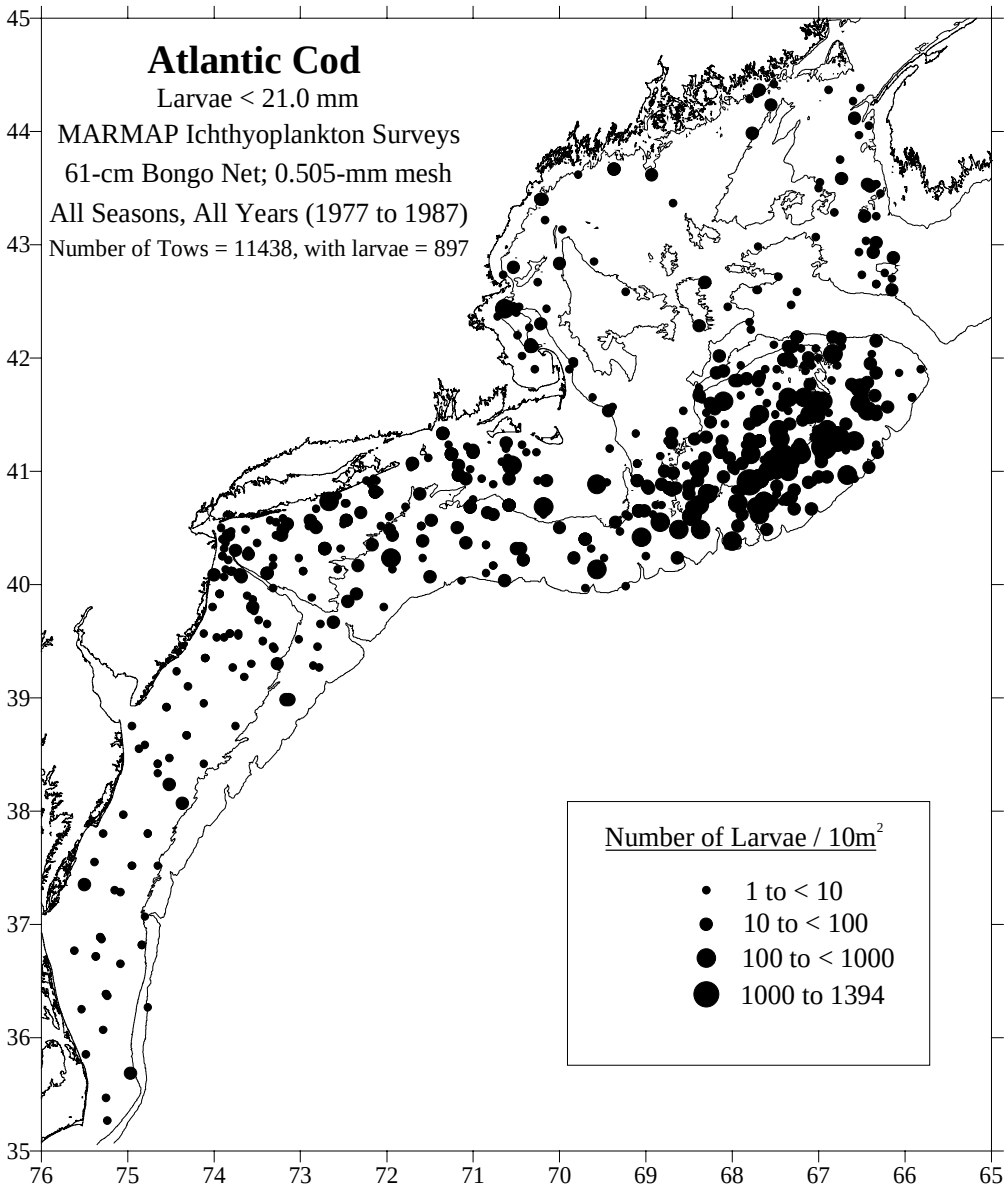
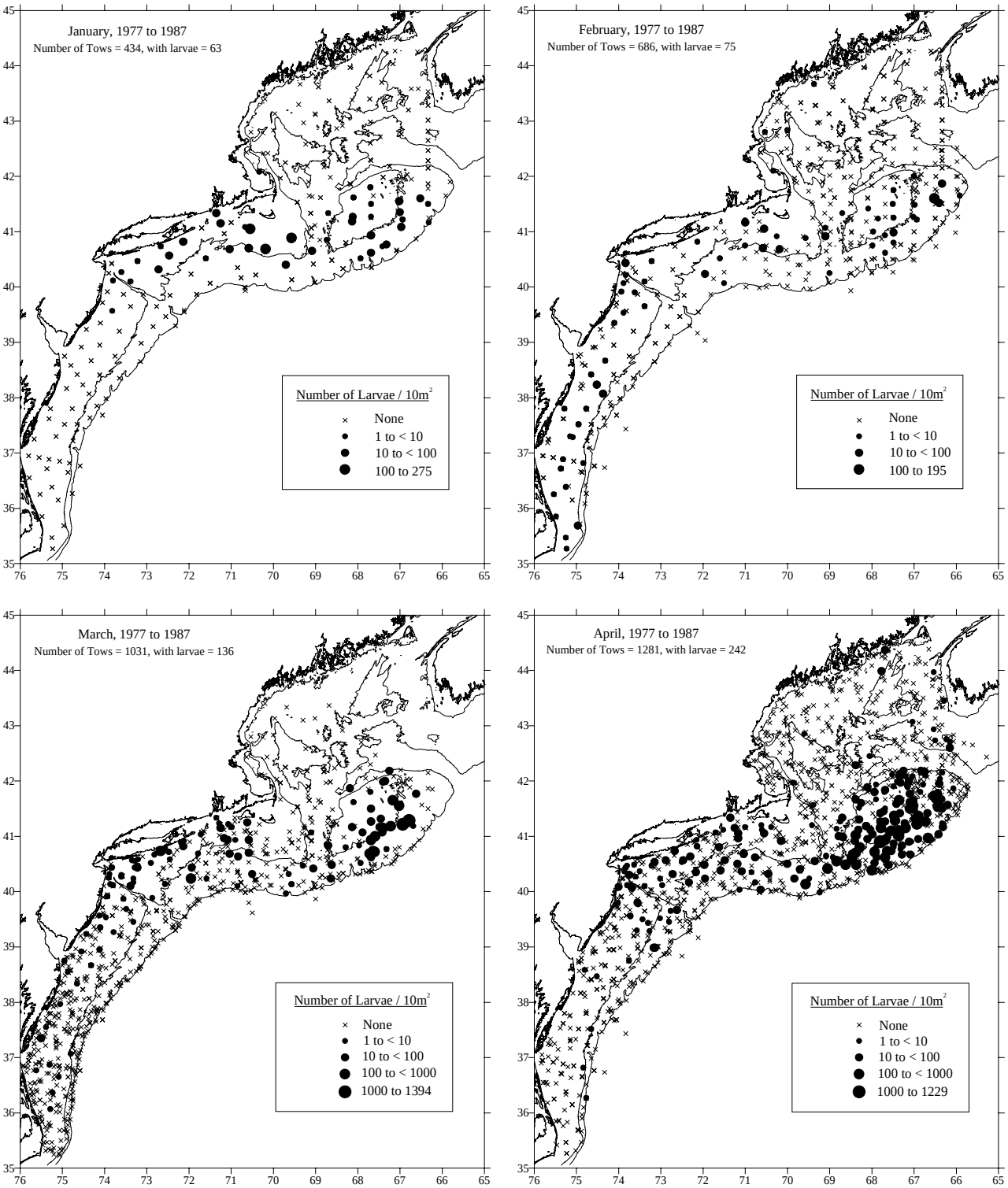


Figure 6. Distribution and abundance of Atlantic cod larvae collected during NEFSC MARMAP ichthyoplankton surveys, January to December, 1977-1987 [see Reid *et al.* (1999) for details]. Abundance is represented by dot size, and sampling effort is indicated by small x.



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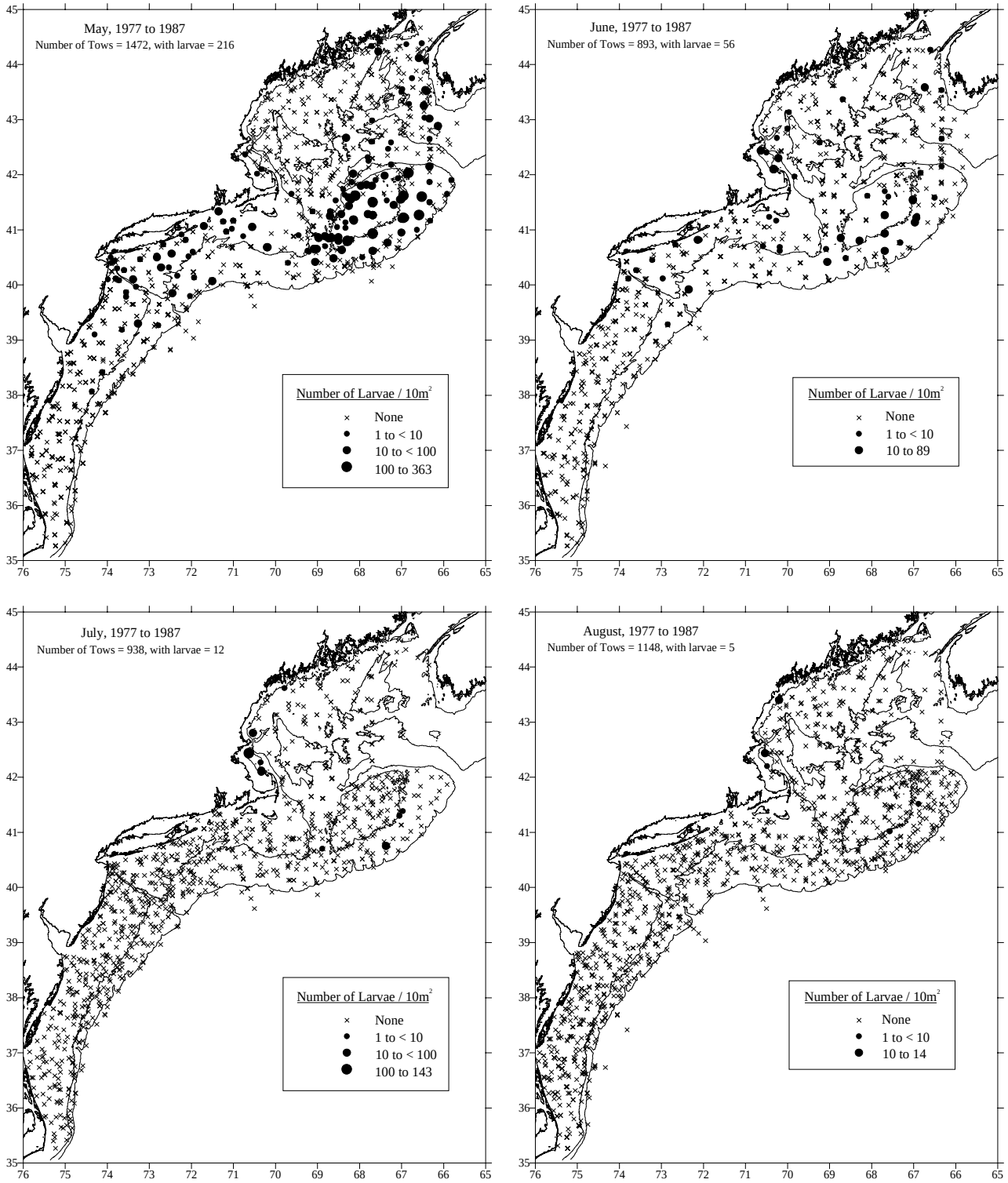

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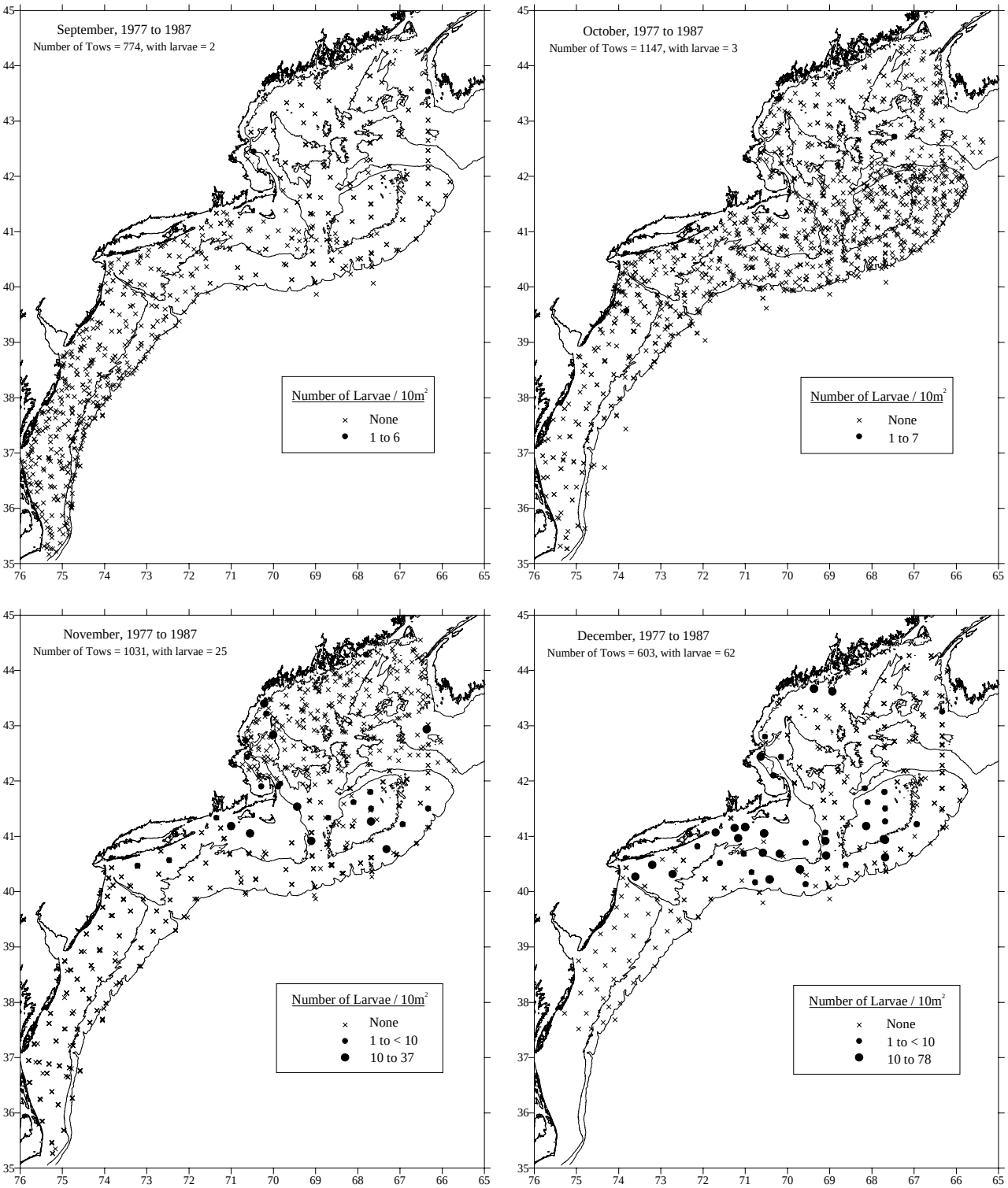

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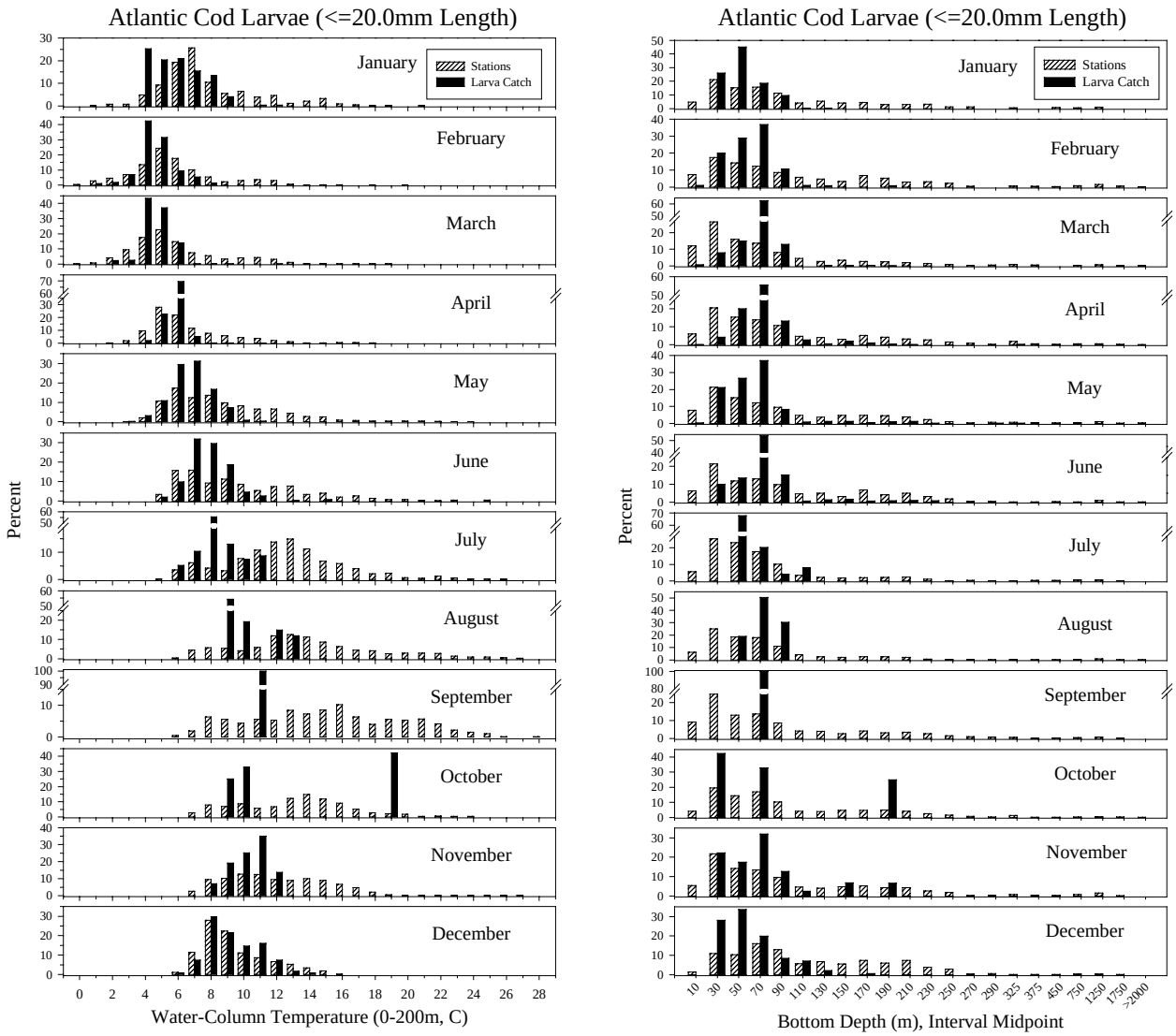


Figure 7. Mean water column temperature and bottom depth associated with collections of Atlantic cod larvae during NEFSC MARMAP ichthyoplankton surveys (1977-1987) by month for all years combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

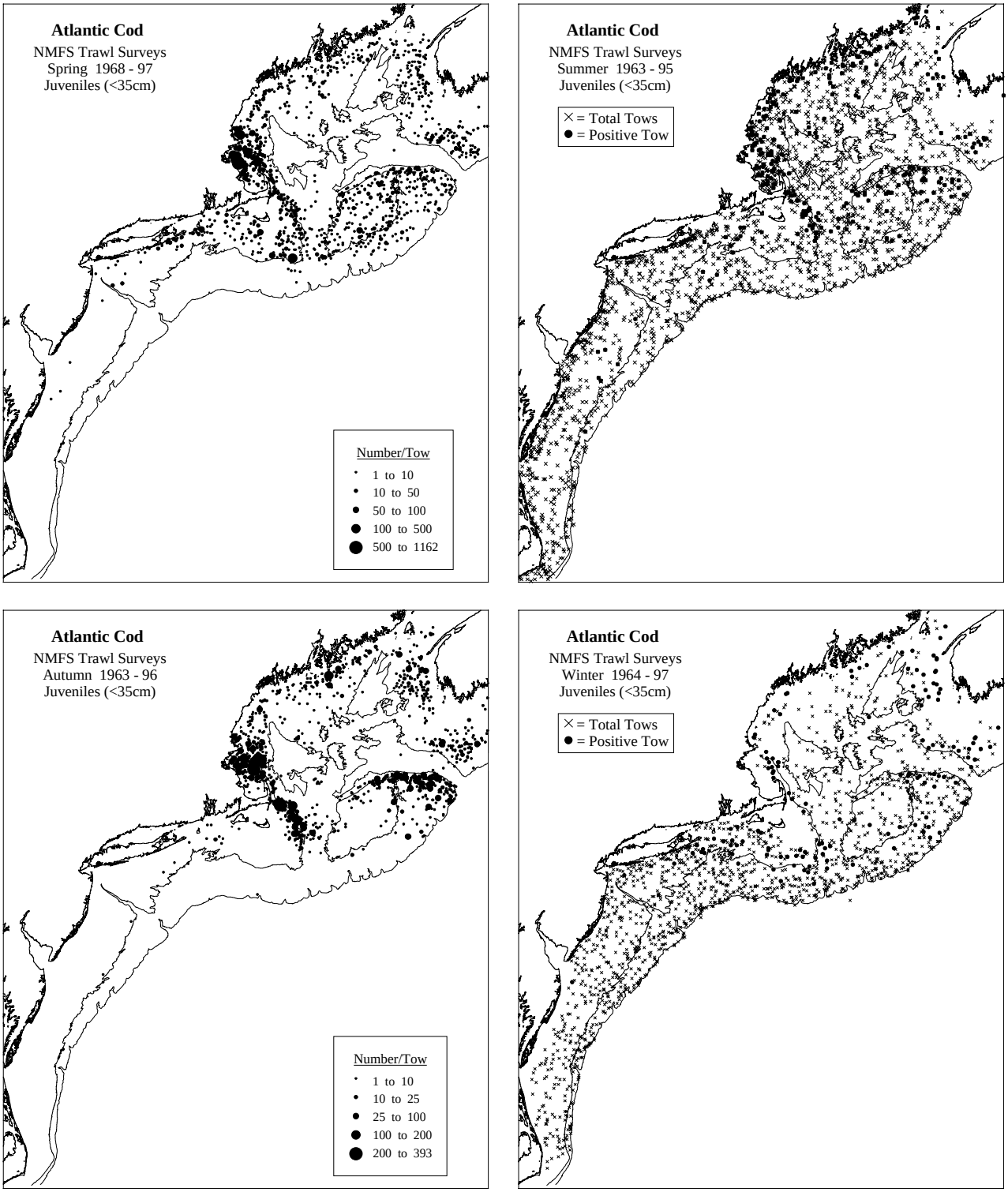
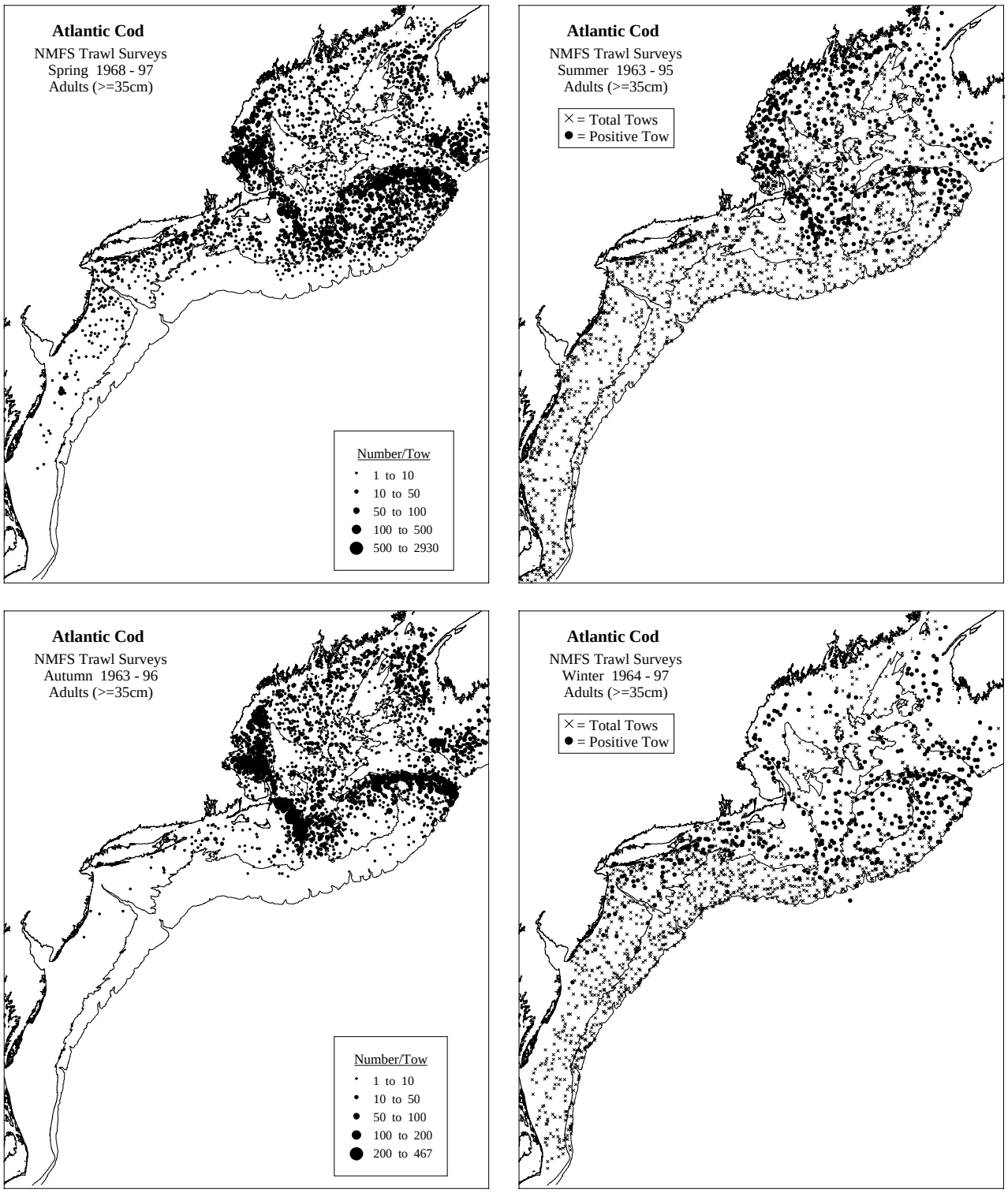


Figure 8. Distribution and abundance of juvenile (< 35 cm) and adult (≥ 35 cm) Atlantic cod from spring (1968-1997), summer (1963-1995), autumn (1963-1996), and winter (1964-1997) NEFSC bottom trawl surveys. Densities are represented by dot size in spring and fall plots, while only presence and absence are represented in winter and summer plots [see Reid *et al.* (1999) for details].



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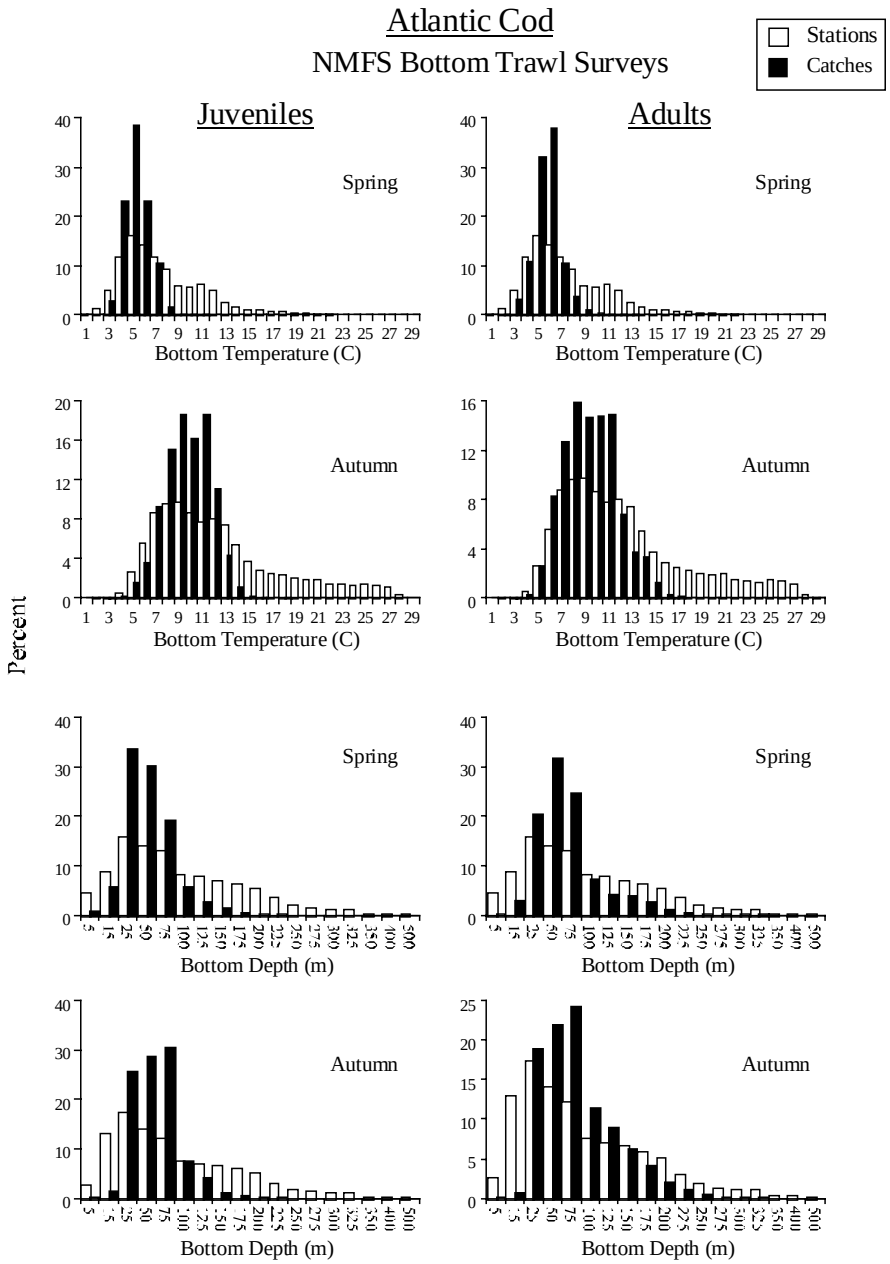

Figure 9. Distribution of juvenile and adult Atlantic cod in relation to bottom temperature and depth based on spring (1968-1997) and autumn (1963-1996) NEFSC bottom trawl surveys. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

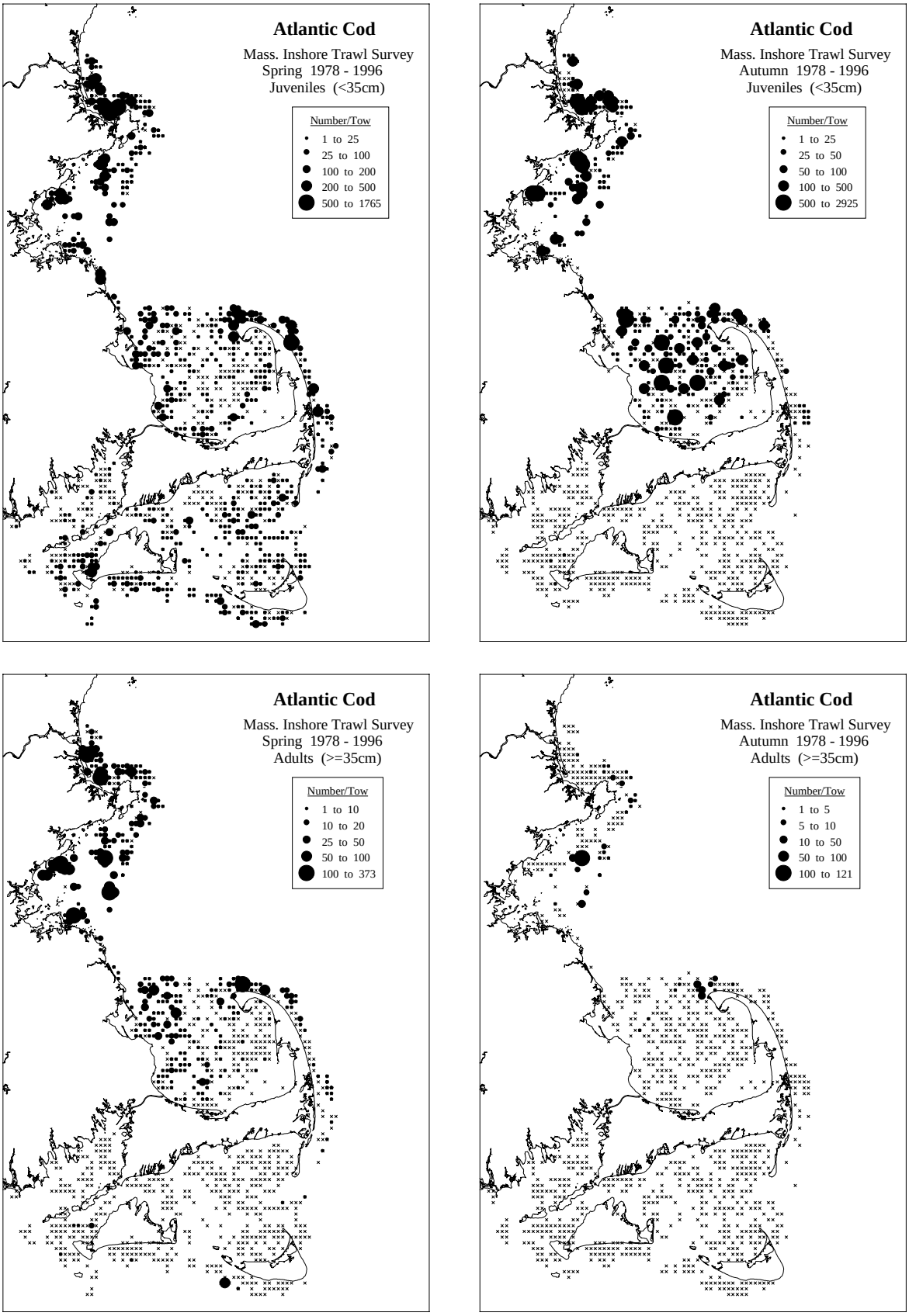

Figure 10. Distribution and abundance of juvenile (< 35 cm) and adult (≥ 35 cm) Atlantic cod collected during spring and autumn Massachusetts inshore bottom trawl surveys, 1978-1996 [see Reid *et al.* (1999) for details].

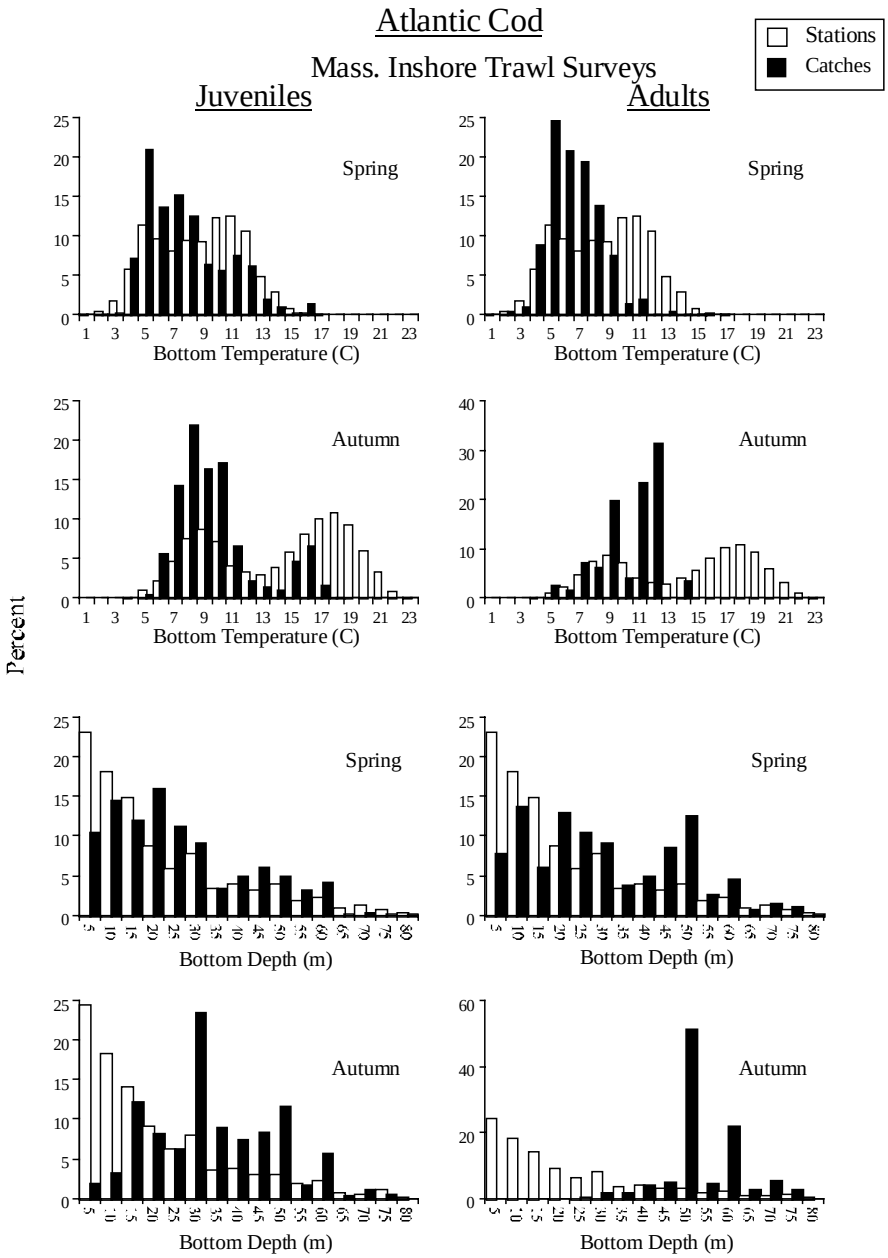

Figure 11. Distribution of juvenile and adult Atlantic cod in relation to bottom temperature and depth based on spring and autumn Massachusetts inshore bottom trawl surveys, 1978-1996. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

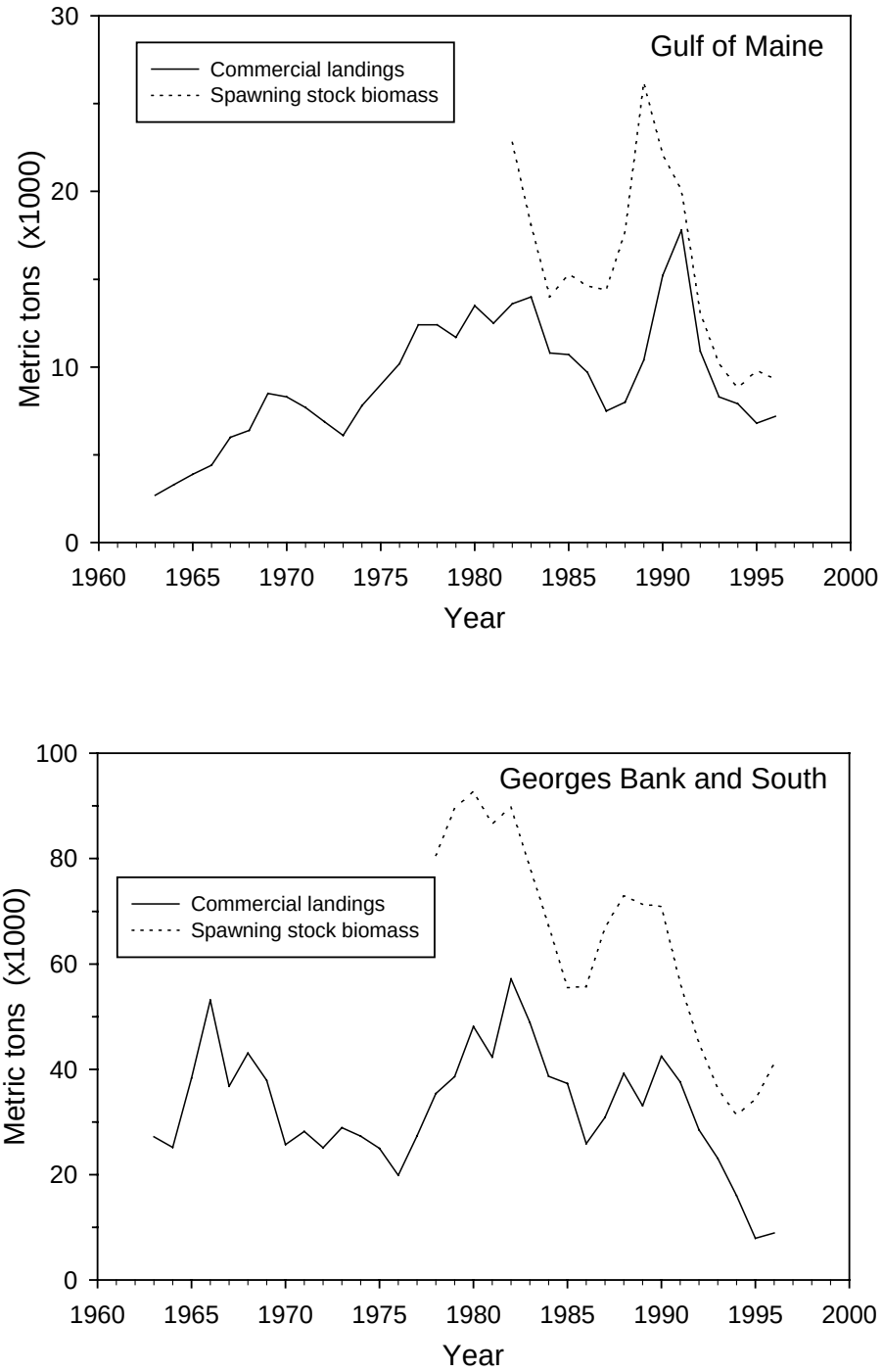

Figure 12. Annual commercial landings (including recreational catches) and estimates of spawning stock biomass (from the NEFSC bottom trawl surveys) for the Gulf of Maine and Georges Bank and south stocks of Atlantic cod.

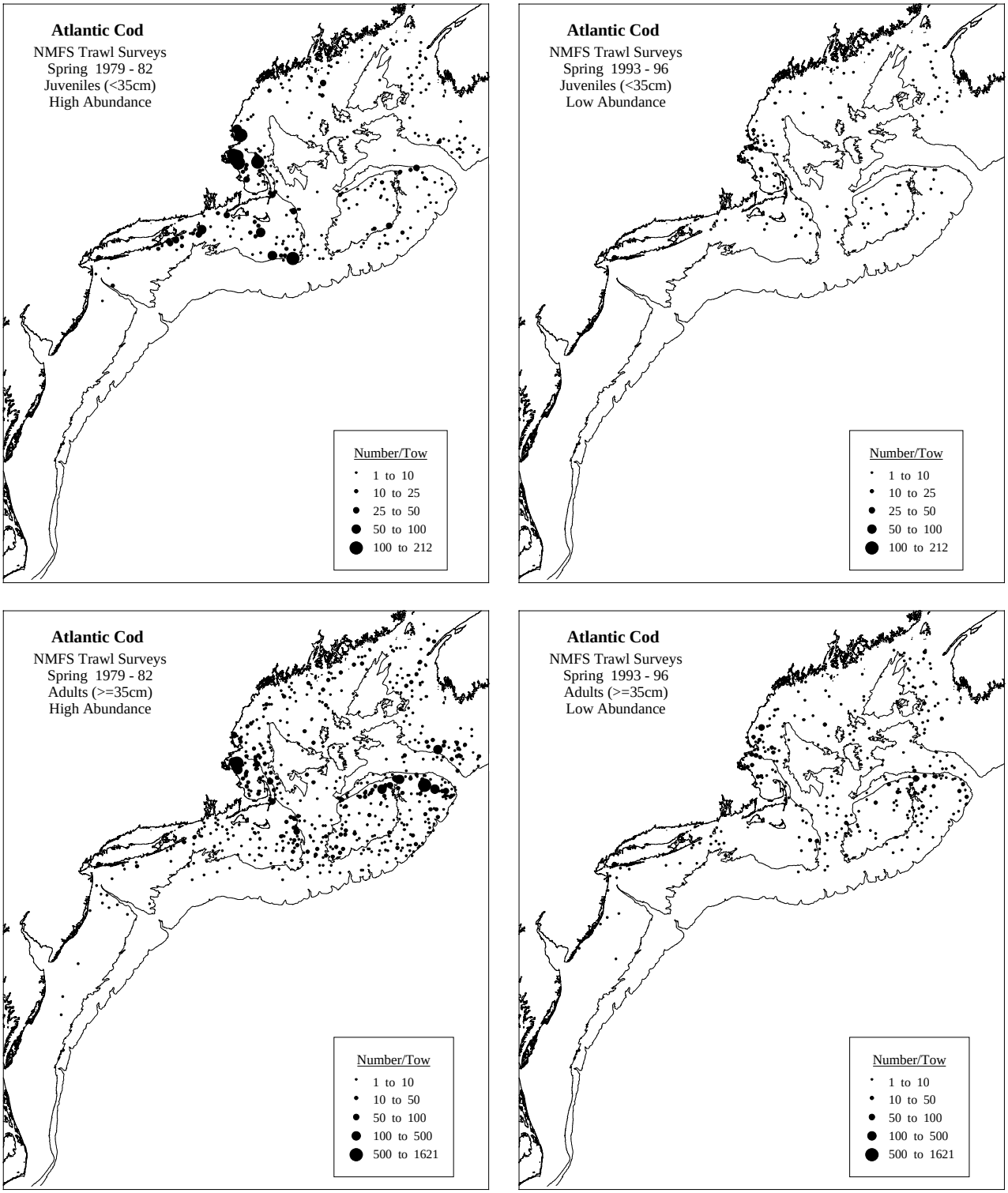

Figure 13. Distribution and abundance of juvenile (< 35 cm) and adult (≥ 35 cm) Atlantic cod during a period of relatively high abundance (1979-1982) and a period of relatively low abundance (1993-1996), from spring NEFSC bottom trawl surveys.

Appendix 1. Table of Habitat Parameters for Atlantic cod, *Gadus morhua*. This table is separated into four parts based on life history stage. "Present Study" refers to data presented herein. Abbreviations: GB = Georges Bank; GOM = Gulf of Maine; GOSL = Gulf of St. Lawrence; Mass Bay = Massachusetts Bay; Nfld. = Newfoundland; SNE = southern New England (Nantucket Shoals to Hudson Canyon); SS = Scotian Shelf.

SPAWNING/EGGS

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Currents/ Circulation	Light/Vertical
Bigelow & Schroeder 1953	GOM	Pelagic. Spawn Mass Bay 3-10 miles from shore Nov-Apr.; Ipswich Bay Feb-May; West coast Maine Mar-May (into mid-summer). Also Isles of Shoals, Casco Bay, Sheepscot R. Always < 50 fm.	Bottom temps 0.6-8.9°C for spawning (2.2-5.6°C in Mass Bay). 5.0-8.3°C optimum for hatching. High mortalities at 0°C.	Sink in spring freshets	Drift southwest following coastline, 10-30 days	Near surface if salinities high
Hardy 1978	GB, GOM	Pelagic. Spawn in inlets, bays, harbors, coastal & offshore banks. Usually < 73 m.	0-6°C for spawning. 2.0-8.5°C optimum for incubation	Spawn salinity thru range: 10.0-35.5 ppt. Eggs sink in spring freshets. High mortality at low salinites (9.9-12.5 ppt)	---	Upper 10 m. Sink with age
Fish 1928	Mass Bay, SW GOM	Peak spawning, Mass Bay, January	10.1°C (Nov) to 0°C (January)	---	Advected out of Mass Bay by currents.	---
Bonnet 1939	Lab study	Ipswich Bay. Spawns at yearly minimum temp. (March)	0.5-3.0°C. 12°C upper limit for development	---	Eggs spawned in Ipswich bay would drift 120 miles before larvae settled to bottom	---
Colton 1978	GOM	Spawn Nantucket Shoals and Mass Bay, January-April (peak January). Also Georges and Browns banks, Ipswich Bay, SW GOM.	---	---	---	---
Cohen *et al.* 1990	North Atlantic	Most productive area in western North Atlantic is eastern half GB & Grand Banks, followed by SW GOM.	0-12°C with most 0-6°C. GOM stock spawns in colder water than others.	---	---	Spawn near bottom, unless temperatures unsuitable, then migrate into water column.
Rau 1974	Browns Bank, GB, Nantucket Shoals, Feb-Mar 1973	Most eggs found over central and northeast GB.	Most collected at 3-5°C	Most collected at 32-33 ppt	---	---
Anderson and de Young 1995	Northeastern Nfld. shelf	Studied vertical distribution and relative condition of eggs.	Temperature has effect on vertical distribution	Salinity (water density) has effect on vertical distribution	---	Eggs in poor condition found deeper in water column.
Miller *et al.* 1995	SS, October-May, 1991-1993	Peak spawn during fall.	Temperature (more than season) exerts most influence on egg size (and hatchling size).	---	---	---
Valerio *et al.* 1992	Nfld.	Studied freeze resistance of eggs & larvae. No antifreeze proteins detected.	If chorion intact, capable of undercooling to -4.0°C. Froze at -4.1 to -17.0°C.	---	---	---
Brander & Hurley 1992	SS	Spring spawning proceeds from SW to NE along shelf.	---	---	Spawning matches production of copepods.	---

Appendix 1. cont'd.

LARVAE

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Currents/ Circulation	Light/ Vertical	Predators/ Prey (See Tables)
Rau 1974	Browns Bank, GB, Nantucket Shoals, Feb-Mar 1973	Most larvae (2-7 mm) between northeast GB and Nantucket Shoals.	Most collected 3-5°C	Most collected 32-33 ppt	---	---	---
Laurence 1978	Laboratory study	Growth rates increase with increasing temperatures.	4°C: 4.15%/d 7°C: 6.67%/d 10°C: 8.75%/d	---	---	---	---
Werner *et al.* 1993.	GB	Examined tidal currents, wind stress, Scotian Shelf inflow, advection and vertical distribution of larvae on Northeast Peak. Spawning shoalward of 50-m isobath enhances eventual retention of larvae on Georges Bank.	---	---	Larvae in surface layers subject to off-shelf advection via Ekman transport. Downwelling near shelf break allows larvae to avoid advection.	---	---
Suthers *et al.* 1989	SS	Recent growth in presumed inshore nursery area was less than in offshore waters, based on examination of birthdate distributions.	Temperature only rarely correlated with growth.	---	---	---	Growth rate strongly correlated with zooplankton biomass.
Perry & Neilson 1988	GB	Studied diel vertical distributions of cod and haddock late larvae in isothermal and stratified sites.	Thermocline may limit nightly upward migration.	---	---	Near bottom during day, in midwater at night. Migrations in reaction to light levels.	Late larval haddock did not change depth as much as cod larvae.
Myers & Drinkwater 1989	Middle Atlantic Bight, GB, Grand Banks	Examined effect of warm core ring activity on recruitment success in 17 groundfish stocks, 1973-1986.	---	---	Increased ring activity reduced recruitment in all stocks except GB cod.	Rings presumably entrained larvae of most stocks offshore.	---

Appendix 1. cont'd.

JUVENILES

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Substrate/ Vegetation	Currents/ Circulation	Light/ Diel	Predators/ Prey
Gotceitas *et al.* 1994	Trinity Bay, Nfld. and laboratory studies, 1993	Nearshore bay, various substrates. July-mid-December.	---	---	Predator absent: preferred finer grains & avoided vegetation. Predator present: preferred cobble & hid in vegetation.	---	---	See Substrate/ Vegetation column
Gotceitas & Brown 1993	Laboratory Study	Studied substrate preference with and without a predator (e.g. a larger cod) present.	---	---	Cobble preferred over finer grained substrates when predator present. After predator leaves, larger juveniles return to fine grains, smaller remain in cobble.	---	---	Fewer juveniles succumb to predation in cobble than in finer grained substrates.
Hardy 1978	Northwest Atlantic	Coastal waters, rock pools, shallow inlets, river mouths, harbors. Leave coastal areas by mid-June (Massachusetts). 0+ average 35 m (range 8-42m); 1+ range 73-274 m.	Range 6-20°C	From < 31.3 to 35.0 ppt	---	---	---	---
Lough *et al.* 1989	GB	Descend to bottom @ 4-6 cm. 0+ (newly settled) fish dense on northeastern GB, 70-100 m depth, during summer.	---	---	Pebble-gravel deposit	Fall, transported southeast-ward by gyre	Migrate into lower water column at night to feed on inverte-brates	Coloration mimics substrate, reduces vulnerability to predation.
Tatyankin 1972	Barents Sea, 1967-1969 (laboratory study)	Determined preferred temperatures in gradient tank. In general, lower temperatures selected in winter, higher in summer. Older age classes preferred colder temperatures than younger.	Age 0+, summer: 7-11 °C. Age 1, winter: 3-6°C. Age 1+, fall: 5-8°C. Age 2, winter: 2-7°C	---	---	---	---	---

Appendix 1. cont'd.

JUVENILES

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Substrate/ Vegetation	Currents/ Circulation	Light/ Diel	Predators/ Prey
MacDonald *et al.* 1984	Bay of Fundy and Passamaquoddy Bay	Juveniles in Passamaquoddy Bay in winter, close to beach in summer. (See "Adults")	0-6°C (winter); 8-13°C (summer)	30-31 ppt winter; 31-32 ppt summer	Mud, gravel, rock (winter); sand, mud, rock (summer)	---	---	---
Clark & Green 1990	Conception Bay, Nfld.	Studied diel, depth, seasonal movements in Broad Cove. Seasonal change in diel behavior due to disappearance of shallow (< 30m), summer thermocline.	Summer: day: 4.1-4.6°C; night: 10-12°C. Fall: stayed in warmer water.	---	Summer: wide-ranging (> 3km/day), between deep, cold & shallow, warmer water; Fall: small home ranges over sand in shallows; resting areas over rocks in shallows.	---	Summer: day, inactive; night, active. Fall: day, active; night, inactive.	Active periods coincide with feeding.
Keats *et al.* 1987	Conception Bay, Eastern Nfld.	Observations of juveniles in macroalgal habitat and adjacent sea-urchin dominated 'barrens'.	---	---	More abundant in macroalgal areas, used as cover, than in 'barrens'.	---	Diel not tested	Epiphytic food source not utilized.
Gotceitas *et al.* 1995	Nfld.	Studied reactions of 0+ cod to predator in combinations of substrates and artificial 'kelp'.	---	---	With no predator, 0+ prefer fine grain substrates, avoid 'kelp'. When predator present, 'kelp' provides protection from predation.	---	---	Juveniles select refuge type (cobble or 'kelp') when predator present.
Gotceitas *et al.* 1997	Nfld.	Studied vegetated and non-vegetated habitats, plus several bottom substrates with & without predator using SCUBA and seines.	---	---	Eelgrass used as nearshore nursery by 0+ cod. For refuge from predation & when combined with cobble, stem density was important.	---	---	Predator absent: 0+ used sand & gravel. Predator present: 0+ hid in cobble or eelgrass.

Appendix 1. cont'd.

JUVENILES

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Substrate/ Vegetation	Currents/ Circulation	Light/ Diel	Predators/ Prey
Fraser *et al.* 1996	Laboratory Study	Studied interactions of 0+, 1+ and 3+ (predator) cod and their reactions to two different substrate types, sand/cobble & sand/gravel.	---	---	Some habitat segregation between Age 0+ and Age 1+, except when Age 3+ present, then both hid in cobble.	---	---	When predator present, 0+ and 1+ cod used same refuge (cobble).
Tupper & Boutilier 1995	St. Margaret's Bay, Nova Scotia	Studied survival and 0+ densities in 4 different bottom habitats (sand, seagrass, cobble, rock-reef).	---	---	Settlement equal among habitats, but subsequent densities highest in structurally complex habitat types.	---	---	Higher survival and densities appear to be related to shelter opportunities and reduced predation.
Keats 1990	Bonavista Bay, Nfld.	Examined diel depth distributions of juveniles.	---	---	---	---	Arrive in shallow water at dusk, remain until pre-dawn, then migrate into deeper water.	
Murawski & Finn 1988	GB	Evaluated species co-occurrences relative to temperature & depth preferences, spatial distribution by species & age. Overlap with silver hake, mostly in fall. See also "Adults"	YOY Means: winter: 2.9°C spring: 5.3°C summer: 9.9°C fall: 9.3°C	---	YOY Means: winter: 56 m spring: 60 m summer: 71 m fall: 71 m	---		---
Grant & Brown 1998a	Nfld.	Studied diel distribution in eelgrass habitat and diet differences between 0+ and 1+ cod.	---	---	After settlement in grass beds, Age 0+ change habits on diel basis.	---	Age 0+ in water column during day, disperse to bottom at night. Older yr. classes do opposite.	Age 0+ feed mostly on zooplankton during day; Age 1+ mostly on benthos and fish at night.
Grant & Brown 1998b	Nfld.	Studied encounters between just-settled juveniles and older cod (predators) in eelgrass and no-eelgrass habitats in Trinity Bay.	---	---	After settlement, juveniles display preference for eelgrass beds, but remain localized over grass and no-grass habitats for several weeks, perhaps through first winter.	---	Juveniles aggregate in grass beds during day, disperse at night. Different pattern by older cod results in reduced encounters.	Risk of cannibalism high in coastal habitats. Localized movements and preference for grass beds are mechanisms to avoid predation.

Appendix 1. cont'd.

ADULTS

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Depth/ Substrate/ Vegetation	Currents/ Circulation	Light/ Diel/ Vertical	Predator/ Prey (See Tables)
Bigelow & Schroeder 1953	GOM	Non-migratory in GOM. Surface to 250 fm, but few > 100 fm. Most 5-75 fm. Usually within 1 fm of bottom. As shallow as 7 fm (summer), 3 fm (winter).	0-12.8°C. Prefer < 10.0 °C	---	Mostly rocky, pebbly, sandy or gravelly bottoms.	---	---	Large sharks and spiny dogfish.
Jean 1965	GOSL; SS	GOSL: 35-145 m (summer); 130-180 m (winter). SS: 65-110 m (summer); 90-135 m (winter).	GOSL: 0-6°C (summer); 1-3 °C (winter). SS: 1-8°C (summer); 2-4 °C (winter).	---	---	---	---	---
Odense *et al.* 1966	Bay of Chaleur (laboratory study)	Studied tolerance to low salinity	5-6°C (not manipulated)	First mortalities when reached 2.7 ppt; complete mortality at 2.3 ppt	---	---	---	---
MacDonald *et al.* 1984	Bay of Fundy and Passamaquoddy Bay	Adults in Passamaquoddy Bay summer, GOM, SS winter. (See "Juveniles")	8-13°C (summer); 4-8°C (winter)	31-32 ppt (summer); 31-32 ppt (winter)	Mud, rock (summer)	---	---	---
Scott 1982a	SS, Bay of Fundy	Determined preferred depths, temperatures & salinities for several groundfish species. Compared to other gadoids, cod prefers shallower, colder and less saline.	0-13°C (mean 4.9°C). Preferred temperature showed increase NE to SW, means 3.2 to 7.8°C.	31-34 ppt (mean 32.8 ppt)	27-366 + m, (mean 95 m). Preferred range 37-90 m.	---	---	---
Colvo-coresses and Musick 1984	Middle Atlantic Bight, continental shelf	Analyzed faunal associations, and zones occupied seasonally. Occurs with *Pseudo-pleuronectes americanus* and *Hemitripterus americanus*.	Boreal species, spring, < 10°C. "Relatively absent" during fall	---	< 100 m	---	---	---

Appendix 1. cont'd.

ADULTS

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Depth/ Substrate/ Vegetation	Currents/ Circulation	Light/ Diel/ Vertical	Predators/ Prey (See Tables)
Tyler 1971	Passamaquoddy Bay, compared to bays south. Analyzed regular and periodic components in fish community.	Cod was member of 'regular' community (present throughout year), but most abundant March-April.	As annual temperature fluctuations increase (in southern bays), fewer 'regular' species.	29.5-29.6 ppt in Mar-Apr.; 32.3 ppt in September .	Sampled brown mud bottom, sloping from 38-55m.	---	---	---
Rose & Leggett 1988	GOSL	Onshore movements and inshore abundance of cod were affected by winds, upwellings, and downwellings.	Cod usually located where temps -0.5 to 8.5°C.	---	---	When alongshore winds create temperature changes, cod numbers decrease.	---	---
Rose & Leggett 1989	GOSL	Cod were aggregated within narrow temperature range, unless prey present, then found in wider range.	Without prey, usually between 0 & 5°C	---	---	---	---	When capelin present, range -0.5 to 8.5°C
Helser & Brodziak 1996	GOM, GB, SNE, Middle Atlantic Bight	Demonstrated seasonal differences in depth and bottom temperature preferences.	Spring: < 4.9 °C Fall: weaker association with temperatures	---	Spring: < 72 m Fall: weaker association with depth	---	---	---
Murawski & Finn 1988	GB	Evaluated species co-occurrences relative to temperature & depth preferences, spatial distribution by species & age. Overlap with silver hake, mostly in fall. Also see "Juveniles"	Age 1+ Means: winter: 4.2°C spring: 5.4°C summer: 8.0 °C fall: 9.3°C	---	Age 1+ Means: winter: 88 m spring: 67 m summer: 72 m fall: 84 m	---	---	---

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Essential Fish Habitat Source Document:

Atlantic Halibut, *Hippoglossus hippoglossus*, Life History and Habitat Characteristics

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Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

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FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

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INTRODUCTION

The Atlantic halibut, *Hippoglossus hippoglossus*, is the largest of all flatfish (Figure 1). It is found on both sides of the North Atlantic Ocean and in parts of the Arctic Ocean. A directed fishery for Atlantic halibut in U.S. waters began in the early 19th century and peaked from 1845 to 1900 (A.B. Howe, Massachusetts Division of Marine Fisheries, personal communication). By the 1940's it had collapsed and for many years there was no directed Atlantic halibut fishery in U.S. waters. Consequently, no management plan was developed for the species.

Currently, a small-scale fishery for "chicken" halibut (3.6-6.8 kg) exists off the coast of Maine. The September 1997 'Status of Fisheries of the United States' (National Marine Fisheries Service 1997) reports that the U.S. Atlantic halibut population is currently in an overfished condition, and the New England Fishery Management Council intends to place Atlantic halibut within the Northeast Multispecies Fishery Management Plan (NEFMC 1996).

This Essential Fish Habitat Source Document provides information on the life history and habitat characteristics of Atlantic halibut.

LIFE HISTORY

A synopsis of the life history of Atlantic halibut is presented here. More detailed information is provided in reviews by Haug (1990), Trumble *et al.* (1993), and Collette and Klein-MacPhee (in prep.).

EGGS

The halibut egg is among the largest of planktonic fish eggs (Russell 1976). Fertilized halibut eggs in the western Atlantic have a diameter of 3-4 mm (Fahay 1983; Scott and Scott 1988; Miller *et al*. 1991). In Norway, eggs range from 2.86-2.98 mm (Trumble *et al*. 1993) to 3.06-3.49 mm (Haug *et al*. 1984).

The eggs are bathypelagic, floating not at the surface, but rather, suspended in the water column at depths ranging from 54 m (Scott and Scott 1988) to 200 m (Blaxter *et al*. 1983). In the eastern Atlantic, eggs rise for 2-4 days after deposition to a depth of neutral buoyancy (Haug 1990; Trumble *et al*. 1993). Laboratory studies indicate that eggs are neutrally buoyant at salinities of 35-37 ppt (Blaxter *et al*. 1983; Trumble *et al*. 1993); however, this is considerably higher than salinities found on the continental shelves of the North Atlantic. Thus, eggs are negatively buoyant due to their high organic matter content (Riis-Vestergaard 1982) and sink towards the bottom where development is thought to proceed (Blaxter *et al*. 1983). In northern Norway, eggs were found at intermediate depths, temperatures of 4.5-7°C, and salinities of 33.8-35.0 ppt (Haug *et al*. 1984). The incubation period is strongly temperature-dependent, lasting from 13-20 days at 4.7-7°C (Miller *et al*. 1991; Collette and Klein-MacPhee, in prep.).

LARVAE

Information on larvae is scarce since they have been difficult to catch in sufficient numbers (Haug 1990; Trumble *et al*. 1993). The 6 to 7 mm long larvae (Lonning *et al*. 1982; Blaxter *et al*. 1983) hatch at an early stage of development, with no pigment, functional eyes or mouth, and possess a very large yolk sac (Blaxter *et al*. 1982; Lonning *et al*. 1982; Haug 1990). Little information on the distribution of the pelagic stages is known, but larvae are thought to remain close to the water surface until metamorphosis (Nickerson 1978). Browns Bank may be a significant rearing area for young Atlantic halibut (Neilson *et al*. 1993).

The larval development period is long. Exogenous feeding commences 28-35 days after hatching, and the yolk sac is completely absorbed 50 days after hatching at 5.3^{o}C (Blaxter *et al*. 1983), at which point the larvae are 11.5-13.0 mm in length (Pittman *et al*. 1987). Metamorphosis begins with the migration of the left eye about 80 days after hatching, at a length of about 20 mm at 6°C (Pittman *et al*. 1987). Settlement occurs at 34-40 mm, prior to completion of eye movement and metamorphosis is complete by approximately 50 mm (Haug 1990). However, Nickerson (1978) reports that the left eye completes its migration one year after hatching, at a length of 10 cm, at which point settlement to the bottom occurs.

JUVENILES

In the western Atlantic, juveniles are known to exist in distinct nursery grounds (Haug 1990; Miller *et al*. 1991). Metamorphosis into the adult stage begins at a length of approximately 24 mm and, depending on temperature, after approximately 90 days of development. Transformation is complete by 4-10 cm, and may take up to one year (Miller *et al*. 1991).

ADULTS

Atlantic halibut show considerable sexual dimorphism in size at length, with females attaining a substantially larger size than males (McCracken 1958; Bowering 1986). Sizes as large as 3 m in length and 300 kg in weight, and ages of 50 years have been documented (Trumble *et al*. 1993). During the height of the halibut fishery in the 19th century, the average size of females

was 100 to 150 pounds and males rarely exceeded 50 pounds (Goode 1884). More recent studies report smaller sizes: Bowering (1986) reported captures of males up to 189 cm and females up to 229 cm in length off Newfoundland, and Miller *et al*. (1991) reported females up to 220 cm and 35 years of age. Most halibut caught in recent years weighed less than 100 kg (Nickerson 1978).

In the northeast Atlantic, adults are thought to leave spawning areas and disperse randomly, apparently in search of food (Haug 1990), to shallow and deep waters as well as inshore and offshore areas (Godø and Haug 1988). Similar observations have been made in North American waters (McCracken 1958; Bowering 1986). Stobo *et al*. (1988) hypothesized that larger, sexually mature halibut (i.e., adults) exhibit limited dispersal and an annual return migration to spawning grounds.

REPRODUCTION

The age and size at maturity of Atlantic halibut vary considerably; females mature at a much larger size and older age than males (Table 1).

Atlantic halibut are annual, group-synchronous spawners (Neilson *et al*. 1993). Females are batch spawners, able to ovulate several batches of eggs in a single reproductive season (Methven *et al*. 1992). Depending on body size, females can produce from 0.5-7 million eggs in a single season (Haug and Gulliksen 1988). Spawning in the western Atlantic is believed to occur on the slopes of the continental shelf and on the offshore banks (McCracken 1958; Nickerson 1978; Neilson *et al*. 1993), at depths of at least 183 m (Scott and Scott 1988), over rough or rocky bottom (Collins 1887). In Norwegian coastal waters, halibut spawning has been reported over soft clay or mud bottom, in deepwater (300-700 m) locations at temperatures ranging from 5-7°C and salinities of 34.5-34.9 ppt (Haug 1990).

Spawning occurs during late winter and early spring (McCracken 1958; Scott and Scott 1988; Miller *et al*. 1991; Methven *et al*. 1992; Trumble *et al*. 1993), with peak spawning having been reported during November to December (Neilson *et al*. 1993). Kohler (1964) reported that spawning occurred during winter to early spring on the Scotian Shelf, during February to April in the Gulf of St. Lawrence, and during winter to late spring off Newfoundland (Kohler 1964). In northern Norway, spawning has been reported during December to March, with peak spawning at the end of January/beginning of February (Haug 1990). However, historical descriptions of spawning have reported ripe halibut as late as August (Goode 1884).

FOOD HABITS

The diet of Atlantic halibut changes with increasing size. Fish up to 30 cm in length feed almost exclusively on invertebrates, mainly annelids and crustaceans (crabs, shrimps); those 30-80 cm in length feed on both invertebrates (mainly crustaceans, some mollusks) and fish; and those greater than 80 cm in length feed almost exclusively on fish (Kohler 1967). In the Gulf of Maine, the most important prey of adult halibut during 1977-1980 were squid (*Illex*), crabs (*Cancer*), and fish (silver hake, northern sand lance, ocean pout, and alewife) (Collette and Klein-MacPhee, in prep.). Maurer and Bowman (1975) report that 91% of the stomach contents of juvenile and adult halibut (by weight) were fish (> 50% were longhorn sculpin and its eggs, but also cod and other gadids), and 8% were crustaceans. Nickerson (1978) reports that the fish prey of halibut includes cod, cusk, haddock, ocean perch, sculpins, silver hake, herring, capelin, skates, flounder and mackerel.

The Northeast Fisheries Science Center (NEFSC) bottom trawl survey data on food habits [see Reid *et al.* (1999) for details] show a similar ontogenetic shift in the diet of Atlantic halibut (Figure 2). The 1973-1980 data clearly illustrate that, while crustaceans dominate the diet of smaller halibut, fish increase in importance with size to dominate the diets of larger halibut (Figure 2a). Halibut 21-30 cm in length fed exclusively on crustaceans, especially decapods. Those 31-80 cm in length fed on crustaceans (45%, mostly decapods), fish (33%, including gadids and clupeids), and mollusks (6.5%, all cephalopods). The occurrence of fish and mollusks (cephalopods) in the diet of 81-120 cm halibut increased to 50% and 17% respectively, while the occurrence of crustaceans decreased to 25%. The 1981-1990 data show a similar trend (Figure 2b). The diet of 31-80 cm halibut was dominated by crustaceans (66%, mostly decapods); fish and mollusks comprised 25% and 4% respectively. The diet of 81-134 cm long halibut was almost exclusively comprised of fish (80%), but also included decapods (20%, all Majidae).

MIGRATION

Juveniles start to emigrate from nursery areas when the fish are 3-4 years old (Haug and Sundby 1987). They then undergo a period during which most movement occurs; juveniles (< 75 cm) undergo greater migrations than adults (Stobo *et al*. 1988). Although most tagging study recaptures have been made within the same main region where the juvenile fish were tagged, very long distance migrations have been documented from Labrador to the western coast of Greenland (Godø and Haug 1988), the Gulf of St. Lawrence to Iceland (McCracken and Martin 1955), the Scotian Shelf to the Grand Bank (Jensen and Wise 1961; Kohler 1964; Stobo *et al*. 1988),

and the western coast of Greenland to the Grand Bank (Godø and Haug 1988). Extensive migrations have also been documented from northern Norway to the White Sea, Iceland and Greenland, from the Faroe Islands to the North Sea and Iceland, and from Iceland to the Faroe Islands, Greenland and Newfoundland (Haug 1990).

HABITAT CHARACTERISTICS

Detailed information on the habitat characteristics of Atlantic halibut follows and is summarized in Table 2.

EGGS AND LARVAE

The eggs of Atlantic halibut are spawned at temperatures of 4-7°C (Miller *et al*. 1991), depths as deep as 700 m (Blaxter *et al*. 1983), salinities of ≤ 35 ppt (Blaxter *et al*. 1983; Haug *et al*. 1986), and on harder substrates of sand, gravel, and clay (Collette and Klein-MacPhee, in prep.). The larvae are pelagic, floating within 50 m of the surface (Nickerson 1978), are buoyant at salinities of 34.8-36.4 ppt, and prefer salinities in the 30-34 ppt range (Blaxter *et al*. 1983).

JUVENILES AND ADULTS

Juvenile Atlantic halibut are quite localized, being found in apparently well-defined nursery grounds and in coastal areas 20-60 m deep with sandy bottoms (Haug 1990). Stobo *et al*. (1988) hypothesize that the area around Sable Island Gully on the Scotian Shelf may serve as a nursery area for juveniles before they begin their dispersive phase. Juveniles are able to survive sub-zero temperatures, but prefer temperatures > 2°C (Goff *et al*. 1989). Adults are found over sand, gravel or clay substrates (Collette and Klein-MacPhee, in prep.), at temperatures ranging from -0.5 to 13.6^{o}C (Mahon 1997). However, most are caught within 3-9°C, and generally prefer temperatures > 4°C (McCracken 1958; Bowering 1986). They are typically found at depths of 100-700 m (720-900 m is their depth limit) (Bowering 1986, Miller *et al*. 1991), and most commercial catches are made at depths of 200-300 m (Scott and Scott 1988).

Most of the Atlantic halibut taken during the NEFSC trawl surveys (see Geographical Distribution below) were at temperatures of 4-13 ^{o}C and depths of 25-200 m.

GEOGRAPHICAL DISTRIBUTION

Atlantic halibut in the northwest Atlantic were distributed from north of Labrador south to Long Island during 1975-1994 (Figure 3). The areas of highest abundance of the species seem to be along the southern edge of the Grand Bank and on the Scotian Shelf from Browns Bank to Banquereau Bank. This corresponds to their accepted center of abundance (Trumble *et al*. 1993). In U.S. waters, halibut are found on the northeast part of Georges Bank, Nantucket Shoals, Stellwagen Bank, and off the coast of Maine and Massachusetts. Although Atlantic halibut have been taken as far south as Virginia, these are few and considered stragglers from the main population (Smith *et al*. 1975).

In Canadian waters, historical distributions of Atlantic halibut ranged along the entire coast of Labrador and Newfoundland, the Gulf of St. Lawrence, the eastern shores of Nova Scotia, and the Bay of Fundy. In U.S. waters, halibut were abundant on Georges Bank, Nantucket Shoals, and between Gloucester and Cape Cod, Massachusetts, and were occasionally found as far south as New Jersey (Goode 1884, 1887).

EGGS AND LARVAE

No Atlantic halibut eggs were captured during the 1977-1991 NEFSC offshore ichthyoplankton surveys. They are negatively buoyant and thought to develop on or near the sea bed (Riis-Vestergaard 1982; Blaxter *et al*. 1983) and thus are not sampled in the ichthyoplankton surveys.

Larvae were captured at only two of 1,672 stations sampled during the NEFSC ichthyoplankton surveys [see Reid *et al.* (1999) for details], on the northeast part of Georges Bank, and near Petit Manan Island off the eastern coast of Maine (Figure 4). This is not surprising since very few larvae have ever been captured in the wild (Haug 1990) and since spawning is believed to no longer occur in the Gulf of Maine (Collette and Klein-MacPhee, in prep.).

JUVENILES AND ADULTS

NEFSC Bottom Trawl Survey

In the western Atlantic, juveniles are typically found on the southwestern Scotian Shelf, but rarely off Newfoundland, supporting the view that the former is an important rearing or nursery area (Neilson *et al*. 1993). Catches of juvenile and adult Atlantic halibut from the 1963-1997 NEFSC bottom trawl surveys [see Reid *et al.* (1999) for details] are presented in Figure 5. Halibut were caught in low numbers from throughout the Gulf of Maine area, as far south as Nantucket Shoals; a single halibut was caught southwest of Cape Cod. The highest concentrations were found in Canadian waters, on Browns Bank and off southwestern Nova Scotia. In U.S. waters, lower concentrations were found on the northern slope of Georges Bank, Nantucket Shoals, Stellwagen Bank, and off the coast of Maine. There does not appear to be a

significant seasonal effect on distribution and abundance (Figure 5).

There was a definite seasonal effect on the temperature inhabited by Atlantic halibut (Figure 6). In spring, > 70% of halibut were caught at 4-6°C, while in autumn, > 65% were caught at 9-13°C. Similarly, Scott and Scott (1988) found that commercial catches were most common at 3-9°C. Halibut were caught at depths ranging from 25-200 m, with the majority caught between 50-100 m (Figure 6). In spring, > 65% were found at 75-100 m, whereas in autumn, > 70% were caught at 50-75 m. Miller et al. (1991) states that Atlantic halibut in the western North Atlantic have been found over depths ranging from 37-1000 m.

Massachusetts Inshore Trawl Survey

Only 18 Atlantic halibut (all juveniles, 19-75 cm in length) have been taken in Massachusetts inshore waters between 1978 and 1997.

STATUS OF THE STOCKS

Historical landings of Atlantic halibut in the Gulf of Maine/Georges Bank area are presented in Figure 7. In 1900, landings had already declined 95% from 1879 levels (A.B. Howe, Massachusetts Division of Marine Fisheries, personal communication), and catches have since declined even further.

Prior to 1930, landings were variable, but often exceeded 600 metric tons (mt) annually, and catches exceeding 800 mt were common. Since then, landings have exceeded 400 mt only twice, and have generally been well below 200 mt. Landings averaged 756 mt per year from 1893 to 1930 (516 mt if the two especially high years are omitted), compared to only 164 mt annually from 1931 to the present. Since 1953 U.S. landings have been 100 mt or below, and have hit historical lows in recent years. Canadian landings in area 5 were more than twice the U.S. landings in the 1960's, but have since also declined considerably. Currently, the area of highest exploitation of the species in the northwestern Atlantic is the Scotian Shelf area (Neilson *et al*. 1993).

NEFSC survey indices have fluctuated considerably since the 1960's (Figure 7), and overall, have declined considerably. Mean weight per tow during spring surveys has remained at an historic low since 1988. During both spring and autumn surveys, mean number per tow has been considerably higher than mean weight per tow, indicating a decrease in the size of halibut. In fact, based on size, almost all halibut caught in the NEFSC surveys from 1988-1998 were juveniles (Figure 8).

The September 1997 'Status of Fisheries of the United States' (National Marine Fisheries Service 1997) reports that the U.S. Atlantic halibut population is currently in an overfished condition.

RESEARCH NEEDS

- There is very little information in the published literature on the biology of northwest Atlantic stocks (relative to European stocks), and almost no information from U.S. waters.
- Information on the egg and larval stages is very scarce. They have proven to be very difficult to catch in large enough numbers to be useful (Haug 1990). More directed sampling effort, better sampling techniques, and better information about the location of spawning events are required. Data on these highly dispersive, pelagic stages are important to understanding recruitment and stock structure.
- Information on the spawning event and the location of spawning sites is vague.
- Information on the migratory patterns of juveniles is lacking. It is believed that the juvenile stage is highly dispersive, but no migration patterns have been shown.
- Mapping of size groups relative to habitat types (e.g., bottom type) based on groundfish survey catches would be of great benefit to defining EFH for the species.
- Improved information on the onset of maturity and stock identification (e.g., genetic differentiation of stocks) is required.

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Table 1. Age and size at maturity of Atlantic halibut, *Hippoglossus hippoglossus*.

Location	**A_{50} (years)**		**L_{50} (cm)**		**Reference**
	male	*Female*	*male*	*female*	
Scotian Shelf, Grand Bank	-	-	66-70	100	Kohler (1967)
Newfoundland, Labrador	8	12	80	125	Bowering (1986)
Western North Atlantic	-	7-12	-	105-150	Miller *et al*. (1991)
Grand Bank, Newfoundland	-	-	80*	115-120*	Methven *et al*. (1992)

**minimum length at maturity*

Table 2. Summary of life history and habitat parameters for Atlantic halibut, *Hippoglossus hippoglossus*.

Life Stage	Size and Growth	Habitat	Substrate	Temperature
Eggs [1]	Eggs are spherical and large. Average egg diameter (post-fertilization) = 3-4 mm. Average incubation = 18 days at 5°C. Norwegian studies show eggs achieve higher specific gravity with age (i.e., become less buoyant).	Unfertilized eggs are not buoyant, but sink to bottom where they are fertilized by males. Norwegian studies show vertical distribution of eggs associated with hydrography. In areas with strongly defined pycnocline, vertical distribution had one clear peak; in areas with less defined pycnocline and weaker stratification, vertical distribution less distinct. In well-stratified areas, older eggs found deeper than younger eggs (but not in more mixed areas).		Optimal temperatures in lab experiments: 5 and 7°C. Incubation time to 50% hatch varies with temperature: 20 days at 4.7°C, 18 days at 5°C, and 13 days at 7°C.
Larvae [2]	Hatch at an immature stage, with no pigmentation and mouth closed, and very large yolk sac, at size of: 6-7 mm length. Norwegian studies found larvae are able to feed 28-35 days post-hatch at 5°C (still with large yolk sac), at a body length of 11 mm; yolk sac resorption complete after 50 days post-hatch at 5.3°C; growth 0.1mm/d up to day 50. Metamorphosis begins with left eye migration at ~2 cm.	Larvae are pelagic and tend to rise toward surface and drift inshore until metamorphosis. The smallest bottom stages collected from waters < 50 m.		
Juveniles [3]	Metamorphosis begins at ~24 mm, at ~90 days. Transformation complete by 4-10 cm and up to 1 year.	Juveniles are most common in shallow water, 20-60 m, in Atlantic Canada. Nursery areas located on the shelf; Sable Island Gully area may serve as nursery area before juveniles begin their dispersive phase.		In a Newfoundland laboratory study, juveniles were able to survive extended periods at subzero winter temperatures in good condition. Became inactive and ceased to feed at temps < 2.0°C.
Adults [4]	Historically halibut caught off US east coast weighed up to > 300 kg; more recently < 100 kg. In NF and Labrador males range from 40-189 cm TL (majority 50-79 cm); females range from 40-229 cm TL (majority 80-89 cm). Full grown females in the Gulf of Maine average 45.5-68 kg. Female max. age/size = 35 yrs/220 cm; male max. size = 89% of female size at same age. Growth: females grow faster and attain larger size than males. Halibut older than 10 years exhibit a more rapid rate of growth than any other flatfish. Maturity: males mature at an earlier age than females. SS: male L_{50}=66-70 cm, female L_{50}= 100 cm; NW Atlantic: female A_{50}=7-12 yrs, L_{50}=105-150 cm; NF/Labrador: male L_{50}=8 yrs, A_{50}=80 cm, first appeared sexually mature at 40-59 cm (4 yrs), all mature by 110-119 cm; female A_{50}=12 yrs, L_{50}=125 cm; first mature at 50-79 cm (6 yrs), all were mature by 130-149 cm; GrB: males first mature at 80 cm, females first mature at 115-120 cm.	Range from Labrador shelf, along edges of the Grand Bank, outer Scotian Shelf and Georges Bank, south to Virginia (but very few south of Long Island). Range from 37-1000 m; depth limit uncertain. Gulf of Maine: shift from deeper waters in winter to shallower in summer, food supply influences seasonal distribution. Scotian Shelf: found mainly on banks and in the head of the BF, in deeper waters, 165-229 m; most abundant in deep water in spring and early fall, shallower in summer (< 37 m); commercial catches most common at 200-300 m. Newfoundland/Labrador: most abundant in deepwater channels (100-700 m); absent from shallower areas and along coastline; peak numbers caught in Aug.; max. abundance during Jan-June at 501-600 m, and during July-Dec at 300-500 m.	Usually found on sand, gravel or clay; not on soft mud or on rock bottom.	Found at temperatures ranging from -0.5 to 13.6°C, avoid < 2.5°C. Most halibut caught within temperatures of 3-9°C, average 5-6°C.

[1] Nickerson (1978), Blaxter *et al.* (1983), Haug *et al.* (1986), Scott and Scott (1988), Miller *et al.* (1991), Collette and Klein-MacPhee (in prep.)
[2] Nickerson (1978), Blaxter *et al.* (1983), Collette and Klein-MacPhee (in prep.)
[3] Nickerson (1978), Scott and Scott (1988), Goff *et al.* (1989), Miller *et al.* (1991), Stobo *et al.* (1993)
[4] McCracken (1958), Kohler (1967), Nickerson (1978), Scott (1982), Bowering (1986), Scott and Scott (1988), Miller *et al.* (1991), Methven *et al.* (1992), Neilson *et al.* (1993), Stobo *et al.* (1993), Mahon (1997), Collette and Klein-MacPhee (in prep.)

Table 2. cont'd.

Life Stage	Salinity	Prey	Predators	Spawning	Notes
Eggs [1]	Various reports of neutral buoyancy of eggs at 34.7-36.5 ppt; thus at lower salinities eggs are negatively buoyant and thought to develop on or near the sea bed. Norwegian studies show negative buoyancy is due to high organic matter content of the egg; older eggs found at higher salinities (i.e., greater depths) than earlier egg stages in well-stratified areas.		High specific density of eggs is a possible adaptation to reduce mortality; i.e., sinking eggs are less vulnerable to predation near sea floor than in pelagic zone.	Spawning occurs at great depths (see adults section for details).	Very large eggs are unusual when compared to most other marine teleosts. Eggs bathypelagic: they're buoyant but don't float at surface; drift suspended in water column (> 54-90 m in the Gulf of Maine). Tend to sink toward bottom as development proceeds.
Larvae [2]	Norwegian lab experiments have shown that salinities of 30-35 ppt are preferred and that larvae are neutrally buoyant in 35.8 ppt sea water at hatching, in 34.8 ppt on day 12, and in 36.4 ppt on day 35.				Long time to first exogenous feeding and in general long period of larval development is unusual compared to other marine fish larvae in this part of the Atlantic.
Juveniles [3]					The juvenile phase is when most movement occurs. The area near BB may serve as a nursery area for immature halibut; tagging data suggests that many NF fish originated from BB nursery area.
Adults [4]	Scotian Shelf: found at salinities ranging from 30.4-35.3 ppt, average ~33 ppt.	Voracious feeders. Diet changes with size: 1) up to 30 cm: almost exclusively invertebrates, mainly annelids and crustaceans, also mollusks; 2) 30-80 cm: invertebrates, fish or both; 3) > 80 cm: almost exclusively fish. Most important prey in GM (1977-1980) were squid *(Illex*), crabs (*Cancer*), silver hake, northern sand lance, ocean pout, and alewife. Other commonly eaten fish species: cod, cusk, haddock, ocean perch, sculpins, herring, capelin, skates, flounder and mackerel.	Halibut are a staple for Greenland sharks (*Somniosus microcephalus*); also preyed on by seals and spiny dogfish (*Squalus acanthus*).	Spawning grounds not well known; various spawning areas from Georges Bank to Grand Bank; no longer any spawning population in the Gulf of Maine. Believed to occur on the slopes of offshore banks as well as on the continental slope. Depths of spawning not clear but are thought to spawn in deep waters (> 180 m, to 700 m), on the bottom. Time of spawning: a) Scotian Shelf: winter-early spring (mostly Feb-April); b) Gulf of St. Lawrence: Feb-April; c) Newfoundland: winter-later spring; d) Browns Bank to Grand Bank: peaks Nov-Dec. Large females may produce up to 2 million eggs; can spawn numerous batches of eggs within a single reproductive season.	Halibut in the GM are thought to originate from halibut immigrating from east and north of Cape Sable rather than from local production. Smaller fish generally exhibit more extensive movement than adults. Typically not highly migratory; most fish remain in main shelf areas where they are tagged. Recaptures show movement to east; deepwater crossing of channels probable. Some movement from sw NS to GB and GrB (distance traveled ranges from 161-968 km); possible return to SS for spawning. Capable of extensive movement; one fish tagged in GSL recovered in Iceland (1600 miles away).

[1] Riis-Vestergaard (1982), Blaxter *et al.* (1983), Haug *et al.* (1986), Scott and Scott (1988), Collette and Klein-MacPhee (in prep.)
[2] Blaxter *et al.* (1983)
[3] Neilson *et al.* (1993), Stobo *et al.* (1993)
[4] McCracken and Martin (1955), McCracken (1958), Wise and Jensen (1959), Jensen and Wise (1961), Kohler (1964, 1967), Maurer and Bowman (1975), Nickerson (1978), Riis-Vestergaard (1982), Scott (1982), Godo and Haug (1988), Scott and Scott (1988), Miller *et al.* (1991), Methven *et al.* (1992), Neilson *et al.* (1993), Stobo *et al.* (1993), Mahon (1997), Collette and Klein-MacPhee (in prep.)

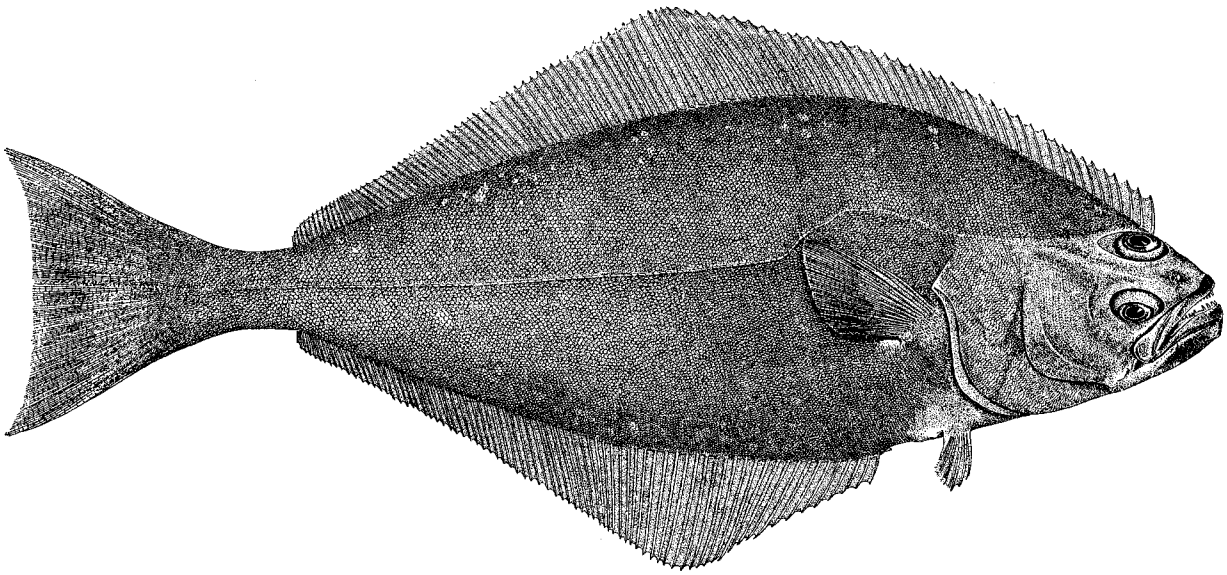


Figure 1. The Atlantic halibut, *Hippoglossus hippoglossus* (from Goode 1884).

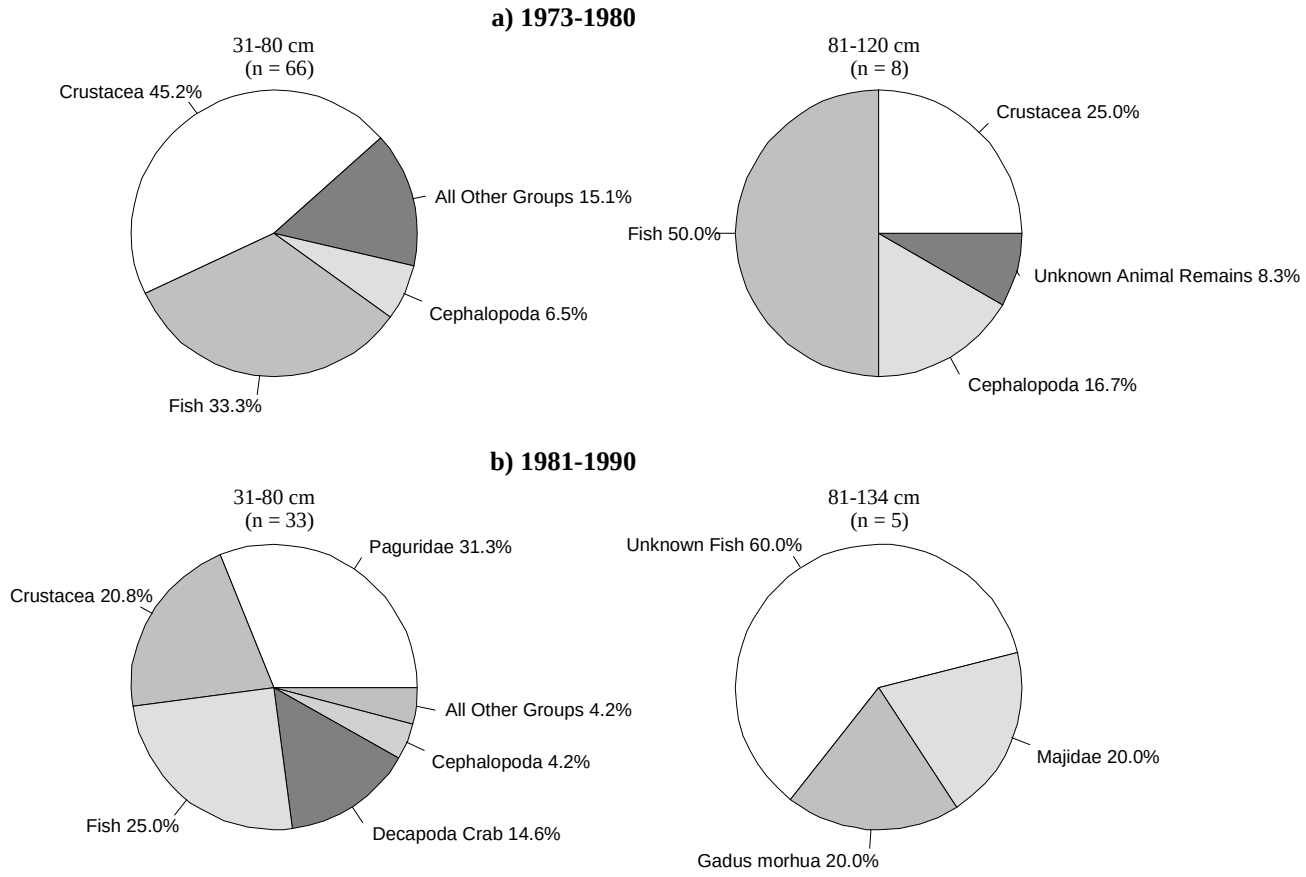


Figure 2. Abundance (% occurrence) of the major prey items in the diet of Atlantic halibut from NEFSC trawl surveys. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details]. The category "unknown animal remains" refers to unidentifiable animal matter.

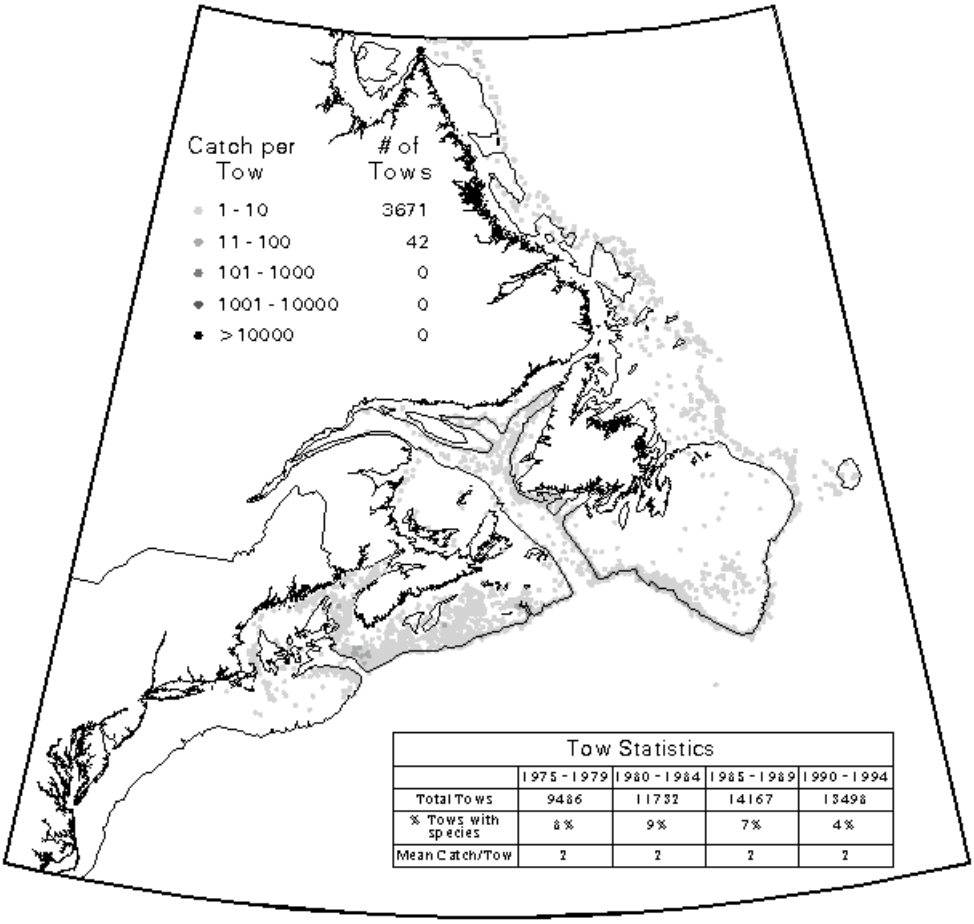


Figure 3. Distribution and abundance of Atlantic halibut from Newfoundland to Cape Hatteras during 1975-1994. Data are from the U.S. NOAA/Canada DFO East Coast of North America Strategic Assessment Project (http://www-orca.nos.noaa.gov/ projects/ecnasap/ecnasap_table1.html).

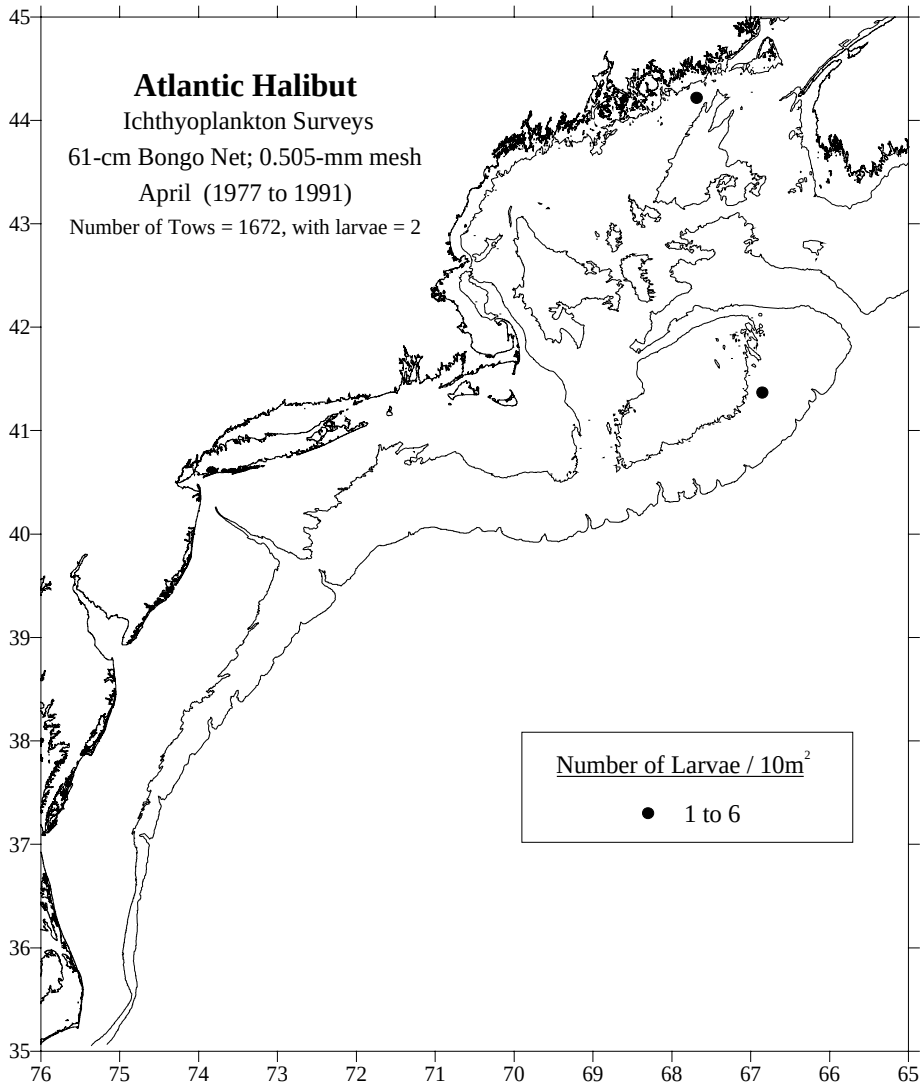


Figure 4. Distribution of Atlantic halibut larvae collected during NEFSC ichthyoplankton surveys, 1977-1991 [see Reid *et al.* (1999) for details]. Larval densities are represented by dot size; the 60 and 200 m contour lines are also shown.

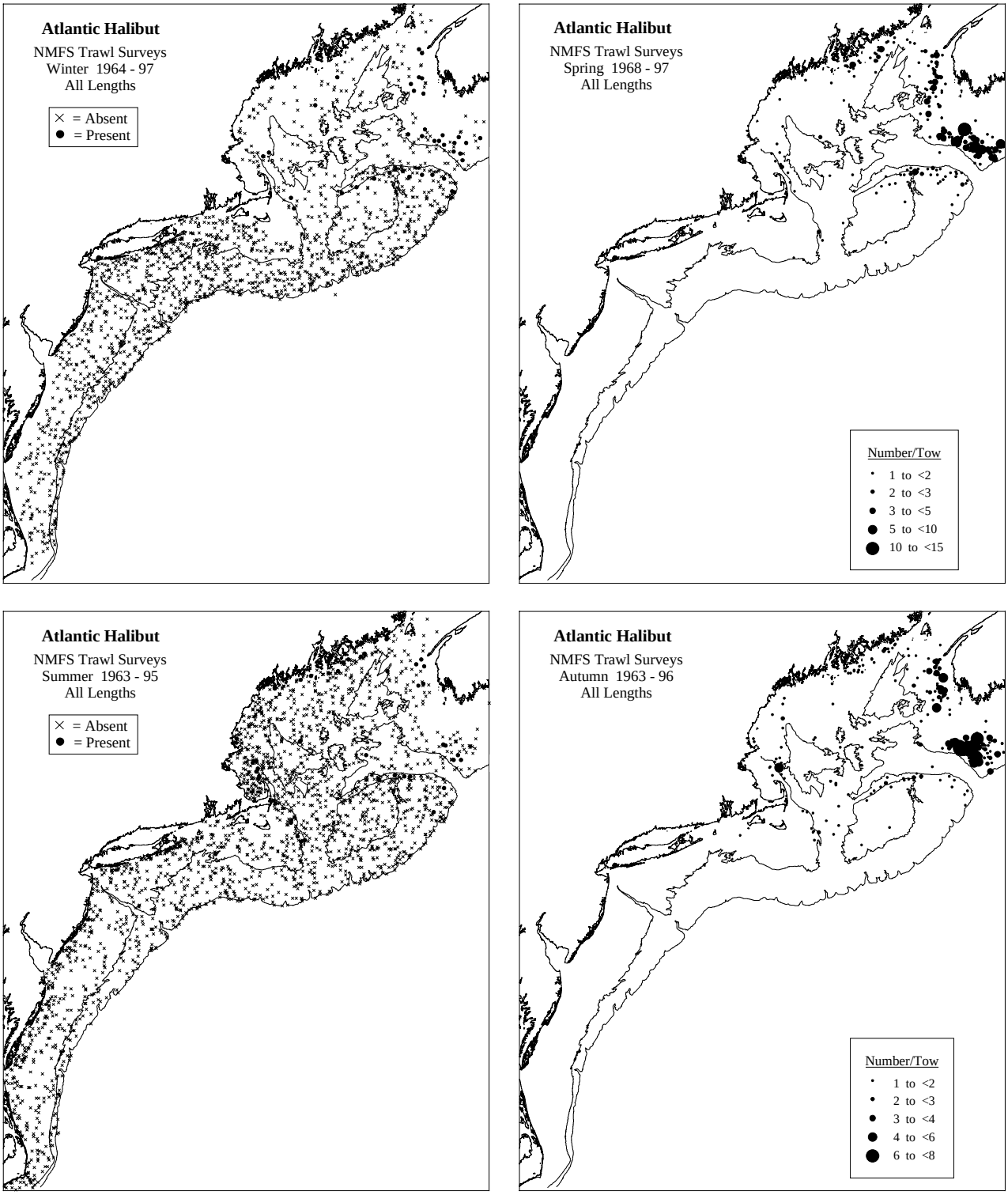


Figure 5. Distribution of juvenile and adult Atlantic halibut collected during NEFSC bottom trawl surveys (winter, spring, summer, and autumn, 1963-1997). Densities (number per tow) are represented by dot size in spring and autumn plots, while only presence and absence are represented in winter and summer plots [see Reid *et al.* (1999) for details].

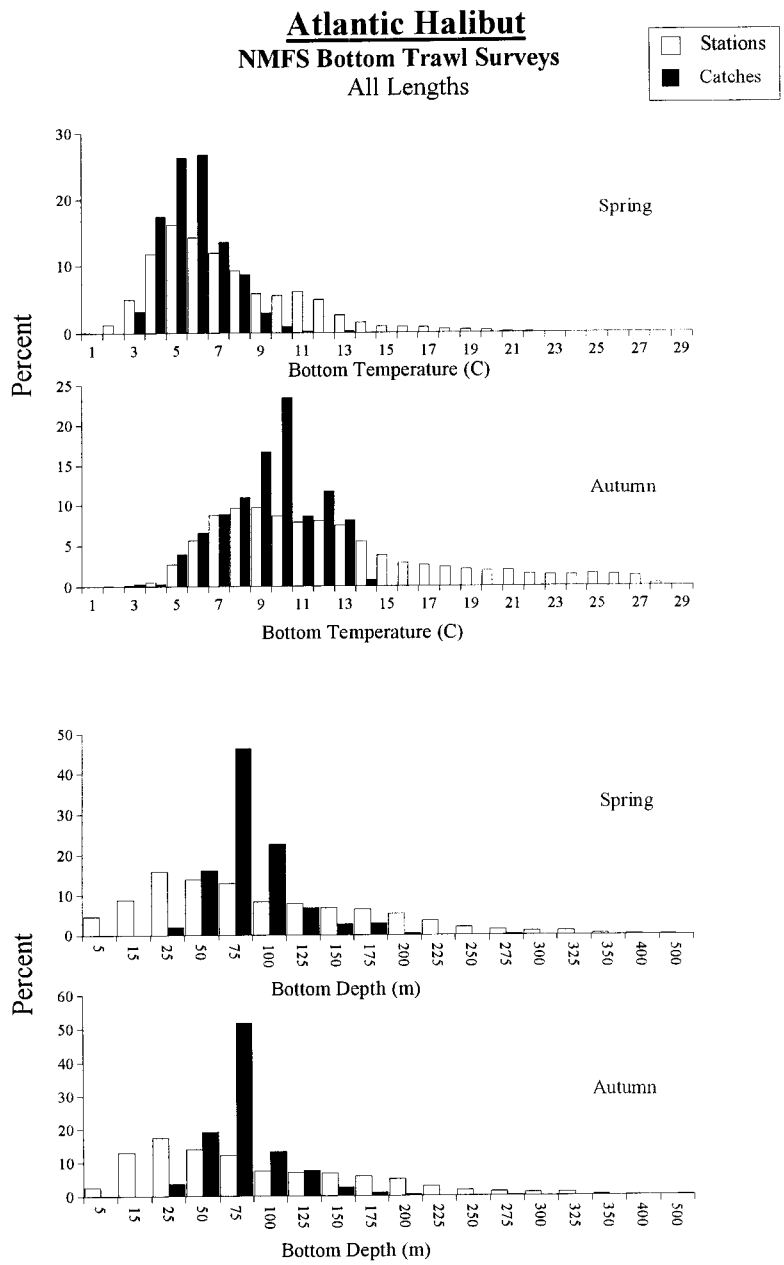
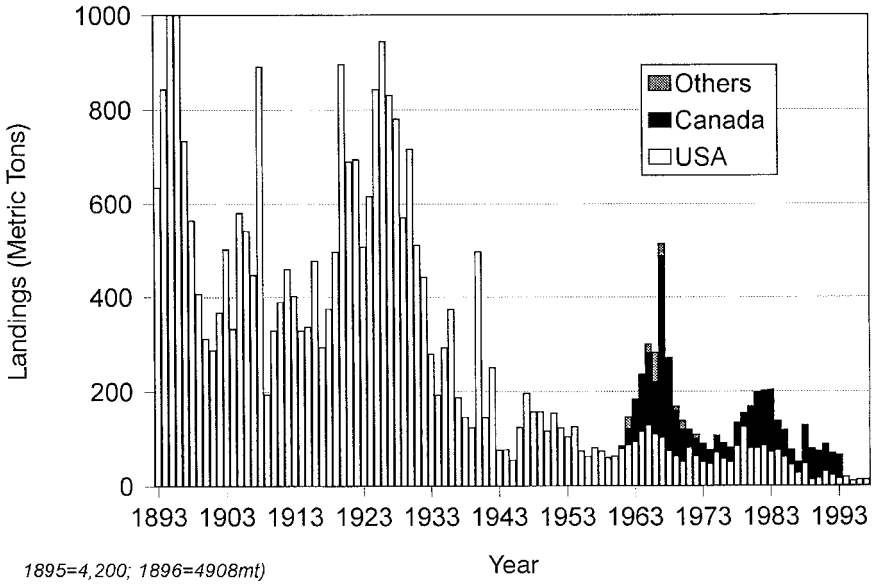


Figure 6. Abundance of juvenile and adult Atlantic halibut relative to water temperature and depth based on spring and autumn NEFSC trawl surveys (1963-1997). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).



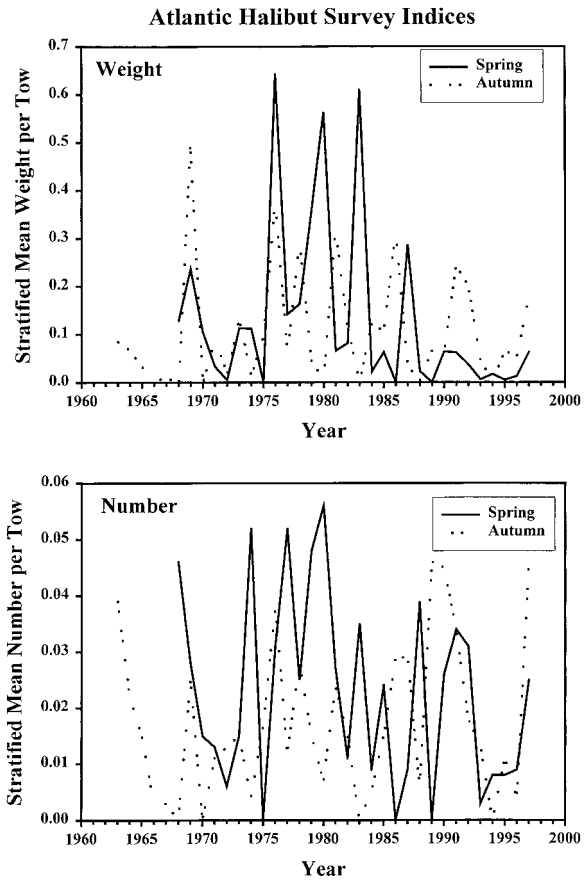


Figure 7. Commercial landings (1893-1997) and survey indices (1963-1997) for Atlantic halibut in the Gulf of Maine and Georges Bank.

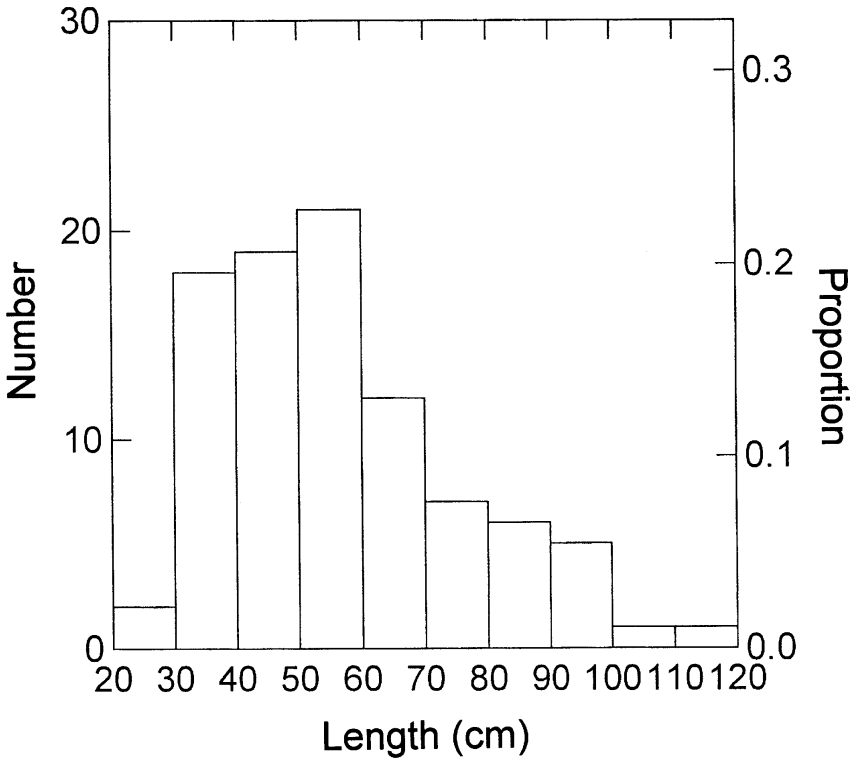


Figure 8. Length distribution of Atlantic halibut caught in NEFSC trawl surveys during 1988-1998.

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The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific ournals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

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Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series includes: data reports on field and lab observations or experiments; progress reports on continuing experiments, monitoring, and assessments; background papers for scientific or technical workshops; and simple bibliographies. Issues receive internal scientific review but no technical or copy editing. No subscriptions. Free distribution of single copies.

Fishermen's Report **and** ***The Shark Tagger*** -- The ***Fishermen's Report*** (FR) is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of the FR; copies are available through free subscription. ***The Shark Tagger*** (TST) is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of the TST; copies are available only to participants in the tagging program.

To obtain a copy of a technical memorandum or a reference document, or to subscribe to the fishermen's report, write: Research Communications Unit, Northeast Fisheries Science Center, 166 Water St., Woods Hole, MA 02543-1026. An annual list of NEFSC publications and reports is available upon request at the above address. Any use of trade names in any NEFSC publication or report does not imply endorsement.

NOAA Technical Memorandum NMFS-NE-126

Essential Fish Habitat Source Document:

Atlantic Herring, *Clupea harengus*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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NOAA Technical Memorandum NMFS-NE-126

This series represents a secondary level of scientifiic publishing. All issues employ thorough internal scientific review; some issues employ external scientific review. Reviews are -- by design -- transparent collegial reviews, not anonymous peer reviews. All issues may be cited in formal scientific communications.

Essential Fish Habitat Source Document:

Atlantic Herring, *Clupea harengus*, Life History and Habitat Characteristics

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September 1999

Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

---

[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, CHIEF
ECOSYSTEMS PROCESSES DIVISION
NORTHEAST FISHERIES SCIENCE CENTER

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INTRODUCTION

The Atlantic herring, *Clupea harengus* (Figure 1), is a schooling, coastal pelagic species that inhabits both sides of the North Atlantic Ocean. In the western North Atlantic they range from Labrador to Cape Hatteras where spring and autumn spawning populations support major commercial fisheries (Messieh 1988). Juveniles and adults undergo complex north-south and inshore-offshore migrations for feeding, spawning, and overwintering. In U.S. waters, herring from the Gulf of Maine and Georges Bank are assessed and managed as a single stock complex with two major spawning components (Atlantic States Marine Fisheries Commission 1995; Northeast Fisheries Science Center 1996).

This report provides information on the life history and habitat characteristics of Atlantic herring stocks that inhabit U.S. waters. This includes spawning populations of the Gulf of Maine and Georges Bank/Nantucket Shoals, as well as the southwestern Nova Scotia population that is believed to mix with the coastal Maine herring population (Stobo 1983).

LIFE HISTORY

This section provides a brief review of the biology of Gulf of Maine area Atlantic herring. More detailed reviews are provided by Bigelow and Schroeder (1953), Sindermann (1979), Kelly and Moring 1986, the Atlantic States Marine Fisheries Commission (1998), Munroe (in prep.), and Tupper *et al.* (in prep.).

EGGS

Herring deposit demersal eggs on a variety of substrates ranging from boulders, rocks, and gravel to sand, shell fragments, and macrophytes in 20 to 80 m of water in areas with strong tidal currents. The eggs are 1.0-1.4 mm in diameter (Bigelow and Schroeder 1953; Fahay 1983) and adhere to the bottom, forming extensive egg beds that are often many layers deep (Stevenson and Knowles 1988). Gravel is the preferred spawning substrate (Drapeau 1973), but eggs have been reported on aquatic macrophytes on Jeffreys Ledge (Cooper *et al*. 1975) and in the Gulf of St. Lawrence, (Messieh *et al*. 1985). The eggs hatch in 10-15 days (Bigelow and Schroeder 1953).

LARVAE

The larvae are pelagic, free-floating, and 4-9 mm long (Das 1972; Graham and Chenoweth 1973; Cooper *et al*. 1975). The larval stage of fall-spawned herring in the Gulf of Maine lasts 4-8 months, depending on the timing of spawning. The larval stage is shortest for early-spawned (August) larvae, and longest for late-spawned (December) herring. Currents affect the pelagic larvae; however, they may or may not disperse randomly from the spawning grounds. Some larvae are retained for several months after hatching on or near the spawning site, while other larvae are dispersed soon after hatching and drift with residual currents (Iles and Sinclair 1982; Townsend *et al*. 1986; Chenowith *et al*. 1989; Smith and Morse 1993).

Larvae from Nantucket Shoals and Georges Bank tend to drift to the southwest (Lough *et al.* 1980; Grimm 1983). Larvae produced off southwestern Nova Scotia are retained initially near the spawning ground and then drift up into the Bay of Fundy (Iles 1971; Stephenson and Power 1988). Larvae produced in coastal Gulf of Maine generally remain inshore (Graham 1982; Townsend 1992) and disperse in a westerly direction and enter bays and estuaries where they overwinter (Graham *et al*. 1972; Chenoweth *et al*. 1989; Townsend 1992). In some years, late-hatched larvae from Jeffreys Ledge and Stellwagen Bank are transported eastward and overwinter in the Sheepscot River (Lazzari and Stevenson 1992). During the first winter after hatching, herring larvae are exposed to extremely low temperatures and food levels (Townsend and Graham 1981; Graham *et al*. 1990). It is not clear if larval survival is enhanced as a result of overwintering in nearshore and estuarine waters (Graham 1982) or in coastal waters (Townsend 1992).

Herring are one of the few species that perform extensive vertical migrations as larvae. They make diel or semi-diel vertical migrations throughout the water column that may be linked to time of day or turbidity (related to light level), tidal currents, or shifts in prey abundance (Lough and Cohen 1982). Vertical movements may be a larval retention mechanism enabling them to control their displacement by tidal currents (Graham 1972; Stephenson and Power 1988).

JUVENILES

Larvae metamorphose into juveniles at 40-50 mm total length (TL) in early spring (April-May). Juveniles form large schools in coastal waters throughout the Gulf of Maine (Munroe, in prep.) and off southern New England, where they have been collected in surveys off Connecticut and southern Massachusetts in May and June (A.B. Howe, Massachusetts Division of Marine Fisheries, East Sandwich, MA, personal communication). In the summer and fall, juveniles move out of nearshore waters to overwinter in deep bays or near the bottom in offshore areas (Boyar 1968). Two-year old juveniles return inshore the following spring when they are fully recruited to the coastal fishery.

Juveniles (and adults) perform vertical migrations that are linked to changing light intensity, most likely in

response to movements of their prey (Blaxter 1985). They move up in the water column at twilight and remain near the surface when light intensity is low (Johnson 1940; Brawn 1960a); activity is highest just after sunrise and just before sunset. Blaxter (1985) suggested that herring move away from the surface in daylight to avoid predation by diving birds.

ADULTS

Both males and females generally mature between 25-27 cm (O'Brien *et al*. 1993). Mean lengths of herring on Georges Bank ranged from 23.7-25.6 cm at age 3 to 33.0-33.3 cm at age 7 (Boyar 1968). Maximum size is about 39 cm TL and 0.68 kg, and maximum age is 15-18 years (Anthony 1972). Adults almost invariably occur in large schools. Vertical migrations linked to changing light intensity are pronounced and are probably related to movements of prey and avoidance of predatory seabirds (Blaxter 1985).

A reduction in mean weight at age of adults has occurred since 1983. The mean weight of fish averaged across ages 3 to 7 was 247 g in 1983, 160 g in 1988, 137 g in 1994, and 146 g in 1997. Changes in the seasonal distribution of fishing and changes in the contribution of faster-growing Georges Bank fish did not affect the reductions in mean weight because the fishery has occurred only in the Gulf of Maine since 1983 (D.K. Stevenson, Maine Deptartment of Marine Resources, West Boothbay Harbor, ME, personal communication).

REPRODUCTION

In general, males and females mature at around 3-4 years old. Length at maturity of herring has remained fairly constant for 40 years (Table 1) in contrast with other New England marine fish species that have experienced significant declines in size at maturity in recent years. In this report, size at maturity follows O'Brien *et al*. (1993) and lengths were rounded to the nearest whole centimeter. Thus, herring ≥ 25 cm are considered adults.

Age at maturity may be density dependent; a higher percentage of age 3 fish mature when abundance is low (Tupper *et al*., in prep.). Beginning in 1983, coincident with increasing population size (stock recovery), herring growth rates decreased and the percentage of fish maturing at age 3 declined, especially on Georges Bank and Nantucket Shoals (D.K. Stevenson, Maine Deptartment of Marine Resources, West Boothbay Harbor, ME, personal communication). The percent of mature age 3 fish declined from 50-70% in the mid-1980s to 10-30% in 1990-1996.

Historically, three herring spawning stocks have been recognized in the U.S. fishery: southwestern Nova Scotia, coastal Gulf of Maine, and Georges Bank/Nantucket Shoals (Figure 2). Spawning off Nova Scotia occurs in the Trinity Ledge/Lurcher Shoals/German Bank area (Stephenson and Power 1988). In the inshore coastal areas of the Gulf of Maine, spawning occurs in Scots Bay in the Bay of Fundy, off eastern Maine and the southwest shore of Grand Manan Island, off Penobscot Bay, and in the western gulf off Wood Island, Jeffreys Ledge, and Stellwagen Bank (Tupper *et al*., in prep.). On Georges Bank, major spawning sites have historically been located near the Northeast Peak, Cultivator Shoals, and Nantucket Shoals (Boyar 1968; Anthony and Waring 1980; Grimm 1983; Lough *et al*. 1985) (Figure 3).

Gulf of Maine herring spawn in the fall, typically between July and November (Sinclair and Tremblay 1984). Spawning begins in the northern areas of the Gulf and occurs progressively later with decreasing latitude; spawning commences last on Nantucket Shoals (Bigelow and Schroeder 1953). Spawning off southwestern Nova Scotia occurs from July to November and peaks in September-October (Boyar 1968; Das 1968, 1972). In the coastal Gulf of Maine, spawning occurs from August to October (Kelly and Stevenson 1985), and peaks in mid-September to mid-October in eastern Maine and in October in western Maine (Graham *et al*. 1972). On Jeffreys Ledge, spawning occurs from September to November (Kelly and Stevenson 1985). On Georges Bank, spawning occurs from late August to December (Boyar 1968; Berenbeim and Sigaev 1978; Lough *et al*. 1980) with a peak in September-October (Boyar 1968; Pankratov and Sigaev 1973; Grimm 1983). On Nantucket Shoals, spawning peaks from October to early November, 1-2 weeks later than on Georges Bank (Lough *et al*. 1980; Grimm 1983).

There is some evidence of spring spawning. Approximately 2% of the fish sampled in the coastal Gulf of Maine and on the southwestern Scotian Shelf during spring were in spawning condition (Boyar 1968).

FOOD HABITS

Larvae begin exogenous feeding before the yolk sac is completely absorbed (Bigelow and Schroeder 1953). They feed opportunistically on whatever zooplankton of appropriate size are abundant (Sherman and Perkins 1971). Their primary prey are copepods (Bigelow and Schroeder 1953; Sherman and Honey 1971), in particular, *Pseudocalanus* sp., *Paracalanus parvus*, and *Centropages typicus* (Cohen and Lough 1983). Juveniles feed on up to 15 different groups of zooplankton; the most common are copepods, decapod larvae, cirriped larvae, cladocerans, and pelecypod larvae (Sherman and Perkins 1971). Adults have a diet dominated by euphausiids, chaetognaths, and copepods (Bigelow and Schroeder 1953). Maurer (1976) reported that the most important prey items of adult herring collected on Georges Bank

were chaetognaths (*Sagitta elegans*, 43% by weight), euphausiids (*Meganyctiphanes norvegica*, 23%; *Thysanoessa inermis*, 6.1%), pteropods (*Limacina retroversa*, 6.2%), and copepods (3%).

During 1973-1980, the diets of juveniles and adults collected in the Gulf of Maine during Northeast Fisheries Science Center (NEFSC) trawl surveys were dominated by euphausiids (47% by weight), of which more than 50% were *M. norvegica*, and copepods (26%) (Figure 4a). On the Scotian Shelf, euphausiids composed more than 50% of the herring diet. During 1981-1990, amphipods were the most common prey item on Georges Bank, followed by mysids (Figure 4b). Present in smaller amounts were euphausiids, copepods, chaetognaths, and unidentified fish larvae. Herring diets in southern New England and the Mid-Atlantic during 1981-1990 were more varied.

PREDATION

Juvenile and adult herring are preyed on by many marine species, including sand lance (*Ammodytes hexapterus*), cod *(Gadus morhua)*, pollock (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*), silver hake, white hake (*Urophycis tenuis*), striped bass, mackerel, billfish, tuna, salmon, sculpins, winter flounder (*Pseudopleuronectes americanus*), dogfish, porbeagle shark, and skates (*Raja* spp.). Fish predation can be a significant source of mortality, especially at spawning time. Several fish species, as well as American lobster (*Homarus americanus*) and starfish, eat herring eggs. Sand lance may consume large quantities of eggs and larvae, which are sometimes cannibalized by adult herring as well. Jellyfish may also be an important predator on the early life stages. Large numbers of herring are also eaten by marine birds, northern shortfin squid, seals, porpoises, and whales (Munroe, in prep.).

MIGRATION

Adult herring make extensive feeding, spawning, and overwintering migrations. Schooling behavior begins at metamorphosis (Sindermann 1979). Schools are usually composed of fish of similar size (Bigelow and Schroeder 1953), and to a large extent, of the same year class (Munroe, in prep.). In the Gulf of Maine, juveniles spend the summer in inshore areas off Maine and New Brunswick. In autumn, they move south to waters off Massachusetts and Rhode Island; they return to Maine the following spring (Tupper *et al*., in prep.). Some juveniles spend at least the spring and early summer off southern New England, especially off southern Massachusetts (through at least mid-June) before moving into the Gulf of Maine or offshore, presumably east of Cape Cod. Juveniles are sometimes abundant in winter and spring in the Hudson-Raritan estuary and in fall in Long Island Sound. Young-of-the-year herring are not effectively retained by standard resource survey trawls, but in Long Island Sound, 15-min tows using a trawl with 0.25-inch codend liner have yielded up to 80,000 herring (Gottschall *et al*., in review).

Adult herring are highly migratory and there is evidence of intermixing of adults from different spawning groups during the non-spawning phase of their seasonal cycle (Sinclair and Iles 1985). Three general migratory patterns are recognized off the northeast coast of the U.S. (NAFO regions 4X, 5, and 6) (Sindermann 1979; Figure 5). Herring that spend the summer and fall in southwest Nova Scotia overwinter in Chedabucto Bay in northeast Nova Scotia. The Georges Bank/Nantucket Shoals stock overwinters south of Cape Cod and along the mid-Atlantic coast. The stock moves north onto Georges Bank and into the Gulf of Maine in the spring before congregating on spawning grounds southeast of Nantucket and on Georges Bank in the fall. The migrations of coastal adults are less well known. Adults in the western Gulf of Maine may migrate southwest along the coast after spawning and overwinter at the western extreme of their migratory path, possibly south of Cape Cod. Adults in the eastern Gulf of Maine may migrate southwest and overwinter in Massachusetts Bay and southern New England.

STOCK STRUCTURE

Atlantic herring may have the most complex stock structure of any marine fish (Iles and Sinclair 1982) and attempts to define stock structure have a long history (Kornfield *et al*. 1982). Herring in the Gulf of Maine region have historically been considered three distinct spawning stocks: Nova Scotia, coastal Gulf of Maine, and Georges Bank/Nantucket Shoals (Iles 1972; Atlantic States Marine Fisheries Commission 1995) (Figure 2). In U.S. waters, they are treated as one coastal stock complex for assessment (Northeast Fisheries Science Center 1996). Evidence for and against the discreteness of local herring stocks includes spawning and larval distributions, tagging studies, morphometrics and meristics, genetics, and parasites.

Genetic studies indicate that herring spawning groups are not discrete, genetically distinct stocks. Safford and Booke (1992) did not find consistent differences between herring from two well-separated spawning areas, Jeffreys Ledge and Trinity Ledge, using traditional enzyme electrophoresis. Analysis of mitochondrial DNA also failed to distinguish between fish from these areas (Kornfield and Bogdanowicz 1987). Kornfield *et al*. (1982) found low levels of genetic heterogeneity among fall spawning herring in the Gulf of St. Lawrence and the Gulf of Maine, and concluded there is only one genetic population of fall spawners in the northwest Atlantic. They did, however, find that spring spawning herring

from the Gulf of St. Lawrence were genetically distinct from fall spawners in the Gulf of St. Lawrence and the Gulf of Maine.

There has been speculation that adult herring return to spawn at the spawning grounds where they were born, but this has only been demonstrated in one study. Herring off Newfoundland were shown to have a homing rate of 66-93% (Wheeler and Winters 1984). The inability to tag herring larvae has made it impossible to determine whether individuals are actually returning to the site where they were spawned. Results from an international herring tagging program and from the Canadian Department of Fisheries and Oceans (summarized in Stobo 1983) indicate that stocks are generally mixed throughout most of the year and that spatial and temporal isolation occurs chiefly during spawning. However, migration patterns of individual stocks persist among years and there is little straying of fish from a given stock. Tagging along the Maine and New Hampshire coasts by the Maine Department of Marine Resources showed consistency of migration patterns over time (Creaser and Libby 1988). Patterns were similar for juveniles and adults, but adults often covered greater distances; many adults tagged in summer in eastern Maine overwintered in Massachusetts Bay. There was some tendency for adults tagged in eastern Maine to be recovered in the southwestern Nova Scotian fishery.

Herring in the Gulf of Maine and on Georges Bank and the Scotian Shelf spawn in well-defined areas, although homing to natal spawning grounds has not been demonstrated. Distinct and spatially stable larval retention areas may also promote genetic isolation. Iles and Sinclair (1982) stated that larval herring were concentrated in such areas in the northwest Atlantic and hypothesized that the number of retention areas determined the number of genetically distinct stocks. However, Smith and Morse (1993) discussed evidence for larval drift in the region and questioned whether stocks could be separated through larval retention. Chenoweth *et al*. (1989) reported extensive westward transport of larvae from Gulf of Maine spawning sites and possible larval retention by a sharp oceanographic front near Grand Manan Island.

Pectoral fin ray counts were once considered the most promising meristic character for discriminating stocks. The number of pectoral fin rays is related to water temperatures and is determined at an early age. Adult herring from Georges Bank-Cape Cod have lower pectoral fin ray counts than adults from waters to the north, presumably due to warmer temperatures. In the 1958-1963 year-classes, herring from eastern Maine and Nova Scotia had the highest pectoral fin ray counts and fish from western Maine were intermediate in fin ray numbers. However, juvenile fish from Maine had counts similar to fish from Georges Bank-Cape Cod, indicating that they probably came from that area. It is likely that some of those juveniles subsequently entered the Georges Bank fishery (Anthony 1981).

Significant phenotypic differences have been identified among herring spawning groups, but this may reflect different environmental histories rather than genetic differentiation. Safford and Booke (1992) found differences in several morphometric characters between herring from Jeffreys Ledge and Trinity Ledge, but overall results supported the single-population hypothesis. They postulate that either sufficient gene flow exists between spawning groups to prevent the evolution of genetically distinct stocks, or that genetic isolation is a recent phenomenon and genetic differences have not had time to evolve.

Parasites may be useful as biological indicators to differentiate between fish populations. Parasites of Georges Bank and Gulf of Maine herring have apparently not been studied, but Bay of Fundy, Scotian Shelf, and Gulf of St. Lawrence fish have been surveyed (McGladdery and Burt 1985). Seven of 18 parasite species identified were potential indicators. Patterns of occurrence of the parasites indicated movement of fish to and from the Bay of Fundy, and extensive mixing of stocks in feeding and nursery areas.

McQuinn (1997) reviewed arguments for a discrete versus dynamic balance population concept for Atlantic herring. He proposed that the population structure and dynamics of herring fit well within a metapopulation model. This model allows for significant mixing and gene flow among units that still retain considerable persistence and discreteness due to behaviorally-induced homing to spawning grounds. Although the metapopulation (or stock complex) is the practical unit for management, local populations must be conserved to preserve spawning potential and viable coastal fisheries. The metapopulation may increase resilience of local populations because a strong year class may enhance several local populations (McQuinn 1997).

HABITAT CHARACTERISTICS

Information on the life history and habitat characteristics of Altantic herring are presented here and are summarized in Tables 2-5. This information is limited to the Georges Bank, coastal Gulf of Maine, and Nova Scotia stocks, which occur in U.S. waters at some time during the year. Information for other stocks in the northwest and northeast Atlantic were not considered.

EGGS

Herring eggs are usually spawned on horizontal beds at depths of 40-80 m on Georges Bank, 20-50 m in coastal Gulf of Maine, and as shallow as 11-13 m off southwest Nova Scotia. Eggs are laid on gravel (the preferred substrate), sand, rocks, shell fragments, aquatic

macrophytes, and structures such as lobster pots. Spawning occurs in areas of well-mixed water with tidal currents of 1.5-3.0 knots. These high energy environments provide aeration and reduce siltation and accumulation of metabolites. Spawning occurs at temperatures of 12-15°C on Georges Bank, 6-13°C on Nantucket Shoals, and 8-12°C near Grand Manan Island, and at salinities of 31.9-33.0 ppt. Laboratory studies found normal egg development and hatching at 10 and 15°C, no development at 0 and 5°, and rapid initial development followed by 100% mortality at ≥ 20°C.

LARVAE

Larvae occur at temperatures of 9-16°C and salinities of 32 ppt in the Gulf of Maine. Survival and growth in winter may be enhanced in offshore waters, which are up to 5°C warmer than inshore waters. Larvae may acclimate to lower temperatures when the rate of temperature decline is slow; in the laboratory, survival was ≤ 30% when the rate of change was 0.1-0.25°C/day, but up to 70% when the rate of change was < 0.1°/day. Larvae occur at depths > 50 m on Georges Bank where they are retained in the clockwise current gyre for several months. Light, turbidity, and tidal currents may control their vertical migrations.

In the NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) survey, most larvae were collected at 8-14°C from September to November; maximum abundance was at 9-12°C (Figure 6). In December, larvae occurred at 6-11°C with the majority collected at 8-9°C. Temperatures at the time of collection decreased each month from January to March and increased from April to August. Larvae were collected at stations with bottom depths ranging from 10-250 m, although most were collected at stations with depths of 50-90 m (Figure 6).

JUVENILES

In the Sheepscot River, juveniles prefer temperatures of 10-16°C. They may overwinter in Passamaquoddy Bay until the temperature drops to 0°C. In the laboratory, the upper lethal temperature is 19.5-21.2°C, the lower lethal temperature is -1.1°C, and the preferred temperature is 8-12°C. Juveniles in the Gulf of Maine occur at average surface salinities of 31-32.4 ppt. In the Sheepscot River, they occur at 16-32 ppt, although most occur at 30-32 ppt. Laboratory studies indicate a general preference for 26-32 ppt. This salinity preference is temperature dependent; there is a preference for > 29 ppt at < 10°C. There is a tendency to prefer higher salinities and to avoid brackish conditions with increasing fish age.

Juveniles caught during NEFSC bottom trawl surveys were most abundant at temperatures of 3-4°C and depths of 30-90 m in spring, 6-9°C and 15-135 m in summer, 8°C and 30-60 m in fall, and 2-4°C and 30-60 m in winter (Figure 7a). There is a bimodal distribution in occurrence relative to temperature based on Massachusetts inshore trawl survey catches; relative abundance was highest at 4-7°C and 12°C in spring, and 7-12°C and 17°C in the fall (Figure 8). The bimodality may be related to temperature differences north relative to south of Cape Cod. Relative abundance was greatest at bottom depths of 5-30 m in spring and 5-75 m in the fall. In Narragansett Bay, juveniles were most abundant at 3-6°C in winter, 10-12°C in spring, 17-19°C in summer, and 18-20°C in fall (Figure 9a). Relative abundance was high at bottom depths of 100 ft (30 m) in all seasons and at 30 and 60 ft (9 and 18 m) in spring. In the Hudson-Raritan Estuary, herring were found at 2-6°C and 12-22°C but were most abundant at 4-6°C and at 15-18°C (Figure 10a). There were few differences in abundance over the range of depths and salinities sampled.

ADULTS

In the Gulf of Maine, herring spawn at 7-15°C. Spawning begins earlier in years when August water temperatures are warmer. Adults may overwinter at temperatures as low as 0°C in Passamaquoddy Bay. They generally occur at salinities > 28 ppt and spawn at 31.9-33.0 ppt (never in brackish water). The distribution of schools is often related to concentrations of their euphausiid prey; areas with phytoplankton blooms may be avoided.

Catches of adult herring in the NEFSC bottom trawl survey were greatest at 5°C and 30-50 m in spring, 6°C and 20-130 m in summer, 5-6°C and 60-170 m in fall, and 7-8°C and 70-100 m in winter (Figure 7b). In the Massachusetts inshore trawl survey, the largest catches occurred at 4-6°C in depths of 5-75 m in spring and at 7°C in depths of 50-80 m in the fall (Figure 8). Abundance in Narragansett Bay was highest at 3-6°C and 100 ft (30 m) in winter, 3-5°C and 100 ft in spring and 7-11°C, and 30 ft (9 m) in fall; no adults were caught in summer (Figure 9b). In Long Island Sound, springtime abundance was highest at 9-10°C, 10-30 m, and salinities of 25-28 ppt. The largest autumn catches occurred at 17-21°C, 10-18 m, and 27-28 ppt. In the Hudson-Raritan estuary, catches were highest at 3-6°C and 15-45 ft (4.5-13.5 m) (Figure 10b).

GEOGRAPHICAL DISTRIBUTION

EGGS

The eggs of herring are demersal and adhere to the substrate (Bigelow and Schroeder 1953; Fahay 1983) and were not usually collected during the NEFSC MARMAP

survey. The general location of herring spawning areas in the northwest Atlantic Ocean is presented in Figure 2.

LARVAE

The NEFSC MARMAP survey collected herring larvae from New Jersey to the Bay of Fundy inshore to the seaward limit of the survey (Figure 11). Larvae were collected in all months, even though herring in the Gulf of Maine do not spawn in the spring and larvae undergo metamorphosis in April and May. The highest mean monthly density (351 larvae/10 m^2) occurred in September off southwestern Nova Scotia (Figure 11) when larvae were restricted to the northeastern Gulf of Maine. Larvae were relatively abundant in October (39 larvae/10 m^2) and November (49 larvae/10 m^2); high larval densities occurred from the western Gulf of Maine and Massachusetts Bay to western Georges Bank and Nantucket Shoals indicating that spawning began earlier in the northeast (see also Bigelow and Schroeder 1953; Tupper *et al*., in prep.). Mean densities were much lower (less than 6 larvae/10m^2) from December through August. Herring spawn in the fall (Sinclair and Tremblay 1984) and with a peak from September to October (Boyar 1968).

The distribution of herring larvae changed considerably around Georges Bank from 1971 to 1990, a period of widely fluctuating adult spawning biomass (Figure 12; Smith and Morse 1993). In 1971, herring spawned throughout Georges Bank and Nantucket Shoals; the principal spawning ground was on the Northeast Peak of Georges Bank. Following the collapse of the Georges Bank fishery, spawning was restricted to Nantucket Shoals by 1976. By 1979, larvae were found only around Stellwagen Bank in Massachusetts Bay. The reappearance of larvae on Nantucket Shoals in 1985 indicates an increase in spawning stock distribution. By 1988, larvae were collected on Cultivator Shoals on Georges Bank, but were not found on the Northeast Peak through 1990.

JUVENILES AND ADULTS

NEFSC Bottom Trawl Survey

The seasonal distribution pattern and abundance of juvenile and adult herring were similar. Juveniles and adults range from south of Cape Hatteras to the Bay of Fundy and Browns Bank (Figure 13). In spring, juveniles and adults were most abundant on the inner shelf from North Carolina to New Jersey, shelf-wide from Long Island to Cape Cod, and in Massachusetts Bay, and moderately abundant on Georges Bank. Juveniles were also abundant along the coast of Maine. In summer, juveniles and adults occurred most frequently in the Gulf of Maine and to a lesser extent on Georges Bank. Densities in autumn were highest in Massachusetts Bay, on northern Georges Bank, and Nantucket Shoals. In winter, herring were caught throughout the Middle Atlantic Bight and on southern Georges Bank; juveniles also occurred in the Gulf of Maine. These distributions show the overwintering migrations to areas south of Cape Cod (Tupper *et al*., in prep.).

Massachusetts Inshore Trawl Survey

In spring, juvenile herring were most abundant northwest of Cape Ann, throughout Cape Cod Bay, along the northern shore of Nantucket Island and southern shore of Martha's Vineyard, and in Buzzards Bay (Figure 14). In the fall, the largest catches occurred around Cape Ann, in central and western Cape Cod Bay, off Buzzards Bay, and off the southern shore of Martha's Vineyard. Adults were most abundant in northern Cape Cod Bay and around Cape Ann in spring and fall.

Rhode Island Trawl Survey

Catches of juveniles were patchy in Narragansett Bay (Figure 15). Catches were highest in summer when the largest mean catch (254 fish/tow) occurred at the station farthest offshore and five of the 12 stations in the bay had > 100 per tow. Abundance was lower during the remaining seasons. Adults were scarce in winter when the highest mean catch was 12 per tow. Catches were smaller in other months and no adults were caught in summer.

Connecticut Fisheries Division Survey

In spring, herring were abundant in central Long Island Sound (Figure 16). Juveniles were not separated from adults, but most fish were 26-30 cm long (i.e., adults). Catches were much smaller in autumn and occurred mostly along the west-central coast. Most fish in autumn were 9-12 cm (Gottschall *et al*., in review).

Hudson-Raritan Estuary Trawl Survey

Catches of all sizes of herring were distributed fairly evenly throughout the Hudson-Raritan estuary (Figure 17). Juveniles were most abundant in winter and spring throughout the lower estuary. They were sometimes common at the mouth of the estuary in summer, and were rare in fall. Adults were most common in winter, which is consistent with the fact that adults from the Gulf of Maine overwinter south of Cape Cod (Sindermann 1979; Tupper *et al*. in prep.). Adult herring were occasionally collected throughout the survey area in spring and fall, however none were caught in summer.

Estuarine Living Marine Resources

The NOAA Estuarine Living Marine Resources Program (ELMR) compiled information on the distribution and abundance of all life stages of Atlantic herring in estuaries in the New England (Jury *et al*. 1994) and the Middle Atlantic (Stone *et al*. 1994) (Table 6). Adults and juveniles were 'highly abundant' in the northernmost estuaries (Passamaquoddy Bay through Penobscot Bay). Larvae were 'highly abundant' from Englishman-Machias Bays through the Sheepscot River. Abundance of all life stages was lower in the Middle Atlantic estuaries; only adults were abundant in Narragansett Bay (Jan-Apr), Long Island Sound (Nov-May) and Great South Bay, Long Island (Nov-Feb). Herring occurred in all major estuaries south to Chesapeake Bay.

STATUS OF THE STOCKS

Atlantic herring were extremely abundant in northeastern U.S. waters during the 1960s and were fished intensively by a large foreign fleet. The Georges Bank-Nantucket Shoals fishery extracted a peak of 373,598 mt in 1968, and an average of 168,750 mt/year over a 16-year period before the stock collapsed in the early 1970s (Atlantic States Marine Fisheries Commission 1995). Landings remained low for about 10 years, but stock biomass is now high and apparently increasing (Figure 18; Northeast Fisheries Science Center 1996). The stock complex is under-utilized (Northeast Fisheries Science Center 1996), but the Gulf of Maine portion of the complex may be fully exploited (Atlantic States Marine Fisheries Commission, unpublished data).

RESEARCH NEEDS

Historically, Atlantic herring in the Gulf of Maine have supported large, economically important fisheries (Friedland 1995). Herring have a complex life history and many areas still require study. The Gulf of Maine Aquarium Development Corporation has identified several research needs for Gulf of Maine herring (Tupper *et al*., in prep.):

- Identify discrete populations/metapopulations and major and minor spawning components in the Gulf of Maine/Bay of Fundy region and the degree of intermixing. Consider using scales, otolith structure, and possibly morphometrics. Concentrate on spawning grounds and tag ripe and running fish only. Perhaps combine with acoustic surveys.
- Explore new technologies (e.g., acoustics or laser illumination) for improving surveys of all life stages.
- Validate the current natural mortality estimate for Gulf of Maine/Bay of Fundy (18%). Synthesize information on mammal, seabird, and other predation. Examine size/age-specific natural mortality. Identify oceanographic influences on larval survival, particularly effects of temperature, climate change, and plankton patch dynamics.
- Conduct surveys to provide an overview of larval abundance/distribution throughout the Gulf of Maine for a single year. Determining the fate of herring spawned on Jeffreys Ledge is a high priority.

Other research needs that became apparent during development of this report include:

- Sample the Northeast Peak of Georges Bank for larvae, which were present there 30 years ago but not in 1990.
- Conduct experimental studies of temperature and salinity preferences; most existing information is for European stocks.
- Prior attempts to discriminate stocks by analyzing otolith elemental composition have been unsuccessful, but given recent improvements in analytical techniques this line of research may now be more promising.
- Map the distribution of seabed habitat types, including determining the scale of detail needed for habitat mapping.
- Continue efforts to locate all significant herring spawning areas.
- Determine effects of bottom-tending fishing gears and natural processes on spawning grounds.
- Determine the value of marine protected areas for conserving and enhancing herring stocks. Identify how these areas would function as larval exporters and collectors.

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Table 1. Size and age at sexual maturity for Atlantic herring, *Clupea harengus.*

Period	**Age at Maturity (A_{50}, years)**		**Size at Maturity (L_{50}, cm)**		**Reference**
	male	*female*	*male*	*female*	
1987-1989	2.9	3.0	25.3	25.4	O'Brien *et al*. (1993)
1966-1975	-	-	25.4-27.4		Sinclair *et al*. (1982)
1949-1952	-	-	26.9		Scattergood (1952)

Table 2. Summary of life history and habitat parameters for Atlantic herring, *Clupea harengus* – Georges Bank.

Life Stage	Size and Growth	Habitat	Substrate	Temperature	Salinity
Eggs [1]		Spawning beds level and horizontal with only occasional shallow depressions or ridges; at 40-80 m depth. Major spawning site on NE part of Georges Bank.	Herring spawn found only on gravel (2-10 mm diameter) associated with strong bottom currents. Although gravel substrate is extensive, egg beds are limited to small region on western edge of northeast area of the Bank.	Temperatures in the vicinity of the Georges Bank egg beds tend to be 12-15°C. Nantucket Shoals tends to be colder (6-13°C). There was an increase of 2-3°C on Georges/Gulf of Maine from the late 1960s to 1977.	High salinities of 32 ppt reported in surface waters around egg beds.
Larvae [2]	Recently hatched: 4-9 mm TL, mean = 7 mm. Total size range: 4-45 mm. Growth = 0.2 mm/4 days.				
Adults [3]	(age: avg. length, cm) III: 23.7 - 25.6 IV: 27.1 - 27.9 V: 28.9 - 29.4 VI: 30.6 - 30.8 VII: 31.4 - 32.1 VIII: 33.0 - 33.3		Spawn on gravel sea floors; attachment of eggs to stable material prevents translocation by strong currents.	Correlation has been demonstrated between summer thermal regime (i.e., temperature in August) and the date of peak spawning; a warm August results in an earlier spawning peak.	

[1] Boyar (1968), Caddy and Iles (1973), Drapeau (1973), Graham and Chenoweth (1973), Pankratov and Sigaev (1973), Berenbeim and Sigaev (1978), Lough *et al.* (1980, 1985), Grimm (1983), Valentine and Lough (1991)
[2] Boyar *et al*. (1973), Graham and Chenoweth (1973), Lough *et al.* (1980, 1985), Cohen and Lough (1983), Grimm (1983)
[3] Boyar (1968), Drapeau (1973), Pankratov and Sigaev (1973), Maurer (1976), Berenbeim and Sigaev (1978)

Table 2. cont'd.

Life Stage	Currents	Prey	Predators	Notes
Eggs [1]	High energy environments; tidal action provides aeration, prevents siltation and accumulation of metabolites.	N/A	Increased abundance of other fish species in areas of spawn; 4 most common fish: red hake, sculpin, dogfish, skate; also increase in starfish and moon snails.	1-2 cm (7-14 layers) thick egg mat. Area of egg bed ranges from 4500 to 10000 km^2. Egg mortality varies: on north and south spawning beds, approx. 8% of spawn removed within 1-2 days of hatching. Surveys on eastern Georges Bank over 5 spawning seasons (1964-1970) show year to year decrease in area occupied by egg beds. Spawning time: late Aug - Oct; peaks in mid/late Sept - Oct.
Larvae [2]	Clockwise current gyre; larvae generally dispersed in a SW direction (2-15 km/d), towards coastal Gulf of Maine.	Primary prey: juvenile stages and adults of seasonally dominant copepods. The 3 most important species were *Pseudocalanus* sp., *Paracalanus parvus* and *Centropages typicus*. Feeding activity peaked twice daily: shortly after sunrise and in mid-afternoon.		Northeast Georges Bank: highest larval abundance on Bank; maximum abundance mid-late Oct. Nantucket Shoals: maximum larval abundance late Oct - early Nov. > 80% larval production occurred on Nantucket Shoals in 1976-1978. Estimated larval mortality in NW in 5 day period = 75% (< 10 mm); winter mortality on Maine coast much lower.
Adults [3]	High energy environments; tidal currents and storm waves.	Primary prey: the chaetognath *Sagitta elegans* (43% by weight); the euphausiids *Meganyctiphanes norvegica* (23.1%) and *Thysanoessa inermis* (6.1%), the pteropod *Limacina retroversa* (6.2%), copepods (3%). May avoid feeding in areas with phytoplankton blooms.		Mean size of spawning fish = 29.5 cm; sex ratio 1:1 (Aug - Sept).

[1] Boyar (1968), Caddy and Iles (1973), Drapeau (1973), Graham and Chenoweth (1973), Pankratov and Sigaev (1973), Berenbeim and Sigaev (1978), Lough *et al.* (1980, 1985), Grimm (1983), Valentine and Lough (1991)
[2] Boyar *et al*. (1973), Graham and Chenoweth (1973), Lough *et al.* (1980, 1985), Cohen and Lough (1983), Grimm (1983)
[3] Boyar (1968), Drapeau (1973), Pankratov and Sigaev (1973), Maurer (1976), Berenbeim and Sigaev (1978)

Table 3. Summary of life history and habitat parameters for Atlantic herring, *Clupea harengus* – Coastal Gulf of Maine.

Life Stage	Size and Growth	Habitat	Substrate	Temperature	Salinity
Eggs [1]		Depths of egg beds varies from 20 to 50 m, averaging 45 m; deeper beds have been shown to be more successful: 35% greater egg density and 2X higher mean egg abundance.	Preferred substrate is gravel associated with strong bottom currents. Gravel often mixed with shell fragments and/or sand; can be almost 100% shell fragments. On Jeffreys Ledge, eggs spawned on boulders & rocks, gravel & coarse sand, and on red alga *Ptilota serrata* .	Hatching success temperature dependent. Lab results: 10°C and 15°C: egg development & hatching normal; 0 and 5°C: no development; 20, 25 and 30°C: rapid development began but 100% mortality. Field results: 9.6°C, average bottom temperature at spawning .	
Larvae [2]	Newly hatched: 4-6 mm autumn: 7-10 mm winter: 21-30 mm spring: 31-40 mm			Larvae may be able to acclimate to lower winter temps. when T declines more slowly. Survival < 30% when T changes 0.1-0.25°C/d; more variable (20-70%) when < 0.1°C/d. Low temp. effects may be avoided through acclimation & occupancy of warmer coastal water.	Larvae that overwinter in estuaries typically experience reduced salinities.
Juveniles [3]	4-23 cm	Tendency to move to surface at night results in increased vulnerability to fixed gear fishery during dark phases of the moon. One study has shown that juveniles overwinter with adults in Passamaquoddy Bay; they remain in the bay until temp. reaches 0°C.		Lab: upper lethal = 19.5-21.2°C, lower = -1.1°C, preferred = 8-12 °C. Field: preference for 10-16°C in Sheepscot River; Sardine production positively correlated to stock size & temp., but density overrides temp. when abundance high. Highest catches in the nearshore weir/stop seine fisheries at 10-13°C; > 13°C activity declines. Juvenile schools disappear in colder months (Nov.-Mar.). Effects of temp. on determination of yr-class strength occurs during late larval/early juvenile phase.	Lab: preference for 26-32 ppt, can resist salinities as low as 5 ppt for brief periods; at < 10°C a preference for > 29 ppt; at > 10°C no salinity preference seen. Field: present in 16-32 ppt; highest abundance at 30-32 ppt. Older juveniles generally avoid brackish conditions.
Adults [4]	(age: avg. length, cm) III: 23 - 26 IV: 27 - 28 V: 29 - 30 VI: 30 - 31 VII: 31.9 - 32 VIII: 33 - 33.4			One study has shown that adults overwinter (along with juveniles) in Passamaquoddy Bay; remain there down to 0°C. Spawning in Grand Manan and northern Gulf primarily at 8-12°C.	

[1] MacFarland (1931), Boyar (1968), Graham *et al.* (1972), Cooper *et al.* (1975), Kelly and Stevenson (1985), Townsend *et al.* (1986), Stevenson and Knowles (1988), Chenoweth *et al.* (1989), Stevenson (1989)
[2] Sherman and Honey (1971), Graham (1972), Boyar *et al*. (1973), Cooper *et al*. (1975), Graham and Townsend (1985), Chenoweth *et al.* (1989), Graham *et al.* (1990)
[3] Brawn (1960a, b, c), Anthony (1971), Stickney (1969), Sherman and Perkins (1971), Recksiek and McCleave (1973), Sindermann (1979), Anthony and Fogarty (1985)
[4] Bigelow and Schroeder (1953), Boyar (1968), Sherman and Perkins (1971), Cooper *et al.* (1975), Kelly and Stevenson (1985), Munroe (in prep.)

Table 3. cont'd.

Life Stage	Currents	Prey	Predators	Notes
Eggs [1]	Bottom currents at spawning beds 0 - 1.0 knots.	N/A	Level of egg predation varies. Most abundant predators on eggs: 1) cunner, *Tautogolabrus adspersus*, 2) cod, *Gadus morhua*.	1-3 cm thick egg mat (20-30 eggs deep) and low egg mortality (< 5%) reported. Egg beds elliptical to irregular in shape; 2/3 to 1 1/3 km^2 in area. 90% of eggs on rock-gravel. Not known if Jeffreys herring spawn selectively over algal clumps or if algae function as egg traps. Hatching success (excluding predation) 99%. Spawning time: mid Aug - Nov; peaks Sept - Oct.
Larvae [2]	Use tidal flows to migrate. On ebb, majority of larvae shallow; on flood, majority deep. More larvae at landward end of channel than seaward.	Seasonal differences in diet; prey principally on 5 groups of zooplankton: copepods, crustacean eggs, crustacean nauplii, cirriped larvae, and tintinnids. Prey volume (cc/10m^3): summer = 1.1, autumn = 0.5, winter = 0.2, spring = 0.8.	Low temp. may indirectly increase starvation & vulnerability to predation.	Selective tidal transport (larvae retained within estuary despite seaward flow). Mortality avg. 2%/d; growth 0.199 mm/d. No growth difference in early vs. late spawned cohorts. Mortality & G inversely correlated. Larvae drift from eastern Maine spawning ground to estuaries.
Juveniles [3]		Opportunistic feeders. 15 groups of zooplankton eaten; only 5 by > 20% of fish: (1) copepods, (2) decapod larvae, (3) cirriped larvae, (4) cladocerans, (5) pelecypod larvae; copepods are the most important food item year round.		Diurnal vertical movements in response to changing light intensity. Regardless of year class, western Maine herring grow faster through age 3 than eastern Maine; at the end of age 2 avg. ~3 cm longer. Plankton less abundant, water temp. lower, salinity greater in eastern Maine than in central or western Maine.
Adults [4]		Selective, opportunistic feeders. Primary prey: shrimp and copepods. Distribution of schools of large herring likely related to presence/absence of euphausiids.	Spawning adults preyed on by bluefish and pollock; ranging from 30-65 cm TL. Predation mostly at night.	Spawning areas from Jeffreys Ledge to eastern Maine should be considered as a single spawning population.

[1] MacFarland (1931), Boyar (1968), Graham *et al.* (1972), Cooper *et al.* (1975), Kelly and Stevenson (1985), Townsend *et al.* (1986), Stevenson and Knowles (1988), Chenoweth *et al.* (1989), Stevenson (1989)
[2] Sherman and Honey (1971), Graham (1972), Boyar *et al.* (1973), Cooper *et al.* (1975), Graham and Townsend (1985), Chenoweth *et al.* (1989), Graham *et al.* (1990)
[3] Brawn (1960a, b, c), Stickney (1969), Anthony (1971), Sherman and Perkins (1971), Recksiek and McCleave (1973), Sindermann (1979), Anthony and Fogarty (1985)
[4] Bigelow and Schroeder (1953), Boyar (1968), Sherman and Perkins (1971), Cooper *et al.* (1975), Kelly and Stevenson (1985), Munroe (in prep.)

Table 4. Summary of life history and habitat parameters for Atlantic herring, *Clupea harengus* – Nova Scotia.

Life Stage	Size and Growth	Habitat	Substrate	Temperature	Salinity	Currents	Prey	Predators	Notes
Eggs [1]		Spawning bed at Black Point, NS at depth of 11-13 m.	Egg beds on sand and small stones.	Temperature of water column in spawning area ranged from 9-15 ^{o}C.		Tidal currents at egg beds 1.5-2.0 knots.	N/A	Haddock is main egg predator.	3.25 cm thick egg bed reported. Spawning time: Aug - Oct; peaks late Aug - Sept.
Larvae [2]	Recently hatched: 5-9 mm TL. Initial growth rate = 2 mm/week; late autumn/winter months $\leq$ 1 mm/week; spring/early summer = 2.5 mm/week.	Spawning site in SW Nova Scotia in an area of well mixed water.		Temperature of water column in spawning area ranged from 9-15 ^{o}C.	Salinity ranged very little from 32.09 - 32.56 ppt.				Semidiel pattern of vertical migration demonstrated; possibly linked to time of day (light) and/or tidal currents.
Adults [3]	(age: average length, cm) III: 23.7 IV: 26.4 - 27.9 V: 28.9 - 29.6 VI: 30.7 - 30.9 VII: 32.0 - 32.1 VIII: 33.0 - 33.4								

[1] McKenzie (1964), Boyar (1968), Das (1968, 1972), Stephenson and Power (1988)
[2] McKenzie (1964), Das (1972), Stephenson and Power (1988)
[3] Boyar (1968)

Table 5. Summary of life history and habitat parameters for Atlantic herring, *Clupea harengus* – No specific location given in literature.

Life Stage	Size and Growth	Habitat	Substrate	Temperature	Salinity
Eggs [1]	1.0-1.4 mm in diameter.	All spawning grounds in high energy environments, either nearshore shallows subject to wave/tidal flux, or deeper water with tidal action.	Spawning substrate varied (stones, gravel); free of fine sediments that might prevent gaseous exchange between eggs and environment.	Bottom temp. of 5-15°C required. Average incubation time for autumn spawned eggs is 10-15 days. Developmental rate inversely related to temp.: 40 d at 4-5°C, 15 d at 6-8°C, 11 d at 10-12°C, 6-8 d at 14.4-16°C.	
Larvae [2]				Occur in 9-16°C in the Gulf of Maine. Offshore waters in winter generally have higher temperatures than inshore waters (up to 5°C difference); may favor a more rapid development in offshore waters, thereby reducing time of vulnerability to predation.	
Juveniles [3]					Preference for higher salinities with increasing age.
Adults [4]			Spawn on stable material: small stones, gravel.	Movements become sluggish at less than 4°C. Spawning occurs at temperatures of 7-15°C. Spawning in western Gulf of Maine occurs at warmer temperatures than east.	Enter bays and estuaries, but 28 ppt is lower limit of occurrence. Spawn at high salinities, ranging from 31.9 - 33.0 ppt; never brackish water.

[1] Bigelow and Schroeder (1953), Haegele and Schweigert (1985), Munroe (in prep.)
[2] Colton and Byron (1977), Munroe (in prep.)
[3] Recksiek and McCleave (1973), Munroe (in prep.)
[4] Haegele and Schweigert (1985), Munroe (in prep.)

Table 5. cont'd.

Life Stage	Currents	Prey	Predators	Notes
Eggs [1]	Spawning generally occurs in areas with good tidal exchange: average 1.5-3 knots tidal current.	N/A	Predation by a variety of bottom predators (Winter Flounder major egg predator). Cannibalism by adult herring occurs.	Eggs are demersal, adhesive. Eggs laid in sheets in successive layers; rarely exceeds 2 cm in thickness. Egg mortality is primarily due to suffocation (from high egg densities and siltation) and predation. Spawning time: Sept - early Nov.
Larvae [2]		Begin exogenous feeding before yolk sac disappears. Select the most abundant prey of a suitable size range; seasonal differences occur. Primary prey: copepod eggs, nauplii, copepods, mollusk larvae. As larvae grow, consume larger proportion of copepods.	Solitary and pelagic; vulnerable to planktonic predators: jellyfish, chaetognaths, larger copepods, euphausiids and pelagic fishes.	Larvae exhibit diurnal migratory behavior. Possible controlling mechanisms: light level, turbidity, shifts in prey location & tidal effects.
Juveniles [3]		Selective, opportunistic feeders; predominantly copepod diet. In darkness: stop schooling behavior; swim in tight paths & feed only by filtering (unable to feed by biting). In the light: can feed by either particle biting or filtering.	Preyed upon by almost all pelagic predators, including fishes, marine birds, northern shortfin squid, and marine mammals.	Vertical diurnal movements occur in all seasons. Juveniles often active near/at the surface at night; generally move up water column at dusk.
Adults [4]		Selective, opportunistic feeders; predominantly euphausiid diet, also chaetognaths and copepods.	Preyed upon by almost all pelagic predators, including fishes, marine birds, northern shortfin squid, and marine mammals. Predation by fish is intense during spawning.	

[1] Bigelow and Schroeder (1953), Haegele and Schweigert (1985), Munroe (in prep.)
[2] Colton and Byron (1977), Munroe (in prep.)
[3] Recksiek and McCleave (1973), Munroe (in prep.)
[4] Haegele and Schweigert (1985), Munroe (in prep.)

Table 6. Relative abundance of eggs, larvae, and juvenile Atlantic herring (*Clupea harengus*) in New England and Mid-Atlantic estuaries by salinity zone, based on Estuarine Living Marine Resources (ELMR) data in Jury *et al*. (1994) and Stone *et al.* (1994). Salinity zone: T = tidal fresh, M = mixing zone, S = seawater, • = salinity zone not present. Relative abundance: H = highly abundant, A = abundant, C = common, R = rare, blank = not present.

	Eggs			**Larvae**			**Juveniles**		
	T	**M**	**S**	**T**	**M**	**S**	**T**	**M**	**S**
Passamaquoddy Bay					C	A		A	H
Englishman/Machias Bays			C		A	H		C	H
Narraguagus Bay					A	H		C	H
Blue Hill Bay					A	H		C	H
Penobscot Bay					H	H		C	H
Muscongus Bay					A	H		A	A
Damariscotta River				A	H		C	A	
Sheepscot River				A	H		C	A	
Kennebec/Androscoggin Rivers				C	C		C	C	
Casco Bay			R		A	A		C	A
Saco Bay					C	A		C	A
Wells Harbor	•			•	C	A	•	A	H
Great Bay					C	C		C	C
Merrimack River		•		C	•		C	•	
Massachusetts Bay	•	•		•	•	A	•	•	A
Boston Harbor	•			•	R	A	•	C	A
Cape Cod Bay	•		R	•		C	•	C	A
Waquoit Bay						R		R	R
Buzzards Bay						R		C	C
Narragansett Bay						C		C	C
Long Island Sound					R	R		C	C
Connecticut River			•			•		R	•
Gardiners Bay	•			•			•	R	C
Great South Bay, NY	•			•			•		C
Hudson River/Raritan Bay					C	C		C	C
Barnegat Bay, NJ					R	R		C	C
New Jersey Inland Bays					R	R		C	C
Delaware Bay					R	R		C	C
Delaware Inland Bays	•			•			•		R
Chincoteague Bay	•	•		•	•		•	•	R
Chesapeake Bay Mainstem									R
Chester River			•			•			•
Choptank River			•			•			•
Patuxent River			•			•			•
Potomac River			•			•			•
Tangier/Pocomoke Sound	•		•	•		•	•		•
Rappahannock River			•			•			•
York River, VA			•			•			•
James River, VA			•			•			•

Table 6. cont'd. Relative abundance of spawning adult and adult Atlantic herring (*Clupea harengus*) in New England and Mid-Atlantic estuaries by salinity zone based on Estuarine Living Marine Resources (ELMR) data in Jury *et al.* (1994) and Stone *et al.* (1994). Salinity zone: T = tidal fresh, M = mixing zone, S = seawater, • = salinity zone not present. Relative abundance: H = highly abundant, A = abundant, C = common, R = rare, blank = not present.

	Spawning Adults			**Adults**		
	T	**M**	**S**	**T**	**M**	**S**
Passamaquoddy Bay					A	H
Englishman/Machias Bays			C		C	H
Narraguagus Bay					C	H
Blue Hill Bay					C	H
Penobscot Bay					C	H
Muscongus Bay					C	A
Damariscotta River					C	A
Sheepscot River					C	A
Kennebec/Androscoggin Rivers					C	C
Casco Bay				R		R
Saco Bay						R
Wells Harbor	•			•	R	C
Great Bay					R	C
Merrimack River			•		R	•
Massachusetts Bay	•	•		•	•	A
Boston Harbor	•			•	C	A
Cape Cod Bay	•		R	•	C	A
Waquoit Bay	•			•		R
Buzzards Bay	•			•	C	C
Narragansett Bay					C	A
Long Island Sound					C	A
Connecticut River			•		R	•
Gardiners Bay	•			•	R	C
Great South Bay, NY	•			•		A
Hudson River/Raritan Bay					C	C
Barnegat Bay, NJ					C	C
New Jersey Inland Bays					C	C
Delaware Bay					R	C
Delaware Inland Bays	•			•		R
Chincoteague Bay	•	•		•	•	
Chesapeake Bay Mainstem					R	C
Chester River			•			•
Choptank River			•			•
Patuxent River			•			•
Potomac River			•			•
Tangier/Pocomoke Sound	•		•	•		•
Rappahannock River			•		R	•
York River, VA			•		R	•
James River, VA			•		R	•

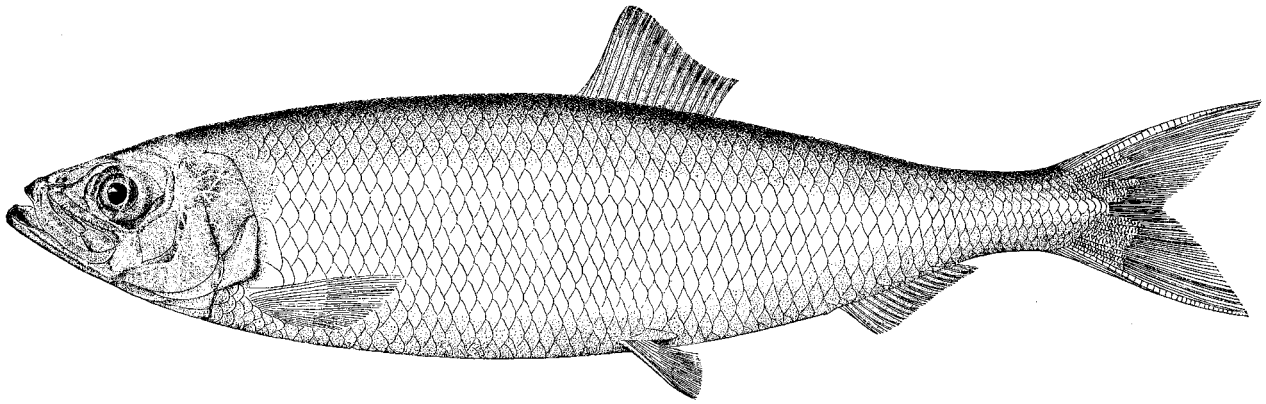


Figure 1. The Atlantic herring, *Clupea harengus* L. (from Goode 1884).

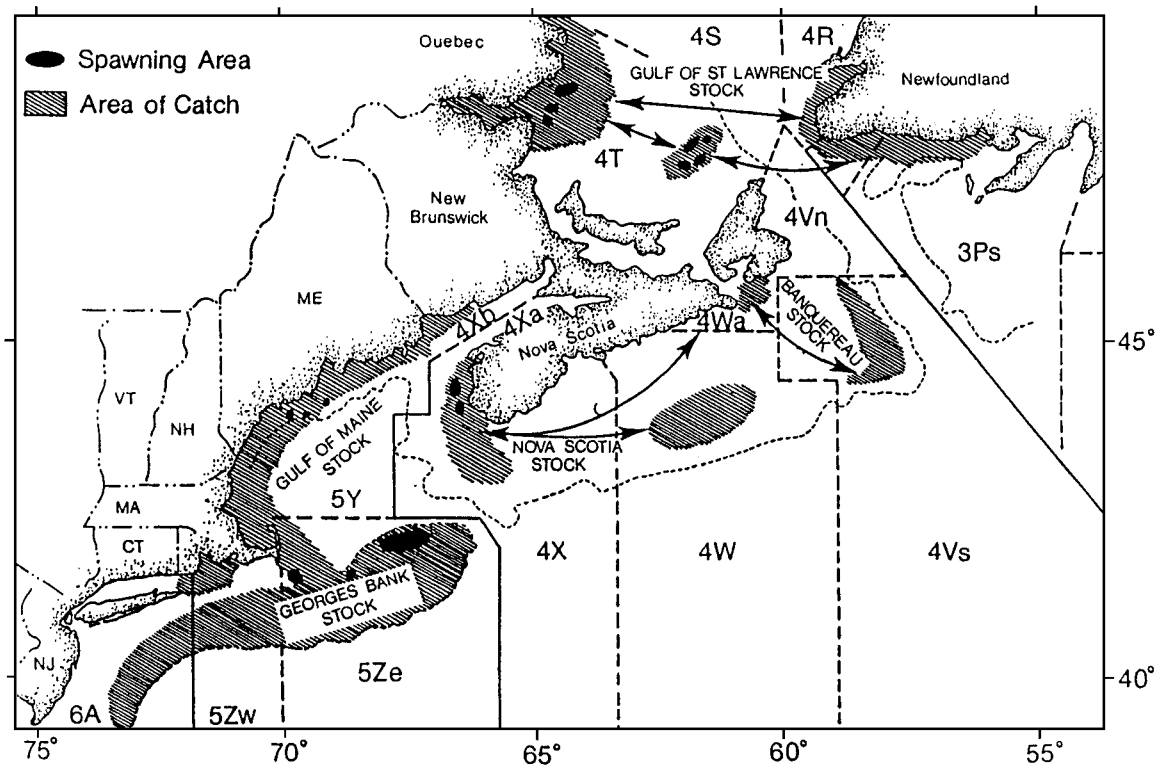


Figure 2. Location of Atlantic herring spawning populations within the Gulf of Maine area. Solid black represents spawning areas, while hatched lines represent areas of herring catch (from Iles 1972).

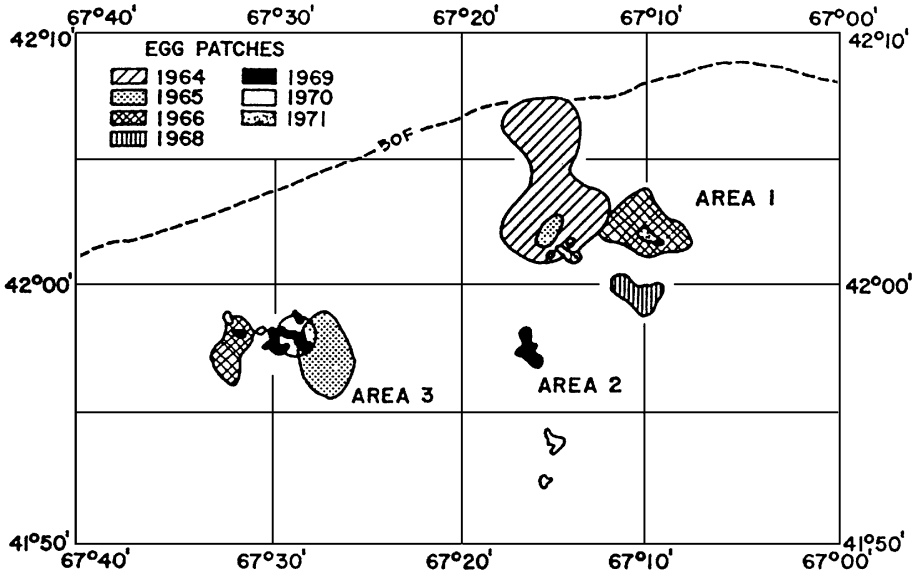


Figure 3. Principal spawning grounds on Georges Bank, 1964-1971 (excluding 1967), with a comparison of egg patch sizes among years (from Anthony and Waring 1980).

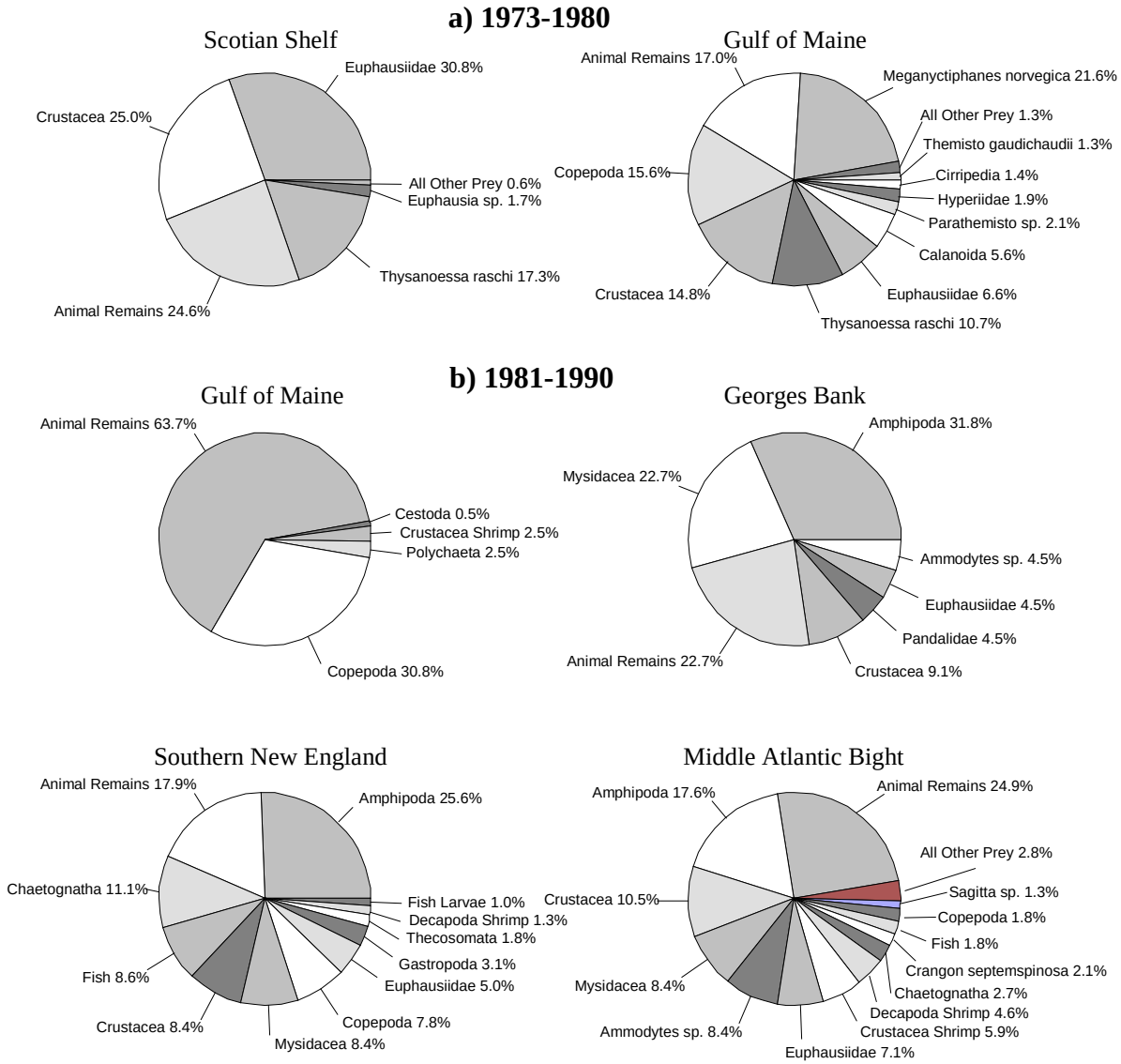


Figure 4. Abundance (percent of total prey volume) of the major prey items in the diet of Atlantic herring from the Scotian Shelf, the Gulf of Maine, Georges Bank, southern New England, and the Middle Atlantic based on NEFSC bottom trawl survey data on food habits, a) 1973-1980 and b) 1981-1990. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details]. The category "animal remains" refers to unidentifiable animal matter.

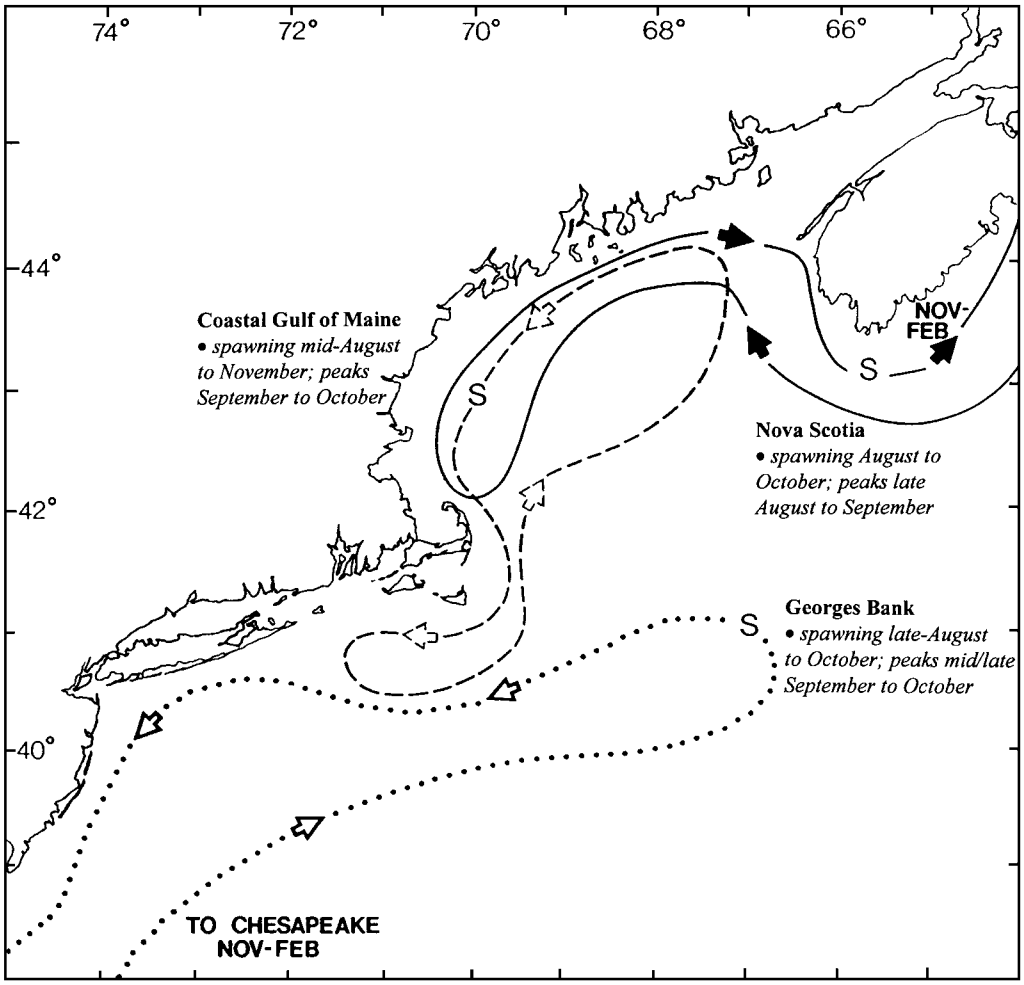


Figure 5. Hypothesized seasonal movements of three Atlantic herring spawning stocks inhabiting U.S. waters (modified from Sindermann 1979).

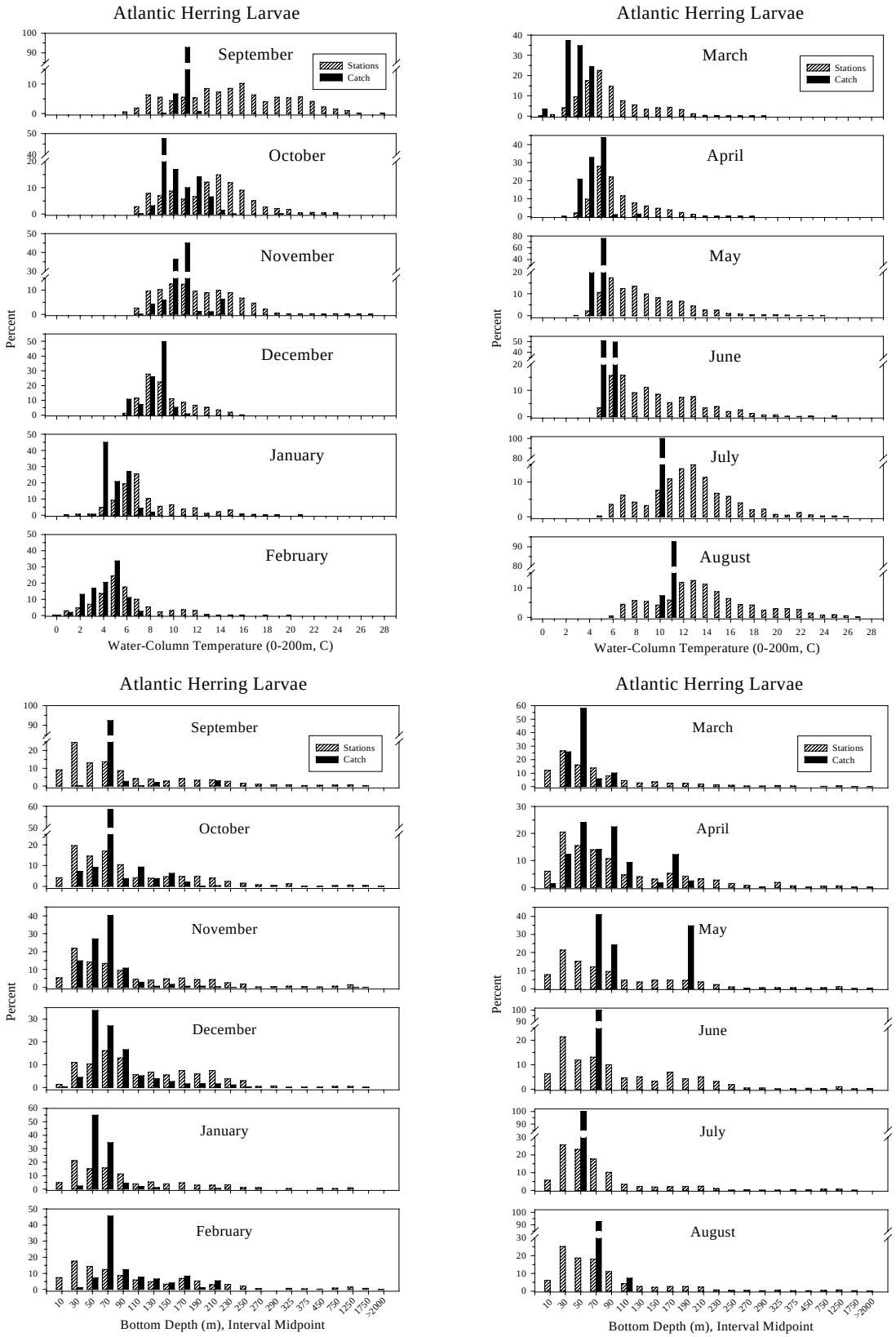


Figure 6. Mean water column temperature and bottom depth at stations where Atlantic herring larvae were collected (solid bars) and at all stations sampled (open bars) during NEFSC MARMAP ichthyoplankton surveys, 1977-1987.

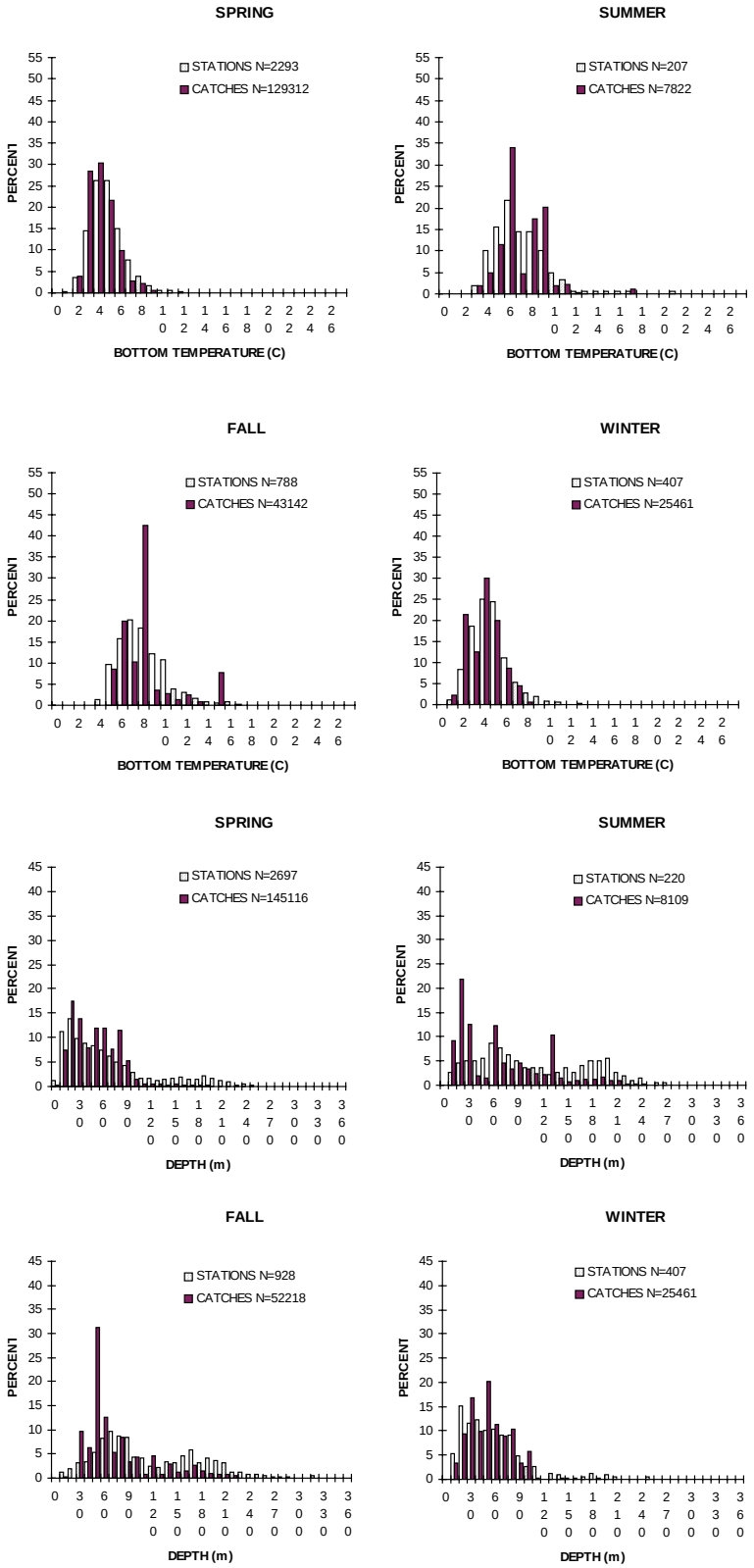


Figure 7a. Mean bottom water temperature and depth at stations where juvenile (< 25 cm TL) Atlantic herring were collected (solid bars) and at all stations sampled (open bars) during NEFSC bottom trawl surveys.

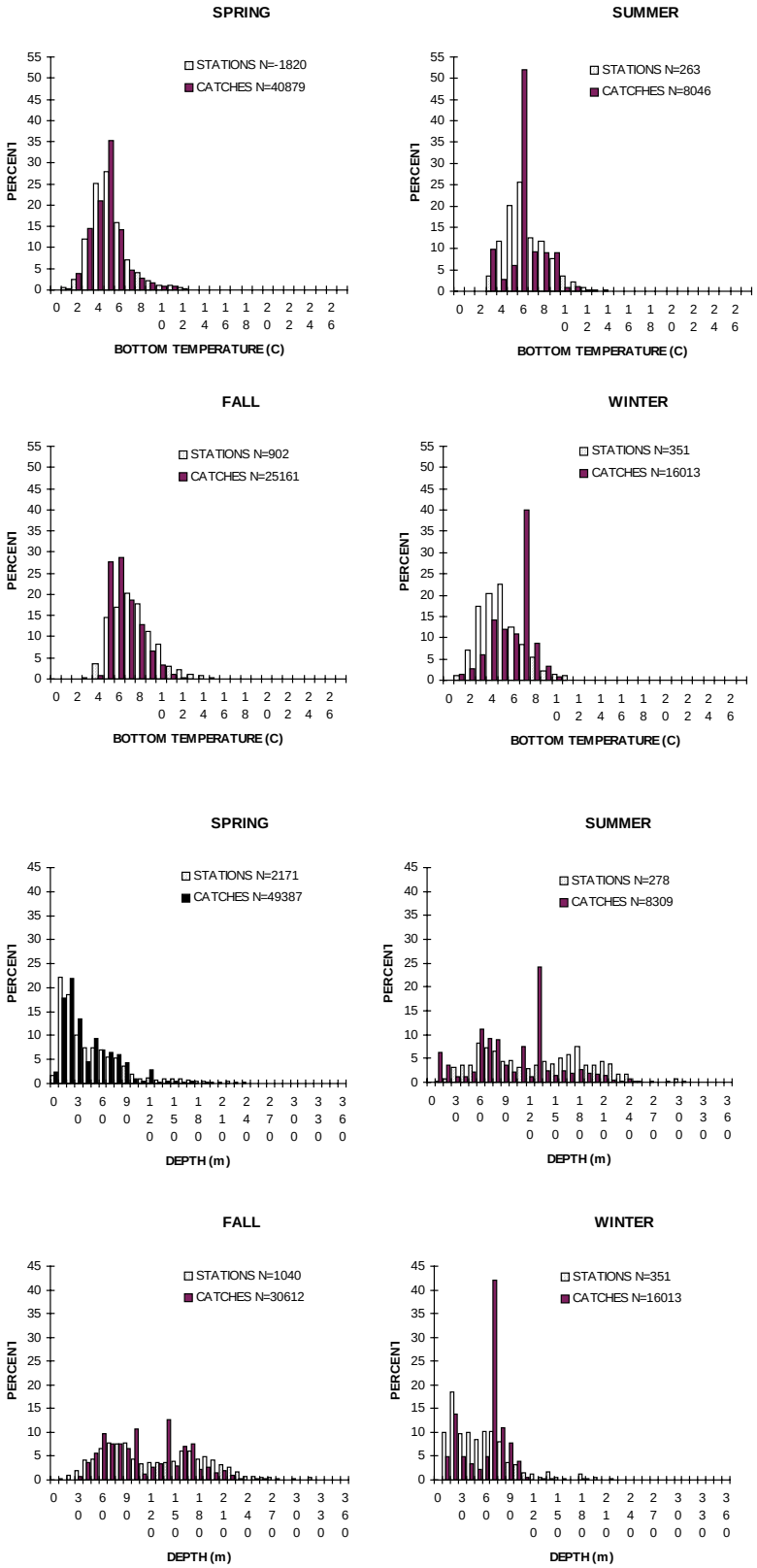


Figure 7b. Mean bottom water temperature and depth at stations where adult (≥ 25 cm TL) Atlantic herring were collected (solid bars) and at all stations (open bars) sampled during NEFSC bottom trawl surveys.

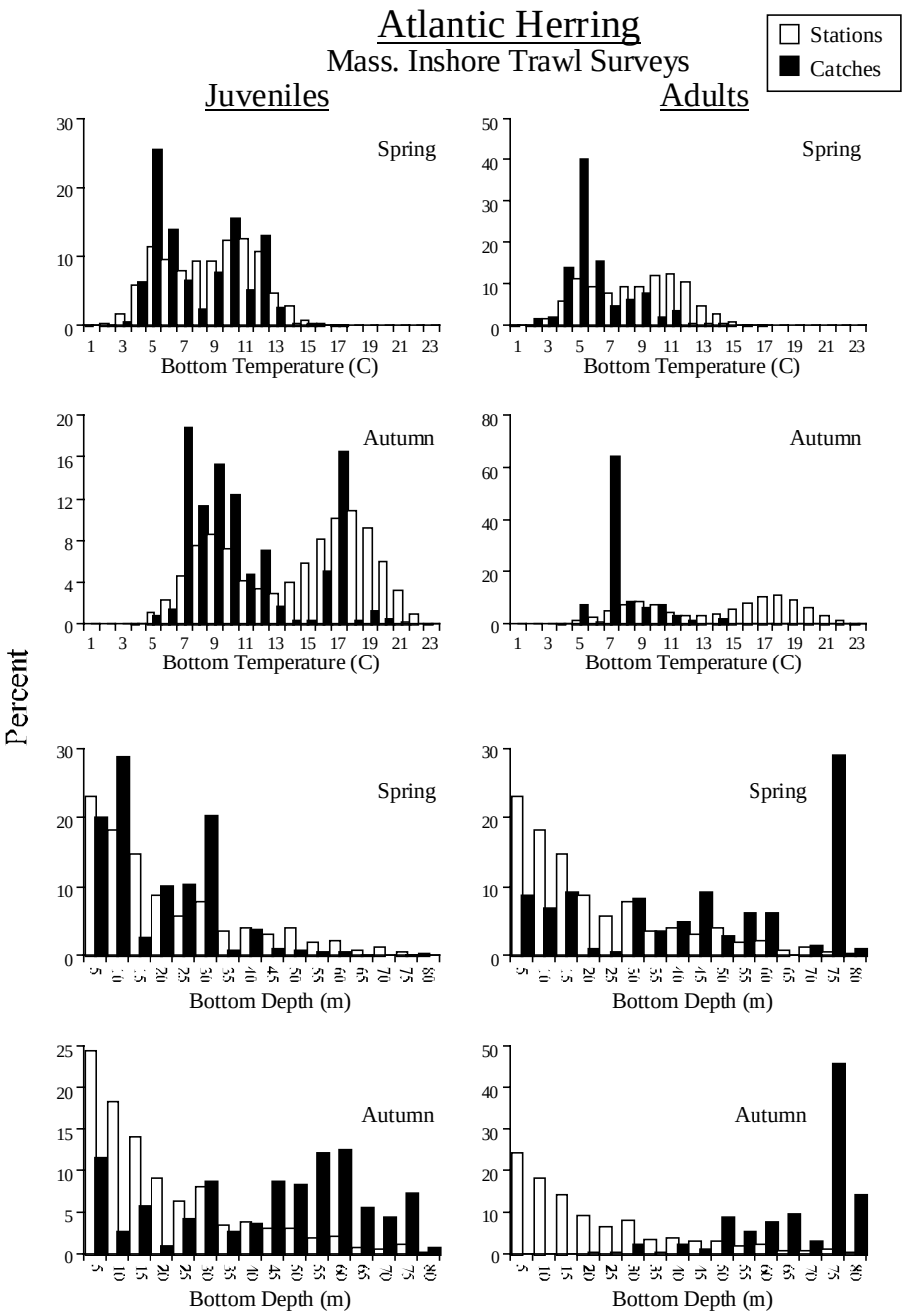


Figure 8. Mean bottom water temperature and depth at stations where juvenile and adult Atlantic herring were collected (solid bars) and at all stations sampled (open bars) during Massachusetts inshore bottom trawl surveys, 1978-1996.

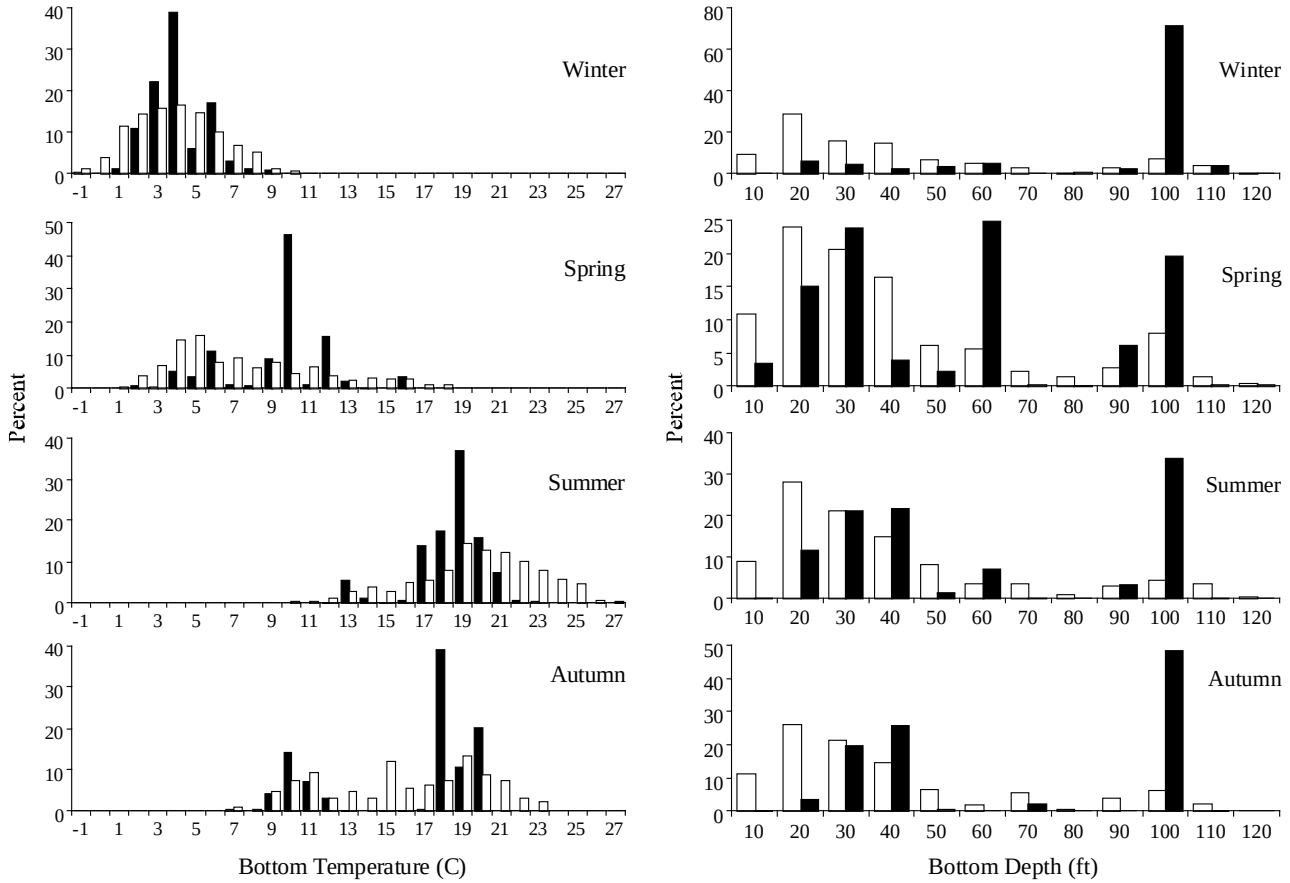


Figure 9a. Mean bottom water temperature and depth at stations where juvenile Atlantic herring were collected (solid bars) and at all stations sampled (open bars) during Rhode Island Narragansett Bay trawl surveys.

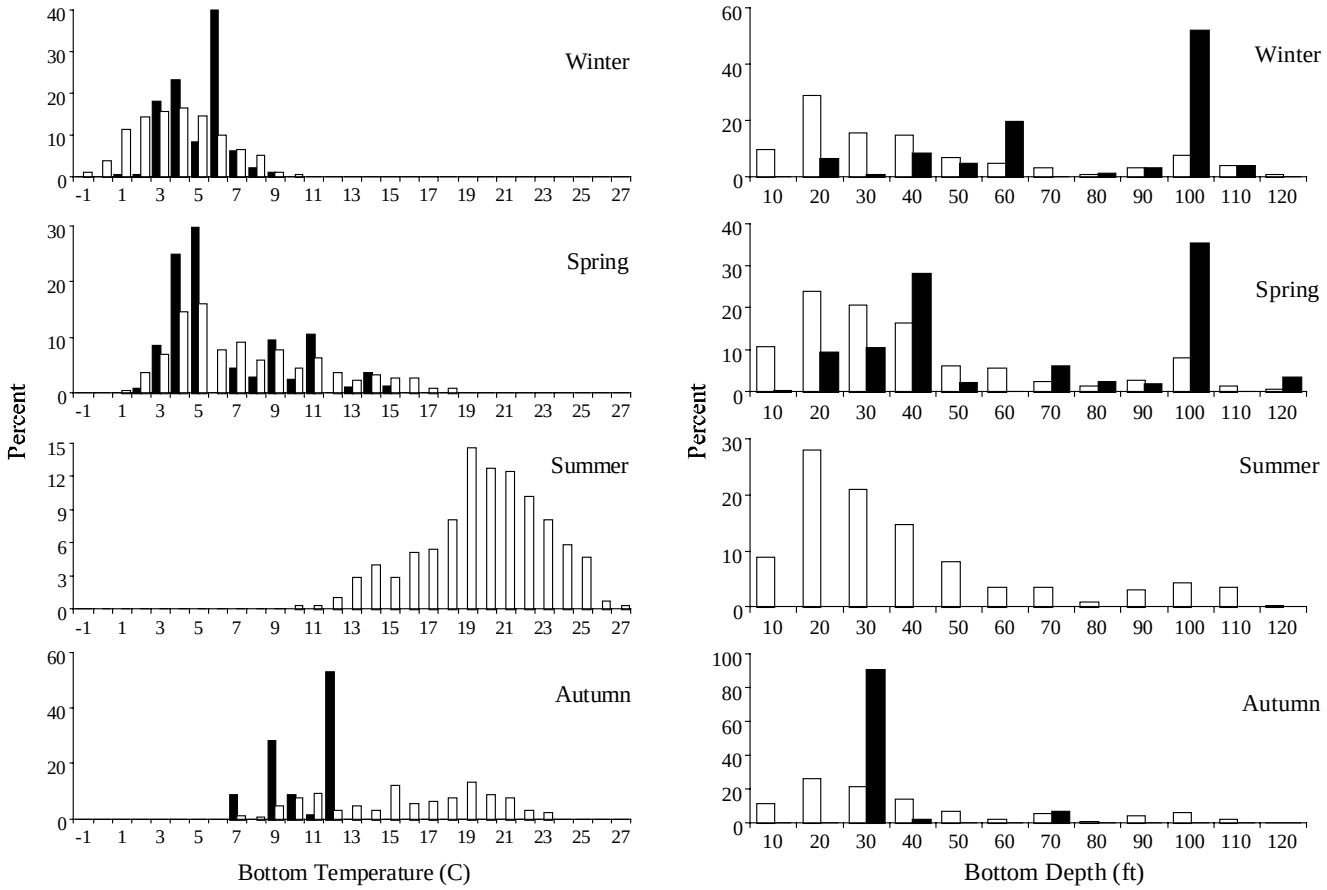


Figure 9b. Mean bottom water temperature and depth at stations where adult Atlantic herring were collected (solid bars) and at all stations sampled (open bars) during Rhode Island Narragansett Bay trawl surveys.

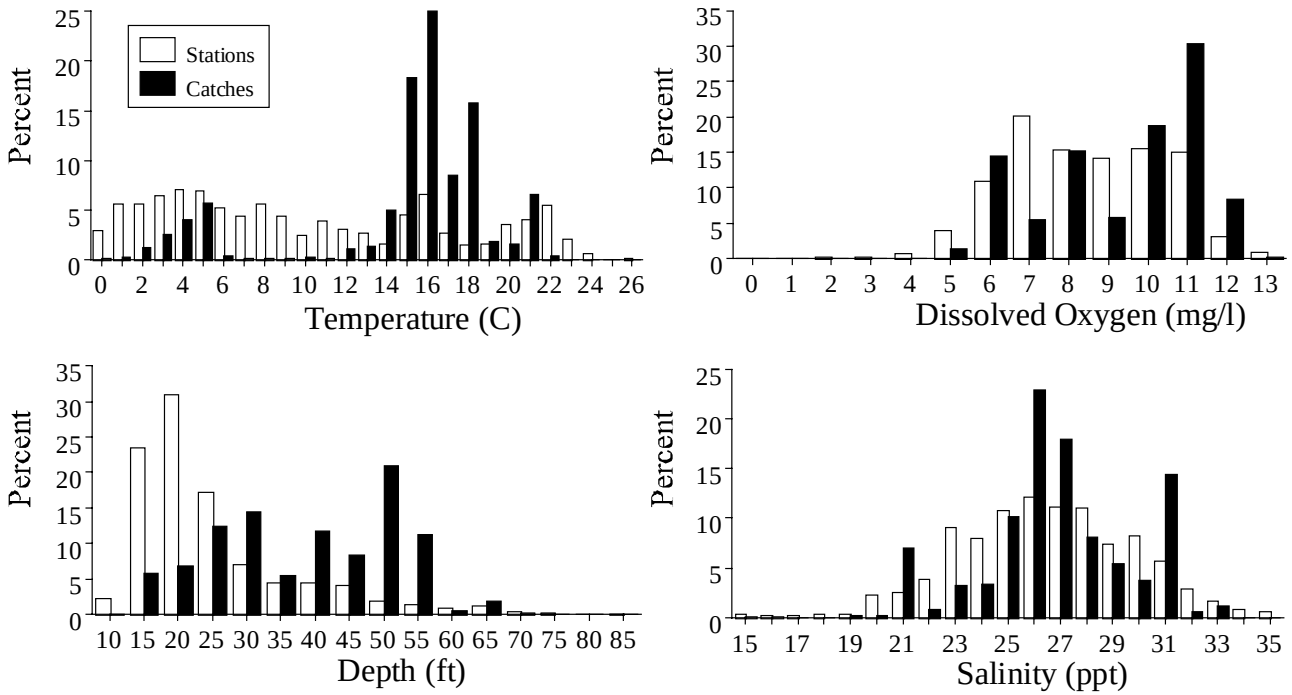


Figure 10a. Mean water temperature, depth, dissolved oxygen, and salinity at stations where juvenile Atlantic herring were collected (solid bars) and at all stations (open bars) during Hudson-Raritan trawl surveys.

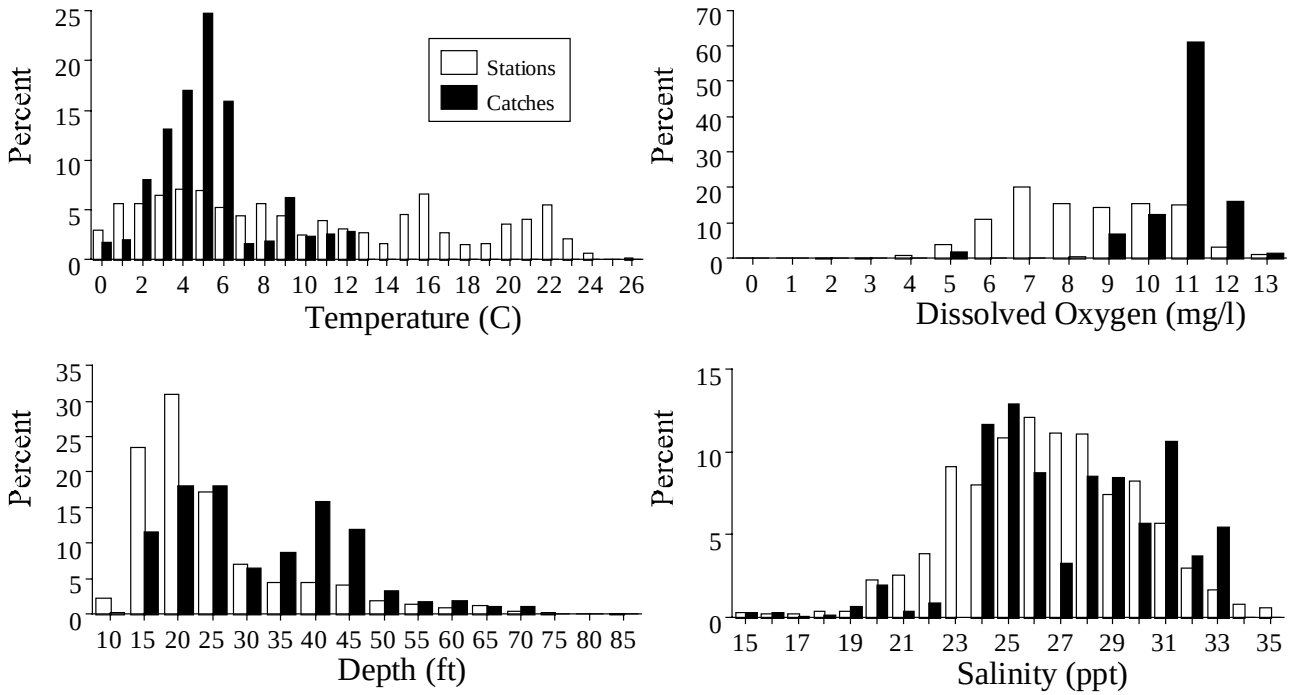


Figure 10b. Mean water temperature, depth, dissolved oxygen, and salinity at stations where adult Atlantic herring were collected (solid bars) and at all stations (open bars) during Hudson-Raritan trawl surveys.

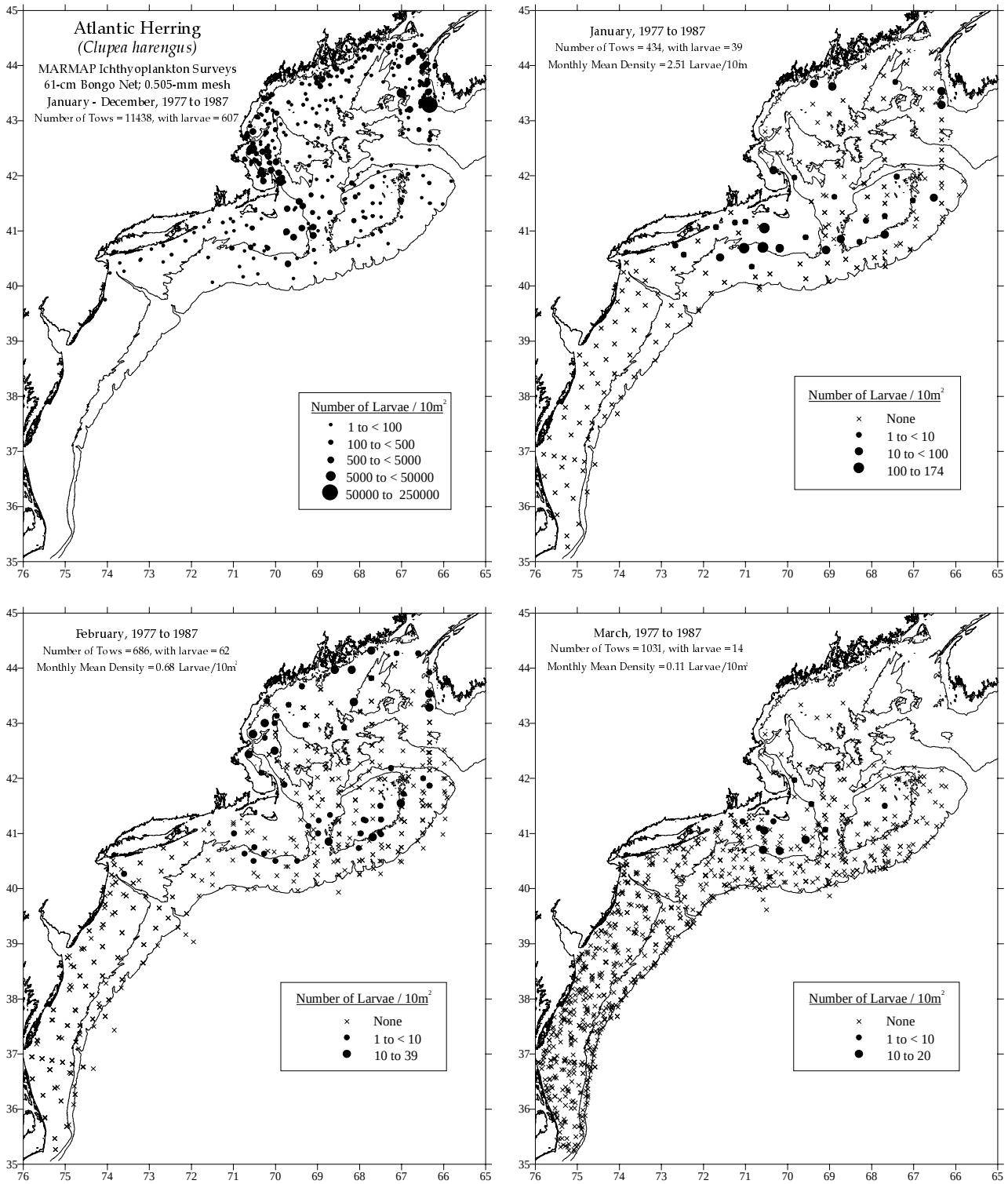


Figure 11. Distribution and abundance of Atlantic herring larvae collected during NEFSC MARMAP ichthyoplankton surveys, January to December, 1977-1987 [see Reid *et al.* (1999) for details].

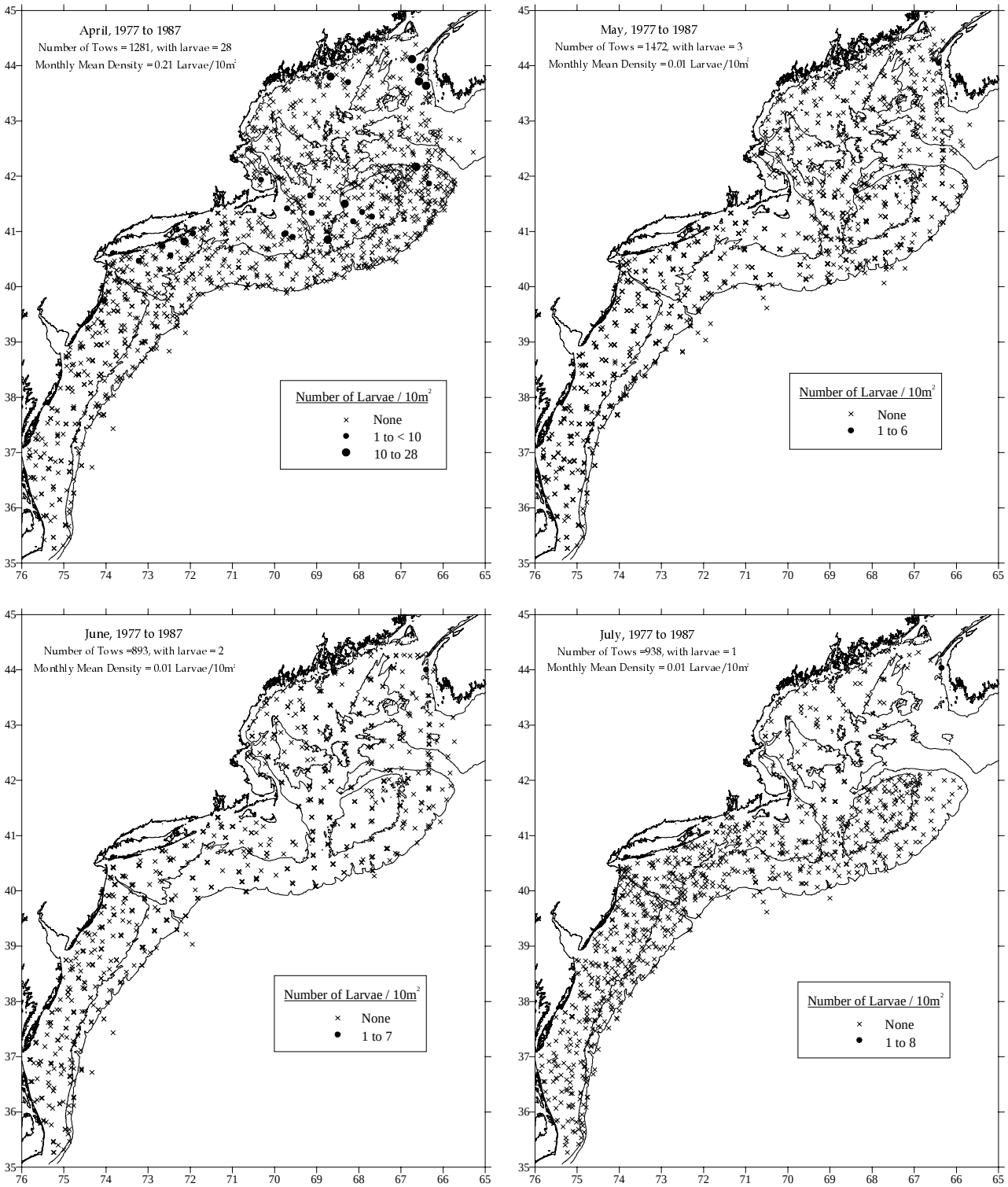


Figure 11. cont'd.

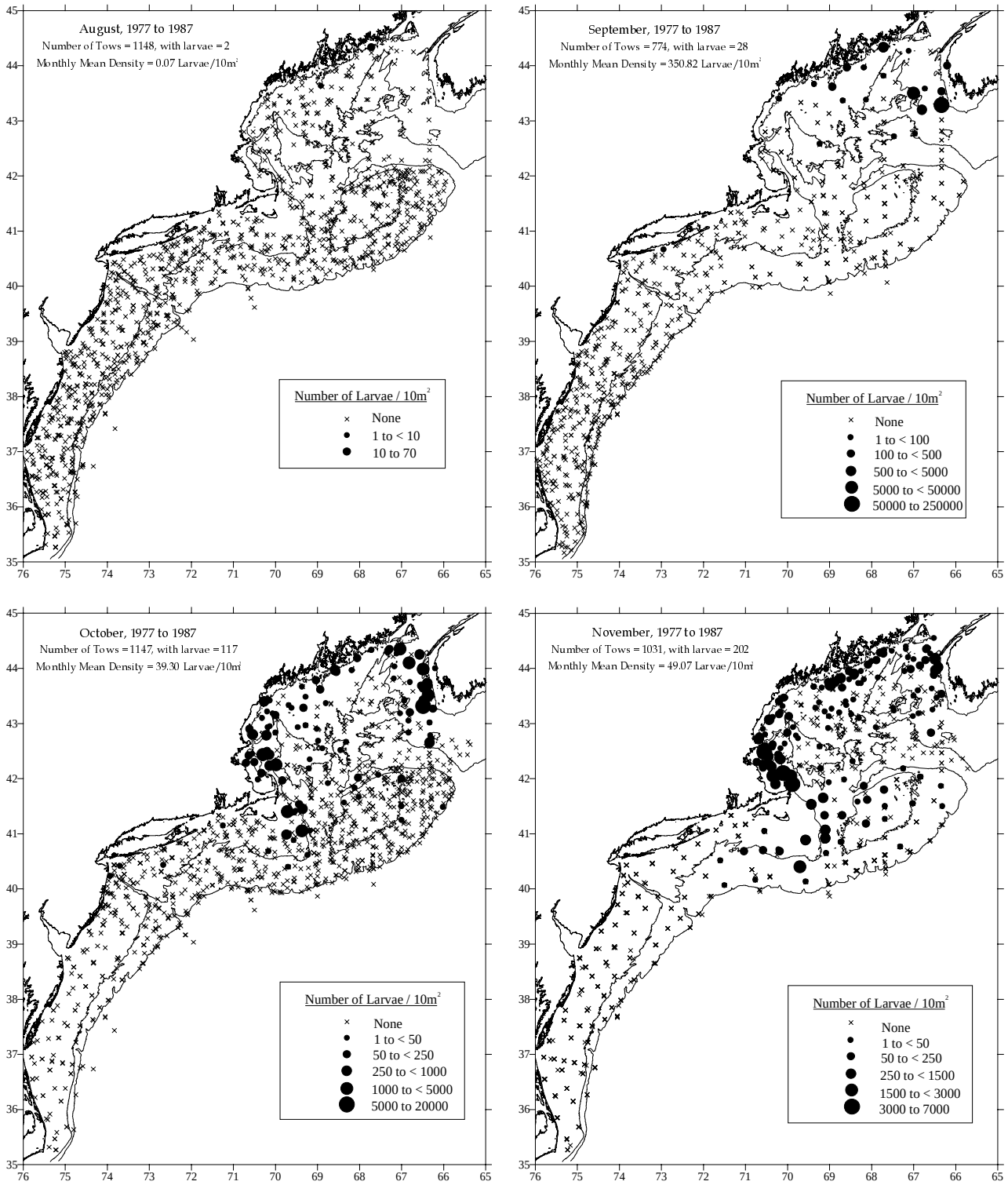


Figure 11. cont'd.

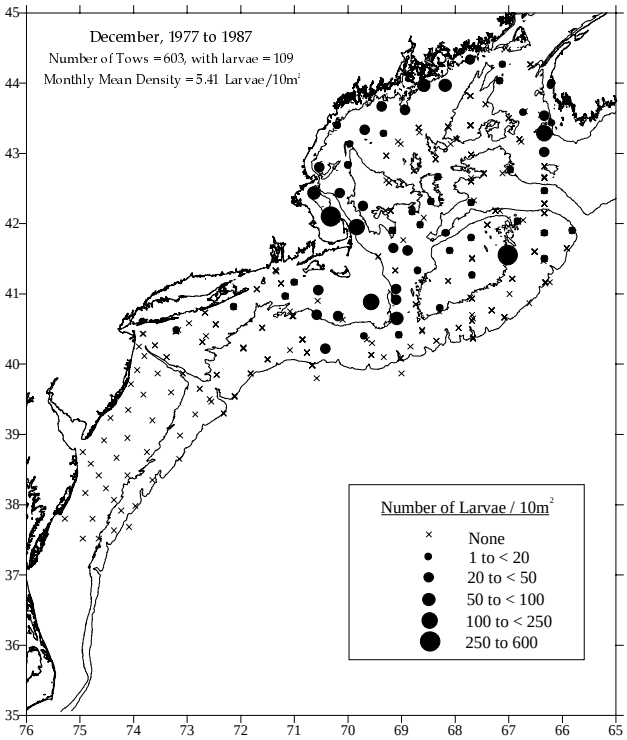


Figure 11. cont'd.

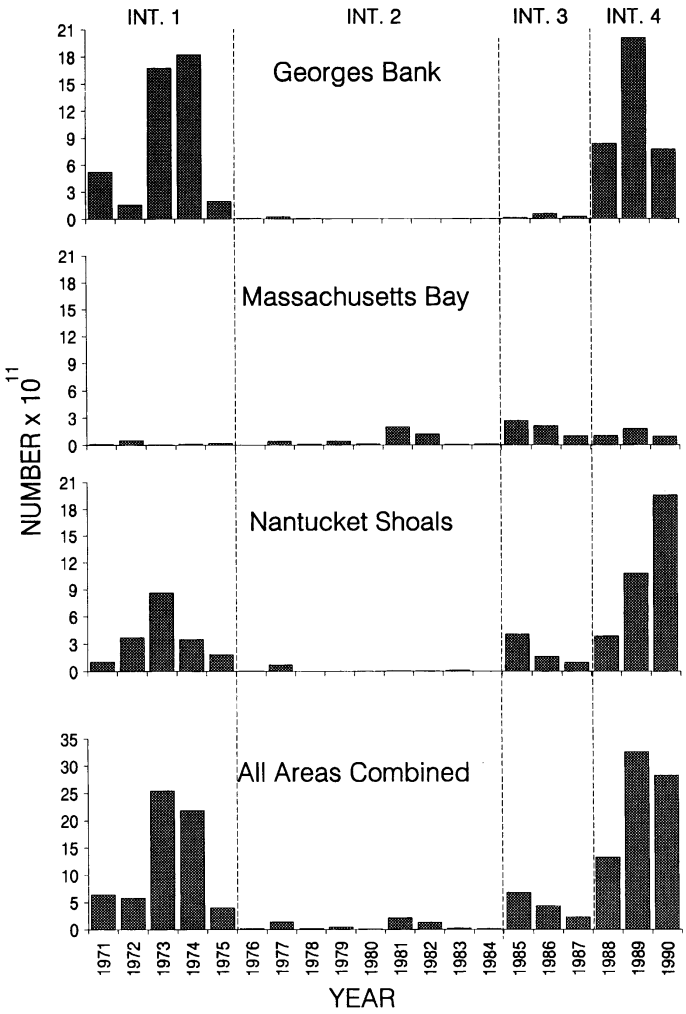


Figure 12. Changes in abundance of Atlantic herring larvae on Georges Bank, Nantucket Shoals, and in Massachusetts Bay from 1971-1990 (from Smith and Morse 1993). Intervals (Int.) denote periods of changing spawning patterns.

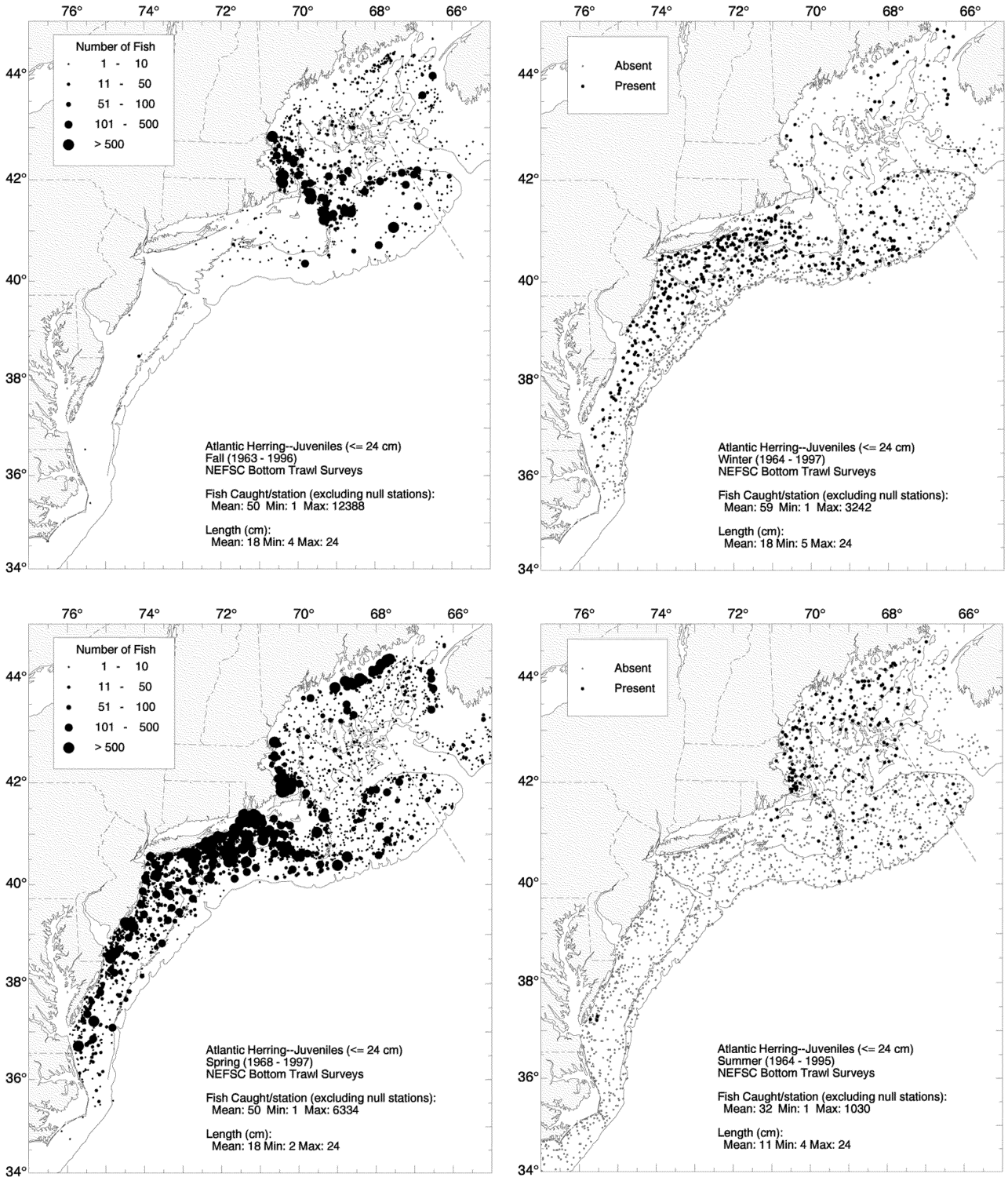


Figure 13. Distribution and abundance of juvenile (≤ 24 cm) and adult (≥ 25 cm) Atlantic herring collected during NEFSC bottom trawl surveys, 1963-1997. Densities are represented by dot size in spring and fall plots, while only presence and absence are represented in winter and summer plots [see Reid *et al.* (1999) for details].

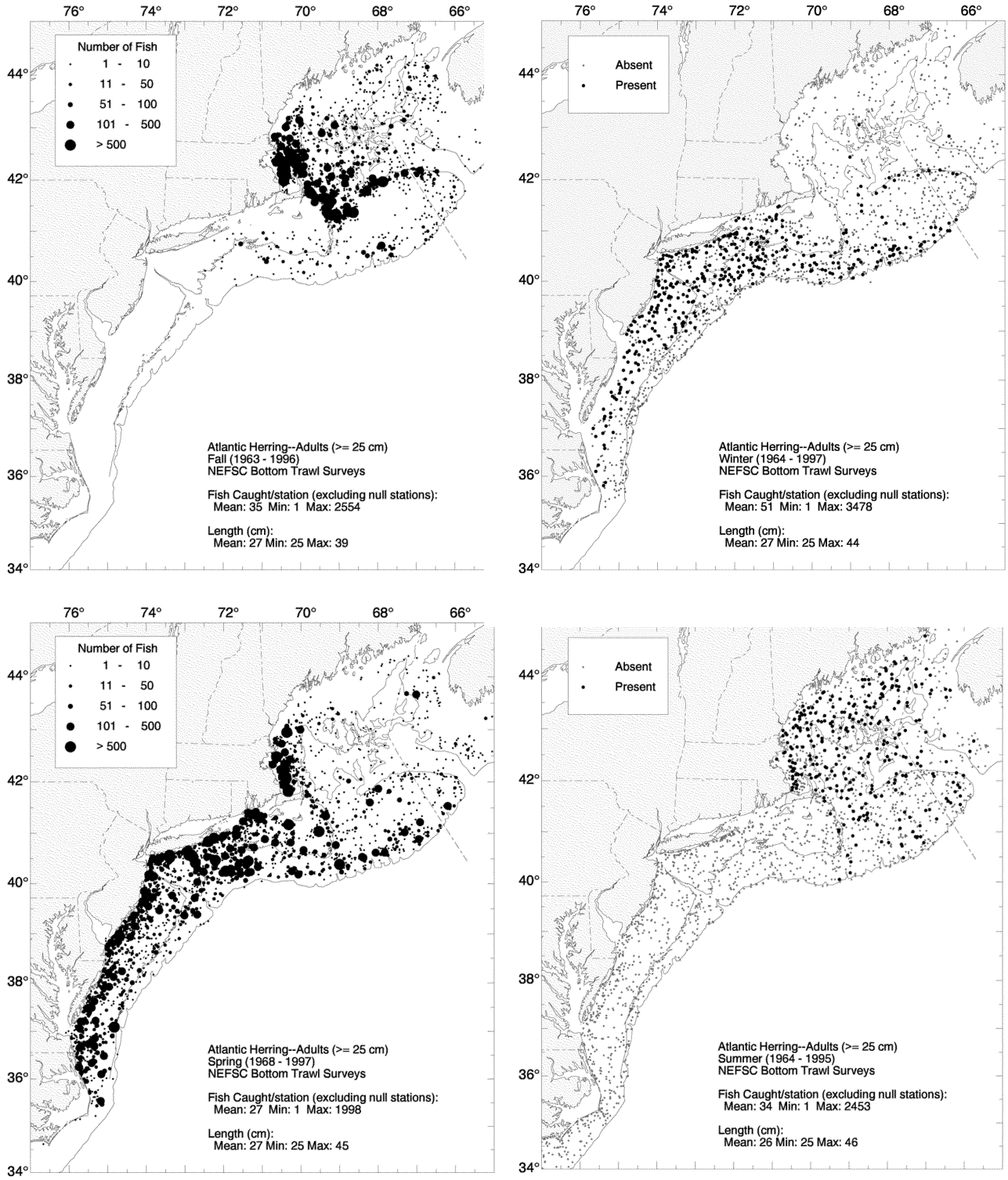


Figure 13. cont'd.

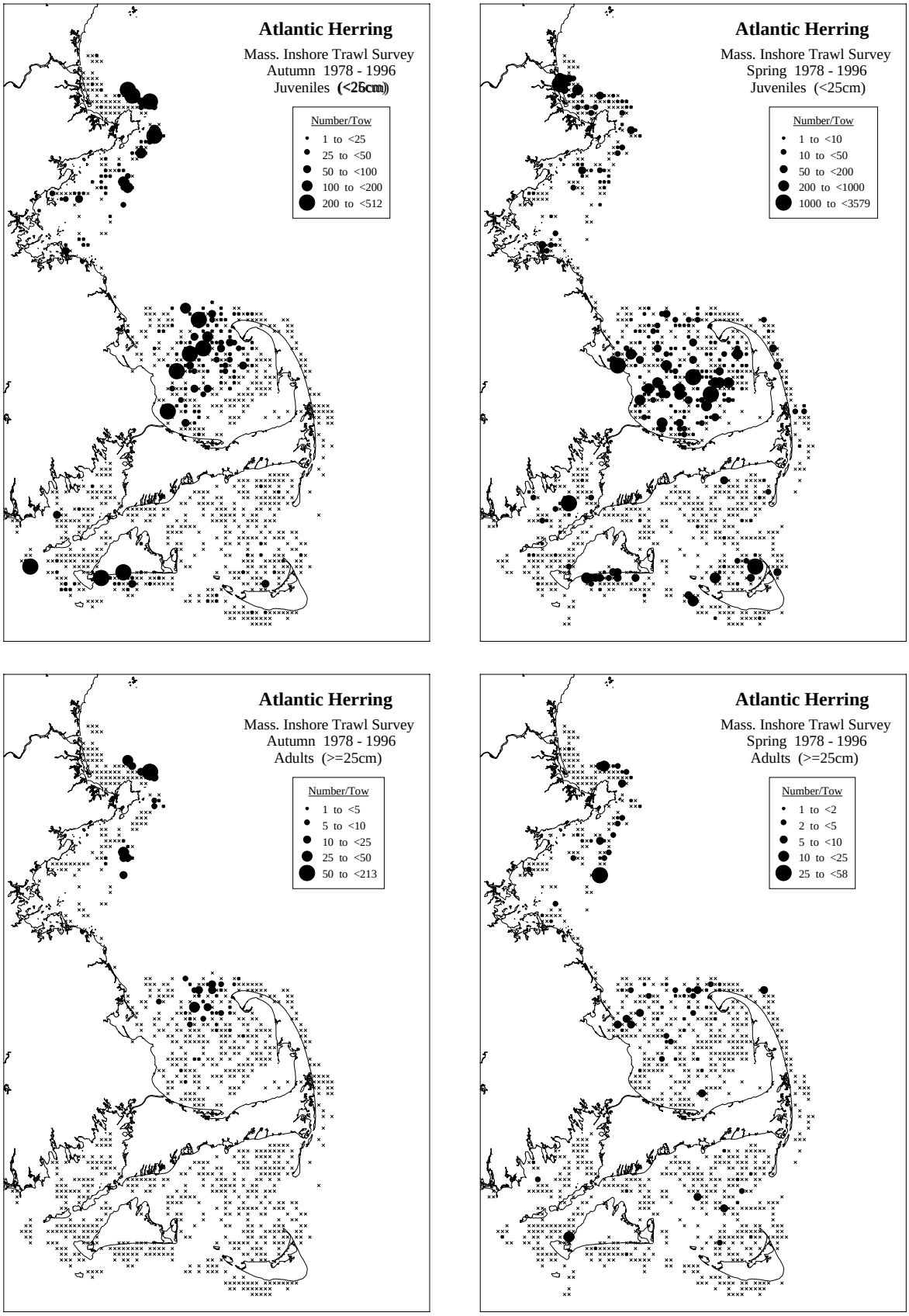


Figure 14. Distribution and abundance of juvenile (< 25 cm) and adult (≥ 25 cm) Atlantic herring collected in spring and autumn during Massachusetts inshore bottom trawl surveys (1978-1996) [see Reid *et al.* (1999) for details].

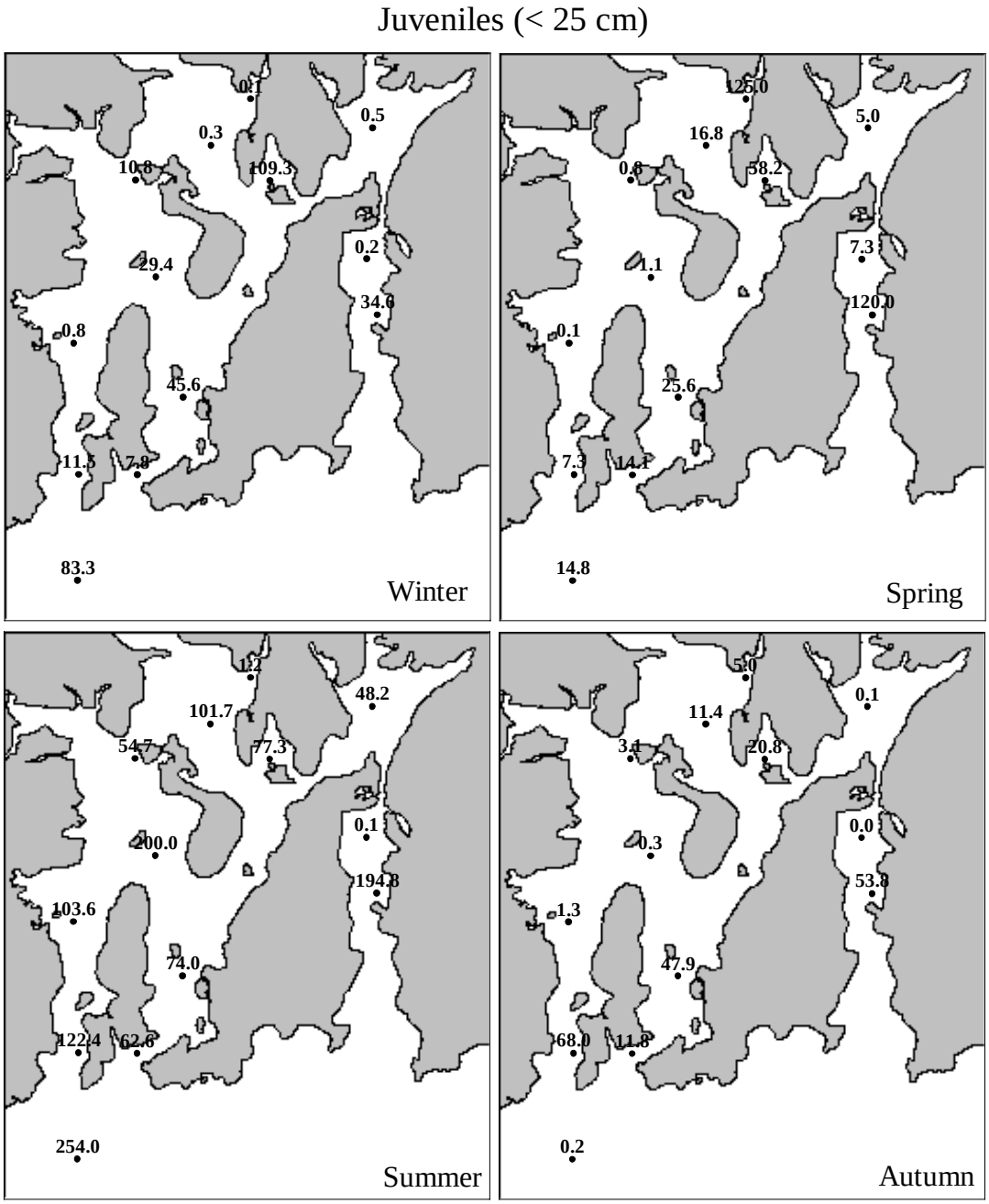


Figure 15. Distribution and abundance of juvenile (< 25 cm) and adult (≥ 25 cm) Atlantic herring collected in Narragansett Bay during the Rhode Island bottom trawl survey, 1990-1996. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].

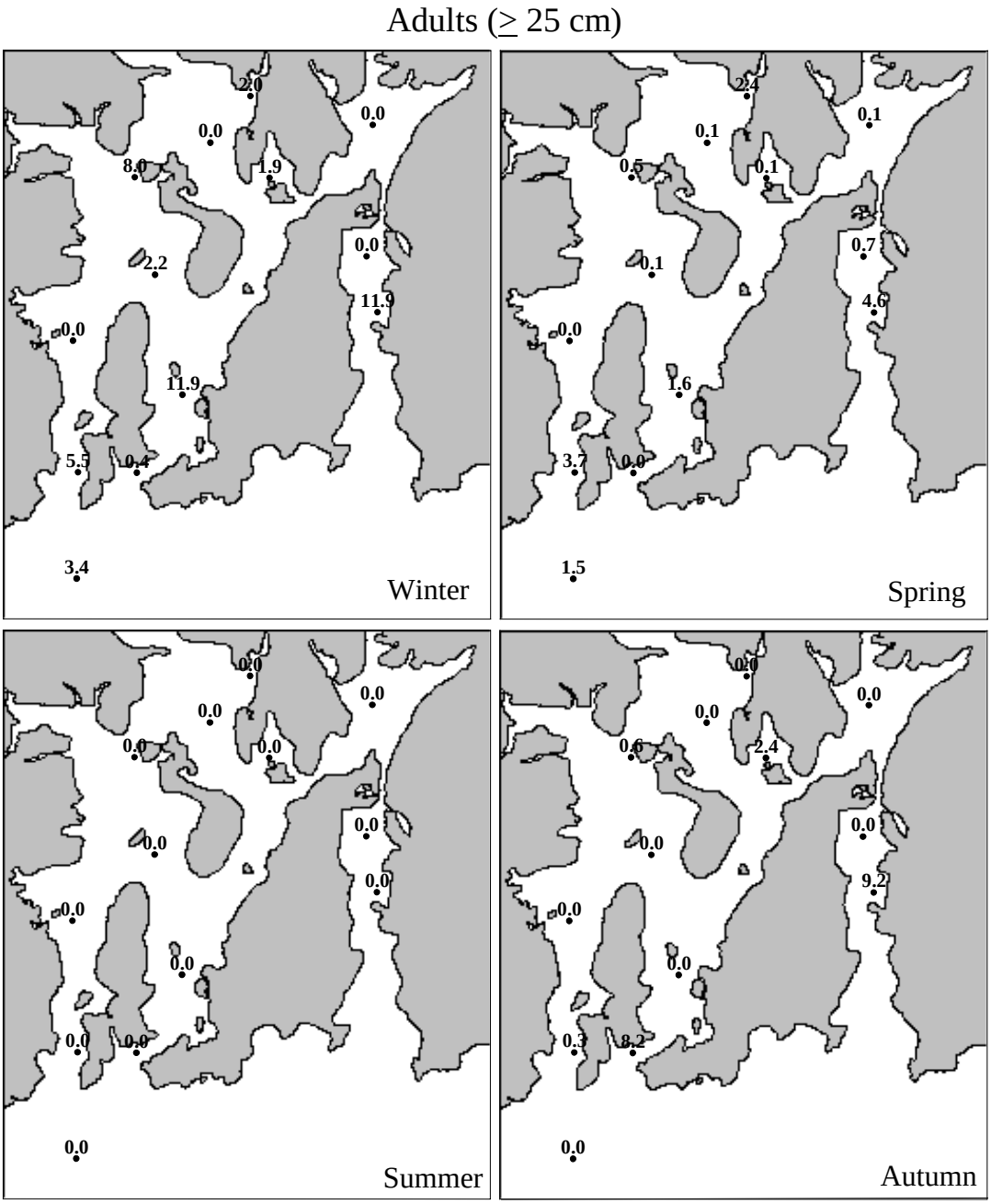
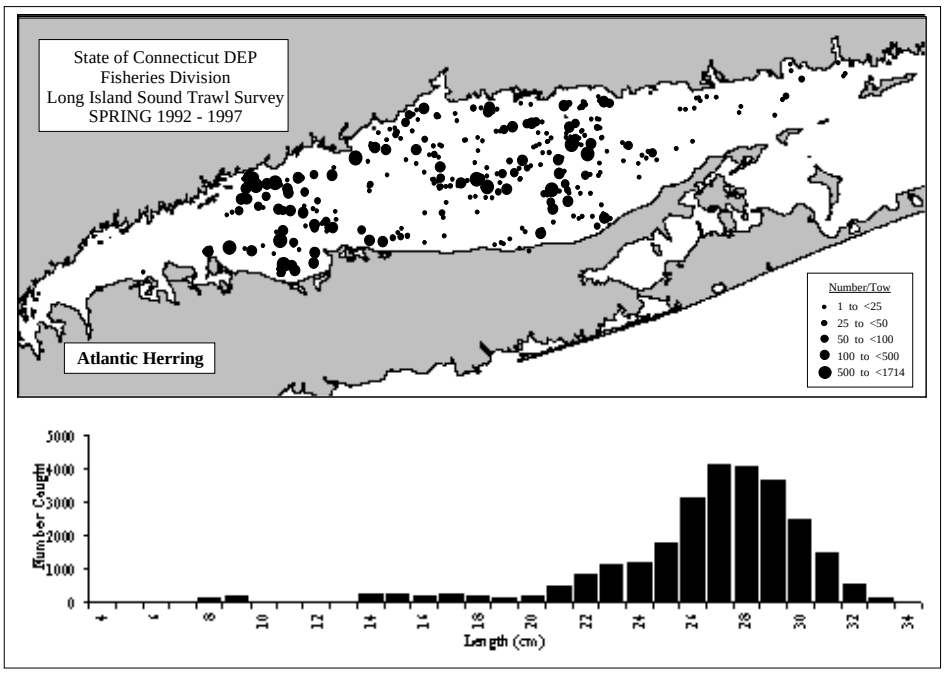


Figure 15. cont'd.



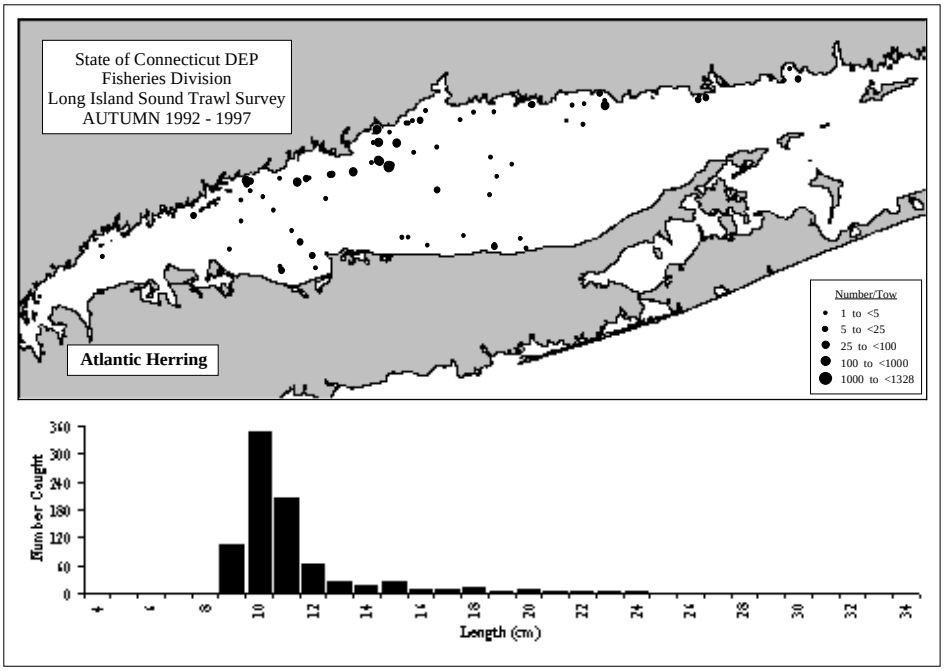


Figure 16. Distribution and abundance of Atlantic herring collected in Long Island Sound during spring and autumn Connecticut bottom trawl surveys, 1992-1997 [see Reid *et al.* (1999) for details]. Histograms show lengths of herring during spring and autumn from a subset of 1992-1997 and earlier collections.

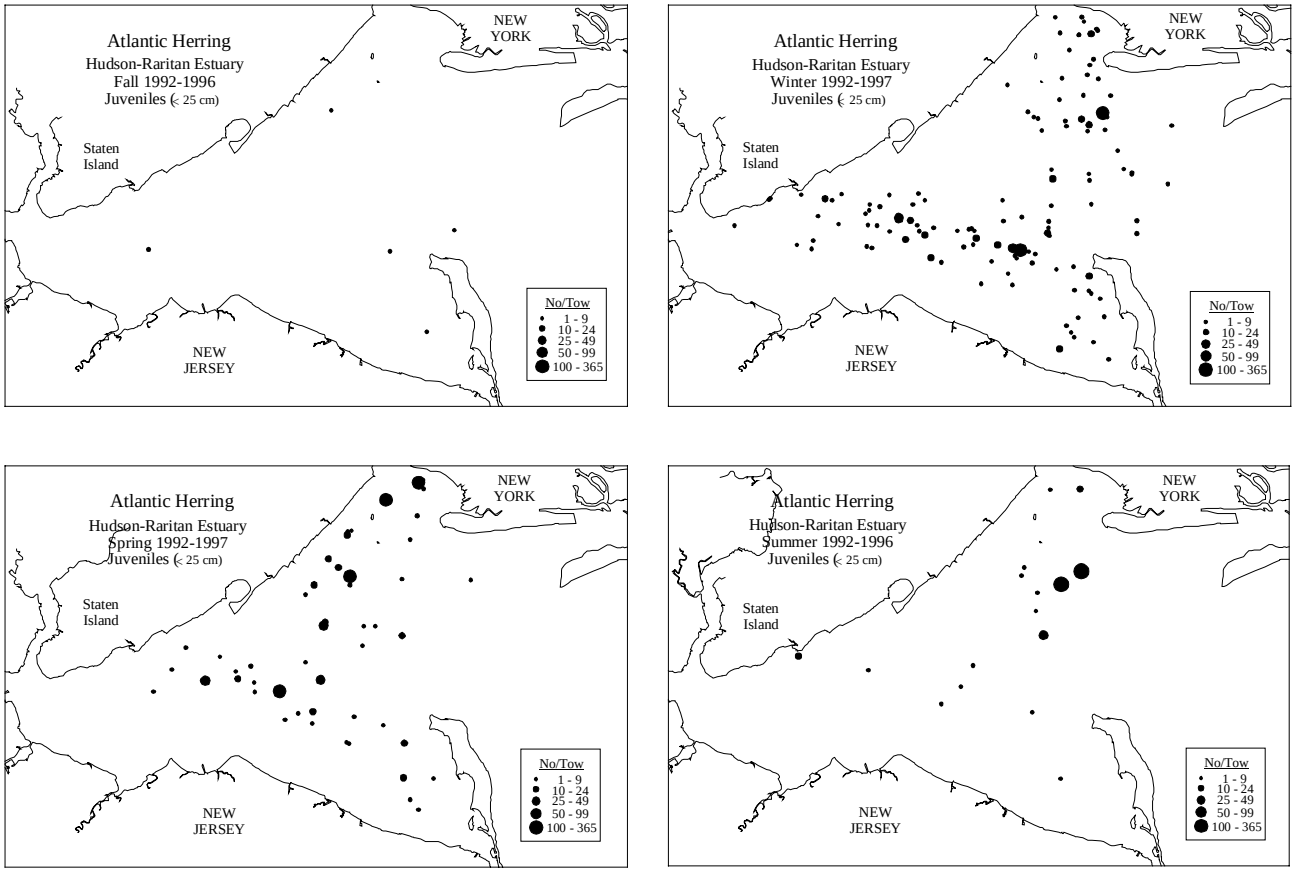


Figure 17. Distribution and abundance of juvenile (< 25 cm) and adult (≥ 25 cm) Atlantic herring collected in the Hudson-Raritan estuary during Hudson-Raritan trawl surveys, 1992-1997 [see Reid *et al.* (1999) for details].

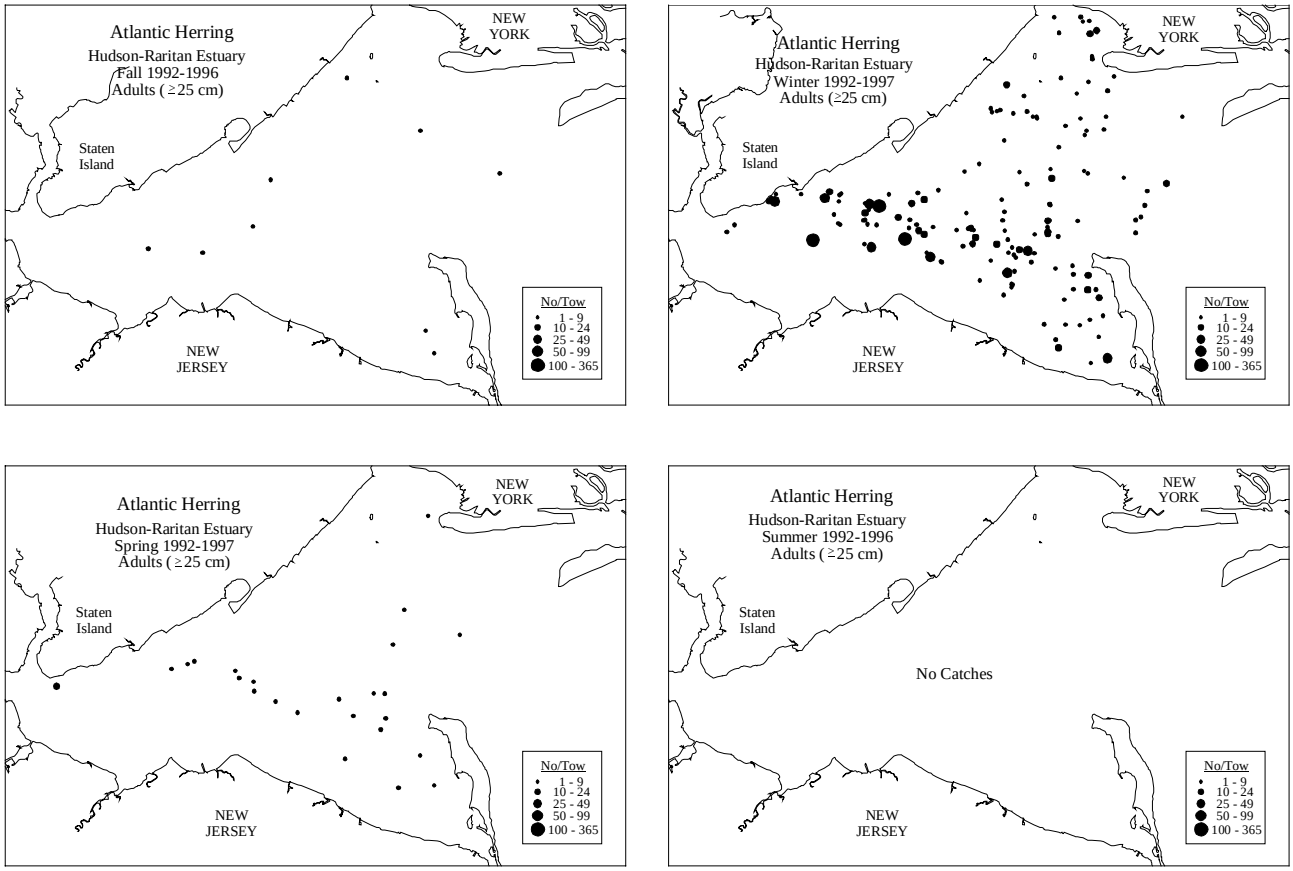


Figure 17. cont'd.

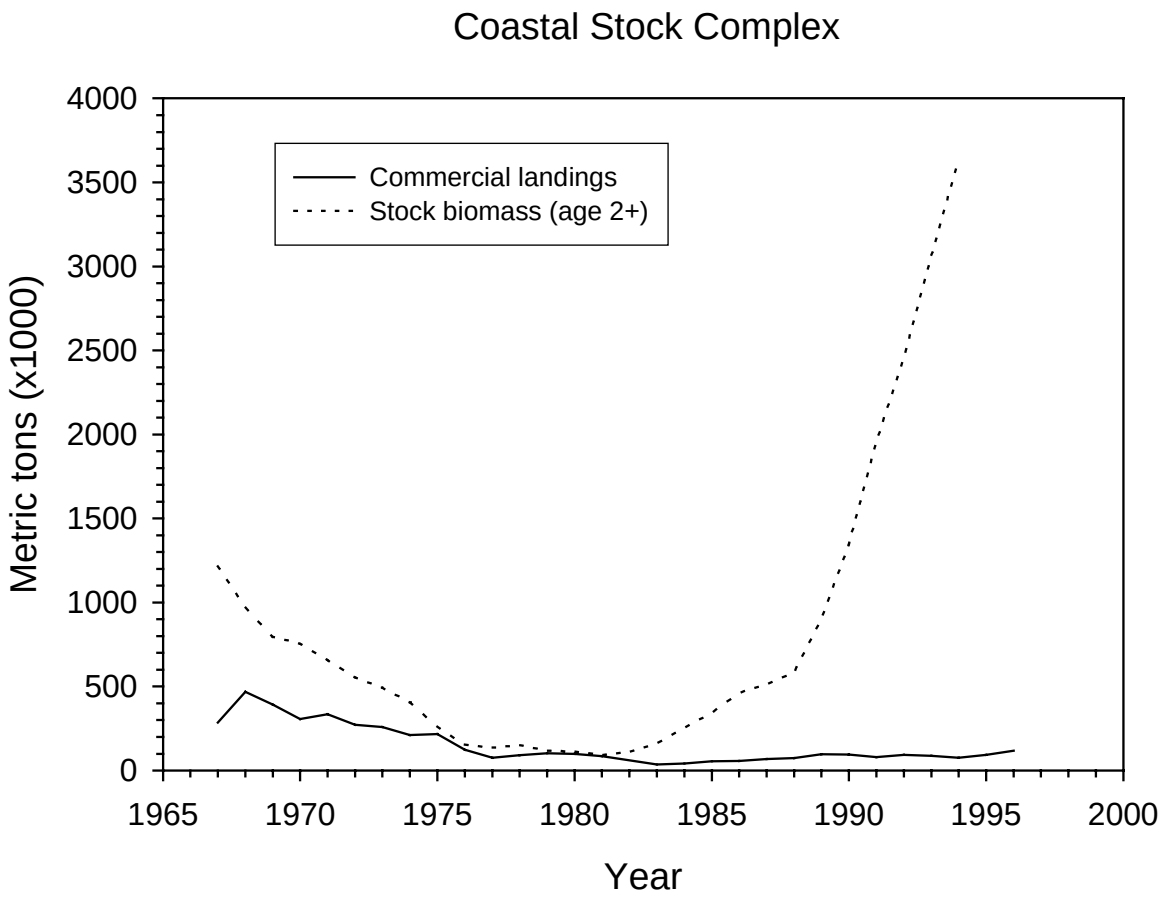


Figure 18. Commercial landings and estimated stock biomass index (ages 2+) of Atlantic herring, 1967-1992 (Friedland 1995, 1998).

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NOAA Technical Memorandum NMFS-NE-128

Essential Fish Habitat Source Document:

Haddock, *Melanogrammus aeglefinus*, Life History and Habitat Characteristics

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September 1999

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Essential Fish Habitat Source Document:

Haddock, *Melanogrammus aeglefinus*, Life History and Habitat Characteristics

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Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

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[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

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INTRODUCTION

The haddock, *Melanogrammus aeglefinus*, is a demersal gadoid species found on both sides of the North Atlantic (Figure 1). In the western Atlantic, haddock are distributed from Greenland to Cape Hatteras, North Carolina. Five haddock stocks have been identified in the northwest Atlantic from Newfoundland to Georges Bank (Cushing 1986). Haddock are managed under the New England Fishery Management Council's Northeast Multispecies Fishery Management Plan (NEFMC 1993), which recognizes two principal haddock stocks, Georges Bank and the Gulf of Maine, partially or wholly in U.S. waters. There is evidence, however, that larvae from Browns Bank, which is in Canadian waters, drift inshore as far south as Cape Cod (Colton and Temple 1961) and spend at least a portion of their lives in U.S. coastal waters.

This Essential Fish Habitat Source Document provides information on the life history and habitat requirements of the three haddock stocks inhabiting U.S. waters in the Gulf of Maine area: (1) Gulf of Maine, (2) Georges Bank, and (3) Browns Bank.

LIFE HISTORY

A brief synopsis of the life history characteristics of haddock is provided in Amendment 5 to the Northeast Multispecies Fishery Management Plan (NEFMC 1993). More detailed information is provided here and in reviews by Bigelow and Schroeder (1953), Blacker (1971), Hardy (1978), Chenoweth *et al.* (1986), and Collette and Klein-MacPhee (in prep.).

EGGS

Haddock spawn over pebble gravel substrate, avoiding ledges, rocks, kelp and soft mud (Bigelow and Schroeder 1953). The eggs are spawned at the bottom but become buoyant after fertilization, rising into the water column where subsequent development occurs (Hardy 1978; Page *et al.* 1989). Depending on water temperature, eggs hatch in 9-32 days after spawning (Laurence and Rogers 1976; Hardy 1978).

LARVAE

Larvae range in size from 2.0-4.99 mm in length. Size varies geographically, and the mean for Georges Bank-Gulf of Maine fish is 4.08 mm (Collette and Klein-MacPhee, in prep.).

JUVENILES

Larvae metamorphose into juveniles in 30-42 days (Laurence 1978) and at a length of 2-3 cm (Fahay 1983). Juveniles initially remain in the upper part of the water column, but at 3-5 months and 3-10 cm [or 3-4 cm (Hardy 1978), 4-6 cm (Lough and Bolz 1989), 6-8 cm (Fahay 1983), 7-8 cm (Perry and Neilson 1988), 9-10 cm (Mahon and Neilson 1987)] they descend toward the bottom and adopt a demersal lifestyle (Bigelow and Schroeder 1953).

ADULTS

Adult haddock can reach sizes exceeding 110 cm and 16 kg, although commercially caught haddock average 35.5-58.5 cm and 0.5-2 kg. The maximum age documented from Northeast Fisheries Science Center (NEFSC) surveys from 1970-1988 is 14 years (Penttila *et al.* 1989), but ages greater than 9 years are uncommon.

REPRODUCTION

Size and age at first maturity vary considerably among haddock stocks (Table 1), although several trends are obvious. First, females mature at a larger size and older age than males, and second, Georges Bank haddock mature at a much smaller size and younger age than haddock from Browns Bank and the Gulf of Maine (also see Clark 1959). There is evidence that the age and size at maturity of Georges Bank haddock have declined in recent years (O'Brien *et al.* 1993; Trippel *et al.* 1997). For example, the median length of maturity during 1977 to 1983 was 37 cm for males and 40 cm for females, compared to 26.8 cm and 29.7 cm in recent years (O'Brien *et al.* 1993). Since age and size at maturity in haddock have been shown to be density-dependent (Waiwood and Buzeta 1989; Ross and Nelson 1992), declines in the abundance of the Georges Bank stock (see Status of Stocks below) may explain these declines in age and size at maturity.

Georges Bank and Browns Bank are the principal spawning areas in the Gulf of Maine area. Generally, the greatest production is from Georges Bank. Limited spawning also occurs on Nantucket Shoals (Smith and Morse 1985) and along the South Channel and the New England coast (Colton and Temple 1961). Jeffreys Ledge and Stellwagen Bank are two major spawning sites along the coast of New England (Colton 1972). Ames (1997) reports many small, relatively isolated spawning areas in inshore Gulf of Maine waters. Based on interviews with retired commercial fishers from Maine and New Hampshire, 100 haddock spawning sites were identified, covering a total of 499 square miles, from Ipswich Bay to Grand Manan Channel. It is unclear which of these

spawning areas are historical versus current.

The timing of spawning varies among sites; the general pattern is for spawning to occur later as one moves north (Page and Frank 1989). Presumably, this is due to decreasing water temperatures with increasing latitude. There is considerable inter-annual variation in spawning time within sites. On Georges Bank, spawning occurs from January to June (Smith and Morse 1985), usually peaking in late-March to early-April (Smith and Morse 1985; Lough and Bolz 1989; Page and Frank 1989; Brander and Hurley 1992). On Browns Bank, spawning occurs from early March to June (Campana 1989), usually peaking in late-April to early-May (Page and Frank 1989). In the Gulf of Maine, spawning occurs from early February to May, usually peaking in February to April (Bigelow and Schroeder 1953). The inter-annual variation in the onset and peak of spawning can be explained, at least in part, by environmental conditions, more specifically the severity (in terms of temperature and duration) of the preceding autumn and winter (Smith *et al.* 1981).

FOOD HABITS

Haddock initially inhabit the upper reaches of the water column, feeding on pelagic prey (zooplankton). Larvae and early stage (pelagic) juveniles are passive foragers on less motile prey such as invertebrate eggs, copepods and phytoplankton (Kane 1984). Juveniles undergo a transformation at age 3 to 5 months, after which they are closely associated with the bottom and feed on benthic prey. Juveniles show a distinct transition from planktonic to benthic feeding (Mahon and Neilson 1987). Planktonic prey such as copepods and pteropods decrease in importance after juveniles become demersal, while ophiuroids and polychaetes increase in importance. Amphipods remain relatively important through the first year, but there is a shift from planktonic to benthic species. Benthic juveniles and adults are indiscriminant consumers of invertebrates, feeding primarily on crustaceans, polychaetes, mollusks, echinoderms and some fish (Bowman and Michaels 1984; Mahon and Neilson 1987; Collette and Klein-MacPhee, in prep.).

The 1973-1990 Northeast Fisheries Science Center (NEFSC) bottom trawl survey data on food habits [see Reid *et al.* (1999) for details] for juveniles and adults combined (1973-1980: 8-87 cm; 1981-1990: 10-88 cm) reveal that crustaceans, echinoderms, polychaetes and mollusks are the most important prey items of haddock (Figure 2). Crustaceans make up the major part of the diet of juveniles; amphipods are the most abundant crustacean, followed by decapods, euphausiids, and mysids. However, crustaceans are less important (although still the most common prey type) in the adult diet, while echinoderms (particularly Ophiuroidea, *Ophiopholis aculeata*, and *Ophiura sarsi*) and polychaetes increase in importance. This trend is evident during both sampling periods. Mollusks are less abundant in the haddock diet, but are present in all size classes, as are low numbers of fish

LARVAL RETENTION

A factor that may be critical to the survival of the egg and larval stages, and thus to the determination of haddock year-class strength, is the degree of larval retention on or near the spawning grounds. For example, there is a southerly flow of surface water from the area of haddock spawning on Georges Bank. Colton and Temple (1961) concluded that eggs and larvae in the surface layers would therefore be carried either into the slope water zone or the coastal waters southwest of the Bank. Any larvae drifting into the slope water zone would be carried in a northeasterly direction away from Georges Bank and the continental shelf and would be lost to the fishery. Thus, strong year-classes may arise in years when circulation results in retention of larvae on the Bank (Smith and Morse 1985) or in nursery grounds to the southwest of the Bank (Colton and Temple 1961; Polacheck *et al.* 1992). Lough and Bolz (1989) found that the southerly drift of larvae may be slowed, and retention on the shoals of Georges Bank enhanced, by larvae residing nearer to the bottom in waters shallower than 70 m. Ames (1997) suggests that eggs and larvae in the coastal Gulf of Maine are retained over critical habitat by tidal currents, and that this serves to enhance survival.

HABITAT CHARACTERISTICS

Detailed information on the life history and habitat characteristics of haddock is summarized in Table 2. This information is limited to stocks inhabiting U.S. waters (including Browns Bank, see Introduction); information from other stocks, e.g., Canadian and European, was not considered.

EGGS AND LARVAE

The egg and larval stages occur in the water column at depths of 10-50 m below the surface (Marak 1960; Colton and Temple 1961; Miller *et al.* 1963; Hardy 1978). Temperatures of 4-10°C (Laurence and Rogers 1976; Laurence 1978) and high salinities, 34-36 ppt (Laurence and Rogers 1976), are preferred.

Most of the haddock eggs taken during Marine Resources Monitoring, Assessment and Prediction (MARMAP) surveys (see Geographical Distribution below) were at temperatures of 4-10°C and depths of 50-

130 m. Most larvae were taken at 4-14°C and 30-90 m.

JUVENILES AND ADULTS

After transformation, haddock are almost exclusively a groundfish, closely associated with pebble gravel bottom (Bigelow and Schroeder 1953; Lough *et al.* 1989). Benthic juveniles and adults are generally found at depths of 40-150 m (Bigelow and Schroeder 1953; Murawski and Finn 1988; Perry and Neilson 1988); 50-100 m is the preferred depth range (Scott 1982; Waiwood and Buzeta 1989) However, they but can be found as shallow as 10 m (Blacker 1971) and as deep as 200+ m (Colton 1972; Hardy 1978), although few are found deeper than 183 m (Bigelow and Schroeder 1953).

Juveniles are most abundant at temperatures of 4.5-10°C (Murawski and Finn 1988). Adults are found at temperatures of 0-13°C (Hardy 1978), but are most common at 2-9°C (Bigelow and Schroeder 1953; Colton 1972; Waiwood and Buzeta 1989), and salinities of 31-35 ppt, although 32 ppt is optimal (Bigelow and Schroeder 1953; Scott 1982; Waiwood and Buzeta 1989).

Most of the juvenile haddock taken during NEFSC trawl surveys (see Geographical Distribution below) were at temperatures of 4-12°C (4-9°C in spring and 7-12°C in autumn) and depths of 25-125 m. Most adults were taken at 4-12°C (4-8°C in spring and 7-12°C in autumn) and 50-100 m. Most juveniles taken during Massachusetts trawl surveys (see Geographical Distribution below) were at 5-10°C (5-8°C in spring and 8-10°C in autumn) and 30-50 m. Most adults were taken at 5-12°C and 25-60 m.

SUBSTRATE

The distribution of substrate sediments in the Gulf of Maine area is presented in Figure 3. There seems to be considerable amounts of suitable substrate for haddock (i.e., gravelly sand and gravel) throughout southwestern Nova Scotia and in patches on Georges Bank; there is relatively very little in the Gulf of Maine. Consequently, haddock are most abundant on Browns and Georges Banks (see Section 4 below).

The primary haddock spawning sites, the northeast part of Georges Bank and Browns Bank (Colton and Temple 1961, Lough and Bolz 1989), are in areas containing large amount of suitable substrate. There is relatively little suitable substrate and spawning in the Gulf of Maine, however, two areas where haddock spawning has been reported, Stellwagen Bank and Jeffreys Ledge (Colton 1972), contain gravelly sand substrate. As well, all haddock spawning sites identified by Ames (1997) occurred in areas of gravel or sandy substrate. A more rigorous analysis overlaying groundfish distribution onto substrate sediment distribution is currently being performed.

GEOGRAPHICAL DISTRIBUTION

Haddock in the northwest Atlantic were distributed from Cape Charles, Virginia to Labrador, Canada during 1975-1994 (Figure 4). Areas of highest abundance include Georges Bank, the Scotian Shelf (including Browns Bank), and the southern Grand Bank.

EGGS

The 1978-1987 MARMAP ichthyoplankton surveys [see Reid *et al.* (1999) for details] found eggs from New Jersey to southwest Nova Scotia (Figure 5). The highest densities were over southwest Nova Scotia and Georges Bank, which is expected since Georges and Browns Banks are the principal haddock spawning areas (Colton and Temple 1961; Laurence and Rogers 1976; Brander and Hurley 1992). Eggs were collected from January through August, with the highest abundance collected in April, followed by March and May. This corresponds with observations that peak spawning occurs from March to May (Bigelow and Schroeder 1953; Page and Frank 1989; Brander and Hurley 1992). The highest mean density of eggs occurred in April (77.3 eggs/10 m^2), followed by March (21.1 eggs/10 m^2), with high concentrations spreading to the Gulf of Maine. By July and August, mean densities had decreased considerably (< 0.1 eggs/10 m^2).

All eggs were collected within a narrow range of temperatures, 2-10°C; the vast majority occurred within 4-10°C (Figure 6), which is the temperature range at which egg survival is highest (Hardy 1978). In January, the highest abundance of eggs was found at 6-7°C, while in February, March and April highest abundance was at 4-6°C. Colton (1972) and Hardy (1978) have reported that the optimum spawning temperature for haddock is 2-7°C. In May and June the highest abundance of eggs was at 5-7°C, and during July and August almost all eggs were found at 8-10°C.

Eggs were collected at depths in the water column ranging from 10-450 m, however the majority were found at 50-130 m (Figure 6). From January to May the highest abundance of eggs occurred at depths of 70-90 m, while in June the majority of eggs were deeper, at 110-150 m. In July, all eggs were found between 90-110 m, and in August all eggs were found at 50-70 m.

LARVAE

The 1977-1987 MARMAP ichthyoplankton surveys [see Reid *et al.* (1999) for details] found larvae from the

Delmarva Peninsula to southwest Nova Scotia, and from inshore waters to the seaward limits of the surveys (Figure 7). Larvae were collected from January through July, with the highest average mean density occurring in May (8.3 larvae/10 m^2) and April (8.1 larvae/10 m^2). High concentrations of larvae were found off southwest Nova Scotia and Georges Bank spreading southward. Mean densities were very low in January and February, and had declined drastically by July (< 0.1 larvae/10 m^2). These data concur with previous studies that indicate that hatching begins in earnest in March and peaks in April and May (Smith and Morse 1985; Campana 1989).

Larvae were collected within a wider range of temperatures than eggs, 2-15°C, with the majority occurring at 4-14°C (Figure 8). In January, the majority of larvae were found at 9-10°C, during February to April, most larvae were at 4-7°C, during May to June at 6-9°C, and in July the majority of larvae were found at 9-11°C and 14°C.

Larvae were collected at depths in the water column ranging from 10-325 m, however the majority were found at 30-90 m (Figure 8). The majority of larvae tend to inhabit the upper 50 m of the water column (Marak 1960; Hardy 1978). From January to June, the majority of larvae were found at 70-90 m, and during July all larvae were found at 30-90 m, with the highest abundance at 30-50 m.

JUVENILES AND ADULTS

NEFSC Bottom Trawl Surveys

Catches from the 1963-1997 NEFSC bottom trawl surveys [see Reid *et al.* (1999) for details] indicate that the distribution of juvenile and adult haddock are similar (Figure 9), although juveniles tend to be distributed further to the south in summer and autumn. Juveniles and adults were caught in all seasons from throughout the Gulf of Maine, Scotian Shelf and Georges Bank. More large catches were made in autumn than spring, presumably because adults migrate offshore to winter pre-spawning aggregations (Halliday and McCraken 1970). The greatest abundance occurs on Georges and Browns Banks, followed by the Scotian Shelf off southwest Nova Scotia, Nantucket Shoals, and Stellwagen Bank. In the spring, juveniles and adults were most abundant on Georges Bank and the Scotian Shelf, particularly Browns Bank. Winter and summer distributions are presented as presence/absence, thus precluding a discussion of abundances (Reid *et al.* 1999).

Haddock were caught at a wide range of temperatures (3-16°C; Figure 10). The temperature distributions of juveniles and adults were similar. There was a definite seasonal effect on the temperature preferences of both juveniles and adults, with higher temperatures preferred in autumn. In spring, juveniles were found at 3-13°C, with the majority at 4-9°C, and the highest abundance at 6°C, while in autumn, juveniles were found at 4-15°C, with the majority at 7-12°C, and the highest abundance at 9°C. In spring, adults were found at 3-13°C, with the highest abundance at 5-6°C and the majority at 4-8°C, while in autumn, adults were found at 4-16°C, with the highest abundance at 8°C and most at 7-12°C. Bigelow and Schroeder (1953) and Hardy (1978) state that adults are found between 0-13°C, and rarely < 2°C.

Haddock were caught at depths ranging from 15-350 m (Figure 10). The depth distributions of adults and juveniles are very similar, and there is no appreciable seasonal effect other than a slightly wider range of depths inhabited in autumn. Overall, the majority of haddock were caught between 50-100 m, and the greatest abundance of both life stages during both autumn and spring was at 75 m. In spring, juveniles were found at 25-200 m, with the majority at 50-125 m, and at 15-250 m, with the majority at 25-100 m, during autumn. Adults were found at 25-225 m with the majority at 50-100 m in spring, and at 15-350 m with the majority at 50-100 m in autumn. Adults in the Gulf of Maine have previously been reported to inhabit depths of 46-137 m (Bigelow and Schroeder 1953).

Massachusetts Inshore Trawl Surveys

Juveniles were far more abundant in coastal Massachusetts waters than adults (Figure 11). Juveniles were more abundant in autumn than spring. In autumn, juveniles were most abundant directly north and northeast of Cape Ann and in northeastern Massachusetts Bay. They were also found in two aggregations off the east coast of Cape Cod, and in low numbers throughout Cape Cod Bay. In the spring, juveniles were still most abundant north of Cape Ann, in northeastern Massachusetts Bay, and in two aggregations off eastern Cape Cod, but were no longer widespread in Cape Cod Bay. A fairly large aggregation was also found northwest of Provincetown, Cape Cod.

Adults were more abundant in spring than in autumn. This corresponds to adult migrations with offshore winter pre-spawning and spawning aggregations (Halliday and McCraken 1970). In autumn, they were virtually non-existent from inshore Massachusetts waters; in spring, adults were most abundant in northeast Massachusetts Bay, and were also found northeast of Cape Ann.

Juveniles and adults were found at temperatures ranging from 4-14°C (Figure 12) and were found at warmer temperatures in autumn than spring. Juveniles were most abundant at 5-8°C in spring and 8-10°C in autumn. Adults were most abundant at 5-9°C in spring, and the few found in autumn were at 11-12°C. Juveniles and adults were found at depths of 15-80 m (Figure 12).

Juveniles were most abundant at 35-50 m in spring and 30-45 m in autumn. Adults were most abundant at 25-50 m in spring, and the few found in autumn were at 50-60 m.

OFFSHORE VS. INSHORE

No inshore distribution data are available for eggs and larvae, but the NOAA Estuarine Living Marine Resources (ELMR) program lists haddock eggs and larvae as 'not present' in the majority of bays and estuaries in New England and the Mid-Atlantic Bight. In the few inshore areas where they have been reported (Great Bay, Massachusetts Bay, Cape Cod Bay, Buzzards Bay, Narragansett Bay), they are listed as 'rare' (Jury *et al.* 1994; Stone *et al.* 1994).

Juveniles were more abundant inshore in autumn than spring. They occurred in shallower water and at lower temperatures inshore than offshore. Adults were far more abundant offshore than inshore. They were more abundant inshore in spring than autumn, and conversely, more abundant offshore in autumn than spring. This most likely reflects the offshore migration to pre-spawning and spawning aggregations (Halliday and McCraken 1970). They occurred at warmer temperatures and shallower depths inshore than offshore.

STATUS OF THE STOCKS

The total landings (U.S. and Canada) in 1996 from the Georges Bank and Gulf of Maine haddock stocks were 4226 metric tons (mt), 71% higher than 1995, 54% higher than 1994, but 8% lower than 1993 and 34% lower than 1992 (Mayo 1995; Brown 1998).

In the Gulf of Maine, commercial landings declined from a high of about 5000 mt in the mid-1960s to less than 1000 mt in 1973 (Figure 13). Total annual landings increased sharply between 1974 and 1980 and averaged 7000 mt from 1980 to 1983. Since 1983, catches have declined to record lows. The NEFSC autumn survey biomass index has declined steadily since 1978 and reached a record low of 0.09 in 1992 (less than 1% of the peak 1963 survey). Abundance remains at an all time low and recruitment has been insufficient to support landings, resulting in recruitment overfishing and continued stock depletion (Mayo 1995).

On Georges Bank, total commercial landings increased from about 50,000 mt annually prior to 1965 to nearly triple that in 1965 and 1966 (Figure 13). Landings declined through 1976, but catches increased between 1977 and 1980 reaching 28000 mt. Catches declined after 1980 to 4500 mt in 1989 and since 1989 catches have ranged between 2300 and 6900 mt (Northeast Fisheries Science Center 1997). The NEFSC spring and autumn bottom trawl surveys indicate that the biomass has declined markedly since the late 1970s (Mayo 1995). The 1995 and 1996 autumn survey indices are higher than recent years, but are still extremely low relative to historic levels (Figure 13; Brown 1998). The stock remains in a state of collapse: total stock size declined from 133 million in 1979 to 14 million in 1991 (Mayo 1995). Total stock has increased somewhat in 1995 and 1996 (Figure 13). Spawning stock biomass reached a record low of 11,000 mt in 1993, but has since rebounded to over 32,000 mt in 1996 (Northeast Fisheries Science Center 1997). This is a sharp increase, but is still far below historical average levels.

The September 1997 'Status of Fisheries of the United States' (National Marine Fisheries Service 1997) reports that the Georges Bank haddock stock is presently not being overfished, nor is it approaching an overfished condition. However, the 24th Stock Assessment Workshop concludes that the Georges Bank stock is at a low biomass level and is in an over-exploited state (Northeast Fisheries Science Center 1997). The status of the Gulf of Maine stock is listed as unknown (National Marine Fisheries Service 1997).

Data from the NEFSC bottom trawl surveys is presented in Figure 14 to contrast the distribution of haddock from recent periods of low abundance (1992-1996) with periods of high abundance (1963-1967). The pattern is similar for juveniles and adults, with the exception that juveniles are distributed further south in years of low abundance, while adults were not. In years of low abundance, juveniles and adults were rare on Georges Bank (the apparent absence of haddock on Browns Bank during this period is due to the absence of sampling effort in this area after 1987). In years of high abundance, they were far more abundant on Georges Bank, Nantucket Shoals, and Stellwagen Bank.

RESEARCH NEEDS

The biology of northwest Atlantic haddock is quite well-known, as evidenced by the completeness of the habitat matrix presented in this report (Table 2). However, there is a need for more detailed information in certain areas:

- More information on the genetic structure of haddock stocks is needed. The present stock definitions are based on tagging studies, meristic data, age composition, and growth data (Northeast Fisheries Science Center 1997). Few studies of genetic structure currently exist. Purcell *et al.* (1996) identified significant temporal variation in gene frequencies on Georges Bank, and suggested that spawning on the Bank may not be genetically discrete. However, Zwanenburg *et al.* (1992) found that gene flow among spawning aggregations on five

banks in the northwestern Atlantic, including Georges Bank, was restricted and that deep channels can be significant barriers to gene flow. They recommend that additional sampling effort is needed to provide a clearer understanding of haddock population structure.

- A better understanding of the factors affecting recruitment and year-class strength is also needed. Research into obvious factors such as the effects of water temperatures, food levels, and predation on the survival of the early life stages is needed. Also, the role of other factors such as hydrographic effects (e.g., tidal and non-tidal currents) which affect the retention and transport of eggs and larvae, should be investigated more thoroughly.
- Interactions with other closely related species (e.g., cod) are probably important, and need to be better understood.
- Detailed information on spawning is needed; our literature search uncovered very few spawning details, other than the fact that spawning occurs at the bottom over gravel substrate.
- Information on growth and survival rates by habitat type (i.e., Level 4 EFH information) is needed to accurately designate Essential Fish Habitat for haddock.

The October 1997 report of the 24th Stock Assessment Workshop (Northeast Fisheries Science Center 1997) lists research recommendations for improving haddock stock assessments:

- Improve biological sampling of commercial landings and discards.
- Examine effects of large tows on overall and age-specific abundance indices for haddock, specifically with reference to closed areas.
- Examine effects of abrupt changes in mean weight at age during the 1990s, specifically with respect to the 1989-1991 year-classes in the eastern part of Georges Bank.
- Investigate factors associated with apparent recent improvements in survival rations (R/SSB).

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Table 1. Size and age at maturity of haddock, *Melanogrammus aeglefinus*.

Stock	Time Period	A_{50} (years) *male*	A_{50} (years) *female*	L_{50} (cm) *Male*	L_{50} (cm) *female*	Reference
Georges Bank	1985-1989	1.3	1.5	26.8	29.7	O'Brien *et al.* 1993
	1986-1989	1.1-1.9	1.8-2.6	24-34	33-41	Trippel *et al.* 1997
	1989-1995	1.1-1.4	1.6-2.0	23-30	34-36	Trippel *et al.* 1997
Browns Bank	1970-1985	-	-	36.4	42.6	Waiwood and Buzeta 1989
	1979-1985	2.8-3.3	2.8-3.6	33-35	34-38	Trippel *et al.* 1997
Gulf of Maine	1985-1989	2.1	1.8	35.0	34.5	O'Brien *et al.* 1993

Table 2. Summary of life history and habitat parameters for haddock, *Melanogrammus aeglefinus*. Information that could not be distinguished as either juvenile or adult is listed under 'Juveniles/Adults'.

Life Stage	Size and Growth	Habitat	Substrate	Temperature
Eggs [1]	Mean size at hatch is 3.33 mm. Largest size at hatch occurs at approximately 8°C; decrease in size at lower and higher temperatures.	Early stage eggs concentrated near the surface; later stages are distributed more uniformly over depth or have a sub-surface maximum. One study shows that stage I, II and III eggs were within the top 20 m, while the center of mass of stage IV eggs was 31 m.	Eggs are spawned over pebble gravel bottom. After spawning, eggs become buoyant, rise and float near the surface where subsequent development occurs.	Peak spawning occurs when mean surface temperature is 2-10°C. Incubation duration varies with temperature: 20-32 days at 2°C, 11-23 days at 4°C, 11-17 days at 6°C, 9-13 days at 8°C, and 6-8 days at 11°C. Highest survival rate occurs at 4-10°C (mean 6°C).
Larvae [2]	Size at hatch ranges from 2 - 5 mm (mean = 4 mm).	Generally pelagic. Maximum depth approximately 150 m. Majority found at depths of 10-50 m.		Upper lethal = 10°C; lower lethal = 4°C. Time to metamorphosis: at 9°C = 30 days after hatching; at 4°C = 36-42 days. Growth rates: at 4°C = 3.68 %/day, at 7°C = 5.53, at 9°C = 13.36. On Georges Bank, hatching occurs in 2-3 weeks at normal spring temperatures.
Juveniles [3]	Metamorphosis of larvae occurs at approximately 3 cm .	Small juveniles found near the surface (10-40 m), more or less stationary in the open sea. Descent to bottom (35-100 m) occurs at age 3-5 months and length 5-10 cm (after metamorphosis). YOY found in nursery area between Nantucket Shoals & Hudson Canyon. Occur on same grounds as adults.	Pebble gravel bottom.	Occur at 4.5-11.0°C. Occur at colder temperatures in winter/spring than summer/fall.
Adults [4]	Mean size at maturity (female/male, cm): Georges Bank: 29.7/26.8 Gulf of Maine: 34.5/35.0 Browns Bank: 42.5/36.5 Size at maturity positively density dependent.	Occur throughout the Gulf and offshore banks; greatest concentration on Georges Bank. More exclusively a groundfish than cod. Generally below 10 m, most in 40-150 m, few deeper than 200 m. No extreme migrations, only short inshore/offshore movements.	Selective as to type of substrate: chiefly broken ground, gravel, pebbles, smooth hard sand & smooth areas between rocky patches. Avoid ledges, rocks, kelp or soft mud.	Occur at 0-13°C, but are most abundant at 2-9°C and prefer 4-7°C; mortality at < 1°C; avoid > 10°C. Spawn at 2-7°C, optimum is 4-6°C.
Juveniles/ Adults [5]	Average size at age: 1 - 17.5 cm, 2 - 33.8 cm, 3 - 45.5 cm, 4 - 54.0 cm, 5 - 60.1 cm, 6 - 64.5 cm, 7 - 67.6 cm, 8 - 69.9 cm, 9 - 71.5 cm, 10 - 72.7 cm, 11 - 73. 6cm, 12 - 74.2 cm, 13 - 74.6 cm, 14 - 75.0 cm, 15 - 75.2 cm.			

[1] Bigelow and Schroeder (1953), Miller *et al.* (1963), Laurence and Rogers (1976), Hardy (1978), Lough *et al.* (1989), Page and Frank (1989), Page *et al.* (1989), Waiwood and Buzeta (1989)
[2] Marak (1960), Colton and Temple (1961), Miller et al. (1963), Laurence (1974, 1978), Hardy (1978), Kane (1984), Lough and Bolz (1989)
[3] Bigelow and Schroeder (1953), Colton and Temple (1961), Blacker (1971), Colton (1972), Hardy (1978), Mahon and Neilson (1987), Murawski and Finn (1988), Perry and Neilson (1988), Lough and Bolz (1989), Lough *et al.* (1989)
[4] Bigelow and Schroeder (1953), Marak and Livingstone (1970), Colton (1972), Hardy (1978), Scott (1982), Waiwood and Buzeta (1989), O'Brien *et al.* (1993)
[5] Penttila *et al.* (1989)

Table 2. cont'd.

Life Stage	Salinity	Currents	Prey
Eggs [1]	Highest egg survival occurs at 34-36 ppt. Egg mortality below 25 ppt; mortality decreases with increasing salinity (26-36 ppt).	SW flow of water off Georges Bank results in a southerly flow of eggs and larvae from the NE spawning center. NW flow of water off Browns Bank to western Nova Scotia, New Brunswick and New England as far south as Cape Cod.	
Larvae [2]		Larvae drift with surface currents. Georges Bank larvae may be swept off the Bank to the SW (@ 0.65 cm/s), otherwise are retained; on Browns Bank some larvae retained due to the Browns Bank gyre, others dispersed inshore due to the Nova Scotia coastal current.	Passive foragers on less motile prey: invertebrate eggs, copepods and phytoplankton. In general, ate most abundant species but restricted to prey of a certain size; for example larvae 4-18 mm fed on larval copepods, > 18 mm fed on adult copepods. Feeding peaks shortly before sunset. Larvae may need prey concentrations of 0.5 - 3.0 plankters/ml for suitable growth.
Juveniles [3]		Tidal current weaker near bottom, for example at Georges Bank, current = 1-5 cm/s at 10 cm above bottom, and 7-24 cm/s at 1 m above bottom.	Indiscriminate consumers of invertebrates. Distinct transition from planktonic to benthic feeding. Planktonic prey declines after becoming demersal: copepods and pteropods decreased, while ophiuroids & polychaetes increased. Major benthic prey items (proportion of diet by weight) are crustaceans (56.5%), polychaetes (15.1%), and fish (1.4%).
Adults [4]	Generally found within 31.5 - 35 ppt; Spawn at 31.5 - 34 ppt.		Indiscriminate consumers of sedentary or slow moving invertebrates: crustaceans, annelids, polychaetes, mollusks and echinoderms. Fish make up small part of diet. Heaviest feeding in June; distinct seasonal changes in diet composition.
Juveniles/ Adults [5]			Omnivorous & highly opportunistic. Prey almost exclusively on benthic invertebrates. Order of importance (proportion of diet by weight): echinoderms, 29.9%; polychaetes, 17.6%; crustaceans, 16.2%; fish eggs, 14.6%; other polychaetes, 12.7%. Prey items by area (Gulf of Maine/ Georges Bank/Scotian Shelf) (% by weight): fish-2.2/28.4/3.8 polychaetes-14.7/23.5/11.8 crustacean-15.2/16.0/14.4 mollusks-1.6/3.8/3.0 echinoderms-51.9/7.8/49.0.

[1] Colton and Temple (1961), Laurence and Rogers (1976), Smith and Morse (1985), Page *et al.* (1989)
[2] Marak (1960), Laurence (1974), Hardy (1978), Kane (1984), Smith and Morse (1985), Campana *et al.* (1989), Lough and Bolz (1989)
[3] Bigelow and Schroeder (1953), Blacker (1971), Bowman and Michaels (1984), Mahon and Neilson (1987), Perry and Neilson (1988), Lough *et al.* (1989)
[4] Bigelow and Schroeder (1953), Wigley and Theroux (1965), Tyler (1972), Hardy (1978), Scott (1982), Bowman and Michaels (1984), Waiwood and Buzeta (1989)
[5] Langton and Bowman (1980), Bowman and Michaels (1984)

Table 2. cont'd.

Life Stage	Predators	Spawning	Notes
Eggs [1]	Preyed upon by a wide range of pelagic predators.	Georges and Browns Banks are the principle spawning areas (GB > BB). Limited spawning along South Channel and New England coast. Spawning occurs over all of Georges, but main spawning center is in NE part of the bank. Spawning occurs from January to July; delay in peak spawning time as one moves north. Gulf of Maine: Feb-May, peak varies Feb-April; Georges Bank: Jan-June, peak late-March-April; Browns Bank: early March-June, peaks late April-early May.	Egg duration on Georges Bank varied from 10-20 days over 34 year period; mean egg duration during peak spawning was 15.5 days. Egg duration on Browns Bank varied from 10-30 days over the same 34 years; mean egg duration during peak spawning was 18.6 days. Haddock embryos less tolerant of temperature and salinity extremes than cod embryos
Larvae [2]	Preyed upon by a wide range of pelagic predators.	Nursery grounds lie (a) between Georges Bank and Nova Scotia and (b) to the east of Cape Cod.	Young tend to drift under bells of jellyfish (*Cyanea*). Lab results imply that the first weeks after hatching are a critical period for larvae. One study estimated daily mortality rate at 7.1%.
Juveniles [3]	0+ and 1+ fish primarily preyed on by cod, pollock and silver hake.		1-2 yr old fish particularly abundant on Georges Bank. Vertical migrations may depend on diel light cycle, thermal structure, interspecific competition, prey availability & tidal current speed.
Adults [4]	Preyed upon by seals.	Onset of spawning related to environmental conditions; earlier in years with moderate autumn-winter temperatures than in years with cold autumn/winter. Eggs released at intervals over a 3 week period. Fecundity ranges from 12,000-3,000,000 eggs; varies with size; year to year variation may be correlated with temp. Median age at maturity (female/male, years): Georges Bank: 1.5/1.3 Gulf of Maine: 1.8/2.1; evidence that median length at maturity on Georges Bank has decreased (during 1977-1983 was 40/37).	Move into shallower water in spring & summer; coincides with the inshore fishery. Offshore fishery occurs during the winter and early spring. Distribution influenced more by restrictive spawning area & bottom type conditions than by temperature variation.
Juveniles/ Adults [5]			Stock abundance clearly influenced growth rates: higher correlations occurred during time periods of highest stock abundance than at times when stocks were depleted. Stock size was significantly correlated with juvenile growth but not young adult growth.

[1] Walford (1950), Colton and Temple (1961), Marak and Livingstone (1970), Laurence and Rogers (1976), Hardy (1978), Smith and Morse (1985), Perry and Neilson (1988), Campana (1989), Lough and Bolz (1989), Page and Frank (1989)
[2] Laurence (1974), Hardy (1978), Smith *et al.* (1981), Cushing (1986)
[3] Bigelow and Schroeder (1953), Miller *et al.* (1963), Blacker (1971), Murawski and Finn (1988), Perry and Neilson (1988)
[4] Bigelow and Schroeder (1953), Colton (1972), Hardy (1978), Smith *et al.* (1981), O'Brien *et al.* (1993)
[5] Ross and Nelson (1992)

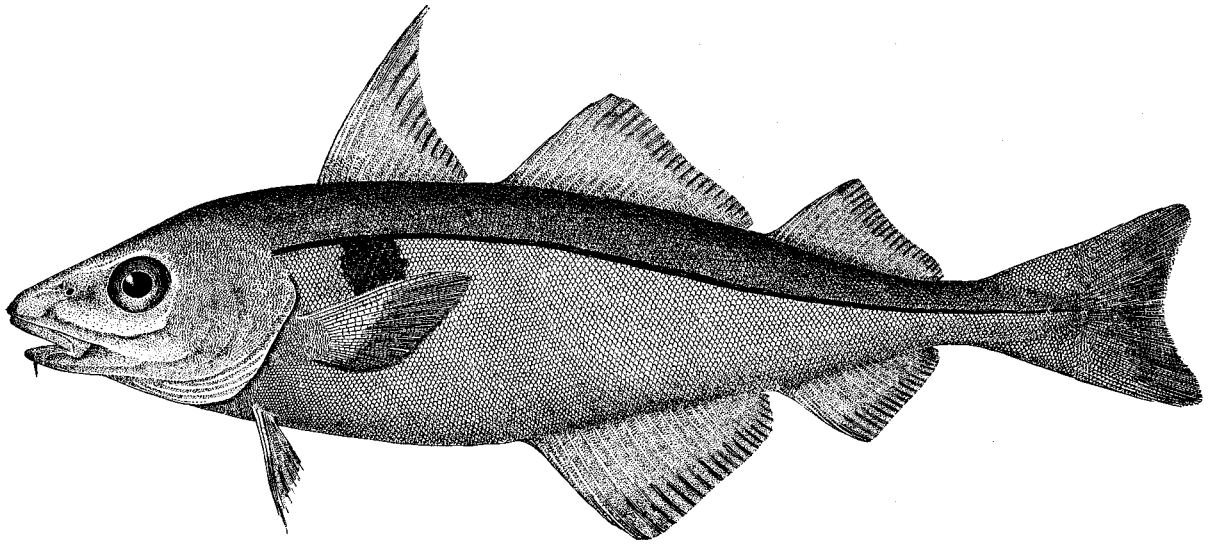


Figure 1. The haddock, M*elanogrammus aeglefinus* (from Goode 1884).

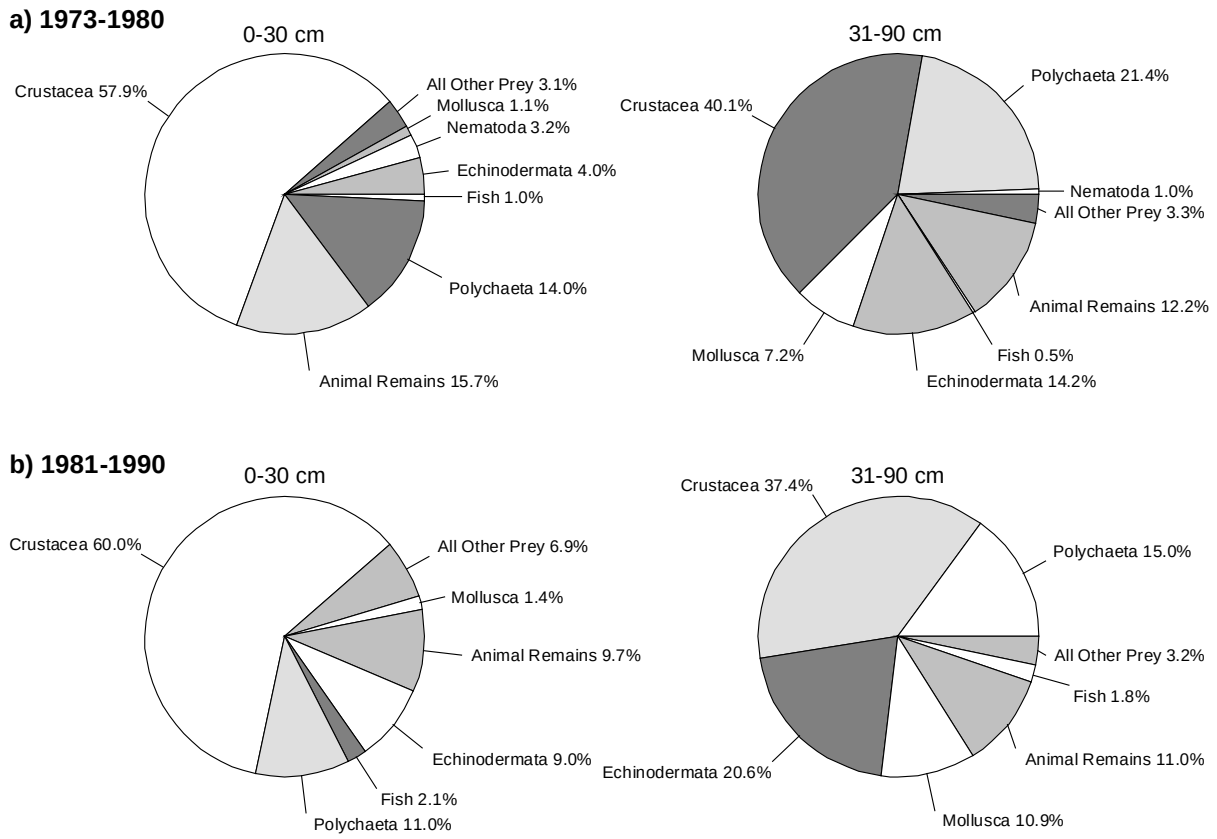


Figure 2. Abundance (% occurrence) of the major prey items of haddock collected during NEFSC bottom trawl surveys from 1973-1980 and 1981-1990. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al*. (1999) for details]. (a) 1973-1980, 0-30 cm: n=532, 31-90 cm: n=1356; (b) 1981-1990, 0-30 cm: n=98, 31-90 cm: n=930. The 0-30 cm size category corresponds, at least roughly, to the juvenile life stage, and the 31-90 cm size class corresponds to adults. The category “animal remains” refers to unidentifiable animal matter.

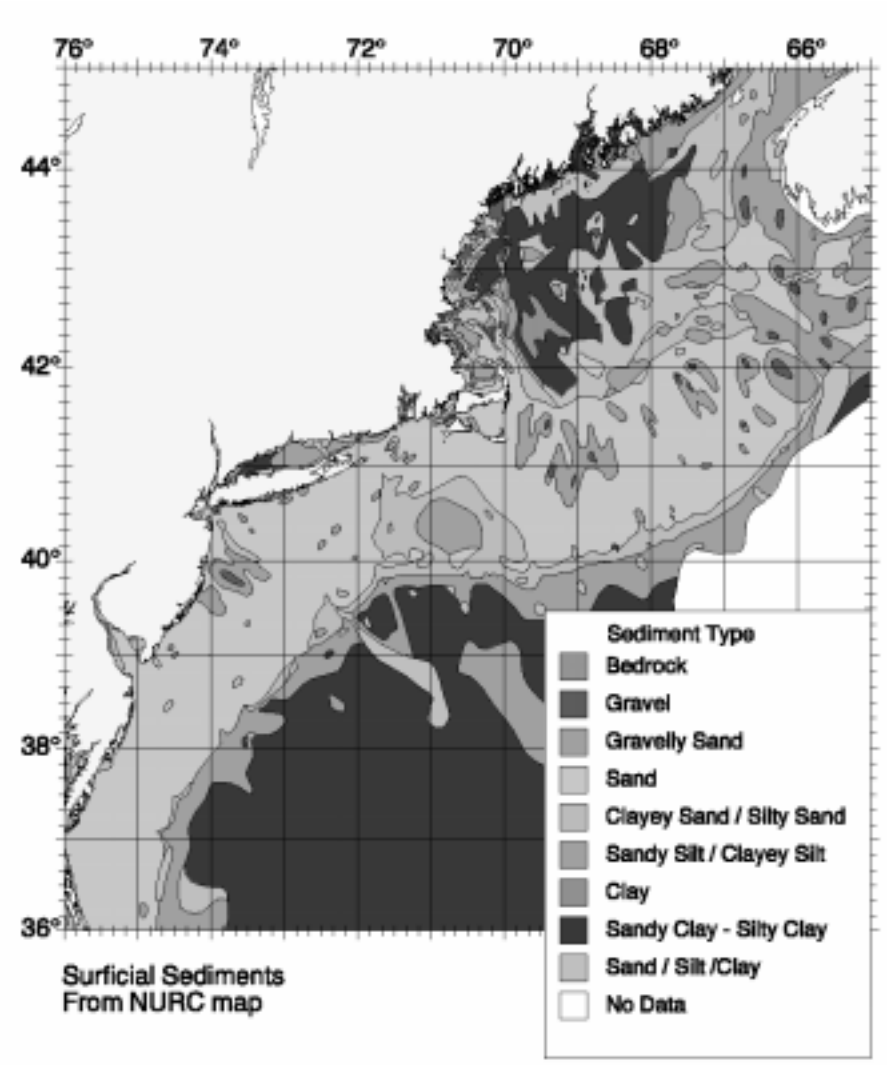
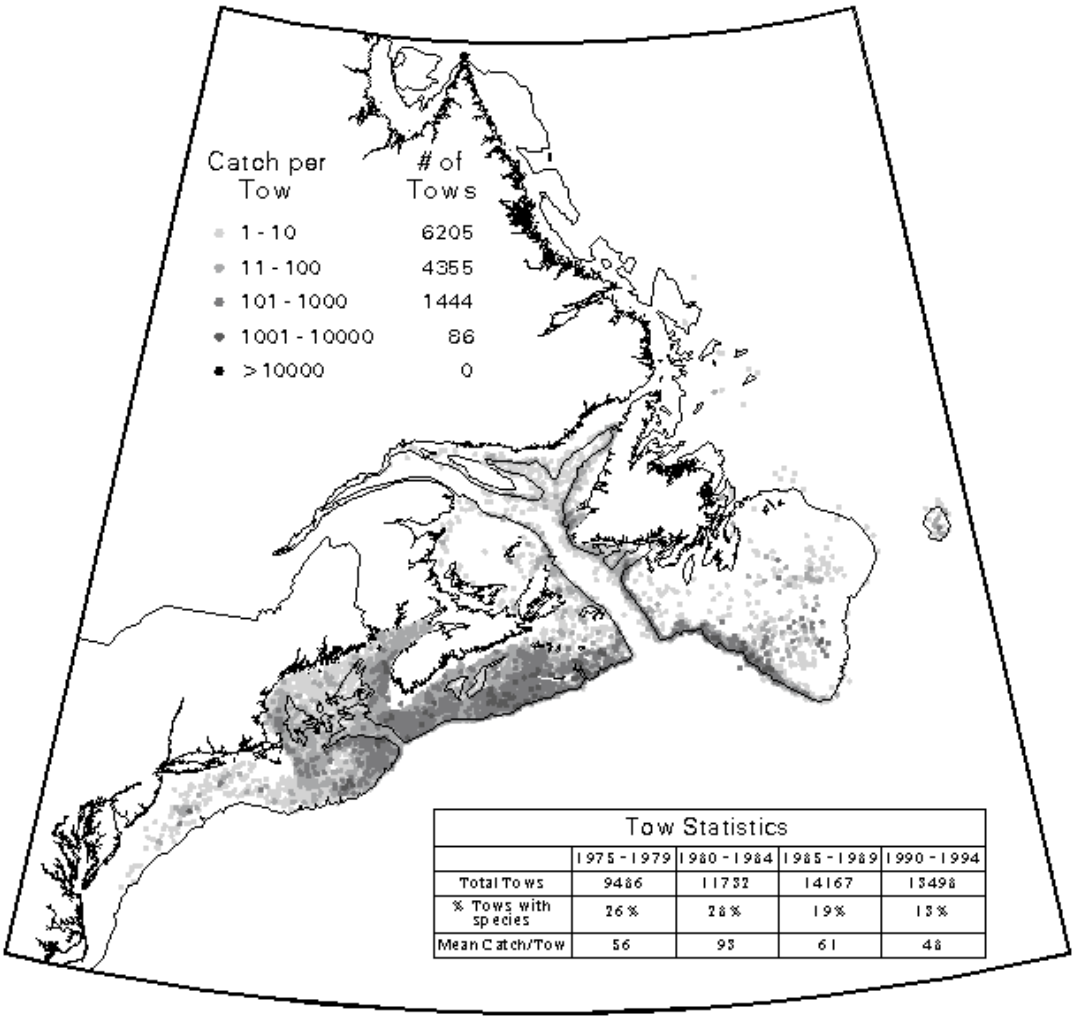


Figure 3. Distribution of surficial sediments along the northeast coast of the United States. Data are from the United States Geological Survey and NOAA.



Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	26 %	28 %	19 %	13 %
Mean Catch/Tow	56	93	61	48

Figure 4. Distribution and abundance of haddock from Newfoundland to Cape Hatteras during 1975-1994. Data are from the U.S. NOAA/Canada DFO East Coast of North America Strategic Assessment Project (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

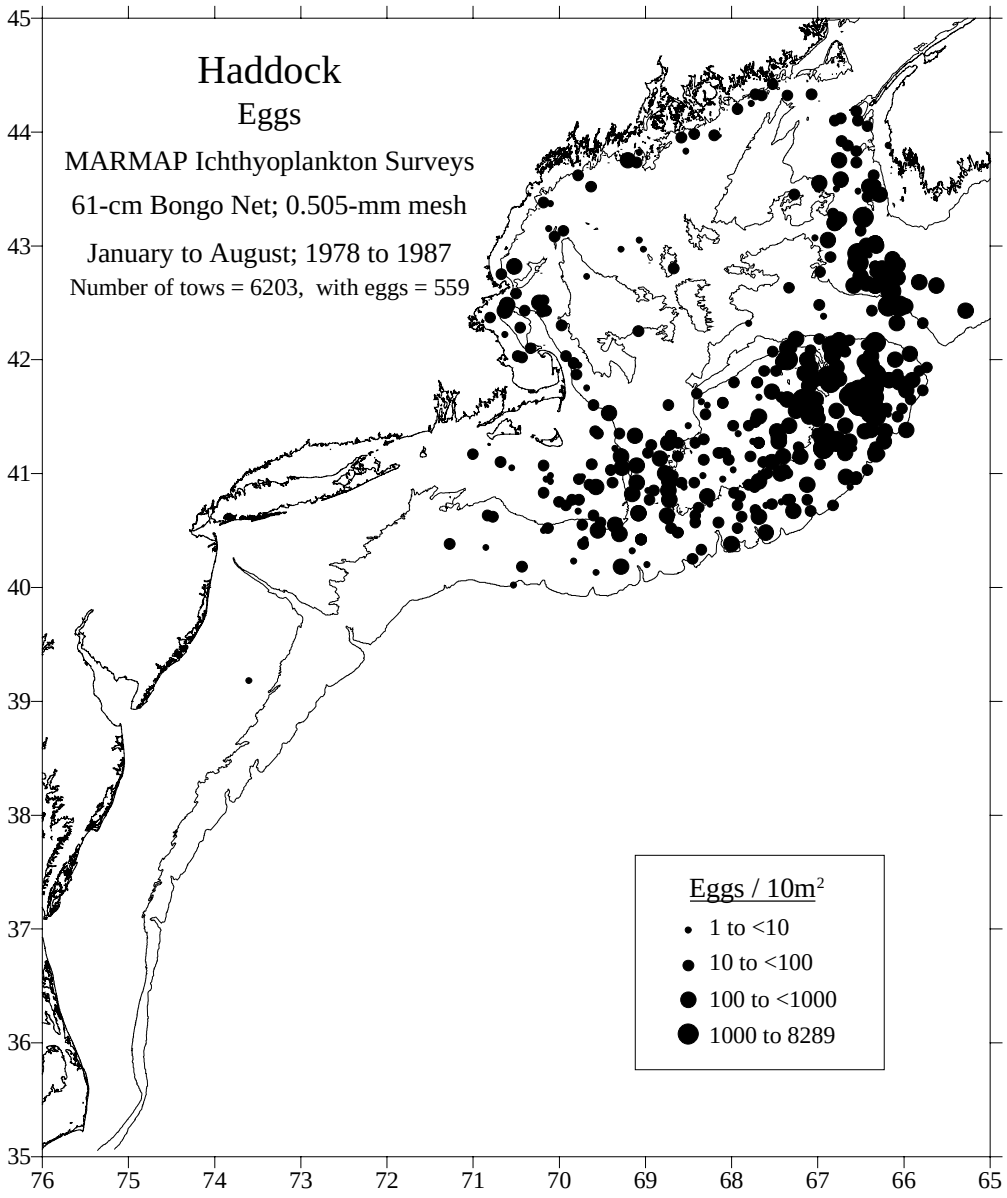
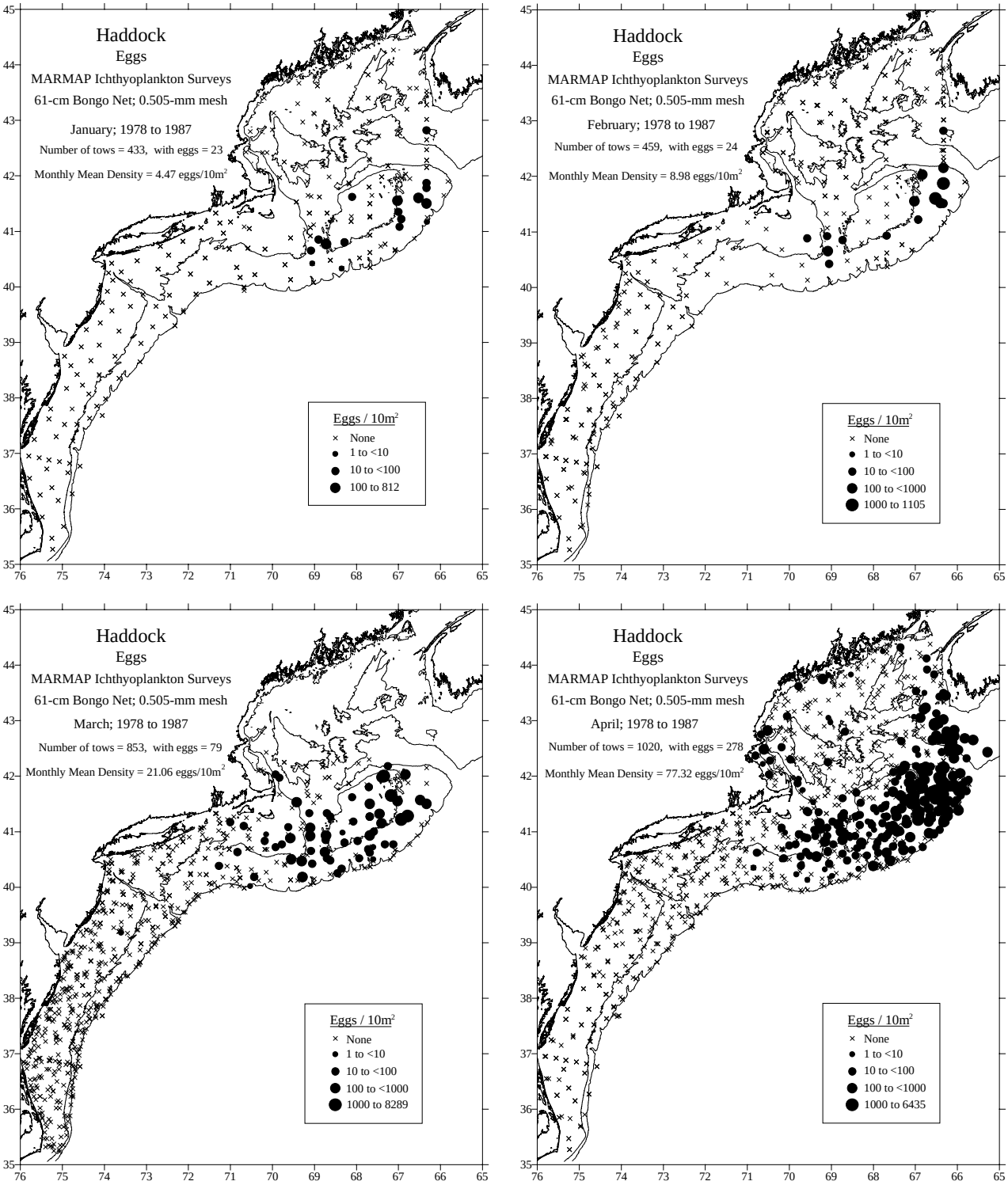


Figure 5. Distribution of haddock eggs collected during NEFSC MARMAP offshore ichthyoplankton surveys (January to August, 1978-1987). Egg densities are represented by dot size [see Reid *et al.* (1999) for details].



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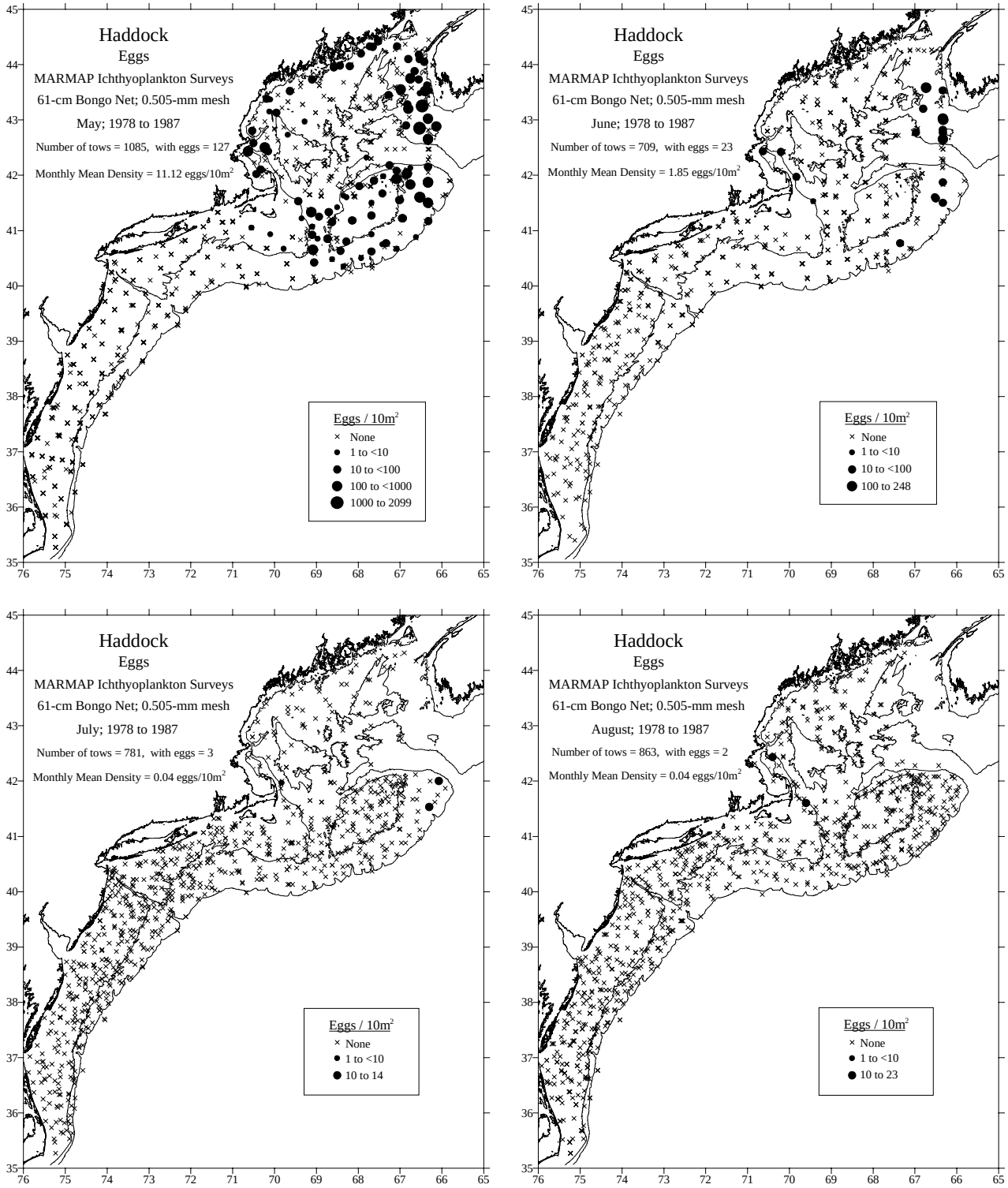

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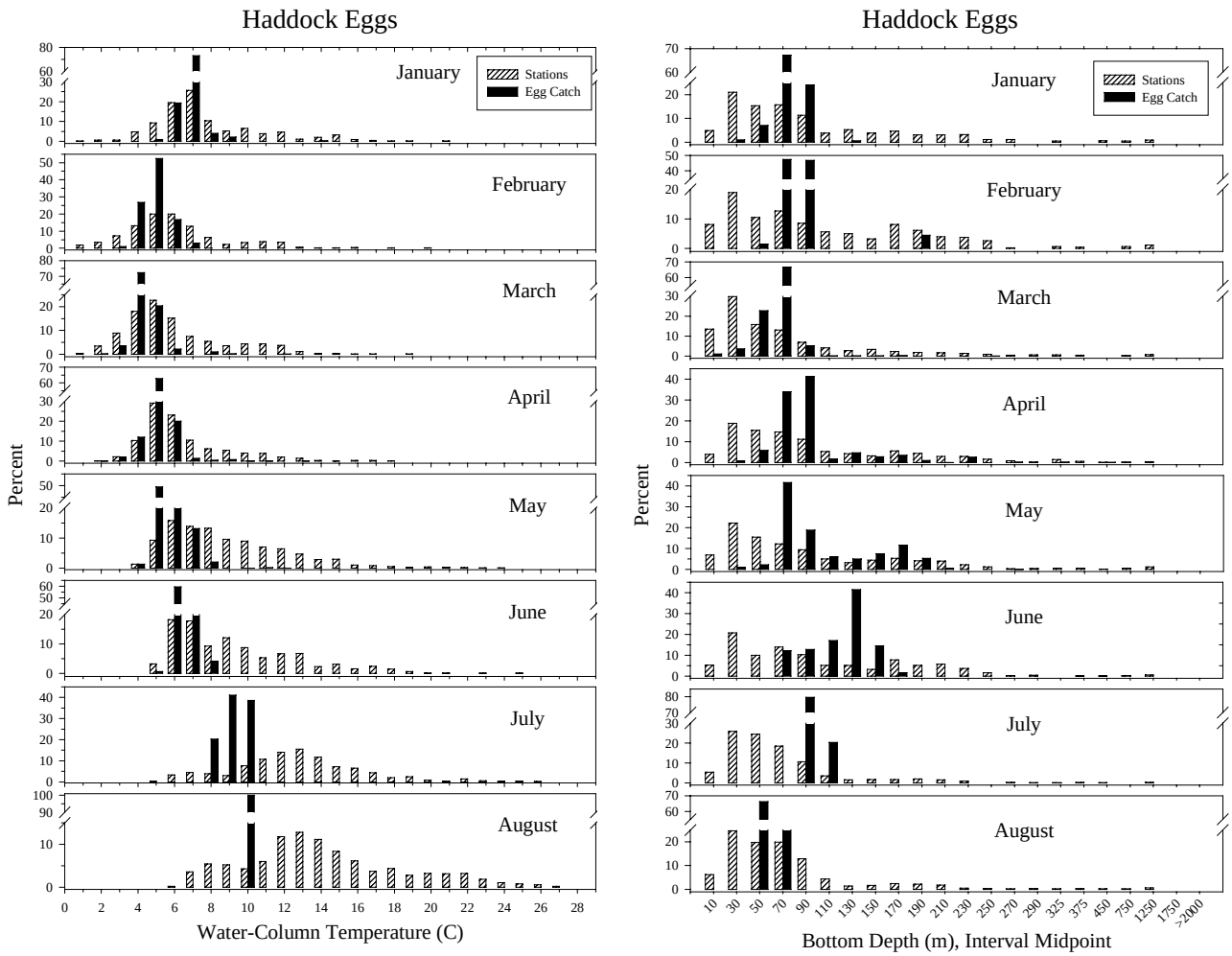


Figure 6. Monthly abundance of haddock eggs relative to water column temperature (to a maximum of 200 m) and bottom depth based on NEFSC MARMAP ichthyoplankton surveys, all years combined (January to August, 1978-1987). Open bars represent the proportion of all stations which were surveyed; solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

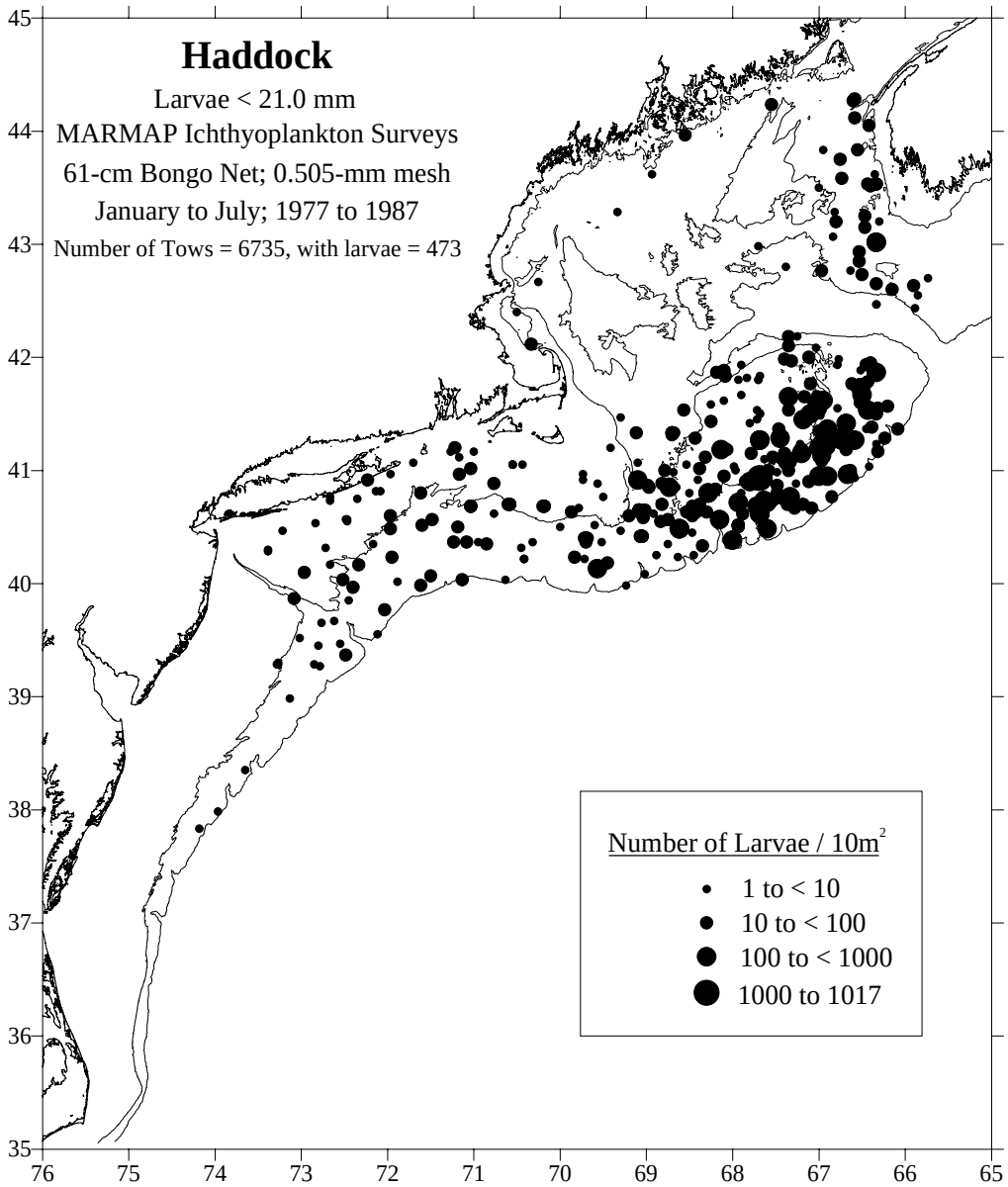
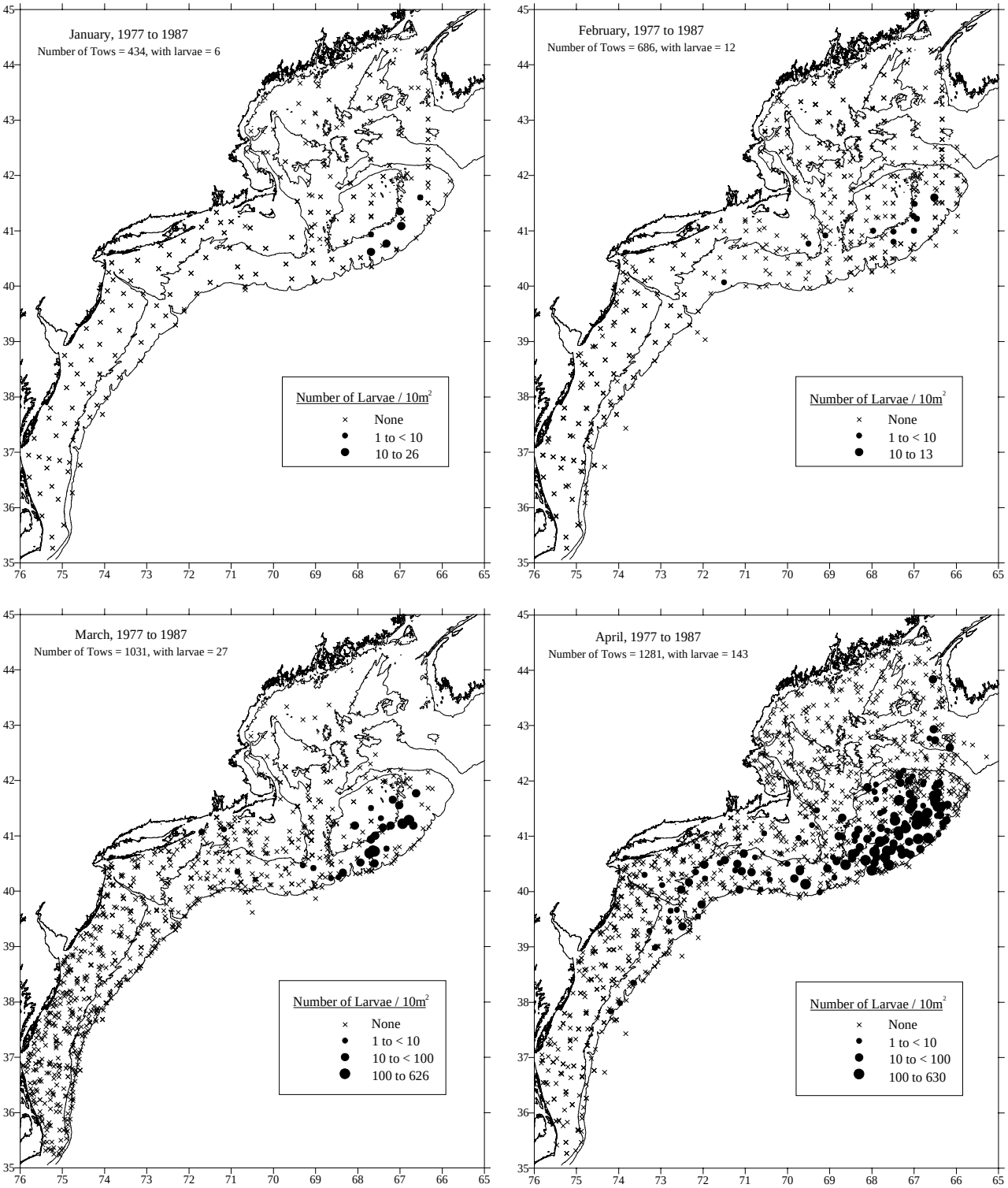


Figure 7. Distribution of haddock larvae collected during NEFSC MARMAP offshore ichthyoplankton surveys (January to July, 1977-1987). Larval densities are represented by dot size [see Reid *et al.* (1999) for details].



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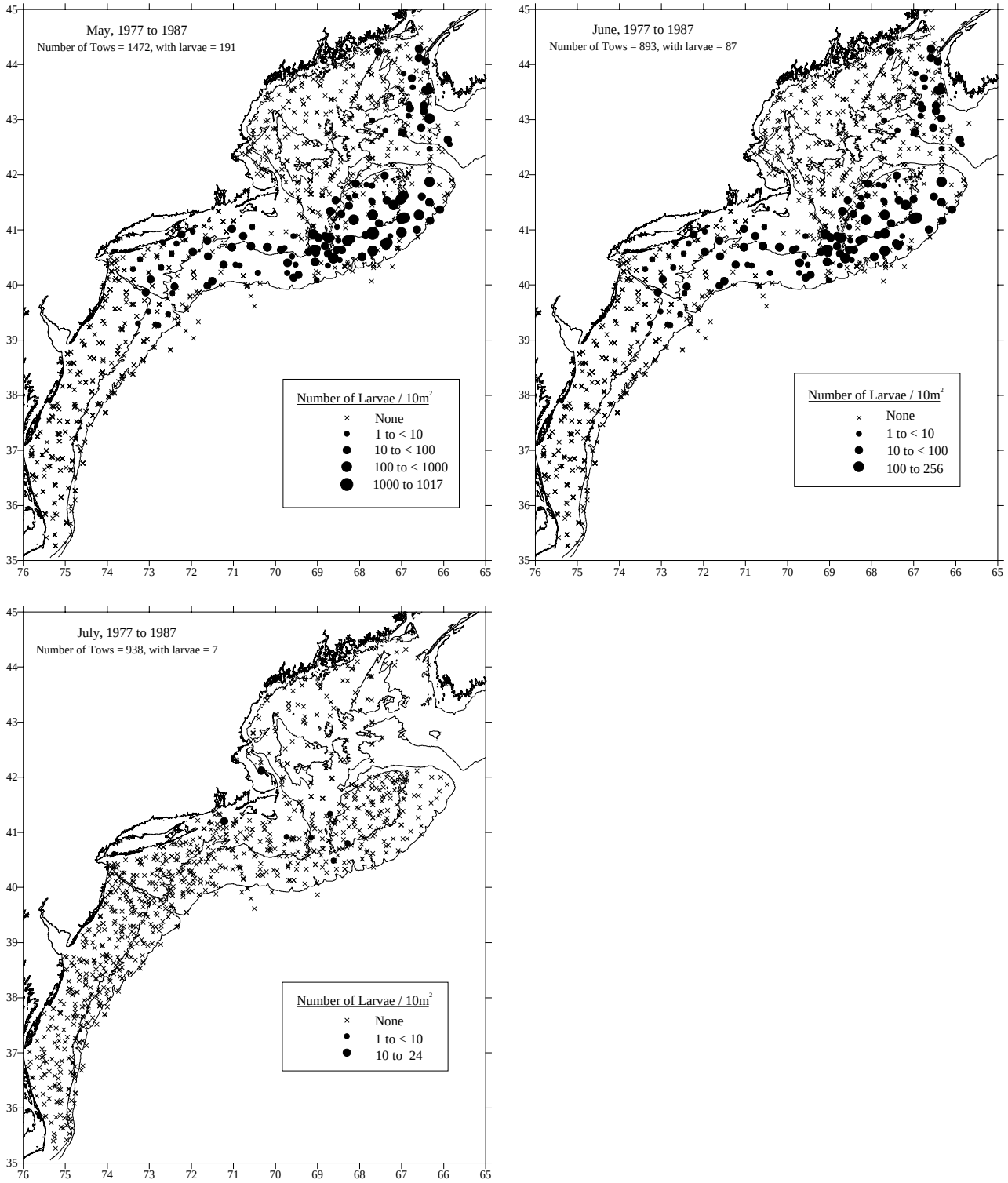

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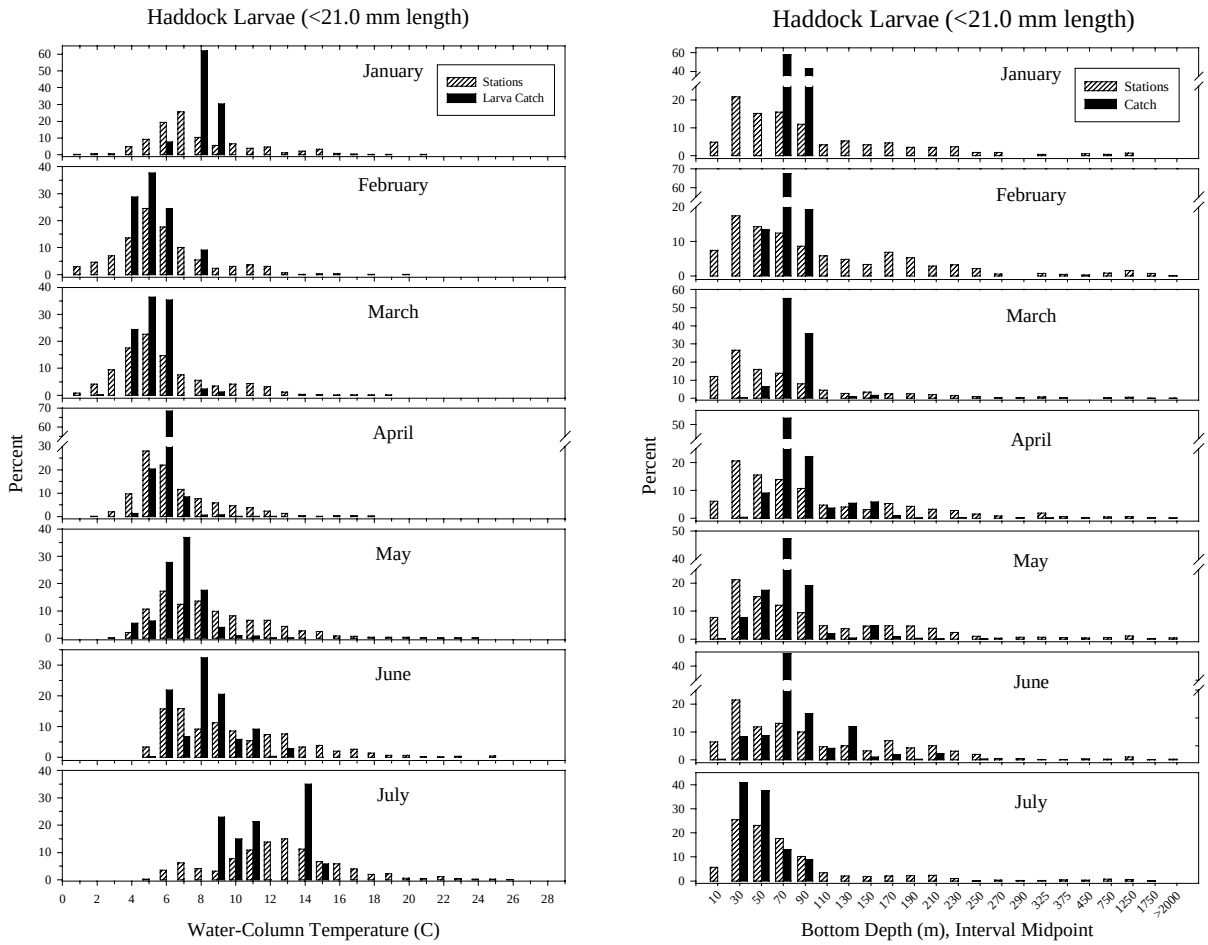

Figure 8. Monthly abundance of haddock larvae relative to water column temperature (to a maximum of 200 m) and bottom depth from NEFSC MARMAP ichthyoplankton surveys, all years combined (January to July, 1977-1987). Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

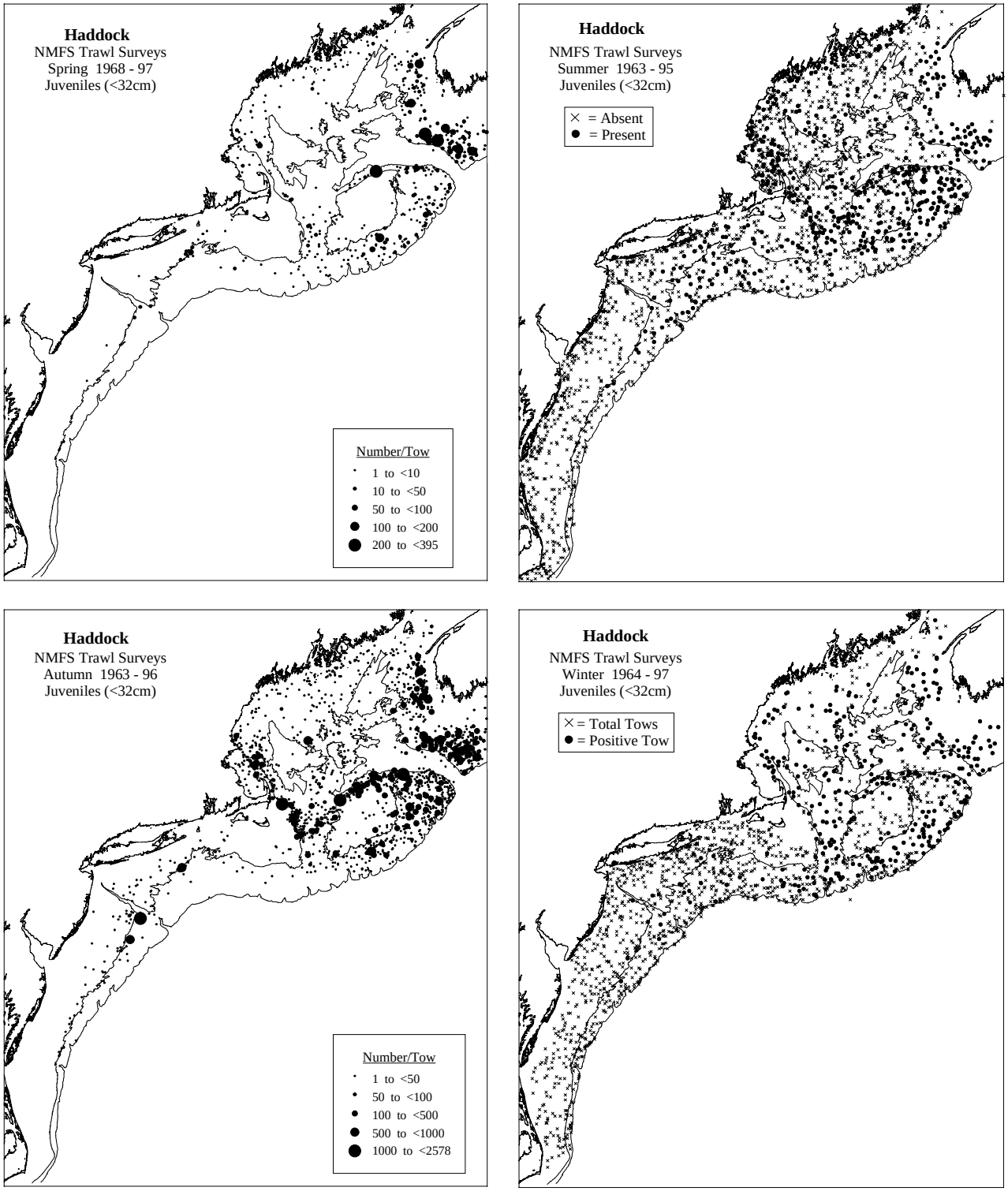

Figure 9. Distribution of juvenile and adult haddock collected during NEFSC bottom trawl surveys, (spring, summer, autumn and winter, 1963-1997). Densities are represented by dot size in spring and autumn plots, while only presence and absence is represented in summer and winter plots [see Reid *et al.* (1999) for details].

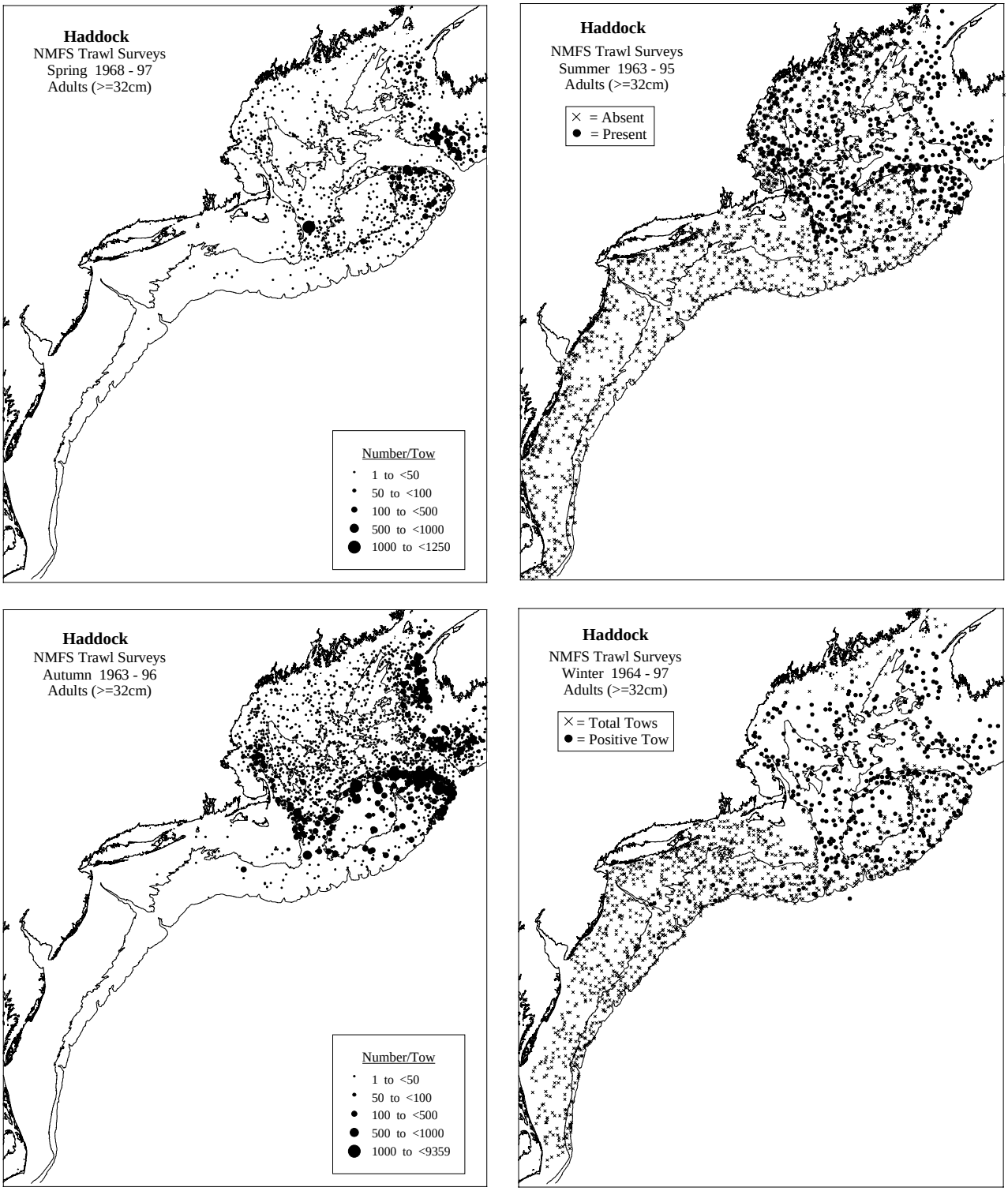

Figure 9. cont'd.

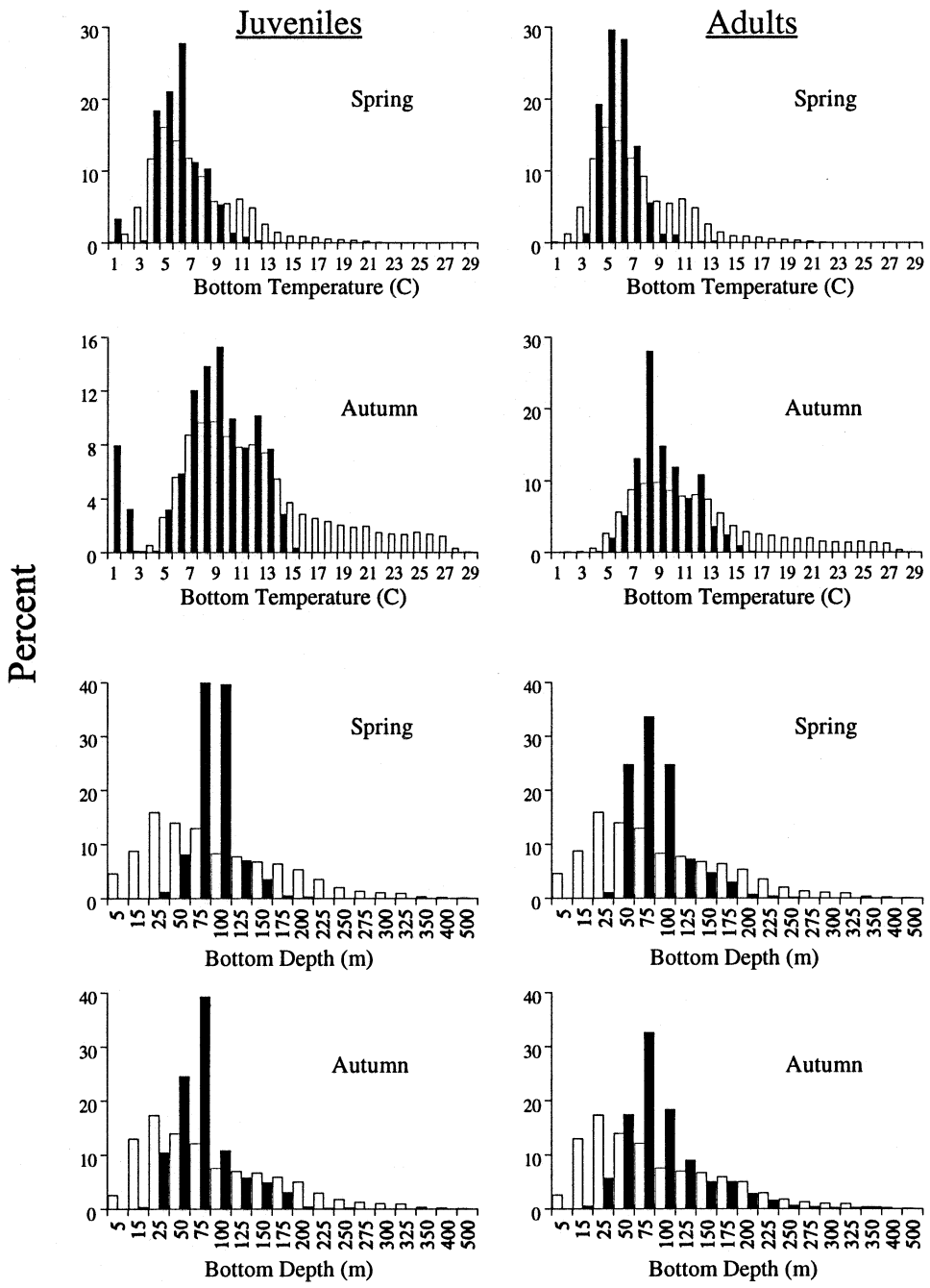

Figure 10. Abundance of juvenile and adult haddock relative to bottom water temperature and depth based on spring and autumn NEFSC trawl surveys, all years combined (1963-1997). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

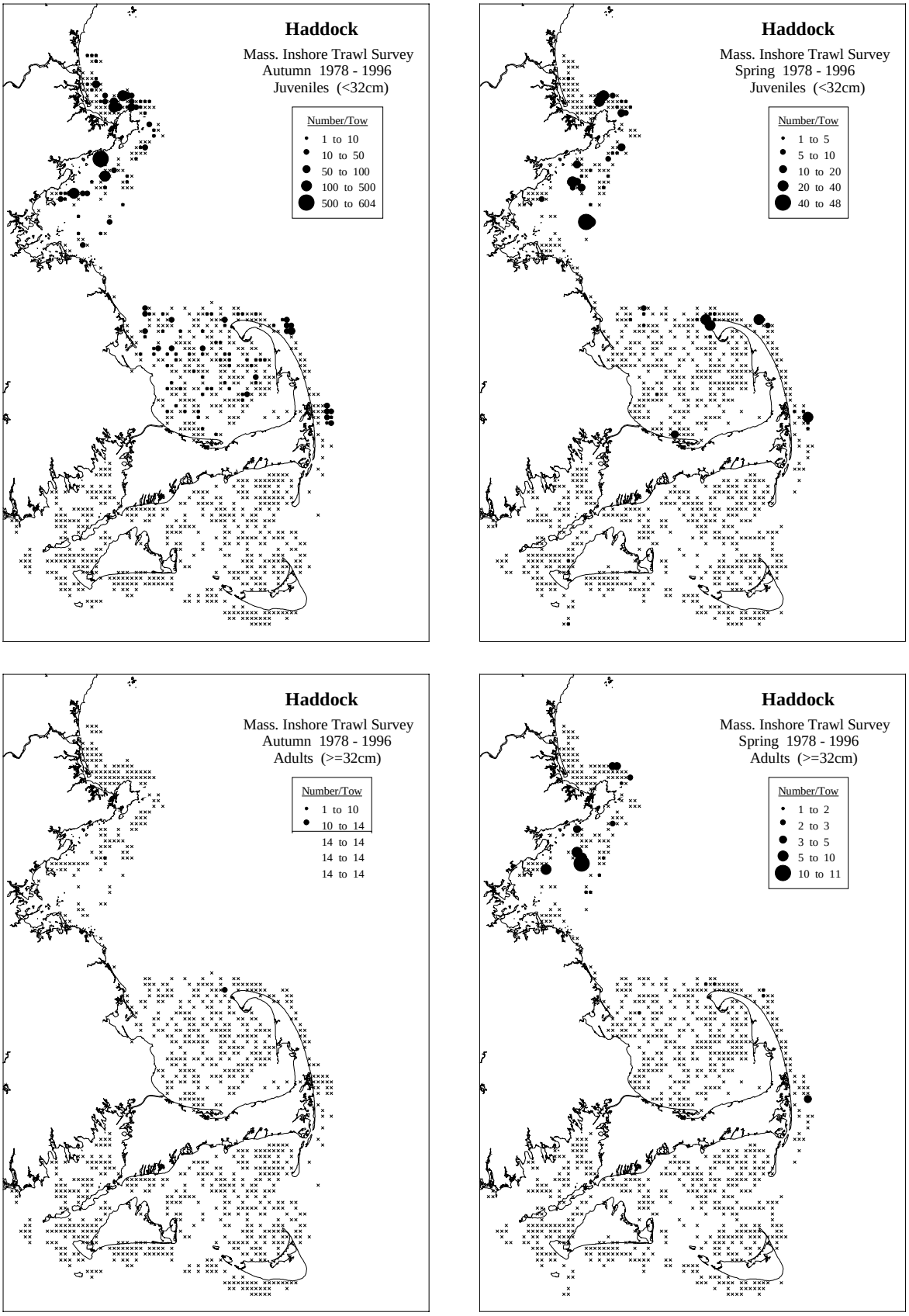

Figure 11. Distribution of juvenile and adult haddock collected in coastal waters of Massachusetts during Massachusetts inshore trawl surveys (autumn and spring, 1978-1996) [see Reid *et al.* (1999) for details].

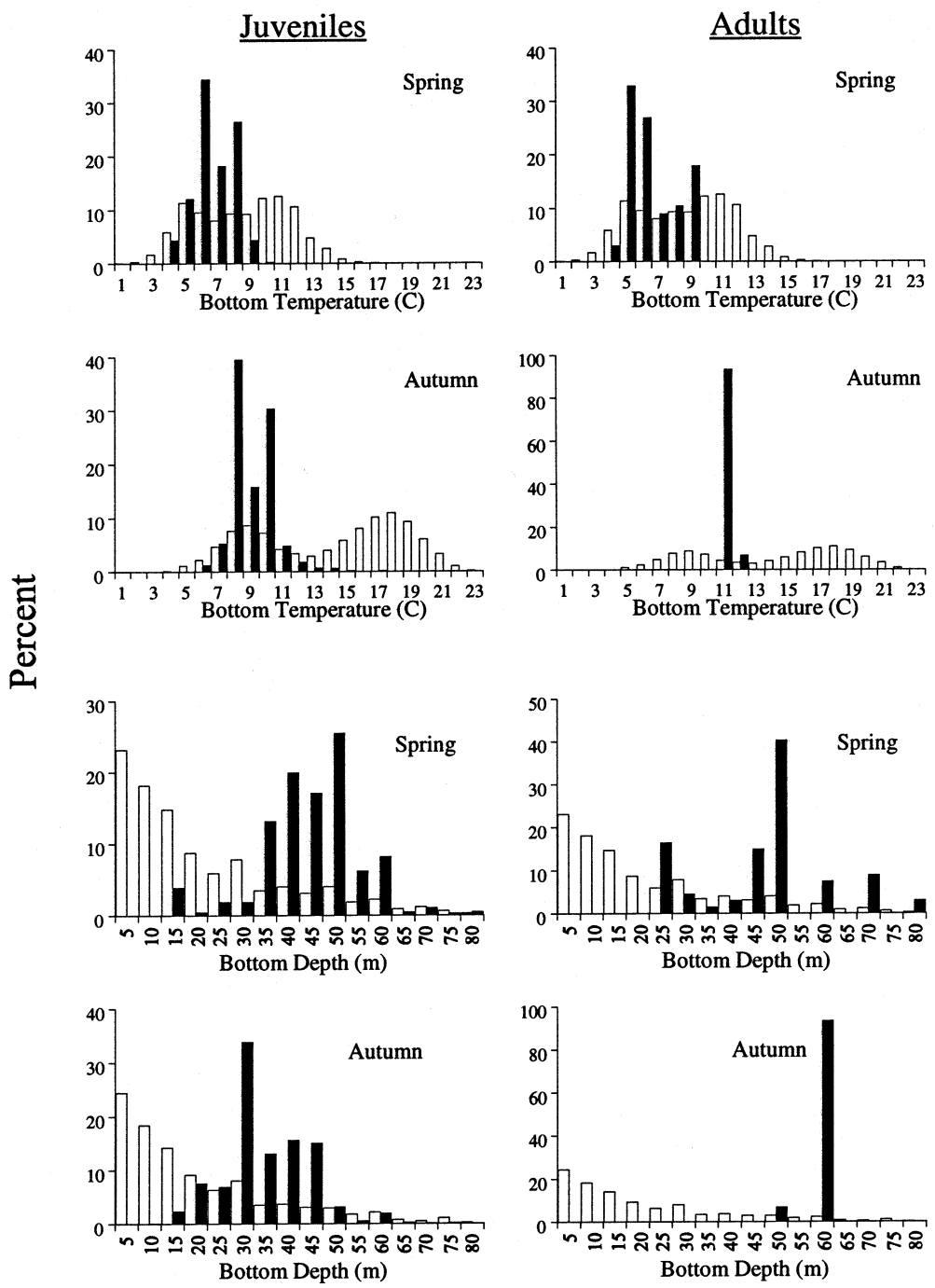

Figure 12. Abundance of juvenile and adult haddock relative to bottom water temperature and depth based on Massachusetts inshore trawl surveys for all years combined (spring and autumn, 1978-1996). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

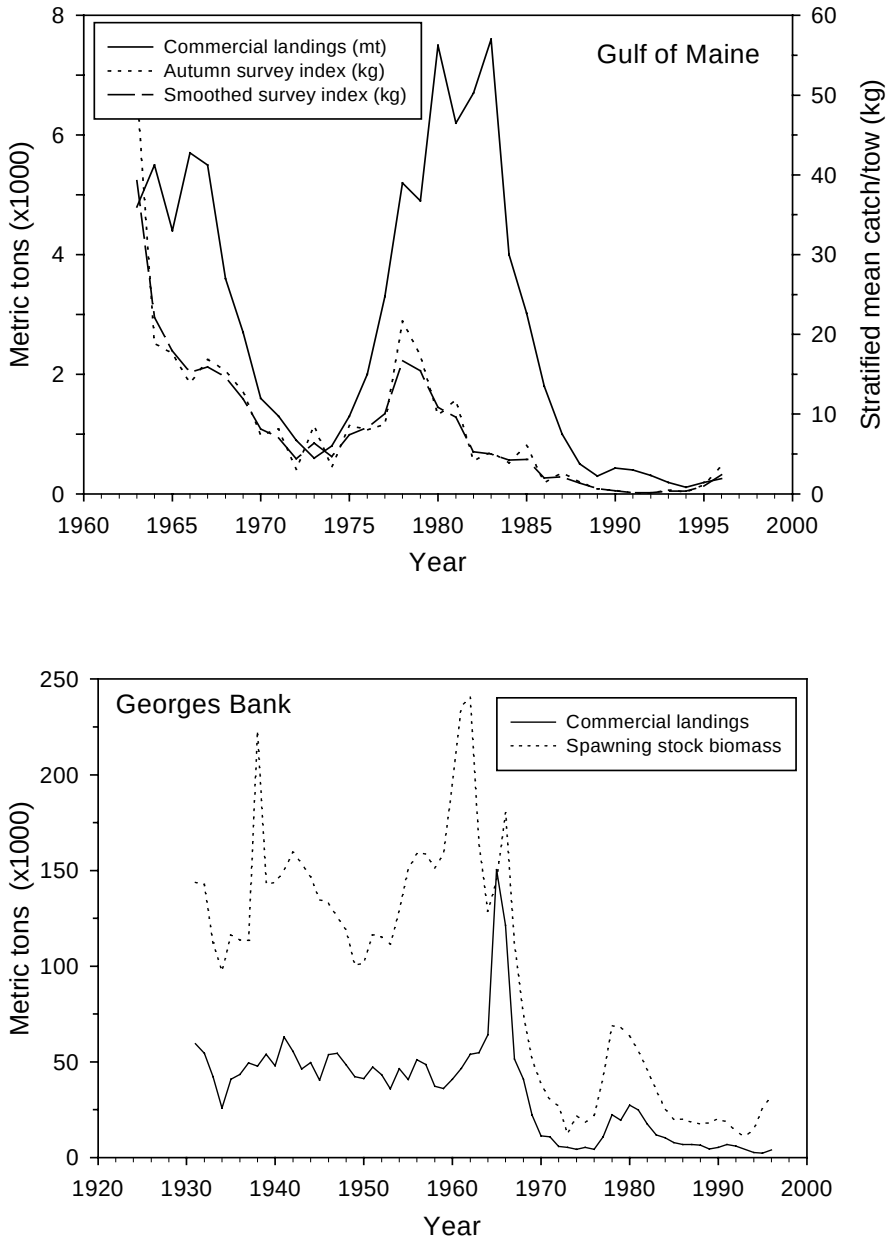

Figure 13. Commercial landings and survey indices (from the NEFSC bottom trawl surveys) of haddock from the Gulf of Maine, 1963-1996 (top) and commercial landings and spawning stock biomass (from the NEFSC bottom trawl surveys) of haddock from Georges Bank, 1930-1996 (bottom).

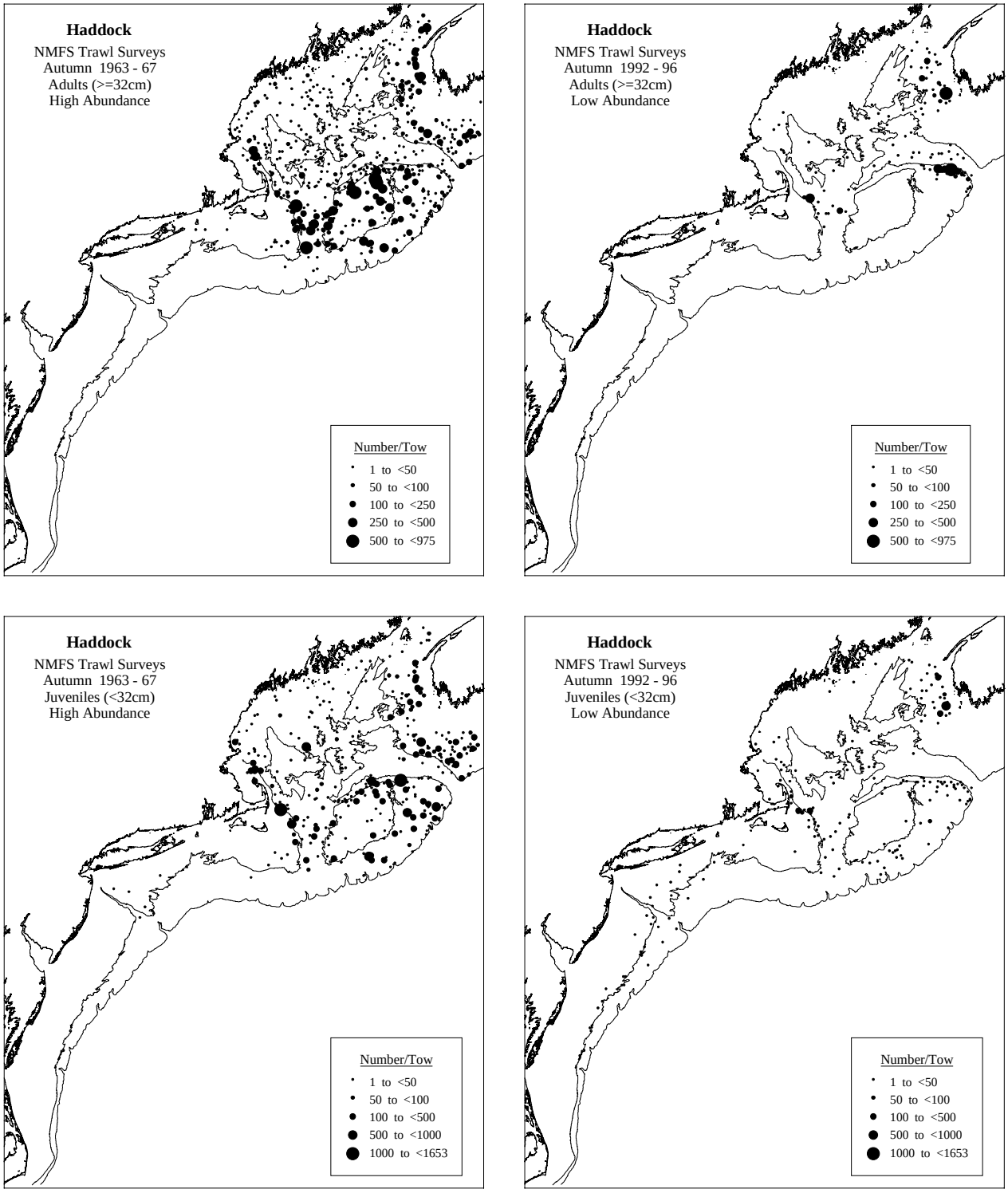

Figure 14. Distribution of juvenile and adult haddock during years of high abundance (1963-1967) and years of low abundance (1992-1996) from autumn NEFSC bottom trawl surveys.

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STANDARD MAIL A

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NOAA Technical Memorandum NMFS-NE-133

Essential Fish Habitat Source Document:

Red Hake, *Urophycis chuss*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Essential Fish Habitat Source Document:

Red Hake, *Urophycis chuss*, Life History and Habitat Characteristics

Frank W. Steimle, Wallace W. Morse, Peter L. Berrien, and Donna L. Johnson

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September 1999

Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

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[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

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INTRODUCTION

Red hake (*Urophycis chuss*; Walbaum 1792; Figure 1) is a demersal fish that occurs from North Carolina to Southern Newfoundland and is most abundant between Georges Bank and New Jersey (Sosebee 1998). Although rarely found in the Gulf of St. Lawrence, it is sometimes caught on the southern Grand Banks (Scott and Scott 1988). In U.S. waters the species is managed under the Northeast Multispecies Fishery Management Plan (NEFMC 1993).

This document provides information on the life history and habitat characteristics of red hake inhabiting the Gulf of Maine, Georges Bank, and the Middle Atlantic Bight.

LIFE HISTORY

Red hake are relatively short-lived, reaching a maximum age of 14 years and a maximum size of 63 cm TL for females (Dery 1988), but few are collected that are over 8 years old and more than 50 cm in length. Their growth rate is initially rapid but declines at maturity; the species does not reach the large size of its congener the white hake (*U. tenuis*).

Red hake make seasonal migrations to follow preferred temperature ranges. During warmer months, they are most common in depths less than 100 m; during colder months, they are most common in depths greater than 100 m. Fritz (1965) reported that they range from 30 to 370 m and that they are most common in the fall between 50 and 210 m.

EGGS

Our understanding of the environmental associations of the eggs of this species is poor because the eggs of several species of *Urophycis* and *Phycis* hake co-occur north of Cape Hatteras and presently they are not readily separable to species in plankton collections (Berrien and Sibunka 1999) despite the discussion on their tentative identification in Bigelow and Schroeder (1953). Based on eggs taken from spawning red hake, the eggs are about 0.6-1.0 mm in diameter, buoyant, and float near the surface. Hatching occurs in 3-7 days at typical spawning temperatures (Able and Fahay 1998).

LARVAE

Red hake larvae are < 2.0 mm at hatching (Able and Fahay 1998). Larval red hake dominate the summer ichthyoplankton in the Middle Atlantic Bight and were most abundant at mid- and outer continental shelf stations (Comyns and Grant 1993). Few red hake larvae have been collected in the Gulf of Maine suggesting that spawning in the Middle Atlantic Bight produces the majority of recruits to the Gulf of Maine stock. Larval red hake have been collected in the upper water column from May through December (Collette and Klein-MacPhee, in prep.).

Accurate identification and separation of red and white hake larvae in the Gulf of Maine was problematic and records prior to Methven (1985) may be in error or include mixtures of two or more species (Collette and Klein-MacPhee, in prep.). To complicate things further, post-larval hake in the northern Gulf of Maine and Canadian waters have morphometric characteristics (e.g., scale count and otolith shape) that appear intermediate between red hake and white hake (Bigelow and Schroeder 1953; Dery 1988). Although egg identification is problematic in collections, red hake larvae can be identified because of artificial spawning and rearing studies (Miller and Marak 1959). The larvae were not confidently identified in Northeast Fishery Science Center (NEFSC) Marine Resources Monitoring, Assessment and Prediction (MARMAP) surveys until 1982 (Reid *et al.* 1999).

JUVENILES

Recently metamorphosed juveniles remain pelagic until they reach 25-30 mm TL in about two months (Methven 1985). They gradually descend to the bottom at a size of about 35-40 mm TL (Fahay 1983; Able and Fahay 1998). Pelagic juvenile red hake gather around floating debris, under patches of sargassum, and occasionally within the tentacles of jellyfish (Wicklund 1966).

Demersal settlement generally occurs between September and December with peaks in October-November (Collette and Klein-MacPhee, in prep.). Laboratory studies suggest that a strong thermocline in the water column can inhibit benthic settlement when cold water below the thermocline requires descending juveniles to hesitate and acclimate to cooler bottom temperatures. Delayed descent to the bottom may expose juveniles to greater risk of predation within the thermocline while they acclimate. Red hake undergo additional changes in body shape and color upon reaching their benthic habitat (Steiner and Olla 1985).

Shelter is a critical habitat requirement for red hake (Steiner *et al.* 1982). Newly settled juveniles occur in depressions on the open seabed (Able and Fahay 1998). Older juveniles commonly associate with shelter or structure, often with living sea scallops (*Placopecten magellanicus*) where they can be found under the scallops on the sediment or within their open mantle cavity (Steiner *et al.* 1982; Garman 1983; Able and Fahay 1998). Juveniles maintain this association until they are about 10-13 cm TL. Small scallops tend to shelter small juvenile

red hake and larger scallops shelter a wider range of sizes. Juveniles also use Atlantic surf clam (*Spisula solidissima*) shells, seabed depressions made by larger fish or decapod crustaceans, moon snail egg case collars, anemone and polychaete tubes (Wicklund 1966; Ogren *et al.* 1968; Stanley 1971; Shepard *et al.* 1986), submerged man-made objects, debris, and artificial reefs (Eklund 1988). Larger juveniles remain near scallop beds and other structures in coastal areas and embayments; later they join older fish in an offshore migration in the Middle Atlantic Bight. By the end of the first summer, red hake juveniles are about 10 cm TL. There is little growth over the winter and at the end of 12 months they are about 15-17 cm TL (Able and Fahay 1998). They occur in larger estuaries, including the Chesapeake Bay main stem, Delaware Bay, and Hudson-Raritan estuary, during cooler seasons, and along coastal New England into Canadian waters from spring to fall (Jury *et al.* 1994; Stone *et al.* 1994; Wilk *et al*. 1998).

ADULTS

Adult red hake are common on soft sediments and much less common on gravel or hard bottoms. They are not confined to the bottom and can be found in the water column (Collette and Klein-MacPhee, in prep.; Gottschall *et al.*, in review). Adults are usually found in depressions in softer sediments or shell beds and not on open sandy bottom. They create the depressions or use existing depressions (Auster *et al.* 1991). Adults also inhabit inshore artificial reefs off New York during the summer (Ogren *et al*. 1968), and Eklund (1988) reported that they were most abundant on natural and artificial reefs off Delaware-Virginia during April-May.

REPRODUCTION

Major spawning areas occur on the southwest part of Georges Bank and on the continental shelf off southern New England and eastern Long Island; however, a nearly ripe female was collected during April in Chesapeake Bay (Hildebrand and Schroeder 1928). Spawning adults and eggs are also common in the marine parts of most coastal bays between Narragansett Bay, Rhode Island, and Massachusetts Bay, but rarely in coastal areas to the south or north (Jury *et al.* 1994; Stone *et al.* 1994). Based on condition of the gonads, red hake spawning occurs at temperatures between 5-10°C from April through November (Wilk *et al.* 1990). In the Gulf of Maine, spawning may not begin until June with a peak during July-August (Dery 1988; Scott and Scott 1988). Spawning red hake are most abundant in May-June in the New York Bight and on Georges Bank (Collette and Klein-MacPhee, in prep.). Eklund (1988) reported a peak in their gonadosomatic index (GSI) during May-July and the presence of ripe eggs in June-July off Delaware. Their fecundity is unknown.

Female red hake are generally larger and live longer than males (Dery 1988). O'Brien *et al.* (1993) reported that for the northern stock, 50% of females are mature at an age of 1.8 years and 26.9 cm TL, and 50 % of males are mature at 1.4 years and 22.2 cm TL. For the southern stock, size at 50% maturity is 25.1 cm TL for females and 23.8 cm TL for males; both sexes reach maturity at 1.7-1.8 years. Size and age at maturity may increase near the southern limits of the range.

FOOD HABITS

Larvae prey mainly on copepods and other micro-crustaceans, and are sometimes found under floating eelgrass or algae looking for prey.

Juvenile red hake leave shelter at night and commonly prey on small benthic and pelagic crustaceans, including larval and small decapod shrimp and crabs, mysids, euphausiids, and amphipods (Steiner *et al.* 1982; Garman 1983; Bowman *et al.* 1987) (Figure 2). In the Hudson-Raritan estuary, *Crangon* shrimp, the mysid *Neomysis americana* and other small epibenthic crustaceans are the dominant prey (Steimle *et al.*, in prep.). Night feeding is possible because their pelvic fins and chin barbels are chemo-sensitive to presence of prey (Pearson *et al.* 1980). Amphipods, small decapods (e.g., *Crangon* shrimp), and polychaetes are important prey in the Middle Atlantic Bight, but dominant prey can change seasonally and include copepods and chaetognaths (Bowman 1981; Luczkovich and Olla 1983; Sedberry 1983; Bowman *et al.* 1987). In the laboratory, red hake feed day and night and can eat up to 7.4 % of their body weight per day; feeding rates in the wild may be higher (Luczkovich and Olla 1983; Collette and Klein-MacPhee, in prep.).

Adult red hake, like juveniles, prey upon crustaceans, but also consume a variety of demersal and pelagic fish and squid (Langton and Bowman 1980; Bowman and Michaels 1984; Vinogradov 1984; Steimle 1985) (Figure 2). Rachlin and Warkentine (1988) showed that the diet of red hake overlaps the diet of the two other *Urophycis* spp. in the New York Bight.

PREDATION

Red hake (presumably mostly juveniles) are eaten by larger predators such as striped bass (*Morone saxatilus*), spiny dogfish (*Squalus acanthias*), goosefish (*Lophius americanus*), white hake *(Urophycis tenuis*), silver hake (*Merluccius bilinearis*), sea raven (*Hemitripterus americanus*), harbor porpoise (*Phocoena phocoena*) and other predators (Schaefer 1960; Bowman *et al*. 1984;

Gannon *et al.* 1997). Adult red hake are also cannibalistic on their young.

Despres-Patanjo *et al.* (1982) reported that red hake were found with fin rot and skin ulcers, but at a relatively low incidence (about 1%). These diseases are often associated with degraded environmental conditions.

MIGRATION

Red hake make extensive seasonal, depth- and temperature-related migrations. They are most common in depths < 100 m during warmer months and in depths > 100 m during colder months.

Red hake are summer migrants into coastal waters and estuaries of the Gulf of Maine and southern New England where they commonly occur in coastal bays and estuaries < 10 m deep (Tyler 1971; Jury *et al.* 1994; Stone *et al.* 1994). Juveniles commonly occur in some coastal bays south to the main stem of the Chesapeake Bay in the winter-spring, but less so in the summer (Hildebrand and Schroeder 1928; Stone *et al.* 1994; Murdy *et al.* 1997). Red hake migrate into deeper waters (to 980 m) during the winter in the Gulf of Maine, the outer continental shelf south of Georges Bank (Bigelow and Schroeder 1953; Murawski and Finn 1988), and into the submerged Hudson Shelf Valley south of Long Island.

In the Gulf of Maine, red hake move inshore in the autumn and winter as the coastal waters cool; if temperatures drop too low, red hake will move offshore. They move into Passamaquoddy Bay, Canada, in the summer and leave in the autumn, possibly because temperatures remain cooler in the summer and become too cold in the winter (Bigelow and Schroeder 1953).

In the Middle Atlantic Bight, red hake occur most frequently in coastal waters in the spring and fall; they move offshore to avoid the warm summer temperatures (Bigelow and Schroeder 1953), although juveniles are found in deep holes and channels in coastal bays during the summer. In the winter, most of the population moves offshore, but the degree of movement probably depends on the severity of the winter. Winter migrants return inshore the following spring (Able and Fahay 1998).

STOCK STRUCTURE

Red hake are managed as two U.S. stocks: a northern stock, from the Gulf of Maine to northern Georges Bank and a southern stock, from southern Georges Bank into the Middle Atlantic Bight. The stocks are divided along the central east-west axis of Georges Bank (Sosebee 1998).

HABITAT CHARACTERISTICS

The hydrographic and physical characteristics of the habitat associated with the occurrence of red hake are presented in Table 1.

EGGS

The pelagic eggs of red hake are not separated from eggs of similar species in field collections, thus the characteristics of the habitat in which red hake eggs are commonly found are poorly known. Spawning occurs in the summer on the continental shelf in the Middle Atlantic Bight and is concentrated off southern New England (Able and Fahay 1998).

LARVAE

Red hake larvae were collected on the middle to outer continental shelf of the Middle Atlantic Bight at temperatures between 8 and 23°C (most were collected between 11-19°C) within water depths between 10 and 200 m, with a few deeper occurrences (Figure 3). Few larvae were collected in the Gulf of Maine.

JUVENILES

Bigelow and Schroeder (1953) report that the "youngest fry" were observed swimming at the surface in the west-central Gulf of Maine during the summer at a temperature of about 20°C. In the bays and estuaries south of Cape Cod during the summer, juveniles (< 24 cm TL) usually avoid shallow waters that are warmer than about 22°C, but they do inhabit deeper bays such as Narragansett Bay, Rhode Island (Figure 4). North of Cape Cod where waters are cooler, juveniles can remain inshore throughout the summer; they were abundant in spring (May) and in early autumn (September) (Figure 5).

In the NEFSC bottom trawl survey, juvenile red hake were collected at a wide range of temperatures (2-20°C) and depths (5 m to > 100 m), but they were most abundant at temperatures of 3-16°C and at depths < 120 m; there were seasonal shifts in apparent preferences (Figure 6).

In the inshore waters off southern New England, juvenile red hake were collected at temperatures of 2-22°C, in depths from 5 m to > 50 m, and at salinities of 24-32 ppt (Figures 4 and 5). In Long Island Sound, they were found mostly on mud substrates (Gottschall *et al.*, in review). Comparing red hake distribution in the Connecticut trawl survey to the sediment distribution in Reid *et al.* (1979) suggests that red hake prefer silty, fine sand sediments. In the Hudson-Raritan estuary, juveniles were collected at similar temperature and depth ranges as in southern New England when salinities were above

about 22 ppt, but collection frequency declined above 28 ppt (Figure 7).

Age 0+ fish are sensitive to DO levels < 4.2 mg/L; in laboratory experiments, they left their bottom shelter and ascended into the water column, which increases their risk to predation (Bejda *et al.* 1987). This DO preference is reflected in their distribution in the Hudson-Raritan estuary (Figure 7). Older fish were less sensitive to low DO.

ADULTS

In general, adults are found at temperatures of 2-22°C and at depths of about 5 m to > 300 m (Figures 5, 6, 8, and 9; Fritz 1965). In the Massachusetts, Rhode Island, and Long Island Sound surveys, adults were generally found in waters > 25 m deep, especially during the summer and fall (Figures 5 and 8). Adult red hake were usually found at a salinity range of 20-33 ppt in Long Island Sound and the Hudson-Raritan estuary (Figure 9). They appear to be sensitive to hypoxia; mortalities were noted during the 1976 anoxia episode off New Jersey (Azarovitz *et al.* 1979). In the Hudson-Raritan estuary they prefer DO concentrations > 6 mg/L (Figure 9). In Long Island Sound, they were found mostly on mud substrates (Gottschall *et al.*, in review). Even in deep water they have been observed using various types of shelter (Collette and Klein-MacPhee, in prep.).

GEOGRAPHICAL DISTRIBUTION

In the northwest Atlantic Ocean, red hake occur from Nova Scotia to Cape Hatteras, North Carolina. They are most abundant on Georges Bank, in the Gulf of Maine off Cape Cod, and in the northern Middle Atlantic Bight off Long Island (Figure 10).

EGGS

During cooler months (Dec-Apr), the undifferentiated *Urophycis-Phycis* hake spp. eggs were collected mostly at the edge of the continental shelf on southern Georges Bank and the Middle Atlantic Bight. During warmer months, hake eggs were collected across the entire shelf in this area. Relatively few hake eggs occur in the Gulf of Maine (Bigelow and Schroeder 1953; Berrien and Sibunka 1999). During the NEFSC MARMAP ichthyoplankton survey (1978-1987), *Urophycis-Phycis* spp. eggs were collected across the continental shelf in the Middle Atlantic Bight, on Georges Bank, and to a lesser degree in the Gulf of Maine (Figure 11).

LARVAE

In the NEFSC MARMAP ichthyoplankton survey (1982-1987), identified red hake larvae were collected on southern Georges Bank and on the mid- to outer continental shelf throughout the Middle Atlantic Bight (Figure 12); few larvae were collected in the Gulf of Maine. Larvae were collected most abundantly during surveys in the early fall, September-October. Red hake larvae dominate the summer ichthyoplankton in the Middle Atlantic Bight and were most abundant at middle and outer continental shelf stations (Comyns and Grant 1993). Few red hake larvae have been collected in the Gulf of Maine suggesting that spawning in the Middle Atlantic Bight supplies the majority of recruits to the Gulf of Maine stock.

Larvae have been also reported in the marine parts of several bays and estuaries in the Middle Atlantic Bight, including the Hudson-Raritan estuary, Narragansett Bay, Buzzards Bay, and in bays north of Cape Cod to about the Merrimack River, New Hampshire (Jury *et al.* 1994; Stone *et al.* 1994).

JUVENILES

In the NEFSC bottom trawl survey, juveniles were collected offshore primarily in the New York Bight, southern New England, and Georges Bank during the winter; in coastal waters of the Middle Atlantic Bight, and were widespread across the continental shelf east of Long Island, in the spring and summer; and off southern New England and on Georges Bank in the fall (Figure 13). Juveniles were common in the main stem of Chesapeake Bay (Hildebrand and Schroeder 1928), in the channels of the Hudson-Raritan estuary (Figure 14), in central Long Island Sound, especially in the spring (Figure 15), and in other southern and northern New England bays and estuaries (Figures 16 and 17). Red hake were rare or not reported in most other Middle Atlantic Bight bays and estuaries (Jury *et al.* 1994; Stone *et al.* 1994).

The distribution of juveniles varies with season. In the winter, juveniles were collected on the continental shelf from southern Georges Bank into the Middle Atlantic Bight. In spring-summer, they were collected mostly from coastal waters of the Middle Atlantic Bight to northern Georges Bank and into the Gulf of Maine. In summer-fall, there is an apparent return movement offshore; notable concentrations of juveniles occurred off southern New England and on Georges Bank (Figure 13). Juveniles were relatively common throughout the year in the Hudson-Raritan estuary and Narragansett Bay, and most abundant in Long Island Sound in the summer (Figures 14-16). Juvenile red hake were common south and north of Cape Cod in the spring, but in the fall they were common only north of the Cape (Figure 17).

ADULTS

Adult red hake (northern stock) were collected in the deeper basins of the Gulf of Maine and along the northern edge of Georges Bank in all seasons; they were also collected in inshore waters and on Georges Bank during the summer and autumn (Figure 13). In the Middle Atlantic Bight, adult red hake (southern stock) were collected most commonly offshore and along the deeper southern edge of Georges Bank during the winter and spring (Figure 13). They were also collected inshore near Martha's Vineyard, Massachusetts. In summer-fall, adult red hake were collected on Georges Bank, in coastal waters from ~10 m deep across the continental shelf to around 300 m; they were especially abundant off southern New England (Figure 13). They occur in larger estuaries, including the Chesapeake Bay main stem, Delaware Bay, and the Hudson-Raritan estuary, during cooler seasons, and along coastal New England into Canadian waters from spring to fall (Jury *et al.* 1994; Stone *et al.* 1994). They were abundant in Long Island Sound and Narragansett Bay (Figures 15 and 16), but not off southern Cape Cod in the fall (Figure 17) or in the Hudson-Raritan estuary during any season (Figure 14).

STATUS OF THE STOCKS

The NEFSC has monitored and assessed red hake as two stocks, northern and southern, separated by the central axis of Georges Bank. The bottom trawl survey abundance index for the northern stock was relatively low in the 1960s and early 1970s, increased until about 1990, and has since declined slightly (Figure 18). The southern stock index was relatively stable from the mid-1960s until the 1980s when it declined with a short period of increase about 1990-1991. The northern and southern stocks were considered under exploited until recently (Sosebee 1998). The red hake population is considered overfished because the abundance index is below the lowest quartile of the monitoring time series (National Marine Fisheries Service 1997), but only the southern stock (or overall stock) is currently considered overfished (Sosebee 1998).

RESEARCH NEEDS

- Red hake spawning grounds and the habitat characteristics of the grounds need to be identified.
- A cost-effective way to separate and identify the eggs of various *Urophycis* spp. is needed to better define what habitats support the eggs of each species (Fahay 1983).
- The use by and relative importance to juveniles of shelter habits other than scallop and clam shells needs to be determined.
- What are the effects of sea scallop dredging on juvenile red hake habitat (Steiner *et al.* 1982)?
- Is the degree of cannibalism associated with larval and/or juvenile red hake habitat quality or quantity (shelter availability) (Luczkovich 1982)?
- More information is needed about the construction of sediment depressions by adult red hake for shelter or ambush-feeding, the use of these depressions by other species, and the effects of trawling and scallop dredging on the use of these shelters.
- More information is needed about the occurrence and use of shallow coastal habitats in the Gulf of Maine by red hake larvae (K. Sosebee, NMFS, Northeast Fisheries Science Center, Woods Hole, MA, personal communication).
- Better estimates of the fecundity are needed for females from the northern and southern stocks.
- The occurrence of morphometric characteristics that are intermediate between red and white hake in the northern Gulf of Maine and Canada suggests further studies should be made on possible environmental or genetic causes.

ACKNOWLEDGMENTS

This review was prepared with abundant assistance from others on the Essential Fish Habitat team: Claire Steimle, Judy Berrien and Rande Ramsey-Cross provided literature searches, interlibrary loans, and reference material; Don McMillan, Bob Pikanowski, Chris Zetlin, Sara Griesbach, Sukwoo Chang, Joe Vitaliano, Jeff Cross, and others helped locate and retrieve data to make the maps and tables. The comments of several anonymous reviewers were helpful.

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Table 1. Summary of life history and habitat characteristics for red hake, *Urophycis chuss*. (NS = northern stock; SS = southern stock; MAB = Middle Atlantic Bight; NYB = New York Bight; SNE = southern New England; GB = Georges Bank; GOM = Gulf of Maine)

Life Stage	Time of Year	Size and Growth	Geographic Location	Habitat	Substrate
Spawning	**NS**: May-Nov.; peak Jul.-Aug.; **SS**: Apr.- Oct.; peak: May-June.	Mature at ~22-30 cm	Southwest GB to SNE; peak in SNE.	< 110 m, to coastal bays	Unknown
Eggs [a]	Dec.-Nov.; peak: June-July	0.6-1.0 mm	MAB, Dec.- Apr. off-shore; May-Oct. widespread.	Water column, inner shelf.	Buoyant in upper water column.
Larvae	**NS**: May-Dec.; peak: Sept.-Oct. **SS**: May -Nov.; peak Aug.-Sept.	Hatch at ~2.0 mm; after 2 months begin descent to bottom.	Mainly western GB, mid-shelf in SNE and NYB; few in GOM.	Coastal, < 200 m; pelagic followed by a benthic phase.	Newly settled larvae need shelter, including live sea scallops.
Juveniles	Throughout	Settle at 23-49 mm TL; can grow ~16 mm/month; reach 10 cm by end of first fall and 15-17 cm by 1 year.	Estuaries-outer shelf; **NS**: offshore in winter; inshore in summer; **SS**: inshore in spring-fall; offshore in summer and winter.	Mostly < 120 m to low tide line.	< 14 cm TL fish use shells or live scallops for shelter; > 14 cm use various sediment types and shelter.
Adults	Throughout	**NS**: females mature at 1.8 yrs and 27 cm TL; males at 1.4 yrs and 22 cm; **SS**: females mature at 25 cm TL and males at 24 cm.	Same as juveniles; center of abundance is in SNE.	5-300+ m; prefer 30-130 m	Sand-mud, and in holes and depressions.

[a] The eggs of this species are not reliably separated from other *Urophycis* or *Phycis* species in this area.

Table 1. cont'd.

Life Stage	Temperature	Salinity	Dissolved Oxygen	Prey	Predators	Notes
Spawning	10-12°C					
Eggs [a]						Hatch in 3-7 days.
Larvae	8-23°C; most abundant at 11-19°C; acclimation to lower bottom temperatures needed in summer.			Copepods, micro-crustaceans; feeding is usually nocturnal.		Larvae and pelagic juveniles use floating or midwater objects for shelter.
Juveniles	2-22°C, most abundant at 3-16°C; avoid < 3°C and > 22°C.	Usually > 22 ppt; most abundant at 31-33 ppt.	Avoid < 4.2 ppm	Mainly crustaceans such as *Crangon*, but also amphipods and polychaetes.	Dogfish, striped bass, goosefish, white, red and silver hakes, and sea raven.	Primarily active at night; avoid hypoxic conditions; on- and offshore movements are temperature dependent.
Adults	2-22°C; most abundant at 8-10°C; avoid < 5°C	> 20 ppt; most abundant at 33-34 ppt	Avoid < 3.0 ppm; most abundant > 6.0	Fish and crustaceans.	Probably striped bass, goosefish, and other larger fish.	Same as juveniles.

[a] The eggs of this species are not reliably separated from other *Urophycis* or *Phycis* species in this area.

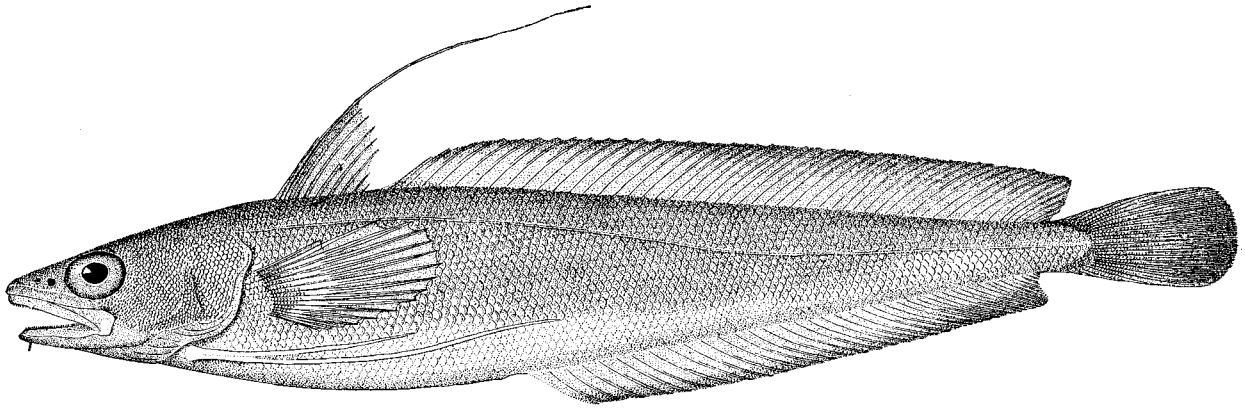


Figure 1. The red hake, *Urophycis chuss* (from Goode 1884).

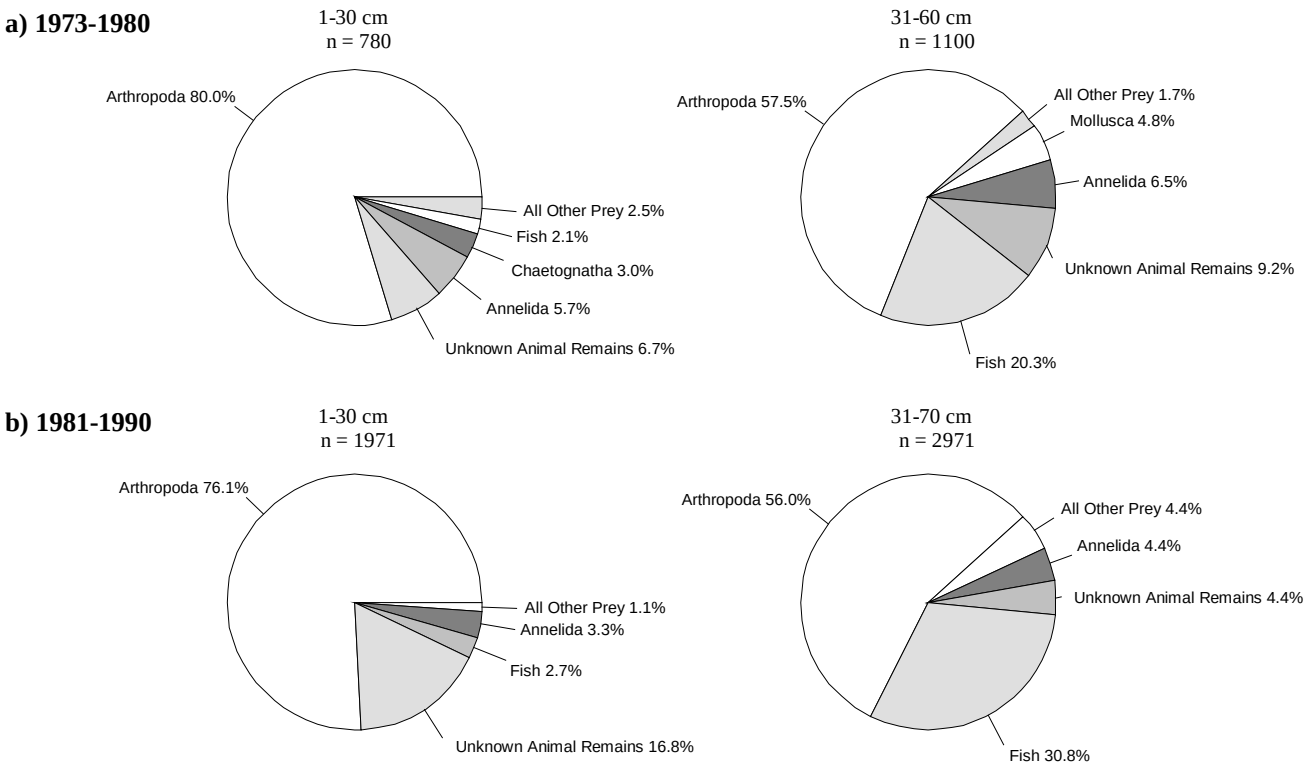


Figure 2. Abundance of the major prey items of red hake collected during NEFSC bottom trawl surveys from 1973-1980 and 1981-1990. Abundance in the 1973-1980 samples is defined by mean percent prey weights, and in the 1981-1990 samples as mean percent prey volume. The category "unknown animal remains" refers to unidentifiable animal matter. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details]. The use of 30 cm as the segregation size between juveniles and adults differs from the actual size generally used (26 cm) and is an artifact of the diet database that summarized results in 10 cm length intervals.

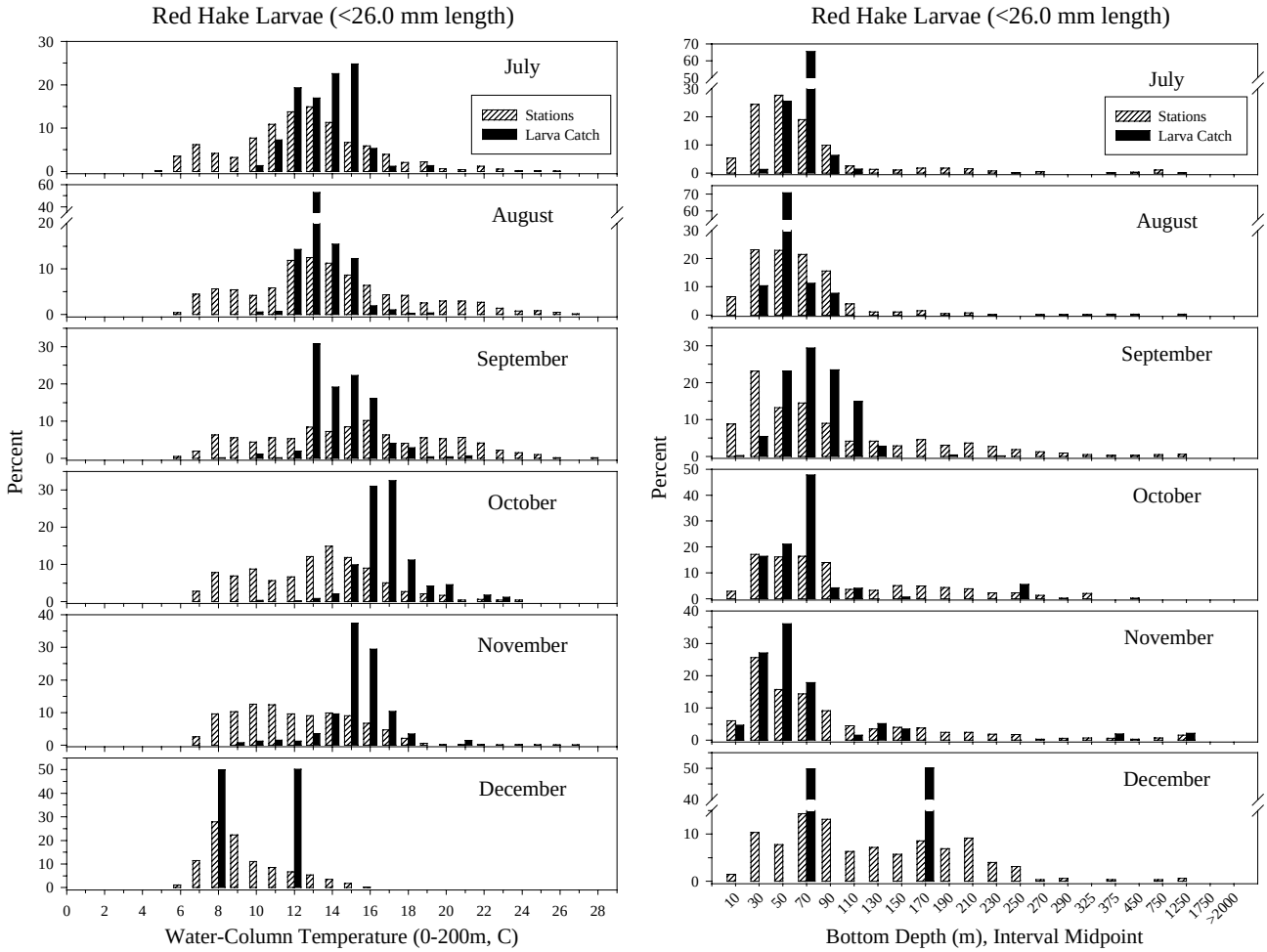


Figure 3. Abundance of red hake larvae relative to water column temperature (to a maximum of 200 m) and bottom depth from NEFSC MARMAP ichthyoplankton surveys (1982-1987) by month for all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

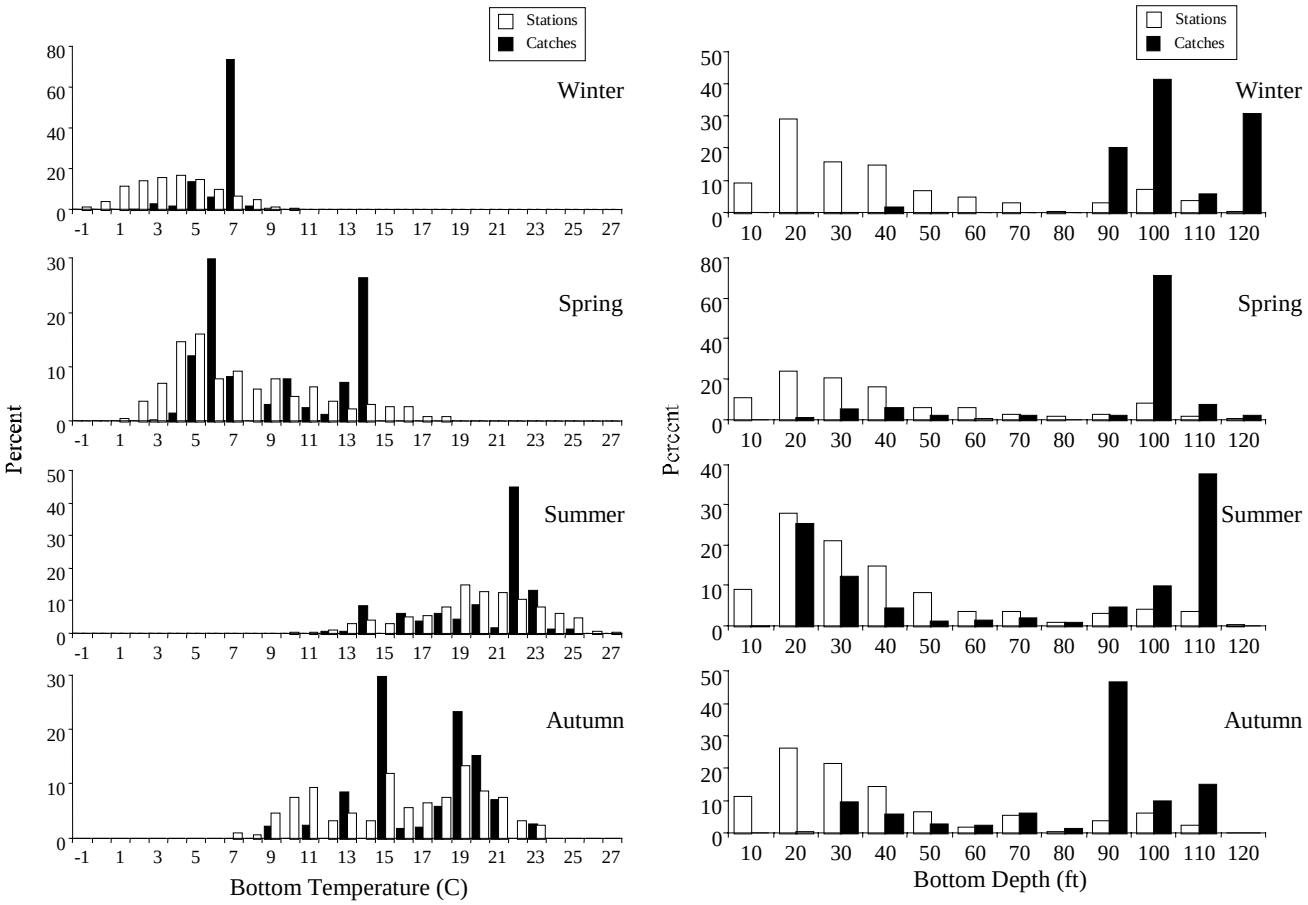


Figure 4. Seasonal abundance of juvenile red hake relative to mean bottom water temperature and bottom depth from Rhode Island Narragansett Bay trawl surveys, 1990-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

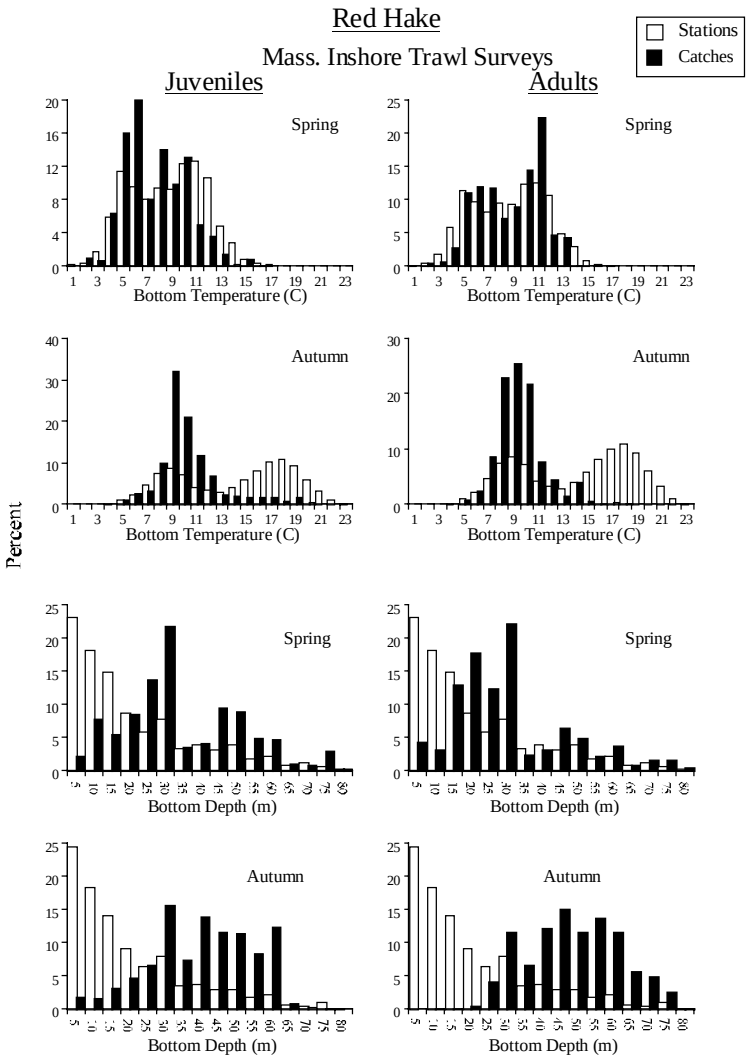


Figure 5. Abundance of juvenile and adult red hake relative to mean bottom water temperature and bottom depth from Massachusetts inshore bottom trawl surveys, spring and autumn 1978-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

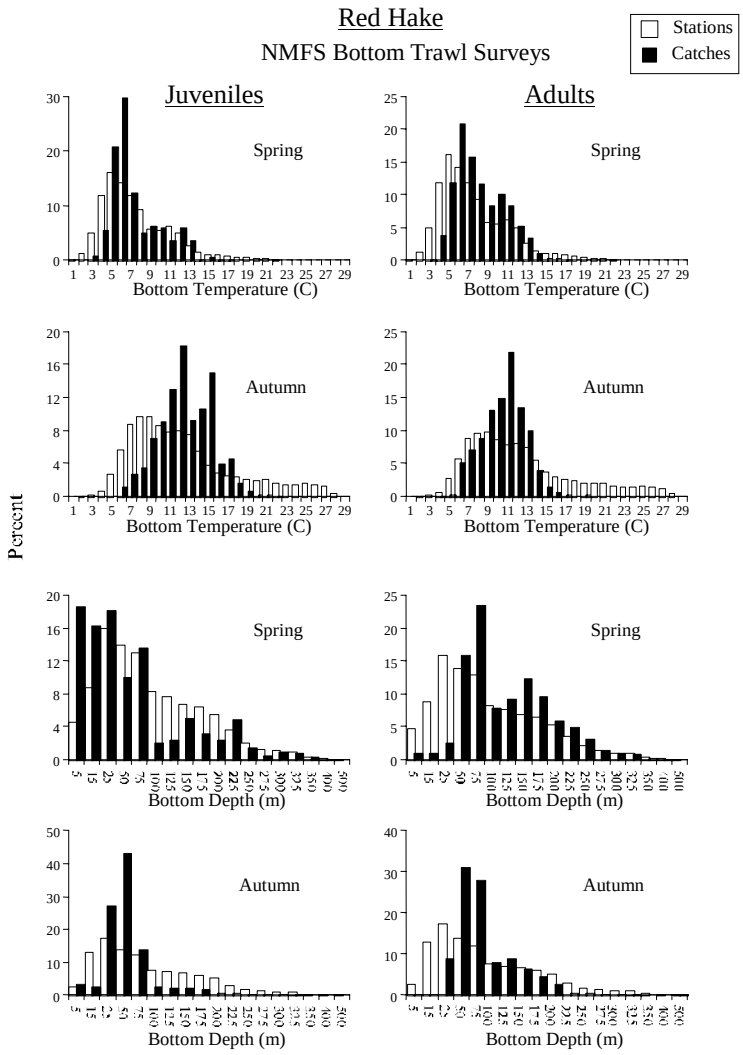


Figure 6. Abundance of juvenile and adult red hake relative to bottom water temperature and depth based on spring and fall NEFSC bottom trawl surveys (1963-1997, all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

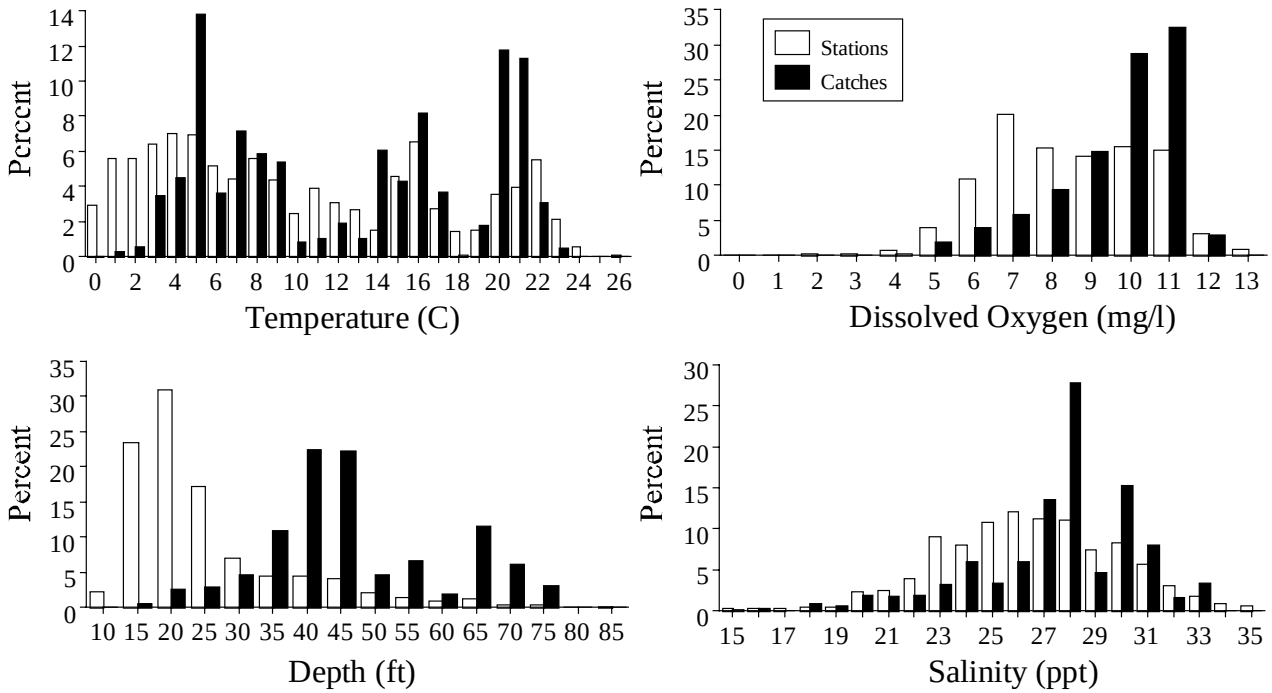


Figure 7. Abundance of juvenile (< 25 cm) red hake relative to mean bottom water temperature, dissolved oxygen, depth, and salinity from Hudson-Raritan estuary trawl surveys, January 1992-June 1997 (all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

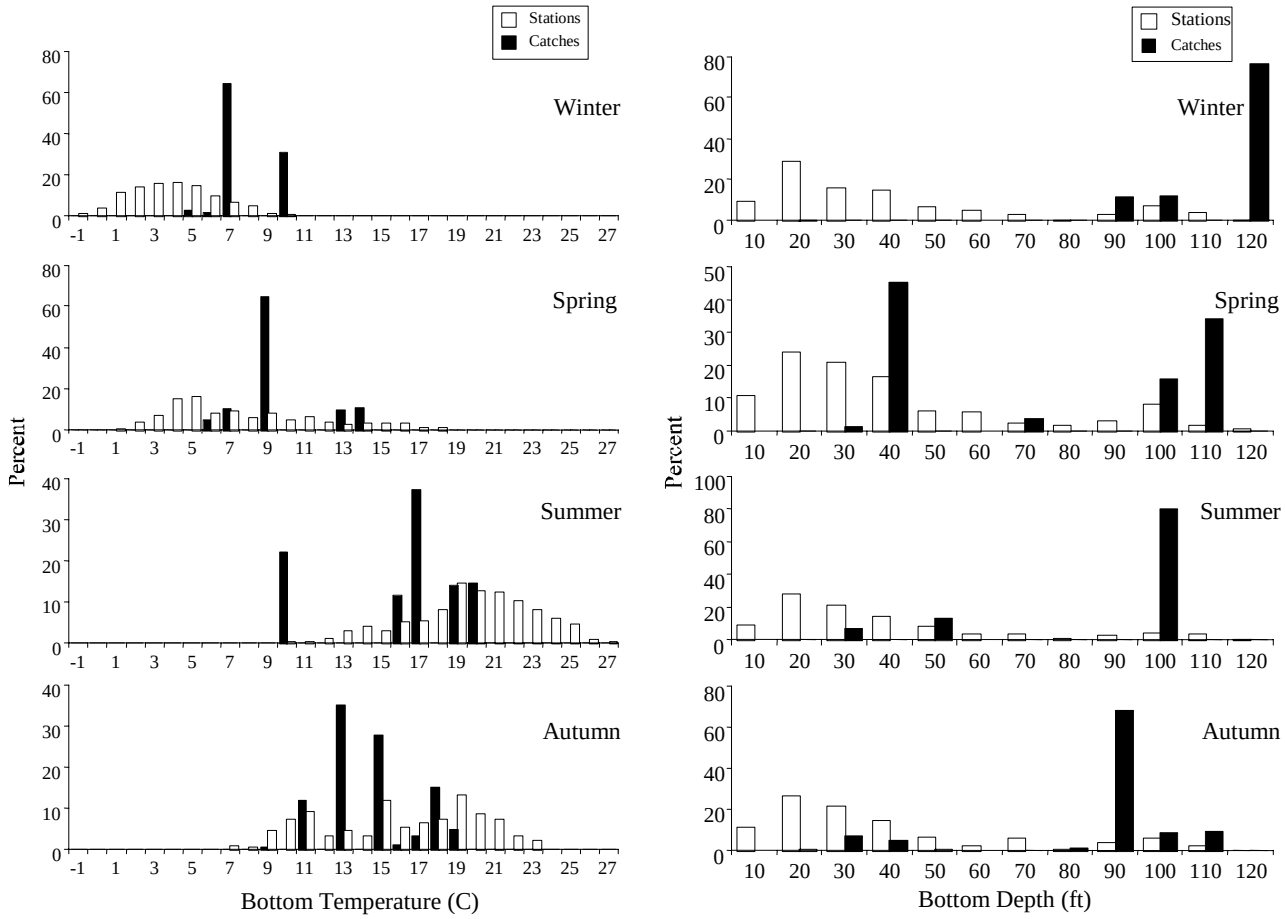


Figure 8. Seasonal abundance of adult red hake (≥ 26 cm) relative to mean bottom water temperature and bottom depth from Rhode Island Narragansett Bay trawl surveys, 1990-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

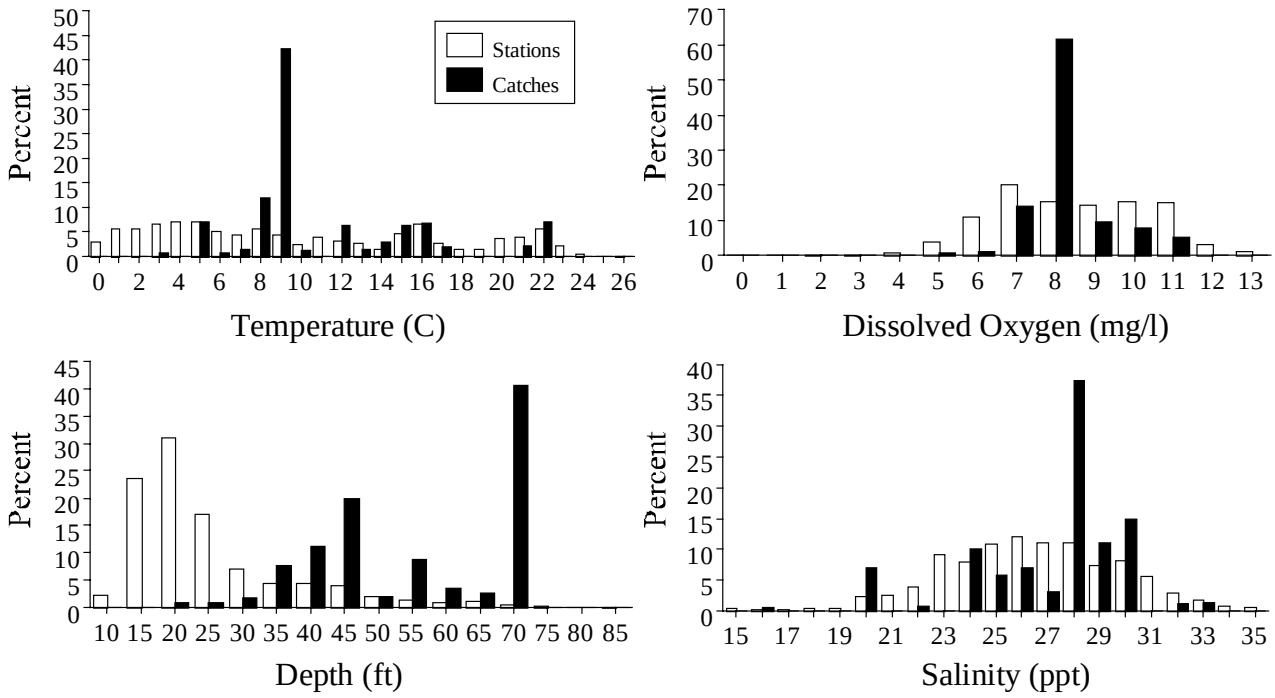


Figure 9. Abundance of adult (> 24 cm) red hake relative to mean bottom water temperature, dissolved oxygen, depth, and salinity from Hudson-Raritan estuary trawl surveys, January 1992-June 1997 (all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

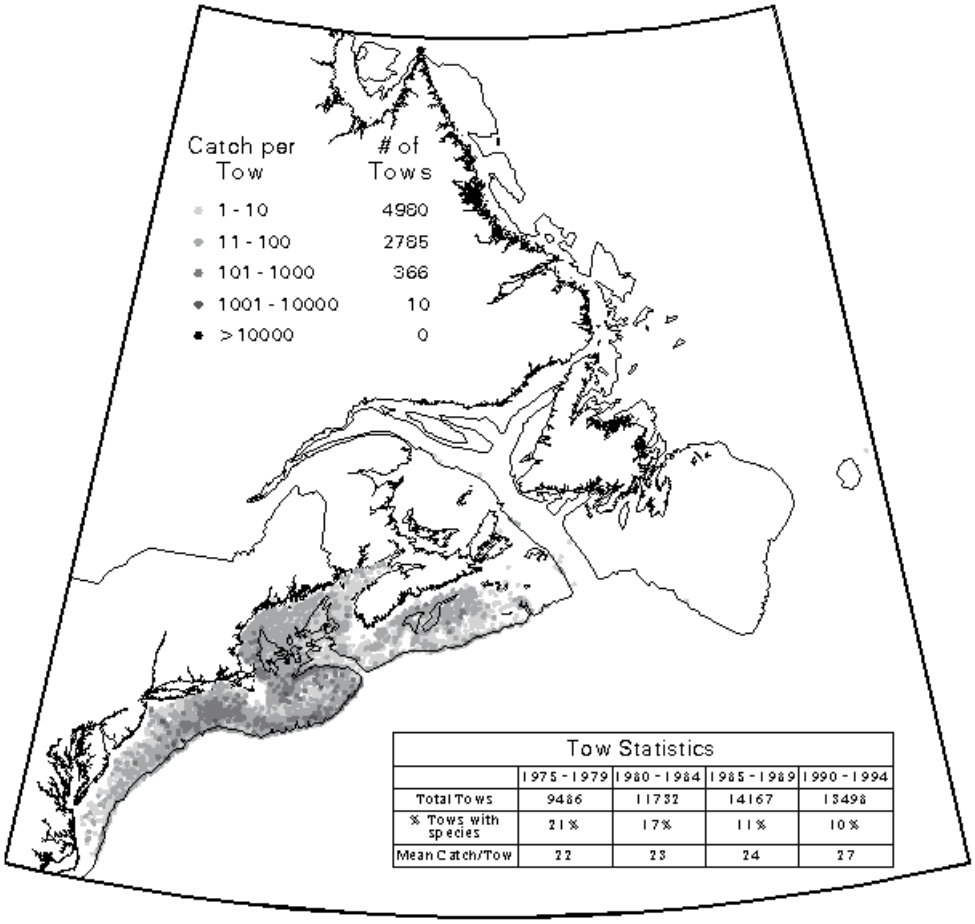


Figure 10. Distribution and abundance of red hake from Newfoundland to Cape Hatteras during 1975-1994. Data are from the U.S. NOAA/Canada DFO East Coast of North America Strategic Assessment Project (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

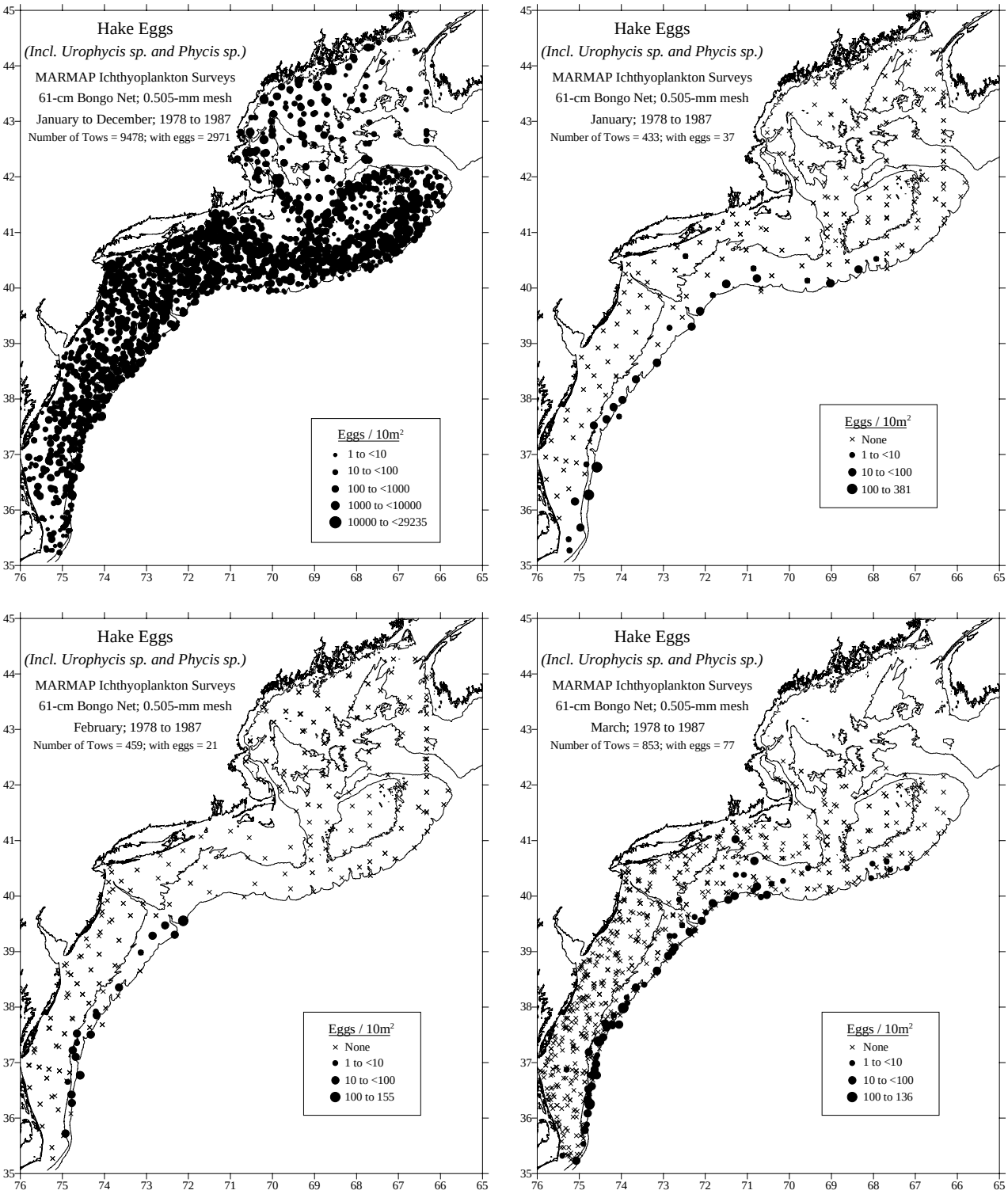
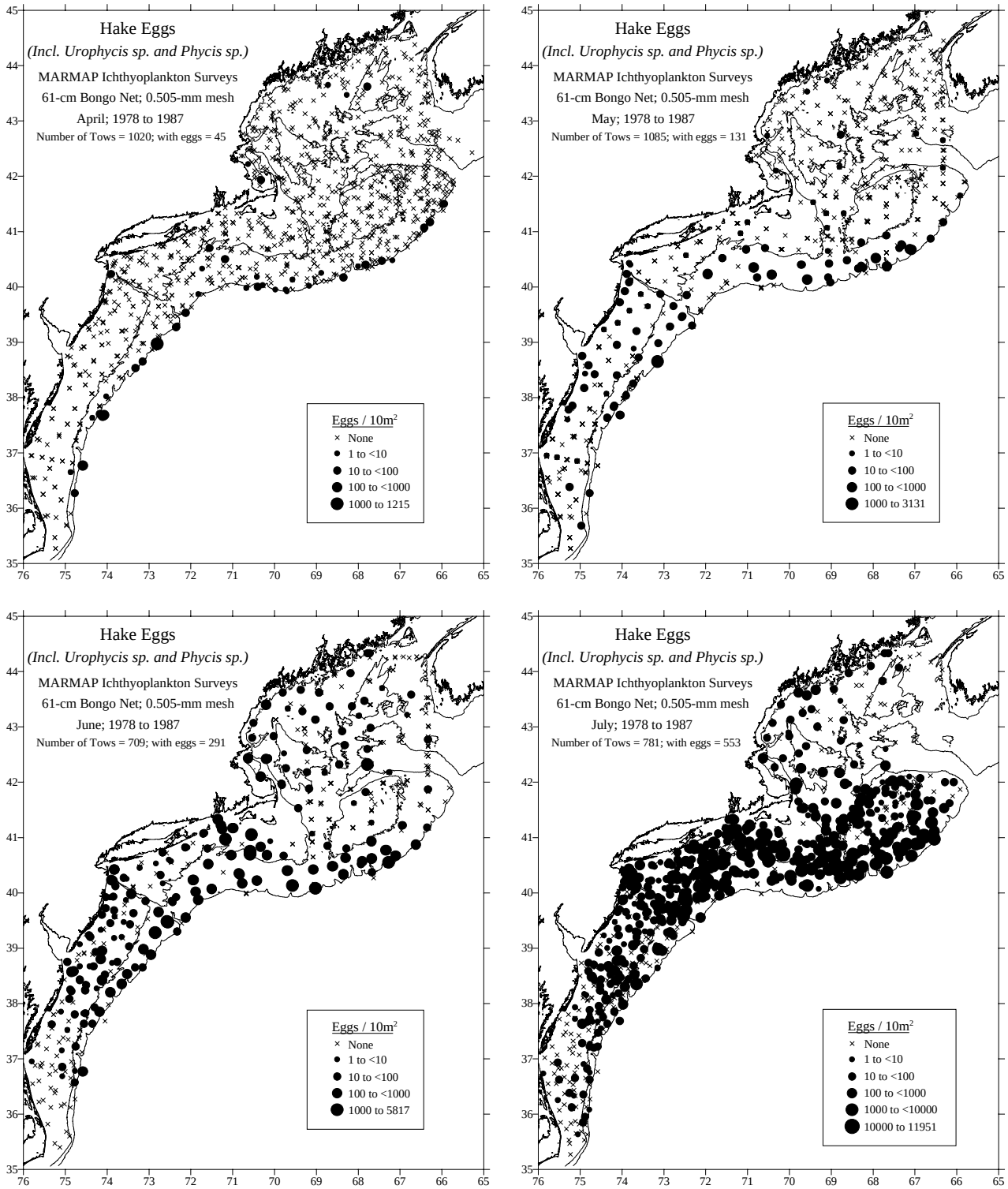


Figure 11. Distribution of hake (*Urophycis* and *Physcis* spp.) eggs collected during NEFSC MARMAP ichthyoplankton surveys from January to December, 1978-1987 [see Reid *et al.* (1999) for details].



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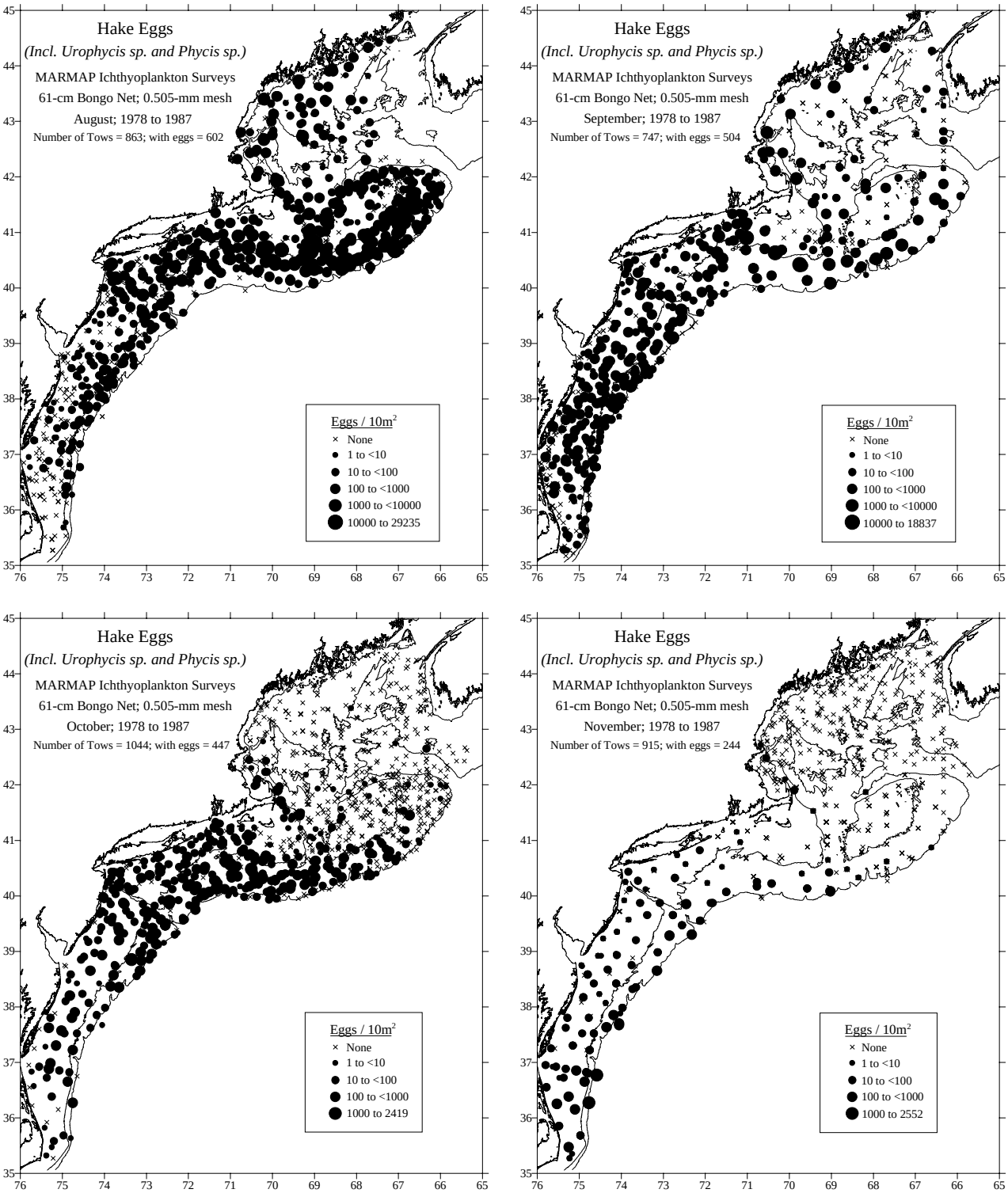

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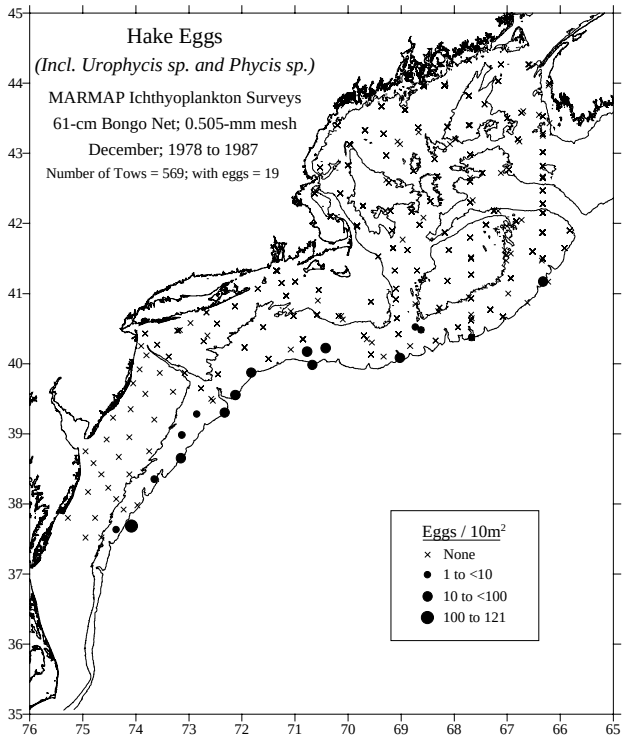

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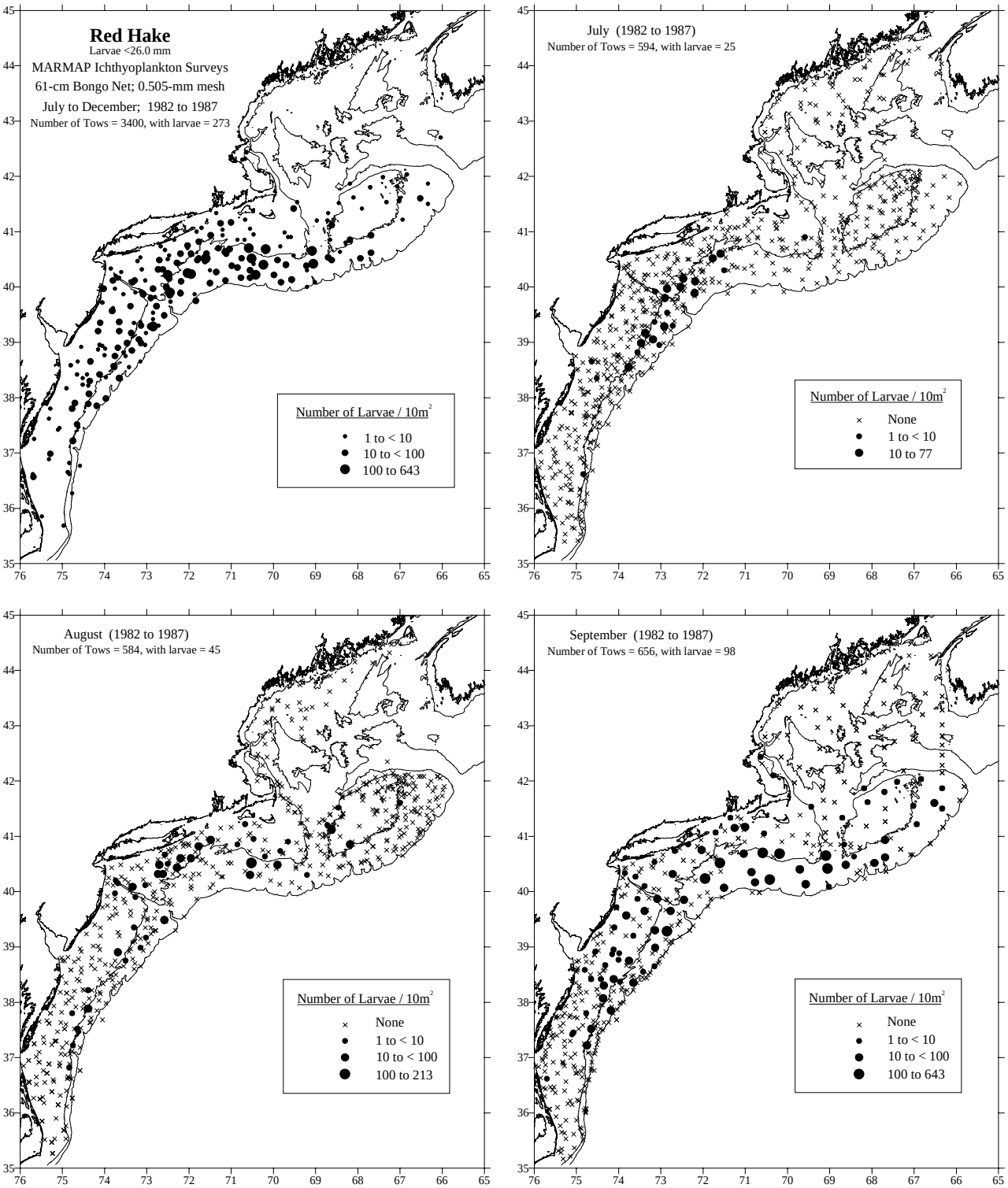
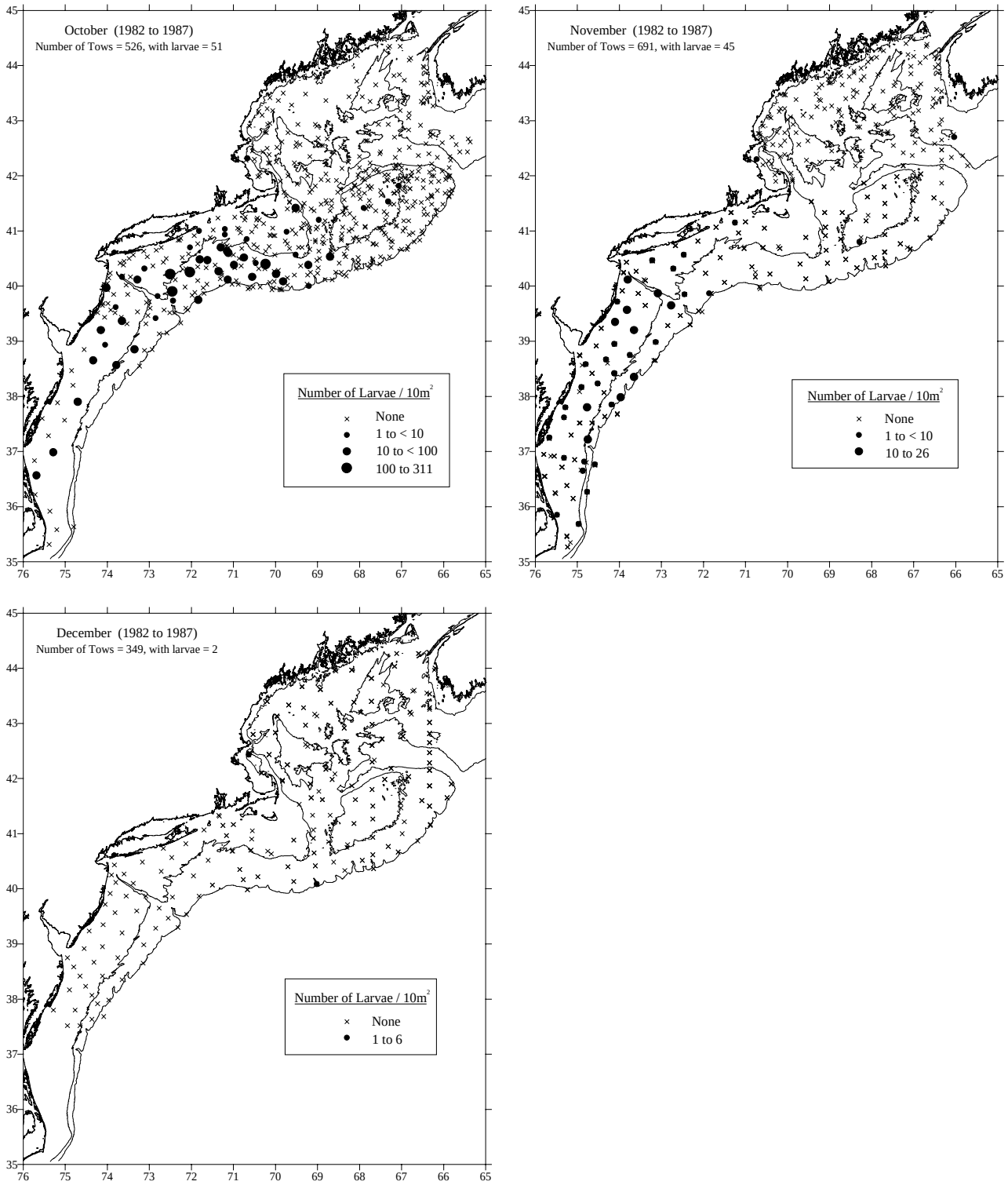


Figure 12. Distribution of red hake larvae collected during NEFSC MARMAP ichthyoplankton surveys, July through December 1982-1987 [see Reid *et al.* (1999) for details]. *Urophycis* larvae are difficult to identify to species, and misidentification was a problem until 1982. Due to the short period of reliable identifications, the distribution presented in this figure probably represents a minimum occurrence.



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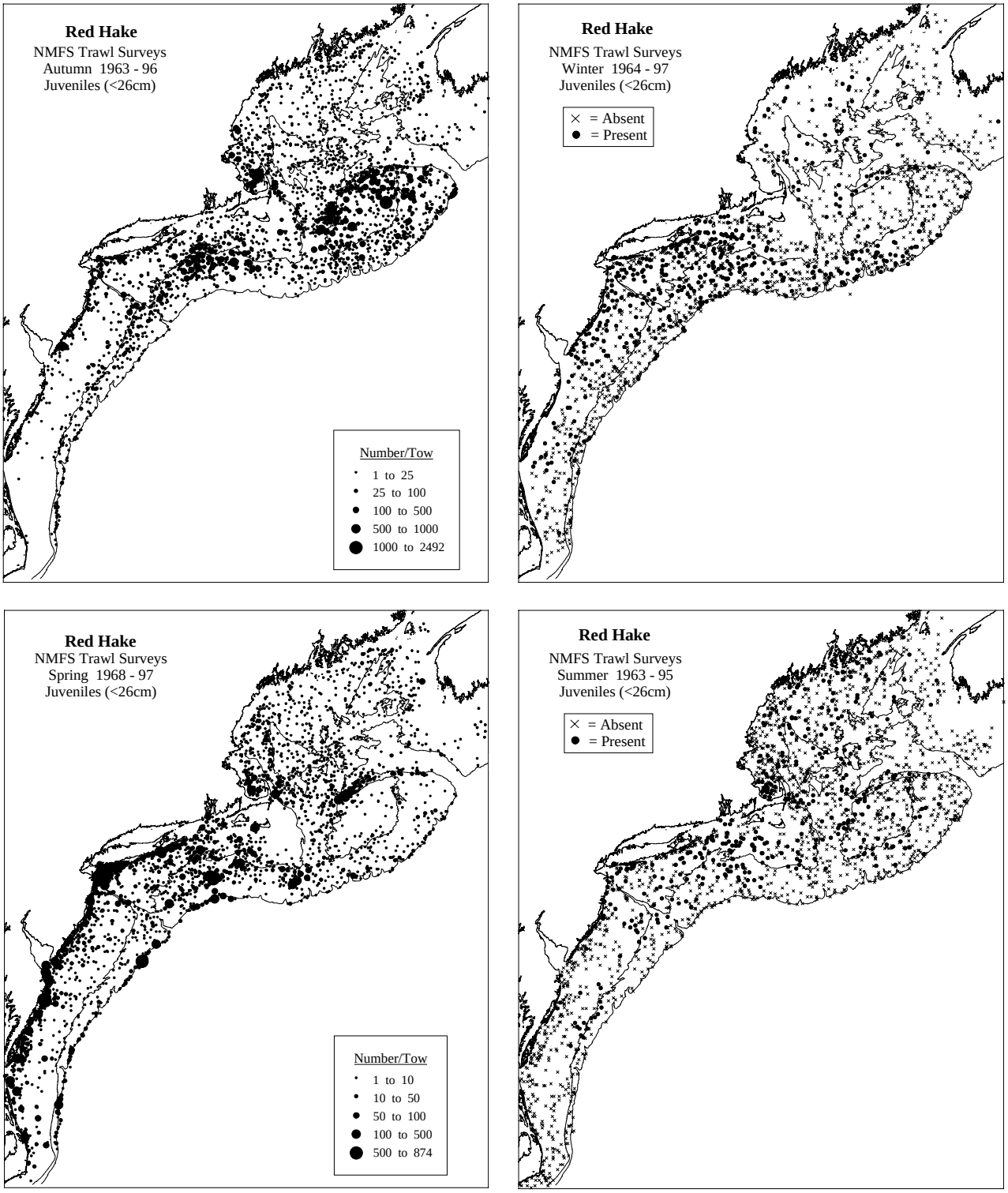
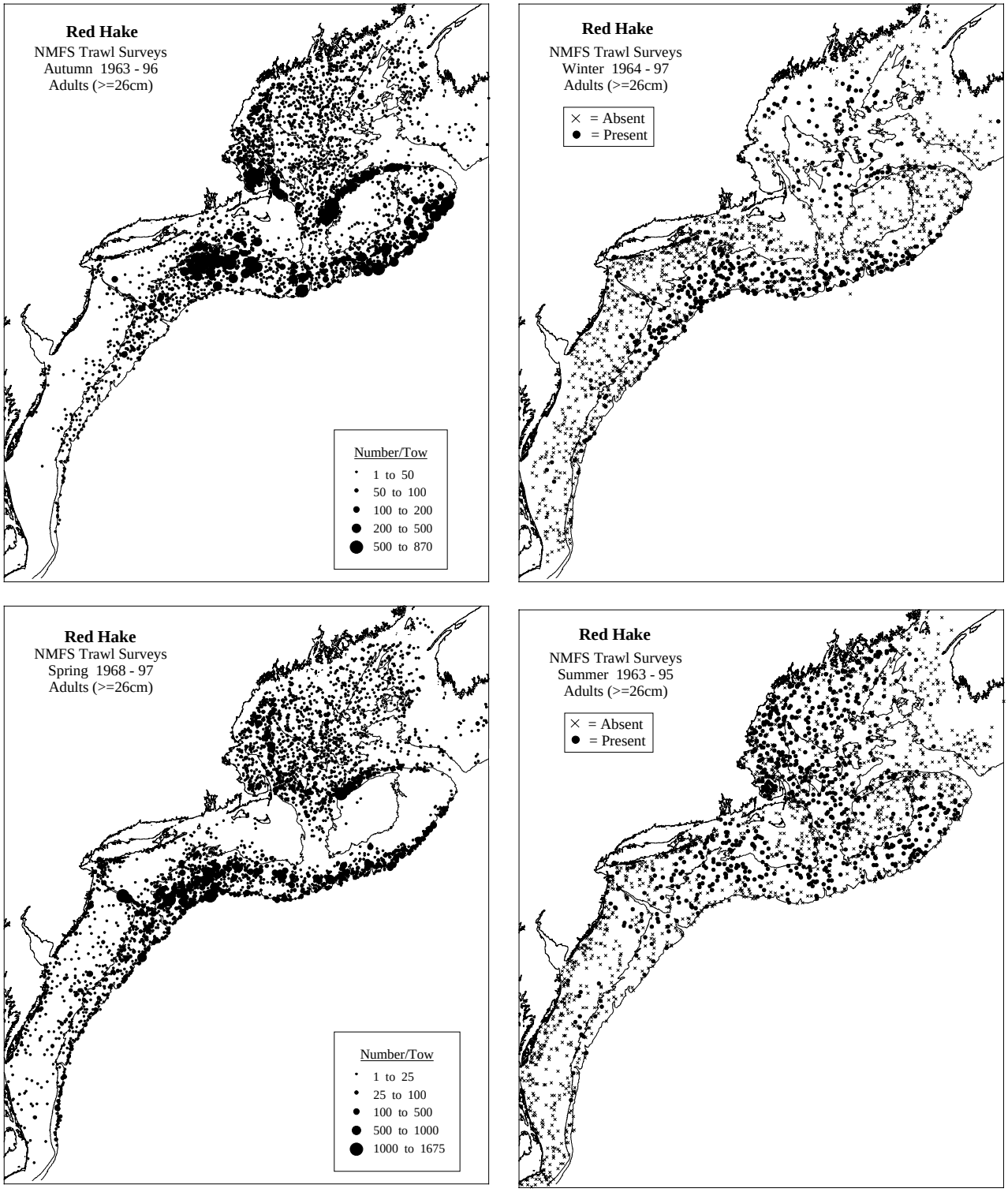


Figure 13. Distribution of juvenile (< 26 cm) and adult (≥ 26 cm) red hake collected during NEFSC bottom trawl surveys during all seasons, 1963-1997. Densities are represented by dot size in spring and fall plots, while only presence and absence are represented in winter and summer plots [see Reid *et al.* (1999) for details].



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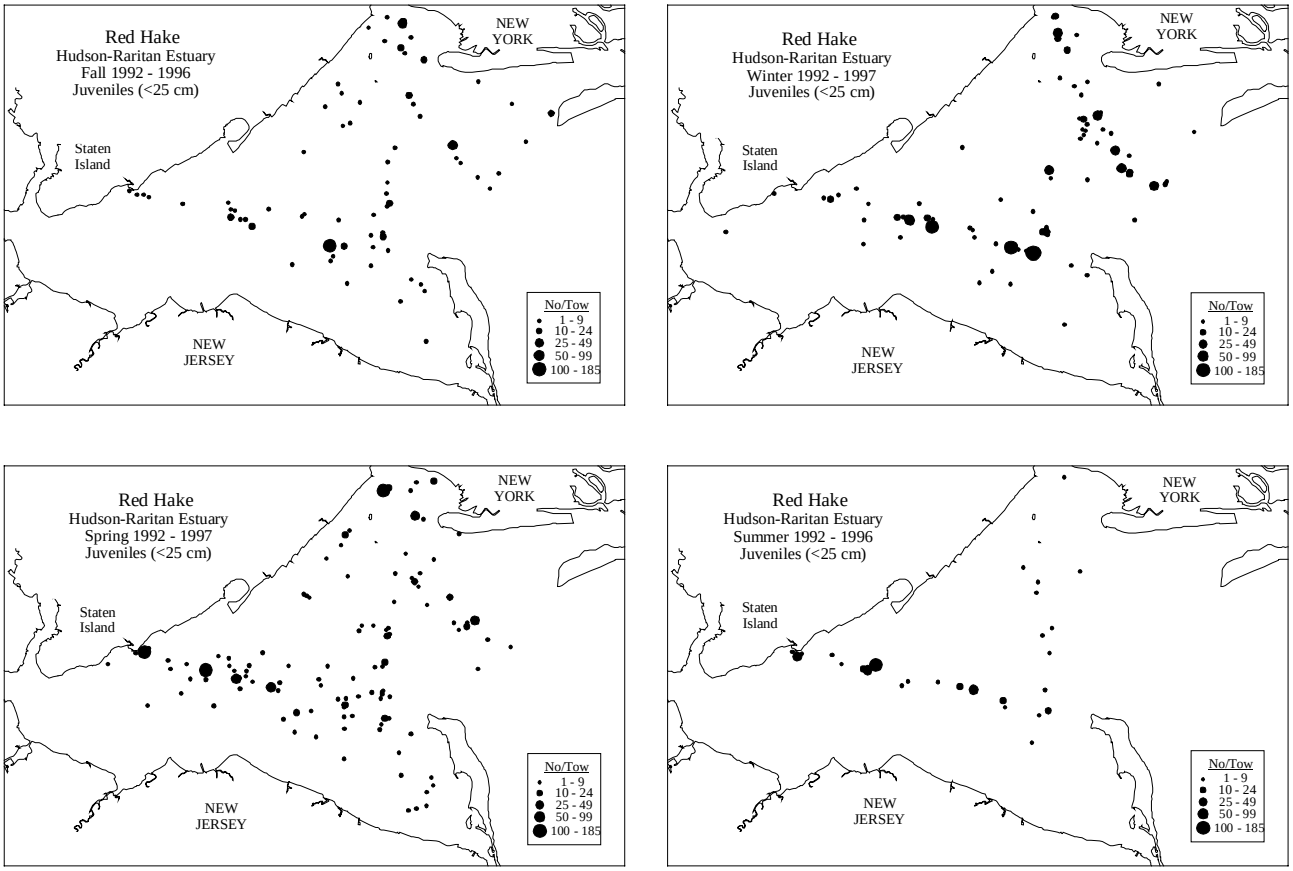


Figure 14. Distribution of juvenile (< 25 cm) and adult (> 24 cm) red hake collected in the Hudson-Raritan estuary, based on Hudson-Raritan trawl surveys during winter (January-March), spring (April and June), summer (July–August), and fall (October-December) from January 1992 to June 1997 [see Reid *et al.* (1999) for details].

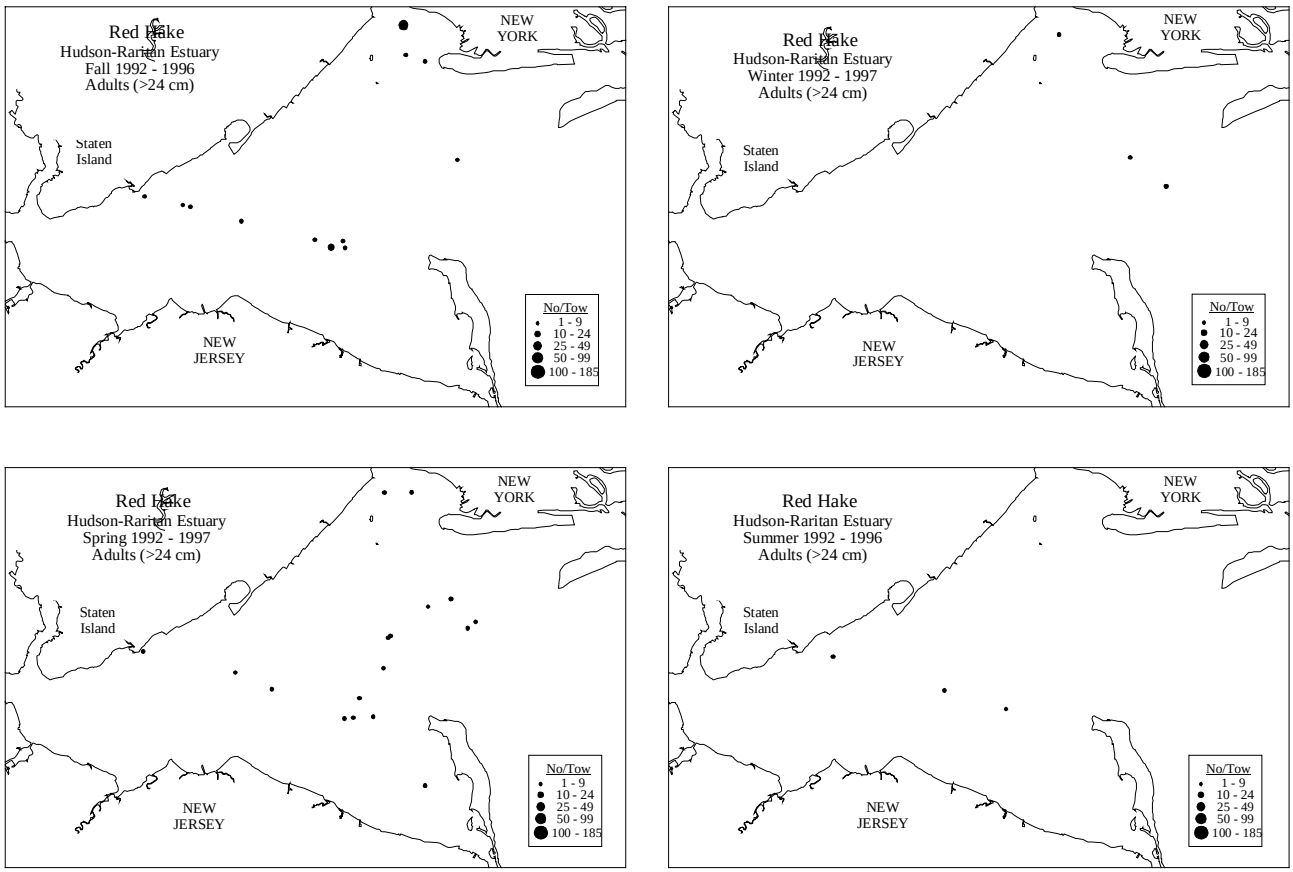
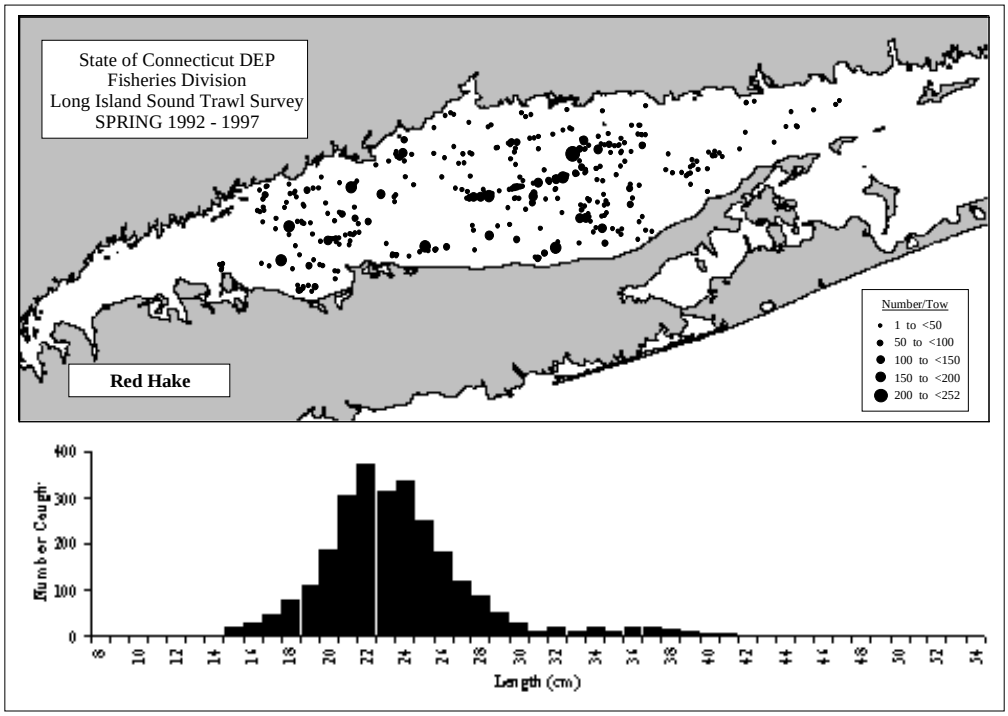


Figure 14. cont'd.



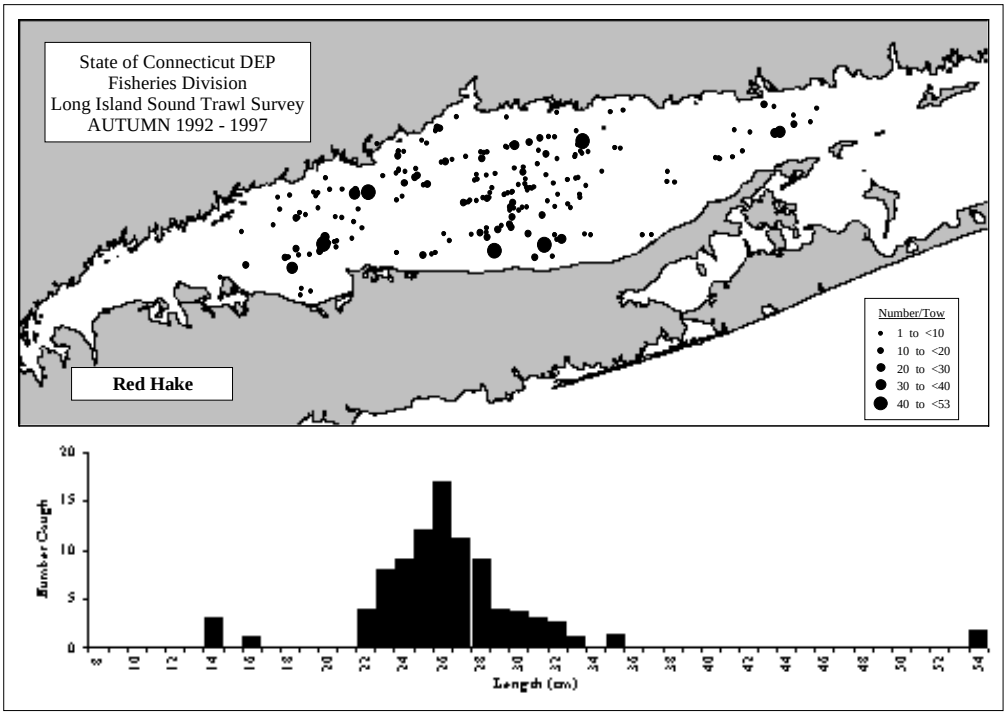


Figure 15. Abundance, distribution and size frequency distribution of red hake in Long Island Sound in spring and autumn, from the Connecticut bottom trawl surveys, 1992-1997 [see Reid *et al.* (1999) for details].

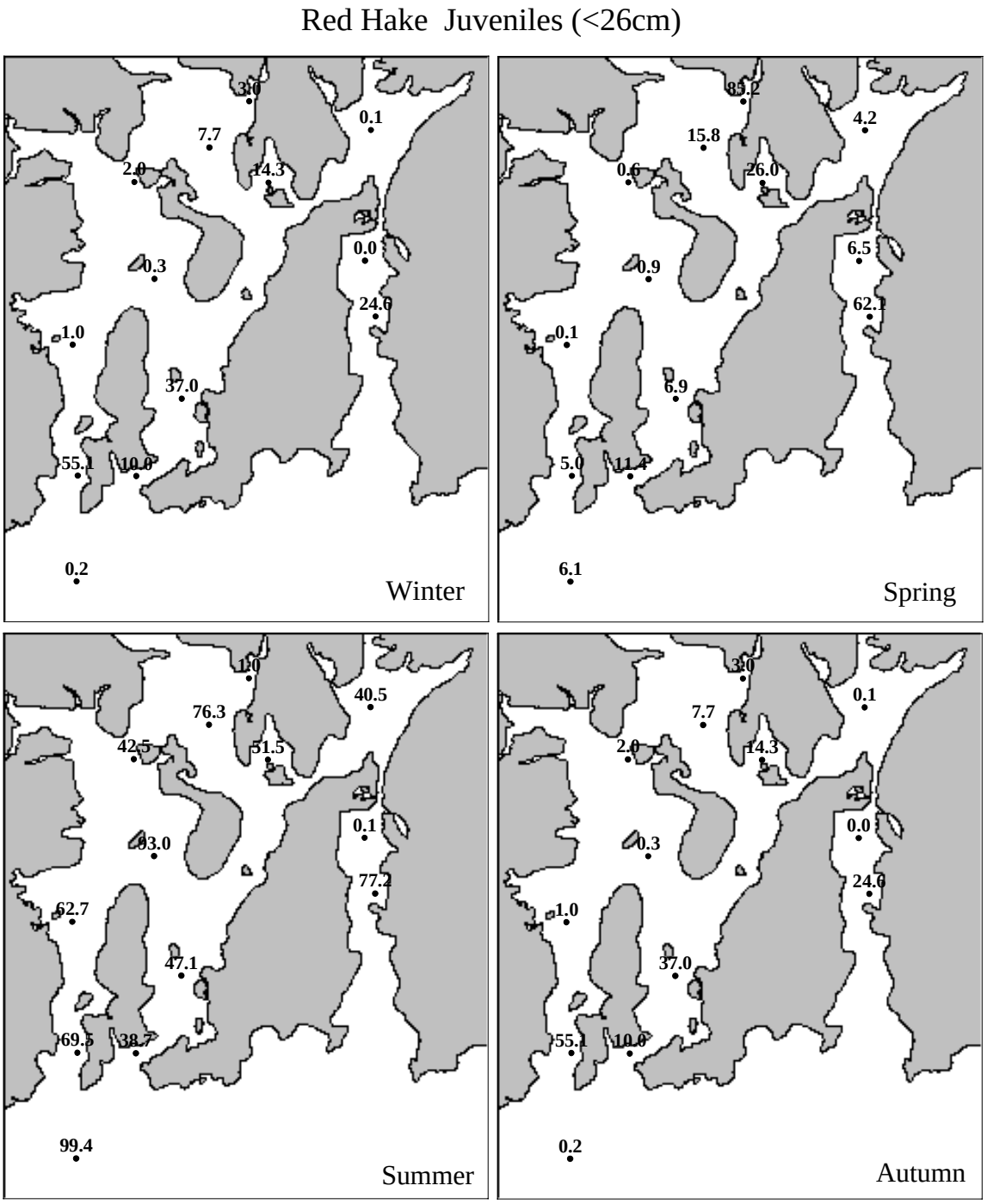
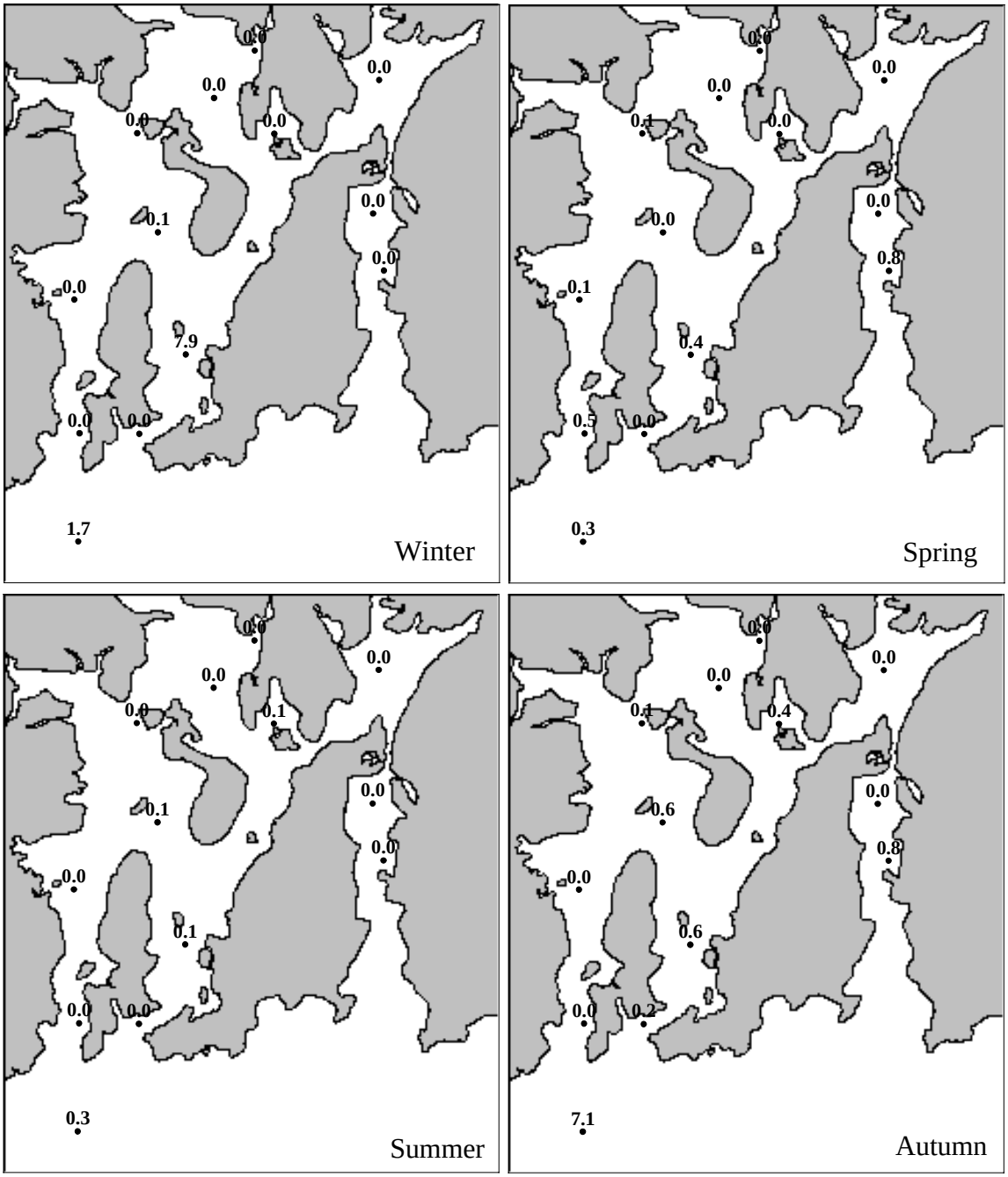


Figure 16. Seasonal distribution of juvenile (< 26 cm) and adult (≥ 26 cm) red hake collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].

Red Hake Adults (>=26cm)



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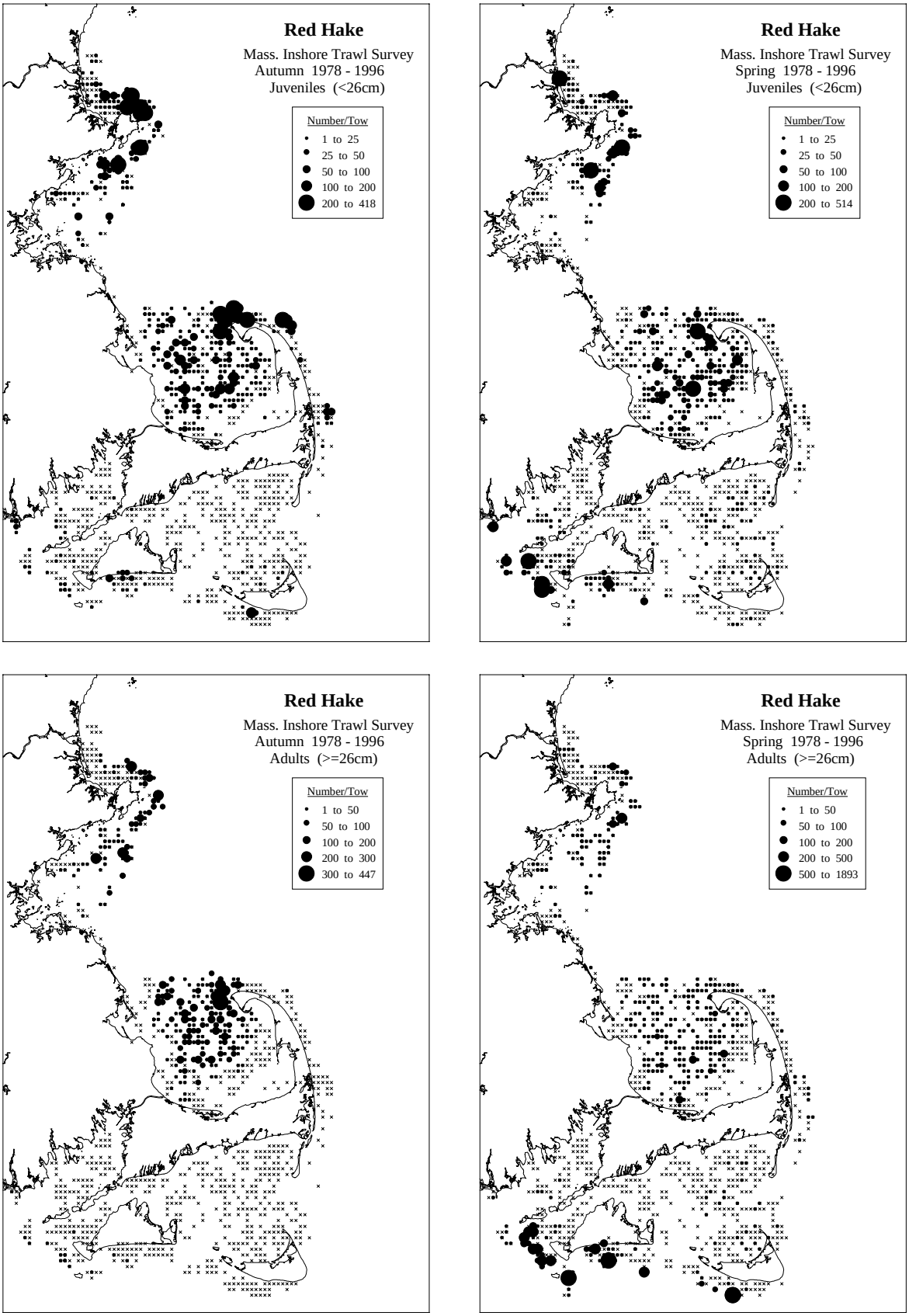
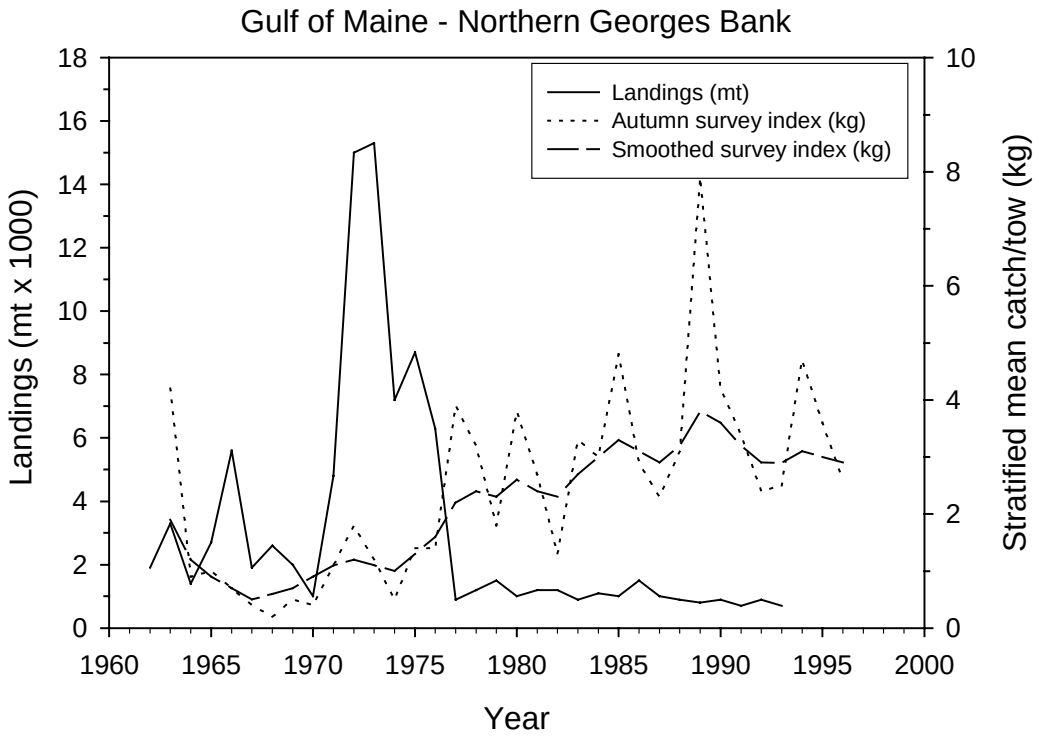


Figure 17. Distribution of juvenile (< 26 cm) and adult (≥ 26 cm) red hake in Massachusetts coastal waters during spring and autumn Massachusetts trawl surveys, 1978-1996 [see Reid *et al.* (1999) for details].



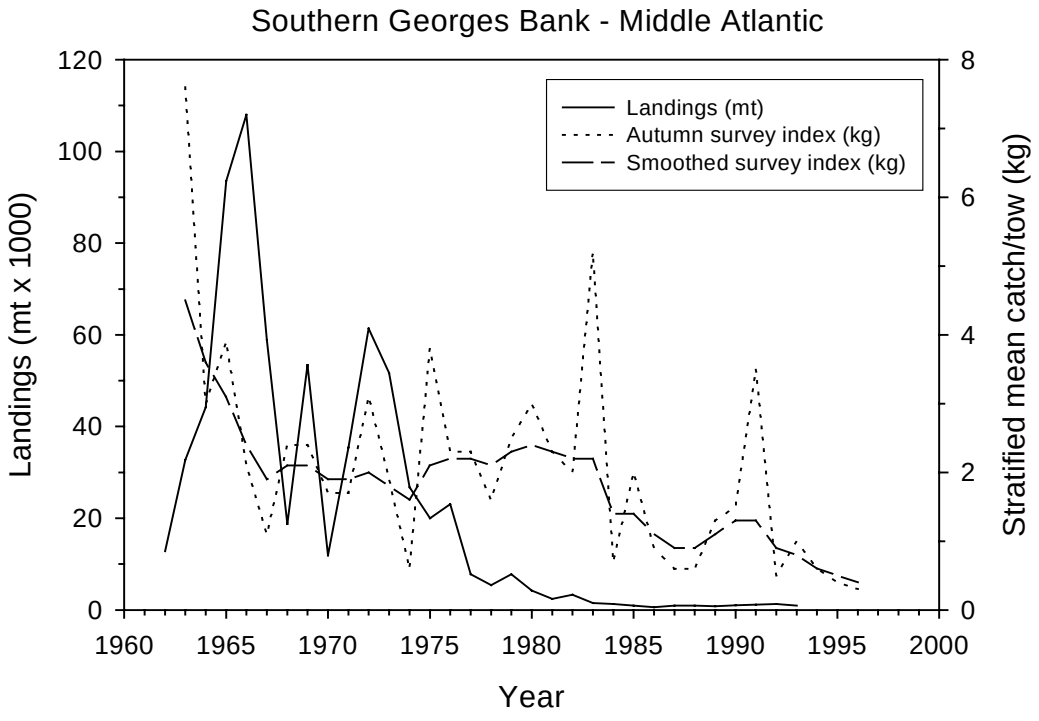


Figure 18. Commercial landings and abundance indices (from the NEFSC bottom trawl surveys) for northern and southern red hake populations.

Publishing in *NOAA Technical Memorandum NMFS-NE*

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This series represents a secondary level of scientific publishing in the National Marine Fisheries Service (NMFS). For all issues, the series employs thorough internal scientific review, but not necessarily external scientific review. For most issues, the series employs rigorous technical and copy editing. Manuscripts that may warrant a primary level of scientific publishing should be initially submitted to one of NMFS's primary series (*i.e., Fishery Bulletin, NOAA Technical Report NMFS,* or *Marine Fisheries Review*).

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Authors must submit one paper copy of the double-spaced manuscript, one magnetic copy on a disk, and original figures (if applicable). NEFSC authors must include a completely signed-off "NEFSC Manuscript/Abstract/Webpage Review Form." Non-NEFSC authors who are not federal employees will be required to sign a "Release of Copyright" form.

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STANDARD MAIL A

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific ournals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series includes: data reports of long-term or large area studies; synthesis reports for major resources or habitats; annual reports of assessment or monitoring programs; documentary reports of oceanographic conditions or phenomena; manuals describing field and lab techniques; literature surveys of major resource or habitat topics; findings of task forces or working groups; summary reports of scientific or technical workshops; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing. Limited free copies are available from authors or the NEFSC. Issues are also available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series includes: data reports on field and lab observations or experiments; progress reports on continuing experiments, monitoring, and assessments; background papers for scientific or technical workshops; and simple bibliographies. Issues receive internal scientific review but no technical or copy editing. No subscriptions. Free distribution of single copies.

Fishermen's Report **and** ***The Shark Tagger*** -- The ***Fishermen's Report*** (FR) is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of the FR; copies are available through free subscription. ***The Shark Tagger*** (TST) is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of the TST; copies are available only to participants in the tagging program.

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NOAA Technical Memorandum NMFS-NE-137

Essential Fish Habitat Source Document:

Windowpane, *Scophthalmus aquosus*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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This series represents a secondary level of scientifiic publishing. All issues employ thorough internal scientific review; some issues employ external scientific review. Reviews are -- by design -- transparent collegial reviews, not anonymous peer reviews. All issues may be cited in formal scientific communications.

Essential Fish Habitat Source Document:

Windowpane, *Scophthalmus aquosus*, Life History and Habitat Characteristics

Sukwoo Chang, Peter L. Berrien, Donna L. Johnson, and Wallace W. Morse

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Woods Hole, Massachusetts

September 1999

Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

---

[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, CHIEF
ECOSYSTEMS PROCESSES DIVISION
NORTHEAST FISHERIES SCIENCE CENTER

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INTRODUCTION

The windowpane, *Scophthalmus aquosus*, is an eurythemal, euryhaline, and fast-growing fish with a thin body (Figure 1). It inhabits estuaries, near-shore waters, and the continental shelf in the northwest Atlantic. Windowpane is not a target of the commercial fishing industry, but is mainly caught as bycatch in bottom trawl fisheries. It is managed by the New England Fishery Management Council under the Multispecies Fishery Management Plan (NEFMC 1993). This Essential Fish Habitat source document provides information on the life history and habitat characteristics of windowpane.

LIFE HISTORY

The windowpane is a left-eyed flounder with a thin body and nearly round outline. It occurs from the Gulf of Saint Lawrence to Florida (Scott and Scott 1988), but is most abundant from Georges Bank to Chesapeake Bay (Figures 2 and 3; Bigelow and Schroeder 1953; Dery and Livingstone 1982; Chang 1990). Windowpane generally inhabit shallow waters (< 110 m) with sand to sand/silt or mud substrates; they are most abundant from depths of 1-2 m (Warfel and Merriman 1944) to depths < 56 m (Thorpe 1991). They occur in most of the bays and estuaries south of Cape Cod, including Chesapeake Bay (Hildebrand and Schroeder 1928), Delaware Bay (de Sylva *et al.* 1962), Sandy Hook Bay (Wilk and Silverman 1976), Raritan Bay (Wilk *et al*. 1996), Long Island Sound (Moore 1947; Gottschall *et al*., in review), and Narragansett Bay (Jefferies and Johnson 1973). North of Cape Cod, windowpane inhabit nearshore waters, but their occurrence in estuaries is not well documented. Table 1 presents a qualitative summary of the distribution and relative abundance of windowpane life history stages in estuaries from Maine to Virginia (Jury *et al*. 1994; Stone *et al*. 1994).

EGGS

The eggs are buoyant and spherical, with a diameter of 0.9-1.4 mm), and a single oil globule 0.2-0.3 mm in diameter (Wheatland 1956). At a typical spawning temperature of 11°C, hatching occurs in eight days (Miller *et al*. 1991).

LARVAE

At hatching, windowpane larvae are approximately 2 mm long (Fahay 1983; Able and Fahay 1998). Flexion begins at about 5.5 mm TL (Fahay 1983); eye transformation during metamorphosis begins at about 6.5 mm TL (Colton and Marak 1969; Fahay 1983). The body is darkly pigmented over most of its length. As development proceeds, the body becomes deeper and more laterally compressed. Fin ray formation is complete at about 11.5 mm TL. Details of larval development are provided by Moore (1947).

JUVENILES

The body is oval and wider (60-70% SL) than in other left-eyed flounders. The body and fins are heavily pigmented in larger young-of-the-year; smaller individuals are characterized by broad alternating dark and light bands. The mouth is large, extending to the eye or beyond and the lateral line is arched over the pectoral fin (Figure 1; Able and Fahay 1998). The growth patterns of young juveniles in estuaries and on the shelf vary with the timing of spawning. Fish spawned in the spring grow quickly and reach sizes of 11-19 cm TL by September, about four months after spawning. By the following spring, most fish of this cohort are larger than 16 cm TL. Fish spawned in the autumn are 4-7 cm TL in December and reach 18-21 cm TL by the following October (Morse and Able 1995; Able and Fahay 1998).

ADULTS

Windowpane attain a maximum total length of about 46 cm (Scott and Scott 1988). Few age and growth studies of windowpane have been conducted (Moore 1947; Shelton 1979; Thorpe, 1991). It is a fast growing species and spring and summer is the period of greatest growth (Moore 1947).

REPRODUCTION

Gonadal development indices (Wilk *et al.* 1990) and egg and larval distributions (Colton and St. Onge 1974; Smith *et al.* 1975; Colton *et al*. 1979; Morse *et al.* 1987) indicate that spawning occurs throughout most of the year. Spawning begins in February or March in inner shelf waters, peaks in the Middle Atlantic Bight in May, and extends onto Georges Bank during the summer (Able and Fahay 1998). Spawning also occurs in the southern portion of the Middle Atlantic Bight in the autumn (Smith *et al.* 1975). There is a split spawning season in the central Middle Atlantic Bight with peaks in the spring and autumn (Morse and Able 1995; Able and Fahay 1998). Evidence for a split spawning season is available for Virginia and North Carolina (Smith *et al.* 1975), for Long Island Sound, New York (Wheatland 1956), and for Great South Bay, New York (Dugay *et al.* 1989; Monteleone 1992). Gonad development indicated that split spawning off New Jersey and New York peaks in May and in September (Wilk *et al.* 1990). However, neither

Perlmutter (1939) nor Smith *et al.* (1975) found evidence for a split spawning season in Long Island Sound or in oceanic waters north of Virginia. Colton and St. Onge (1974) collected larvae on Georges Bank from July to November but found no indication of a split spawning season.

Some spawning may occur in the high salinity portions of estuaries in the Middle Atlantic Bight, including Great South Bay, New York (Monteleone 1992), Sandy Hook Bay, New Jersey (Croker 1965), inside Hereford Inlet, New Jersey (Allen *et al.* 1978), and in the coastal habitats of the Carolinas (Wenner and Sedberry 1989). Windowpane spawn in the evening or at night (Ferraro 1980) on or near bottom at temperatures ranging from 6-21°C (Bigelow and Schroeder 1953; Wheatland 1956; Smith *et al.* 1975). Most spawning (70%) was found at bottom water temperatures between 8.5-13.5^{o}C; spawning stopped off Virginia and North Carolina when water temperatures exceeded 15°C (Smith *et al.* 1975).

Sexual maturity occurs at 3-4 years of age when about 50% of females that are 22 cm TL are sexually mature. Females grow larger and faster than males after sexual maturity (O'Brien *et al.* 1993).

FOOD HABITS

Juvenile and adult windowpane feed exclusively on mysid shrimps in Johns Bay, Maine (Hacunda 1981). Stomach content data collected during Northeast Fisheries Science Center (NEFSC) bottom trawl surveys indicate windowpane feed on small crustaceans (e.g., mysids and decapod shrimp) and various fish larvae including hakes and tomcod, as well as their own species (Langton and Bowman 1981; Figure 4).

PREDATION

Spiny dogfish, thorny skate, goosefish, Atlantic cod, black sea bass, weakfish and summer flounder are major predator of windowpane, primarily juveniles.

MIGRATION

Juveniles that settle in shallow inshore waters move to deeper offshore waters as they grow (Klein-MacPhee, in prep.). Juveniles and adults may migrate to nearshore or estuarine habitats in the southern Middle Atlantic Bight in the autumn (Figures 2 and 3), however, juveniles are probably not adequately sampled by standard Northeast Fisheries Science Center trawl gear (Morse and Able 1995). Juveniles inhabiting Georges Bank (< 60 m) undergo seasonal movements to deeper waters along the southern flank of the Bank occur during late autumn, as bottom temperatures drop, and overwintering occurs in deeper areas until late spring (Figure 2).

STOCK STRUCTURE

Fish stocks are generally defined as having a fixed spawning ground, a definite spawning season, and a consistent migratory or movement pattern. Nonetheless, spawning in windowpane occurs throughout most of the year (April-December) and is closely linked to bottom temperature (Colton and St. Onge 1974; Smith *et al*. 1975; Colton *et al*. 1979; Morse *et al*. 1987). Thus, stock structure of windowpane could not clearly be identified. However, the species is managed as two stocks: a northern stock, Gulf of Maine-Georges Bank region, and a southern stock, southern New England-Middle Atlantic Bight region.

HABITAT CHARACTERISTICS

The habitat characteristics and preferences of windowpane are summarized in Table 2. The methods used to collect the fishery-independent survey data used in this characterization are summarized in Reid *et al*. (1999).

EGGS

Windowpane eggs were collected at integrated water column temperatures of 5-20°C. Most eggs were collected at 4-16°C in spring (March-May), 10-16°C in summer (June-August) and 14-20°C in autumn (September-November) in depths < 70 m (Figure 5).

LARVAE

Larvae settle to the bottom at approximately 10 mm TL (Bigelow and Schroeder 1953). However, individuals collected on Georges Bank may be planktonic up to 20 mm (Morse and Able 1995). Based on collections from southern New Jersey, it appears that settlement of spring-spawned individuals occurs in estuaries and on the shelf, while settlement of autumn-spawned individuals occurs primarily on the shelf. Larvae are found throughout the polyhaline portion of estuaries in the spring, but primarily on the shelf in the autumn (Morse and Able 1995).

The maximum abundance of small larvae (< 5 mm TL) occurred from 15-19°C in areas south of Georges Bank and at 14-15°C on Georges Bank. Windowpane larvae were collected during the NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) ichthyoplankton survey at integrated water column temperatures of 5-20°C, but mostly at 3-14°C in spring, 10-17°C in summer, and 13-19°C in autumn in

water < 70 m deep (Figure 6).

JUVENILES

Juveniles were collected on the continental shelf throughout the year during NEFSC bottom trawl surveys (Figure 2) at a wide range of bottom temperatures (3-25°C) and depths (5-125 m). Juveniles were most abundant at bottom temperatures of 4-7°C in spring and 14-16°C in autumn at depths < 50 m (Figure 7).

Juveniles inhabiting Massachusetts inshore waters (Figure 8) were most abundant at 5-12°C in spring and 12-19°C in autumn, and at depths < 20 m (Figure 9).

Windowpane were common in the Rhode Island bottom trawl survey in Narragansett Bay; juveniles were caught throughout the bay in all seasons with no indication of seasonal differences. Juveniles were captured at most bottom depths but showed a preference for depths < 30 m in warmer bottom water temperature periods (9-25°C), and depths > 30 m in colder water temperatures (1-8°C). They occurred at a wide range of bottom water temperatures: winter (1-8°C), spring (1-15°C), summer (13-25°C), and autumn (10-21°C).

The bottom trawl survey in the Hudson-Raritan estuary showed that juveniles were fairly evenly distributed throughout the estuary, but they were most abundant in the deeper channels in winter and summer (Figure 10; Wilk *et al.* 1996). For all seasons combined, juveniles were collected at bottom temperatures of 0-24°C, at depths < 25 m with salinities of 15-33 ppt, and dissolved oxygen (DO) levels of 2-13 mg/l (Figure 11; Wilk *et al.* 1996). Juvenile windowpane were most abundant at bottom water temperatures of 5-23°C, at depths of 7-17 m, at salinities of 22-30 ppt, and DO levels of 7-11 mg/l (Figure 11; Wilk *et al.* 1996).

ADULTS

The windowpane is a year-round resident off southern New Jersey and probably in the Gulf of Maine (Klein-MacPhee, in prep.). Adult windowpane tolerate a wide range of temperatures (0-26.8°C) and temperature may control the northern extent of the species as well as its local abundance (Moore 1947). In the Northeast Fisheries Science Center bottom trawl survey (Figure 3), adults were caught at bottom temperatures of 4-8°C and depths < 75 m in spring and at 12-18°C and depths < 50 m in autumn (Figure 7).

Data from the Massachusetts inshore trawl survey (Figure 8) indicated that most adults were caught south of Cape Cod during spring at bottom temperatures of 9-13°C and at depths < 15 m. In autumn, adults were more widely distributed and were caught at bottom temperatures of 9-19°C and depths < 30 m (Figure 9).

Adults were caught throughout Narragansett Bay in all seasons with no apparent seasonal shift in abundance. Adults preferred deeper waters (> 30 m) in cold bottom water temperature periods (1-8°C) and remained in a shallow water (< 30 m) in the warmer bottom water temperature periods (9-23°C).

The bottom trawl survey in Long Island Sound found that juvenile and adult windowpane were most abundant in spring (April-June) (Figure 12; Gottschall *et al.*, in review). In spring, they were caught at bottom temperatures of 3-18°C, at salinities of 21-31 ppt, and at depths < 60 m. The distribution pattern in autumn (September-November) was similar to the pattern in spring, but abundance was reduced (Figure 12). In autumn, windowpane adults were caught at bottom temperatures of 8-23°C, at salinities of 18-32 ppt, and at depths < 50 m (Gottschall *et al.*, in review).

Adults were fairly evenly distributed throughout the Hudson-Raritan estuary, but they were more abundant in deeper channels in the summer (Figure 10; Wilk *et al.* 1996). For all seasons combined, adults were collected at bottom temperatures of 0-24°C, at depths < 25 m, at salinities of 15-33 ppt, and DO levels of 2-13 mg/l (Figure 11; Wilk *et al.* 1996).

Adult windowpane occur primarily on sand substrates off southern New England and the Middle Atlantic Bight, but are frequently caught on mud grounds in the Gulf of Maine (Langton *et al.* 1994). Adults are euryhaline; they occur at salinities of 5.5-36.0 ppt (Tagatz 1967). Windowpane are sensitive to hypoxic conditions; few were collected where DO concentrations were < 3 mg/l, presumably because they avoid such conditions (Howell and Simpson 1994).

Adult windowpane may travel along the coast for considerable distances; in one case, they moved 129 km in three months (Moore 1947). These movements may play an important role in the intermingling of local populations (Klein-MacPhee, in prep.).

In a species association study using NEFSC groundfish survey bottom trawl data, windowpane commonly occurred with yellowtail flounder (*Limanda ferruginea*), ocean pout (*Macrozoarces americanus*), and little skate (*Raja erinacea*) during spring (Colvocoresses and Musick 1984). In autumn, windowpane were more widely distributed across the shelf and occurred with yellowtail flounder, little skate, northern searobin (*Prionotus carolinus*), and spiny dogfish (*Squalus acanthias*).

GEOGRAPHICAL DISTRIBUTION

The windowpane is distributed from the Gulf of St. Lawrence to Cape Hatteras, North Carolina, but it is most common south of Nova Scotia (Figure 13). The largest catches occur on Georges Bank.

EGGS

Windowpane eggs have been collected in several studies (Colton and St. Onge 1974; Smith *et al.* 1975; Colton *et al.* 1979; Morse *et al.* 1987; Berrien and Sibunka 1999). Windowpane egg distributions from NEFSC MARMAP ichthyoplankton surveys are summarized in Figure 14. Eggs were collected at 16% of the stations sampled; primarily at depths < 40 m between Georges Bank and Cape Hatteras. Eggs densities were generally low in the Gulf of Maine. Eggs were collected in nearshore shelf waters in the Middle Atlantic Bight from February to November. Egg densities peaked in May and October. Eggs were present on Georges Bank from April through October and density peaked during July-August.

LARVAE

The spatial distribution of windowpane larvae collected in NEFSC MARMAP ichthyoplankton surveys is summarized in Figure 15. More than 99% of the larvae collected were 2-10 mm TL. Peak densities of recently-spawned larvae (2-4 mm TL) occurred in the southern Middle Atlantic Bight in May and November, and on Georges Bank in July-October (Morse and Able 1995; Figure 15). The larval distribution mirrors that of the eggs in space and time.

JUVENILES

The spatial pattern of abundance for juvenile windowpane on the continental shelf in the Middle Atlantic Bight is similar to the spatial pattern for larvae (Morse and Able 1995). Juveniles occur nearshore in the Middle Atlantic Bight (< 40 m) and off southern New England (< 50 m) throughout the year (Figure 2). On Georges Bank, the spatial distribution of densities of juveniles differs between spring and autumn (Wigley and Gabriel 1991), and adults migration is similar to juveniles. Spatial distribution of juveniles in the Gulf of Maine shows low densities in nearshore areas in spring and autumn.

In the Hudson-Raritan estuary, juveniles were fairly evenly distributed throughout the estuary, but juveniles were most abundant in the deeper channels in winter and summer (Figure 10; Wilk *et al.* 1996).

ADULTS

The spatial distribution of adults on the continental shelf (Figure 3) is similar to the distribution of juveniles (Figure 2). Adults may migrate to nearshore or estuarine habitats in the southern Middle Atlantic Bight during spring through autumn. Adults on Georges Bank also show seasonal movements to deeper waters from late autumn through spring similar to juveniles. Adults in the Gulf of Maine use nearshore waters during the spring and autumn. The spring aggregation of adult windowpane in Nantucket Sound and on Nantucket Shoals is evident in the Massachusetts trawl survey (Figure 8). This aggregation suggests spawning or feeding activities; however, there is no supporting information on the densities of eggs, larvae, or prey organisms.

STATUS OF THE STOCKS

The NEFSC autumn bottom trawl survey has been used to estimate the relative abundance and biomass of windowpane (Hendrickson 1998). The abundance index for the Gulf of Maine-Georges Bank region generally increased from the mid-1960s to a peak in 1984 and then declined (Figure 16). The abundance index for the southern New England-Middle Atlantic Bight region declined sharply from 1963 to 1975 and has remained relatively low since then (Figure 16).

The windowpane is managed by the New England Fishery Management Council under the Multispecies Fishery Management Plan (NEFMC 1993). This plan defines overfishing for windowpane when the 3-year moving average of the autumn stock abundance index falls below the lowest quartile of the time series. Accordingly, windowpane stock in the Gulf of Maine-Georges Bank is considered to be fully exploited (Hendrickson 1998) while southern New England-Middle Atlantic Bight stock is overfished (National Marine Fisheries Service 1997; Hendrickson 1998).

The distributions of windowpane were compared between a period of high abundance (1984-1988) and a period of low abundance (1992-1996) based on the autumn Northeast Fisheries Science Center bottom trawl survey (Figure 17). The spatial extent of adults and juveniles was similar between the two periods.

RESEARCH NEEDS

- Studies to determine if the windowpane population is a unit stock or multiple stocks (e.g., genetics, otolith, cohort analysis).
- Windowpane spawning times and locations, and spawning habitat requirements (e.g., high salinity).
- Studies (tagging, more efficient gear to catch younger fish) to determine seasonal use of estuaries (residency during colder months) and nearshore waters.
- Habitat requirements for windowpane eggs, larvae, and juveniles.
- Growth rate studies.

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Table 1. Summary of the distribution and abundance of windowpane in North Atlantic and Mid-Atlantic estuaries based on Jury *et al.* (1994) and Stone *et al.* (1994).

Estuary	**Adults**			**Spawning Adults**			**Juveniles**			**Larvae**			**Eggs**		
	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
Passamaquoddy Bay		**c**	**c**		**c**	**c**		**c**	**c**		**c**	**c**		**c**	**c**
Englishman/Machias Bays		c	c		c	c		c	c		c	c		c	c
Narragaugus Bay		c	c		c	c		c	c		c	c		c	c
Blue Hill Bay		c	c		c	c		c	c		c	c		c	c
Penobscot Bay		**c**	**a**		**c**	**a**		**c**	**a**		**c**	**a**		**c**	**a**
Muscongus Bay		c	c		c	c		**c**	**c**		c	c		c	c
Damariscotta Bay		**c**	**c**		**c**	**c**		**c**	**c**		**c**	**c**		**c**	**c**
Sheepscot Bay		**c**	**c**		**c**	**c**		**c**	**c**		**c**	**c**		**c**	**c**
Kennebec/Androscoggin Rivers		**c**	**c**		c	c		**c**	**c**		c	c		c	c
Casco Bay		c	c		c	c		c	c		c	c		c	c
Saco Bay		c	c		c	c		c	c		c	c		c	c
Wells Harbor	nz	c	c	nz	c	c	nz	c	c	nz	c	c	nz	c	c
Great Bay		**r**	**c**		**r**	**c**		**r**	**c**		**r**	**c**		**r**	**c**
Merrimack River		r	nz		r	nz		r	nz		r	nz		r	nz
Massachusetts Bay	**nz**	**nz**	**c**	**nz**	**nz**	**c**	**nz**	**nz**	**c**	**nz**	**nz**	**c**	**nz**	**nz**	**c**
Boston Harbor	nz	c	c	nz	c	c	**nz**	**c**	**c**	nz	c	c	nz	c	c
Cape Cod Bay	**nz**	**a**	**a**	**nz**	**c**	**c**	**nz**	**a**	**a**	**nz**	**c**	**c**	**nz**	**c**	**c**
Waquoit Bay	nz	c	c	nz	c	c	nz	c	c	nz	c	c	nz	c	c
Buzzards Bay	nz	a	a	nz	c	c	nz	a	a	nz	c	c	nz	c	c
Narragansett Bay	r	a	a		c	c	r	a	a		**c**	**c**		c	c
Long Island Sound	r	h	h		**h**	**h**	r	h	h		**c**	**c**		**h**	**h**
Connecticut River		h	nz		h	nz		h	nz		c	nz		h	nz
Gardiners Bay	nz	c	c	**nz**	**c**	**c**	nz	c	c	**nz**	**c**	**c**	**nz**	**c**	**c**
Great South Bay	nz	a	a	**nz**	**a**	**a**	nz	a	a	**nz**	**c**	**c**	**nz**	**a**	**a**
Hudson River/Raritan Bay	r	c	c		r	c	r	c	c	r	c	c	r	r	c
Barnegat Bay		**h**	**h**		**h**	**h**		**h**	**h**		**h**	**h**		**h**	**h**
New Jersey Inland Bays		**h**	**h**		**h**	**h**		**h**	**h**		**h**	**h**		**h**	**h**
Delaware Bay		a	a					**a**	**a**						
Delaware Inland Bays	**nz**	**c**	**c**	nz	c	c	**nz**	**c**	**c**	nz	c	c	nz	c	c
Chincoteague Bay	**nz**	**nz**	**c**	**nz**	**nz**		**nz**	**nz**	**c**	**nz**	**nz**		**nz**	**nz**	
Chesapeake Bay mainstream		**c**	**c**					**c**	**c**			**r**			
Chester River			**nz**			**nz**			**nz**			**nz**			**nz**
Choptank River			**nz**			**nz**			**nz**			**nz**			**nz**
Patuxent River			**nz**			**nz**			**nz**			**nz**			**nz**
Potomac River			**nz**			**nz**			**nz**			**nz**			**nz**
Tangier/Pocomoke Sounds	**nz**	**c**	**nz**	**nz**		**nz**	**nz**	**c**	**nz**	**nz**		**nz**	**nz**		**nz**
Rappahannock River			**nz**			**nz**			**nz**			**nz**			**nz**
York River			**nz**			**nz**		**r**	**nz**			**nz**			**nz**
James River		**r**	**nz**			**nz**		**r**	**nz**			**nz**			**nz**

Relative Abundance
h = highly abundant, a = abundant, c = common, r = rare, blank = not present, n = no data presented, * = no data available, nz = particular zone not present

Data Reliability for Life Stages
Highly Certain = Bold and Underlined Text
Moderately Certain = Bold Text
Reasonable Inference = Normal Text

Tidal Zones
T = Tidal Fresh 0.0-0.5 ppt
M= Mixing Zone 0.5-25 ppt
S = Seawater Zone > 25 ppt

Table 2. Summary of life history and habitat parameters for windowpane.

Life Stage	Size and Growth	Geographic Location	Time of Year	Habitat	Substrate	Temperature, Salinity and DO	Prey/Predators
Eggs [1]	0.9-1.4 mm	Middle Atlantic Bight Georges Bank	Feb-July Sept-Nov May-Oct	Planktonic; less than 70 m	Not applicable	**Water column temp:** 6-14°C spring 10-16°C summer 14-20°C autumn	Eaten by adults of own and other species.
Larvae [2]	2-10 mm	Middle Atlantic Bight Georges Bank	Feb-July Sept-Nov May-Oct	Planktonic; less than 70 m	Not applicable	**Water column temp:** 3-14°C spring 10-17°C summer 13-19°C autumn	Prey on copepods and other zooplankton. Eaten by adults of own and other species.
Juveniles [3]	< 22 cm TL	Gulf of Maine Georges Bank Middle Atlantic Bight	June-Oct June-Oct May-July Oct-Nov	Nearshore bays and estuaries; less than 50 m Less than 50 m (summer/autumn); less than 75 m (winter/spring) Nearshore bays and estuaries; less than 75 m	Muddy sediment in the Gulf of Maine Fine sandy sediment in Georges Bank Fine sandy sediment in New England & Middle Atlantic Bight	**Bottom temp:** Offshore: 4-7°C in spring; 14-16°C in autumn Inshore off MA: 5-12°C in spring 1 2-19°C in autumn Hudson-Raritan Bay 0-24°C (15-33 ppt - Salinity) (2-13 mg/l - DO)	Prey on polychaetes and small crustaceans, especially mysids. Eaten by adults of own and other species (spiny dogfish, thorny skate, goosefish, cod).
Adults [4]	≥ 22 cm TL	Gulf of Maine Georges Bank Middle Atlantic Bight	Year-round	Nearshore bays and estuaries; less than 75 m Less than 50 m (summer and autumn); less than 75 m (winter and spring) Nearshore bays and estuaries; less than 75 m	Muddy sediment in the Gulf of Maine Fine sandy sediment on Georges Bank Fine sandy sediment in New England and Middle Atlantic Bight	**Bottom temp:** Offshore: 4-8°C in spring 12-18°C in autumn Inshore off MA 9-13°C in spring 9-19°C in autumn Hudson-Raritan Bay 0-24°C (15-33 ppt - Salinity) (2-13 mg/l - DO)	Prey on polychaetes, small crustaceans (mysids, decapod shrimp) various small fishes (hakes, tomcod). Eaten by adults of various fishes (spiny dogfish, thorny skate, goosefish, cod).

[1] Colton and St. Onge (1974), Smith *et al.* (1975), Colton *et al.* (1979), Morse *et al.* (1987), Berrien and Sibunka (1999)
[2] Moore (1947), Colton and Marak (1969), Morse and Able (1995)
[3] Moore (1947), Thorpe (1991), Morse and Able (1995), Wilk *et al.* (1996), Able and Fahay (1998), Klein-MacPhee (in prep.)
[4] Colvocoresses and Musick (1984), Morse and Able (1995), Wilk *et al.* (1996), Able and Fahay (1998), Gottschall *et al.* (in review), Klein-MacPhee (in prep.)

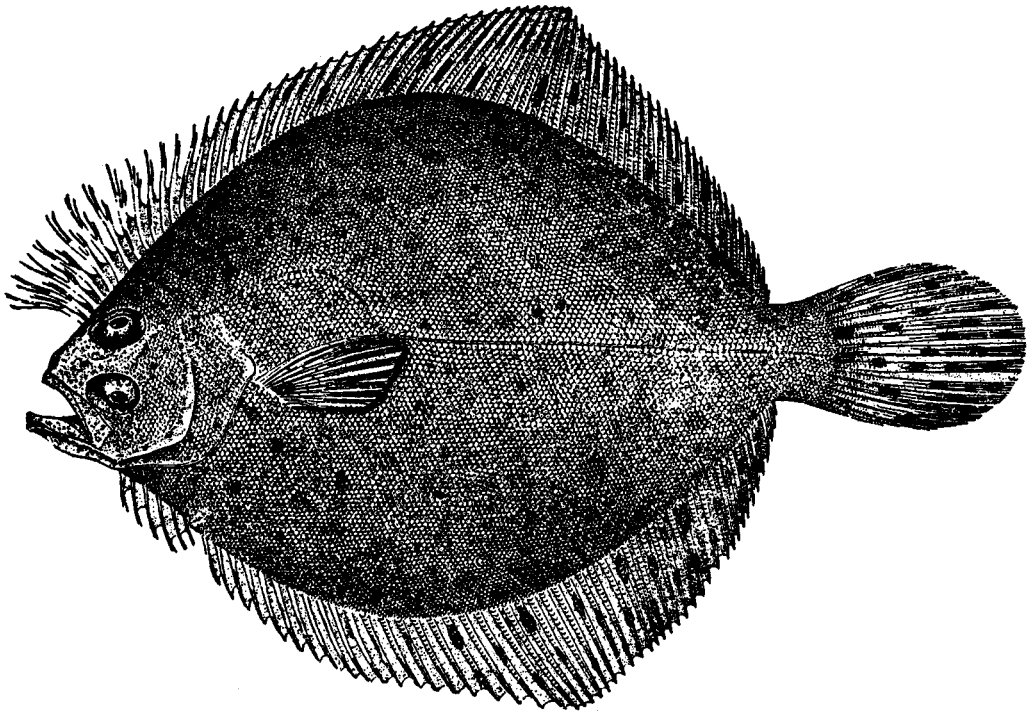

Figure 1. The windowpane, *Scophthalmus aquosus* (from Bigelow and Schroeder 1953).

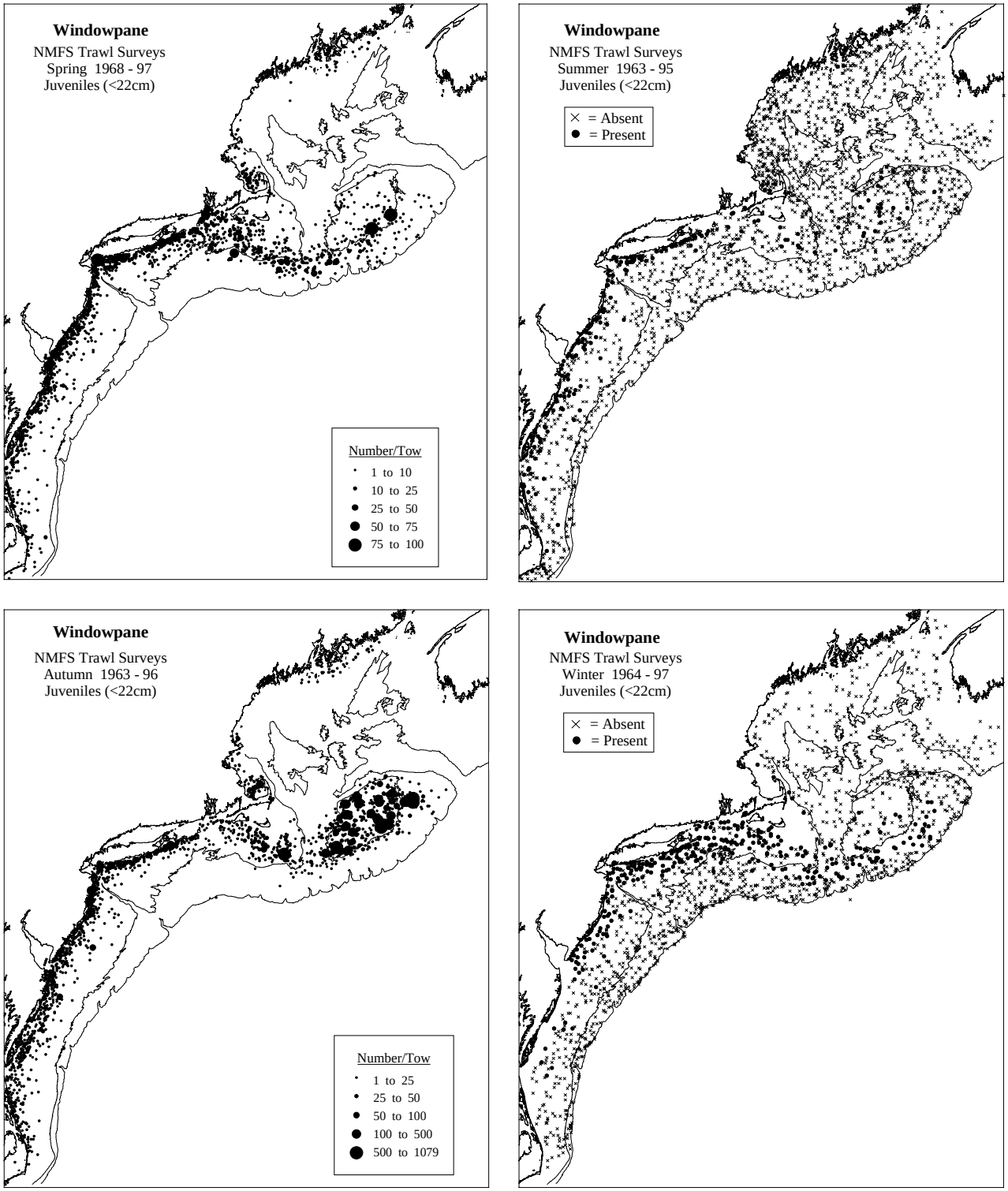

Figure 2. Distribution and relative abundance of juvenile windowpane (< 22 cm) from NEFSC bottom trawl surveys, spring (1968-1997), summer (1963-1995), autumn (1963-1996), and winter (1964-1997). Densities are represented by dot size in spring and fall plots, while only presence and absence are represented in winter and summer plots [see Reid *et al.* (1999) for details].

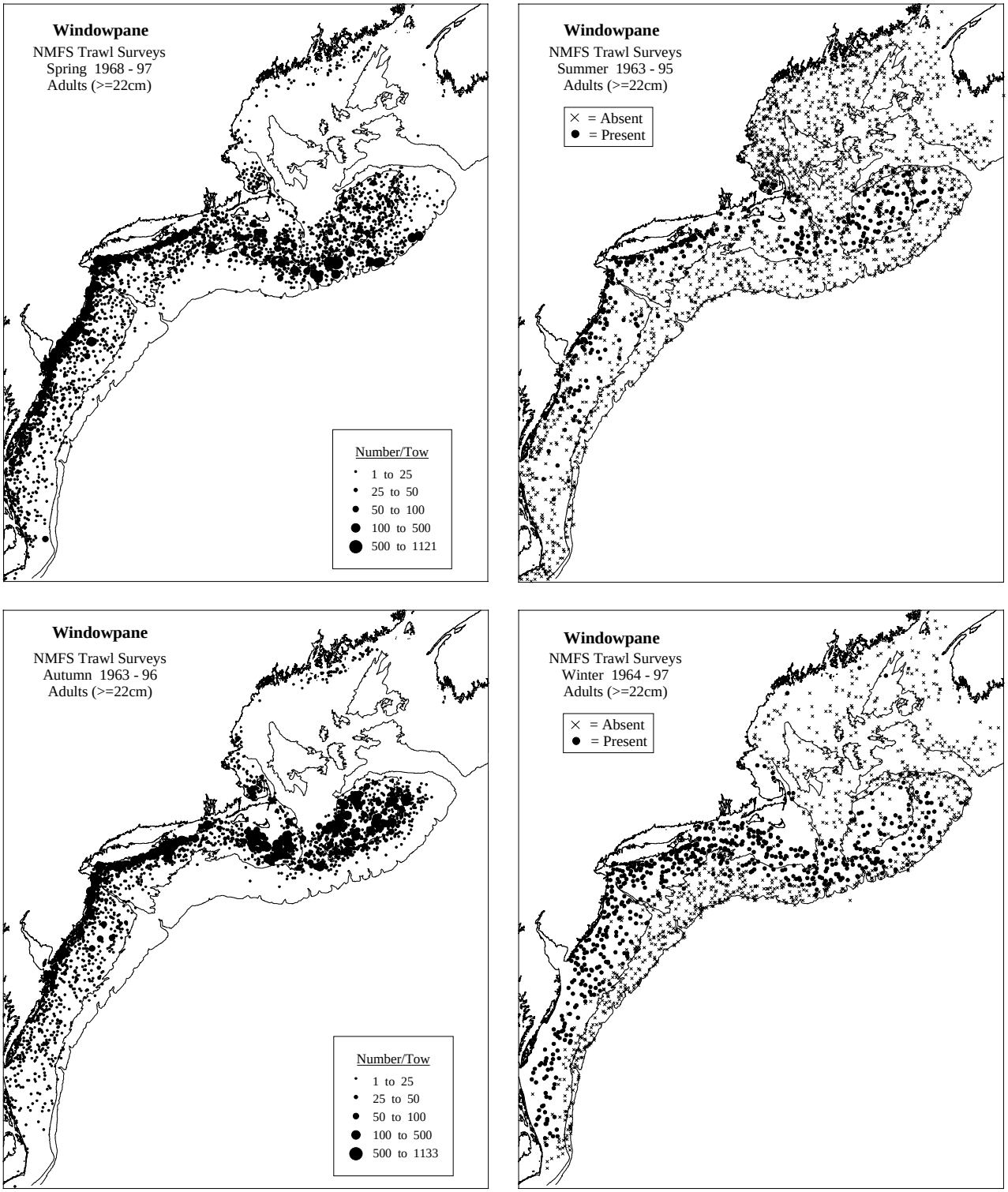

Figure 3. Distribution and relative abundance of adult windowpane (≥ 22 cm) from NEFSC bottom trawl surveys, spring (1968-1997), summer (1963-1995), autumn (1963-1996), and winter (1964-1997). Densities are represented by dot size in spring and fall plots, while only presence and absence are represented in winter and summer plots [see Reid *et al.* (1999) for details].

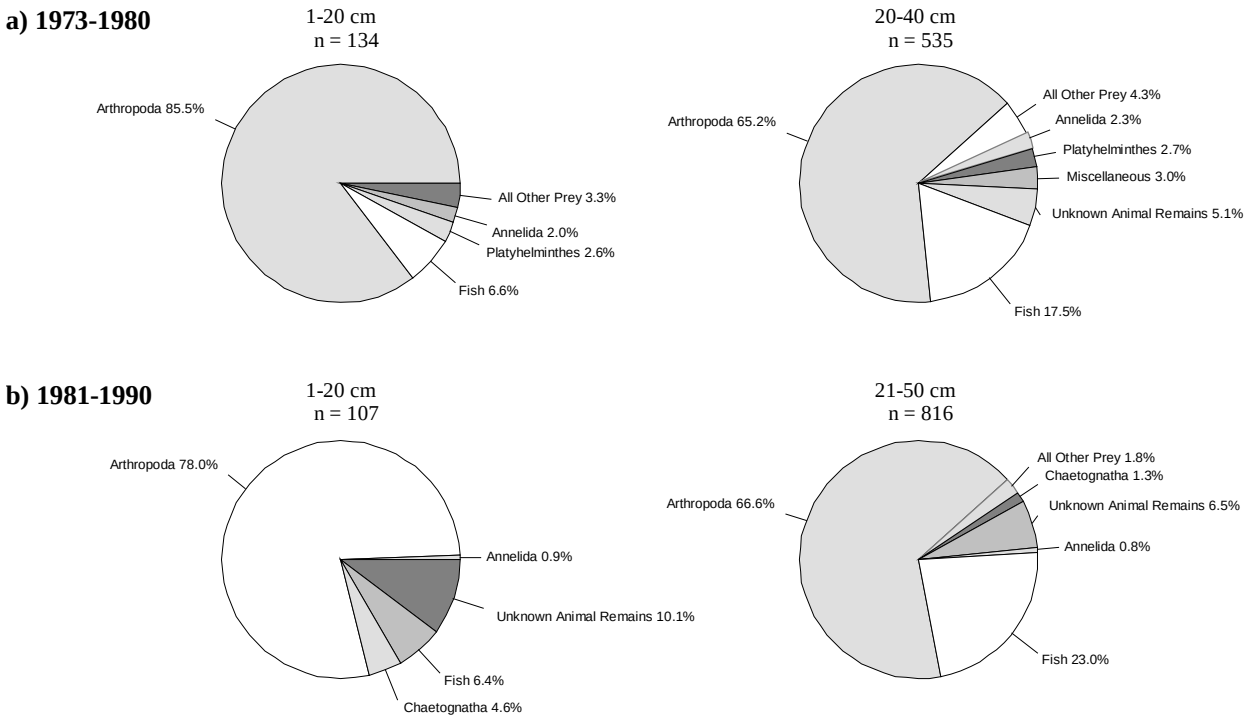

Figure 4. Abundance (percent occurrence) of the major types of prey identified in the stomachs of juvenile and adult windowpane collected during NEFSC bottom trawl surveys during 1973-1980 and 1981-1990. Note that the use of 20 cm as the segregation size between juvenile and adults differs from the actual size generally used (22 cm); this is an artifact of the diet database that summarizes results in 10 cm length intervals. The category “animal remains” refers to unidentifiable animal matter. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details].

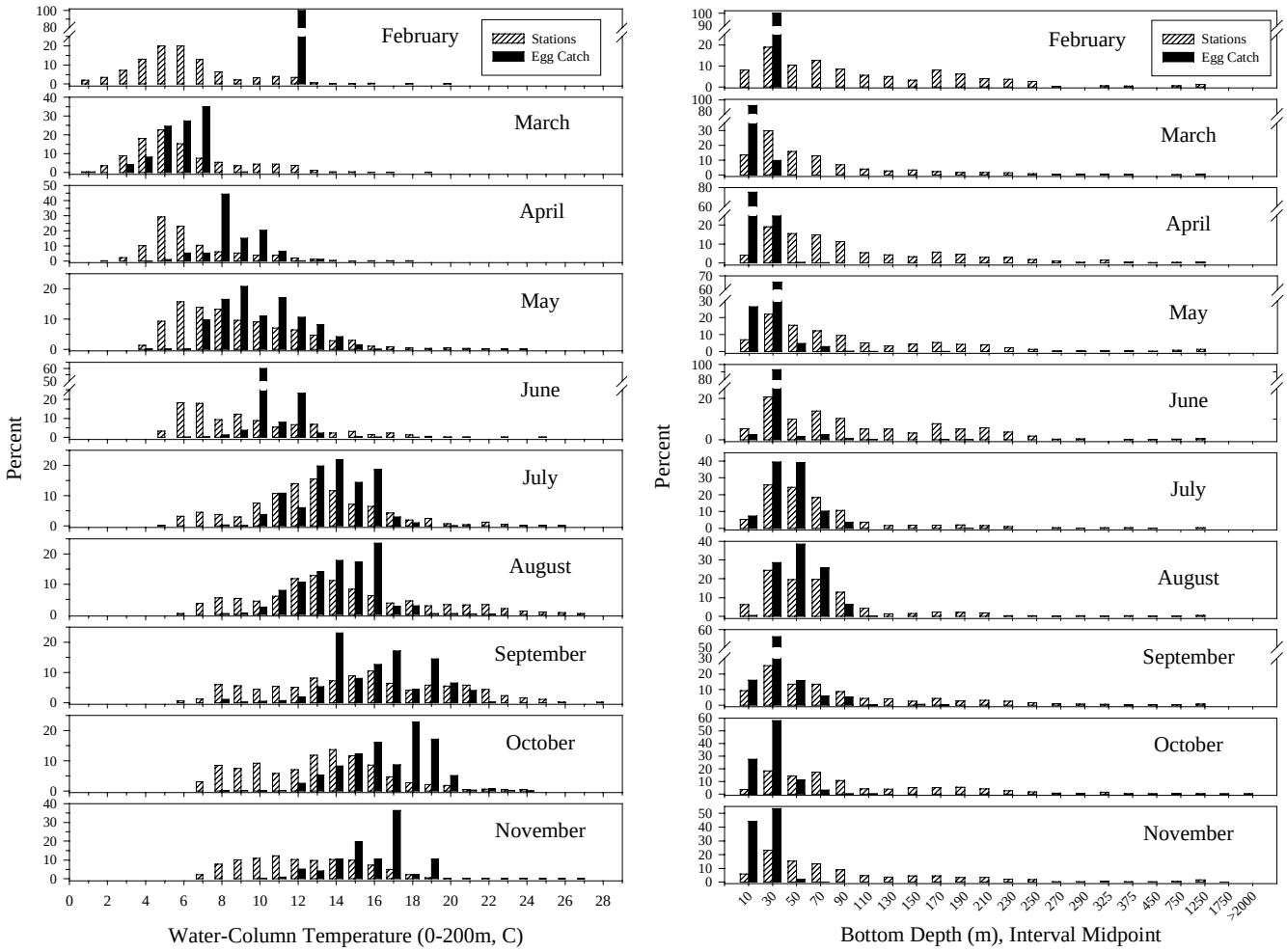

Figure 5. Percentage of windowpane eggs in relation to water column temperature (0-200 m, ^{o}C) and bottom depth (m) from NEFSC MARMAP ichthyoplankton surveys, February to November, 1978-1987 (all years combined). Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

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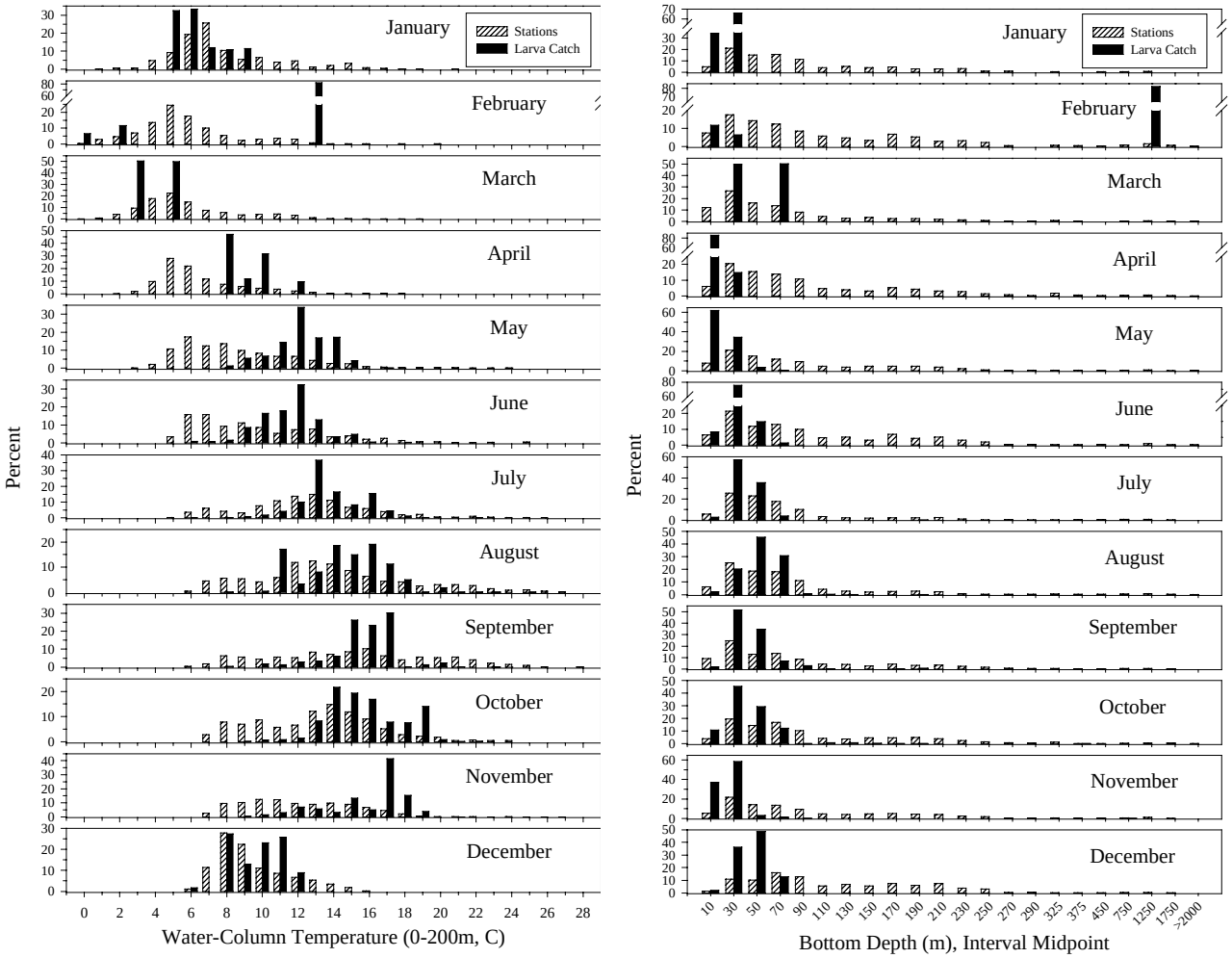


Figure 6. Percentage of windowpane larvae in relation to water column temperature (0-200 m, ^{o}C) and bottom depth (m) from NEFSC MARMAP ichthyoplankton surveys, January to December, 1977-1987 (all years combined). Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

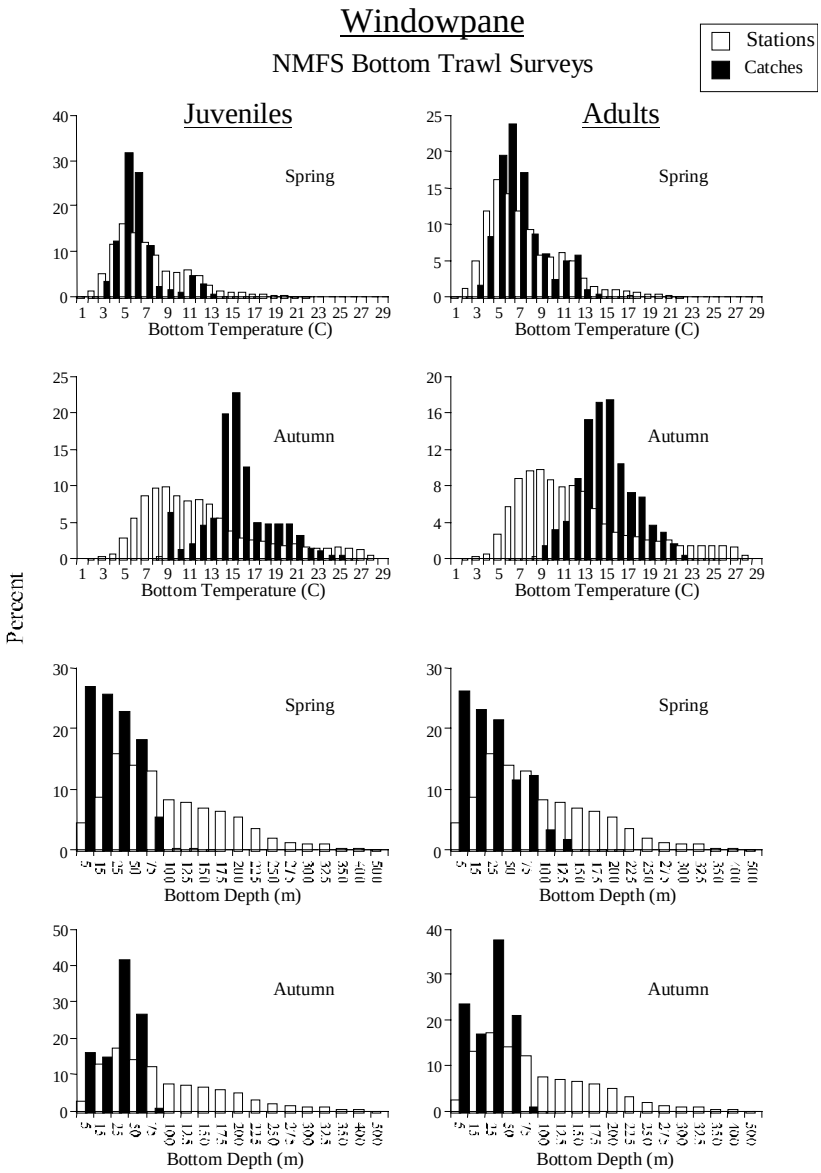


Figure 7. Percentage of juvenile and adult windowpane in relation to bottom water temperature and depth, based on spring (1968-1997) and autumn (1963-1996) NEFSC bottom trawl surveys (all years combined). Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

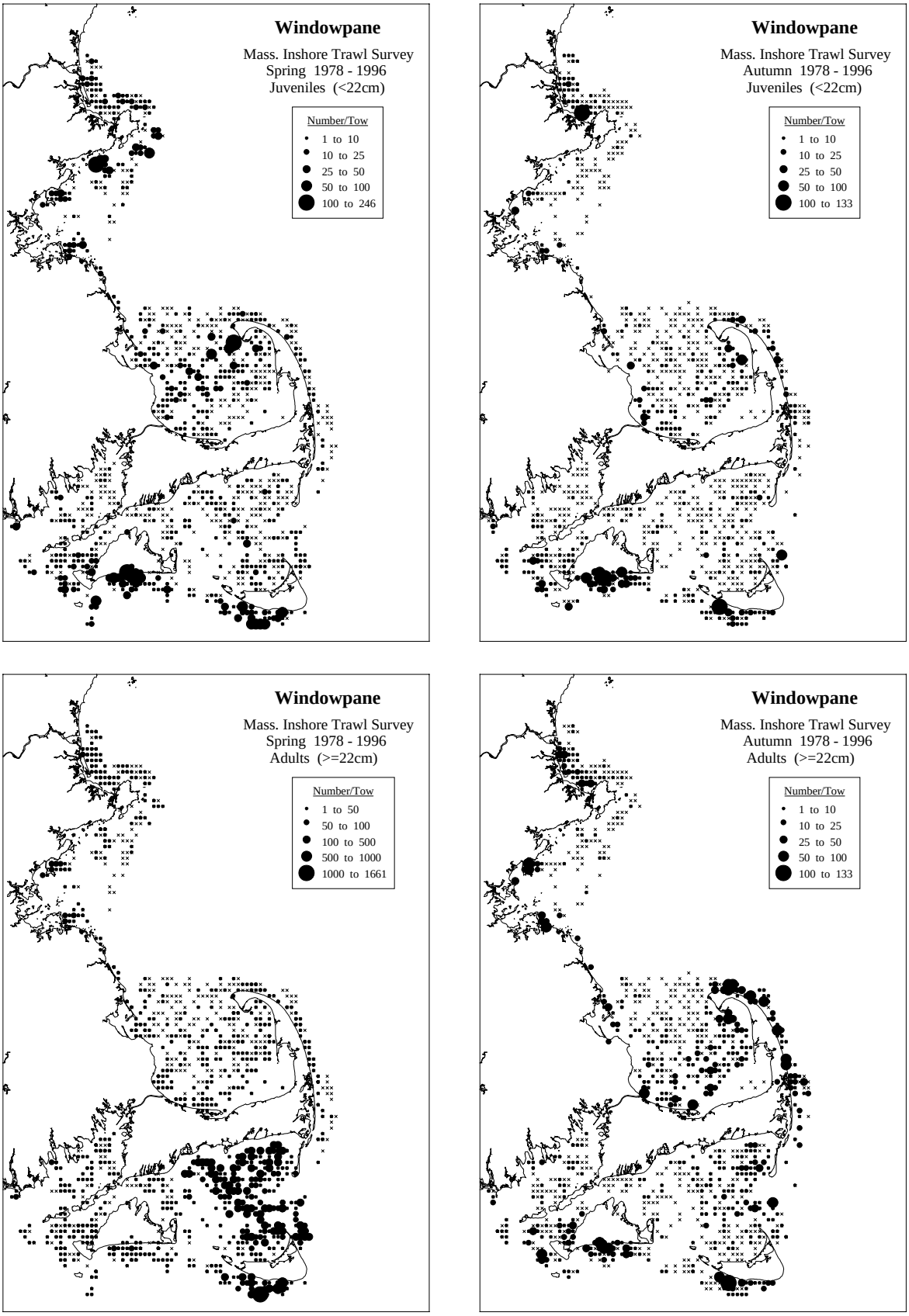


Figure 8. The distribution and relative abundance of juvenile and adult windowpane from Massachusetts inshore trawl surveys, spring and autumn 1978-1996 [see Reid *et al.* (1999) for details].

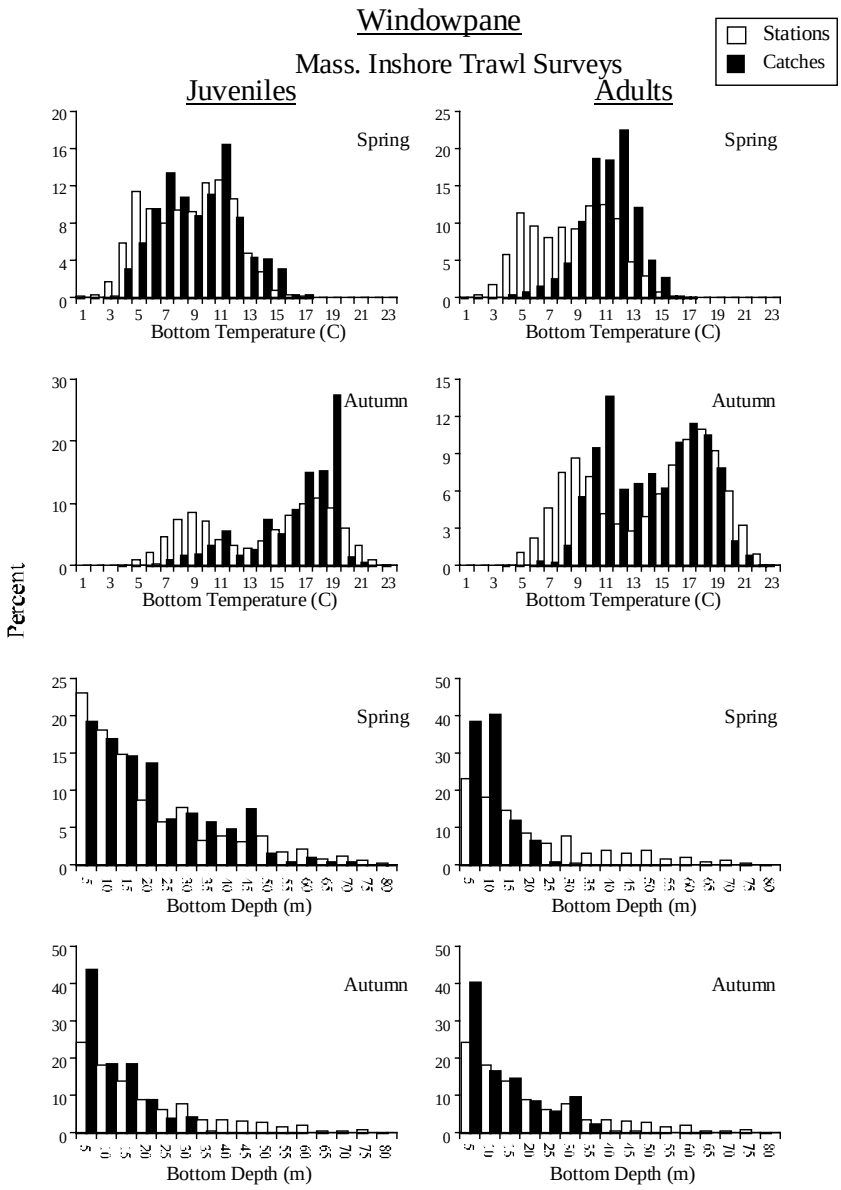


Figure 9. Percentage of juvenile and adult windowpane in relation to bottom water temperature and depth from the spring and autumn Massachusetts inshore bottom trawl surveys (spring and autumn 1978-1996) for all years combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

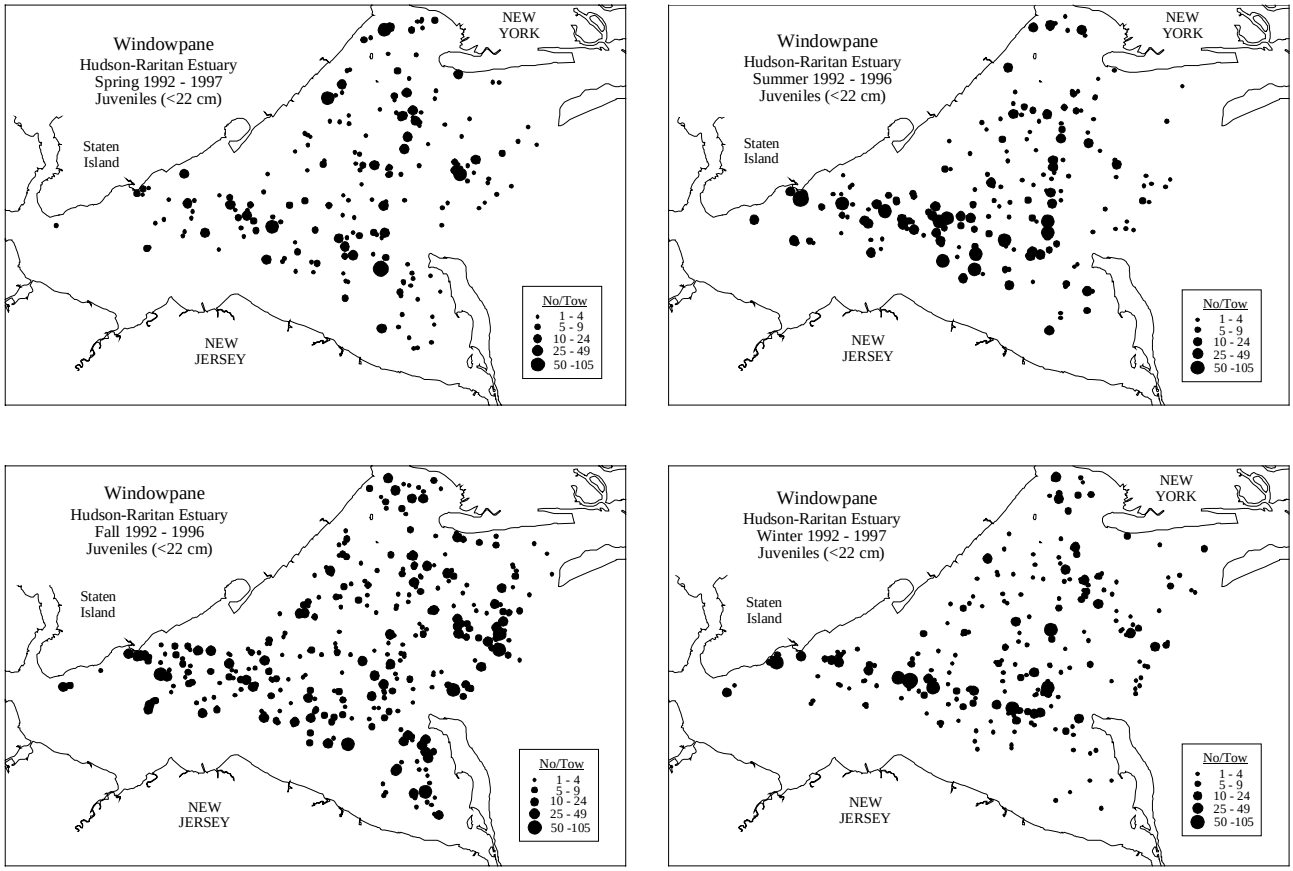
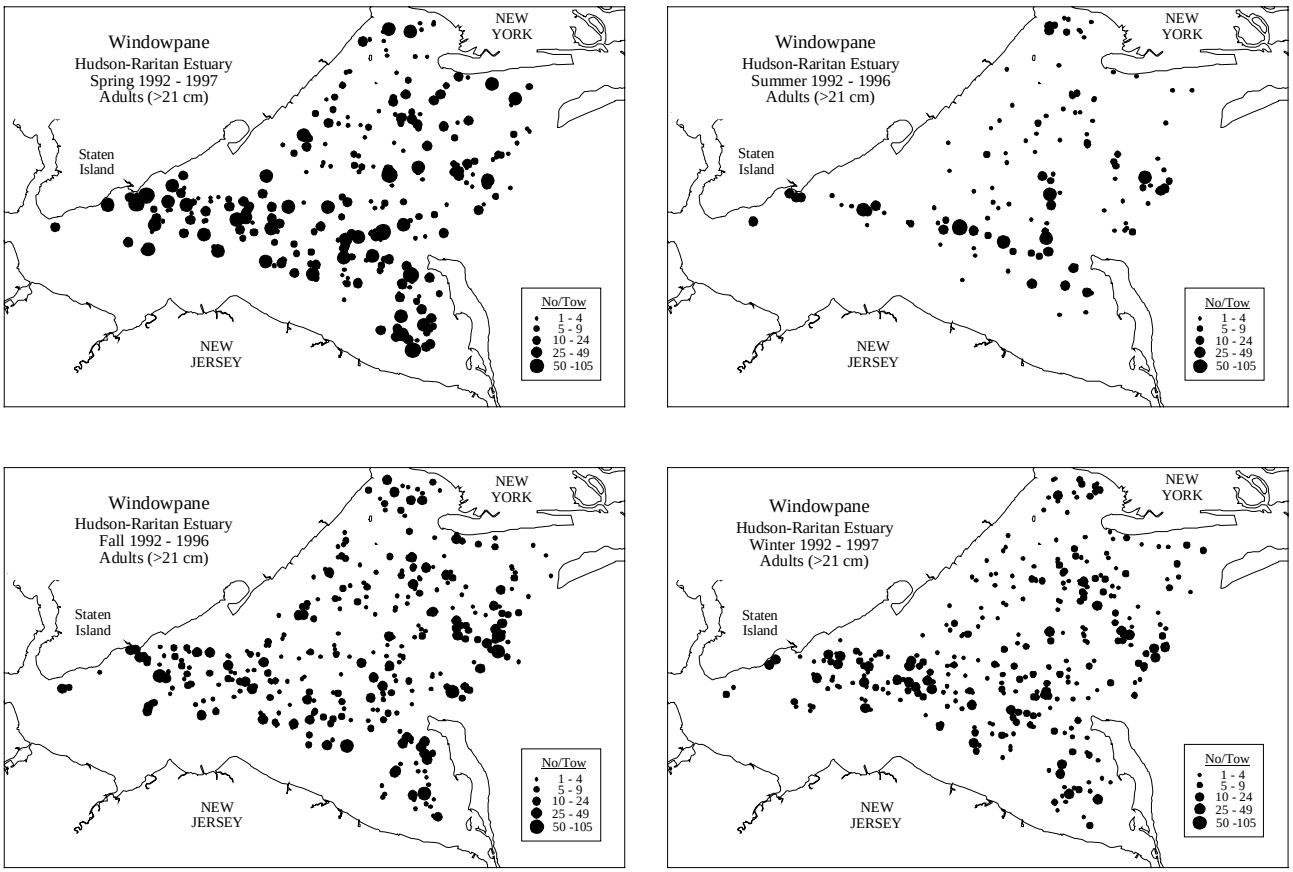


Figure 10. Distribution and relative abundance of juvenile (< 22 cm) and adult (> 21 cm) windowpane collected during spring, summer, autumn and winter in the Hudson-Raritan estuary from January 1992 to June 1997 [see Reid *et al.* (1999) for details].



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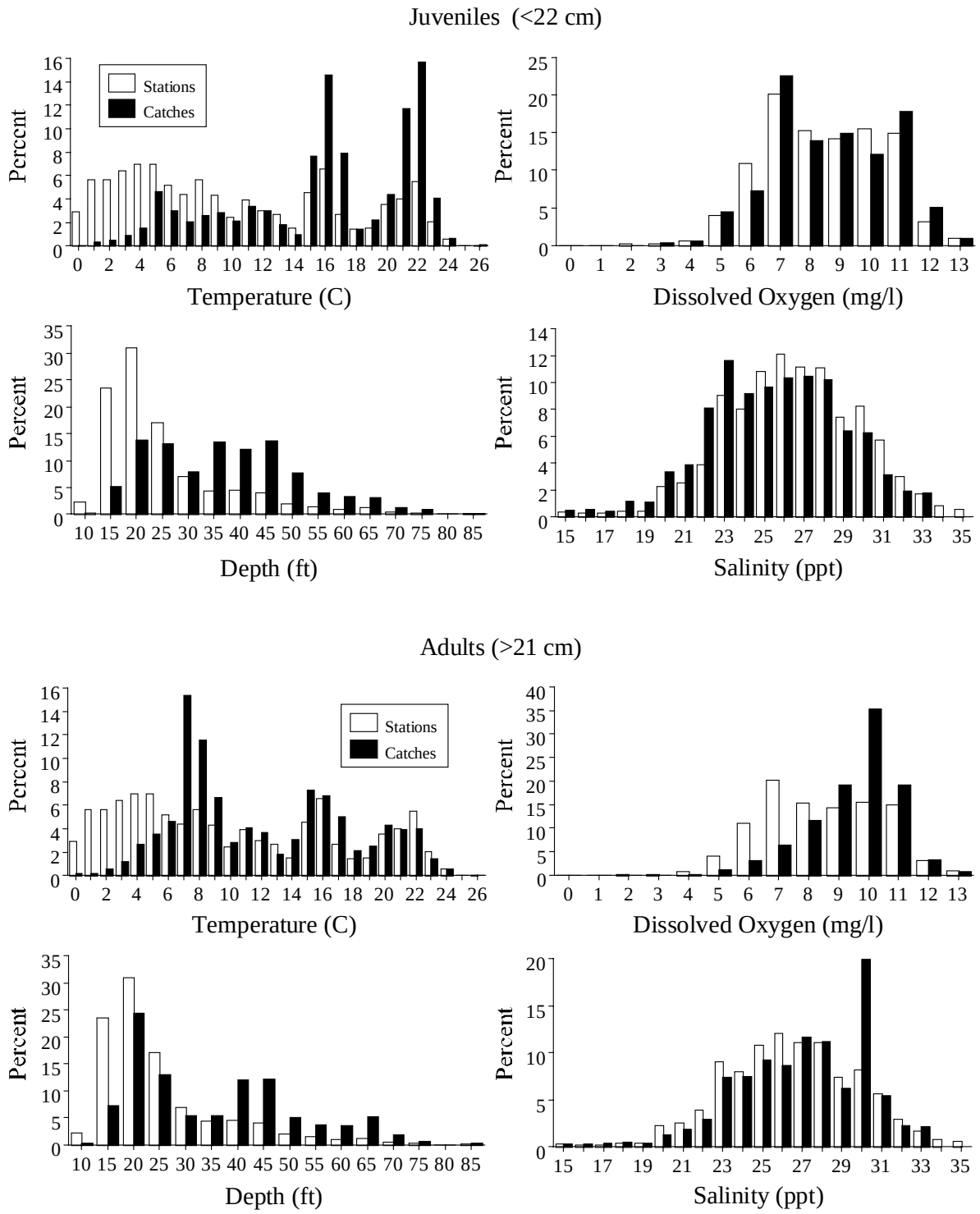


Figure 11. Percent frequency of juvenile and adult windowpane in relation to bottom water temperature, depth, dissolved oxygen, and salinity in the Hudson-Raritan estuary, January 1992 to June 1997 (all years combined).

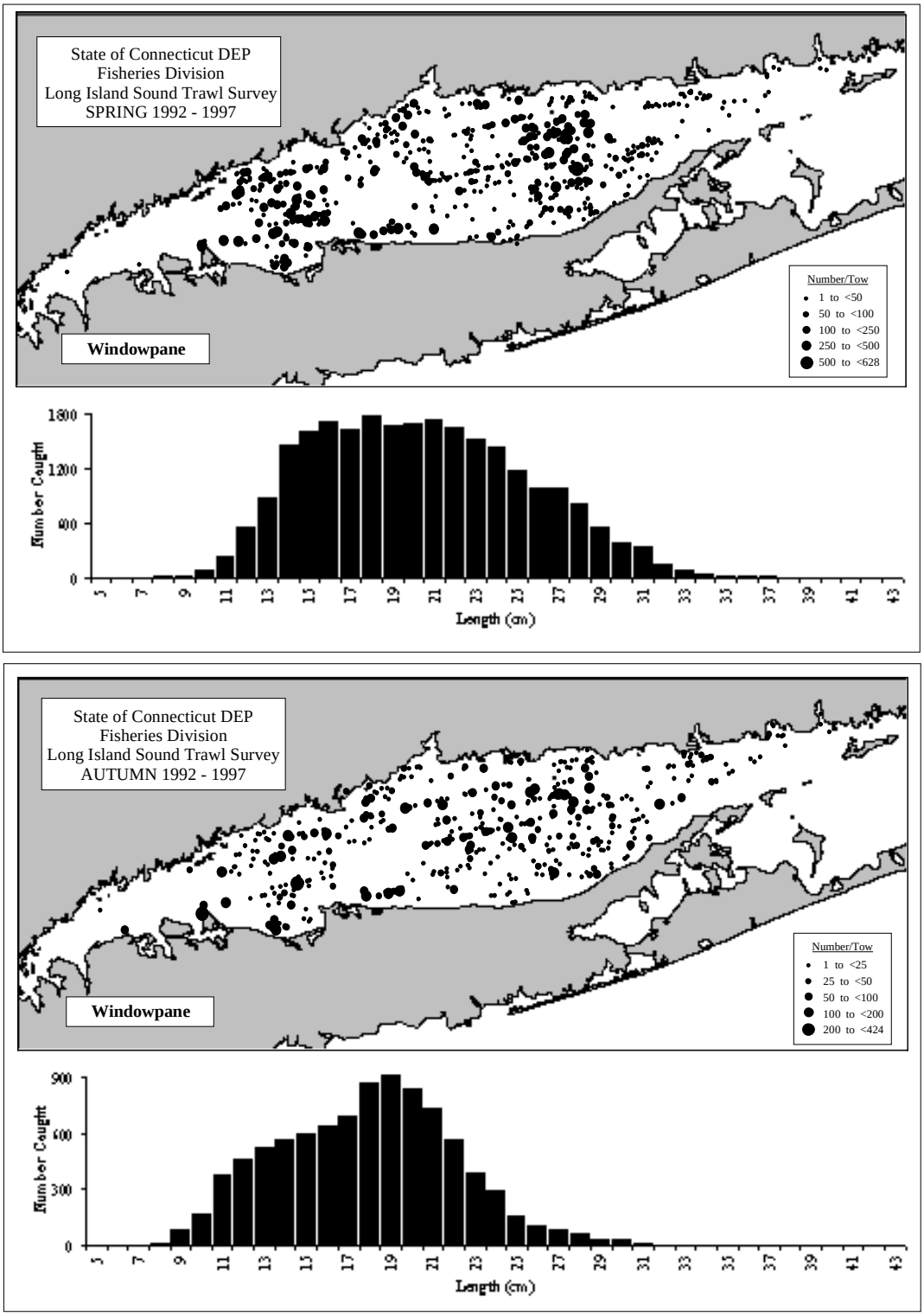


Figure 12. Abundance and length frequency distributions of windowpane in Long Island Sound during spring and autumn, from the Connecticut bottom trawl surveys, 1992-1997 [see Reid *et al.* (1999) for details].

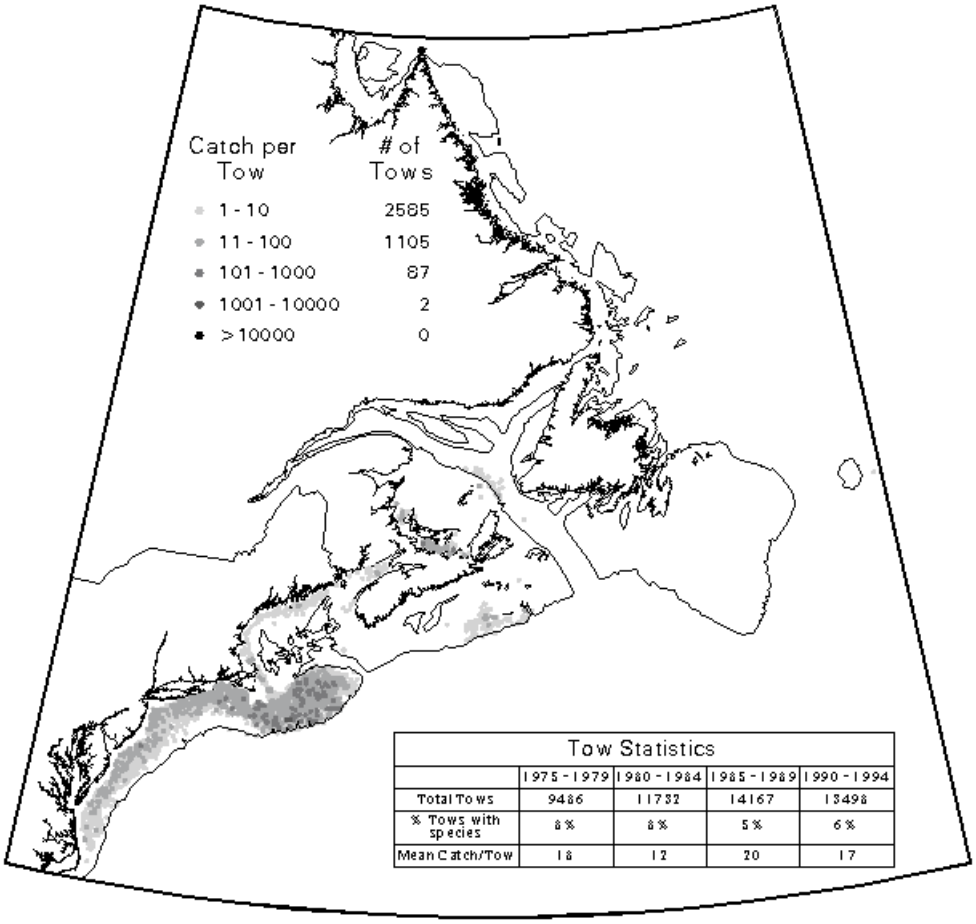


Figure 13. Distribution and abundance of windowpane from Newfoundland to Cape Hatteras during 1975-1994. Data are from the U.S. NOAA/Canada DFO East Coast of North America Strategic Assessment Project (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

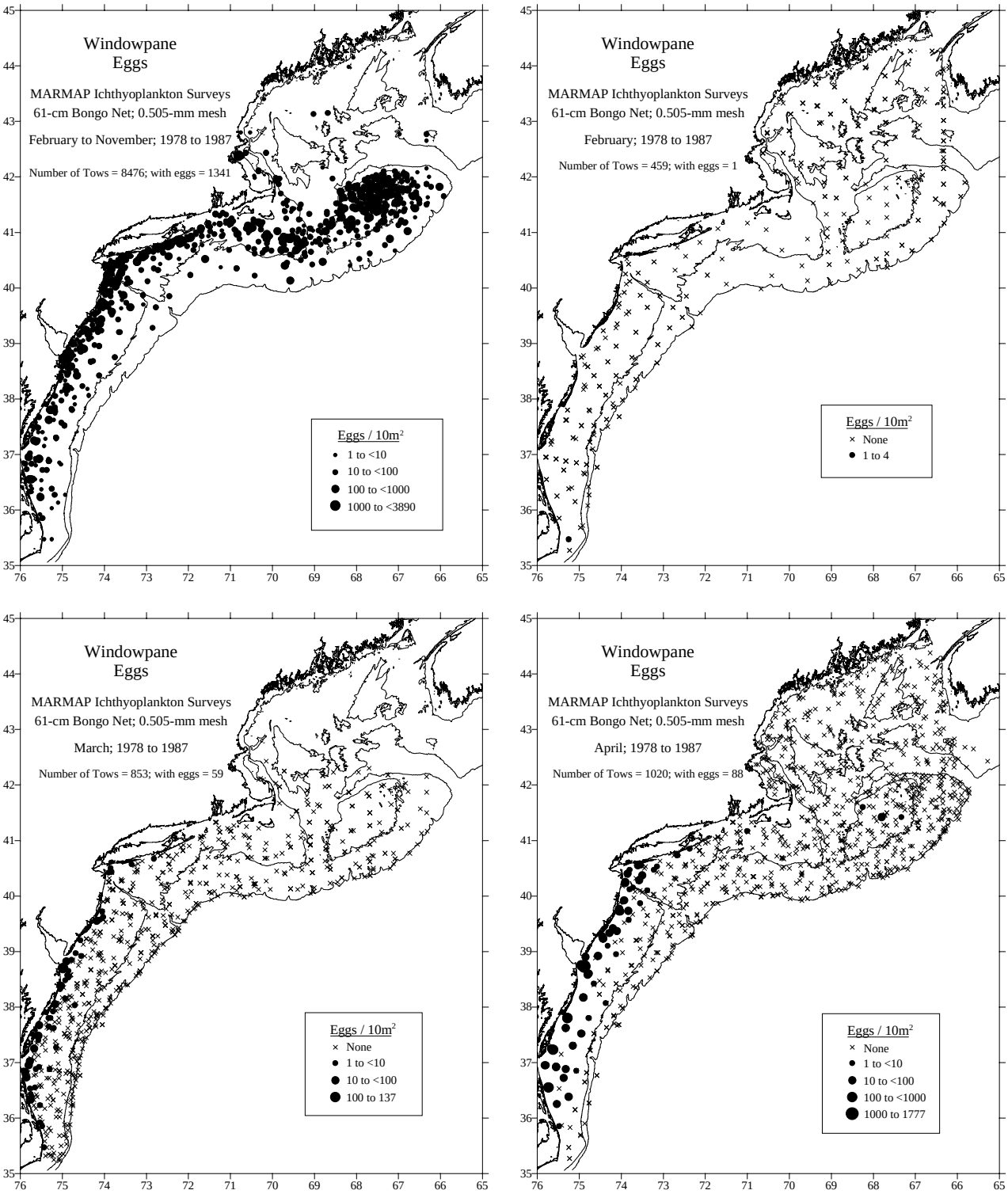
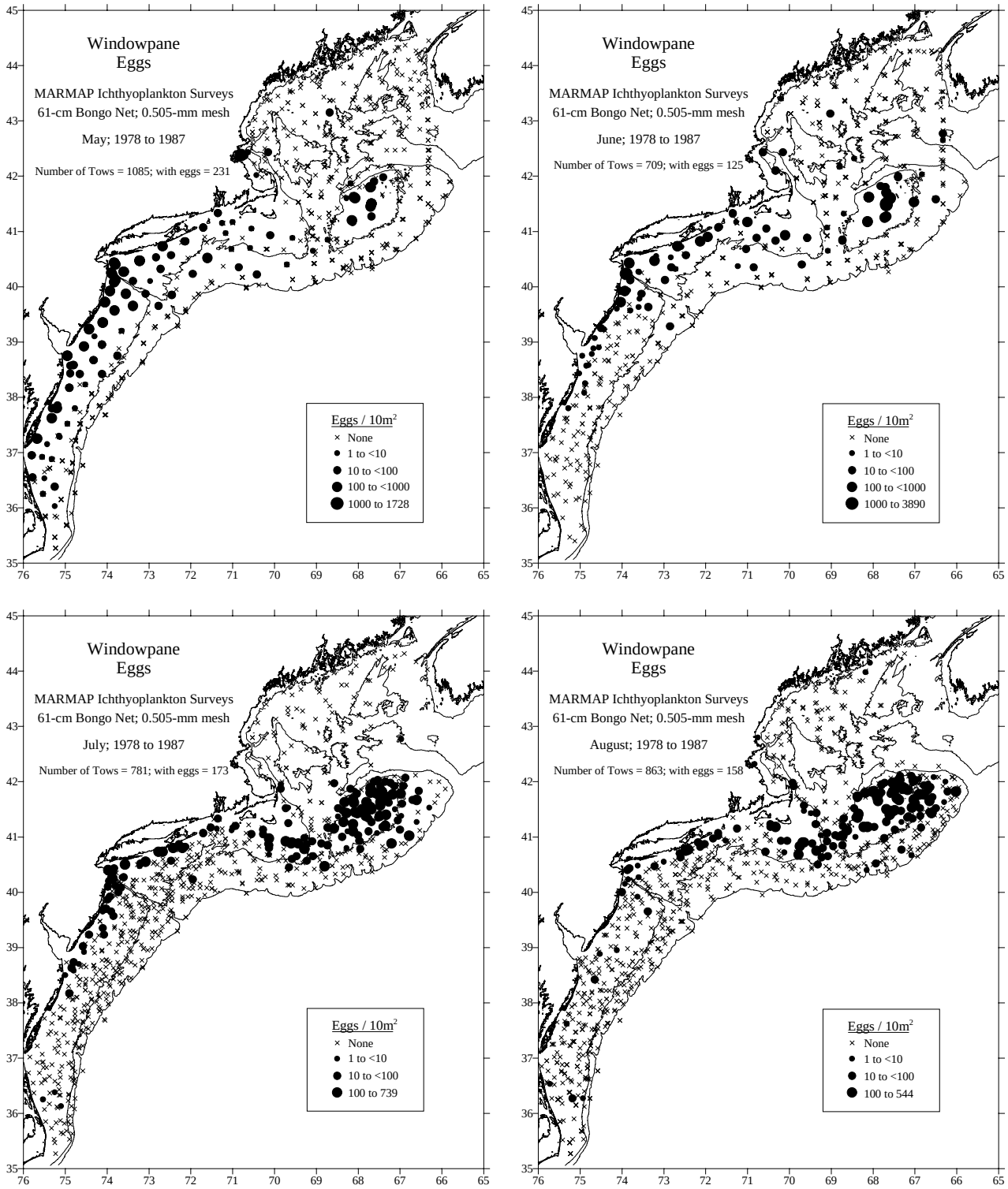


Figure 14. The distribution and abundance of windowpane eggs collected from February to November, 1978-1987 during NEFSC MARMAP ichthyoplankton surveys [see Reid *et al.* (1999) for details].



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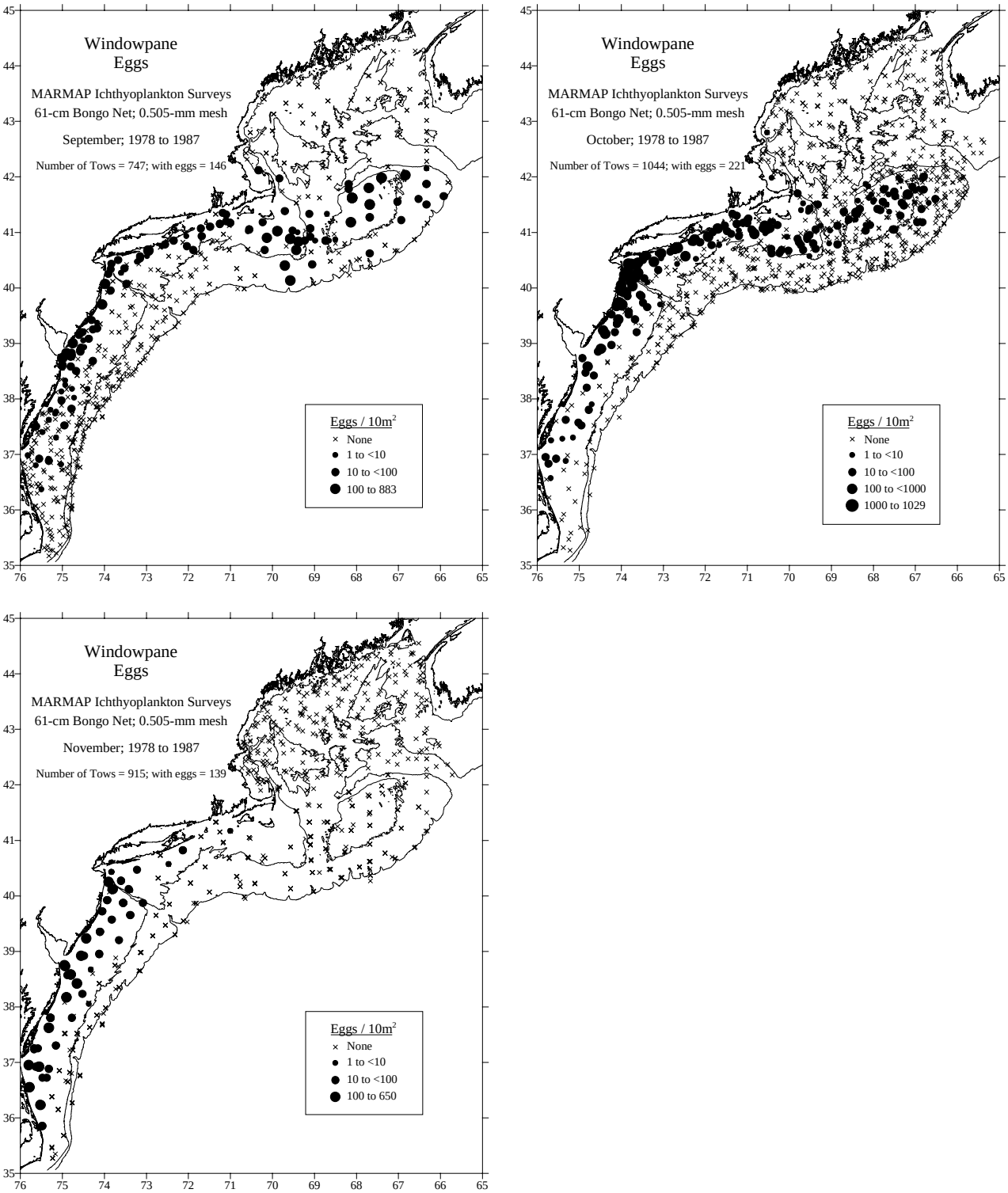

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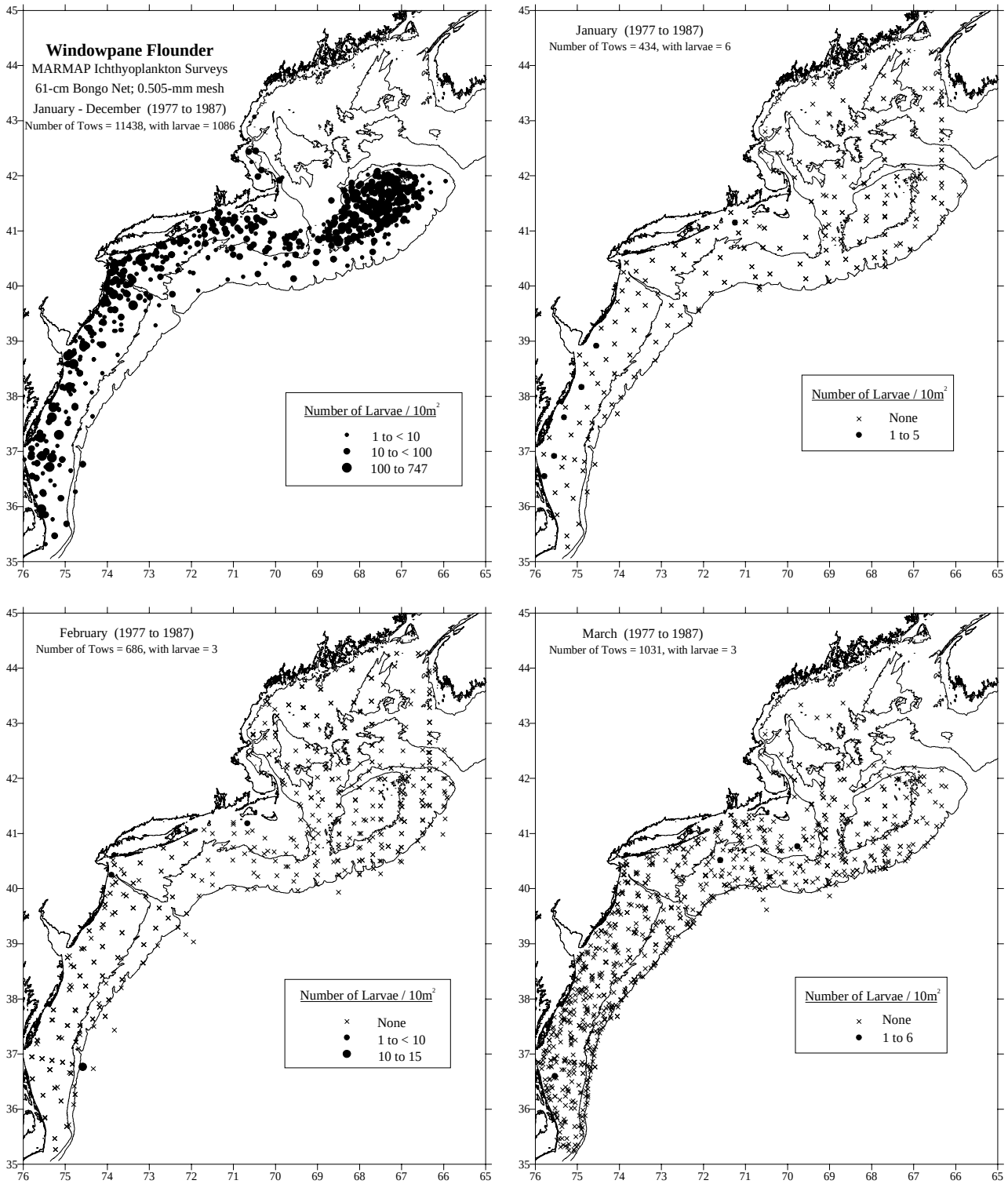
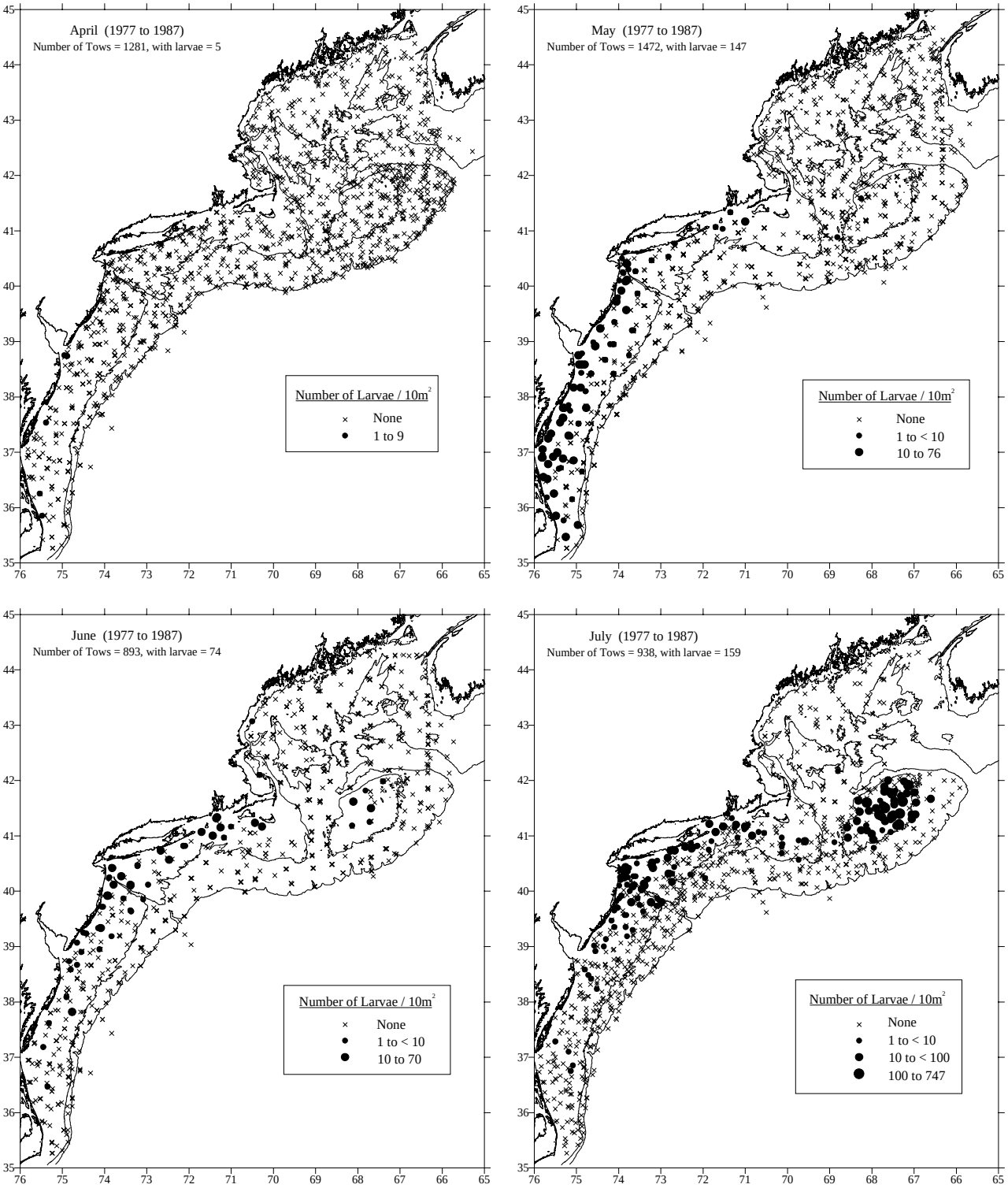


Figure 15. The distribution and abundance of windowpane larvae collected from January to December, 1977-1987 during NEFSC MARMAP ichthyoplankton surveys [see Reid *et al.* (1999) for details].



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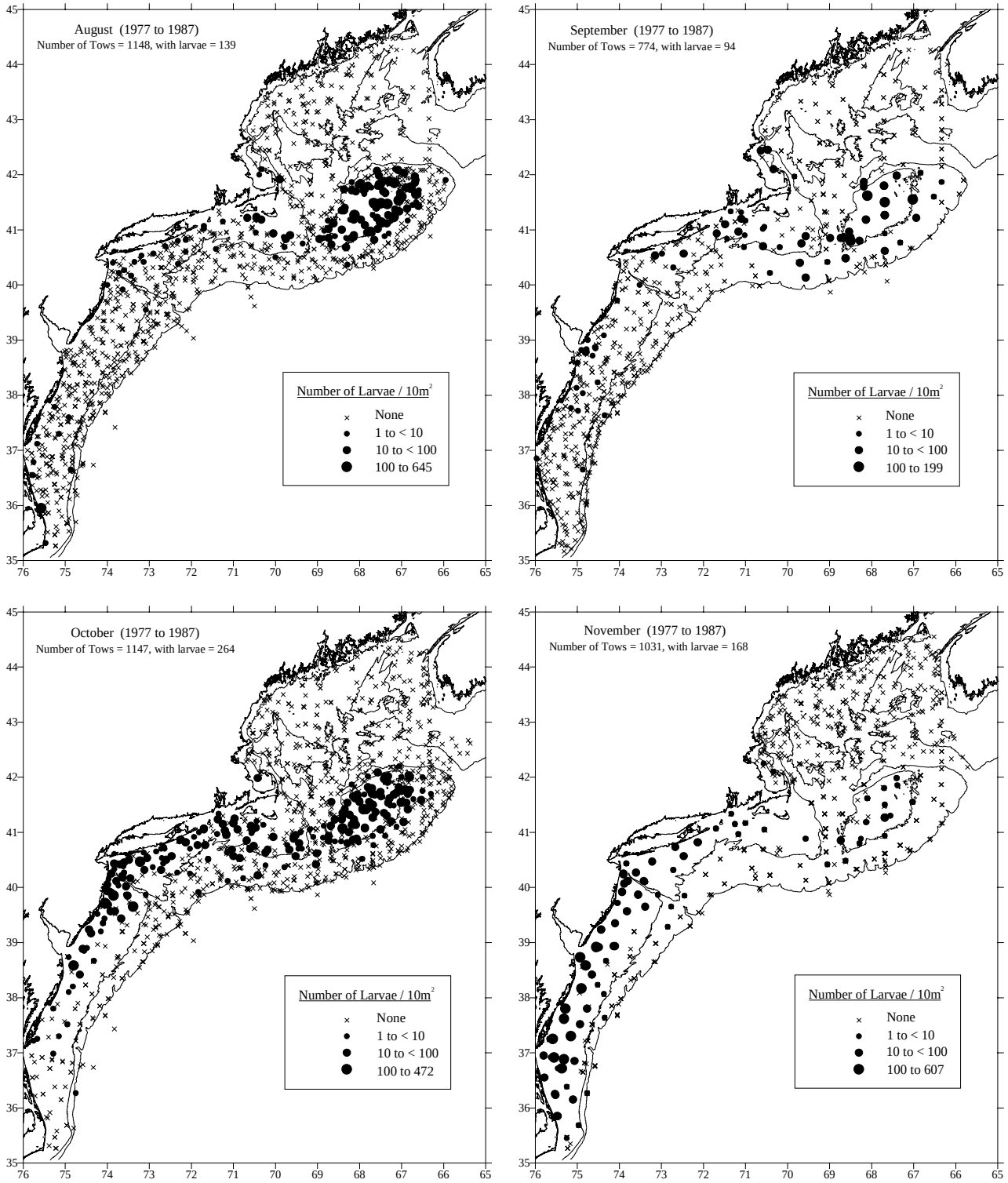

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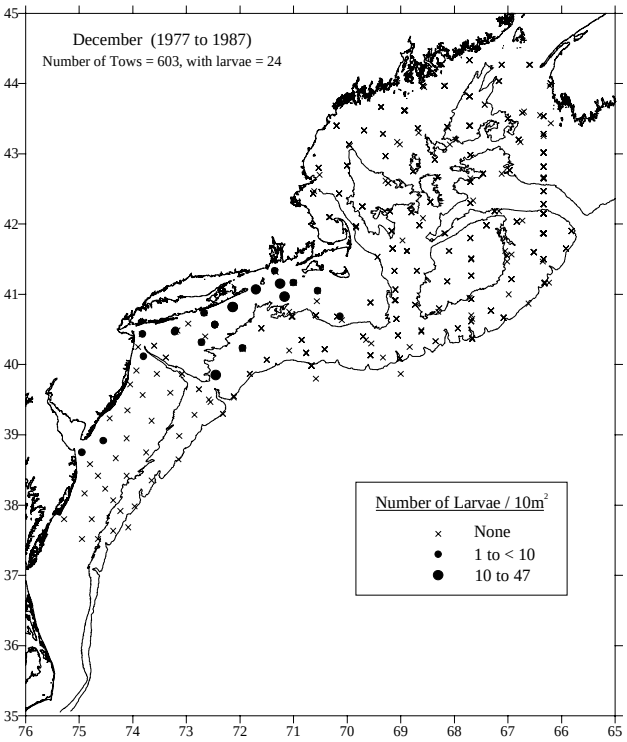

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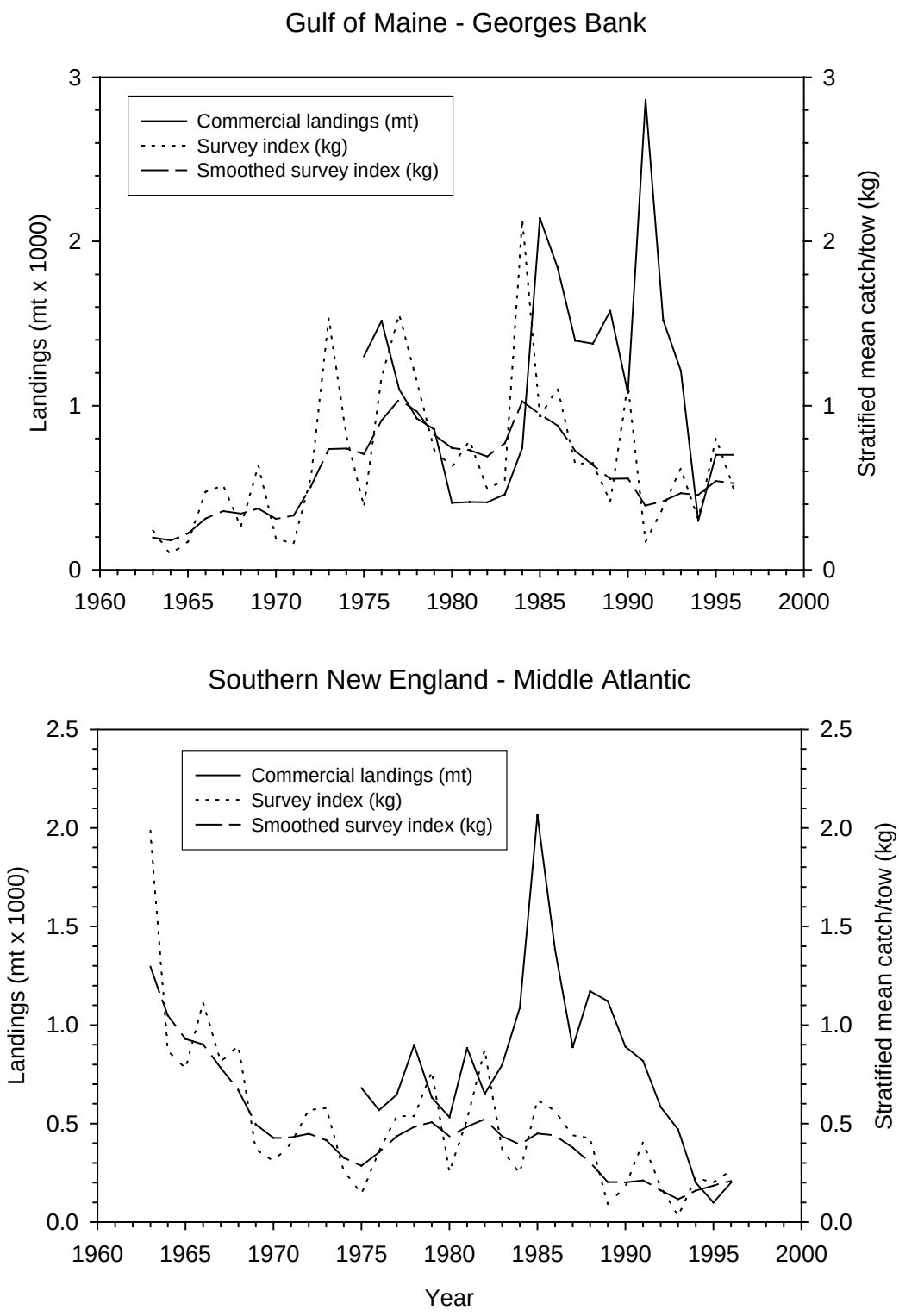

Figure 16. Commercial landings (mt), bottom trawl survey indices (stratified mean catch per tow), and smoothed survey indices (3 year moving average of first order autoregression model to compensate for inter-year variability) for windowpane in the Gulf of Maine-Georges Bank region and the southern New England-Middle Atlantic Bight region.

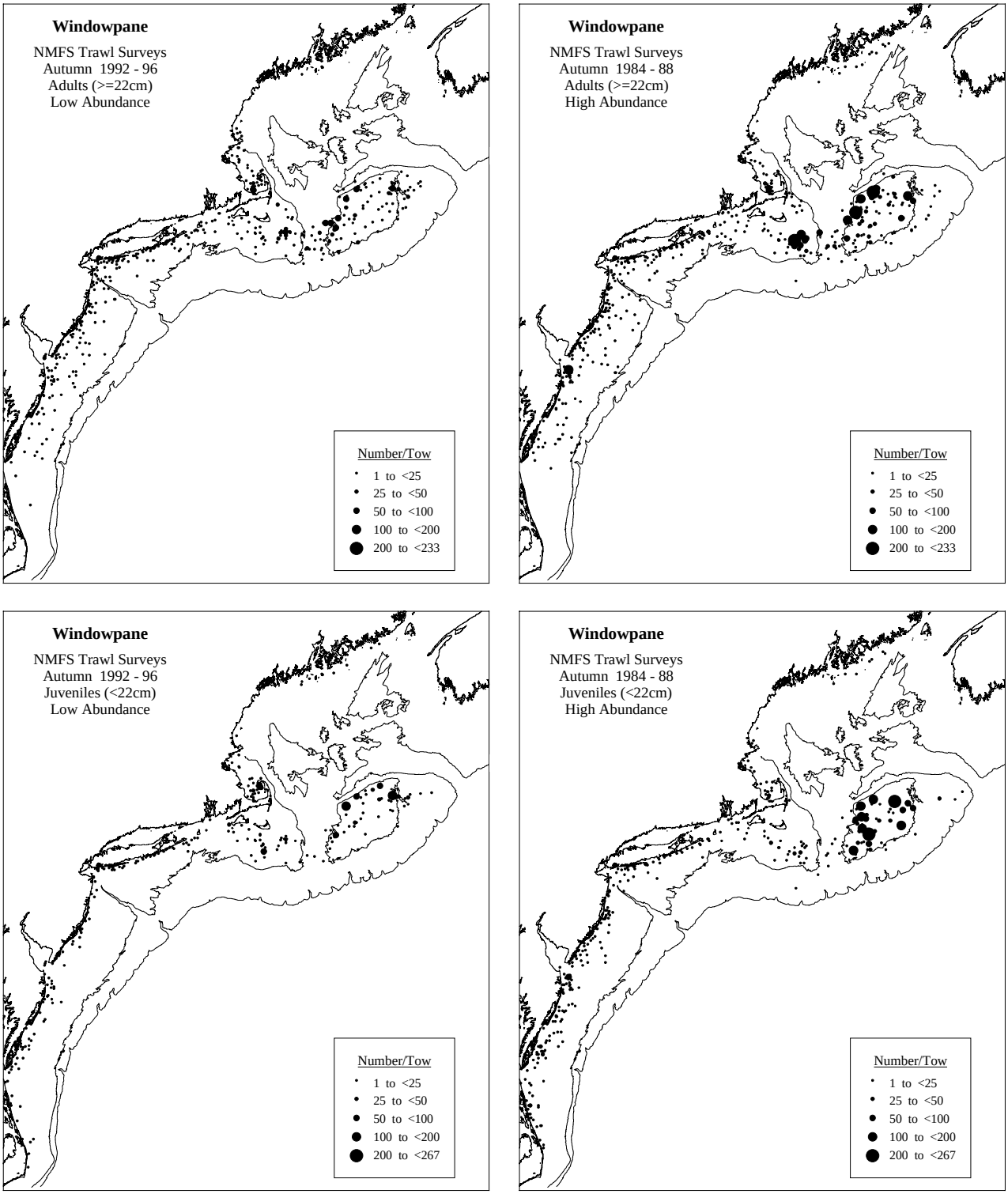

Figure 17. Distribution and abundance of juvenile (< 22 cm) and adult (≥ 22 cm) windowpane during a period of relatively low abundance (1992-1996) and a period of relatively high abundance (1984-1988) from autumn NEFSC bottom trawl surveys.

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NOAA Technical Memorandum NMFS-NE-138

Essential Fish Habitat Source Document:

Winter Flounder, *Pseudopleuronectes americanus*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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NOAA Technical Memorandum NMFS-NE-138

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Essential Fish Habitat Source Document:

Winter Flounder, *Pseudopleuronectes americanus*, Life History and Habitat Characteristics

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September 1999

Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

---

[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

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HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, CHIEF
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INTRODUCTION

The winter flounder, *Pseudopleuronectes americanus*, a small-mouthed, right-eyed flounder (Figure 1), is a valuable commercial and recreational species. It is distributed along the northwest Atlantic coast as far north as Labrador (Kendall 1909; Backus 1957) and as far south as North Carolina and Georgia (Hildebrand and Schroeder 1928; Klein-MacPhee, in prep.). One of the more familiar fishes in the Gulf of Maine (Klein-MacPhee, in prep.), winter flounder are common on Georges Bank and in shelf waters as far south as Chesapeake Bay and are ubiquitous in inshore areas from Massachusetts to New Jersey.

The species is managed as three separate stocks: the Gulf of Maine, southern New England and the Middle Atlantic, and Georges Bank (Brown and Gabriel 1998). However, there have been questions as to whether the population on Georges Bank, where fish tend to grow larger and have different meristic characteristics and movement patterns than those residing inshore (Lux *et al.* 1970; Howe and Coates 1975; Pierce and Howe 1977), is in fact a separate species. It has been concluded that many of these differences could be attributed to temperature (Lux *et al.* 1970).

Except for the Georges Bank population, adult winter flounder migrate inshore in the fall and early winter and spawn in late winter and early spring throughout most of their range (Perlmutter 1947; Bigelow and Schroeder 1953; Pearcy 1962; Dovel 1967; Scarlett 1991). In northern waters, spawning occurs somewhat later: April in Passamaquoddy Bay (Tyler 1971a) and May and June in Newfoundland (Kennedy and Steele 1971; Van Guelpen and Davis 1979). After spawning, adults typically leave inshore areas although some remain inshore year-round.

This Essential Fish Habitat source document will focus on specific habitat requirements of the various life history stages of winter flounder as well as their historical and current geographical distributions.

LIFE HISTORY

The life history of winter flounder has been well studied (see Howell *et al.* 1992) and only a brief outline will be given here. Howell *et al.* (1992) also includes an excellent review of diseases and effects of pollutants. Further information on pollution effects is provided by Gould *et al.* (1994).

EGGS

The eggs of winter flounder are demersal, adhesive, and stick together in clusters. They range in size from 0.74-0.85 mm in diameter. Although Breder (1923) reported that winter flounder eggs develop a “small sphere similar to oil globules in pelagic ova” which disappears with further development, Martin and Drewry (1978) make no mention of this structure. It is possible that the structure reported by Breder (1923) was an artifact. Hatching occurs in 2 to 3 weeks, depending on temperature, and at sizes as small as 2.4 mm in the northwest Atlantic (Fahay 1983) and up to 3.0-3.5 mm in the Gulf of Maine (Bigelow and Schroeder 1953).

LARVAE

Larvae are initially planktonic but become increasingly bottom-oriented as metamorphosis approaches. Settlement occurs at 9-13 mm standard length (SL) (Pearcy 1962; Witting 1995). Metamorphosis, when the left eye migrates to the right side of the body and the larvae become “flounder-like”, begins around 5 to 6 weeks after hatching, and is completed by the time the larvae are 8-9 mm in length at about 8 weeks after hatching (Bigelow and Schroeder 1953). Variation in age at metamorphosis is greater than for size (Chambers and Leggett 1987), with age variation influenced by temperature (Laurence 1975; see also Able and Fahay 1998).

JUVENILES

Off southern New England, newly metamorphosed young-of-the-year (YOY) winter flounder take up residence in shallow water where they may grow to about 100 mm within the first year (Bigelow and Schroeder 1953). Growth rates in the Mystic River, Connecticut estuary averaged 0.28-0.35 mm per day in summer and fall with monthly mortality during the first year averaging 31% and total mortality during larval (and juvenile stages) reaching over 99% (Pearcy 1962). Average density of settled juveniles in this system was higher than $1/m^2$ (Pearcy 1962).

Growth rates may be somewhat faster in more southern waters (Chesapeake Bay) where fish up to 110-180 mm are collected in late winter. In a southern New Jersey system, growth ranged from 0.23-0.47 mm per day (Witting 1995). In this system, settlement appeared to be localized in a small cove, with very high densities (averages reaching as high as 4.1 individuals/m^2) (Witting 1995). In several caging studies at other coastal New Jersey locations, growth rates ranged even higher (Sogard 1992, 0.95 mm per day; Phelan *et al.*, in press, 0.68 mm per day) and settlement appeared more widespread (B.A. Phelan, National Marine Fisheries Service, Highlands, NJ, unpublished data). Although juveniles presumably overwinter in the estuary (Bigelow and Schroeder 1953), large numbers are also found on the shelf (Phelan 1992) and outside southern New Jersey estuaries (Able and

Hagan 1995; Able and Fahay 1998).

ADULTS

Winter flounder may grow up to 58 cm total length (TL) and attain 15+ years of age. Growth varies among geographical areas, with slower growth in the north than in the south. Growth in the Gulf of Maine ($k = 0.41$, $L\infty = 39.8$ cm for males, $k = 0.27$, $L\infty = 49.0$ cm for females) was somewhat lower than on Georges Bank ($k = 0.37$, $L\infty = 55.0$ cm for males, $k = 0.31$, $L\infty = 63.0$ for females) (see Mayo 1994).

REPRODUCTION

Winter flounder spawn from winter through spring, with peak spawning occurring during February and March in Massachusetts Bay and south of Cape Cod and somewhat later along the coast of Maine continuing into May (Bigelow and Schroeder 1953). Spawning occurs earlier (November to April) in the southern part of the range (Klein-MacPhee, in prep.). Major egg production occurs in New England waters before temperatures reach 3.3^{o}C with an upper limit of about 4.4-5.6^{o}C in the inner parts of the Gulf of Maine (Bigelow and Schroeder 1953). Spawning can occur at depths of less than 5 m to more than 45 m on Georges Bank, and at salinities of 11 ppt inshore near Woods Hole to 31-33 ppt offshore.

Winter flounder maturity comparisons are complicated by the complex stock structure of this species (O'Brien *et al.* 1993). Based on the Northeast Fisheries Science Center (NEFSC) trawl surveys, the median length at maturity (L_{50}) for male and female winter flounder from Georges Bank was 25.6 and 24.9 cm respectively; median age at maturity (A_{50}) was 1.9 years for both males and females (O'Brien *et al.* 1993). For inshore stocks north of Cape Cod, values of L_{50} were 29.7 cm for females and 27.6 cm for males; for stocks south of Cape Cod, L_{50} was 27.6 cm for females and 29.0 cm for males. Median age at maturity was 3.5 years for females and 3.3 years for males north of Cape Cod; 3.0 years for females and 3.3 years for males south of the Cape (O'Brien *et al.* 1993).

Other studies report different values. In Long Island Sound, maturity occurred at 2 to 3 years and 20 to 25 cm (Perlmutter 1947); in Newfoundland, L_{50} was 25 cm for females, 21 cm for males, with ages for full maturity reaching 7 years for females and 6 years for males (Kennedy and Steele 1971) indicating that maturity was related to size, not age. However, Beacham (1982) found that maturity of fish from the Scotian Shelf and southern Gulf of St. Lawrence was highly variable from year to year. Burton and Idler (1984) found a 2 to 3 year cycle in oocyte maturation and large numbers of non-reproductive individuals in any given year. Thus, interpretations of winter flounder maturity data should be treated cautiously (O'Brien *et al.* 1993).

Fecundity measurements indicate that in Newfoundland, 220-440 mm females produced from 99,000 to over 2 million eggs (Kennedy and Steele 1971); in Rhode Island, 250-450 mm females produced from 93,000 to over 1.3 million eggs (Saila 1962); and in coastal Massachusetts, 300-450 mm females produced from 435,000 to over 3.3 million eggs (Topp 1968).

Recent laboratory studies have shown that when held at 4°C, winter flounder spawned over a two month period with females and males averaging 40 and 147 spawns, respectively (Stoner *et al.* 1999). Spawning was concentrated between sunset and midnight, with the majority of spawning events involving more than one male, which potentially maximizes fertilization success.

FOOD HABITS

Pearcy (1962) investigated the food habits of winter flounder larvae from hatching through metamorphosis. A large percentage of the stomach contents were unidentifiable but nauplii, harpacticoids, calanoids, polychaetes, invertebrate eggs, and phytoplankton were all present. Food item preference changed with larval size: smaller larvae (3-6 mm) ate more invertebrate eggs and nauplii while larger larvae (6-8 mm) preferred polychaetes and copepods. Plant material was found in larval stomachs but usually with other food items and was probably incidentally ingested (Pearcy 1962).

Pearcy (1962) found that copepods and harpacticoids were important foods for metamorphosing and recently metamorphosed winter flounder. Amphipods and polychaetes gradually become more important for both YOY and yearling flounder (Pearcy 1962). Franz and Tanacredi (1992) found that the amphipod, *Ampelisca abdita*, made up the majority of the diet of young flounder in Jamaica Bay, New York. Stehlik and Meise (in press) found clear ontogenetic patterns in diet, with calanoid copepods disappearing from the diet as fish grew > 50 mm TL and an increase in the number of taxa in diet with growth.

Winter flounder have been described as omnivorous or opportunistic feeders, consuming a wide variety of prey (see Figure 2). Polychaetes and crustaceans (mostly amphipods) generally make up the bulk of the diet (Hacunda 1981; Macdonald 1983; Steimle *et al*. 1993; Martell and McClelland 1994; Carlson *et al*. 1997). Linton (1921) examined the stomachs of 398 winter flounder ranging in size from 25-225 mm. Annelids and amphipods dominate the diet in almost all size classes (Linton 1921). Winter flounder may modify their diet based on availability of prey. They feed on bivalves (Medcoff and MacPhail 1952; Macdonald and Green 1986; Stehlik and Meise, in press), capelin eggs (Kennedy and Steele 1971; Frank and Leggett 1983) and fish

(Kennedy and Steele 1971).

Adult winter flounder are sight feeders, using their dorsal fins to raise their heads off the bottom with eye turrets extended for a better view (Olla *et al*. 1969). Prey are then taken in a 10 to 15 cm lunge. (Olla *et al*. 1969). If no prey are spotted, the fish change location and resume the feeding posture. A fish might change location and direction four to five times a minute. These movements involve a combination of swimming and "shambling" (Kruuk 1963; Macdonald 1983) or literally crawling across the bottom on the tips of the fin rays. Fish were able to maintain this feeding posture in currents exceeding 20 cm/sec by pushing the edges of the fins into the substrate (Olla *et al*. 1969). This same feeding method is used by young-of-the-year and juvenile flounder as well (J. Pereira, National Marine Fisheries Service, Milford, CT, unpublished observation). Increases in turbidity or current speed could interfere with feeding success.

The importance of adequate light for feeding in flounder is demonstrated in a study by Able *et al*. (1999) and Duffy-Anderson and Able (1999). Young-of-the-year flounder held in cages underneath piers in the lower Hudson River lost weight when compared to fish caged in open areas between the piers. One of the contributing factors could have been an inability to feed due to lack of light (Able *et al*. 1999; Duffy-Anderson and Able 1999). Macdonald (1983) noted that flounder were more attracted to moving rather than stationary prey and reemphasized the flounder's dependence on sight for feeding. Frame (1971) noted that the amount and duration of feeding behavior varied with light levels, being reduced on cloudy and winter days and increased on sunny days. Van Guelpen and Davis (1979) found that winter flounder moved out of shallow water during storm events to avoid turbulence. They noted that Gibson (1973) observed similar behavior in other flatfish species particularly for plaice, *Pleuronectes platessa*. It is possible that the suspended sediment caused by turbulence interferes with feeding.

Field observations by Olla *et al*. (1969) show that adult winter flounder are inactive at night. Stomach samples taken from fish during the day almost always contained food while those taken before sunrise were almost always empty indicating that adult flounder do not feed at night (Olla *et al*. 1969). However, fish in the laboratory were nocturnal during the reproductive season, only becoming active during the day during the post-spawning periods under increasing temperature and photoperiod (Stoner *et al.* 1999). Young-of-the-year winter flounder are also more nocturnal during the summer (Manderson *et al*., in review; B.A. Phelan, National Marine Fisheries Service, Highlands, NJ, unpublished observation).

Winter flounder have been reported to cease feeding during the winter months (Kennedy and Steele 1971; Van Guelpen and Davis 1979; Martell and McClelland 1994). Other authors simply report a reduction in feeding in the winter (Frame 1971; Levings 1974). Recent field studies in a New Jersey estuary before, during and after the spawning season indicated that females began feeding, primarily on siphons of the clam, *Mya arenaria*, and ampeliscid amphipods earlier than males (Stoner *et al.* 1999). In the laboratory, males fed only after most spawning had ended (Stoner *et al.* 1999).

Degradation or improvement of environmental conditions causing shifts in benthic invertebrate populations may also cause shifts in prey selection such as eating the pollution-tolerant annelid *Capitella* (Haedrich and Haedrich 1974; Steimle *et al*. 1993) or eating the pollution-sensitive amphipod, *Unciola irrorata*, once environmental conditions have improved (Steimle *et al*. 1993).

PREDATION

Pearcy (1962) reported that the small medusae, *Sarsia tubulosa*, prey upon winter flounder larvae, and that all other potential predators of larvae were numerically unimportant when compared to *Sarsia* medusae. The predatory amphipod, *Calliopius laeviusculus*, was shown to prey upon larval winter flounder in the laboratory (Williams and Brown 1992). Klein-MacPhee *et al.* (1993) suggests the mud anemone, *Ceriantheopsis americana*, as a potential predator on winter flounder larvae. Pepin *et al.* (1987) reported that Atlantic mackerel, *Scomber scombrus*, selectively prey on larval fish between 3 and 10 mm in length. Mackerel would co-occur with winter flounder larvae in early spring. Since winter flounder are 3.5 mm in length at hatch they are certainly vulnerable to predation by mackerel.

Howe *et al*. (1976) found that injured juvenile winter flounder were more common when large numbers of "snapper" bluefish, *Pomatomus saltatrix*, were present in their study area, suggesting that young bluefish are an important predator on young winter flounder. Gulls and cormorants were also suggested as important predators (Howe *et al*. 1976). Witting and Able (1995) have documented in the laboratory the ability of the sevenspine bay shrimp, *Crangon septemspinosa*, to prey on YOY winter flounder ranging in length from newly settled, 10 mm individuals to those up to 20 mm long. Juvenile winter flounder, particularly as they get larger, are probably also preyed upon by the same predators that prey on adults. Summer flounder, *Paralicthys dentatus*, sea robins (*Prionotus evolans*), and windowpane (*Scophthalmus aquosus*) also prey on YOY and juvenile winter flounder (Poole 1964; Richards *et al.* 1979; Manderson *et al.* 1999, in review). As many as 12 winter flounder have been found in a single searobin stomach (P.E. Clark, National Marine Fisheries Service, Milford, CT, unpublished observation).

Adult winter flounder are preyed upon by a wide variety of predators including striped bass (*Morone saxatilis*), bluefish, spiny dogfish (*Squalus acanthias*), goosefish (*Lophius americanus*), oyster toadfish (*Opsanus tau*), and sea raven (*Hemitripterus americanus*), (Lux and Mahoney 1972; Azarovitz 1982). Cormorants, blue herons, seals, and ospreys have also been cited as predators (Pearcy 1962; Tyler 1971b). Payne and Selzer (1989) found that seals ate 5 different species of flounder including winter flounder, but that the flounder group as a whole made up only 10 % of the diet.

MIGRATION

With the exception of the Georges Bank population, adult winter flounder migrate inshore in the fall and early winter and spawn in late winter and early spring. Following spawning, adults typically leave inshore areas when water temperatures exceed 15°C (McCracken 1963; Howe and Coates 1975); however, these movements may not be totally controlled by temperature. Winter flounder may remain inshore year-round if temperatures remain at 15°C or lower and if enough food is available (Kennedy and Steele 1971). In the more northern latitudes, they may be driven out by turbulence or ice formation (Van Guelpen and Davis 1979).

Powell (1989) reviewed tagging studies of winter flounder conducted by Perlmutter (1947), Saila (1961, 1962), McCracken (1963), Poole (1969), Howe and Coates (1975), Van Guelpen and Davis (1979), Danila and Kennish (1982), Scarlett (1983), Weber and Zawacki (1983), Northeast Utilities Service Company (1984), and Weber (1984), and compared them to his own studies in Rhode Island. He concluded that, with the exception of Georges Bank, there were two distinctive patterns of movement. While all studies showed a winter congregation on inshore, shoal spawning grounds and summer dispersal to deeper cooler waters, the extent and the timing of these movements varied with location. Winter flounder distributions in NEFSC bottom trawl surveys (Figure 3), Massachusetts inshore trawl surveys (Figure 4), and Hudson-Raritan trawl surveys (Figure 5) confirm this general pattern of movement.

Howe and Coates (1975) tagged fish during the winter and early spring while they were concentrated near spawning grounds in areas both north and south of Cape Cod and on Georges Bank. Fish tagged north of Cape Cod tended to make shorter post-spawn migrations (average distance traveled from tagging location = 14.3 km or less) probably because of the close proximity of cooler bottom temperatures (Howe and Coates 1975). Studies conducted even further to the north in Nova Scotia (McCracken 1963) and Newfoundland (Van Guelpen and Davis 1979) also showed short onshore-offshore migrations associated with spawning. Most fish tagged on Georges Bank tended to stay on the Bank and there was very little exchange (less than 1% in either direction) with fish on Nantucket Shoals (Howe and Coates 1975). Fish tagged south of Cape Cod migrated farther than their counterparts north of the Cape (average distance traveled up to 61.2 km). Mixing was minimal; only nine fish (0.66% of the tag recoveries) tagged north of the Cape were recovered south and east of the peninsula and only 61 fish (2.50% of recovered tags) tagged south of Cape Cod were recaptured to the north. Tag returns in the fall showed return of fish to inshore, shoal areas when water temperatures had reached 15°C (Howe and Coates 1975).

Studies conducted further south in Connecticut (Northeast Utilities Service Company 1984), New York (Poole 1969; Weber and Zawacki 1983; Weber 1984), and New Jersey (Danila and Kennish 1982; Scarlett 1983) also showed longer onshore-offshore migrations. Powell (1989) also noted that in the tagging studies south of Cape Cod, all post-spawn, summer migrations were to the east, i.e., offshore. This adult migration is shown by seasonal trawl survey catches, especially off New Jersey and southern New England (Figures 3 and 4) as well as by more recent studies. For example, Pereira *et al.* (1994) found that some fish move as far as 113 km to the east during the post-spawn period. Phelan (1992) tagged fish in the New York Bight area and recovered one fish from Nantucket, a distance of 328 km from the tagging site. Timing of these spawning and post-spawning movements varied along the coast, occurring earlier farther south and later farther north.

There are exceptions to these general patterns, and migrations may also be related to food availaility. Kennedy and Steele (1971) reported that winter flounder left Long Pond, Canada and were found in Conception Bay, Canada even though water temperatures in both locations were around 11°C. They attribute the exodus to a lack of food in Long Pond. Van Guelpen and Davis (1979) reported emigration from the study area in July even though water temperatures remained within the winter flounder's acceptable range. They believe this was a feeding migration similar to that reported by Kennedy and Steele (1971). When winter flounder disappeared from study areas again in August, they were found in nearby Horse Cove where they had been feeding heavily on capelin eggs (Van Guelpen and Davis 1979). Feeding migrations by winter flounder have also been documented by Tyler (1971b) who found that adult winter flounder move into the intertidal zone on the high tide to feed. It would seem that if water temperatures are not limiting over a wide area, winter flounder will move in response to availability of food. Howe and Coates (1975), who noted similar movements in the Cape Cod area, doubt that these movements are solely in response to availability of food. Howe *et al.* 1976 and studies in Raritan Bay (Figure 5) provide evidence that some adult fish may remain inshore throughout the summer.

STOCK STRUCTURE

This species is currently managed as three stocks (one north of Cape Cod, one south of the Cape and the third on Georges Bank) which were first differentiated based on differences in fin ray counts and movement patterns (Lux *et al*. 1970; Howe and Coates 1975; Pierce and Howe 1977). The Georges Bank stock not only differed in fin ray count, but has a much higher growth rate (Lux 1973). Some researchers feel that three "stock complexes" are being managed and that there may be one or more stocks in Canadian waters, based on differences in age at maturity (Kennedy and Steele 1971) and migratory habits (Van Guelpen and Davis 1979). Other stocks may exist north of the Massachusetts border along the coast of New Hampshire and Maine.

HABITAT CHARACTERISTICS

A summary of the habitat characteristics of the various life history stages of winter flounder is provided in Table 1.

EGGS

Collection of winter flounder eggs from the wild is difficult because of their adhesive and demersal nature. It is these same characteristics, however, that make them valuable in pinpointing spawning grounds. With the exception of Georges Bank and Nantucket Shoals, winter flounder eggs are generally collected from very shallow waters (less than about 5 m), at water temperatures of 10°C or less, and salinities ranging from 10 to 30 ppt. These shallow water, nearshore habitats are of critical importance because they are most likely to be impacted by human activities. The type of substrate where eggs are found varies, having been reported as sand, muddy sand, mud and gravel, although sand seems to be the most common. Vegetation may or may not be a factor. Spawning areas also occur where hydrodynamics function to keep the hatched larvae from being dispersed (Pearcy 1962; Crawford and Carey 1985; Monteleone 1992). This is true even on Georges Bank where different water masses function to keep larvae on the Bank (Backus and Bourne 1987).

Scott (1929) collected winter flounder eggs near St. Andrews, New Brunswick, with a plankton net in one foot of water along the flats on mud bottom. Surface temperatures in the area ranged from 9.25-10.0^{o}C, but bottom temperatures to which the eggs were exposed were probably lower.

Pearcy (1962) working in the Mystic River, Connecticut, began his sampling in February when water temperatures were around 2-5°C. Specific gravity of seawater where eggs were collected was reported to be 1.01-1.024 (corresponding roughly to a salinity range of 10 to 25 ppt) at 5°C. Crawford and Carey (1985) collected winter flounder eggs using a benthic sled in Point Judith Pond, Rhode Island. The greatest concentration of eggs was found in the vicinity of a tidally submerged gravel bar with eggs clumped on the gravel substrate or attached to fronds of algae. Crawford and Carey (1985) began their sampling only after water temperatures had reached 3°C. It has also been reported that winter flounder eggs collected by divers were attached to vegetation (Anonymous 1972). Scarlett and Allen (1989) found that winter flounder eggs constituted the vast majority of all the eggs found in collections made in the Manasquan River in New Jersey in February and March of 1985. Eggs were found at salinities ranging from 14 to 32 ppt, temperatures of 0.9 to 10°C, and depths of 2-4.5 m. In a subsequent study, Scarlett (1991) used an epibenthic sled for sampling winter flounder eggs in the Shrewsbury and Navesink rivers in New Jersey to identify spawning areas. He collected eggs in water temperatures ranging from 4 to 7.5^{o}C, at salinities of 14 to 22 ppt, and at depths of 2 to 4 m.

More recently, Monteleone (1992) collected winter flounder eggs in a plankton net towed horizontally just under the surface of the water in a relatively shallow (average depth 1.3 m). The turbulence caused by the sampling gear was probably responsible for these demersal eggs finding their way into the net. Like Scott (1929), Monteleone (1992) reported a surface water temperature of 9.1^{o}C during the collection of winter flounder eggs.

Hughes (in prep.) used a benthic sled to collect winter flounder eggs in Point Judith and Ninigret coastal salt ponds in Rhode Island in the vicinity of the *North Cape* oil spill. Samples were taken in March. Depths in the sample areas ranged from 1 to 3 m. Lee *et al*. (1997) measured temperature and salinity near Hughes (in prep.) sample sites at various times between 1985 and 1994. Samples taken in March of various years showed a mean temperature of 6±1.94^{o}C and a mean salinity of 23±8.01 ppt.

Temperature and depth measurements taken in conjunction with the plankton samplings conducted by the NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) program on Georges Bank showed that the eggs were collected at water temperatures between 3 and 8°C and at depths of 90 m or less (Figure 6). These results confirmed the report by Bigelow and Schroeder (1953) that winter flounder spawn on sandy bottom, often in water as shallow as one to three fathoms but as deep as 25 to 40 fathoms (13-22 m) on Georges Bank and, most probably, on Nantucket Shoals.

While evidence from eggs collected in the field provides information about the conditions under which winter flounder prefer to spawn, laboratory studies provide information about how winter flounder eggs might fare in marginal environments. One parameter

typically studied in the laboratory is the number of days required for hatching. Time to hatch is controlled by temperature. Human activities could change ambient temperatures directly by discharge of heated cooling water or indirectly by changing the hydrodynamics and therefore, the water turnover rate of an area.

Scott (1929) collected winter flounder eggs in the field, and in the laboratory determined the number of days for all the eggs to hatch or die, as well as hatching success. He found that 4-5°C produced the best hatch success, averaging 73%. The average time for all the eggs to hatch or die was 26 days. At 0°C, only 50% of the eggs had hatched or died in an average of 21 days and the hatch success was poor, averaging only about 9%. Williams (1975) reported an average of 38.6 days to hatch or die for eggs held at 0°C. Williams (1975) also reported an average hatch time of 21.5 days for eggs held at 3.5^{o}C, very close to the value reported by Scott (1929) for eggs held at 4–5°C. Eggs held at 12 to 17°C hatched sooner (mean 18 days), but the percent hatch only averaged about 52%. An earlier, similar study by Brice (1898) found that eggs hatched in 17-18 days at 3°C. Neither Brice (1898) nor Scott (1929) determined the developmental stage of the field-collected embryos when they were brought into the laboratory or what percent were even fertilized. This may explain some of the variability apparent in the reported time to hatch in these studies.

Rogers (1976) tested the effects of various combinations of temperature (3-15°C) and salinity (0.5 to 45 ppt) on the viability and incubation times of winter flounder embryos and she concluded that winter flounder embryos are euryhaline and hatch at salinities of 5 to 40 ppt. Salinity extremes tended to induce abnormal development, however, and the best survival occurred between 10 and 30 ppt. She concluded that optimal conditions for winter flounder embryo development and survival appear to be 15 to 35 ppt salinity at 3°C and 15 to 25 ppt for temperatures above 3°C. These results agree well with the results of Williams (1975), who reported a minimum mortality range of 0 to 10°C and an upper lethal limit of 15°C.

Rogers (1976) also found that incubation times (days for 50% of the embryos to hatch) were inversely related to temperature: 19 to 31 days at 3°C and 10 ppt salinity, and 5 to 10 days at 14°C, regardless of salinity tested. Buckley (1982) also reported similar results, noting that the time required for 50% hatch of embryos held in the laboratory was 8 days at 10°C and 23 days at 2°C. Increased mortality was noted in developing embryos held at 2°C. These results agreed more closely with the statements of Bigelow and Schroeder (1953), who report that hatching occurred in 12-15 days at a temperature of 2.8 to 3.3^{o}C.

This inverse relationship between incubation time and temperature may provide a mechanism for the phenomenon observed by Frank and Leggett (1983). They found that several species of fish which laid demersal eggs (capelin, sea snail, radiated shanny, and winter flounder) seemed to time their hatching to the advent of favorable environmental conditions. Hatching occurs simultaneous to the onset of onshore winds which cause the replacement of cooler, predator-laden, food-poor, up-welling waters with warmer, predator-poor, food-rich, surface water over the shallow spawning areas. The synchronous hatching is thought to have the effect of swamping predators and enhancing survival of winter flounder because the capelin are so much more numerous than the other species. Crawford and Carey (1985) described a similar phenomenon when they reported that a mid-February pulse of warm weather seemed to stimulate winter flounder spawning in Point Judith Pond, Rhode Island.

LARVAE

Pearcy (1962) concluded that because winter flounder spawn in coves and inlets and the young stages are non-dispersive, breeding and nursery grounds would be close together. This view had been previously expressed by Perlmutter (1947). Thus, larvae (and later juveniles) may offer an important clue to the location of spawning grounds, and are the link between spawning grounds and nursery areas. Data from the NEFSC MARMAP ichthyoplankton surveys show that, with the exception of Georges Bank and Nantucket Shoals, most winter flounder larvae are found inshore and that spawning progresses from the southern end of its range northward (see Geographical Distribution below).

Pearcy (1962) collected winter flounder larvae from the Mystic River, Connecticut. Comparing the number of larvae in surface tows to those collected by bottom tows he found that the bottom tows contained the majority of the larvae. He also knew from laboratory observations that winter flounder larvae are negatively buoyant and sink when they stop swimming. His hydrographic survey of the estuary revealed that in the surface waters the net movement over a tidal cycle was seaward while in the bottom waters it was landward. The natural tendency of the larvae to sink would explain why most were caught near the bottom and would also function to retain the larvae within the estuary rather than get washed out in the surface waters. In fact, he calculated that only about 3% of the larval population was dispersed seaward per tidal cycle.

Crawford and Carey (1985) believe that spawning areas and nursery areas are close together, after locating both eggs and larvae in Point Judith Pond in Rhode Island. They concluded that winter flounder larvae could have been retained in the estuary by the mechanism proposed by Pearcy (1962) but that the hydrodynamics of the area also played a role. They further suggested that winter flounder, when they spawn, take advantage of the hydrodynamic characteristics of small, narrow estuaries

that restrict water flow in order to help retain the larvae in suitable nursery areas. Monteleone (1992) noted the highest concentrations of winter flounder larvae in Great South Bay, New York at stations with low current speeds and turnover rates.

Winter flounder larvae were collected in the higher salinity regions of Miramichi Bay (New Brunswick, Canada) in early to mid-June where bottom salinities ranged from 6 to 26 ppt, and temperatures ranged from 12.5 to 20.5^{o}C (Locke and Courtenay 1995). Scarlett (1991) collected winter flounder larvae in the Navesink and Shrewsbury Rivers in New Jersey from February through April where bottom salinities ranged from 10 to 22 ppt, bottom temperatures ranged from 2 to 19.5^{o}C and depths ranged from 2 to 6 m. Pearcy (1962) found that winter flounder larvae were common in the upper Mystic River Estuary from May to June when temperatures ranged from 3 to 15°C. Average bottom salinities for the upper estuary ranged from 18 to 22 ppt. Scarlett and Allen (1989) collected winter flounder larvae in the Manasquan River in New Jersey at salinities ranging from 4 to 30 ppt and temperatures ranging from 0.9 to 15°C. NEFSC MARMAP surveys collected larvae from March through July, and in September (Figure 7). Most were caught at temperatures of 6-10°C (those caught in September were at 18°C) and depths of 10-70 m.

Winter flounder larvae are surprisingly tolerant of short-term temperature shock. In laboratory studies, Itzkowitz and Schubel (1983) found that mortality in five-day-old winter flounder larvae was minimal when the temperature was increased from the acclimation temperature of 5 to 27°C (a change in temperature of 22°C) so long as the duration was kept to less than 32 minutes. At longer durations, mortality increased rapidly. Similar results were obtained for changes in temperature of 24°C if duration was 16 minutes or less. At changes in temperature $\geq$ 28°C mortality was virtually total and immediate (Itzkowitz and Schubel 1983).

YOUNG-OF-THE-YEAR, YEARLINGS AND JUVENILES

Winter flounder less than one year old (or young-of-the-year, YOY) are treated separately here because their habitat requirements are so different from that of the larger juveniles (fish 1 year old or more). Yearling is a term used for fish which are between one and two years of age; their behavior being transitional between YOY and older juveniles.

Winter flounder spend their first year in very shallow inshore waters. Although temperature tolerance of YOY is higher than for yearlings or adults, Pearcy (1962) concluded that temperatures of 30°C might be too high. He found that an area that had produced fish previously failed to do so when the temperature reached 30°C, but that the fish returned when temperatures were lower. This upper limit is in agreement with studies by Huntsman and Sparks (1924) and Battle (1926) who also noted higher lethal temperatures for smaller flounder than for larger ones, and with McCracken (1963) who determined an upper incipient lethal temperature of 27°C. Pearcy (1962) reported a minimum lethal temperature between -1.5 and -1.0^{o}C. Juvenile winter flounder captured in offshore areas by NEFSC bottom trawl surveys were found at temperatures well outside of these lethal limits. The majority of juveniles were at 4-7°C in the spring and 11-15°C in autumn (Figure 8).

Laboratory studies by Casterlin and Reynolds (1982) on yearling flounder indicated that flounder selected temperatures in the range of 8-27°C, with a mode of 18.5^{o}C. They also noted that in the laboratory, these fish were more active at night.

Young-of-the-year flounder also tolerate lower salinities (5 ppt) than do yearling flounder (10 ppt) (Reynolds and Thomson 1974). Pearcy (1962) reported that the minimum salinity tolerance varied between 1 and 5 ppt for flounder as small as 7-10 mm. Bigelow and Schroeder (1953) reported that winter flounder are commonly found in salinities ranging from 35 ppt to water that was fresh enough to drink. They were probably including all life history stages in that statement.

Ziskowski *et al*. (1991) investigated low dissolved oxygen tolerance and behavior of yearling winter flounder in the laboratory. Mortality occurred when flounder were exposed to 1.1 to 1.5 mg/l dissolved oxygen. Flounder were able to withstand an 8-hr exposure to dissolved oxygen levels in the 1.2 to 1.4 mg/l range. Low oxygen tolerance is not without a price, however. Bejda *et al*. (1992) found that growth of juvenile winter flounder was significantly reduced when dissolved oxygen levels were maintained at 2.2 mg/l or varied diurnally between 2.5 and 6.4 mg/l for periods of up to 11 weeks.

Pearcy (1962) conducted tag-recapture studies that indicate a relatively stable population of juvenile winter flounder within the Mystic River estuary over the summer and much lower numbers of juveniles beyond the mouth. Other investigations confirm that YOY winter flounder remain in the nearshore zone and migrate very little during their first summer (McCracken 1963; Saucerman 1990; Saucerman and Deegan 1991). In winter however, Pearcy (1962) found that catches increased outside of the estuary while densities within the estuary dropped, implying an outward winter migration. Warfel and Merriman (1944) made similar observations. Richards (1963) found increased numbers of juveniles in offshore locations in the winter. Laboratory experiments by McCracken (1963) and Pearcy (1962) showed that YOY winter flounder were less photonegative than yearling flounder. Pearcy (1962) further showed that YOY winter flounder became more photonegative in the winter. Thus it seems that photoresponse and temperature preferences drive the YOY flounder from the shallows in the late fall and early winter of their first year and keep older

juveniles in deeper, cooler water much of the year.

Several investigators have reported that the highest densities of newly settled winter flounder are found on muddy substrates (Saucerman 1990; Howell and Molnar 1995; O'Connor 1997; Phelan *et al.,* in prep.). Paradoxically, Saucerman (1990) also found that growth rates were slowest in these areas. She attributed this difference to increased competition for food caused by the high density of fish and possibly the detrimental effects of low oxygen levels later in the summer. Both Saucerman (1990) and O'Connor (1997) felt that smaller juveniles prefer finer sediments to bury into as was suggested by Gibson and Robb (1992) for the European flounder, *Pleuronectes platessa*. In laboratory experiments, young-of-the-year winter flounder < 40 mm SL consistently preferred fine-grained sediments (Phelan *et al*., in prep.).

Since winter flounder metamorphose at a smaller size than other flatfishes (Bigelow and Schroeder 1953), it seems unlikely that a newly metamorphosed, 8 to 9 mm long flounder actively seeks out these soft muddy areas. It is more likely that they are simply deposited there by currents. Howell and Molnar (1995) reported that the highest catches of YOY winter flounder occurred on muddy substrates or muddy substrates covered by leaf litter or bivalve beds.

Witting (1995) and Able and Fahay (1998) have shown that specific areas, i.e., small coves inside Little Egg Inlet in New Jersey, by virtue of location, proximity to currents or other factors, may serve as critical habitat, supporting high densities of recently settled individuals. What these areas have in common is that they are depositional areas probably with low current speeds. We have already seen that spawning winter flounder take advantage of areas of appropriate hydrodynamics and current speeds to insure that larvae are retained in the nursery areas. Perlmutter (1947) and Pearcy (1962) both concluded that because eggs and larvae are non-dispersive that the nursery grounds will be close to the spawning grounds. In a sense, it is the spawning adults that choose the habitat for YOY winter flounder. Recent studies by Pereira *et al*. (1994) and Curran *et al.* (1996) support this idea.

Sogard and Able (1991) and Sogard (1992) found that YOY winter flounder in Great Bay-Little Egg Harbor in New Jersey were more abundant on unvegetated substrates. Their ability to bury in the sediment and change color to match it frees them from dependence on vegetation for refuge from predators. In this system, Able and Fahay (1998) indicate that juveniles larger than 25 mm are found in a variety of habitats types, regardless of sediment and structure. These habitats include macroalgae (Able *et al*. 1989), marsh creeks (Rountree and Able 1992) and to a lesser extent eelgrass (Goldberg *et al.,* in prep.). Recent comparisons of habitat-specific patterns of abundance and distribution of YOY winter flounder in this system, as well in the Hudson-Raritan estuary and Long Island Sound, support the conclusion that habitat utilization by YOY winter flounder is not consistent across habitat types and is highly variable among systems and from year to year (Goldberg *et al.,* in prep.).

The shallow inshore areas where YOY flounder spend their first 5 or 6 months of life are susceptible to anthropogenic impacts. Briggs and O'Connor (1971) compared the abundance of 40 different species of fish collected from undisturbed areas with natural vegetation with those collected where dredge spoil material (mostly sand) had been deposited. Species diversity was consistently higher over the undisturbed bottoms. Most species, including winter flounder, preferred the undisturbed bottom.

There have been a few attempts to relate juvenile habitat area to winter flounder production. Saila *et al*. (1965) calculated the theoretical biomass of juveniles needed to support the adult fishery. His studies led him to conclude that about 30% of the equilibrium yield weight is present in juveniles at 5 months of age and that efforts to enhance the fishery would be better aimed at culture and release of juveniles rather than larvae (Saila *et al*. 1965).

Howe *et al.* (1976) used tagging methodologies to investigate the contribution of the Waquoit Bay-Eel Pond spawning/nursery areas to the offshore trawl fishery. This fishery includes NMFS statistical subareas number 538 (southern Massachusetts), 521 (west side of South Channel), and 526 (Nantucket Shoals and Lightship Grounds). By accounting for natural mortality and calculating the number of new recruits emigrating from these nursery areas and becoming available to the offshore fishery, they were able to calculate that Waquoit Bay-Eel Pond contributed 0.16% of the recruitment required to maintain an equilibrium catch.

ADULTS

Laboratory experiments by Reynolds (1977) established a preferred habitat temperature for adult winter flounder of 13.5^{o}C. This concurs with the findings of McCracken (1963) who concluded, based on a review of field studies of winter flounder distribution and water temperatures, that adults have a preferred temperature range of 12-15°C. Results from several experimental trawl surveys tend to agree with these results. NEFSC trawl surveys captured adults at temperatures of 4-6°C in spring and 10-15°C in the fall (Figure 8). In the inshore waters of Massachusetts, adults were captured at 5-13°C in spring and 9-13°C in the fall (Figure 9). In the Hudson-Raritan estuary, most adults were captured at 4-12°C (Figure 10).

In contrast, Olla *et al*. (1969) observed actively feeding winter flounder where bottom temperatures always exceeded 17.2^{o}C. They found active feeding at temperatures up to 22.2^{o}C; but at 23°C feeding ceased and

the flounder buried themselves in the substrate, where temperatures 5 or 6 cm below the surface of the sediment were 19.8 to 20°C. They concluded that winter flounder escape short-term thermal stress by burying in the cooler sediments. Although this research seems to be at odds with the findings of McCracken (1963) and Reynolds (1977), Olla *et al*. (1969) did not report the size of the flounder they observed at these high temperatures. In another part of the study these authors reported stomach contents of fish ranging in size from 15 to 36 cm. If the fish observed during the high temperature period were toward the smaller end of the range reported for the feeding portion of their study (i.e., closer to the 15 cm end of the range of fish studied), that would likely make them yearlings. Reynolds (1977) determined that yearlings prefer a temperature of 18.5°C and may be able to tolerate these higher temperatures. Larger fish may have left the area because many have a lower temperature tolerance than smaller fish (McCracken 1963).

Acclimation is another important factor in determining temperature tolerance. Laboratory manipulation of acclimation temperature from 4 to 23°C increased the critical thermal maximum from 26 to 32°C (Everich and González 1977). If the temperature increase was gradual enough, acclimation could have occurred in the fish studied by Olla *et al*. (1969), thereby resulting in a higher temperature tolerance.

Pearcy (1962) reported that catches of adults in the upper estuary of the Mystic River, Connecticut, increased in February, peaked in March, and continued to be relatively high into April. Bottom temperatures during this period range from 1-10°C. He reported that peak spawning occurred when temperatures were between 2 and 5°C. Kennedy and Steele (1971) reported that peak spawning of winter flounder in Long Pond, Conception Bay, Canada occurred in May and early June. Water temperatures in May when the bulk of the spawning occurred were 8°C (Kennedy and Steele 1971). Van Guelpen and Davis (1979) reported that peak spawning in Conception Bay occurred in June in 1979 when water temperatures were 6°C.

McCracken (1963) found that winter flounder survived in salinities as low as 15 ppt, confirming earlier work done by Sumner (1907). Although Bigelow and Schroeder (1953) reported that winter flounder commonly live in areas where salinities are so low that the water was fresh enough to drink to areas where salinity was 35 ppt, McCracken (1963) found that winter flounder died in 72 to 96 hours when exposed to salinities of 8 ppt. It is difficult to assess the significance of these studies by McCracken (1963) since he did not always make it clear what size fish he used in these experiments. Bigelow and Schroeder (1953) probably are including all age groups in the salinity range that they cite and salinity tolerance is known to be age dependent. Adults captured in the Hudson-Raritan estuary were found at salinities as low as 15 ppt, although most were found at > 22 ppt (Figure 10).

Since adult winter flounder prefer to live in cooler waters, they do not often encounter low oxygen events. However, these do occur from time to time in response to high nutrient loading. Howell and Simpson (1994) described the distribution and abundance of finfish and lobsters in Long Island Sound in relation to near-bottom dissolved oxygen levels. Winter flounder abundance was significantly lower when dissolved oxygen was below 2.0 to 2.9 mg/l. Also significant was the decline in mean length of winter flounder as dissolved oxygen levels declined. Since the catch included fish ranging in size from 7 to 35 cm, it is probable that the decline in size of fish results from larger fish leaving the area before smaller fish which are more tolerant of low dissolved oxygen conditions (see above). Howell and Simpson (1994) also raised the possibility that the mean length difference was caused by slower growth rates caused by low dissolved oxygen (Bejda *et al*. 1992). This may be possible if low oxygen events are of long duration or periodic in nature.

With the exception of Georges Bank and Nantucket Shoals (see Figure 3), mature winter flounder are found in very shallow waters during the spawning season. Bigelow and Schroeder (1953) reported that winter flounder spawn on sandy bottom, often in water as shoal as one to three fathoms but as deep as 25 to 40 fathoms on Georges Bank. Kennedy and Steele (1971), working in Conception Bay, Newfoundland found that winter flounder spawn in May and June on sandy bottoms at depths less than 6 m. McCracken (1963) reported that spawning in Passamaquoddy Bay, New Brunswick occurred at depths of 0 to 9 m. Pearcy (1962) reported that winter flounder spawn in the Mystic River, Connecticut at depths of 5 m or less.

After spawning, adults may remain in the spawning areas before moving to deeper waters when water temperatures reach 15°C (McCracken 1963). Kennedy and Steele (1971) found them at depths of 7-10 m in the post-spawning period. McCracken (1963) found that winter flounder remained in Passamaquoddy Bay after spawning, but in deeper water (around 20 m). Trawl surveys conducted by NEFSC show the bulk of the adult catch occurred in water 25 m or less in the spring (during and just after spawning) and 25 m or deeper in the fall (prior to spawning) (Figure 8). The Massachusetts survey shows similar results (Figure 9). Post-spawning migrations of winter flounder along the New Jersey coast appear to be limited by the 40 m contour (Danila and Kennish 1982; Scarlett 1983). Migration of flounder from shoal areas south and east of Cape Cod appears to be limited by the 55 m contour (Howe and Coates 1975).

Laboratory experiments by McCracken (1963) demonstrated that adult winter flounder are less sensitive to light than YOY and juvenile winter flounder. Small flounder (6-9 cm) tended to be photophilic while intermediate fish (12-18 cm) were photophobic. Large fish (28-33 cm) responded negatively to bright lights but

not to lower levels of illumination. Casterlin and Reynolds (1982) showed that the locomotor activity patterns of sixteen 12 to 13 cm flounder they examined in the laboratory were decidedly nocturnal. The spatial distribution of flounder observed in the field (YOY in the nearshore zone, older juveniles further offshore) may in part be due to these differences.

GEOGRAPHICAL DISTRIBUTION

Winter flounder are distributed from the Strait of Belle Isle, off northwest Newfoundland, to Cape Charles, Virginia (Figure 11). The area of highest abundance is the Gulf of St. Lawrence, off New Brunswick and northern Nova Scotia.

EGGS AND LARVAE

The geographical distribution of winter flounder eggs and larvae matches that reported for the adults. Eggs and larvae have been collected from Canadian waters (Scott 1929; Locke and Courtenay 1995) to Chesapeake Bay (Dovel 1967). Govoni (1973) studied the icthyoplankton communities of the Acushnet and Westport Rivers in Massachusetts and found winter flounder larvae in his collections. Collection of winter flounder eggs in benthic sled samples show that coastal salt ponds in Rhode Island play host to much of the spawning activity in Rhode Island waters (Crawford and Carey 1985; Hughes, in prep.). The Pettaquamscut River and Narragansett Bay also support winter flounder spawning (Anonymous 1972; Bourne and Govoni 1988).

Collection of eggs and larvae by Pearcy (1962) and Monteleone (1992) confirm that the waters of Connecticut and Great South Bay, New York also serve as spawning areas for winter flounder. Winter flounder were the most common larva collected by Croker (1965) in the Sandy Hook estuary in New Jersey. The Navesink, the Shrewsbury, (Scarlett 1991), and the Manasquan rivers (Scarlett and Allen 1989) in New Jersey all harbor winter flounder larvae during the spawning season. Both the Indian River and Rehoboth Bay in Delaware also serve as spawning areas for winter flounder (Daiber *et al.* 1976).

Eggs and larvae of winter flounder have been reported from several areas (the Magothy and Patuxent Rivers and the upper bay near the Susquehanna River) at the northern end of Chesapeake Bay (Dovel 1967, 1971). It seems unlikely, at first, to find winter flounder spawning so far south, in Chesapeake Bay. However, Chesapeake Bay runs almost north and south, and the Magothy River is located at the same latitude as the important spawning areas mentioned above in Delaware Bay, the Indian River and Rehoboth bays located a short distance to the east.

Winter flounder eggs and larvae have also been collected in standard plankton tows utilizing bongo nets by the NEFSC MARMAP survey (Figures 12 and 13). In some cases this was probably due to the nets accidentally hitting the bottom, but this explanation is not sufficient to explain the large numbers of eggs collected on Georges Bank and Nantucket Shoals. The large numbers of eggs collected on Georges Bank are probably due to the unique hydrodynamic conditions found there. The water mass on central Georges Bank is characterized by lack of stratification at any time of year due to good vertical mixing (Backus and Bourne 1987). These same forces probably lift demersal eggs up into the water column and make them available to sampling by bongo net.

YOUNG-OF-THE-YEAR AND JUVENILES

Young winter flounder are ubiquitous along the east coast of the United States from Canada (McCracken 1963) to Virginia's eastern shore where Richards and Castagna (1970) found that of seventy species collected, winter flounder was the tenth most numerous. Saco Bay in Maine has young winter flounder (Casterlin and Reynolds 1982) and there was a hatchery for winter flounder for many years in Boothbay (Bigelow and Schroeder 1953). Massachusetts (Pierce and Howe 1977; Heck *et al.* 1989; Saucerman 1990), Rhode Island (Saila *et al.* 1965; Oviatt and Nixon 1977) and Connecticut (Pearcy 1962; Richards 1963; Howell and Simpson 1994; Carlson *et al.* 1997; Gottschall *et al.*, in review) are all home to young winter flounder. Briggs and O'Connor (1971) documented the presence of young winter flounder on the south shore of Long Island, New York, while Franz and Tanacredi (1992) described the food habits of young winter flounder in Jamaica Bay, New York. Juvenile winter flounder are a year-round resident of the New York Bight (Figure 5). Juveniles are common in the inshore waters of New Jersey (Rountree and Able 1992; Sogard 1992) and Delaware (Daiber *et al.* 1976). Offshore, the presence of winter flounder juveniles has been demonstrated by numerous surveys conducted by the Northeast Fisheries Science Center (Figure 3).

ADULTS

Winter flounder have been captured as far north as Ungava Bay in Labrador (Kendall 1909) and as far south as Georgia (Hildebrand and Schroeder 1928). In bottom-trawl surveys conducted by the NEFSC, winter flounder adults and juveniles are common on Georges Bank and in shelf waters as far south as the mouth of Chesapeake Bay during all seasons (Figure 3). Inshore trawl surveys in Massachusetts (Figure 4), Rhode Island (Saila 1961; Jeffries and Terceiro 1985) and Long Island Sound (Simpson *et al*. 1994) show them to be ubiquitous in those areas as well. Winter flounder are also common in the

lower reaches of the Hudson River (Boyce Thompson Institute for Plant Research, Estuarine Study Group 1977; Able *et al*. 1999) and the New York Bight/Hudson-Raritan estuary (Phelan 1992; Figure 5). They also use other protected bays and coastal ponds along the New Jersey coast (Tatham *et al.* 1984).

STATUS OF THE STOCKS

HISTORICAL PERSPECTIVE

Commercial fisheries for winter flounder flourished prior to 1980, even in the southern end of the range. Winter flounder was one of the dominant species in the Indian River and Rehoboth Bays in Delaware in the 1960's, but catches have since declined (Daiber *et al*. 1976). The commercial landings of winter flounder in 1970 in Delaware totaled only 2,300 pounds, but a moderate sport fishing effort persisted at that time especially in Indian River Bay (Daiber *et al*. 1976). Hildebrand and Schroeder (1928) reported the existence of a winter commercial fishery for winter flounder in Chesapeake Bay in the 1920s; it was the principal fish caught in fyke nets in the winter (Hildebrand and Schroeder 1928). The bulk of the landings were in Maryland, and the rest in Virginia. The Maryland landings would seem to support the statement made by Hildebrand and Schroeder (1928) that winter flounder are more common in Maryland waters than in the lower (more southern) areas of Chesapeake Bay. Although Hildebrand and Schroeder (1928) reported the presence of winter flounder as far south as Georgia, they also note that they were not taken in commercial numbers south of Chesapeake Bay. Commercial landings of winter flounder peaked in the 1980s throughout its range (Brown and Gabriel 1998) and have since declined.

CURRENT STATUS OF THE STOCKS

Winter flounder are currently managed as three stocks, Gulf of Maine, southern New England-Middle Atlantic, and Georges Bank (Brown and Gabriel 1998). Both the Gulf of Maine Stock and the southern New England-Middle Atlantic stocks are considered over-exploited. Although there is some evidence that stock rebuilding has begun on Georges Bank, stock levels remain well below the historic average (Brown and Gabriel 1998).

Biomass in the Gulf of Maine stock declined from 19,600 mt in 1979 to a low of 6,000 mt in 1991 (Brown and Gabriel 1998) (Figure 14). The current biomass estimate for 1997 stands at 8,900 mt less than half of the 1979 value (Brown and Gabriel 1998). In the southern New England-Middle Atlantic stock, stock biomass declined from 39,000 mt in 1981 to a record low of 8,500 mt in 1992 (Brown and Gabriel 1998; Figure 14). Contributions from strong year classes in 1992 and 1994 have rebuilt the stock biomass to 18,000 mt in 1996 but the stock remains overexploited (Brown and Gabriel 1998). The NEFSC autumn bottom trawl survey biomass index declined from the mid-1970's until 1991 when it reached a record low of 0.14 kg per tow (Brown and Gabriel 1998; Figure 14). Although it has increased somewhat since then (1.76 kg per tow in 1996) it remains significantly below former levels (Brown and Gabriel 1998).

RESEARCH NEEDS

Although we know more about winter flounder than many other species, there are many more questions waiting to be answered. The driving forces behind winter flounder movements are still poorly understood. Temperature certainly plays a role, but does not explain all movements. The role of light intensity, food availability, and predators needs further attention.

Although we speak about spawning habitat and juvenile habitat as if they are separate things it is clear that they must be linked somehow. If spawning habitat is lost through man's activities, is the adjacent juvenile habitat lost as well for lack of juveniles to fill it? Pinpointing and mapping of habitats through the use of GIS technology on a large scale and over different ontogenetic stages will help us to maintain a more holistic outlook on habitat.

The utilization of shallow bays and estuaries by winter flounder for spawning and nursery areas has been well documented. Less well studied is the utilization of nearby coastal waters. Lux and Kelly (1982) found winter flounder eggs at 13 coastal stations and 3 offshore stations and larvae at 17 coastal stations and 7 offshore stations between Provincetown to Cape Ann. A similar study by Howe (1973) also collected winter flounder eggs and larvae. Both studies generally collected relatively low densities of eggs and larvae but Howe (1973) showed that larval densities were highest at the mouths of estuaries. These collections probably represent eggs and larvae washed out of the estuaries by tidal flushing. Subsequent beam trawling in these areas failed to collect substantial numbers of YOY flounder indicating a low survival rate.

In contrast, Marine Research, Inc. (1986) reported good growth in winter flounder larvae that had been washed out of the Plymouth Harbor-Duxbury Bay estuary. Epibenthic sled collections of winter flounder eggs outside the estuary along the coast showed that spawning occurred there as well. The relative contribution of this coastal spawning to winter flounder recruitment needs further study.

The different components of these "stock complexes" need to be better described and their habitat preferences and needs documented. An attempt was made in 1980 to

separate stocks using eye lens proteins (Schenck and Saila 1982) but this effort only covered a small area near the Millstone Point area. The study showed that even in this small area there was a significant mixing of different stocks. A more comprehensive effort, spanning the entire range of the species needs to be done utilizing more modern techniques such as mitochondrial DNA.

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Table 1. Summary of life history and habitat parameters for winter flounder, *Pseudopleuronectes americanus*.

Life Stage	Temperature	Salinity	Dissolved Oxygen
Eggs [1]	Spawning initiated at about 3°C; highest percent hatch at 3-5°C; 18°C lethal.	Found from 10-32 ppt; salinity has little effect on survival or hatch.	Found at 11.1-14.2 mg/l.
Larvae [2]	No feeding or metamorphosis at 2°C; hatch from 1-12°C; larvae most abundant at 2-15°C.	Found at 3.2-30 ppt; higher on Georges Bank.	Found at 10.0-16.1 mg/l.
YOY [3]	Found at 2-29.4°C; Laboratory study suggests preferred temperature is 19.5°C; 30°C may be lethal.	Found at 23-33 ppt; 5 ppt suggested by laboratory study as lower avoidance salinity.	Constant 2.2 mg/l or diurnal variation from 2.6-6.4 mg/l adversely affects growth.
Juveniles [4]	Commonly found at 10-25°C during summer and fall.	Collected 19-21 ppt; 10 ppt suggested as lower avoidance level.	
Adults [5]	0.6-23°C; 12-15°C suggested as preferred; upper incipient lethal limit is 27°C.	Found at 15-33 ppt.	Lower dissolved oxygen associated with lower mean length of catch suggesting avoidance by larger fish or reduced growth.

[1] Breder 1923; Scott 1929; Bigelow and Schroeder 1953; Pearcy 1962; Williams 1975; Rogers 1976; Buckley 1982; Crawford and Carey 1985; Scarlett and Allen 1989; Monteleone 1992
[2] Bigelow and Schroeder 1953; Pearcy 1962; Dovel 1967, 1971; Buckley 1982; Frank and Leggett 1983; Scarlett and Allen 1989; Monteleone 1992
[3] Pearcy 1962; Richards and Castagna 1970; Briggs and O'Connor 1971; Oviatt and Nixon 1977; Pierce and Howe 1977; Reynolds and Casterlin 1985; Heck *et al*. 1989; Bejda *et al.* 1992; Rountree and Able 1992
[4] Pearcy 1962; Oviatt and Nixon 1977; Casterlin and Reynolds 1982; Reynolds and Casterlin 1985; Carlson *et al.* 1997
[5] Breder 1923; McCracken 1963; Olla *et al.* 1969; Richards and Castagna 1970; Haedrich and Haedrich 1974; Howe and Coates 1975; Tyler and Dunn 1976; Oviatt and Nixon 1977; Van Guelpen and Davis 1979; Jeffries and Terceiro 1985; Reynolds and Casterlin 1985; Howell and Simpson 1994; Carlson *et al.* 1997

Table 1. cont'd.

Life Stage	Depth	Substrate	Vegetation	Currents
Eggs [1]	Found at 0.3-4.5 m (inshore); 90 m or less on Georges Bank.	Mud to sand or gravel.	Diatom mats, drifting macroalgae.	
Larvae [2]	1-4.5 m inshore.	Fine sand, gravel.		Hydrodynamics work to retain larvae in nursery areas.
YOY [3]	0.5-12 m inshore.	Mud to sand with shell or leaf litter.	*Ulva*, eelgrass and unvegetated adjacent areas.	
Juveniles [4]	Peak abundance of flounder less than 200 mm occurs in 18-27 m of water in Long Island Sound in April and May. In Canadian waters, juveniles were most abundant at 11-18 m. Less than 100 m offshore.	Equally abundant on mud or sand shell.		
Adults [5]	Most 1-30 m inshore, shallowest during spawning; less than 100 m offshore.	Mud, sand, cobble, rocks, boulders.		

[1] Scott 1929; Bigelow and Schroeder 1953; Pearcy 1962; Anonymous 1972; Crawford and Carey 1985; Scarlett and Allen 1989; Monteleone 1992
[2] Pearcy 1962; Frank and Leggett 1983; Crawford and Carey 1985; Scarlett and Allen 1989; Monteleone 1992
[3] Briggs and O'Connor 1971; Heck *et al.* 1989; Saucerman 1990; Sogard 1992; Howell and Molnar 1995; Gottschall *et al.*, in review
[4] McCracken 1963; Richards 1963
[5] Breder 1923; Mansueti 1962; McCracken 1963; Olla *et al.* 1969; Kennedy and Steele 1971; Van Guelpen and Davis 1979; Macdonald and Green 1986; Steimle *et al.* 1993

Table 1. cont'd.

Life Stage	Predators	Prey	Migration
Eggs [1]			
Larvae [2]	Mackerel, *Sarsia tubulosa*	Nauplii, invertebrate eggs, protozoans, polychaetes	
YOY [3]	*Crangon* sp., summer flounder, striped searobin (*Prionotus evolans*)	Amphipods, copepods, polychaetes, bivalve siphons	Limited; deeper for first winter.
Juveniles [4]	Cormorants, snapper bluefish, gulls	Sand dollars, bivalve siphons, polychaetes, amphipods, *Crangon* sp.	Movement to deeper waters as size increases.
Adults [5]	Goosefish, spiny dogfish, sea ravens, striped bass, seals, sculpins	Amphipods, polychaetes, bivalves or siphons, capelin eggs, crustaceans	Inshore in fall; offshore in spring; long post-spawn migrations in some fish.

[2] Pearcy 1962; Dovel 1971; Frank and Leggett 1983
[3] Linton 1921; Poole 1964; Saucerman 1990; Saucerman and Deegan 1991; Witting and Able 1993; Howell and Molnar 1995; Witting and Able 1995; Manderson *et al*. 1999; Stehlik and Meise, in press
[4] Linton 1921; Howe *et al*. 1976; Reynolds and Casterlin 1985; Franz and Tanacredi 1992; Carlson *et al.* 1997; Stehlik and Meise, in press
[5] Medcoff and MacPhail 1952; Bigelow and Schroeder 1953; Dickie and McCracken 1955; Fisher and Mackenzie 1955; Saila 1961; Mansfield 1967; Olla *et al.* 1969; Kennedy and Steele 1971; Tyler 1971a; Haedrich and Haedrich 1974; Howe and Coates 1975; Tyler and Dunn 1976; Van Guelpen and Davis 1979; Azarovitz 1982; Macdonald 1983; Jeffries and Terceiro 1985; Macdonald and Green 1986; Phelan 1992; Martell and McClelland 1994; Steimle *et al*. 1993; Carlson *et al*. 1997

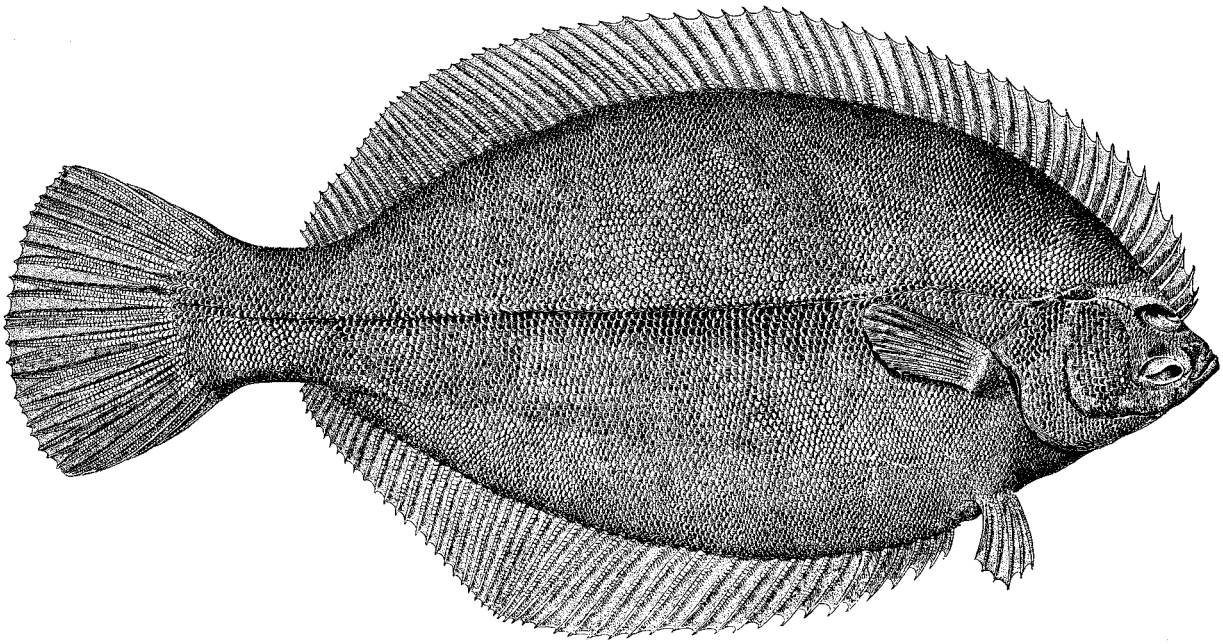


Figure 1. The winter flounder, *Pseudopleuronectes americanus* (Walbaum) (from Goode 1884).

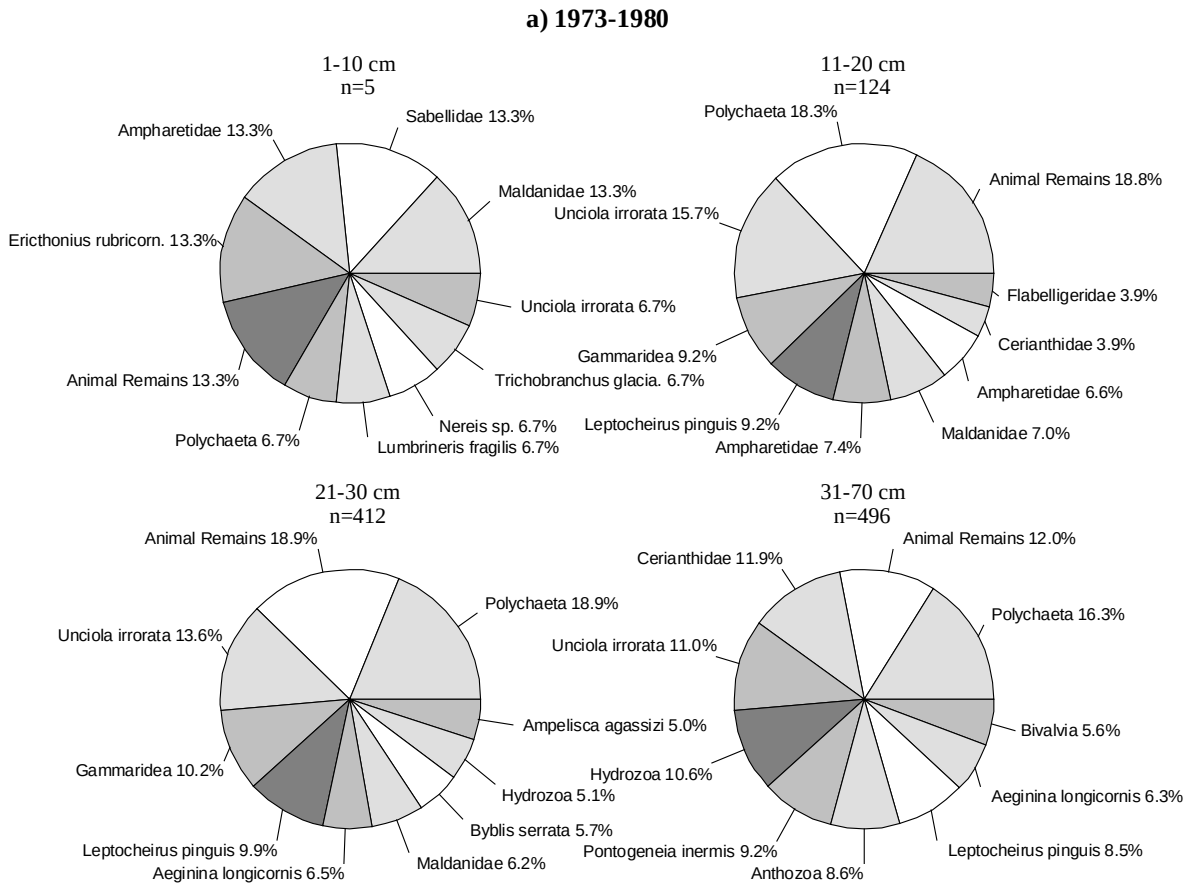


Figure 2. Abundance (percent occurrence of 10 most common prey items) of the major prey items of winter flounder, by size class, collected during NEFSC bottom trawl surveys from 1973-1980 and 1981-1990. The category “animal remains” refers to unidentifiable animal matter. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details].

b) 1981-1990

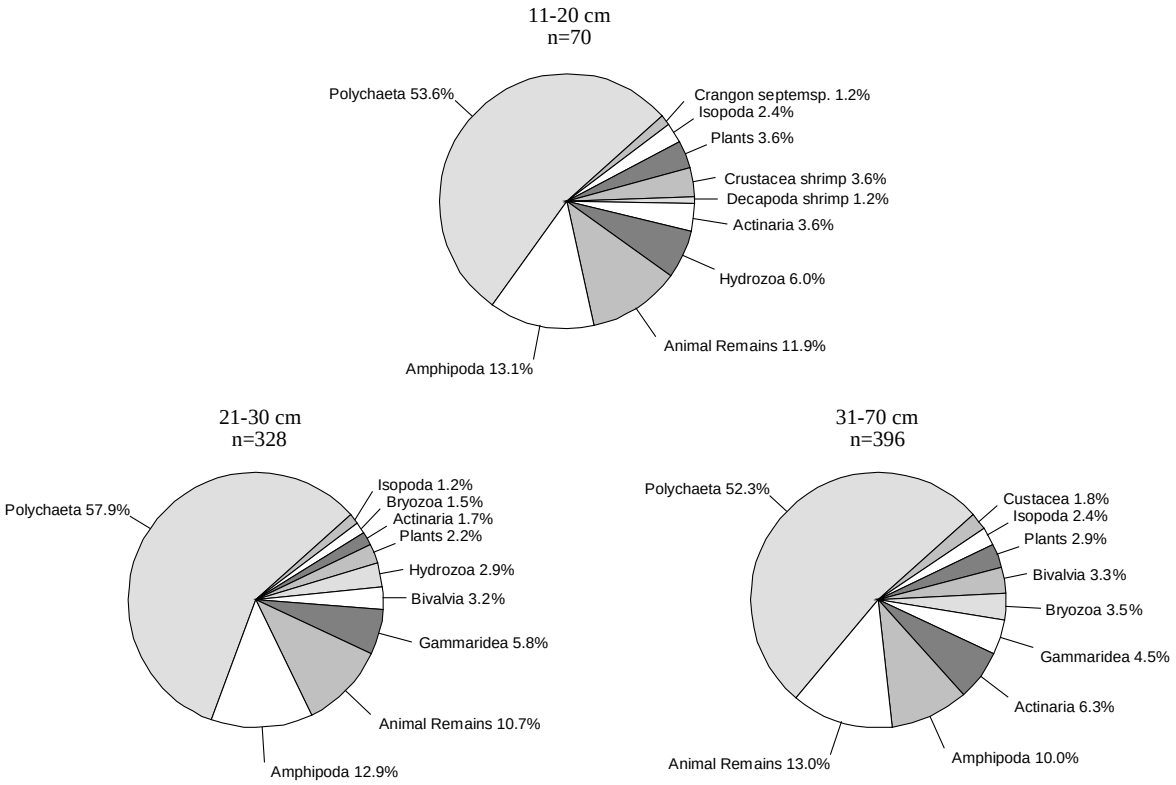


Figure 2. cont'd.

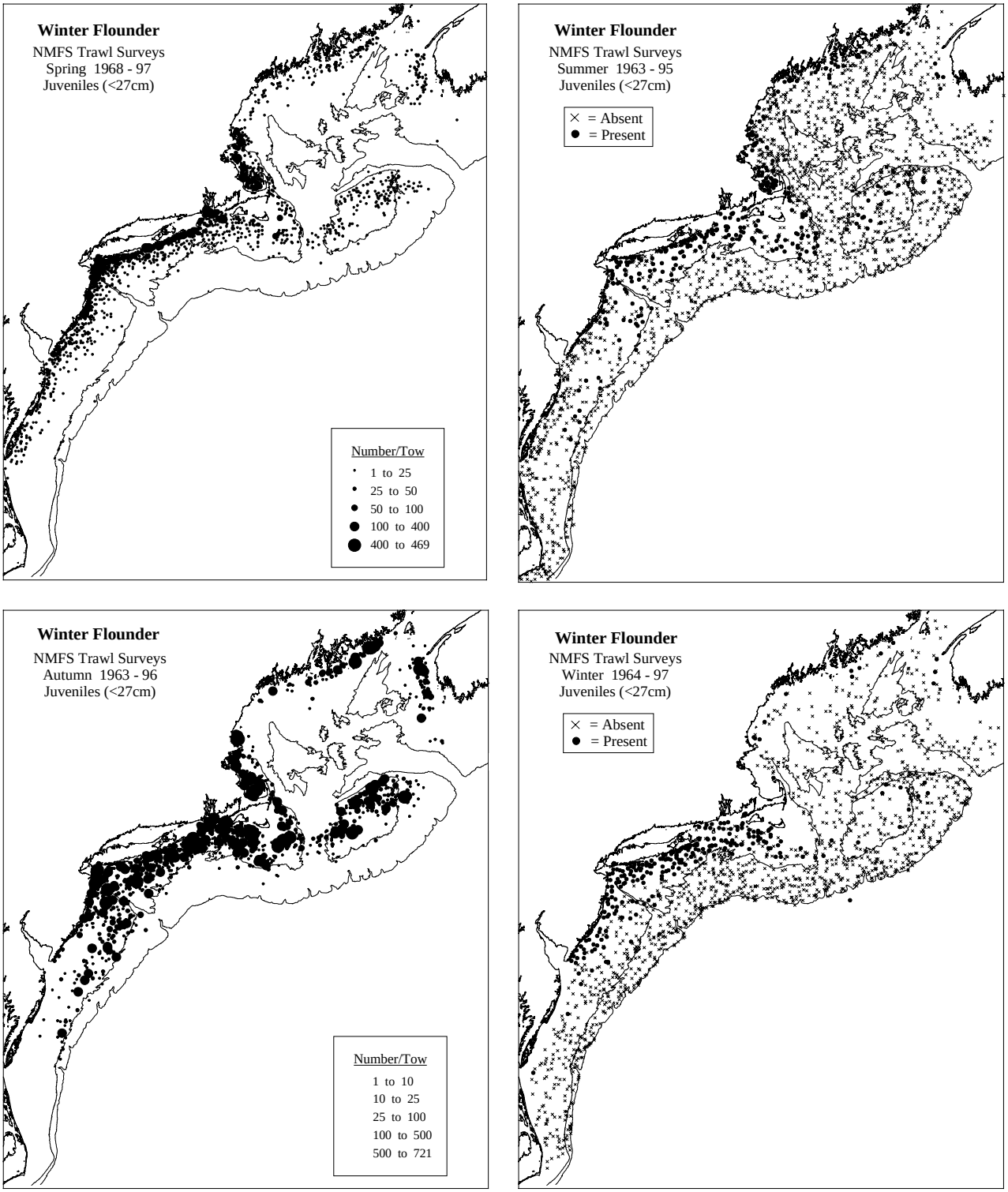


Figure 3. Distribution and abundance of juvenile and adult winter flounder collected during NEFSC bottom trawl surveys during all seasons from 1963-1997. Densities are represented by dot size in spring and fall plots, while only presence and absence are represented in winter and summer plots [see Reid *et al.* (1999) for details].

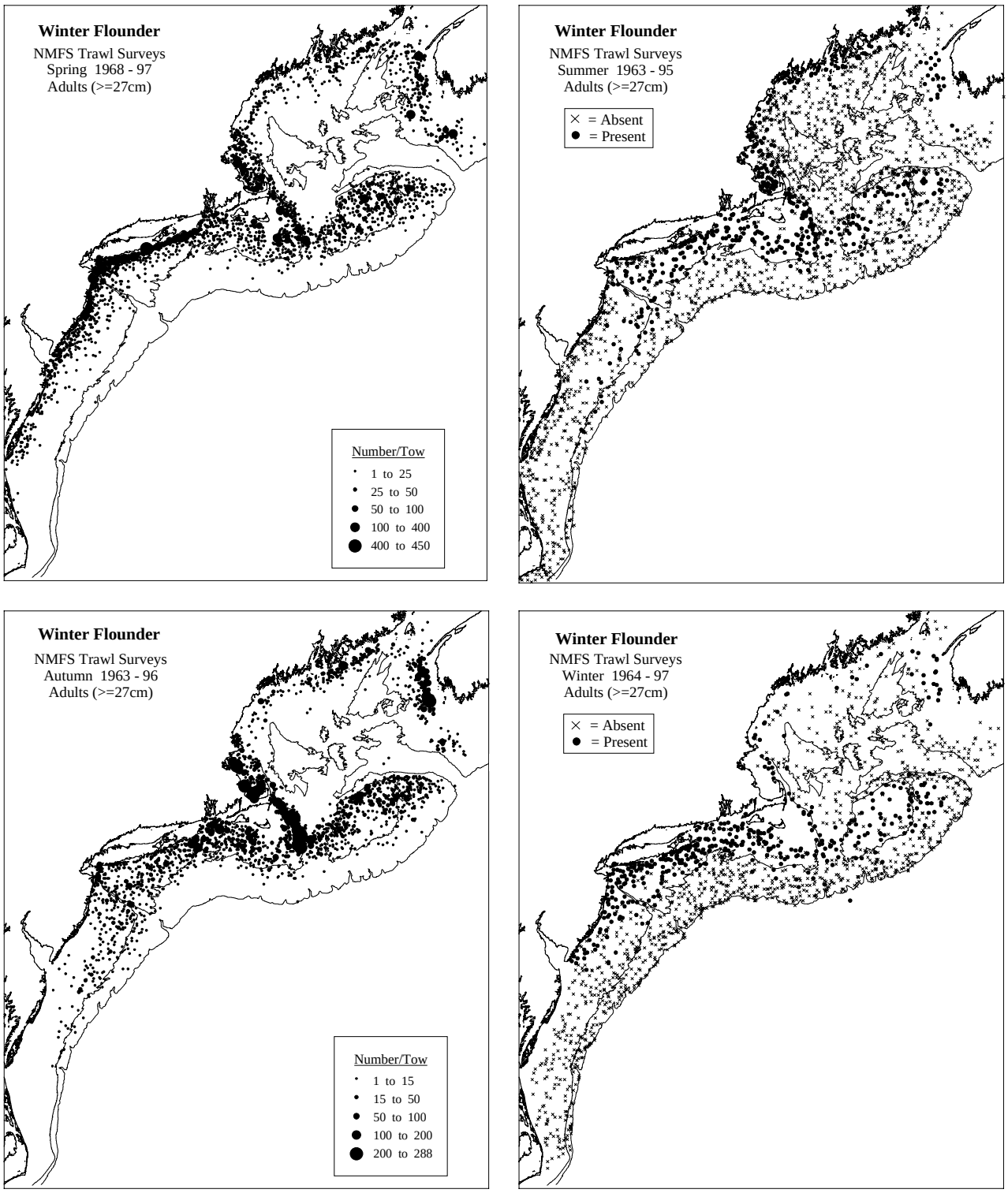


Figure 3. cont'd.

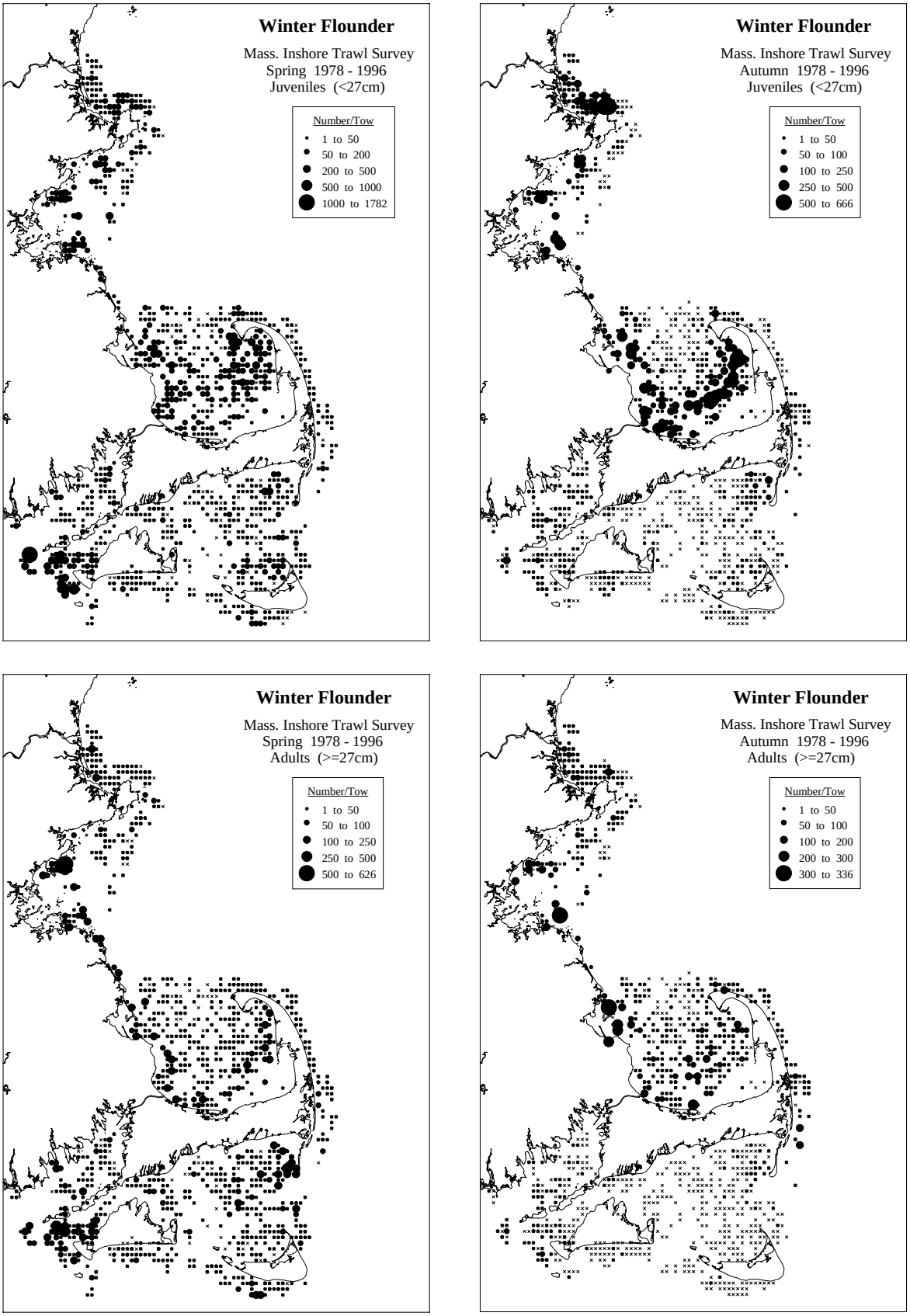


Figure 4. Distribution and abundance of juvenile and adult winter flounder in Massachusetts coastal waters collected during the spring and autumn Massachusetts trawl surveys, 1978-1996 [see Reid *et al.* (1999) for details].

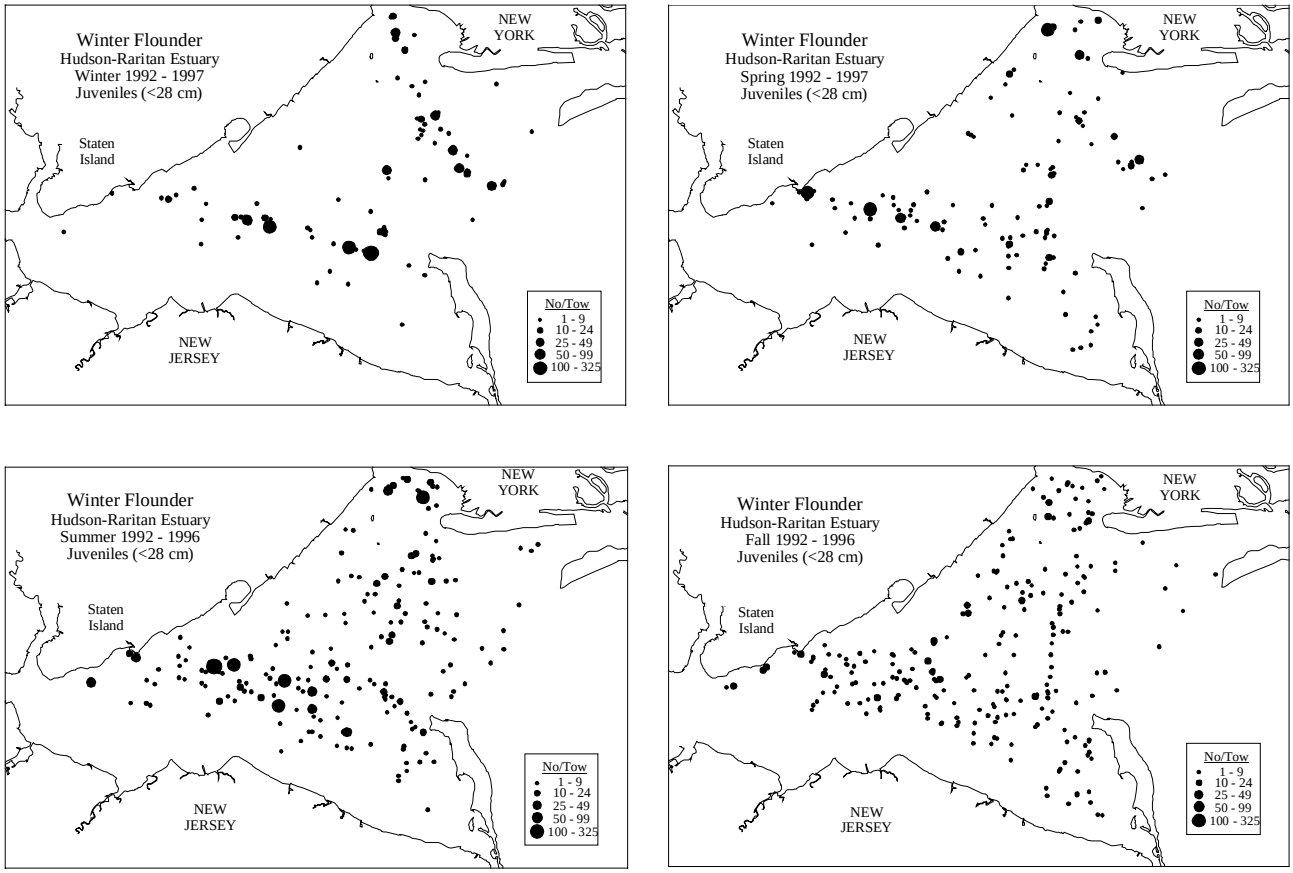
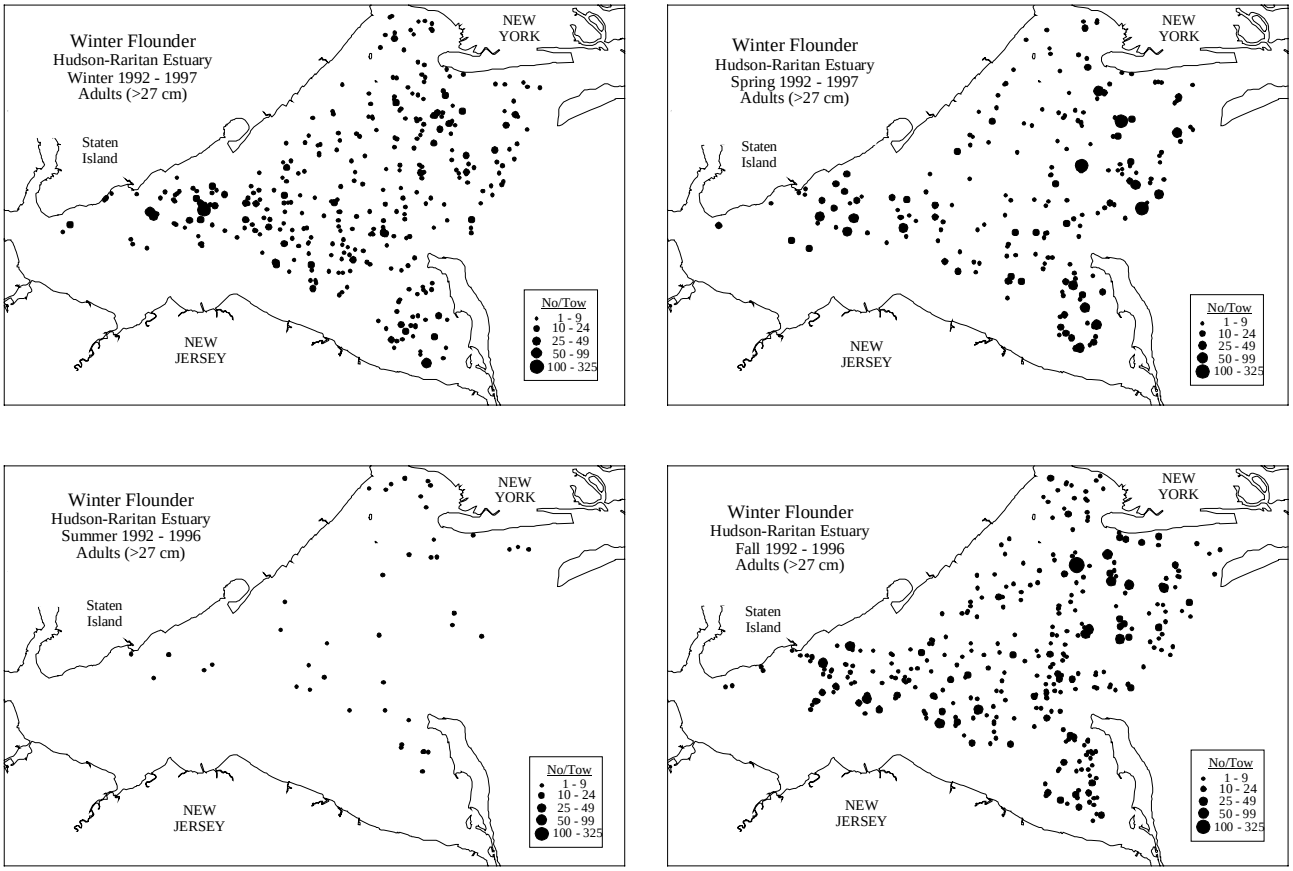


Figure 5. Distribution and abundance of juvenile and adult winter flounder collected in the Hudson-Raritan estuary, based on Hudson-Raritan trawl surveys during winter (January-March), spring (April and June), summer (July–August), and fall (October-December) from January 1992 to June 1997 [see Reid *et al.* (1999) for details].



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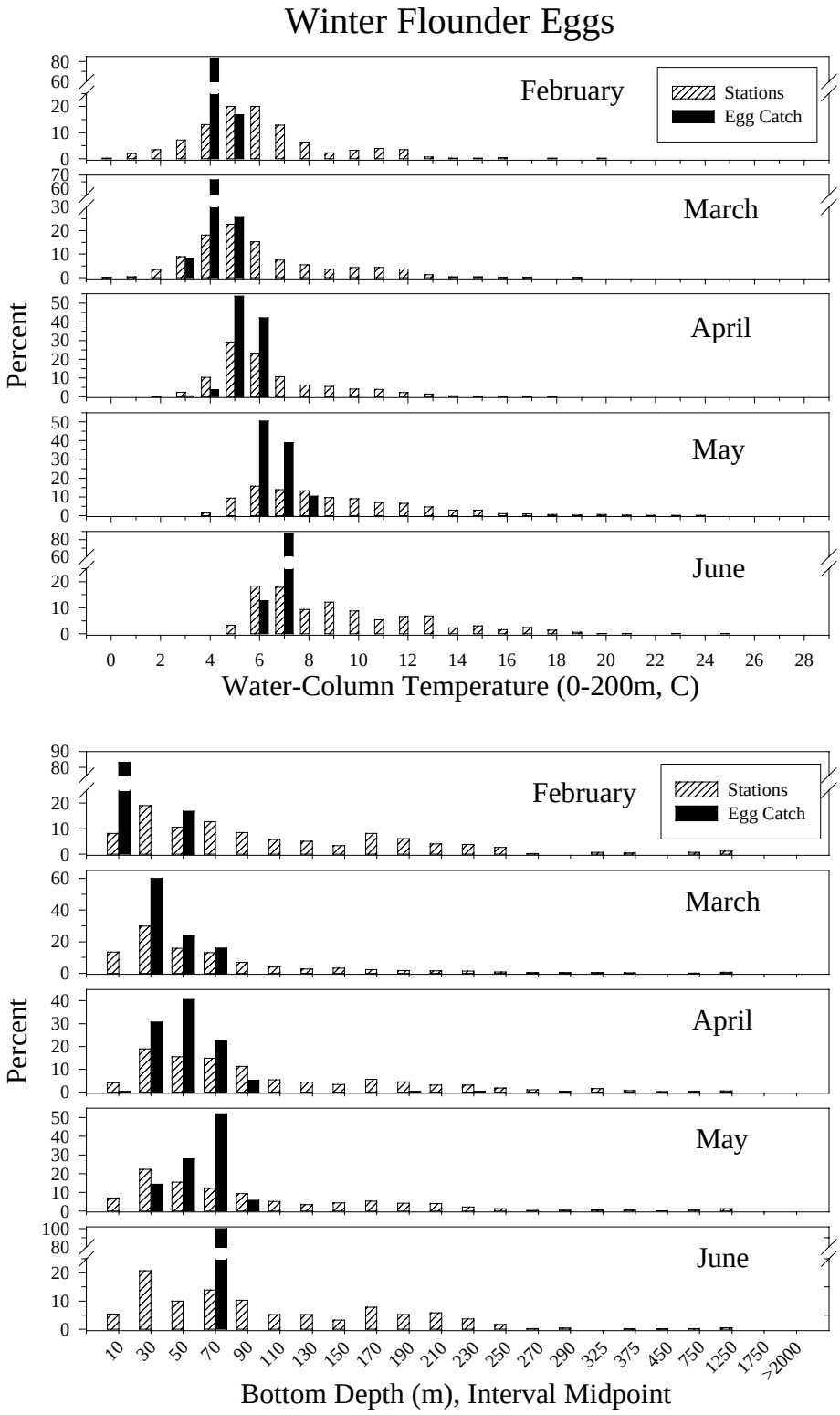


Figure 6. Abundance of winter flounder eggs relative to water column temperature (to a maximum of 200 m) and bottom depth from NEFSC MARMAP ichthyoplankton surveys, February to June, 1978-1987 (all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

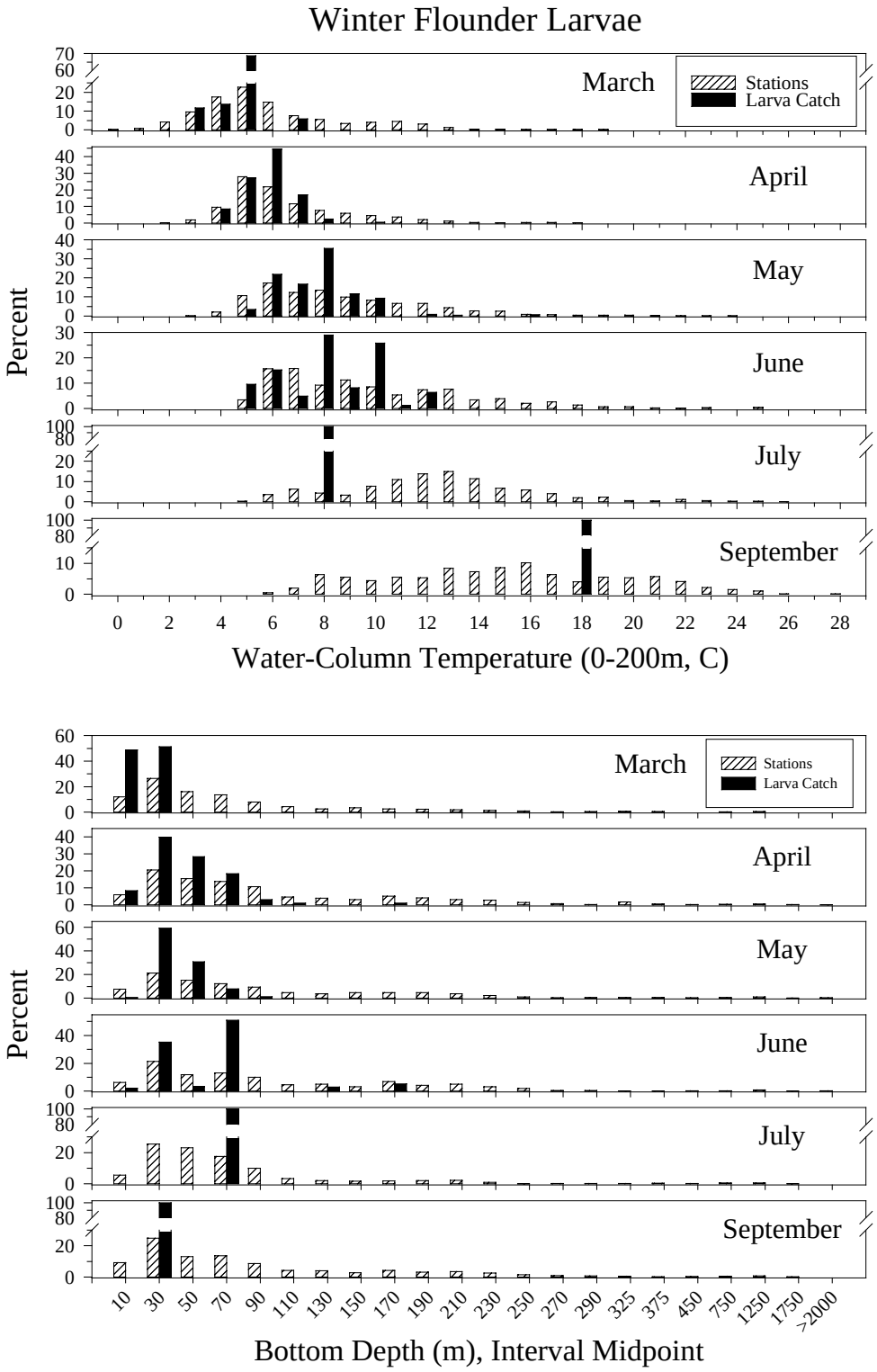


Figure 7. Abundance of winter flounder larvae relative to water column temperature (to a maximum of 200 m) and bottom depth from NEFSC MARMAP ichthyoplankton surveys, March to September, 1977-1987 (all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

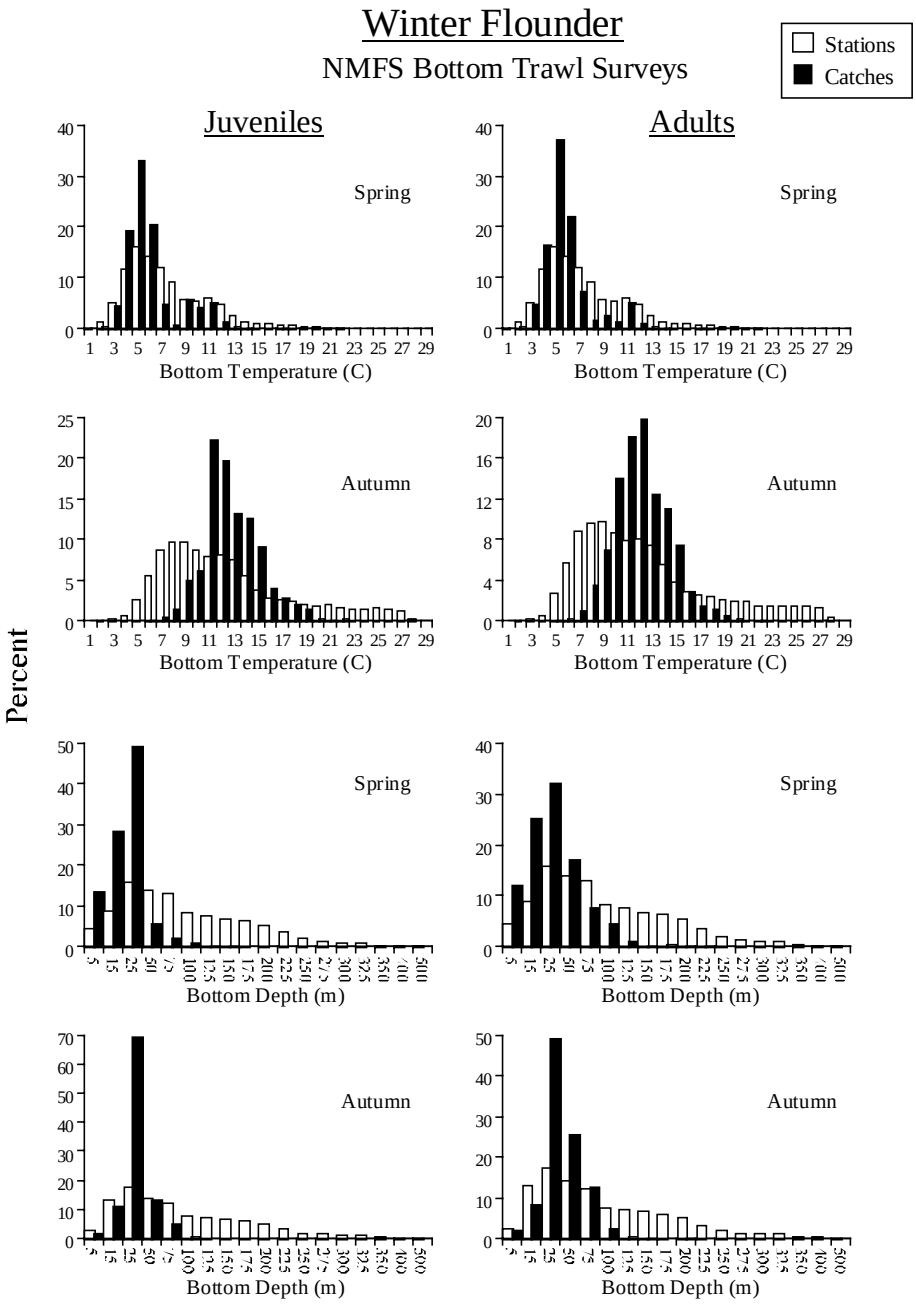


Figure 8. Abundance of juvenile and adult winter flounder relative to bottom water temperature and depth based on spring and autumn NEFSC bottom trawl surveys. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

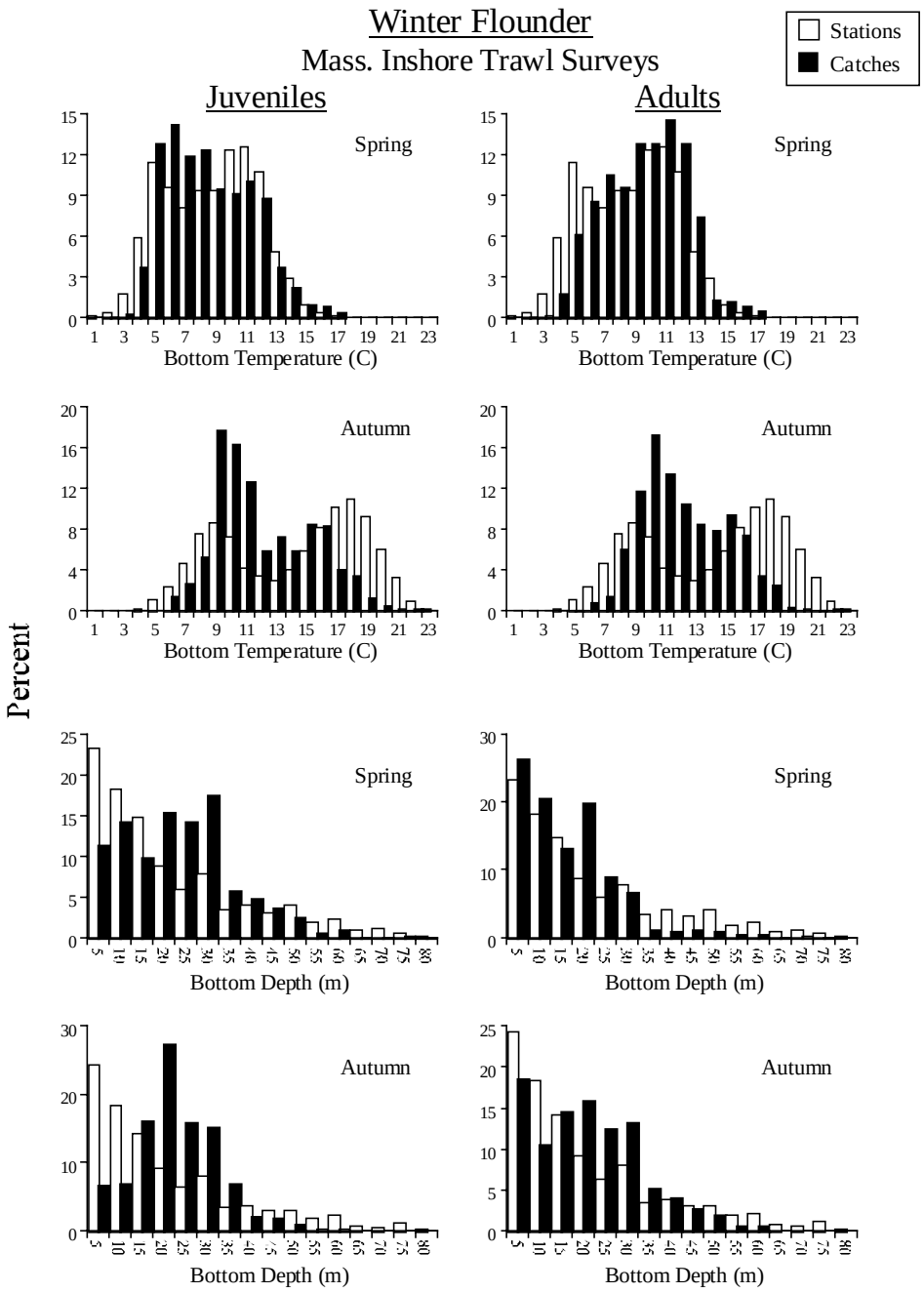


Figure 9. Abundance of juvenile and adult winter flounder relative to bottom water temperature and depth based on Massachusetts inshore bottom trawl surveys (spring and autumn 1978-1996, all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

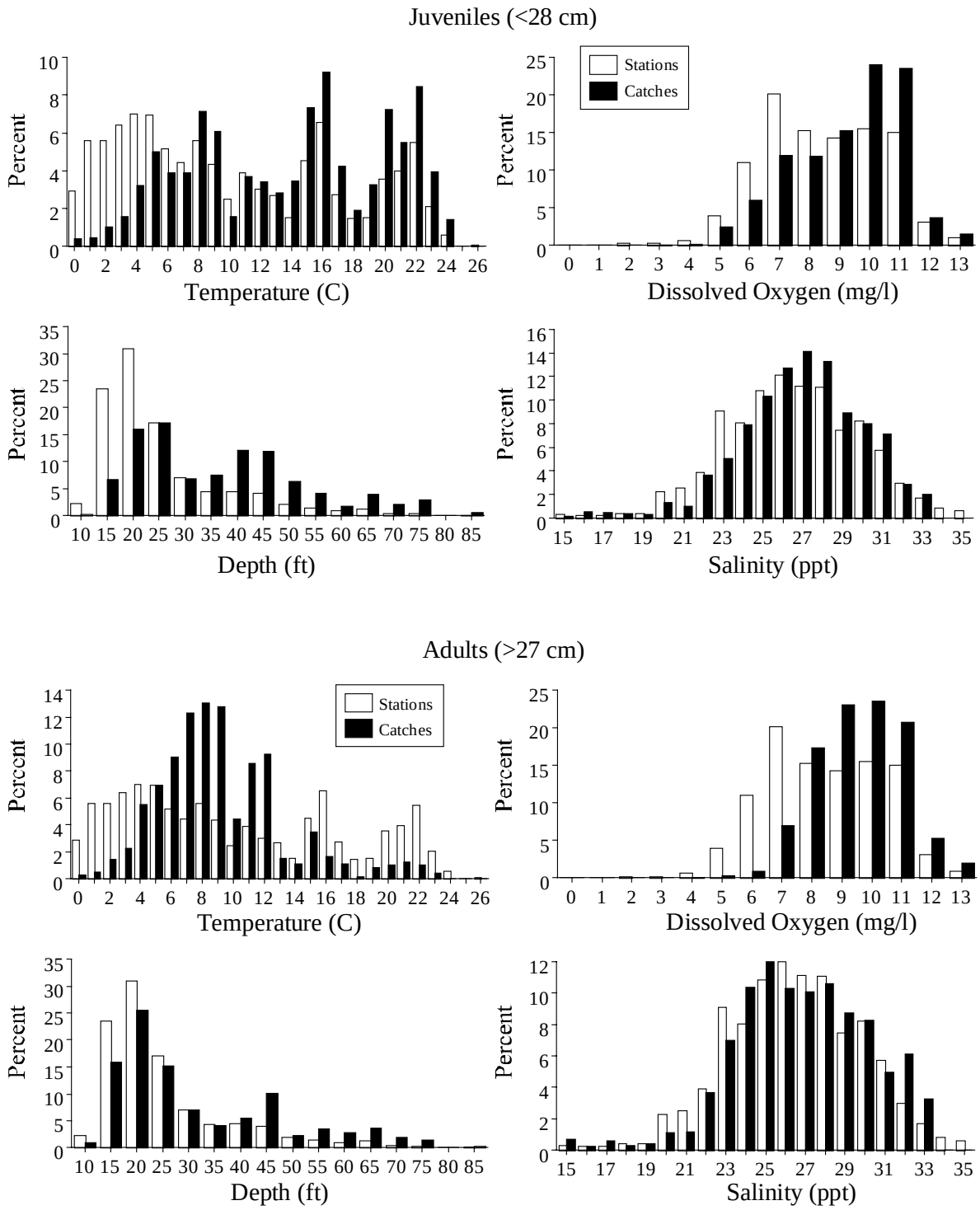


Figure 10. Abundance of juvenile and adult winter flounder relative to bottom water temperature, dissolved oxygen, depth, and salinity from Hudson-Raritan estuary trawl surveys (January 1992 - June 1997, all years combined).

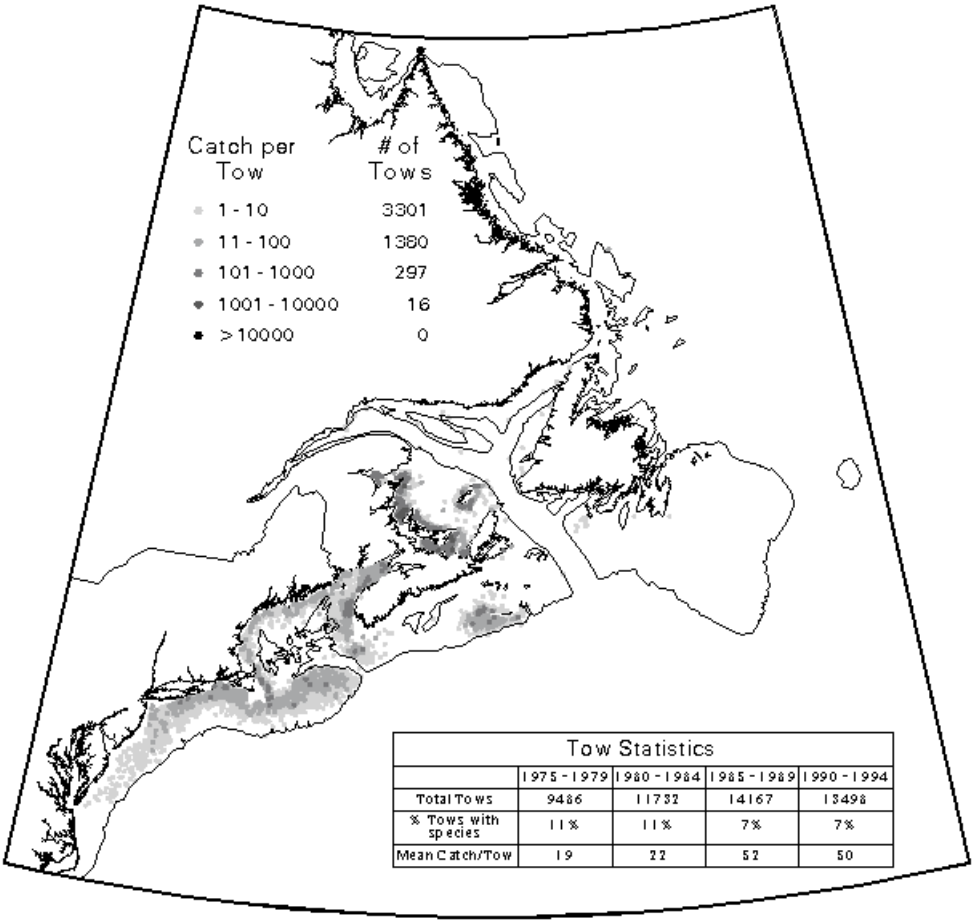


Figure 11. Distribution and abundance of winter flounder from Newfoundland to Cape Hatteras based on research trawl surveys conducted by Canada (DFO) and the United States (NMFS) from 1975-1994 (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

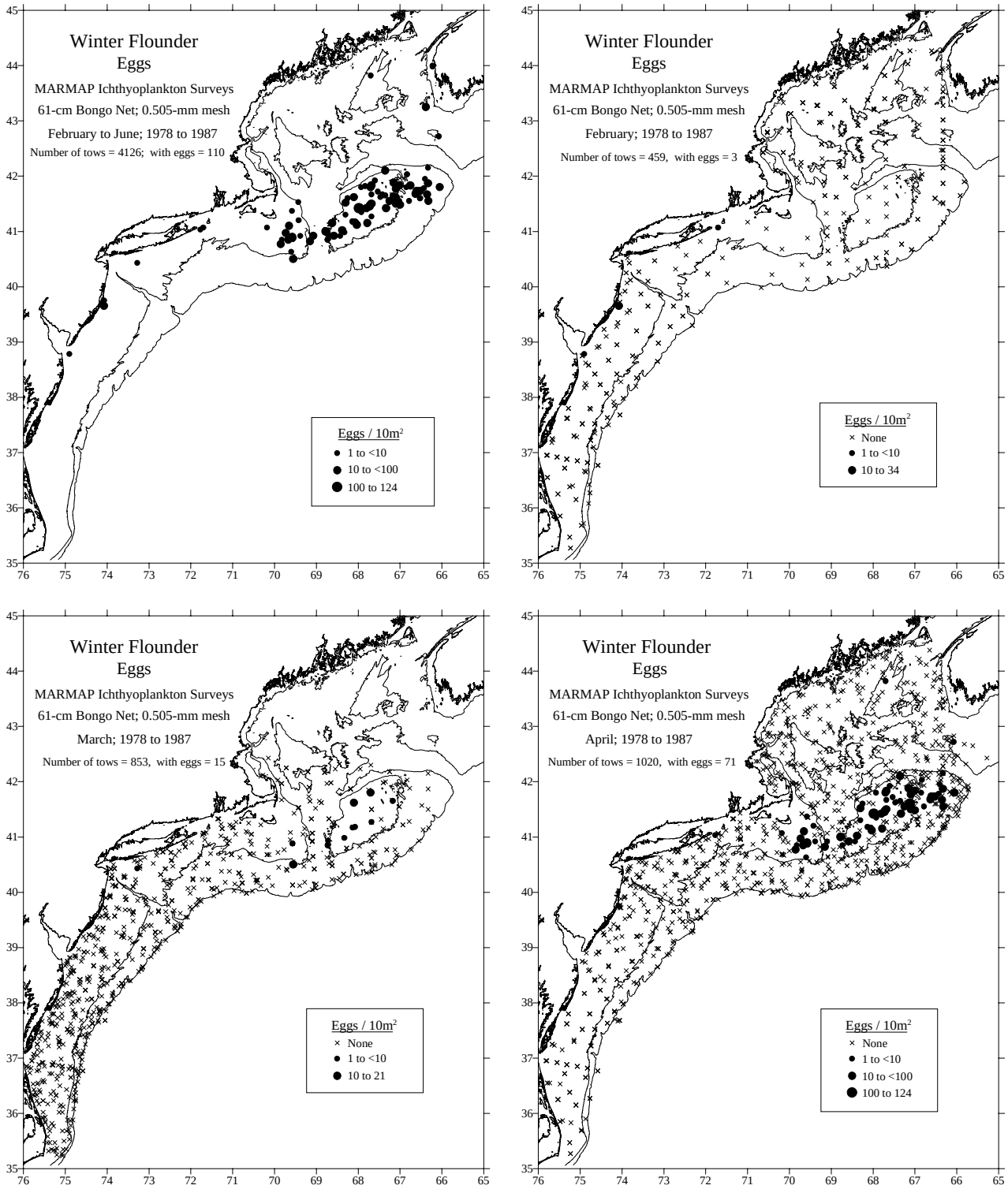


Figure 12. Distribution and abundance of winter flounder eggs collected during NEFSC MARMAP ichthyoplankton surveys from February to June, 1978-1987 [see Reid *et al.* (1999) for details].

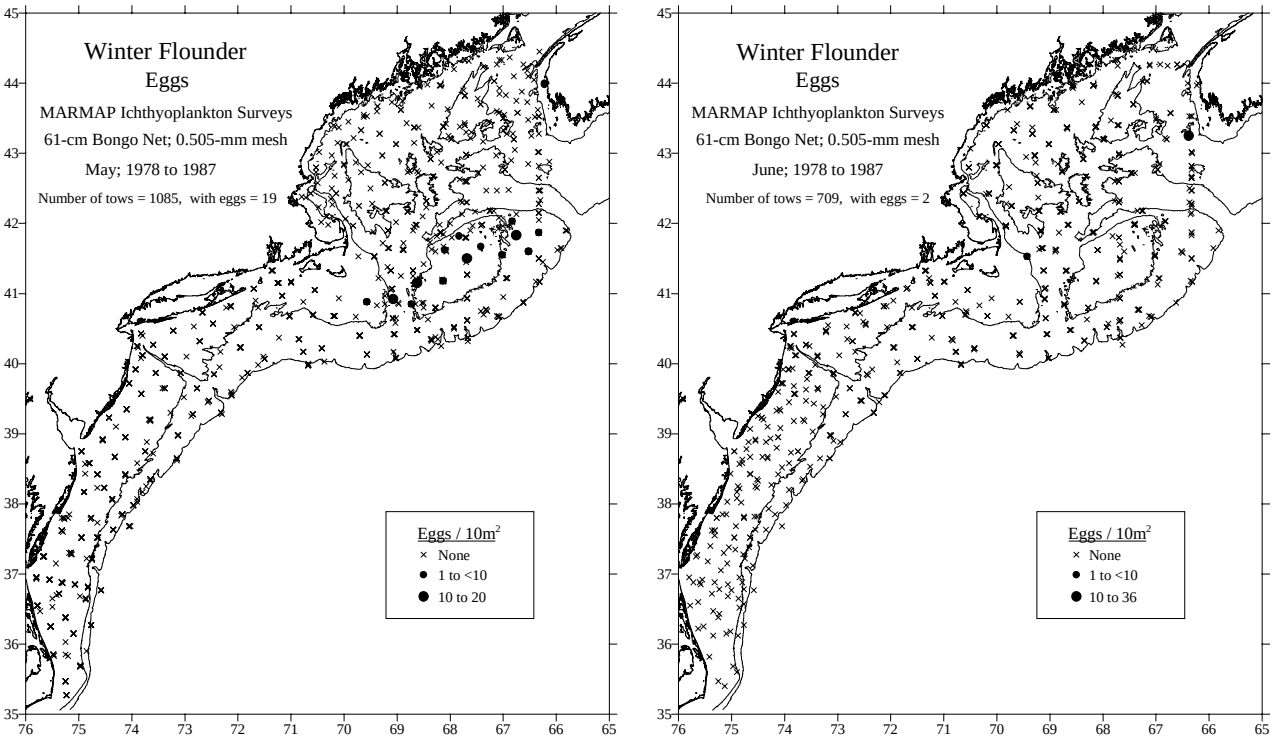


Figure 12. cont'd.

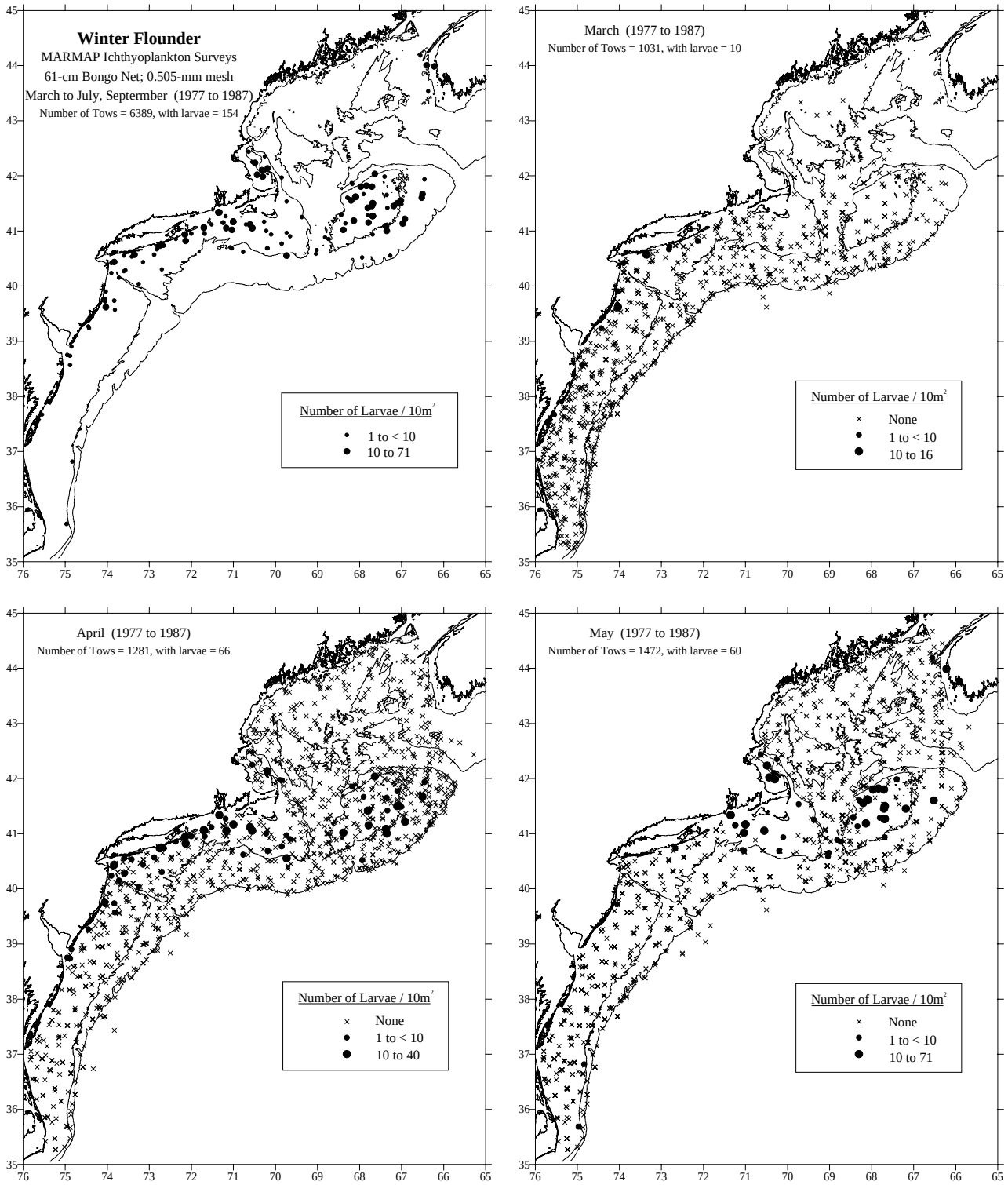
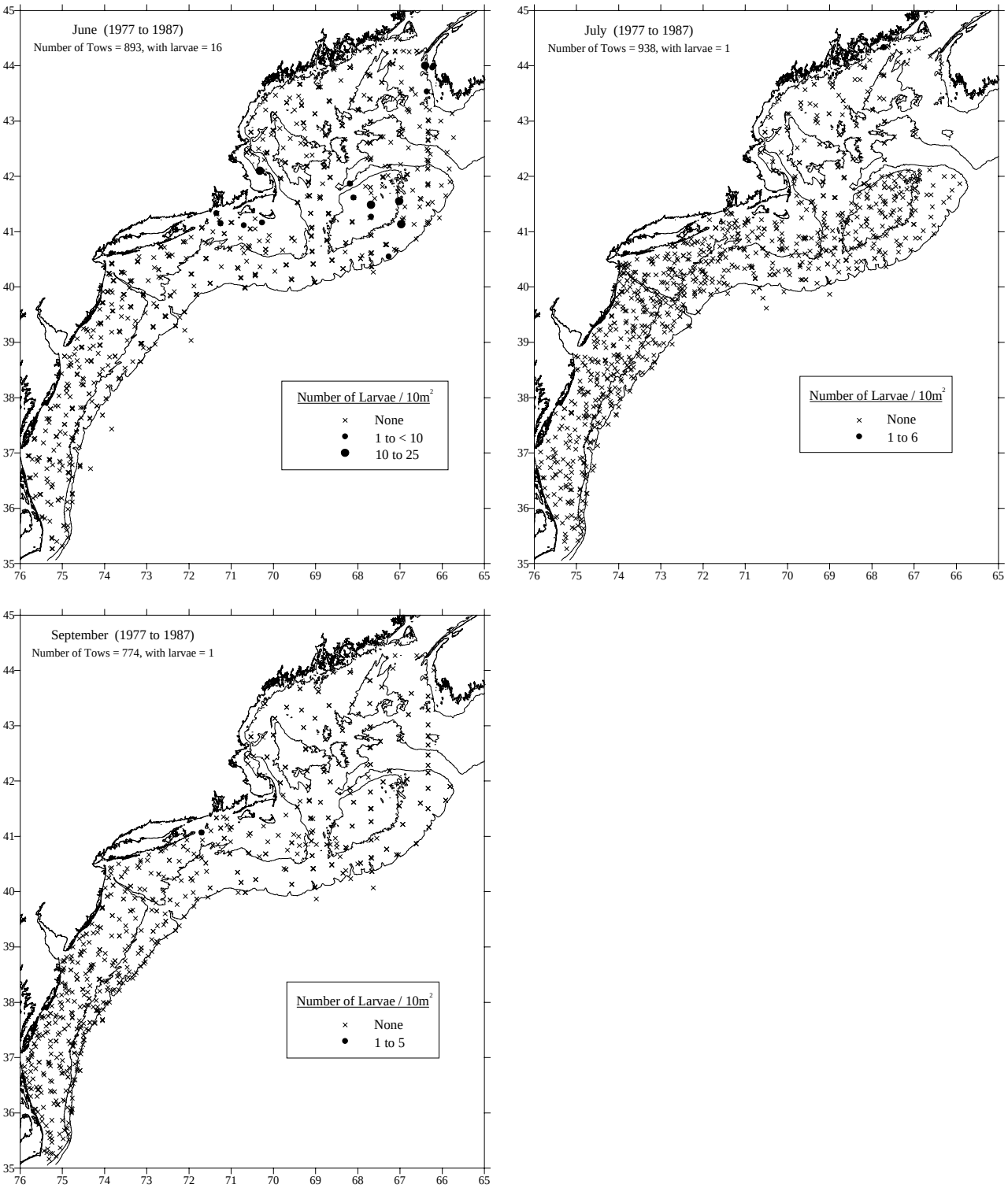


Figure 13. Distribution and abundance of winter flounder larvae collected during NEFSC MARMAP ichthyoplankton surveys from March to July, and September, 1977-1987 [see Reid *et al.* (1999) for details].



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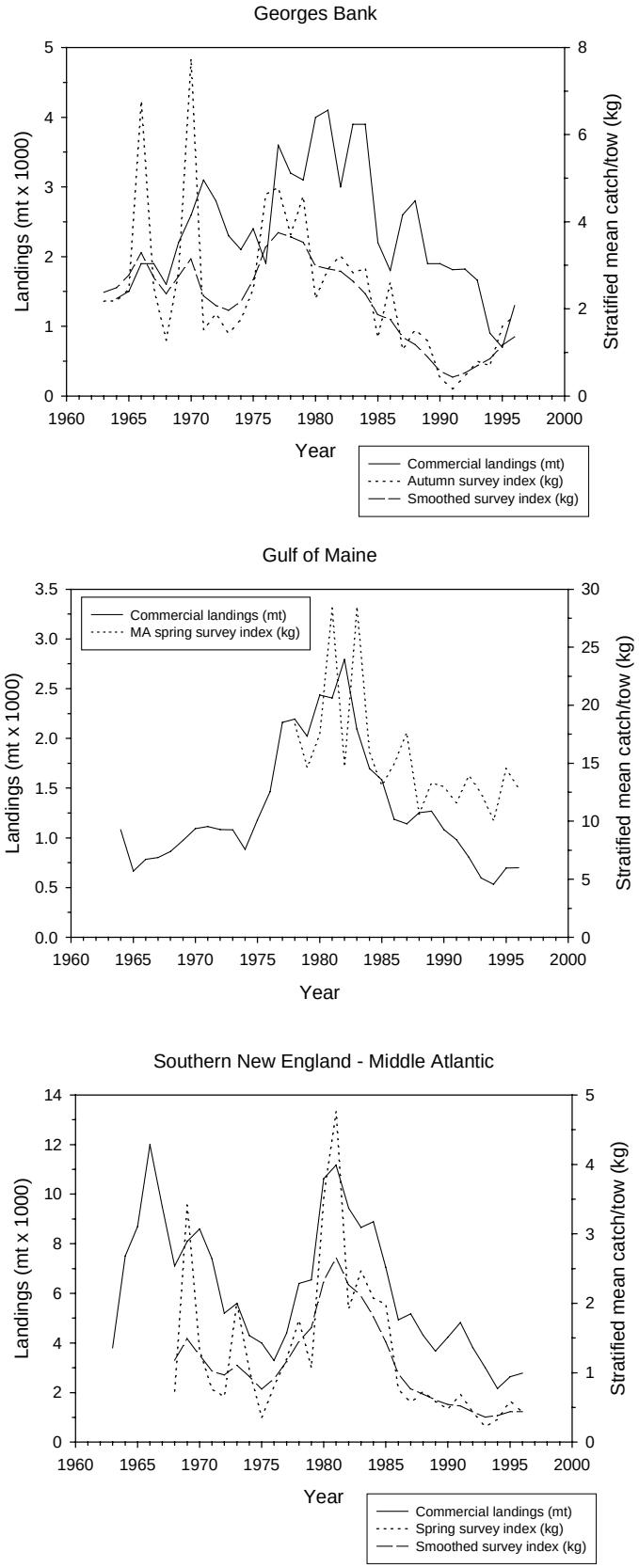

Figure 14. Commercial landings and survey indices (from the NEFSC bottom trawl surveys) for winter flounder stocks from Georges Bank, the Gulf of Maine, and southern New England-Middle Atlantic Bight.

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This series represents a secondary level of scientific publishing in the National Marine Fisheries Service (NMFS). For all issues, the series employs thorough internal scientific review, but not necessarily external scientific review. For most issues, the series employs rigorous technical and copy editing. Manuscripts that may warrant a primary level of scientific publishing should be initially submitted to one of NMFS's primary series (*i.e., Fishery Bulletin, NOAA Technical Report NMFS,* or *Marine Fisheries Review*).

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STANDARD MAIL A

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific ournals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series includes: data reports of long-term or large area studies; synthesis reports for major resources or habitats; annual reports of assessment or monitoring programs; documentary reports of oceanographic conditions or phenomena; manuals describing field and lab techniques; literature surveys of major resource or habitat topics; findings of task forces or working groups; summary reports of scientific or technical workshops; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing. Limited free copies are available from authors or the NEFSC. Issues are also available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series includes: data reports on field and lab observations or experiments; progress reports on continuing experiments, monitoring, and assessments; background papers for scientific or technical workshops; and simple bibliographies. Issues receive internal scientific review but no technical or copy editing. No subscriptions. Free distribution of single copies.

Fishermen's Report **and** ***The Shark Tagger*** -- The ***Fishermen's Report*** (FR) is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of the FR; copies are available through free subscription. ***The Shark Tagger*** (TST) is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of the TST; copies are available only to participants in the tagging program.

To obtain a copy of a technical memorandum or a reference document, or to subscribe to the fishermen's report, write: Research Communications Unit, Northeast Fisheries Science Center, 166 Water St., Woods Hole, MA 02543-1026. An annual list of NEFSC publications and reports is available upon request at the above address. Any use of trade names in any NEFSC publication or report does not imply endorsement.

NOAA Technical Memorandum NMFS-NE-141

Essential Fish Habitat Source Document:

Atlantic Mackerel, *Scomber scombrus*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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NOAA Technical Memorandum NMFS-NE-141

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Essential Fish Habitat Source Document:

Atlantic Mackerel, *Scomber scombrus*, Life History and Habitat Characteristics

Anne L. Studholme, David B. Packer, Peter L. Berrien, Donna L. Johnson, Christine A. Zetlin, and Wallace W. Morse

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Woods Hole, Massachusetts

September 1999

Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

---

[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, CHIEF
ECOSYSTEMS PROCESSES DIVISION
NORTHEAST FISHERIES SCIENCE CENTER

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INTRODUCTION

Atlantic mackerel, *Scomber scombrus* L. (Figure 1), is a fast swimming, pelagic schooling species distributed in the northwest Atlantic from the Gulf of St. Lawrence to Cape Lookout, North Carolina (Sette 1943, 1950; Anderson 1976; MAFMC 1994). While there are two separate spawning contingents in the northwest Atlantic (Sette 1950), since 1975 all mackerel in this area have been assessed as a unit stock (Anderson 1982) and are considered one stock for management purposes (MAFMC 1994). Atlantic mackerel are managed under the Mid-Atlantic Fishery Management Plan for Atlantic mackerel, squid and butterfish (MAFMC 1994). This EFH source document provides information on the distribution, life history and habitat characteristics of Atlantic mackerel in the northwest Atlantic extending from Cape Hatteras to Georges Bank and the Gulf of Maine.

LIFE HISTORY

A brief synopsis of the life history of Atlantic mackerel is provided in Amendment #5 to the Fishery Management Plan for Atlantic Mackerel, Squid and Butterfish Fisheries (MAFMC 1994). More specific information is provided here and in other reviews (see Sette 1943, 1950; Bigelow and Schroeder 1953; Collette, in prep.). Since there is an important winter fishery on Atlantic mackerel on the eastern continental shelf where they occur (Maguire *et al*. 1987), the two major spawning contingents (see below) are managed as a single transboundary stock. Thus, where appropriate, information will be provided on both northern and southern groups.

EGGS

The eggs of Atlantic mackerel are pelagic and spherical, ranging in size from 1.01-1.28 mm (avg. = 1.3 mm) in diameter, and have one oil globule ranging from 0.22-0.38 mm (avg. = 0.29 mm) in diameter (Berrien 1975). Sampling in the Gulf of St. Lawrence indicates that egg size decreased over time and in relation to ambient temperatures (Ware 1977).

LARVAE

Larvae average about 3.1-3.3 mm standard length (SL) at hatching and have a large yolk sac; the eyes are large and unpigmented (Sette 1943; Bigelow and Schroeder 1953; Colton and Marak 1969; Berrien 1975; Ware and Lambert 1985; Scott and Scott 1988). Hatching occurs at 90-120 h post-fertilization at an average temperature of 13.8°C (Berrien 1975). The 50% threshold for the onset of feeding is 3.8 mm (Ware and Lambert 1985). At about 4-6 mm the yolk sac is absorbed by which time there is a considerable change in body pigmentation and by 192 h, teeth are present (Berrien 1975). Larvae undergo major changes in body form and Sette (1943) describes a transition stage between the larval and post-larval stages (~ 9-10 mm) where fins are in various stages of development. This probably enhances successful prey capture as well as predator avoidance (Ware and Lambert 1985). To maintain rapid growth rates, with average digestive times of 1-2 h, Peterson and Ausubel (1984) concluded that the larvae must feed constantly.

JUVENILES

Post-larvae gradually transform from planktonic to swimming and schooling behavior at about 30-50 mm (Sette 1943). Fish reach a length of about 50 mm in approximately two months at which time they closely resemble adults and reach 20 cm in December after about one year of growth (Sette 1943; Bigelow and Schroeder 1953; Anderson and Paciorkowski 1980; Berrien 1982; Collette, in prep.). Kendall and Gordon (1981) show somewhat faster larval and juvenile growth rates based on daily growth increments from otoliths taken from fish collected in the Middle Atlantic Bight; i.e., approximately 70-80 mm in two months; however, these were not verified by comparison with fish of known age. Ware and Lambert (1985) found that in St. Georges Bay, Nova Scotia, at 15-17°C, growth rates of juveniles (> 15 mm) averaged 0.73 mm/d from birth to metamorphosis, similar to the estimates by Kendall and Gordon (1981). Using daily growth rings, D'Amours *et al*. (1990) estimated that young mackerel from the northern contingent would grow faster earlier in their first growing season which would be consistent with Sette's (1950) conclusions. However, Simard *et al*. (1992) calculated that growth curves of juvenile Atlantic mackerel, based on otolith samples from the northern and southern spawning groups were not significantly different at least up to 90 days in age.

ADULTS

By the end of their second year, Atlantic mackerel attain a size of about 26 cm and after five years about 33 cm (Anderson 1973; Isakov 1973; Stobo and Hunt 1974). Fish that are 6 years old can reach a length of 39-40 cm. Based on studies of Canadian mackerel, MacKay (1967) theorized that growth is population density dependent; i.e., that abundant year classes grow more slowly than less abundant year classes, although Moores *et al*. (1975) did not find this to be true for Newfoundland fish. Overholtz (1989) found the 1982 cohort to be one of the slowest growing on record; it is one of the largest recruiting year-classes recorded. Large differences in mackerel growth suggest that year-class size partially influences the initial pattern of growth during a cohort's first years (Overholtz *et al*. 1991b). Thus, early growth may be related to year-class size, while stock size

may be more influential after the juveniles join the offshore adults (Overholtz *et al*. 1991b; Collette, in prep.).

The adults are highly mobile and school. They are obligate swimmers due to the absence of a swimbladder and the necessity for ram gill ventilation to meet blood oxygenation demands (Roberts 1975). Nevertheless this species exhibits diurnal changes in activity, swimming faster during the day than at night (Olla *et al*. 1975, 1976). Under laboratory conditions, at temperatures ranging from 7.3-15.8°C (within their preferred range), swimming speed of adults averaged 36 cm/s during the day and 29 cm/s at night (Olla *et al*. 1975, 1976). The fish continued to school both day and night although there were diurnal changes in cohesiveness of the group.

REPRODUCTION

There is some variation in estimates of size and age at maturity. Based on samples of Atlantic mackerel collected from 1987-1989 by the Northeast Fisheries Science Center (NEFSC) groundfish surveys, median length at maturity (L_{50}) was 25.7 cm for females and 26.0 cm for males; median age (A_{50}) was 1.9 years for both (O'Brien *et al*. 1993). By age 3, 99% of the females and 97% of the males were mature (O'Brien *et al*. 1993). Fish collected in Newfoundland waters from June-September 1970-1973 had higher values for L_{50} of 34 cm and 35 cm for females and males respectively (Moores *et al*. 1975). MacKay (1967) reported first spawning for mackerel occurred at age 2 and at lengths > 30 cm for fish collected in May-July 1965-1966 from the Gulf of St Lawrence and coastal Nova Scotia and Massachusetts. These differences in median maturity may be due to the slower growth of larger year classes that may delay spawning from one to three years (MacKay 1973; Overholtz 1989). Consequently, both year-class size and adult stock size may be important factors regulating growth in Atlantic mackerel (Overholtz 1989; Overholtz *et al*. 1991b).

Spawning occurs during spring and summer and progresses from south to north as the surface waters warm and fish migrate (Sette 1943). There are two spawning contingents; a southern group that spawns primarily in the Mid-Atlantic Bight and Gulf of Maine from mid-April to June and a northern contingent that spawns in the southern Gulf of St. Lawrence from the end of May to mid-August (Berrien 1982). The southern contingent begins the spring spawning migration by moving inshore between Delaware Bay and Cape Hatteras, usually between mid-March and mid-April depending to some extent on water temperature (Berrien 1982). The northern contingent begins to move inshore off southern New England usually in late May, mixing temporarily with part of the southern contingent before migrating eastward along the coast of Nova Scotia. Here other mackerel schools from offshore join the fish before moving into the Gulf of St. Lawrence to spawn (Berrien 1982). Small fish (< 30 cm) lag behind larger fish and spawn later (Berrien 1982).

Most of the spawning occurs in the shoreward half of continental shelf waters, although there is some spawning on the shelf edge and beyond (Berrien 1982; Collette, in prep.). Sette (1943) described the area bordered by southern New England and the Middle Atlantic states as the most important spawning grounds for mackerel. Current information indicates that the oceanic bight between Chesapeake Bay and southern New England is the most productive area. The Gulf of St. Lawrence is somewhat less so although the southern side is considered extremely productive for the northern contingent (MacKay 1973) while the Gulf of Maine and coast of outer Nova Scotia are the least (Sette 1950; Collette, in prep.). Some open bays; i.e., Cape Cod Bay and Massachusetts Bay, are sites of some importance with spawning fish abundant or common from May to July and August (Table 1). While according to Wheatland (1956), spawning occurs rarely in Gardiner's Bay and Long Island Sound, recent assessments of relative abundance of eggs and larvae in these areas show that both life stages are highly abundant and abundant in April and May (Table 2). Well-enclosed bays, especially those receiving considerable river inflow such as Chesapeake Bay and Delaware Bay show little evidence of spawning (Table 2).

Atlantic mackerel are serial, or batch spawners, with estimates of total fecundity ranging from 285,000 to 1.98 million eggs for southern contingent mackerel between 31 and 44 cm fork length (FL) (Morse 1980). Based on a very limited sample of northern contingent mackerel, fecundity estimates ranged from 211,000 to 397,000 eggs for 35 and 40 cm females respectively (MacKay 1973). Analysis of egg diameter frequencies indicate that five to seven egg batches are spawned by each female (Morse 1980).

FOOD HABITS

Atlantic mackerel are opportunistic feeders that can ingest prey either by individual selection of organisms or by passive filter feeding (Pepin *et al*. 1988). Filter feeding occurs when small plankton are abundant and mackerel swim through patches with mouth slightly agape, filtering food through their gill rakers (MacKay 1979). According to MacKay (1979), particulate feeding is the principal feeding mode in the spring and fall, while filter feeding predominates in the summer in the Gulf of St. Lawrence. Moores *et al*. (1975) maintain that the diet of fish from Newfoundland suggests that particulate feeding occurs there throughout the season.

Larvae feed primarily on zooplankton (Collette, in prep.). First-feeding larvae (3.5 mm) collected from Long Island Sound were found to be phytophagous while slightly larger individuals (> 4.4 mm) fed on copepod nauplii (Peterson and Ausubel 1984; Ware and Lambert 1985). Fish > 5 mm fed on copepodites of *Acartia* and *Temora*

while diets of fish > 6 mm contained adult copepods (Peterson and Ausubel 1984). Larvae > 6.4 mm were also cannibalistic, feeding on 3.5-4.5 mm conspecifics (Peterson and Ausubel 1984; Fortier and Villeneuve 1996). Consumption rates of larvae average between 25 and 75% body weight per day and they probably feed continuously. Larvae feed selectively, primarily on the basis of prey visibility (Peterson and Ausubel 1984). Fortier and Villeneuve (1996), studying larval mackerel from the Scotian Shelf, found that with increasing larval length, the diet shifted from copepod nauplii to copepod and fish larvae; the fish larvae included yellowtail flounder, silver hake, redfish and a large proportion of conspecifics. Predation was stage-specific; only the newly hatched larvae of a given species were ingested. However, piscivory was limited at densities of fish larvae < $0.1/m^3$ and declined with increasing density of nauplii and with increasing number of alternative copepod prey ingested.

Juveniles eat mostly small crustaceans such as copepods, amphipods, mysid shrimp and decapod larvae (Collette, in prep.). They also feed on small pelagic mollusks (*Spiratella* and *Clione*) when available (Collette, in prep.). Adults feed on the same food as juveniles but diets also include a wider assortment of organisms and larger prey items. For example, euphausiid, pandalid and crangonid shrimp are common prey; chaetognaths, larvaceans, pelagic polychaetes and larvae of many marine species have been identified in mackerel stomachs (Collette, in prep.). Bigelow and Schroeder (1953) found many Gulf of Maine mackerel feeding on *Calanus* as well as other copepods. Larger prey such as squids (*Loligo*) and fishes (silver and other hakes, sand lance, herring, and sculpins) are not uncommon, especially for large mackerel (Bowman *et al*. 1984). Under laboratory conditions, mackerel also fed on *Aglantha digitale*, a small transparent medusa common in temperate and boreal waters (Runge *et al*. 1987). The 1973 -1990 NEFSC bottom trawl survey data on food habits for two size classes of mackerel (11-30 cm; 30-50 cm) for 1973-1980 and 1981-1990 reflects this diversity (Figure 2). While there is variability between the two size classes and between the two survey periods, copepods, euphausiids and various crustaceans could be considered relative staples in the diet.

Immature mackerel begin feeding in the spring; older fish feed until gonadal development begins, stop feeding until spent and then resume prey consumption (Berrien 1982; Collette, in prep.). Under experimental conditions in which larval fish (3-10 mm in length) were presented as part of natural zooplankton assemblages, prey preference by mackerel was positively size selective and predation rates were not influenced by larval fish density (Pepin *et al*. 1987). Subsequent studies indicated that mackerel may achieve a higher rate of energy intake by switching to larger prey and increasing search rate as prey size and total abundance increase (Pepin *et al*. 1988). Filter feeding activity also increased with increasing prey density and Pepin *et al*. (1988) suggest that feeding rates under natural conditions of prey abundance (0.1 g wet weight/m^3) indicate that mackerel would not be satiated if foraging were restricted only to daylight.

PREDATION

Predation has a major influence on the dynamics of northwest Atlantic mackerel (Overholtz *et al*. 1991b). In fact, predation mortality is probably the largest component of natural mortality on this stock, and based on model predictions, may be higher than previously thought (Overholtz *et al*. 1991b). Atlantic mackerel serve as prey for a wide variety of predators including other mackerel, dogfish, tunas, bonito, and striped bass (Collette, in prep.). Small mackerel are prey for Atlantic cod and squid, which feed on fish < 10 to 13 cm in length (Collette, in prep.). Pilot whales, common dolphins, harbor seals, porpoises and seabirds are also significant predators (Smith and Gaskin 1974; Payne and Selzer 1983; Overholtz and Waring 1991; Montevecchi and Myers 1995). Other predators include swordfish, bigeye thresher, thresher, shortfin mako, tiger shark, blue shark, spiny dogfish, dusky shark, king mackerel, thorny skate, silver hake, red hake, bluefish, pollock, white hake, goosefish and weakfish (Scott and Tibbo 1968; Maurer and Bowman 1975; Stillwell and Kohler 1982, 1985; Bowman and Michaels 1984; Collette, in prep.).

MIGRATION/STOCK STRUCTURE

As stated previously, the two major spawning contingents are managed as a single transboundary stock. Sette (1950) described northern and southern population contingents of Atlantic mackerel in the northwest Atlantic with different spring and autumn migration patterns and summer distributions. Various methods have attempted to discriminate the two contingents in the northwest Atlantic, including meristic analyses (MacKay and Garside 1969), comparison of parasitic fauna (Isakov 1976), genetic variability (Maguire *et al*. 1987) and differences in otoliths (Gregoire and Castonguay 1989; Castonguay *et al*. 1991). While there were some significant differences, overlaps in character distributions have prevented the development of a useful discrimination method.

During the winter, Atlantic mackerel apparently overwinter in deep water of the continental shelf from Sable Island Bank, off Nova Scotia to the Chesapeake Bay region and in spring move inshore and northeast; this pattern is reversed in the fall (Sette 1950; Leim and Scott 1966; MacKay 1967; Berrien 1982). In April and early May the fish form the two spawning aggregations; i.e., a southern contingent that spawns off New Jersey and New York, and a northern contingent that spawns in the Gulf of St. Lawrence.

As fish from the southern contingent move northeast along the coast, they are joined by the schools from the

northern contingent which are also moving inshore. The overwintering area and timing of migration varies annually, probably influenced by meteorological events or regional conditions with low spring temperatures significantly delaying the timing, extent and duration (Murray *et al*. 1983; Murray 1984). In fact, the seasonal cycle in temperature in the waters of the Mid-Atlantic and southern New England [well-mixed water column in winter with temperatures < 4°C near the coast to > 8°C near the shelf edge; warming surface layers in spring and gradual warming from south (to 25°C) to north (to about 18°C) and subsequent fall cooling] is certainly an important environmental factor influencing migration and distribution (Overholtz *et al*. 1991a). This is supported by field studies that have shown that mackerel are intolerant of temperatures < 5-6°C or > 15-16°C (Overholtz and Anderson 1976) and laboratory studies that have confirmed that as temperatures departed from preferred ranges (7.3-15.8°C) swimming speeds of adult mackerel increased, reflecting thermal avoidance (Olla *et al*. 1975, 1976). By late April and May, the southern contingent is distributed off New Jersey and Long Island moving into the western side of the Gulf of Maine by June and July, and returning to the shelf edge probably between Long Island and Chesapeake Bay by October (Sette 1950; Berrien 1982).

The northern contingent, by late spring, has moved inshore off southern New England, mixing temporarily with the southern contingent before migrating eastward along the coast of Nova Scotia, and moving into the Gulf of St. Lawrence where they spawn in June and July. Some fish however, remain along the coasts of Maine and Nova Scotia throughout the summer. These fish again mix with fish from the southern group in late fall in the Gulf of Maine before moving to the outer shelf between Sable Island Bank and Long Island to overwinter (Sette 1950; Parsons and Moores 1974; Moores *et al*. 1975). Temperature may not be as limiting for this contingent since D'Amours and Castonguay (1992) found that mackerel occurred in June in the Cabot Strait off of eastern Cape Breton Island at 2.8°C, 4°C colder than the 7°C isotherm proposed by Sette (1950) as the thermal barrier to northern migration.

HABITAT CHARACTERISTICS

An extensive literature review and synthesis has provided detailed information on the life history and habitat requirements of Atlantic mackerel (Table 3). The review is primarily limited to U.S. waters; however, due to the intermixing of the two contingents, some information also relates to fish in Canadian waters.

EGGS

The eggs are pelagic in water over 34 ppt (Fritzsche 1978), floating in surface waters above the thermocline or in the upper 10-15 m (Sette 1943; Berrien 1982). Incubation time depends primarily on temperature: at 11°C, 7.5 days; at 13°C, 5.5 days and at 16°C, 3.6 days (Worley 1933). Lanctot (1980) had similar results: at 11°C, 8 days; at 13°C, 5.8 days and at 16°C, 3.9 days.

Based on the NEFSC Marine Resources Monitoring, Assessment, and Prediction (MARMAP) offshore ichthyoplankton surveys, eggs were collected at near surface temperatures ranging from 5-23°C with the largest proportion between ~ 7°C and 16°C (Figure 3). In April, the highest abundances were collected from 7-9°C; in May, from 9-12°C; in June, from 10-12°C; while the few collected in July and August were at a wide range of temperatures (11-23°C) (Figure 3). This is consistent with findings by Berrien (1978) who reported that for May 1966, the weighted mean surface temperature for all eggs collected from Martha's Vineyard to Chesapeake Bay was 11.0°C (range 6.3-16.9°C) with 97% collected at 8.7-13.8°C. Sette (1943), for eggs collected in 1932, reported a weighted mean of 10.9°C surface temperature with 98% occurring from 9.0-13.5°C.

Mortality may be influenced by acclimation temperatures of adult fish (Lanctot 1980). Worley (1933) found minimal mortality at 16°C which corresponded to capture temperature of the adults. Lockwood *et al*. (1977) found mortalities < 20% between 9.4 and 15.1°C. Ware and Lambert (1985) also found that egg mortality rates of mackerel from St. Georges Bay, Nova Scotia were highly correlated with the rate of warming during the spawning season.

Salinities may also affect survival. Peterson and Ausubel (1984) attributed high egg mortality to unusually low salinities (23 ppt) in Long Island Sound as compared with usual values of 25-27 ppt.

Eggs were collected at depths in the water column ranging from 10-325 m; the majority were collected from 30-70 m (Figure 3). In April, the highest numbers of eggs were collected at depths of 10-30 m; in May from 30-50 m; in June, July and August, at depths of 30-70 m (Figure 3). Ware and Lambert (1985) found that mackerel eggs in St. Georges Bay tended to concentrate near the surface, particularly under light winds and declined exponentially with depth with the rate of decline a function of egg diameter and temperature gradient in the top 5 m.

LARVAE

Based on the NEFSC MARMAP ichthyoplankton surveys, larvae are found at water column temperatures ranging from 6-22°C with the largest proportion between about 8°C and 13°C (Figure 4). In May, the majority of larvae were found at 8-10°C; in June at 8-11°C; in July at 8°C and 10-11°C; and in August at 9°C and 12-13°C (Figure 4). For larvae collected during May, June and August 1966, Berrien (1978) indicated that surface water temperatures ranged from 12.3-20.7°C with 96% occurring from 13.7-16.8°C. Ware and Lambert (1985) found that larval mortality rates (~ 42 %/d) were positively correlated with

temperature.

Larvae were collected at depths ranging from 10-130 m (Figure 4). With the exception of July when 50% were collected at a depth of 70 m, larvae were primarily distributed at depths ≤ 50 m (Figure 4). Sette (1943) reports that larvae vertically migrate diurnally from the surface at night to the thermocline during the day. Ware and Lambert (1985) found that in St. Georges Bay, recently-hatched larvae were collected at depths of 5-10 m and as they grew, moved progressively closer to the surface during the day; at sizes ranging from 3-8 mm, median depth increased at a rate of 0.7 m/d.

JUVENILES

Based on the 1963-1997 NEFSC bottom trawl surveys, juveniles in the fall were caught at temperatures ranging from 4-22°C, with the majority (> 55%) occurring at 10°C. In the winter 90% were collected at 5-6°C (range: 3-12°C) (Figure 5). The temperatures at which juveniles were found were a little broader in spring (4-17°C) and summer (4-19°C). Although the majority of juveniles (> 60%) were still found at 5-6°C in the spring, by summer they wee found at higher temperatures with > 40% collected at 8°C and 40% at 13°C (Figure 5).

In the fall, the majority of juveniles (> 77%) were at depths of 20-40 m (range: surface to 320 m); in the winter > 60% were at slightly deeper depths (50-70 m) while by spring they were widely dispersed through the water column (surface to 340 m) but concentrated (> 75%) at depths ranging from 30-90 m (Figure 5). By summer, fish were higher in the water column (surface to 210 m) with ~ 94% distributed from 20-50 m in two peaks (Figure 5).

Based on collections from the 1978-1996 Massachusetts inshore bottom trawl surveys, juveniles were most abundant at 11°C in spring and 9 and 13°C in autumn, and at depths of 10 and 50 m in the spring and 25 and 60 m in the autumn (Figure 6).

Based on collections from the 1990-1996 Rhode Island Narragansett Bay bottom trawl surveys, juveniles were captured in summer at bottom depths between 6.1-15.2 m (20-50 ft) and were most abundant at 12.2-15.2 m (40-50 ft) (Figure 7). They were caught at bottom temperatures of 19°C in summer and at 11 and 15°C in autumn (Figure 7).

Juveniles collected in otter trawl surveys in the Hudson-Raritan estuary (New York and New Jersey) during July 1997 were found at depths ranging from 4.9-9.8 m. Salinities ranged from 26.1-28.9 ppt, dissolved oxygen from 7.3-8.0 mg/l and temperatures from 17.6-21.7°C (S. Wilk, NMFS, NEFSC, James J. Howard Marine Sciences Laboratory, Highlands, NJ, personal communication).

ADULTS

Based on the NEFSC bottom trawl surveys, adults in the fall were found at a slightly narrower range of temperatures (4-16°C) with > 80% caught from 9-12°C (Figure 8). Winter distribution was similar to that of the juveniles with nearly 70% at 5-6°C (range: 3-13°C) (Figure 8). In the spring, temperature ranges were similar (2-14°C), but adults were distributed more evenly through a temperature band of 5-13°C with > 25% at 13°C (Figure 8). By summer, fish were found at temperatures ranging from 4-14°C with > 30% at 10-11°C and > 35% at 14°C (Figure 8). These temperatures are within the ranges previously reported for mackerel. In addition, Bigelow and Schroeder (1953) indicate that the highest temperature at which mackerel are commonly found is 20°C while commercial catches are sometimes taken at 7°C. In the northern Gulf of St. Lawrence, concentrations of mackerel were found at 4°C; however, the overall probability of occurrence inshore was higher when near-bottom temperatures were ≥ 7°C (Castonguay *et al*. 1992).

As stated previously in the migration section, field studies have shown that mackerel are intolerant of temperatures < 5-6°C or > 15-16°C (Overholtz and Anderson 1976) and laboratory studies have confirmed that as temperatures departed from preferred ranges (7.3-15.8°C), swimming speeds of adult mackerel increased, reflecting thermal avoidance (Olla *et al*.1975, 1976). Again, temperature may not be as limiting for the northern contingent since D'Amours and Castonguay (1992) found that mackerel occurred in June off of eastern Cape Breton Island at 2.8°C, 4°C colder than the 7°C isotherm proposed by Sette (1950) as the thermal barrier to northern migration.

Based on the NEFSC bottom trawl surveys, adults in the fall were spread from 10-340 m; however > 50% were caught at 60-80 m (Figure 8). By winter, while fish were still found at depths of 10-270 m, ~ 50% were found at depths of 20-30 m (Figure 8). By spring fish were broadly dispersed from the surface to as deep as 380 m; however, around 25% were at depths of 160-170 m (Figure 8). By summer, schools had again moved upward in the water column, swimming at depths of 10-180 m with > 60% at depths of 50-70 m (Figure 8). This depth range is broader than reported by Bigelow and Schroeder (1953) who stated that while mackerel can swim as deep as 183 m, in spring, summer and into fall they swim at depths of 46-55 m or less. According to Sette (1950) larger fish tend to swim deeper than smaller ones.

In the northern Gulf of St. Lawrence, vertical distribution was greatest at 15 and 35 m with mackerel occurrences positively correlated with downwelling events and the onshore advection of warm surface waters (Castonguay *et al*. 1992).

Based on Massachusetts inshore bottom trawl surveys, adults were most abundant at 14°C in spring with the few found in autumn at 10 and 15°C. They were also found at depths of 10 m in the spring while the few found in the autumn were at 50 m (Figure 6).

Based on Rhode Island Narragansett Bay bottom trawl surveys, a single adult was caught in winter at a depth of

30.5 m and at a bottom temperature of 5°C.

Factors controlling spawning time are unclear. Morse (1980) indicated that the regularity in spawning shown by Ware (1977) points to an internal control or constant external stimulus; e.g., photoperiod changes, which ensures that peak hatching occurs at the time of maximum zooplankton abundance. Based on field investigations (Nichols and Warnes 1993) and laboratory observations (Walsh and Johnstone 1992), there appears to be no diel periodicity in spawning and no significant peaks either during the day or night. Sette (1943) noted that temperature < 7°C is a limiting factor in migration which subsequently affects timing of spawning in specific locations. Based on the NEFSC MARMAP ichthyoplankton surveys, spawning does not begin until temperatures reach ~ 7-8°C, with most occurring between 9 and 14°C (Berrien 1982; Collette, in prep.). Sette (1943) stated that peak spawning occurs within that range at around 10-12°C at salinities > 30 ppt. These temperatures were in the preferred range (7-16°C) determined for adult mackerel in the laboratory (Olla *et al*. 1975, 1976). Thus the spawning season is progressively later as water temperatures warm and fish migrate from south to north.

GEOGRAPHICAL DISTRIBUTION

Northwest Atlantic mackerel are primarily found in the open sea (although rarely beyond the continental shelf) from Black Island, Labrador (Parsons 1970) to Cape Lookout, North Carolina (Collette and Nauen 1983). Eggs, larvae and juveniles also found at varying levels of abundance in bays and estuarine areas from New Jersey north through New England and into Canadian waters (see also Sette 1950; Tables 1, 2).

EGGS

The NEFSC MARMAP ichthyoplankton surveys found eggs from offshore waters off Chesapeake Bay to Georges Bank and the Gulf of Maine (Figure 9). Egg production progressed northward from April through May, June and July as would be expected based on the spawning/migratory patterns of adults. For example, egg production in April extended from Chesapeake Bay to coastal New Jersey and along the south shore of Long Island. In May, egg production extended from the shelf waters off New Jersey to Nantucket, the southern edge of Georges Bank and the western Gulf of Maine; in June production extended off southern Rhode Island, in the region of Massachusetts Bay and the western Gulf of Maine (Figure 9). By July, some eggs were collected along Georges Bank, while by August, few, if any, eggs were found. Highest densities (eggs/10 m^2) were in May (> 39,000) and June (> 53,000). This pattern of production and distribution is consistent with previous reports (Sette 1943; Bigelow and Schroeder 1953; Collette, in prep.). Eggs have been collected from early June to mid-August on the southern side of the Gulf of St. Lawrence (Sette 1943) and this area is considered an extremely productive spawning ground (Collette, in prep.).

LARVAE

The NEFSC MARMAP ichthyoplankton surveys also found larvae (< 13 mm) from waters off Chesapeake Bay to the Gulf of Maine, although more were concentrated offshore of Delaware Bay to Massachusetts Bay from inshore waters to the seaward limits of the survey (Figure 10). Larvae were collected from May through August with the highest average mean density (> 10,000/10 m^2) occurring in June and ranging from inshore to offshore from southern New England to the Hudson Canyon with considerable numbers collected north of Cape Cod. This was north of where larvae were most abundant (> 2000/10 m^2) in May. Mean densities were low in July (≤ 102/10 m^2) with few, if any, (≤ 32/10 m^2) collected in August (Figure 10). Berrien (1978) reported that in May 1966, larvae were caught between Chesapeake Bay and Oregon Inlet, North Carolina across the continental shelf, while by June larvae had spread from Martha's Vineyard to Currituck Beach, North Carolina. The highest abundance was off Montauk Point, New York. By June, most larvae occurred to the north, while in August few were caught. This pattern also corresponds with previous reports by Sette (1943).

JUVENILES AND ADULTS

Collections of Atlantic mackerel from the NEFSC bottom trawl surveys show that the distributions of juveniles (≤ 25 cm) and adults (≥ 26 cm) ranged from Cape Hatteras to Georges Bank, and southwestern Nova Scotia and the Gulf of Maine (Figure 11). The distribution of both life stages was generally similar although in spring adults tended to be distributed further offshore than the juveniles, along the outer edge of the Continental Shelf. In the fall, a few juveniles were collected in the near coastal waters of the Mid-Atlantic Bight and southern New England, particularly eastern Long Island, while adults were absent. The mean number of fish caught was highest in winter for adults (106/station) and in summer for juveniles (351/station), with more collected in the spring than in the fall reflecting the movements of the southern spawning contingent inshore. The highest abundance in spring occurs in the oceanic waters between Chesapeake Bay and southern New England, as the fish move north. Winter and summer distributions are presented as presence/absence data, precluding a discussion of abundances.

Based on the Massachusetts inshore bottom trawl surveys, occurrences of Atlantic mackerel were higher for juveniles in the autumn and for adults in the spring (Figure 12). In the autumn, most juveniles (10 to < 1391 fish/tow)

were caught in and around the waters off Cape Ann although small numbers (1 to < 500 fish/tow) were collected in Cape Cod Bay, primarily off Race Point. In the spring, the catch was highest (100 to < 101 fish/tow) along Vineyard Sound. In the fall, only two adults were collected (one in Cape Cod Bay, one off Cape Ann). In spring, the greatest numbers of fish (25 to < 37 fish/tow) were found in Nantucket Sound with lesser numbers (5 to < 25 fish /tow) also collected there and south of Cape Ann in the northern end of Massachusetts Bay. From 1 to < 5 fish/tow were also caught at several stations in and around Cape Cod in the spring. This would correspond with the spawning and migration patterns described above.

From 1960-1970, 112 species of fishes were collected in coastal Massachusetts waters as part of the Massachusetts coastal zone survey (Clayton *et al*. 1978). Indices were prepared on percent frequency of occurrence of various life stages with the term "random" used to designate marine species which may randomly occur in the estuary and percentages based on the total number of fish (all species) collected in the whole survey. The following list indicates areas where Atlantic mackerel were recorded, the life stage, and relative frequency.

Location	**Life stage**	**Frequency of Occurrence**
Annisquam/ Gloucester	Adults	Random; < 1% of collection
Salem Harbor	Eggs	Random; < 1% of collection
Lynn/Saugus	Adults	Random; < 1% of collection
Rocky Point/ Plymouth	Eggs/larvae	Common; 1-4.99% of collection
Cape Cod Canal	Eggs/larvae	No information
Taunton River/ Mount Hope Bay	Adults	Random; < 1% of collection

A total of 92 Atlantic mackerel were caught during the Rhode Island Narragansett Bay bottom trawl surveys. They were captured in low numbers at all but four stations and in all years except 1990 and 1995. Juveniles were present in summer and autumn and a single adult was caught in winter. The length frequencies by season show juveniles from 7-17 cm total length (TL) occurred in summer and from 18-23 cm TL occurred in winter. Juveniles were caught throughout much of the Bay but the highest catch was made at the ocean station in autumn (2.3 fish/tow; Figure 13). The single adult was caught farther up the Bay near Newport.

Survey data from the Connecticut bottom trawl surveys in Long Island Sound indicated that although few Atlantic mackerel were collected, analysis of length-frequency data indicated that both juveniles and adults were present at different times and distributed differently (Gottschall *et al*., in review). This is confirmed by recent analysis of the 1992-1997 survey results (Figure 14). Adults (> 28 cm; range 36-49 cm) were present in the spring and according to Gottschall *et al*. (in review) into midsummer and distributed throughout the sound. In contrast, juveniles ranging from 12-24 cm were collected in the autumn (primarily September and October) at depths < 18 m from Norwalk to the Housatonic River along the Connecticut shore (Gottschall *et al*., in review).

Few (n=12) Atlantic mackerel were collected in otter trawl surveys in the Hudson-Raritan estuary from 1992 to 1997. All were juveniles ranging from 7-8 cm and were collected during one survey in July 1997; most were collected on the eastern edge of Staten Island (S. Wilk, personal communication).

Estuarine Distribution (ELMR)

The NOAA/National Ocean Service (NOS) Estuarine Living Marine Resources (ELMR) program reviewed the distribution and relative abundances of mackerel in estuaries from Waquoit Bay, Massachusetts to the Cape Fear River, North Carolina. The data were based on three salinity zones, i.e., tidal (0.0-0.5 ppt), mixed (0.5-25 ppt) and seawater (> 25 ppt). Summaries of these distributions are presented in Table 1 for northwestern Atlantic estuaries (Jury *et al*. 1994) and in Table 2 for southern New England and Mid-Atlantic estuaries (Stone *et al*. 1994).

STATUS OF THE STOCKS

Total domestic landings, including commercial and recreational, of Atlantic mackerel in the northwest Atlantic were 32,100 metric tons (mt) in 1993, 16% less than 1992 landings (Anderson 1995; Figure 15). Canadian landings totaled 26,900 mt in 1993, a record since 1986, whereas United States commercial and recreational landings in 1993 were only 4,500 and 500 mt, respectively (Anderson 1995). Recent improvements in recruitment and reduced average annual landings enabled the Atlantic mackerel stock to recover from low biomass levels in the late 1970's (Anderson 1995; Figure 15).

From 1973-1977, Total Allowable Catches (TAC) were set for the southern spawning contingent in Northwest Atlantic Fisheries Organization (NAFO) Subareas 5 and 6 and for the northern contingent. However, there is no evidence for genetic differences between the contingents (MacKay 1967) and distinctions have not been made to determine individual contingent contributions to the total population (Garrod 1975). As a result, Atlantic mackerel have been managed as a unit stock since 1975 (Anderson 1982).

Atlantic mackerel landings reached a peak in the early 1970s of approximately 400,000 mt but were drastically reduced to 30,000 mt in the late 1970s (Anderson 1995;

Figure 15). Throughout 1980-1988, landings increased to an average 82,700 mt until Total Allowable Level of Foreign Fishing (TALFF) regulations for distant water fleet fishing activities in the northwest Atlantic were eliminated in 1992 and landings subsequently decreased to 32,000 mt in 1993 (Anderson 1995).

Northeast Fisheries Science Center fall and spring trawl survey data and assessment analyses indicate Atlantic mackerel stock biomass levels increased from 300,000 mt to 1.6 million mt in the years 1962-1969; however, levels decreased to an average 776,000 mt during 1977-1981 (Anderson 1995; Figure 15). Stock biomass increased steadily throughout the 1980s and in 1990 to approximately 3 million mt, which is the current estimated biomass level (Anderson 1995; Figure 15). Spawning stock biomass (50% of age 2 and 100% of age 3 and older mackerel) increased from 600,000 mt in 1982 to more than 2 million mt in 1990, and has remained at or above that level since that time.

Regulations on landings of Atlantic mackerel were enforced in 1976 in hopes of reducing fishing effort so as to ensure reproductive success in the population by keeping spawning stock levels above devastating levels. Recruitment has increased since 1976-1980 and strong year classes were evident in 1982, 1987, 1988, and 1990-1993 (Northeast Fisheries Science Center 1996). The northwest Atlantic mackerel stock is currently at a high level of biomass and is underexploited (Northeast Fisheries Science Center 1996).

RESEARCH NEEDS

As stated by Overholtz *et al*. (1991b) and based on the results of model projections, unless the impacts of compensatory mechanisms are accounted for, evaluations of current stock status using the current standard assessment methodology may in fact be optimistic and risky if catches are increased to high levels. These authors indicate that two advances would help to improve assessments: (1) an MSVPA to provide correctly scaled estimates of recruitment, and (2) a general prediction mortality model that would provide useful estimates of M2's for forecasting purposes. Other data that will be important include monitoring weights of individual fish to assess future changes, annual tracking of sexual maturity of age 2 and age 3 fish, additional food habits sampling at critical times and places and information on predation mortality of age-0 mackerel. Improved predation models that account for predator preference and prey abundance would allow for more accurate predictions of the impacts of these factors.

In addition, even though Atlantic mackerel is managed and assessed as one stock throughout the U.S. EEZ, the question of multiple stocks still needs to be settled from a scientific standpoint. This could be addressed via new technologies such as microconstituent analysis of otoliths using inductively coupled plasma mass-spectrometry (ICPMS).

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Table 1. Summary of the distribution and abundance of Atlantic mackerel in northwestern Atlantic estuaries based on Jury *et al*. (1994). Data reliability: *** = Highly Certain, ** = Moderately Certain, * = Reasonable Inference. Relative abundance: H = highly abundant, A = abundant, C = common, R = rare, 0 = not present, N = no data presented, NI = no data available, NZ = zone not present.

Estuaries and Rivers	**Life Stage**	**Relative Abundance and Distribution (months)** months shown as (1)-(12); i.e., January = (1)			**Data Reliability**
		Tidal Fresh 0.0-0.5 ppt	**Mixing Zone 0.5-25 ppt**	**Seawater Zone > 25 ppt**	
Passamaquoddy Bay	**A**dults (A)	0	C(6-9), R(10)	C(6-9), R(10)	**
	Spawning adults (S)	0	0	0	**
	Eggs (E)	0	0	NI	*
	Larvae (L)	0	0	NI	*
	Juveniles (J)	0	C(6-9), R(10)	C(6-9), R(10)	**
Englishman/Machias Bay	**A**	0	C(6-9), R(10)	C(6-9), R(10)	*
	S	0	0	0	*
	E	0	0	NI	*
	L	0	0	NI	*
	J	0	R(6-10)	R(6-10)	*
Narraguagus Bay	**A**	0	C(6-9), R(10)	C(6-9), R(10)	*
	S	0	0	0	*
	E	0	0	NI	*
	L	0	0	NI	*
	J	0	R(6-10)	R(6-10)	*
Blue Hill Bay	**A**	0	C(6-9), R(10)	C(6-9), R(10)	*
	S	0	0	0	*
	E	0	0	NI	*
	L	0	0	NI	*
	J	0	R(6-10)	R(6-10)	*
Penobscot Bay	**A**	0	C(6-9), R(10)	C(6-9), R(10)	**
	S	0	0	0	**
	E	0	0	R(6-7)	**
	L	0	0	R(6-7)	**
	J	0	C(6-9), R(10)	C(6-9), R(10)	**
Muscongus Bay	**A**	0	C(6-9), R(10)	C(6, 8-9), A(7), R(10)	*
	S	0	0	0	**
	E	0	0	0	**
	L	0	0	0	**
	J	0	C(6-9), R(10)	C(6, 8-9), A(7), R(10)	*
Damariscotta River	**A**	0	C(6-9), R(10)	C(6, 8-9), A(7), R(10)	**
	S	0	0	0	**
	E	0	0	0	**
	L	0	0	0	**
	J	0	C(6-9), R(10)	C(6, 8-9), A(7), R(10)	**
Sheepscot River	**A**	0	C(6-9), R(10)	C(6, 8-9), A(7), R(10)	***
	S	0	0	0	**
	E	0	0	0	**
	L	0	0	0	**
	J	0	C(6-9), R(10)	C(6, 8-9), A(7), R(10)	***
Kennebec/Androscoggin Rivers	**A**	0	C(6-9), R(10)	C(6, 8-9), A(7), R(10)	**
	S	0	0	0	**
	E	0	0	0	**
	L	0	0	0	**
	J	0	C(6-9), R(10)	C(6, 8-9), A(7), R(10)	**

Table 1. cont'd.

Estuaries and Rivers	Life Stage	Relative Abundance and Distribution (months) months shown as (1)-(12); i.e., January = (1)			Data Reliability
		Tidal Fresh 0.0-0.5 ppt	Mixing Zone 0.5-25 ppt	Seawater Zone > 25 ppt	
Casco Bay	**A**	0	C(6-9), R(10)	C(6-9), R(10)	*
	S	0	0	0	**
	E	0	0	NI	*
	L	0	0	NI	*
	J	0	C(6-9), R(10)	C(6-9), R(10)	*
Saco Bay	**A**	0	C(6-9), R(10)	C(6-9), R(10)	*
	S	0	0	0	**
	E	0	0	0	*
	L	0	0	0	*
	J	0	C(6-9), R(10)	C(6-9), R(10)	*
Wells Harbor	**A**	NZ	R(6-10)	R(6-10)	*
	S	NZ	0	0	**
	E	NZ	0	0	*
	L	NZ	0	0	*
	J	NZ	R(6-10)	R(6-10)	*
Great Bay	**A**	0	0	R(5-11)	*
	S	0	0	0	***
	E	0	C(5-7)	C(5), A(6-7)	*
	L	0	C(5-7), R(8)	C(5-7), R(8)	*
	J	0	0	C(5-11)	*
Merrimack River	**A**	0	R(5-10)	NZ	**
	S	0	0	NZ	**
	E	0	H(5-6), C(7)	NZ	**
	L	0	C(5-8)	NZ	**
	J	0	R(5-10)	NZ	**
Massachusetts Bay	**A**	NZ	NZ	C(5-10), R(11)	***
	S	NZ	NZ	C(5-8)	*
	E	NZ	NZ	C(5), A(6,7), R(8)	*
	L	NZ	NZ	C(5), A(6,7), R(8)	*
	J	NZ	NZ	C(5-10)	***
Boston Harbor	**A**	NZ	R(5), C(6-9)	R(5), C(6-9)	**
	S	NZ	0	0	*
	E	NZ	R(5, 8), C(6,7)	C(5,8), A(6,7)	*
	L	NZ	R(5), C(6-8)	C(5), A(6,7) R(8)	*
	J	NZ	R(5), C(6-10)	R(5), C(6-10)	**
Cape Cod Bay	**A**	NZ	C(5-8), R(9)	A(5-7), C(8-11)	**
	S	NZ	0	A(5-7)	*
	E	NZ	C(5-8)	H(5,6), A(7), C(8)	**
	L	NZ	C(5-8)	H(5,6), A(7), C(8)	**
	J	NZ	C(5-10)	A(5-8), C(9-11)	**

Table 2. Summary of the distribution and abundance of Atlantic mackerel in southern New England and Mid-Atlantic estuaries based on Stone *et al*. (1994). Data reliability: *** = Highly Certain, ** = Moderately Certain, * = Reasonable Inference. Relative abundance: H = highly abundant, A = abundant, C = common, R = rare, 0 = not present, N = no data presented, NI = no data available, NZ = zone not present.

Estuaries and Rivers	**Life Stage**	**Relative Abundance and Distribution (months)** months shown as (1)-(12); i.e., January = (1)			**Data Reliability**
		Tidal Fresh 0.0-0.5 ppt	**Mixing Zone 0.5-25 ppt**	**Seawater Zone > 25 ppt**	
Waquoit Bay	**A**dults (A)	NZ	0	R(5,6), C(7-9)	*
	Spawning adults (S)	NZ	0	0	**
	Eggs (E)	NZ	0	R(5-8)	*
	Larvae (L)	NZ	0	R(5-8)	*
	Juveniles (J)	NZ	0	R(5-9)	*
Buzzards Bay	**A**	NZ	0	C(3,4,11,12), R(5-9)	**
	S	NZ	0	0	**
	E	NZ	R(5-8)	A(5,6), C(7), R(8)	*
	L	NZ	R(6-8)	R(5-8)	*
	J	NZ	R(5-9)	R(5-9)	*
Narragansett Bay	**A**	0	0	C(5-9)	*
	S	0	0	0	**
	E	0	R(5-7)	A(5,6), C(7)	**
	L	0	R(5-7)	C(5,6), R(7)	*
	J	0	R(5-9)	C(5-9)	*
Long Island Sound	**A**	0	0	C(4-11)	*
	S	0	0	R(4-6)	***
	E	0	0	C(4,6), A(5)	***
	L	0	0	C(5), R(6)	***
	J	0	R(4,5)	C(4-11)	*
Connecticut River	**A**	0	0	NZ	**
	S	0	0	NZ	***
	E	0	0	NZ	**
	L	0	0	NZ	**
	J	0	0	NZ	**
Gardiners Bay	**A**	NZ	0	C(4,5), R(6-11)	*
	S	NZ	0	R(4-6)	*
	E	NZ	0	H(4), A(5), C(6)	**
	L	NZ	0	H(4), A(5), C(6)	**
	J	NZ	0	C(4-11)	**
Great South Bay	**A**	NZ	0	C(4,5), R(6-11)	*
	S	NZ	0	0	**
	E	NZ	0	C(4)	**
	L	NZ	0	C(5)	**
	J	NZ	0	C(4-11)	*
Hudson/Raritan River	**A**	0	0	C(4,5,10,11), R(6,9,12)	*
	S	0	0	0	*
	E	0	0	0	*
	L	0	0	0	*
	J	0	R(4-6,10-12)	C(4-6,10,11), R(7-9,12)	*
Barnegat Bay	**A**	0	0	0	***
	S	0	0	0	***
	E	0	0	R(4-6)	**
	L	0	0	R(4-6)	**
	J	0	0	R(5-9)	**
NJ Inland Bays	**A**	0	0	0	***
	S	0	0	0	***
	E	0	0	R(4-6)	**
	L	0	0	R(4-6)	**
	J	0	0	R(5-9)	**
Delaware Bay	**A**	0	0	R(3-5)	**
	S	0	0	0	***
	E	0	0	0	***
	L	0	0	0	***
	J	0	0	0	***

Table 2. cont'd.

Estuaries and Rivers	Life Stage	Relative Abundance and Distribution (months) months shown as (1)-(12); i.e., January = (1)			Data Reliability
		Tidal Fresh 0.0-0.5 ppt	Mixing Zone 0.5-25 ppt	Seawater Zone > 25 ppt	
Delaware Inland Bays	**A**	NZ	0	R(3-5)	**
	S	NZ	0	0	***
	E	NZ	0	0	***
	L	NZ	0	0	**
	J	NZ	0	0	**
Chincoteague	**A**	NZ	NZ	0	***
	S	NZ	NZ	0	***
	E	NZ	NZ	0	***
	L	NZ	NZ	0	***
	J	NZ	NZ	0	***
Chesapeake Bay	**A**	0	R(1-3)	R(1-3)	**
	S	0	0	0	***
	E	0	0	0/NI(4-5)	**
	L	0	0	R(5)	**
	J	0	R(1-4,11,12)	R(1-4,11,12)	**
Chester River	**A**	0	0	NZ	***
	S	0	0	NZ	***
	E	0	0	NZ	***
	L	0	0	NZ	***
	J	0	0	NZ	***
Choptank River	**A**	0	0	NZ	***
	S	0	0	NZ	***
	E	0	0	NZ	***
	L	0	0	NZ	***
	J	0	0	NZ	***
Patuxent River	**A**	0	0	NZ	***
	S	0	0	NZ	***
	E	0	0	NZ	***
	L	0	0	NZ	***
	J	0	0	NZ	***
Potomac River	**A**	0	0	NZ	***
	S	0	0	NZ	***
	E	0	0	NZ	***
	L	0	0	NZ	***
	J	0	0	NZ	***
Tangier/Pocomoke	**A**	NZ	0	NZ	***
	S	NZ	0	NZ	***
	E	NZ	0	NZ	***
	L	NZ	0	NZ	***
	J	NZ	0	NZ	***
Rappahannock River	**A**	0	R(1-3)	NZ	**
	S	0	0	NZ	***
	E	0	0	NZ	***
	L	0	0	NZ	***
	J	0	R(1-4,11,12)	NZ	**
York River	**A**	0	R(1-3)	NZ	**
	S	0	0	NZ	***
	E	0	0	NZ	***
	L	0	0	NZ	***
	J	0	R(1-4,11,12)	NZ	**
James River	**A**	0	R(1-3)	NZ	**
	S	0	0	NZ	***
	E	0	0	NZ	***
	L	0	0	NZ	***
	J	0	R(1-4,11,12)	NZ	**

Table 3. Summary of life history and habitat parameters for Atlantic mackerel, *Scomber scombrus.*

Life Stage	Size and Growth	Geographic Location	Habitat	Temperature
Eggs [1]	Diameter: 1-1.3 mm, avg. = 1.1 mm. 1 oil globule, avg. 0.3 mm diameter. In Gulf of St. Lawrence egg size decreased over time and in relation to ambient temperature (avg. diam. = 1.3 mm in June, 1.1 mm in August).	Offshore waters of Chesapeake Bay to southern side of Gulf of St. Lawrence with majority on shoreward side of continental shelf. Varying abundances in bays and estuaries from New Jersey to Canada. Highest abundances in May, June in southern New England - Mid-Atlantic region.	Eggs pelagic, distributed at depths ranging from 10-325 m, majority from 30-70 m; depth varies with season, egg diameter, thermocline.	Eggs collected at 5-23°C, highest abundance from ~ 7-16°C with range related to season. In May, weighted mean surface temperature = 11°C for eggs from Martha's Vineyard. Egg mortality rates (~ 41%/d) correlated with rate of warming during spawning season since acclimation temperature of adults related to egg mortality. Mortality < 20% from 9.4-15.1^{o}C. Incubation temperature dependent: 7.5 d at 11°C to ~ 3 d at 20°C. Temperatures must be > ~ 7°C for development.
Larvae [2]	Larvae average 3.1-3.3 mm SL with large yolk sac. Postlarvae are 11-50 mm. Teeth present at 192 h after hatching.	Larvae (< 13 mm) occur primarily in offshore waters from Chesapeake Bay to southern Gulf of St. Lawrence. Similar to distribution of eggs, some larvae also collected in open bays and estuaries. Highest abundances in May offshore from Delaware Bay to Hudson Canyon; by June, highest abundance ranges from Hudson Canyon north to southern New England and north of Cape Cod.	Most distributed at depths from 10-130 m, usually at < 50 m. Depth varies diurnally, also with age and with thermocline; i.e., newly hatched larvae found between 5-10 m during the day, however, as they grow they're at depths closer to the surface.	Hatching occurs ~ 90-120 h at average temperature of 13.8^{o}C. Yolk sac stage complete by 137 h at this temperature. Larvae collected at 6-22°C; highest abundance at 8-13°C. Changes in abundance at different temperature ranges related to season; i.e., increasing from May through August. Larval mortality rates (~ 35-42%/d) may be partially correlated with temperature.
Juveniles [3]	Postlarvae transform from planktonic to swimming and schooling behavior at ~ 30-50 mm; reach 50 mm in ~ 2 months; 20 cm after 1 y (rates may be faster in mid-Atlantic: ~ 70-80 mm in 2 months). Northern contingent fish may grow faster in 1st year than southern contingent, but may not be significantly different for first 90 days.	Southwestern Nova Scotia, Gulf of Maine, Georges Bank to Cape Hatteras - distribution changes seasonally. Late summer/fall primarily along western shores of Gulf of Maine, around Cape Ann, inshore areas of New England (includes estuaries in Rhode Island, Connecticut), eastern Long Island. In spring, although common offshore, some are further inshore than adults and found in some Mid-Atlantic estuaries until fall.	Depth varies seasonally. Offshore in fall, most abundant at ~ 20-40 m, range from 0-320 m. In winter, 50-70 m. Spring, although dispersed through water column, concentrated 30-90 m. Move higher in summer to 20-50 m, range from 0-210 m.	At 15-17°C growth rates of fish > 15 mm averaged 0.73 mm/d. Juveniles found from 4-22°C, most at 10°C. Temperature distribution offshore changes seasonally as average temperature ranges increase: in winter/spring, most found 5-6°, in summer at 8-13°C. Similar associations inshore: Massachusetts, 11° in spring, 9 and 13° in fall; Rhode Island, 19° in summer, 11 and 15°C in fall.
Adults [4]	Males/females grow at same rate, reaching maximum age of ~ 20 y, with maximum fork length of ~ 47 cm. Reach 26 cm by second year, 33 cm by fifth year. By age 6, may be 39-40 cm. Spring weight for 35 cm fish is ~ 0.5 kg; fall is 0.6 kg. Growth may be population density dependent; year class size partially influences initial growth during cohort's first years.	Two major contingents in NW Atlantic. Fish overwinter in deep water of shelf from Nova Scotia to Cape Hatteras. In spring, two groups formed: fish from southern group move inshore and northward along coast, joined by northern group moving inshore. By late Apr./May southern group found off New Jersey, Long Island, moving to western Gulf of Maine by summer, returns to shelf edge between Long Island - Chesapeake Bay in Oct. Northern group mixes briefly with southern group late spring off New England, migrates east along Nova Scotia into Gulf of St. Lawrence; some fish remain along Maine/Nova Scotia coast. By late fall, this contingent mixes with southern group in Gulf of Maine before returning to outer shelf.	Depth changes seasonally, perhaps influenced by prey availability. Fall: 10-340 m, > 50% at 60-80 m. Winter: ~ 50% at 20-30 m. Spring: down to 380 m, ~ 25% at 60-170 m. Summer: > 60% at 50-70 m. Larger fish deeper than smaller ones. Distribution may also be correlated with downwelling events and onshore advection of warm surface water.	Seasonal temperature cycles influence migration/distribution. Field studies: intolerant of temperatures < 5-6°C or > 15-16°C. Lab: prefer 7-16°, lethal at < 2° or > 28.5^{o}. Offshore distribution varies with seasonal temperature changes. Fall: > 80% at 9-12°. Winter: ~ 70% at 5-6°. Spring > 25% at 13°. Summer: > 30% at 10-11°, > 35% at 14°. Massachusetts: spring most at 14°, fall at 10° and 15°. In northern Gulf of St. Lawrence, adults in colder temperatures (4°); however, probability of occurrence higher when temperatures ≥ 7°C.
Spawning Adults [5]	L_{50} for females = 25.7 cm, males = 26.0; A_{50} for both = 1.9 y. By age 3, 99% of females, 97% of males mature. Newfoundland fish have higher L_{50} values: females = 34 cm, males = 35 cm. Gulf of St. Lawrence, coastal Nova Scotia, Massachusetts fish spawn first at age 2, lengths > 30 cm. Differences in median maturity may be due to slower growth of larger year classes that may delay spawning from one to three years.	Spawning progresses from south to north. Southern contingent spawns in Mid-Atlantic Bight and Gulf of Maine mid-Apr.-June, northern in southern Gulf of St. Lawrence May-Aug. Most spawning in shoreward half of continental shelf, some on shelf edge and beyond. Most productive between Chesapeake Bay/southern New England, less in Gulf of St. Lawrence, Gulf of Maine, Nova Scotia coast. Some spawning in open bays; e.g., Cape Cod, Massachusetts Bays. Less in enclosed bays; e.g., Chesapeake, Delaware Bays.		Spawning begins when temperatures are ≥ 7°C (peak 9-14°C) and progresses from southern to northern waters during adult migration.

References on next page

Table 3. cont'd.

Life Stage	Salinity	Prey	Predators	Notes
Eggs [1]	Although eggs are collected in waters ranging from estuaries (18-25 ppt) to full seawater (> 30 ppt), mortality is higher at lower salinities (< 25 ppt).			
Larvae [2]	Although larvae are occasionally collected in open bays and estuaries at salinities < 25 ppt, the largest abundances are found in higher salinities of > 30 ppt in offshore waters. Mortality may be related to salinities of ≤ 23 ppt.	50% threshold for first feeding is 3.8 mm, all larvae feeding by 4.5 mm. Diet related to larval size: first feeding larvae may be phytophagous; individuals > 4.4 mm feed on copepod nauplii; > 5 mm, copepodites; > 6 mm adult copepods. Diets of larger larvae shift to include fish larvae: yellowtail flounder, silver hake, redfish; > 6 mm are cannibalistic on smaller conspecifics which may make up as much as 20% of larval fish consumed. However, piscivory is density dependent; i.e., limited at densities of fish larvae < 0.1 m^3 and declines with increasing density of nauplii, switching to copepods.	Mackerel > 6 mm are cannibalistic on smaller conspecifics of 3.5-4.5 mm.	Calculated mean digestive times ~ 1-2 h; to maintain rapid growth rates larvae must feed continually for about 15 h/d. Diet may reflect most abundant food items capable of being ingested due to width of mouth gape. Factors influencing mortality include zooplankton abundance, wind driven surface currents, epizootics in addition to temperature and appropriate food supply.
Juveniles [3]	Juveniles found in some inshore bays and estuaries as well as offshore at salinities > 25 ppt.	Principal prey include small crustaceans, such as copepods, euphausiids, amphipods, mysid shrimp, decapod larvae. Also small pelagic mollusks, chaetognaths, nematodes, ammodytes, other larval fish.	Same as for adults, but for juveniles specifically: Atlantic cod, squid, seabirds.	Atlantic mackerel are opportunistic feeders that can ingest prey either by individual selection of organisms or by filter feeding (see adults, below).
Adults [4]	Found in open sea although occasionally in open bays with lower salinity limits of ~ 25 ppt.	Opportunist feeders. Filter feeding or individual selection. Diet similar to juveniles, but wider range and larger prey items. Includes euphausid, pandalid, and crangonid shrimps; chaetognaths, larvaceans, pelagic polychaetes, squids. Calanus and other copepods, amphipods, other planktonic organisms. Fishes: sand lances, herring, silver and other hakes, sculpins. Lab studies: small medusae common to temperate waters; also, where prey abundance is only 0.1 g wet weight/m^3, mackerel may not be satiated if feeding was restricted to daylight.	Mortality from predation may be the most important source of natural mortality. Predators include conspecifics, tunas, bonito, striped bass, pilot whales, common dolphins, harbor seals, porpoises, seabirds, swordfish. Sharks: shortfin mako, tiger, blue, bigeye thresher, spiny dogfish. Other predators: king mackerel, thorny skate, silver hake, red hake, bluefish, pollock, white hake, goosefish, weakfish.	Although there are two major contingents of the population they are managed as a single transboundary stock. Shifts in feeding mode may be related to season for fish in the Gulf of St. Lawrence while diet of fish in Newfoundland indicates that particulate feeding may occur throughout the season.
Spawning Adults [5]	Peak spawning occurs at salinities > 30 ppt.	Fish feed until gonadal development begins, then stop feeding until spent, feeding then resumes.	Same as for adults in general.	Mackerel are serial, or batch, spawners. Fecundity of southern contingent: 285,000-1.98 million eggs for 31-44 cm fish. Northern contingent: 211,000 to 397,000 eggs for 35 and 40 cm females, respectively, with 5-7 batches. Control of spawning time is unclear although there may be both endogenous and exogenous factors which ensures peak hatching at the time of maximum zooplankton abundance. No evidence of diel periodicity in spawning.

[1] Worley (1933), Jury *et al.* (1994), Sette (1943), Berrien (1975, 1978), Ware (1977), Fritzsche (1978), Lanctot (1980), Peterson and Ausubel (1984), Ware and Lambert (1985), Stone *et al.* (1994), Collette (in prep.)

[2] Sette (1943), Bigelow and Schroeder (1953), Colton and Marak (1969), Berrien (1975, 1978, 1982), Peterson and Ausubel (1984), Ware and Lambert (1985), Scott and Scott (1988), Jury *et al.* (1994), Stone *et al.* (1994), Fortier and Villeneuve (1996), Collette (in prep.)

[3] Sette (1943, 1950), Bigelow and Schroeder (1953), Anderson and Paciorkwski (1980), Kendall and Gordon (1981), Berrien (1982), Ware and Lambert (1985), Pepin *et al.* (1988), D'Amours *et al.* (1990), Simard *et al.* (1992), Jury *et al.* (1994), Stone *et al.* (1994), Collette (in prep.)

[4] Sette (1950), Leim and Scott (1966), MacKay (1967), Scott and Tibbo (1968), Anderson (1973), Isakov (1973), Parsons and Moores (1974), Stobo and Hunt (1974), Maurer and Bowman (1975), Moores *et al.* (1975), Olla *et al.* (1975), Overholtz and Anderson (1976), MacKay (1979), Berrien (1982), Stillwell and Kohler (1982, 1985), Murray *et al.* (1983), Bowman and Michaels (1984), Bowman *et al.* (1984), Murray (1984), Runge *et al.* (1987), Dery (1988), Pepin *et al.* (1988), Overholtz *et al.* (1991b), Castonguay *et al.* (1992), Collette (in prep.)

[5] Sette (1943), MacKay (1967, 1973), Ware (1977), Morse (1980), Berrien (1982), Overholtz (1989), Overholtz *et al.* (1991b), Walsh and Johnstone (1992), Nichols and Warne (1993), O'Brien *et al.* (1993), Jury *et al.* (1994), Stone *et al.* (1994), Collette (in prep.)

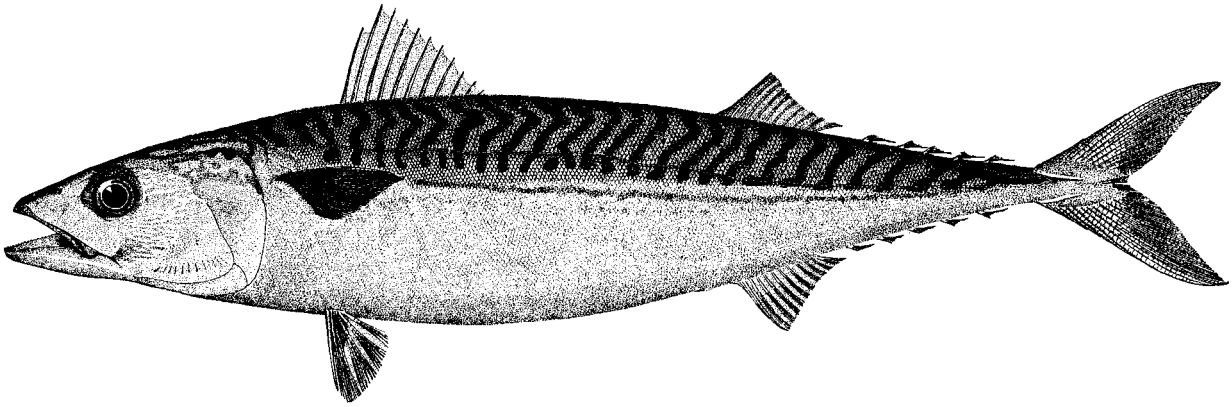


Figure 1. The Atlantic mackerel, *Scomber scombrus* (from Goode 1884).

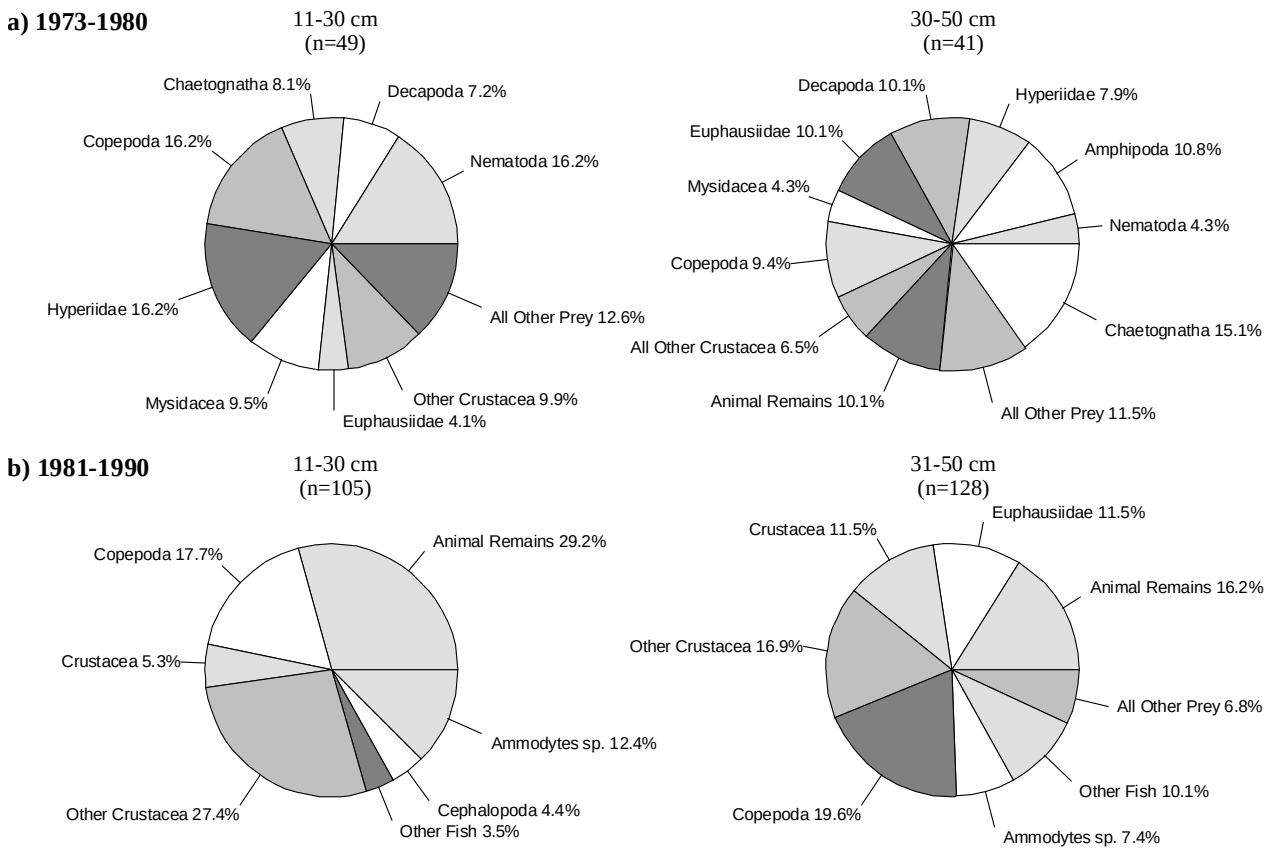


Figure 2. Abundance (percent occurrence) of the major prey items in the diet of Atlantic mackerel collected during NEFSC bottom trawl surveys from 1973-1980 and 1981-1990. The 11-30 cm size range corresponds, at least roughly, to juveniles, and the 30-50 cm size class corresponds to adults. The category “animal remains” refers to unidentifiable animal matter. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details].

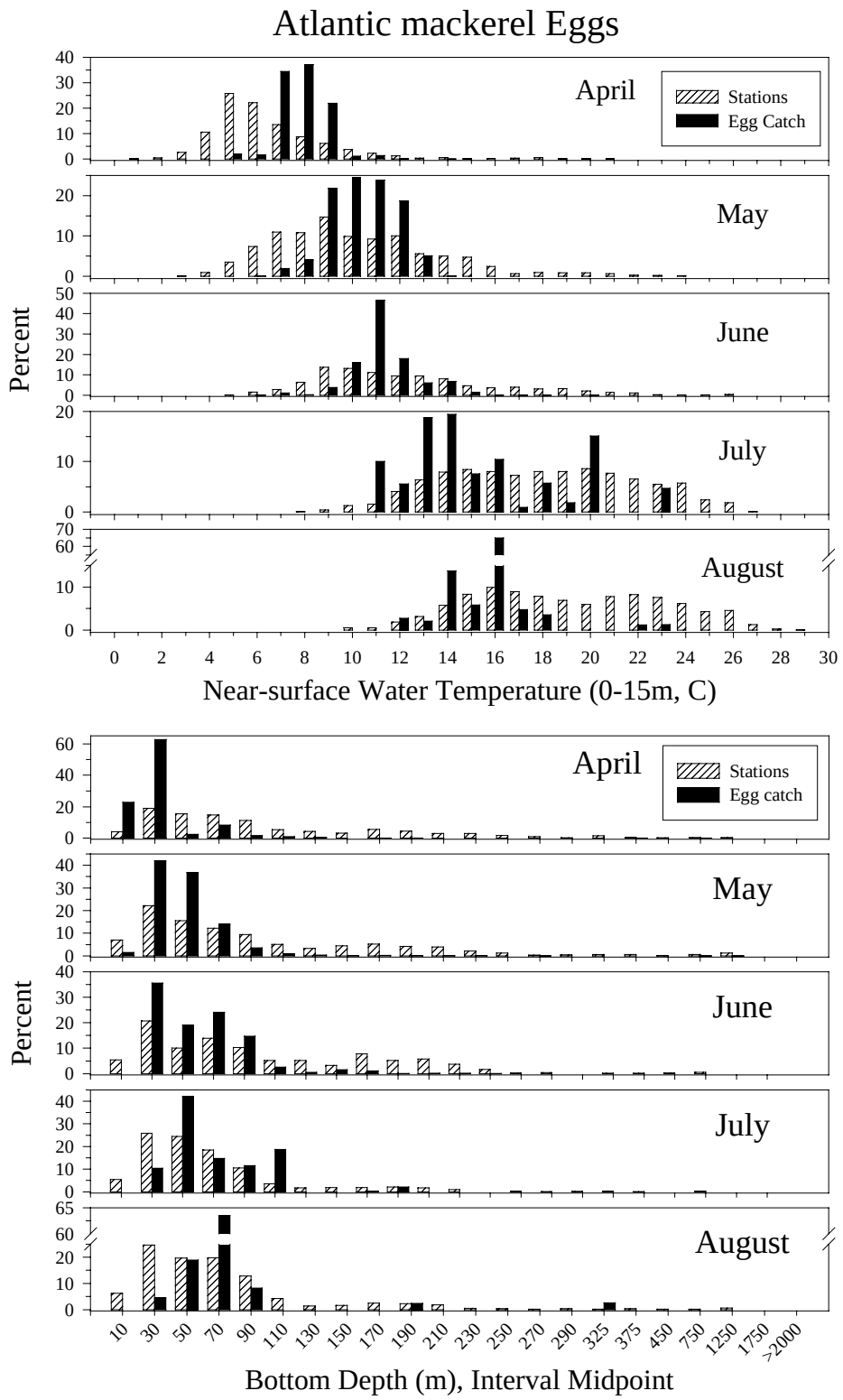


Figure 3. Abundance of Atlantic mackerel eggs relative to surface water temperature (0-15 m) and bottom depth based on NEFSC MARMAP ichthyoplankton surveys (April to August 1978-1987; all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

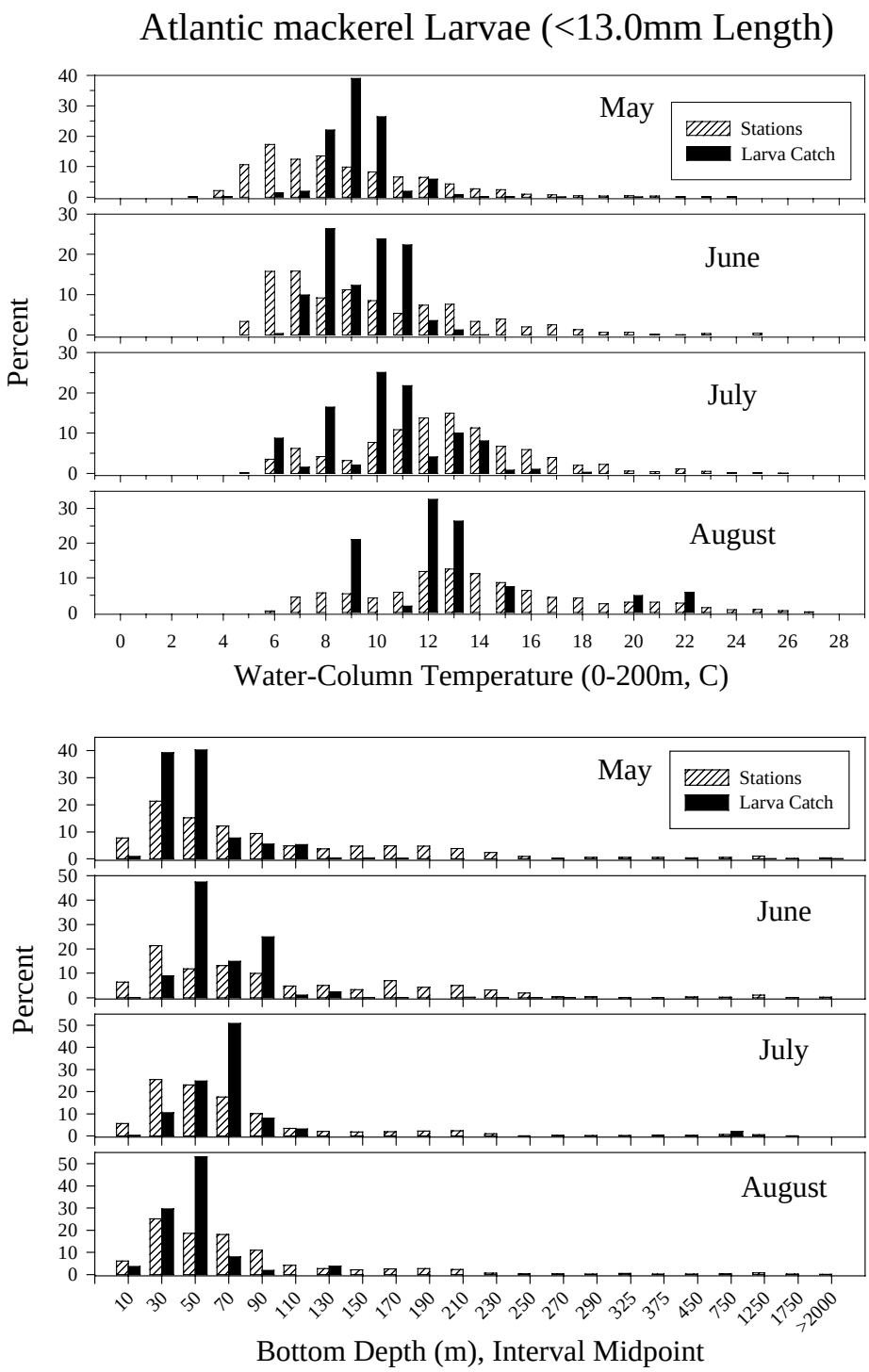


Figure 4. Abundance of Atlantic mackerel larvae (< 13 mm) relative to water column temperature (to a maximum of 200 m) and bottom depth based on NEFSC MARMAP ichthyoplankton surveys (May to August 1977-1987; all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

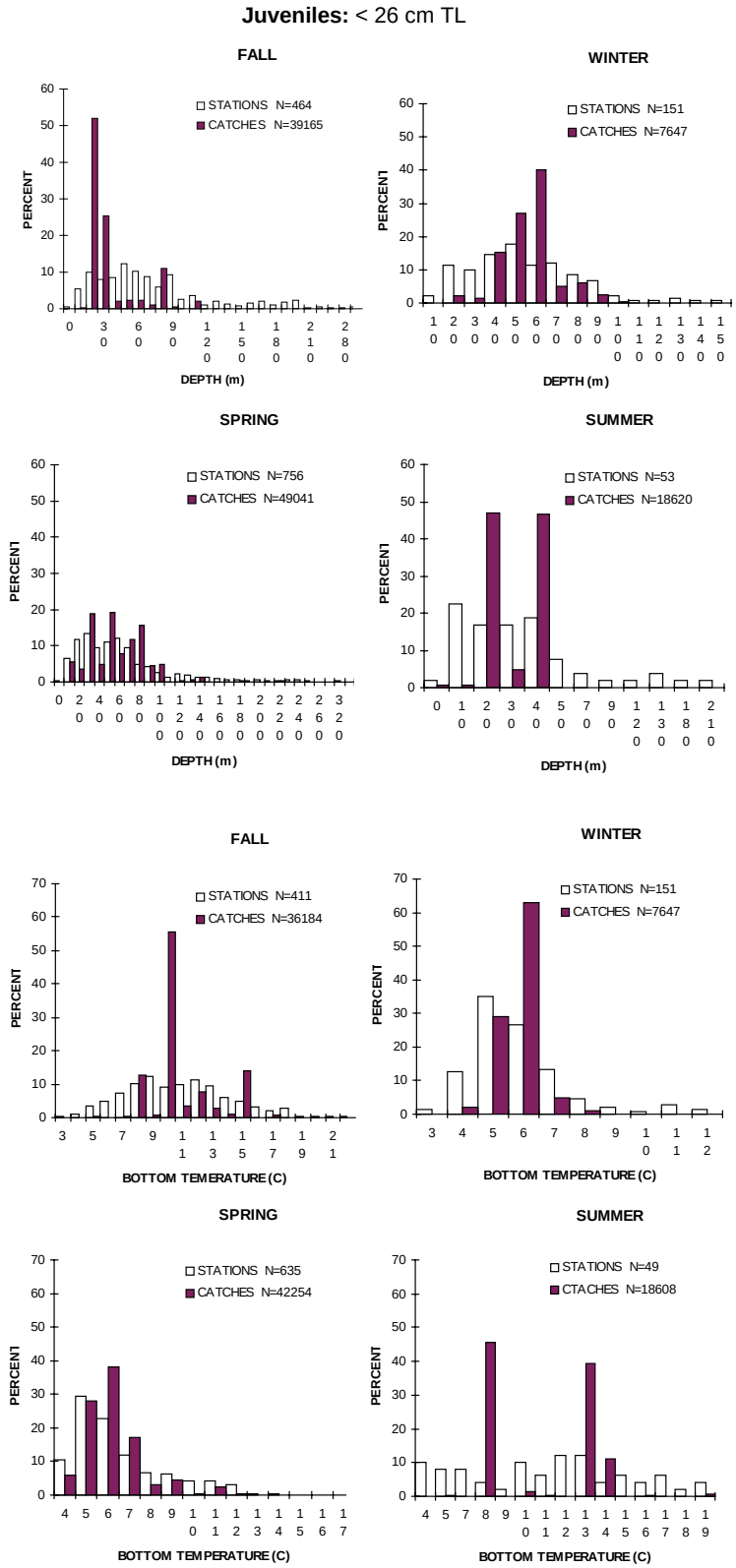


Figure 5. Seasonal abundance of juvenile Atlantic mackerel relative to bottom water temperature and depth based on NEFSC bottom trawl surveys (1963-1997; all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

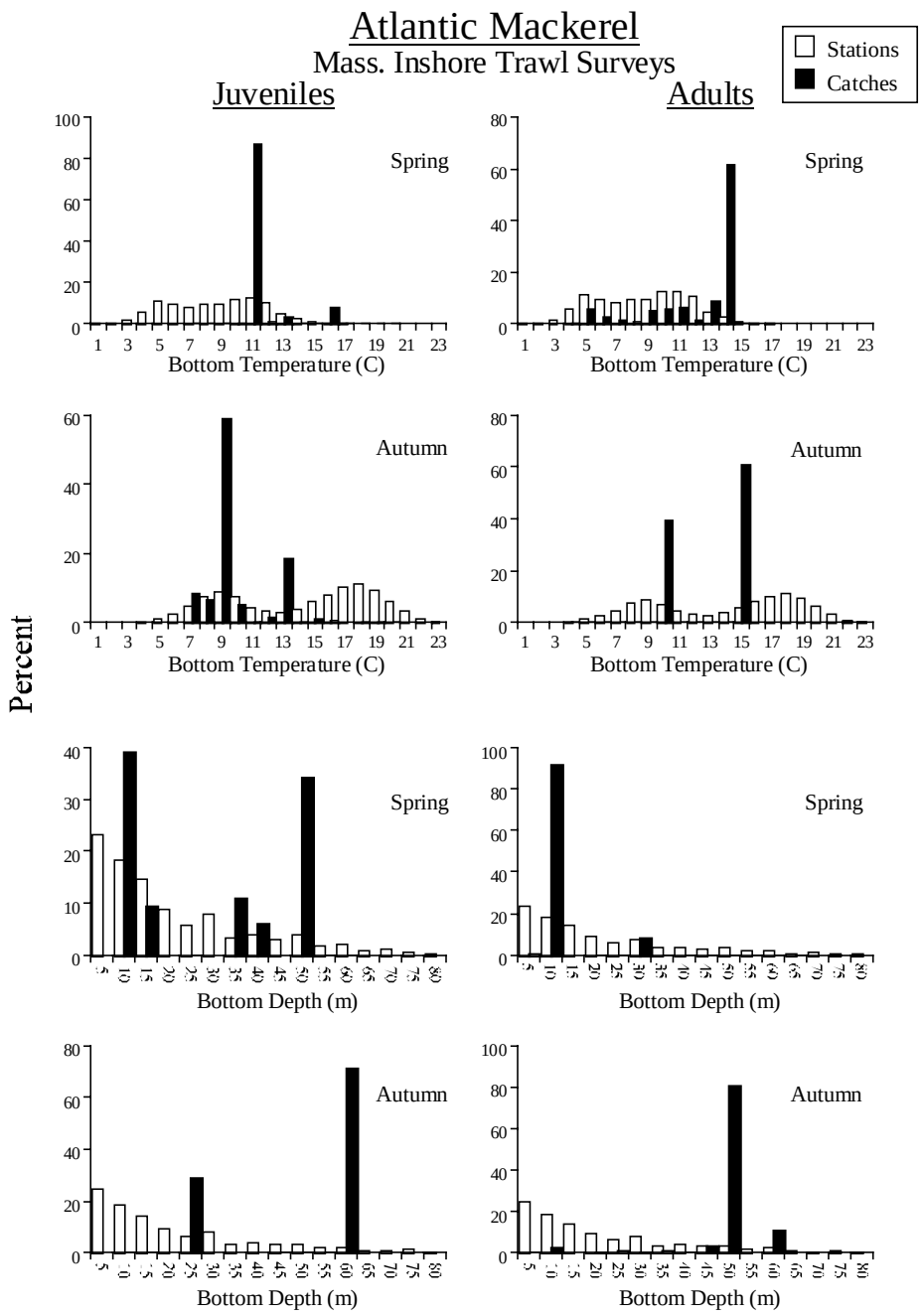


Figure 6. Abundance of juvenile (≤ 25 cm) and adult (≥ 26 cm) Atlantic mackerel relative to bottom water temperature and depth based on spring and autumn Massachusetts inshore bottom trawl surveys (1978-1996; all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

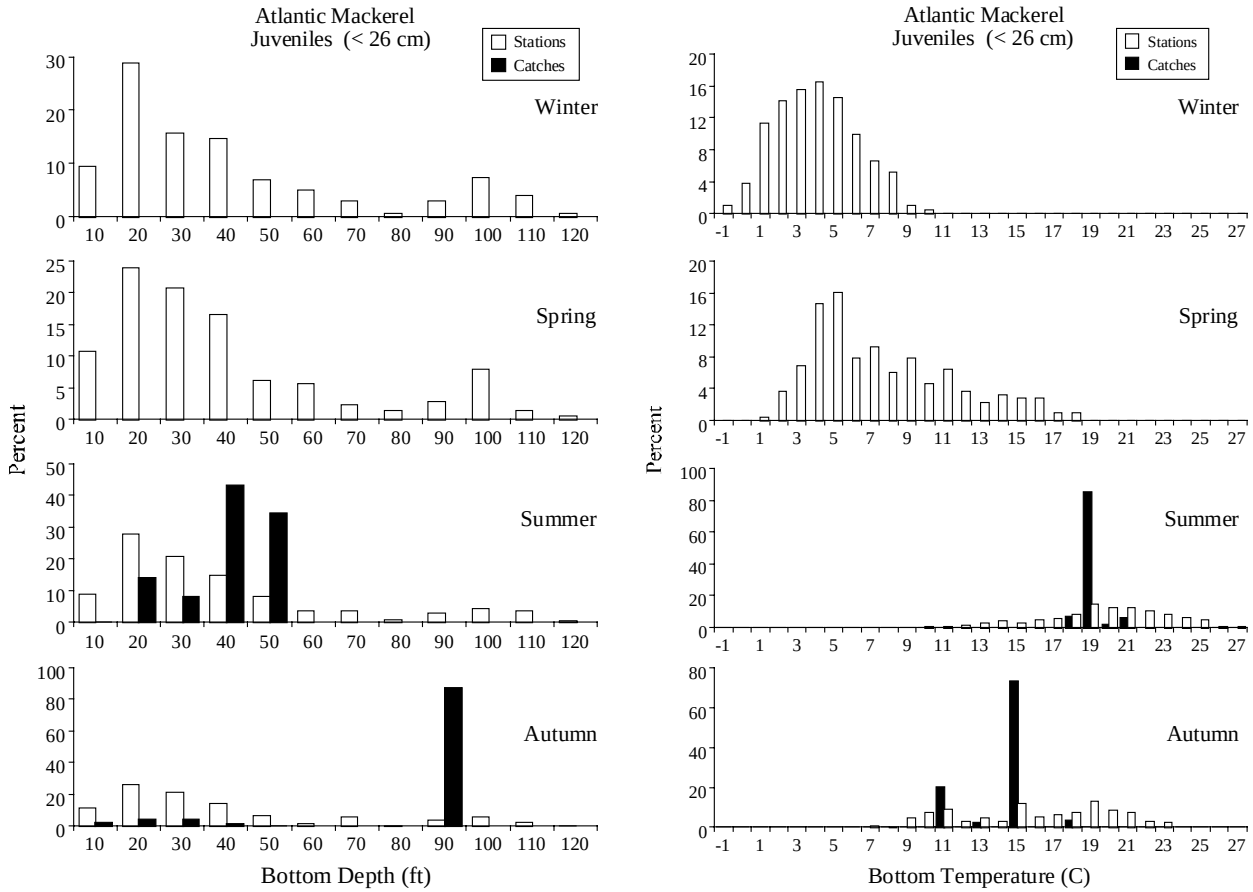


Figure 7. Seasonal abundance of juvenile Atlantic mackerel (< 26 cm) relative to bottom depth and bottom water temperature based on Rhode Island Narragansett Bay trawl surveys (1990-1996; all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

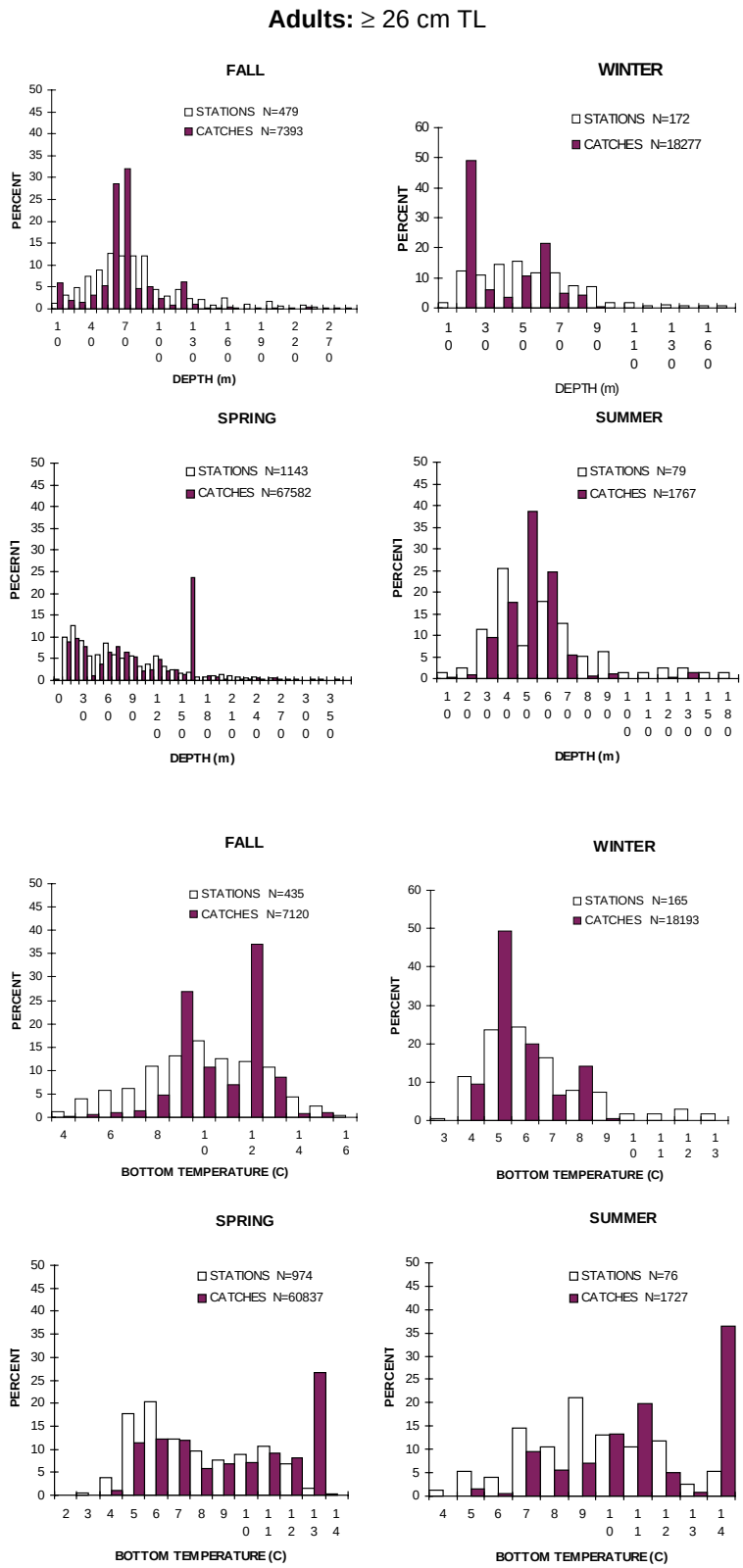


Figure 8. Seasonal abundance of adult Atlantic mackerel relative to bottom water temperature and depth based on NEFSC bottom trawl surveys (1963-1997; all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

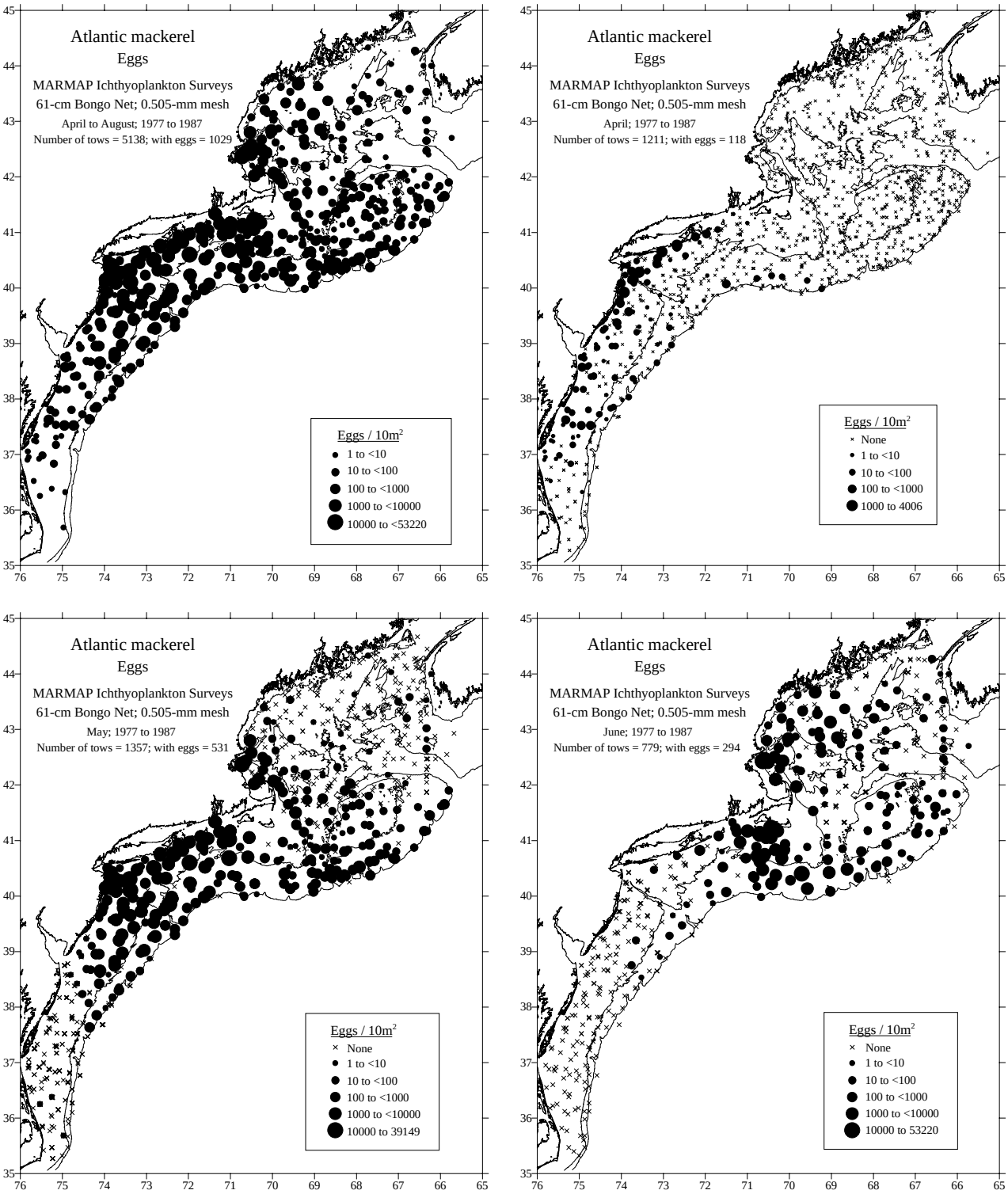


Figure 9. Distribution and abundance of Atlantic mackerel eggs collected during NEFSC MARMAP ichthyoplankton surveys from April to August, 1977-1987 [all years combined; see Reid *et al.* (1999) for details]. Egg densities are represented by dot size.

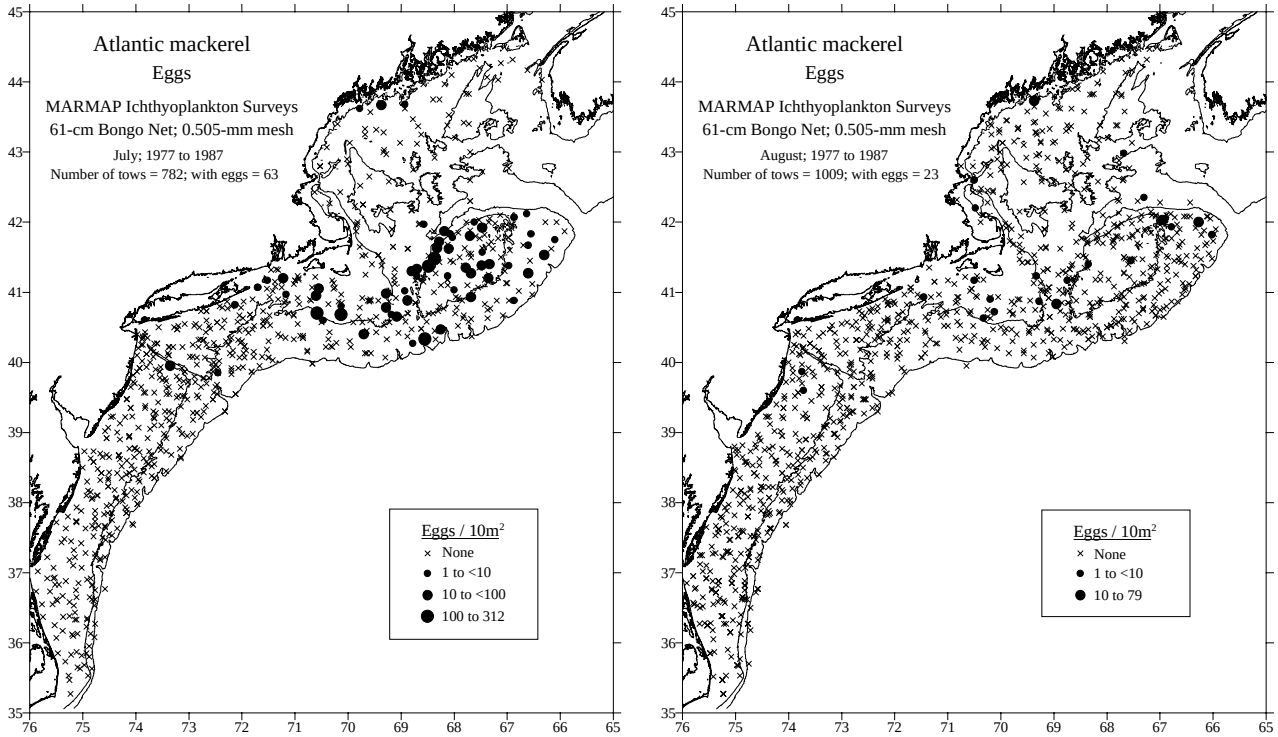


Figure 9. cont'd.

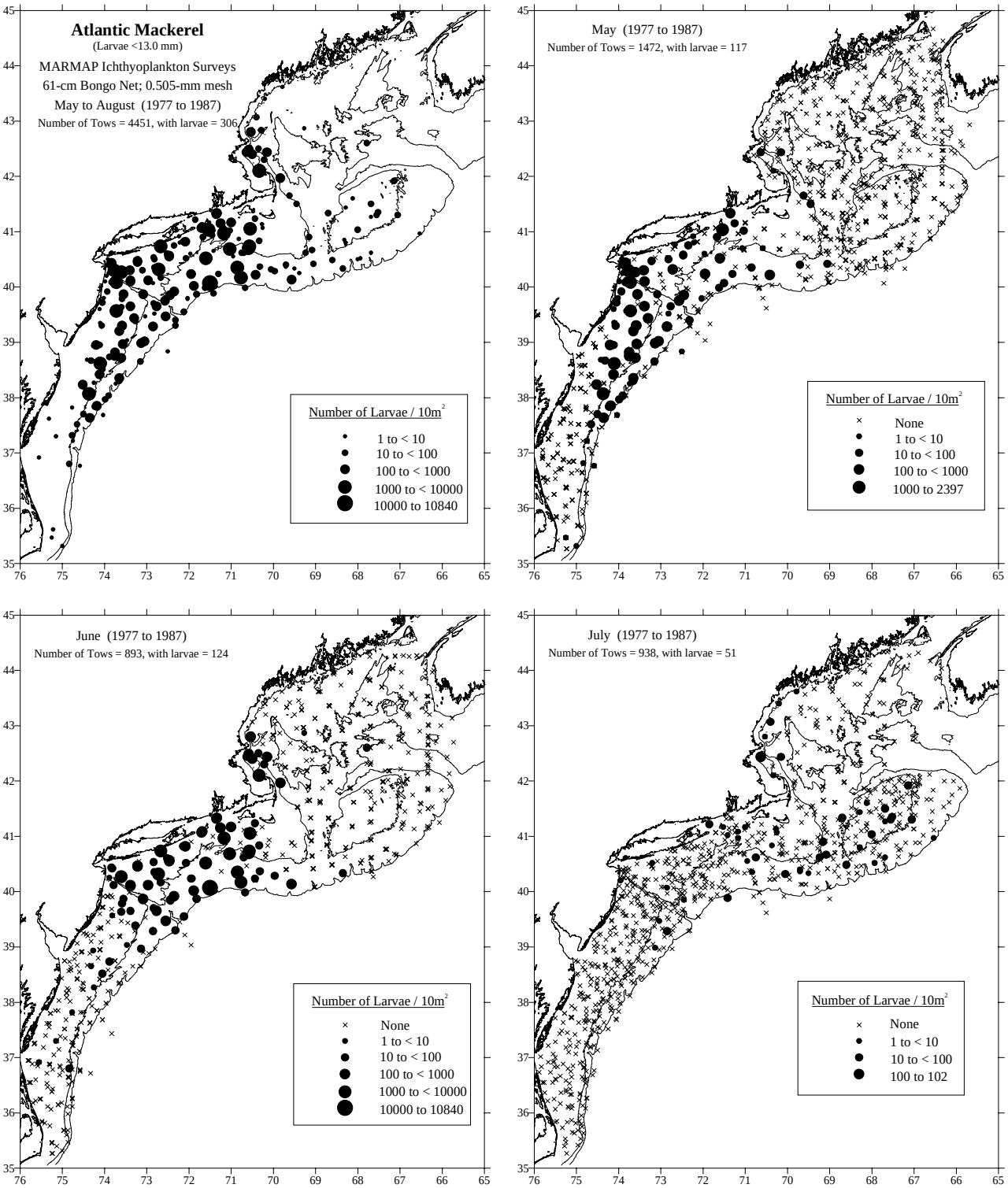
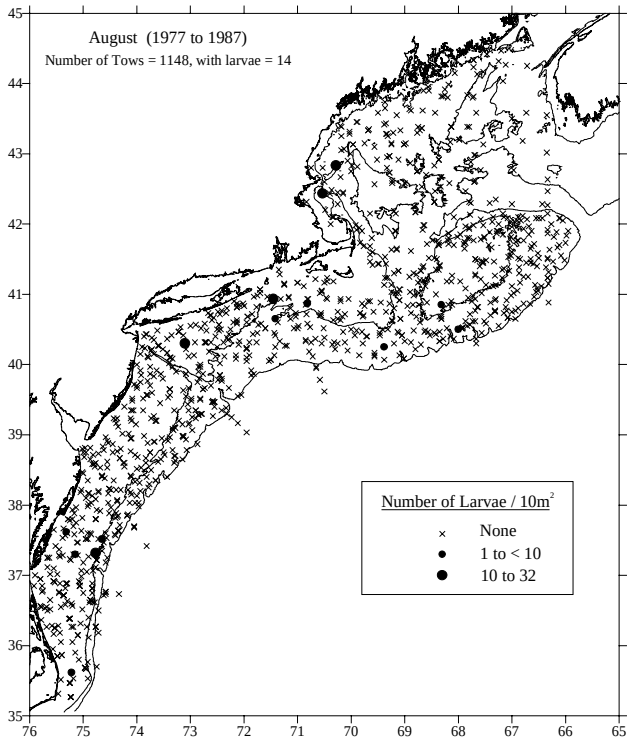


Figure 10. Distribution and abundance of Atlantic mackerel larvae collected during NEFSC MARMAP ichthyoplankton surveys from May to August, 1977-1987 [all years combined; see Reid *et al.* (1999) for details]. Larval densities are represented by dot size.



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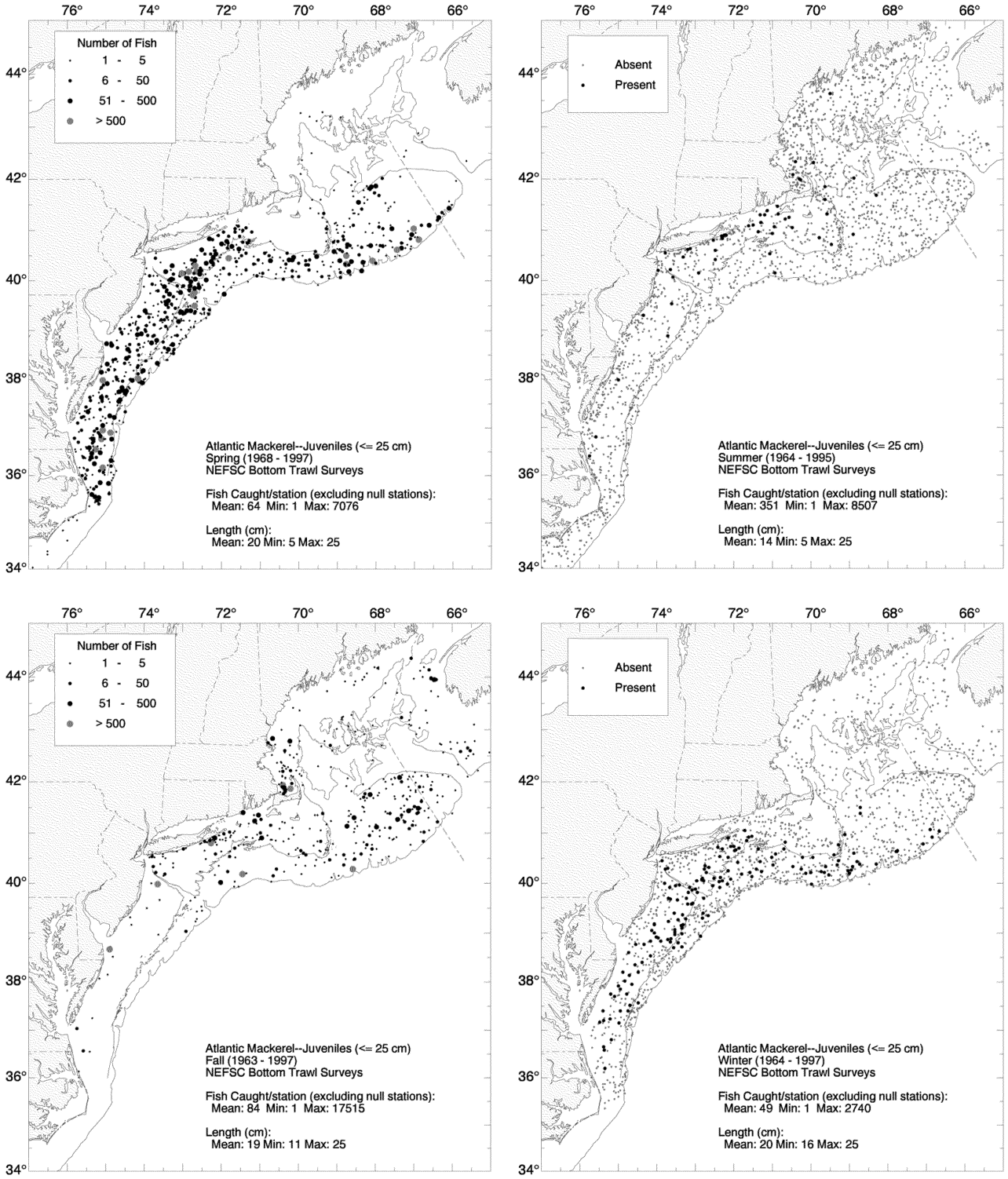


Figure 11. Seasonal distribution and abundance of juvenile (≤ 25 cm) and adult (≥ 26 cm) Atlantic mackerel collected during NEFSC bottom trawl surveys, 1963-1997 (all years combined). Densities are represented by dot size in spring and fall plots, while only presence and absence are represented in summer and winter plots [see Reid *et al.* (1999) for details].

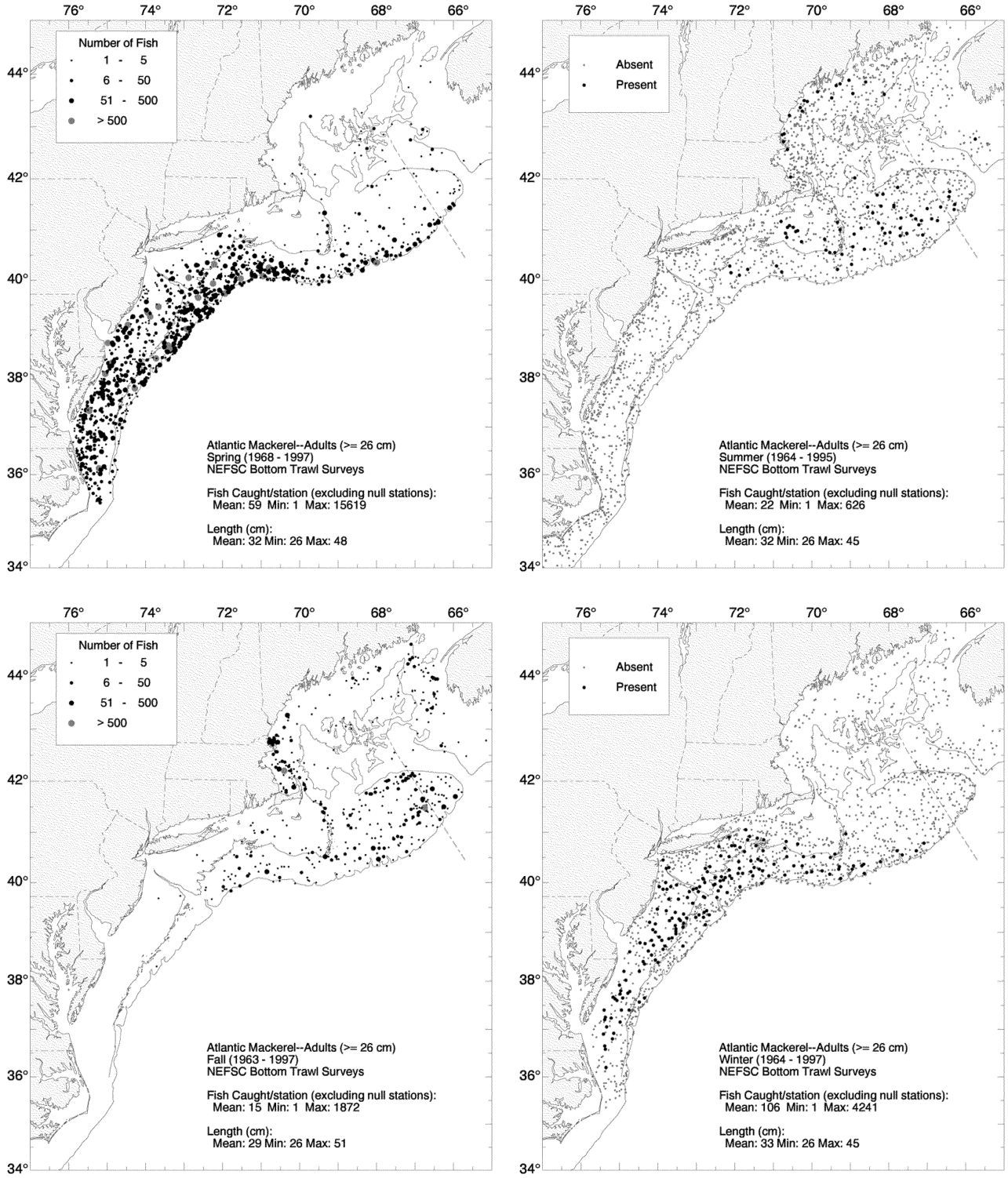


Figure 11. cont'd.

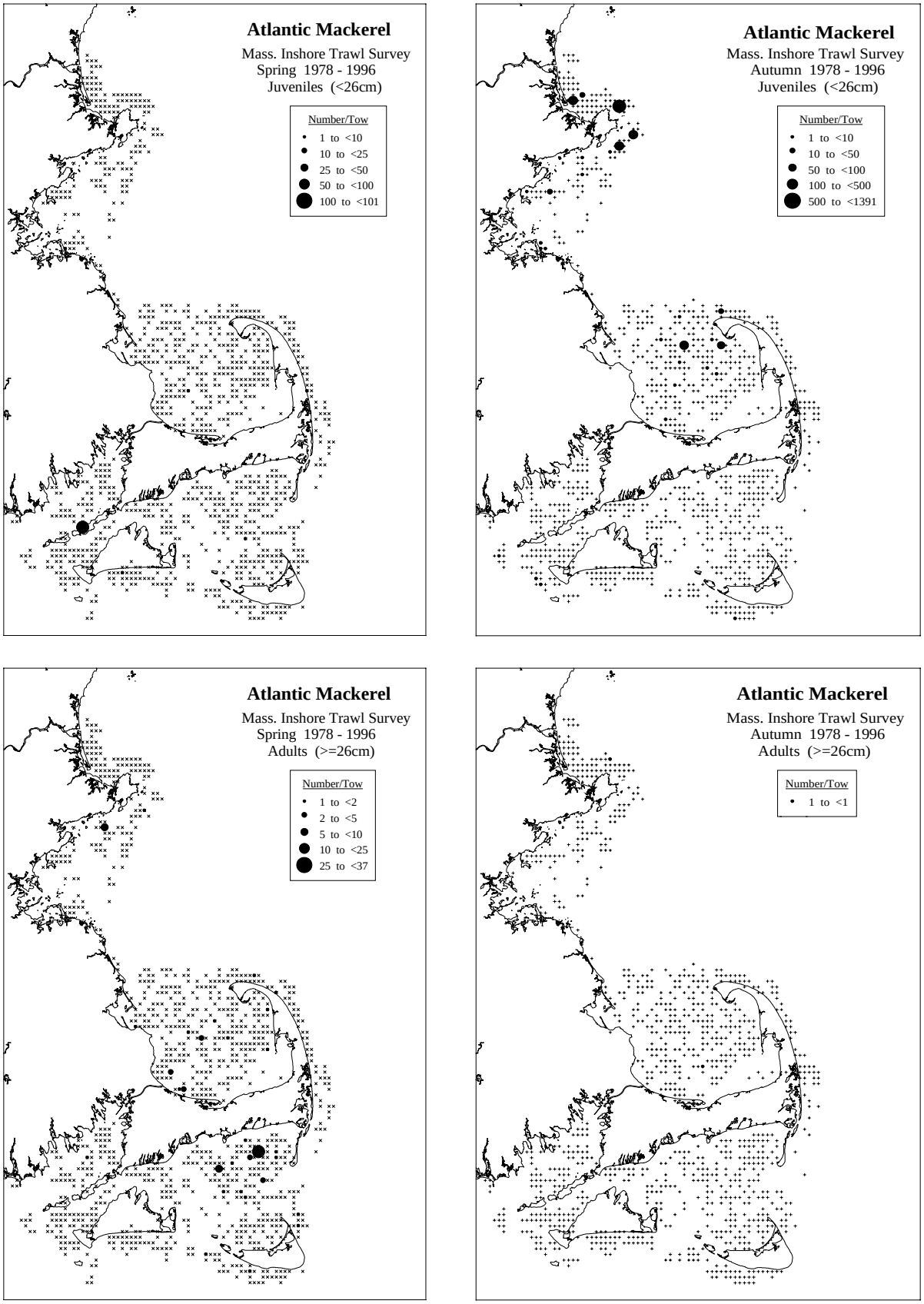


Figure 12. Distribution and abundance of juvenile (< 26 cm) and adult (≥ 26 cm) Atlantic mackerel in Massachusetts coastal waters collected during the spring and autumn Massachusetts inshore trawl surveys [1978-1996, all years combined; see Reid *et al.* (1999) for details].

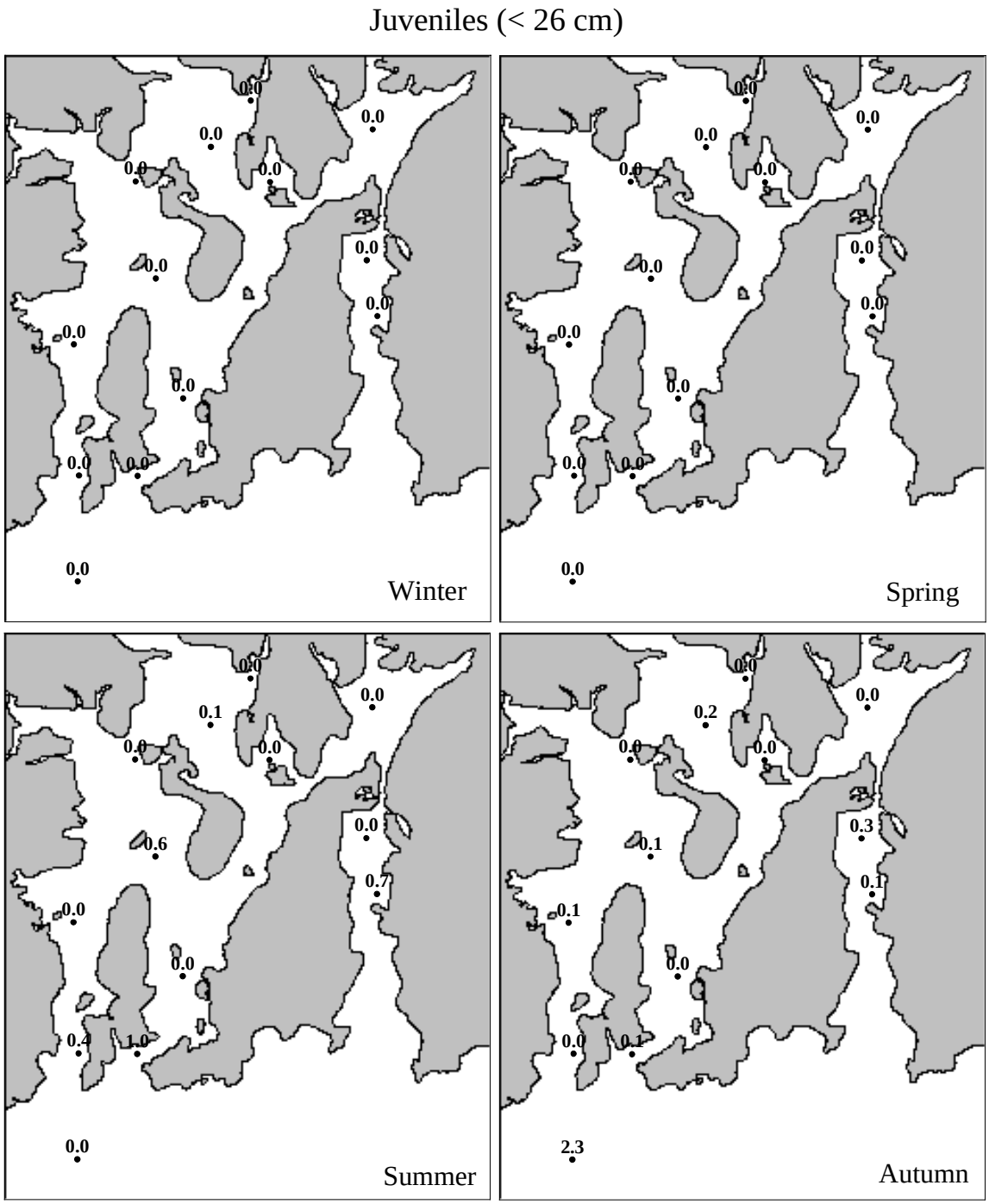
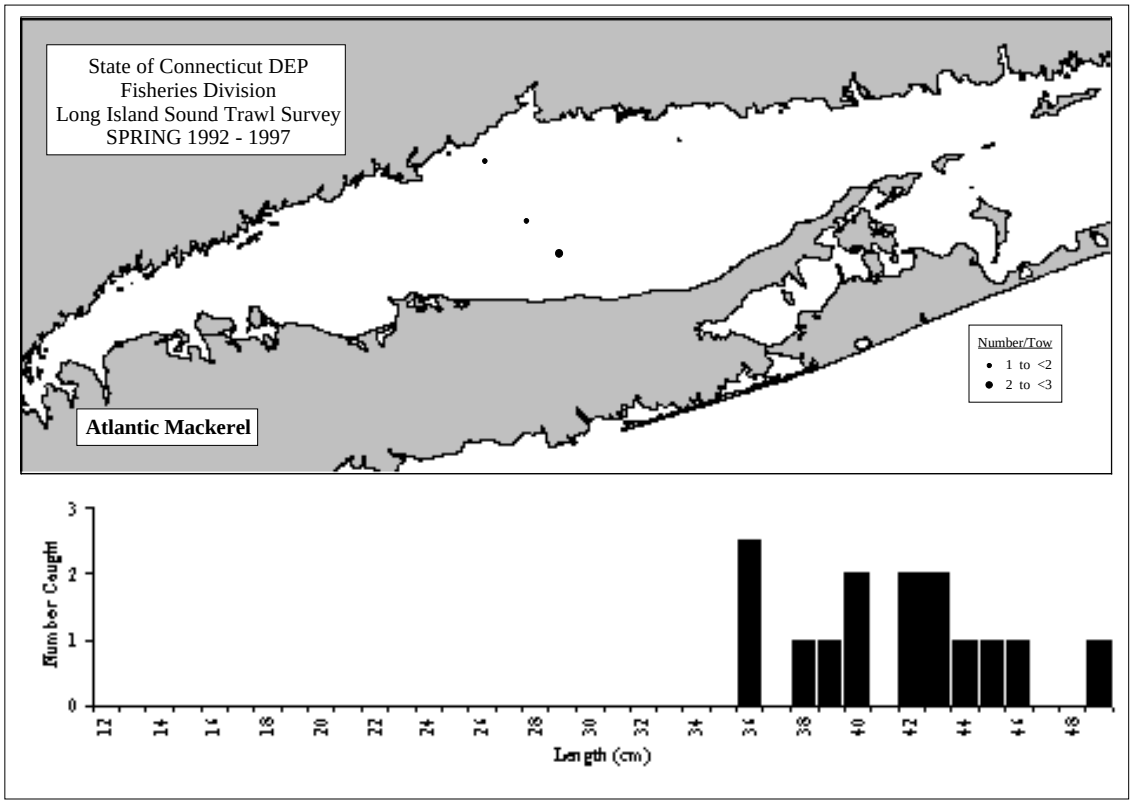


Figure 13. Seasonal distribution and relative abundance of juvenile (< 26 cm) Atlantic mackerel collected in Narragansett Bay during Rhode Island bottom trawl surveys (1990-1996; all years combined). The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al*. (1999) for details].



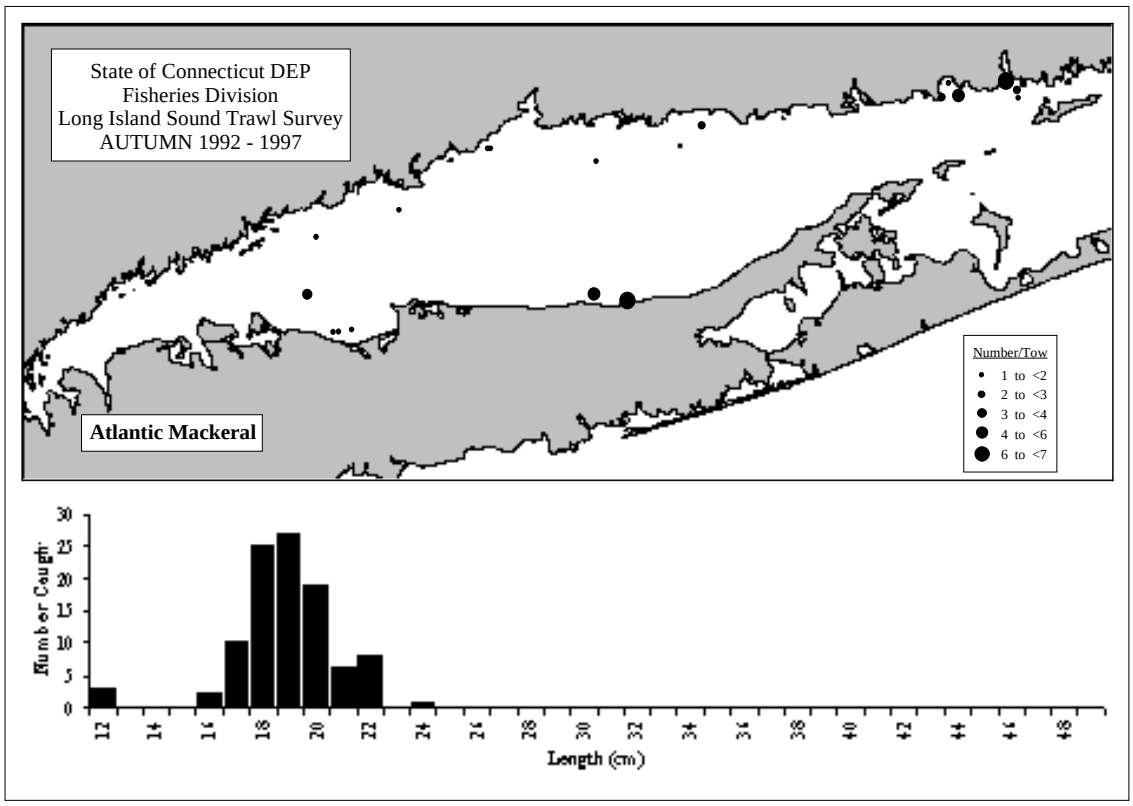


Figure 14. Distribution, abundance, and length frequency distribution of juvenile and adult Atlantic mackerel collected in Long Island Sound during spring and autumn Connecticut bottom trawl surveys [1992-1997, all years combined; see Reid *et al.* (1999) for details].

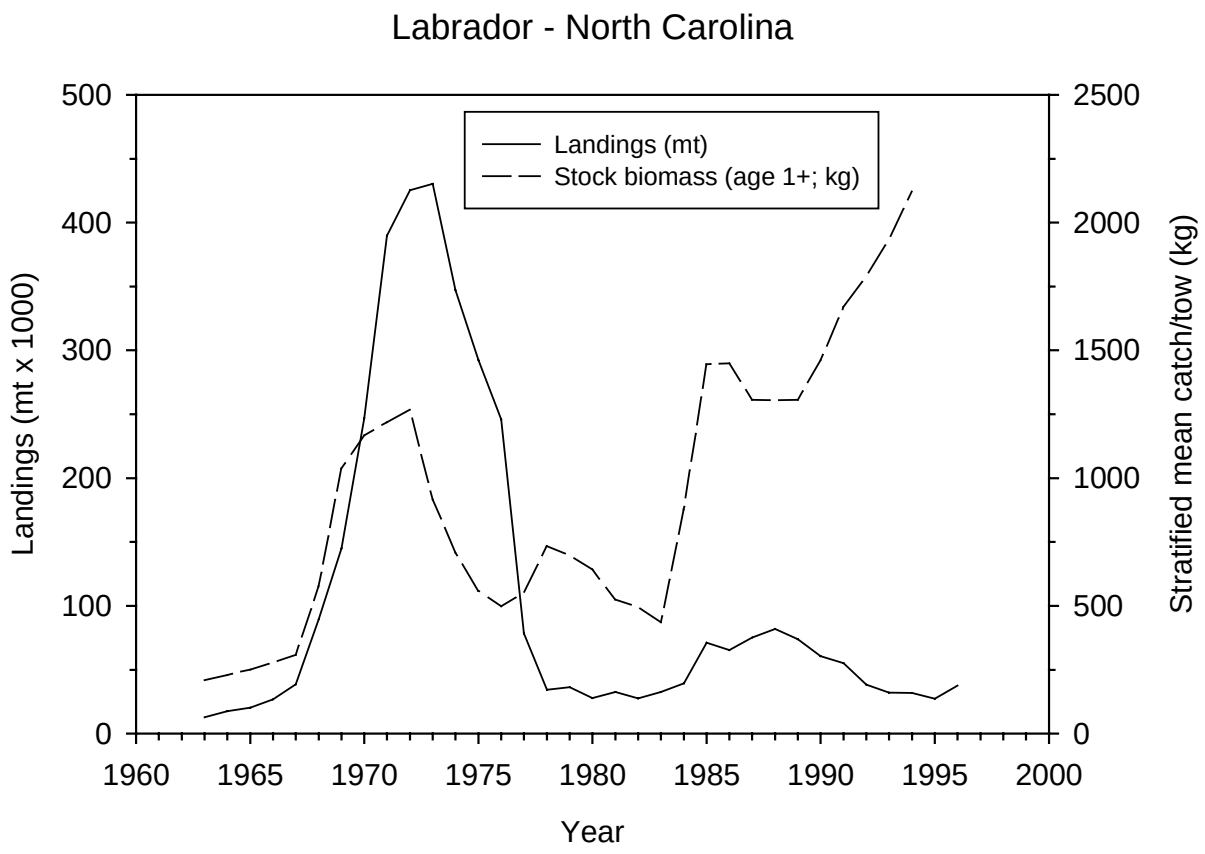


Figure 15. Commercial landings and stock biomass for Atlantic mackerel from Labrador to North Carolina.

Publishing in *NOAA Technical Memorandum NMFS-NE*

Manuscript Qualification

This series represents a secondary level of scientific publishing in the National Marine Fisheries Service (NMFS). For all issues, the series employs thorough internal scientific review, but not necessarily external scientific review. For most issues, the series employs rigorous technical and copy editing. Manuscripts that may warrant a primary level of scientific publishing should be initially submitted to one of NMFS's primary series (*i.e., Fishery Bulletin, NOAA Technical Report NMFS,* or *Marine Fisheries Review*).

Identical, or fundamentally identical, manuscripts should not be concurrently submitted to this and any other publication series. Manuscripts which have been rejected by any primary series strictly because of geographic or temporal limitations may be submitted to this series.

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For spelling of scientific and common names of fishes, mollusks, and decapod crustaceans from the United States and Canada, use *Special Publications* No. 20 (fishes), 26 (mollusks), and 17 (decapod crustaceans) of the American Fisheries Society (Bethesda, MD). For spelling of scientific and common names of marine mammals, use *Special Publication* No. 4 of the Society for Marine Mammalogy (Lawrence, KS). For spelling in general, use the most recent edition of *Webster's Third New International Dictionary of the English Language Unabridged* (Springfield, MA: G.&C. Merriam).

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Tables should be prepared using all tabs or all spaces between columnar data, but not a combination of the two. Figures must be original (even if oversized) and on paper; they cannot be photocopies (*e.g.,* Xerox) unless that is all that is available, nor be on disk. Except under extraordinary circumstances, color will not be used in illustrations.

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Authors must submit one paper copy of the double-spaced manuscript, one magnetic copy on a disk, and original figures (if applicable). NEFSC authors must include a completely signed-off "NEFSC Manuscript/Abstract/Webpage Review Form." Non-NEFSC authors who are not federal employees will be required to sign a "Release of Copyright" form.

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STANDARD MAIL A

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific ournals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

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Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series includes: data reports on field and lab observations or experiments; progress reports on continuing experiments, monitoring, and assessments; background papers for scientific or technical workshops; and simple bibliographies. Issues receive internal scientific review but no technical or copy editing. No subscriptions. Free distribution of single copies.

Fishermen's Report **and** ***The Shark Tagger*** -- The ***Fishermen's Report*** (FR) is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of the FR; copies are available through free subscription. ***The Shark Tagger*** (TST) is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of the TST; copies are available only to participants in the tagging program.

To obtain a copy of a technical memorandum or a reference document, or to subscribe to the fishermen's report, write: Research Communications Unit, Northeast Fisheries Science Center, 166 Water St., Woods Hole, MA 02543-1026. An annual list of NEFSC publications and reports is available upon request at the above address. Any use of trade names in any NEFSC publication or report does not imply endorsement.

NOAA Technical Memorandum NMFS-NE-142

Essential Fish Habitat Source Document:

Atlantic Surfclam, *Spisula solidissima*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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Essential Fish Habitat Source Document:

Atlantic Surfclam, *Spisula solidissima*, Life History and Habitat Characteristics

Luca M. Cargnelli[1], Sara J. Griesbach[1], David B. Packer[1], and Eric Weissberger[2]

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September 1999

Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

---

[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, CHIEF
ECOSYSTEMS PROCESSES DIVISION
NORTHEAST FISHERIES SCIENCE CENTER

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INTRODUCTION

The Atlantic surfclam, *Spisula solidissima* (Figure 1), is a bivalve mollusk that inhabits sandy continental shelf habitats from the southern Gulf of St. Lawrence to Cape Hatteras, North Carolina (Merrill and Ropes 1969). Atlantic surfclams are managed under the Mid-Atlantic Fishery Management Council Atlantic Surfclam and Ocean Quahog Fishery Management Plan (MAFMC 1997).

This Essential Fish Habitat source document provides information on the life history and habitat requirements of Atlantic surfclams inhabiting United States waters in the Gulf of Maine, Georges Bank, and the Mid-Atlantic Bight.

LIFE HISTORY

A brief synopsis of the life history characteristics of Atlantic surfclams is provided in Amendment #10 of the Fishery Management Plan for Atlantic Surfclam and Ocean Quahog Fisheries (MAFMC 1997). More detailed information is provided here and in reviews by Ropes (1980) and Fay *et al.* (1983).

EGGS

Unfertilized Atlantic surfclam eggs are 56 µm in diameter, unpigmented, and relatively free of yolk (Allen 1951, 1953) -- characters that are generally associated with planktotrophic eggs. Fertilization occurs in the water column above the beds of spawning clams (Ropes 1980). In the laboratory, the optimal concentration of gametes for fertilization is 0.8-4 x 10^6 sperm/ml and 5-30 x 10^3 eggs/ml (Clotteau and Dubé 1993). No information on fecundity in *S. solidissima* is available (Fay *et al.* 1983), however, fecundity of the southern subspecies *S. solidissima similis* ranges from 0.14-13 million eggs in individuals 26-50 mm shell height (Walker *et al.* 1996).

LARVAE

Fertilized eggs develop into pyramid-shaped, planktonic trochophore larvae approximately 9 h after fertilization at 21.7^{o}C (Ropes 1980) and 40 h at 14°C (Loosanoff and Davis 1963). Veliger larvae, the first larval stage to possess a bivalved shell, appear in 72 h at 14°C and 28 h at 22°C (Loosanoff and Davis 1963). The pediveliger stage, a transitional "swimming-crawling" larval stage with development of a foot for burrowing (Fay *et al.* 1983), occurs 18 d after fertilization at 21.7^{o}C (Ropes 1980). Metamorphosis to juveniles, which consists of complete absorption of the velum and settlement to the substrate, occurs anywhere from 19 to 35 d after fertilization depending on temperature (Fay *et al.* 1983). Size at metamorphosis is 230-250 µm shell length; however Ropes (1980) noted that larvae metamorphosed at 303 µm.

JUVENILES AND ADULTS

The size and age of sexual maturity is variable. Off New Jersey, Atlantic surfclams may reach maturity as early as 3 months after settlement and at lengths of less than 5 mm (Chintala and Grassle 1995; Chintala 1997). At the other extreme, clams from Prince Edward Island, Canada, may not reach maturity until 4 yrs of age and 80-95 mm shell length (Sephton 1987; Sephton and Bryan 1990). In Virginia, the minimum length at maturity is 45 mm; size rather than age is more important in determining sexual maturity (Ropes 1979). Because of the wide variability in age at maturity, juveniles and adults will be discussed together in this report.

Atlantic surfclams may reach a maximum size of 226 mm (Ropes 1980) and a maximum age of 31 yrs (Jones *et al.* 1978). Growth appears to be similar among different localities during the first 3-5 yrs of life (Ambrose *et al.* 1980; Sephton and Bryan 1990). However, after the first 5 yrs, clams offshore grow faster and attain a larger maximum size than clams inshore (Jones *et al.* 1978; Ambrose *et al.* 1980; Jones 1980; Wagner 1984). High clam density may negatively affect growth rate and maximum size (Fogarty and Murawski 1986; Cerrato and Keith 1992); density effects on growth have been detected at relatively low densities (> 50 clams per 352 m^2) (Weinberg 1998b). Growth lines in Atlantic surfclams are deposited at times of spawning and high temperature, but there is a question as to whether lines are annual (Jones *et al.* 1978; Jones 1980; Wagner 1984; Walker and Heffernan 1994). Growth is not uniform over the year; temperature significantly affects Atlantic surfclam growth, physiology, and behavior (Ambrose *et al.* 1980; Davis *et al.* 1997).

Atlantic surfclams are susceptible to several parasites, including the thigmotrich *Sphenophyra dosinae*, the cyclopoid copepod *Myocheres major*, a cestode of the genus *Echeneribothrium*, a nematode tentatively identified as *Paranisakiopsis pectinis*, and the hyperparasite haplosporidian *Urosporidium spisuli* (Ropes 1980; see also Perkins *et al.* 1975 and Payne *et al.* 1980). Payne *et al.* (1980) found an anisakine nematode of the genus *Sulcascaris* in clams from New Jersey to Virginia. Yancey and Welch (1968) noted the presence of trematodes in Atlantic surfclams, but their effects are unclear.

REPRODUCTION

Atlantic surfclams spawn in the summer and early

fall. In New Jersey, spawning occurs from late June to early August (Ropes 1968a), although spawning may begin as early as late May or early June closer inshore (Tarnowski 1982; J.P. Grassle, Rutgers University, New Brunswick, NJ, unpublished data). Spawning begins and ends earlier in the south; in Virginia, it may begin in May and end in July (Ropes 1979). The southern subspecies *Spisula solidissima similis* spawns in the spring to early summer (Kanti *et al.* 1993).

Spawning is not associated with a particular temperature or abrupt temperature changes (Ropes 1968a), but usually occurs when temperatures are greater than 15°C. There may be a second, minor spawning in October, caused by breakdown of the thermocline; in extremely cold years, this second spawning may not occur (Ropes 1968a). Little is known about the effects of other environmental factors, such as salinity and dissolved oxygen, on Atlantic surfclam spawning.

FOOD HABITS

Atlantic surfclams are planktivorous siphon feeders. Leidy (1878) noted the presence of many genera and species of diatoms in Atlantic surfclam guts. Ciliates were also a common component of the diet in the field. Riisgård (1988) showed that Atlantic surfclams retained particles as small as 4 µm in diameter. High concentrations of suspended clay particles may decrease the amount of algae ingested and digested (Robinson *et al.* 1984).

PREDATION

Atlantic surfclams have many predators, including the naticid snails *Euspira heros* and *Neverita duplicata* (Franz 1977; Dietl and Alexander 1997), the sea star *Asterias forbesi* (Meyer *et al.* 1981), lady crabs (*Ovalipes ocellatus*), Jonah crabs (*Cancer borealis*) (Stehlik 1993), and horseshoe crabs (*Limulus polyphemus*) (Botton and Haskin 1984). Fish predators include haddock (*Melanogrammus aeglefinus*) and Atlantic cod (*Gadus morhua*) (Ropes 1980). The sevenspine bay shrimp, (*Crangon septemspinosa*) preys on recently settled clams (Viscido 1994). In the New York Bight, crabs accounted for 48.3-100% of Atlantic surfclam mortality while naticid moon snails accounted for 2.1% of mortality (MacKenzie *et al.* 1985).

HABITAT CHARACTERISTICS

Information on the habitat characteristics of the Atlantic surfclam is summarized in Table 1. This information focuses primarily on Atlantic surfclam beds in U.S. waters; most of the information is from the Middle Atlantic Bight.

EGGS

Fertilization of Atlantic surfclam eggs is optimal at 6-24°C, 20-35 ppt salinity, and a pH of 7.8-10 (Allen 1953; Castagna and Chanley 1973; Clotteau and Dubé 1993). Eggs and sperm can withstand salinities as low as seawater diluted to 40% for 2-3 h (Schechter 1956).

LARVAE

Larvae tolerate temperatures of 14-30°C, with an optimum at 22°C (Fay *et al.* 1983). High temperatures can be lethal to developing larvae. Substantial mortality occurs in early cleavage stages exposed to 29.5°C water for 10 min, in trochophores exposed to 31.5°C water for 1 hr, and in straight-hinge veligers exposed to 34°C for 3 h (Wright *et al.* 1983; Roosenberg *et al.* 1984). Larvae are capable of growing in salinities as low as 16 ppt (Castagna and Chanley 1973), and can survive in salinities of 8 ppt at 7.7°C (Yancey and Welch 1968). In the laboratory, larvae did not cross salinity discontinuities greater than 15 ppt, and remained in the high-salinity end of a salinity gradient (Mann *et al.* 1991).

Few studies have examined Atlantic surfclam larvae in the field. In New England, Mann (1985) reported high larval concentrations (up to 823 larvae/m^3) associated with 14-18°C water masses and relatively low chlorophyll *a* concentrations. In New Jersey, Tarnowski (1982) noted high concentrations of Atlantic surfclam larvae in the spring and fall. Spring larvae were derived from inshore clams, while fall larvae were from offshore clams. Dispersal by currents occurs during the larval stage (Fay *et al.* 1983) and larval settlement may coincide with the relaxation of upwelling events (Ma 1997). Franz (1976) hypothesized that a convergence of tidal and longshore currents trap Atlantic surfclam larvae off western Long Island, although this theory is based on juvenile and adult distributions rather than larval samples.

JUVENILES AND ADULTS

The greatest concentrations of Atlantic surfclams are usually found in well-sorted, medium sand (Dames and Moore 1993), but they may also occur in fine sand (MacKenzie *et al.* 1985) and silty-fine sand (Meyer *et al.* 1981). Ambrose *et al.* (1980) noted a positive correlation between growth rate and mean sediment grain size when other variables were controlled, although Goldberg and Walker (1990) found that substrate type did not affect the growth rate of clams in the laboratory and field, although clams did not burrow in mud. Atlantic surfclams are most

common at depths of 8-66 m in the turbulent areas beyond the breaker zone (Fay *et al.* 1983).

Henderson (1929) determined the upper lethal temperature of Atlantic surfclams to be 37°C, however, this was based on only five individuals. Mid-Atlantic surfclams reared in a laboratory in Georgia did not survive temperatures above 28°C (Spruck *et al.* 1995). Atlantic surfclams rarely encounter such temperatures in the wild and are usually found in areas where the bottom temperature rarely exceeds 25°C. The minimum temperatures experienced by Atlantic surfclams are probably not < 1°C. Spawning in nature occurs at temperatures > 15°C and is typically heaviest when temperatures are at their highest (Jones 1981b; Sephton 1987).

Growth is not uniform over the year. Ambrose *et al.* (1980) noted that growth of Atlantic surfclams in the Middle Atlantic Bight was positively correlated with temperature and negatively correlated with variation in temperature. Davis *et al.* (1997) found that growth in the coastal Gulf of Maine was higher at warmer temperatures and at higher chlorophyll *a* concentrations. Stable oxygen isotopes revealed that shell growth in New Jersey waters reflects seawater temperature; growth is most rapid in spring and early summer, slow in late-summer and fall, and extremely slow or non-existent in winter (Jones *et al.* 1983). In Delaware waters, Atlantic surfclam production is highest in August and September when temperatures are high (Howe *et al.* 1988). In the laboratory, Atlantic surfclam heart rate increased with increasing temperature from 5-15°C (deFur and Mangum 1979). Savage (1976) found that clams burrowed fastest at 16-26°C, and were unable to burrow at 30°C. Prior *et al.* (1979) noted no uniform effect of temperature on the leaping escape response of Atlantic surfclams, but did note that clams seemed to be more active above 15°C.

Although Atlantic surfclams are found only at salinities higher than 28 ppt in the field, they are capable of surviving salinities as low as 12.5 ppt for 2 d (Castagna and Chanley 1973). This suggests that something other than salinity is controlling the distribution of Atlantic surfclams. In the laboratory, Atlantic surfclam heart rate increased as salinity dropped from 30 ppt to 20 ppt (deFur and Mangum 1979).

Atlantic surfclams are susceptible to low levels of dissolved oxygen (DO). Severe hypoxic events (DO < 3 ppm) in New Jersey have killed Atlantic surfclams several times (Ogren and Chess 1969; Garlo *et al.* 1979; Ropes *et al.* 1979). Weinberg and Helser (1996) showed spatial and temporal changes in growth rate and maximum size and hypothesized these changes may be related to low dissolved oxygen levels. Positive effects of hypoxia include the decimation of Atlantic surfclam predators, allowing successful recruitment of recently-settled clams (Garlo 1982). In the laboratory, Thurberg and Goodlett (1979) noted that a dissolved oxygen level < 1.4 ml/L was nearly always fatal, although clams could survive at levels as low as 0.7 ml/L if acclimated slowly. Atlantic surfclam heart rate remained relatively constant over a wide range of oxygen concentrations (deFur and Mangum 1979). Supersaturation of oxygen may also negatively affect clams. In the laboratory, significant Atlantic surfclam mortality occurred at 114% O_2 saturation (Goldberg 1978). Sublethal effects at lower O_2 levels included tissue blisters and secretion of shell material surrounding air bubbles.

There has been little work on the effects of currents on Atlantic surfclams, particularly on feeding and bedload transport of small clams. The dynamic environments in which Atlantic surfclams live may substantially affect flux of food and population distribution. For example, oceanic storms can displace adults a considerable distance from their burrows (Fay *et al.* 1983).

GEOGRAPHICAL DISTRIBUTION

Atlantic surfclams are distributed in western North Atlantic continental shelf waters from the southern Gulf of St. Lawrence to Cape Hatteras, North Carolina (Merrill and Ropes 1969; Weinberg 1998a). In United States waters, major concentrations of Atlantic surfclams are found on Georges Bank, south of Cape Cod, off Long Island, southern New Jersey, and the Delmarva Peninsula (Merrill and Ropes 1969; Ropes 1978). Although Atlantic surfclams can inhabit waters from the surf zone to a depth of 128 m, most are found at depths of less than 73 m (Ropes 1978). Along Long Island and New Jersey, the highest concentrations occur at < 18 m, whereas off the Delmarva Peninsula, the greatest concentrations occur from 18 to 36 m (Ropes 1978).

A southern subspecies, *Spisula solidissima similis*, occurs south of Cape Hatteras (Walker and Heffernan 1994). *Spisula raveneli* occurs in the southern part of the range of *S. solidissima*. The distinction of the species, based on distribution and morphology (Jacobson and Old 1966; Porter and Schwartz 1981), is controversial (Vecchione and Griffis 1996).

EGGS AND LARVAE

The eggs and larvae of Atlantic surfclam were not counted during the Northeast Fisheries Science Center (NEFSC) Marine Resources Monitoring, Assessment and Prediction (MARMAP) program (P. Berrien, NMFS, NEFSC, James J. Howard Marine Sciences Laboratory, Highlands, NJ, personal communication).

PRE-RECRUITS AND RECRUITS

The terms pre-recruit and recruit are used here to describe Atlantic surfclam distribution. They refer to the

exploited and unexploited portions of the stock. Atlantic surfclams are exploited at a minimum size of 12 cm; pre-recruits are ≤ 11 cm and recruits are ≥ 12 cm.

The NEFSC clam surveys [see Reid *et al*. (1999) for survey methods] collected Atlantic surfclams from Georges Bank to just north of Cape Hatteras (Figure 2). Pre-recruits and recruits had similar distributions, although recruits were not collected quite as far to the south. The greatest number of catches of pre-recruits and recruits were made from the Hudson Canyon to Cape Hatteras inshore of the 60 m contour. The Gulf of Maine was not surveyed, although Atlantic surfclams are found there in areas containing suitable substrate (sand).

STATUS OF THE STOCKS

The total commercial landings of Atlantic surfclam peaked during 1973-1975, with an average meat weight of 40,100 metric tons (mt). This was followed by a decline to an historic low of 15,800 mt by 1979. Landings increased to more than 30,000 mt in 1984 and have remained at comparable levels ever since. Landings in 1996 were 28,800 mt, almost identical to 1995 and 7% below landings in 1994 (Figure 3; Weinberg 1998a). Biomass indices from research vessel surveys generally parallel trends in landings. The results of the 1997 surveys indicate that the majority of the Atlantic surfclam resource is concentrated in northern New Jersey, the Delmarva Peninsula, and Georges Bank (Northeast Fisheries Science Center 1998). Gulf of Maine Atlantic surfclams are currently not harvested commercially (Davis *et al*. 1997).

The EEZ Atlantic surfclam resource is currently at a medium level of biomass and appears under-exploited overall (Northeast Fisheries Science Center 1998). The September 1997 report to Congress, 'Status of Fisheries of the United States' (National Marine Fisheries Service 1997), states that Atlantic surfclams are presently not overfished, nor approaching an overfished condition.

RESEARCH NEEDS

- Accurate estimates of population sizes are needed. Efforts to refine estimates of population abundance in different regions, and to understand factors affecting dredge efficiency, need to be continued. In addition to assessment surveys, total population densities and age structure should be assessed using depletion experiments by commercial vessels, complemented by quantitative techniques.
- The implications of density effects on growth and size for harvesting and optimal yield should be determined. High population density may negatively affect growth rate, size at age, and meat weight, but there is insufficient information to determine optimal densities for management purposes. Region-specific studies on the effects of population density on age-specific growth are needed.
- The genetic structure of populations of *Spisula solidissima* over the geographic range of the species should be determined. Molecular techniques can be used to determine the relationship between *S. solidissima*, the southern subspecies *S. s. similis*, and the named species *S. raveneli*, whose systematic status is uncertain. If the Atlantic surfclam population consists of independent genetic units, this would have important implications for management.
- The effects of dredging on settlement and recently settled clams needs to be examined. While the effects of dredging on juvenile and adult clams have been studied, there are no data on the effects of dredging on the youngest clams. Because of their small size, settling and recently settled clams may be adversely affected by dredging.
- Region-specific studies on the correlation between environmental parameters (e.g., bottom temperature), spawning, and recruitment are needed. Physical data are often available from other research programs on the continental shelf, and these can be correlated with yearly changes in spawning times and subsequent settlement intensity and recruitment.

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Table 1. Summary of life history and habitat characteristics for the Atlantic surfclam, *Spisula solidissima*.

Life Stage	Size and Growth	Habitat	Substrate	Temperature	Salinity
Eggs [1]	Unfertilized eggs are 56 µm in diameter.			6-24°C optimal for fertilization.	Sperm and eggs can withstand salinities as low as 40% diluted seawater for 2-3 h. 20-35 ppt optimal for fertilization; fertilized eggs do not develop at 22 ppt or lower. Hypo- or hypertonicity may cause parthenogenesis (hermaphroditism).
Larvae [2]	At 22°C: 28 hr to straight hinge veligers. At 21.7°C: trochophore larvae 9 h post-fertilization, veligers 19-20 h, pediveligers at 18 d. At 14°C: 40 hr to trochophore, 72 hr to straight hinge veligers. Metamorphosis: 35 d at 14°C, 19 d at 22°C. Most larvae metamorphose at 230-250 µm, although one study reports 303 µm.	One study in Massachusetts found the highest concentration of larvae (823 larvae/m^3) at 30 m in early October. High concentrations of larvae in NJ occur from May-June and Sept-Oct; minor peaks sometimes occur in July. Spring larvae were derived from inshore clams, while fall larvae were derived from offshore clams.		Larvae tolerate 14-30°C; optimum 22°C, mortality > 30°C. Larvae reared at lower temperatures were smaller than those at warmer temperatures. In New England, high larval concentrations are associated with 14-18°C water.	Larvae in the lab can survive and grow at 16 ppt; with acclimation as low as 8 ppt. Larvae starting at 30 ppt crossed a salinity gradient of 5 ppt and 10 ppt, but not 15 ppt. Upward swimming rate increased with salinity, larvae stayed in high salinity.
Juveniles/ Adults [3]	Growth rates are similar for the first 3-5 years of life, then offshore clams grow more rapidly than inshore clams. High population density reduces growth rate and maximum length. Clams may reach lengths of 226 mm and 37 yrs of age.	Range from the Gulf of Maine south to Cape Hatteras, NC. Oceanic, most common in turbulent areas beyond breaker zone, from 8-66 m. Distribution of beds ranges from even aggregations to localized or patchy dense beds.	Adults burrow in medium to coarse sand and gravel substrates, also found in silty to fine sand, do not burrow in mud. Substrate type does not affect growth rate.	37°C is lethal in the lab. Clams survive temperatures as low as 2°C in the field; clams more active > 15°C. Burrowing is fastest at 16-26°C; inhibited ≥ 30°C. Growth rate is positively correlated with temperature, growth most rapid in spring/early summer.	Adults in lab tolerated 14-52 ppt. Atlantic surfclams at 28 ppt in the field survived in the lab at 12.5 ppt for several days, suggesting that a variable other than salinity controls distribution.
Spawning Adults [4]				Spawning occurs from 19.5-30°C; detrimental > 30°C. Laboratory: burrowing increased up to 20°C, but decreased > 20°C. Temperature important for initiation and timing of both gonadal development and spawning. Off NJ, spawning heaviest in summer/fall when temperatures are at their highest; may be a minor Oct spawning, brought about by breakdown of thermocline. Delayed spawning and single annual cycle may be related to cold temperatures. Abrupt temperature changes not a clear cause of spawning in nature.	

[1] Allen (1953), Schechter (1956), Yancey and Welch (1968), Castagna and Chanley (1973), Wright *et al.* (1983), Roosenberg *et al.* (1984), Clotteau and Dubé (1993)

[2] Loosanoff and Davis (1963), Yancey and Welch (1968), Ropes (1980), Tarnowski (1982), Fay *et al.* (1983), Wright *et al.* (1983), Roosenberg *et al.* (1984), Mann (1985), Mann *et al.* (1991), Ma (1997)

[3] Henderson (1929), Clarke (1954), Yancey and Welch (1968), Merrill and Ropes (1969), Ogren and Chess (1969), Ropes and Merrill (1970), Castagna and Chanley (1973), Flowers (1973), Franz (1976), Savage (1976), Loesch and Ropes (1977), Ropes and Ward (1977), Goldberg (1978), Jones *et al.* (1978, 1983), Ropes (1978, 1980), Boesch (1979), Prior *et al.* (1979), Ambrose *et al.* (1980), Garlo (1980), Jones (1980, 1981a), Meyer *et al.* (1981), Fay *et al.* (1983), Wagner (1984), MacKenzie *et al.* (1985), Fogarty and Murawski (1986), Howe *et al.* (1988), Murawski and Serchuk (1989), Goldberg and Walker (1990), Sephton and Bryan (1990), Walker and Heffernan (1990, 1994), Cerrato and Keith (1992), Dames and Moore (1993), Weinberg and Helser (1996), Chintala (1997), Weinberg (1998a, b)

[4] Loosanoff and Davis (1963), Ropes (1968a, b, 1980, 1982), Jones (1981b), Fay *et al.* (1983), Sephton (1987), Kanti *et al.* (1993), Chintala and Grassle (1995)

Table 1. cont'd.

Life Stage	Dissolved Oxygen	Currents	Prey	Predators	Spawning	Notes
Eggs [1]					see spawning adults	Fertilization occurs in water column above spawning beds; pH 7.8-10 optimal for fertilization.
Larvae [2]		Larval settlement coincides with relaxation of upwelling events. Dispersal via water currents, swimming and crawling occur during larval stages. Convergence of tidal and longshore currents may trap larvae off western Long Island.	Larvae are planktotrophic.			Larval stages: trochophore (planktonic), veliger (bivalve shell present), pediveliger (transitional swimming-crawling stage).
Juveniles/ Adults [3]	Hypoxia may be lethal, or lower growth rate and maximum size in the field. In the lab, burrowing time was slower at 1.45 mg/L than at higher DO levels. Clams died after 5 d at a DO of 0.9 mg/L. Anoxic event in 1976 off NJ and Long Island killed 62% of NJ Atlantic surfclam resource; lower lethal limit of 2 ppm DO assumed.	Currents important in determining eventual patterns of distribution and settlement of developing juveniles. Oceanic storms and currents may displace adults considerable distance from burrows; survivors reburrow at new site.	Planktivorous siphon feeders. Food varies with season, geographic location and depth of bed; feed primarily on phytoplankton, especially diatoms and ciliates. Retain particles ≥ 4µm diameter.	Primarily moon snails, also sea stars, horseshoe crabs, lady crabs, Jonah crabs, sea gulls, and shrimp. Predation rate of moon snails lowered by low temperatures and salinities, ceased feeding at < 2 and 5°C respectively, and < 10 and 6 ppt salinity respectively. Haddock and cod prey on injured clams after storms.		Metamorphosis to juveniles and settlement to substrate ranges from 18-35 d (varies with temperature). The age of maturity ranges from 3 months to 4 years post-settlement. Without examining the gonads of small clams, one can't assume level of maturity. Longevity up to 25 years; largest individual recorded 226 mm.
Spawning Adults [4]					Atlantic surfclams can reach sexual maturity and spawn as early as 3 months post-settlement. Off NJ: major spawning early July to mid-Aug; in some years second minor spawning occurs mid-Oct. Spawning is earlier in more southern areas.	Rate of temperature change may be a more important stimulus for spawning than ambient temperature.

[1] Allen (1953), Fay *et al.* (1983), Clotteau and Dubé (1993)
[2] Ropes (1980), Mann (1985), Ma (1997)
[3] Leidy (1878), Ropes and Merrill (1966, 1973), Yancey and Welch (1968), Ogren and Chess (1969), Jacobson (1972), Savage (1976), Franz (1977), Goldberg (1978), Garlo *et al.* (1979), Prior *et al.* (1979), Ropes *et al.* (1979), Thurberg and Goodlett (1979), Garlo (1980, 1982), Ropes (1980), Fay *et al.* (1983), Botton and Haskin (1984), Robinson *et al.* (1984), MacKenzie *et al.* (1985), Howe *et al.* (1988), Riisgård (1988), Walker and Heffernan (1990), Stehlik (1993), Viscido (1994), Chintala and Grassle (1995), Weinberg and Helser (1996), Dietl and Alexander (1997)
[4] Allen (1951), Loosanoff and Davis (1963), Ropes (1968a, b, 1979, 1980, 1982), Yancey and Welch (1968), Jones (1981b), Meyer *et al.* (1981), Tarnowski (1982), Fay *et al.* (1983), Mann (1985), Sephton (1987), Kanti *et al.* (1993), Chintala and Grassle (1995)

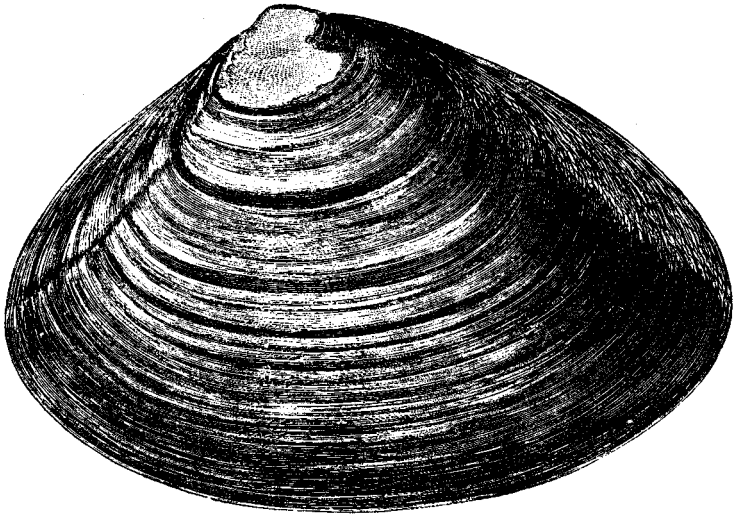

Figure 1. The Atlantic surfclam, *Spisula solidissima* (from Goode 1884).

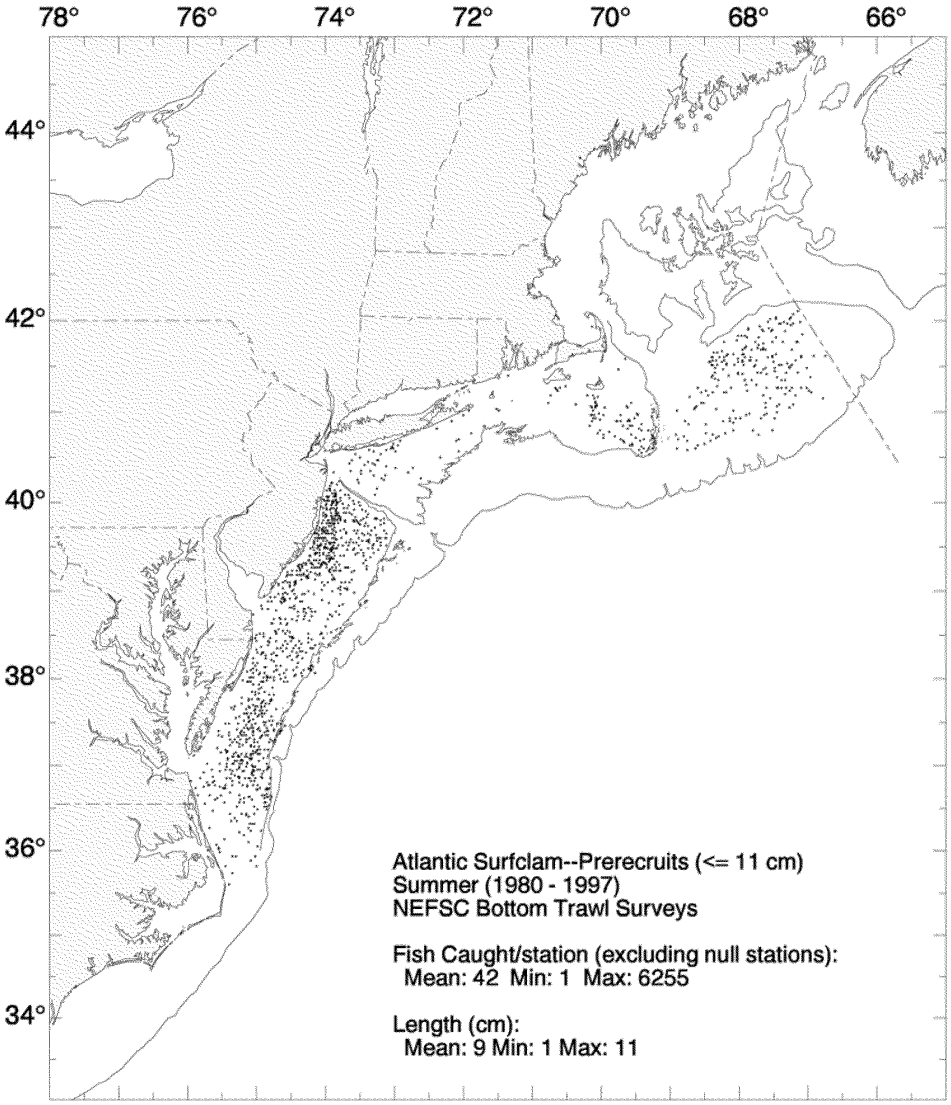

Figure 2. Distribution of Atlantic surfclam pre-recruits (≤ 11 cm) and recruits (≥ 12 cm) collected during NEFSC summer clam surveys from 1980-1997 [see Reid *et al.* (1999) for details]. Black dots represent stations where Atlantic surfclams were taken.

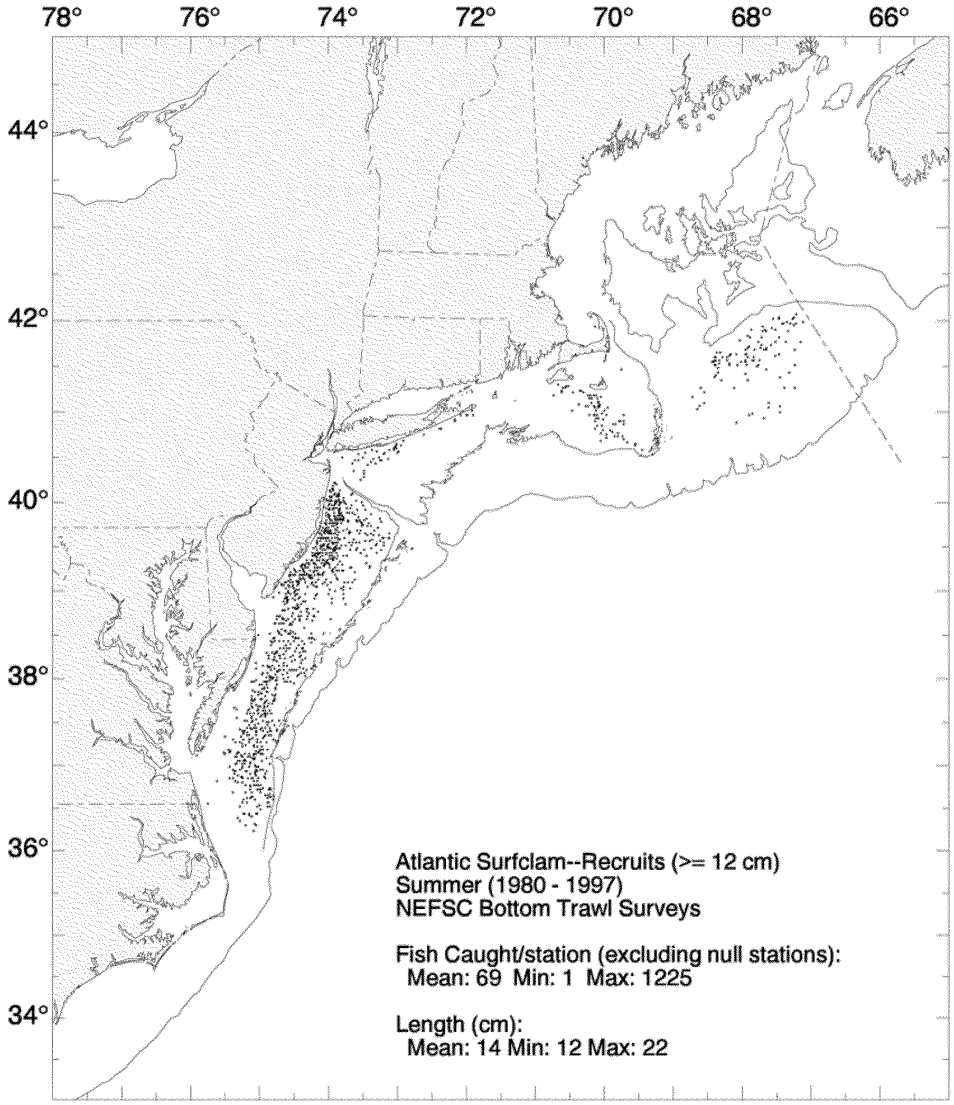

Figure 2. cont'd.

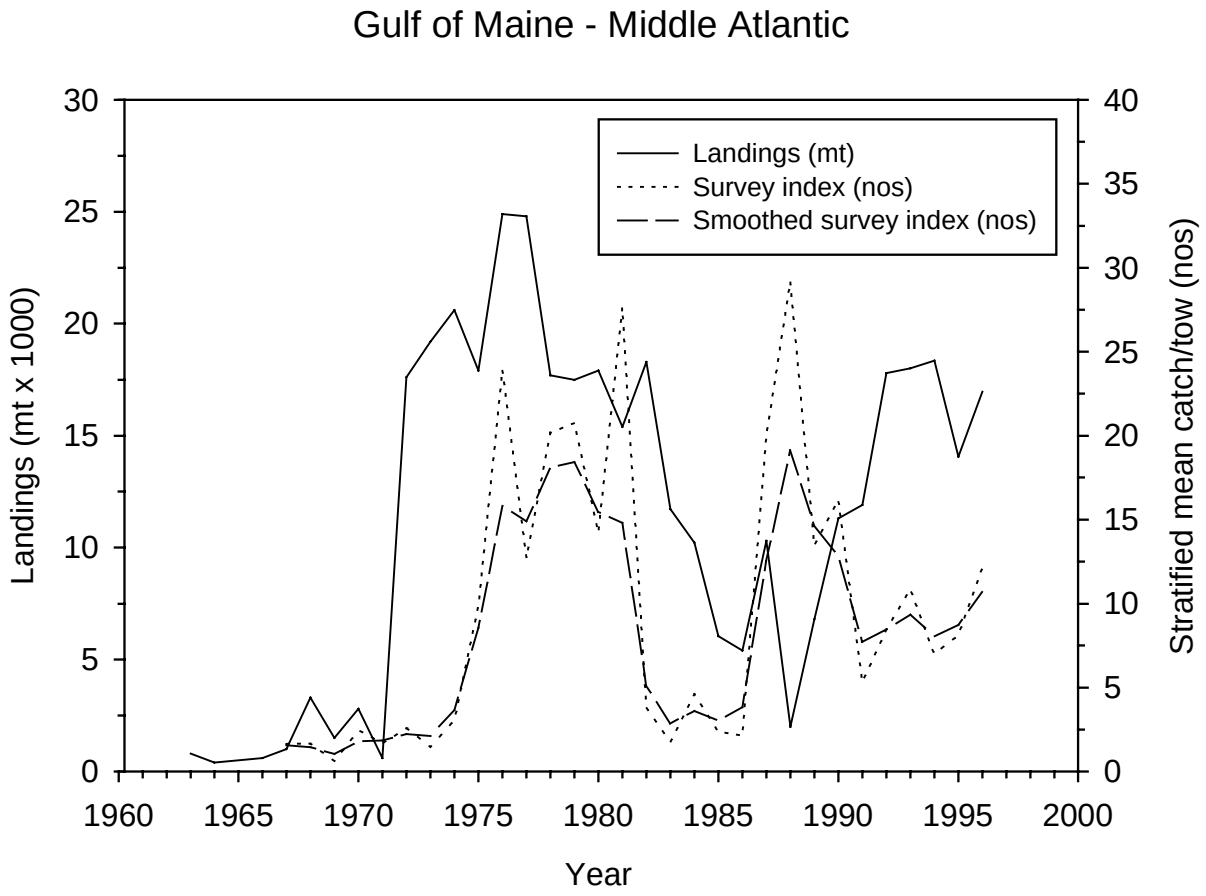

Figure 3. Commercial landings and survey indices (from the NEFSC surveys) for Atlantic surfclam from the Gulf of Maine and Middle Atlantic Bight regions.

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STANDARD MAIL A

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific ournals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

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NOAA Technical Memorandum NMFS-NE-143

Essential Fish Habitat Source Document:

Black Sea Bass, *Centropristis striata*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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September 1999

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Essential Fish Habitat Source Document:

Black Sea Bass, *Centropristis striata*, Life History and Habitat Characteristics

Frank W. Steimle, Christine A. Zetlin, Peter L. Berrien, and Sukwoo Chang

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September 1999

Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

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[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
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INTRODUCTION

The black sea bass (*Centropristis striata* Linnaeus 1758) (Figure 1), is a warm temperate species that is usually associated with structured habitats, such as reefs and shipwrecks, on the continental shelf. It occurs from southern Nova Scotia and the Bay of Fundy (Scott and Scott 1988) to southern Florida (Bowen and Avise 1990) and into the Gulf of Mexico (Figure 2). The summer migrant fish assemblage, with which the black sea bass is associated, has been reported from scattered sites on the Grand Banks of Canada (Brown *et al.* 1996); however, it is uncommon or occurs irregularly in the cool waters north of Cape Cod (Scattergood 1952; DeWitt *et al.* 1981; Short 1992). According to Beebe and Tee-Van (1933), black sea bass were introduced to Bermuda, however this was unsuccessful (B. Collette, National Systematics Laboratory, Smithsonian Institution, Washington, DC, personal communication).

The species exists as three populations or stocks – northern, southern, and Gulf of Mexico. The northern stock, that occurs north of Cape Hatteras, is the focus of this review. The life histories and habitats of the southern and Gulf of Mexico populations are covered in the South Atlantic Fishery Management Council Snapper Grouper Fishery Management Plan.

The eggs and larvae are generally collected from late spring to late summer from mid-shelf into coastal waters. Larvae are believed to settle in coastal waters and move into estuarine or sheltered coastal nursery areas as early juveniles. This can be a two-step process involving nearshore accumulation and estuarine passage (Boehlert and Mundy 1988). During warmer months, juveniles are found in estuaries and coastal areas, often near shelter, between North Carolina and Massachusetts. Adults are found slightly deeper than juveniles and summer in coastal areas, usually near structured habitat, from the Middle Atlantic Bight into the Gulf of Maine. Temperature, not the availability of structured habitat, appears to limit black sea bass distribution north of Cape Cod. In the Middle Atlantic Bight, black sea bass are usually the most common fish on structured habitats, especially south of New Jersey where the abundance of cunner (*Tautogolabrus adspersus*) declines. These structured habitats include shellfish (oyster and mussel) beds, rocky areas, shipwrecks, and artificial reefs (Verrill 1873; Bigelow and Schroeder 1953; Musick and Mercer 1977; Steimle and Figley 1996).

As coastal waters cool below 14°C in the fall, the Middle Atlantic Bight population begins to migrate south and offshore to wintering areas in deeper waters between central New Jersey and North Carolina. As bottom waters warm above about 7°C in the spring, the population migrates inshore into coastal areas and bays in southern New England and the Middle Atlantic Bight. The southern population of black sea bass is not known to make an extensive migration, but may move away from shallow coastal areas during cold winters, especially in the Carolinas. Larger fish are commonly found in deeper waters and usually associated with rough bottom (Smith 1907; Hildebrand and Schroeder 1928; Bigelow and Schroeder 1953).

Black sea bass usually mature as a female and with increasing size, change sex to male. In the Middle Atlantic Bight, they grow to over 60 cm TL, weigh over 3.5 kg, and live up to 20 years; the largest and oldest fish are almost always males (Bigelow and Schroeder 1953).

LIFE HISTORY

EGGS

The northern population spawns buoyant, pelagic eggs on the continental shelf from spring through fall (Able and Fahay 1998; Reiss and McConaugha 1999). Spawning begins in the spring in the southern part of their range (North Carolina and Virginia) and progresses north into southern New England waters from summer through fall. In the Middle Atlantic Bight, the incubation period of the eggs is five days (approximately 120 hrs) at 15°C (Kendall 1972). Able and Fahay (1998) give an incubation period of 35-75 hrs depending on water temperature. Little else is known of this stage.

LARVAE

Larvae are 1.5-2.1 mm SL at hatching (Fahay 1983). The duration of the pelagic larval stage is unknown. Tucker (1989) reported that larval black sea bass can grow for two days before their yolk is exhausted and will die within three days thereafter if they can not acquire enough planktonic food. Cowen *et al.* (1993) classified black sea bass larvae in a New York Bight (bounded by Long Island and New Jersey coasts) mid-summer assemblage, which usually included cusk-eel (*Ophidion* sp.). Larvae settle and become demersal in coastal areas at 10-16 mm TL (Able and Fahay 1998). However, Kendall (1972) reported that settlement might be delayed until 25 mm TL. Allen *et al.* (1978) found 15-17 mm black sea bass larvae (transition to juveniles) in epibenthic sled collections off the oceanic side of the Cape May peninsula (New Jersey) in late July. Larval black sea bass were collected by plankton nets in the surf zone during June-July 1995-1996 off northern New Jersey (D. Clark, U.S. Army Corps Engineers, Vicksburg, MS, personal communication).

JUVENILES (< 19 CM TL)

Most juvenile settlement does not occur in estuaries, but in coastal areas. Recently settled juveniles then find their way to estuarine nurseries. Adams (1993) reported a "major settlement" of juvenile black sea bass (< 3.0 cm) in August 1992 near an artificial reef about 15 km off the Virginia-North Carolina border. He did not observe a large

settlement in 1991. The fish were observed by diving and occurred singly and in small groups near shelter on the artificial reef or in depressions containing shell fragments in the surrounding sand. The transport mechanism and fish behavior that move these early juveniles into estuaries are unknown (Able and Fahay 1998).

Young-of-the-year (YOY) black sea bass enter Middle Atlantic Bight estuaries from July to September (Able *et al.* 1995b; Able and Hales 1997). This occurs earliest in the south. Kimmel (1973) collected 30-146 mm juveniles in Magothy Bay, Virginia as early as March; they occur later elsewhere in Chesapeake Bay (Chesapeake Bay Program 1996). Richards (1963a, b) did not find them in central Long Island Sound until September and October; this was confirmed by more recent surveys (1992-1997) of the Sound, (Gottschall *et al.*, in review). Older juveniles return to estuaries in late spring and early summer, and may follow the migration routes of adults into coastal waters. Bean (1902) reported that juveniles were "very common" in Great South Bay (New York) and Great Egg Harbor Bay (New Jersey). Sherwood and Edwards (1902) noted that, at that time, black sea bass were decreasing in abundance in Vineyard Sound (Massachusetts).

The seasonal recruitment of YOY black sea bass to estuaries is temporally and spatially variable. Juvenile black sea bass were collected in relatively high abundance (1.2-5.5 per tow) from trawls in Raritan Bay (New Jersey) during late summer 1997 (D. McMillan, NMFS, NEFSC, James J. Howard Marine Sciences Laboratory, Highlands, NJ, unpublished data), but they were rarely collected in surveys during the previous five years. Based on trap collections, juvenile black sea bass were a dominant species within and near shoreline pilings in New York Harbor in late summer 1993 (Able *et al.* 1995b). Black sea bass were rare in the Arthur Kill, a tributary to the Hudson-Raritan estuary (Howells and Brundage 1977) and in Raritan and Sandy Hook Bays (Breder 1922; Wilk *et al.* 1996). They were not collected in Newark Bay in the early 1990s (Wilk *et al.* 1997). Black sea bass are rare in Barnegat Bay (New Jersey) (Marcellus 1972; Vouglitois 1983; Tatham *et al.* 1984). However, Allen *et al.* (1978) reported that Hereford Estuary (New Jersey), about 60 km south, was an important black sea bass nursery area during several years of monitoring; they also reported significant fluctuations in annual abundance.

Juvenile black sea bass grow relatively fast in estuaries during the summer. Schwartz (1961) found 30-37 mm TL juveniles in east shore bays of Virginia as early as April; they grew to 98-182 mm by November. Able and Fahay (1998) noted that YOY grow to 100 mm by the fall. Able and Hales (1997) reported mean growth rates of 0.45 mm/day from spring to fall, with a peak rate 0.74 mm/day in the summer, for age 0+ and 1+ juveniles in coastal southern New Jersey. In a previous study, age 1+ fish grew an average of 0.77 mm/day (Able *et al.* 1995a). In contrast, Allen *et al.* (1978) reported that postlarvae (early juveniles) that enter the Hereford Estuary in July at about 18 mm leave at > 40 mm TL in the fall; they also reported that 1 year old fish arrive in this estuary at about 60 mm and leave at about 100 mm TL.

Kim (1987) found that juvenile growth in the laboratory was affected by food type, consumption rates, and fish size. Juvenile growth was increased 4-5 times on an enriched artificial diet. Laboratory studies indicated that temporary hypoxic conditions in estuaries in the summer could inhibit the growth of young-of-the-year fish (Hales and Able 1995). Growth of juveniles was clearly evident in otoliths and showed annulus formation in May or June (Dery and Mayo 1988).

ADULTS (≥ 19 CM TL)

Growth is sexually dimorphic in mature black sea bass; females grow faster but reach a lower maximum size (Lavenda 1949; Mercer 1978; Wilk *et al.* 1978). Shepherd and Idoine (1993) suggest that the species can have three sex-related growth rates: female, male, and transitional. Males grew faster than females off New York based on otolith annuli analyses of year 1 and older fish (Alexander 1981). Black sea bass from Massachusetts had growth rates almost double those reported for New York and Virginia, but different growth estimators were used (Dery and Mayo 1988; Kolek 1990; Caruso 1995). Fish from the Middle Atlantic Bight were larger at age and grew faster than fish from the South Atlantic Bight (Mercer 1978; Wenner *et al.* 1986). Growth is linear to about age 6, then slows; the Middle Atlantic Bight population is larger at age than the South Atlantic Bight population (Wenner *et al.* 1986).

During warm months, black sea bass share the coastal habitat with several other species, including tautog (*Tautoga onitis*), spotted hake (*Urophycis regia*), red hake (*U. chuss*), conger eel (*Conger oceanicus*), ocean pout (*Macrozoarces americanus*), pinfish (*Lagodon rhomboides*), northern searobin (*Prionotus carolinus*), and transients such as gray triggerfish (*Balistes capriscus*) (Chee 1977; Musick and Mercer 1977; Eklund and Targett 1991). Inshore trawl surveys included butterfish (*Peprilus triacanthus*), smooth dogfish (*Mustelus canis*), round herring (*Etrumeus teres*), and windowpane (*Scophthalmus aquosus*) in the summer group containing black sea bass (Phoel 1985; Gabriel 1992; Brown *et al.* 1996). North of Maryland, cunner is a dominant member of the reef ichthyofauna. In estuaries, black sea bass co-occur on oyster shell plantings with summer flounder (*Paralichthys dentatus*), spot (*Leiostomus xanthurus*), oyster toadfish (*Opsanus tau*), and other species (Arve 1960).

REPRODUCTION

Like most of the Serranidae, the black sea bass is a protogynous hermaphrodite; most fish mature as females and change to males with additional growth (Lavenda 1949). In the Middle Atlantic Bight, individuals begin to mature at age

1 (8-17 cm TL) and 50% are mature at about 19 cm SL and 2-3 years of age (O'Brien *et al.* 1993). The majority of fish in this size group are females (Mercer 1978). The average size of transformation from female to male occurs at 23.9-33.7 cm TL (Chesapeake Bay Program 1996). In the South Atlantic Bight, Cupka *et al.* (1973) reported that both sexes mature at smaller sizes (14-18 cm SL). Wenner *et al.* (1986) and Alexander (1981) found mature fish at about 10-11 cm (age 1+) off South Carolina and New York; a majority of fish were mature at about 19 cm TL and at an age of about 2-3 years. Alexander (1981) reported a decrease in the age and size of sex change since the 1940s with fewer mature males in the New York population; he associated this decrease with increasing fishing pressure. Mercer (1978) reported that 2-5 year old females release between 191,000 and 369,500 eggs.

Based on collections of ripe fish and distributions of egg, black sea bass spawn primarily on the inner continental shelf between Chesapeake Bay and Montauk Pt., Long Island at depths of about 20-50 m (Breder 1932; Kendall 1972, 1977; Musick and Mercer 1977; Wilk *et al.* 1990; Eklund and Targett 1990; Berrien and Sibunka 1999). Spawning has been reported as far north as Buzzards Bay and Nantucket Sound, Massachusetts (Wilson 1891; Sherwood and Edwards 1902; Kolek 1990). Gravid females are not generally found in estuaries (Allen *et al.* 1978). Larvae have been collected in Cape Cod Bay, but these were probably stragglers swept from Buzzards Bay through the Cape Cod Canal and not the product of local spawning (MAFMC 1996).

Spawning in the Middle Atlantic Bight population occurs from May to July (Kendall 1972, 1977; Musick and Mercer 1977; Feigenbaum *et al.* 1989; Wilk *et al.* 1990; Eklund and Targett 1990) during inshore migrations, but can extend to October-November (Fahay 1983; Berrien and Sibunka 1999). Larval distributions presented in Able *et al.* (1995a) suggest spawning occurs earliest off Virginia and North Carolina (in the vicinity of the wintering grounds) and progresses northerly and inshore as inner shelf waters warm.

In Massachusetts coastal waters, spawning fish aggregate on sand bottoms broken by ledges; after spawning, the fish disperse to ledges and rocks in deeper water (Kolek 1990; MAFMC 1996). Kolek (1990) reported evidence from tagging studies of homing to spawning grounds. Some tagged adult black sea bass returned to the spawning grounds in northwestern Nantucket Sound where they were tagged. Kolek (1990) also reported this local spawning group spawned earlier and in shallower waters than generally reported by Kendall (1977).

The complex social hierarchy of reef fishes, such as black sea bass, during spawning implies that the number of males may be an important factor limiting reproductive potential (Shepherd and Idoine 1993). They noted that theoretical studies suggest that, to the degree that non-dominant males participate in spawning, the current relative abundance of males may not be limiting in the black sea bass population. Although nothing is known of the mating of this species, pairing is characteristic of the family (Breder and Rosen 1966).

FOOD HABITS

The diet of larval black sea bass are poorly known, but probably consists of zooplankton. Tucker (1989) reported that black sea bass larvae are capable of surviving and growing at lower prey densities, and resist prey abundance fluctuations better, than bay anchovy (*Anchoa mitchilli*) larvae.

Juvenile black sea bass are diurnal, visual predators and often prey on small benthic crustaceans (isopods, amphipods, small crabs, sand shrimp, copepods) and other epibenthic estuarine and coastal organisms, such as mysids and small fish (Richards 1963a; Kimmel 1973; Allen *et al.* 1978; Werme 1981; Figure 3). Kimmel (1973) found that polychaete worms were significant in the diet and reported a shift from mysids (55%) and amphipods (15%) at 3.0-9.0 cm SL to xanthid and other crabs (35%), mysids (19%), and polychaetes (14%) at 9.1-14.6 cm SL. Orth and Heck (1980) reported that sub-adults (14.0-16.5 cm TL) feed in eelgrass beds in lower Chesapeake Bay; their prey included juvenile blue crabs (*Callinectes sapidus*), eelgrass (*Zostera marina*) fragments, isopods, caprellid amphipods, shrimp, and pipefish (*Syngnathus* sp.). Festa (1979) reported lady (*Ovalipes* sp.), blue, and mud (xanthid) crabs, and caridean shrimp as major diet items in a small sample of fish from a central New Jersey estuary. Allen *et al.* (1978) reported an increase in the occurrence of anchovies, silversides (*Menidia* sp.), and plant detritus in the diets of 11-18 cm black sea bass from southern New Jersey coastal and estuarine areas; crustaceans were the most common prey.

During the summer, adult black sea bass feed on a variety of infaunal and epibenthic invertebrates [especially crustaceans, including juvenile American lobster (*Homarus americanus*)], small fish, and pelagic squid and baitfish (Bigelow and Schroeder 1953; Miller 1959; Richards 1963a; Mack and Bowman 1983; Steimle and Figley 1996; Figure 3). Feeding was heaviest after spawning (Hoff 1970).

The diets and feeding of the offshore wintering population are poorly known. The potential benthic invertebrate prey in the wintering area can be dominated by echinoderms [e.g., sand dollars (*Echinarachnius parma*) and sea stars], mollusks [e.g., razor clams (*Ensis directus*)], and polychaetes; average benthic biomasses are 50-75 g/m^2 wet weight (Wigley and Theroux 1981; Steimle 1990). Some co-wintering guild species, e.g. scup (*Stenotomus chrysops*) (Austen *et al.* 1994), may be competitors for habitat or food. Other guild species, such as butterfish and squid (*Loligo* sp. and *Illex* sp.), can be prey for adult black sea bass.

PREDATION AND MORTALITY

There are many potential predators on larval black sea bass. "Jellyfish" can be a significant source of larval

mortality when they are abundant in the coastal zone (Arai 1988).

Hartman and Brandt (1995) found black sea bass, presumably juveniles, in the summer diets of one year old weakfish (*Cynoscion regalis*) and other predators in Chesapeake Bay. Summer flounder, smooth dogfish, and oyster toadfish are potential demersal predators of juvenile black sea bass, and juveniles in exposed areas can also be preyed upon by bluefish (*Pomatomus saltatrix*), striped bass (*Morone saxatilus*), weakfish, and other predators that use the water column, including diving birds. Steimle (unpublished data) found juvenile black sea bass in the stomachs of the following predators from Raritan Bay (New Jersey) during the summer 1997: clearnose skate (*Raja eglanteria*), northern and striped searobin (*Prionotus evolans*), summer flounder, and spot. Weakfish, bluefish, oyster toadfish, smooth dogfish, and fourspot flounder (*Paralichthys oblongus*) contained small, partially digested fish similar to juvenile black sea bass.

The Northeast Fisheries Science Center (NEFSC) food habits database lists the following species as predators of black sea bass: spiny dogfish (*Squalus acanthias*), Atlantic angel shark (*Squatina dumeril*), clearnose skate, little skate (*Raja erinacea*), spotted hake, summer flounder, windowpane, and goosefish (*Lophius americanus*). [See Reid *et al.* (1999) for food habits database methods.]

An extensive hypoxia/anoxia event in the New York Bight in the summer of 1976 resulted in fish mortalities, avoidance of the area by fish (including black sea bass), and extensive loss of benthic invertebrates (Azarovitz *et al.* 1979; Steimle and Radosh 1979). Commercial pot fishermen reported black sea bass mortality and sport divers reported the disappearance of black sea bass and other fish from shipwrecks and artificial reefs along the north-central New Jersey coast. The cause of the condition was the oxygen demand created by the decay of an unusually massive dinoflagellate bloom on the Middle Atlantic Bight continental shelf. This occurred during a period of unusual wind patterns and climate that caused early and strong water column stratification. Anthropogenic influences, such as nutrient exports from urban estuaries to offshore areas, were not confirmed or eliminated as causative factors. Earlier episodes of anoxia/hypoxia in the area caused mortalities or severe stress in fish (ocean pout and cunner) and shellfish (lobster and crabs), but not in black sea bass, tautog, or flounder (Ogren and Chess 1969). The June 25, 1997 Asbury Park Press (New Jersey) newspaper reported black sea bass as one of the fish observed dead in an hypoxic area off the New Jersey coast (dissolved oxygen < 2 ppm).

MIGRATION

Black sea bass belong to a group of warm temperate, migrating species that do not tolerate cold, inshore winter conditions; these include scup, summer flounder, northern searobin, spotted hake, butterfish, and smooth dogfish (Musick and Mercer 1977; Colvocoresses and Musick 1984). The composition of this group varies between spring, summer and fall (Phoel 1985).

The summer coastal population migrates in scattered aggregates in the fall by generally unknown routes from inshore areas across the continental shelf to outer shelf wintering areas south of New Jersey as bottom temperatures decline (Musick and Mercer 1977). Returns from adult fish tagged in Nantucket Sound (Massachusetts) suggest that the fish migrate directly south to the outer shelf near Block Canyon (south of Rhode Island), move southwest along this outer shelf zone to the vicinity of Norfolk Canyon (off Virginia), and return along the same route (Kolek 1990). Offshore migrations are stimulated in the fall as coastal bottom water temperatures approach 7°C and the return inshore migration begins in the spring (about April) as inshore bottom water temperatures rise above 7°C (Nesbit and Neville 1935; June and Reintjes 1957; Colvocoresses and Musick 1984; Chang 1990; Shepherd and Terceiro 1994). Larger fish (a high proportion of which are males) begin migrating offshore sooner than smaller fish (Kendall 1977).

STOCK STRUCTURE

The black sea bass population from Cape Hatteras to Cape Kennedy (Florida) is considered a distinct population (Mercer 1978; Shepherd 1991; Collette and Klein-MacPhee, in prep.) and the Gulf of Mexico population is considered a distinct subspecies (*C. s. melanus*) (Link 1980; Bowen and Avise 1990). Subpopulations have not been identified within the northern population, although the evidence for a putative local population in Nantucket Sound suggested by Kolek (1990) bears further consideration.

HABITAT CHARACTERISTICS

Black sea bass is a warm temperate, demersal species that uses benthic habitats in open water to structured areas for feeding and shelter. Their distribution changes seasonally as fish migrate from coastal areas to the outer continental shelf while water temperatures decline in the fall and from the outer shelf to inshore areas as water temperatures rise in the spring. Information on the habitat use, characteristics, and preferences for the major life stages of the black sea bass population north of Cape Hatteras, North Carolina is summarized in Table 1.

EGGS

The habitat requirements of the planktonic stages of temperate reef fishes are thought to be little different from many tropical species. These requirements involve highly complex biological, physical, and chemical interactions such

as predation, oceanographic processes, and food availability (Richards and Lindeman 1987).

Based on the NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) ichthyoplankton survey [see Reid *et al.* (1999) for details], black sea bass eggs were collected most frequently at average water column temperatures of 12-24°C with a mode at about 15-18°C, except in January and August-September when there was a secondary mode at 20-22°C (Figure 4). The buoyant eggs were collected mostly in < 50 m water depths, but > 5% of the eggs were collected in waters > 240 m in May and October. This wide range undoubtedly reflects the relatively long spawning period, which begins in the spring and extends into the fall, and the seasonal migration of the adult population (from offshore to inshore).

Laboratory spawned *C. striata melanus* eggs and larvae are sensitive to high salinity, low pH, high nitrite-nitrate concentrations, and temperature extremes (Hoff 1970). Similar data are not known for *C. striata*, although comparable sensitivities can reasonably be expected.

LARVAE

Based on NEFSC MARMAP survey data, larvae were collected at average water column temperatures of 11-26°C and were most abundant between 13-21°C (Figure 5), which is a slightly wider range than found for eggs. Larvae were generally collected at depths of < 100 m, but several collections during May-July and October occurred over deeper (> 200 m) water. These deep water occurrences could reflect off-shelf transport effects of Gulf Stream gyres (or other oceanographic processes) and possibly reduce their opportunity to settle inshore and find their way into estuarine nurseries.

JUVENILES

The distribution and abundance data for reef fish based on towed nets probably do not represent all of the benthic habitats occupied. The NEFSC and state trawl surveys may avoid excessively rough bottom, shipwrecks, and reefs, or tow over them with roller gear that does not sample fish that seek shelter in holes. This potentially under estimates the association of fish like the black sea bass with rough bottom habitats and areas with steep depth gradients. The draft of survey vessels limits sampling in shallow waters and potentially underestimates the association with shallow, coastal habitats. The survey results presented herein are based on trawling and may bias the interpretation of habitat use by black sea bass.

Hydrographic data from the NEFSC groundfish surveys indicate that juvenile black sea bass occurred at bottom water temperatures > 5°C and the largest catches occurred at 11-12°C in the winter and spring (Figure 6). Juveniles were collected from about 20-240 m with a mode at 90-100 m. There were temperature modes at about 17° and about 25°C in the summer suggesting use of different habitats or geographic areas; most fish were collected in shallow (around 10-20 m) water. In the fall, the temperature distribution was wide (9-27°C) with a mode at about 14-15°C; inshore waters < 50 m were preferred. [See Reid *et al.* (1999) for NEFSC survey methods.]

Hydrographic data from the Massachusetts spring and fall trawl surveys reflected warmer conditions in shallow coastal areas and were mostly consistent with the NEFSC data (Figure 7). In Narragansett Bay (Rhode Island), juveniles (3-13 cm TL) were rarely collected (average of 0.08 individuals/tow) and only from spring through fall at bottom temperatures of 11-22°C and depths < 24 m (80 ft) (Figure 8). In Long Island Sound during the fall, black sea bass (juveniles and adults) were collected at bottom temperatures of 14-19°C, at depths of 5-50 m, and salinities of 23-32 ppt. In the Hudson-Raritan estuary, juveniles were collected at 6-23°C, around 10 m, at salinities > 20 ppt, and dissolved oxygen levels < 4 mg/L (ppm), although some fish were collected at 2 mg/L (Figure 9). [See Reid *et al.* (1999) for state survey methods.]

Data for juvenile black sea bass in smaller estuaries are scarce; available data are mostly estimates of extremes in tolerance or based on laboratory results (e.g., Hales and Able 1995; Able and Fahay 1998). Within smaller estuaries, natural coastal geological processes can alter the suitability of potential nursery habitat. For example, the natural opening and closing of inlets in barrier islands along the eastern shore of Virginia can change salinity and temperature regimes in lagoons, which changes the distribution of acceptable nursery habitat and juvenile fish, such as black sea bass (Schwartz 1961).

In many studies of reef fish, such as black sea bass, the availability of shelter limits successful postlarval and/or juvenile recruitment (Huntsman *et al.* 1982; Richards and Lindeman 1987). The estuarine nursery habitat of black sea bass is shallow, hard bottom with structure (refuge). These include shellfish (oyster and mussel), sponge, amphipod (*Ampelisca abdita*) tubes, and sea grass beds (especially *Ruppia* sp.), as well as wharves, pilings, wrecks, artificial reefs, crab and conch pots; and cobble and shoal grounds (southern New England to Cape Cod) at salinities > 8 ppt (Bean 1888; Moore 1892; Sherwood and Edwards 1902; Arve 1960; Hildebrand and Schroeder 1928; Kendall 1972; Derickson and Price 1973; Musick and Mercer 1977; Clayton *et al.* 1978; Weinstein and Brooks 1983; Feigenbaum *et al.* 1989; Able *et al.* 1995a). They also occur at the mouths of salt marsh creeks (Werme 1981; Hales and Able 1994; Szedlmayer and Able 1996; Able and Hales 1997). Able *et al.* (1995a) reported little use of eelgrass in New Jersey. Juveniles were not common on open, unvegetated sandy intertidal flats or beaches (Allen *et al.* 1978), or deeper, muddy bottoms (Richards 1963b). Bean (1888) and Allen *et al.* (1978) reported that larger juveniles used deeper estuarine channels. In some urbanized areas, there were early reports of juvenile black sea bass using habitats that were formerly common but are now rare, such

as oyster beds near Staten Island (Nichols and Breder 1927) and eelgrass beds in Gravesend Bay, Brooklyn (Bean 1902). Recent surveys in the Hudson-Raritan estuary collected YOY black sea bass usually only where beds of red beard sponge (*Microciona prolifera*) were common (Steimle, unpublished data).

In estuarine nurseries, YOY and older juveniles can use different habitats. Older juveniles tend to stay in shallower waters (< 10 m) (Musick and Mercer 1977), but not in the shallow shoals and marsh fringe favored by YOY. Older juveniles use channels (Bean 1888; de Sylva *et al.* 1962; Richards and Castagna 1970; Zawacki and Briggs 1976; Szedlmayer and Able 1996), jetties (Schwartz 1964), and bridge abutments (Allen *et al.* 1978). Werme (1981) reported that juvenile black sea bass (3.0-7.5 cm TL) occupied a sandy, saltmarsh creek in southern Massachusetts during August and September with juvenile tautog and winter flounder (*Pseudopleuronectes americanus*). There were differences in diets among these species that would limit competition.

Within structured nursery habitats, YOY black sea bass display high habitat fidelity; they move very little and may be territorial (Werme 1981; Able and Hales 1997). Able and Fahay (1998) observed YOY black sea bass defending a small shell used for shelter from others of its cohort.

There is a lack of information about winter habitats of YOY and yearling black sea bass (M. Dixon, NMFS, NEFSC, Milford Laboratory, Milford, CT, personal communication). Yearlings winter on the continental shelf and return to the estuaries the following spring (as early as March in Chesapeake and other bays); more specific winter habitat information is not available. Some individuals may spend the warmer months along the coast in accumulations of surf clam and ocean quahog shells, or in irregularities or holes in exposed clay (Able *et al.* 1995a). When temperatures drop below 14°C, the juveniles gradually migrate to deeper and warmer water; few are collected below 6°C (Able and Fahay 1998; Collette and Klein-MacPhee, in prep.). At temperatures below 6°C in laboratory studies, juveniles bury in the sand; below 4°C they cease feeding and mortality increases (Hales and Able 1995). Juveniles that overwinter in shallow estuaries in New Jersey can experience thermal stress and mortalities (Able and Hales 1997). A sudden cold spell resulted in mortalities in shallow nursery areas off southeastern New England (Baird 1873). In warmer winters, juveniles overwinter successfully in deeper waters of Chesapeake Bay (MAFMC 1996; Chesapeake Bay Program 1996). Able *et al.* (1995a) reported that windrows, patches, or beds of empty, hinged surf clam and ocean quahog shells may be important coastal habitat for juvenile and sub-adult black sea bass.

ADULTS

Adult black sea bass orient to structures, especially during their summer residency in coastal waters. Unlike juveniles, adults tend to enter only larger estuaries and are most abundant along the coast. Larger fish are found in deeper water than smaller fish. They occur on shipwrecks, rocky and artificial reefs, mussel beds, and other objects on the bottom. They are usually observed by divers hovering near or above these shelters and retreat into them if threatened. They remain near structures during the day, but can move away at dawn and dusk to feed on open bottom (Steimle and Figley 1996).

A characteristic of the northern population of black sea bass is their seasonal migration to southerly and offshore wintering grounds. In the Middle Atlantic Bight, black sea bass adults spend the winter on the middle to outer continental shelf between 30-240 m (with some as deep as 410 m, but most between 60-150 m) generally south of the Hudson Canyon off central New Jersey (Musick and Mercer 1977). Based on commercial catches, some fish spend the winter in deep water (> 80 m) off southern New England (Chang 1990; Kolek 1990; Bigelow and Schroeder 1953). Water mass movements on the continental shelf influence fish winter distribution. The distribution of bottom temperatures > 7.5°C may define the potential winter distribution of the species and its associates (Neville and Talbot 1964). Larger fish (mostly males) tend to occur in deeper water (Nesbit and Neville 1935; Musick and Mercer 1977; Able *et al.* 1995a). Off Virginia, artificial reefs and wrecks are populated with active resident adult black sea bass during most winters and support commercial and recreational fisheries (Chee 1977; Adams 1993). Adams (1993) observed that when bottom water temperatures were near 6°C on inshore artificial reefs, adult fish became inactive and were often found resting in holes and crevices. Schwartz (1964) reported adult black sea bass in aquaria at 15 ppt salinity stopped feeding at water temperatures below 8°C and died at temperatures below about 2°C.

The offshore habitats occupied by adult black sea bass during the winter are poorly known. There are speculative and anecdotal reports that the northern population is associated with rough bottom during the winter (Pearson 1932; June and Reintjes 1957; Neville and Talbot 1964). The existence of significant amounts of rough bottom in wintering areas has not been confirmed. Wigley and Theroux (1981) characterized the wintering area as flat sandy-silt with occasional areas of relict and active sand waves of varying size, without hard bottom. There are reports of hard bottom (consolidated clay or rock) near the head of submarine canyons at the shelf edge and in a few other isolated places (Emory and Uchupi 1972; Stanley *et al.* 1972; Grimes *et al.* 1987). Scattered shipwrecks and man-made debris are also available as offshore wintering habitat. Shellfish beds (current and relict) and shallow pits on the mid to outer shelf (possibly created by large crabs, lobsters, or fish) could be used as sheltering habitat (Emory and Uchupi 1972; Folger *et al.* 1979; Shepard *et al.* 1986; Able *et al.* 1995a). Parker (1990) reports that black sea bass burrow into sediments during cold spells off the Carolinas. This behavior can explain how structure-associated black sea bass accommodate themselves during the winter on the

relatively featureless offshore continental shelf of the Middle Atlantic Bight. However, burrowing in open, soft sediments may not protect them from trawls or the possible harm from suspended sediments (Churchill 1989). Several other resource species use the same habitat as black sea bass in the winter, including scup, summer flounder, butterfish, squid, and American lobster (Chang 1990; Able and Kaiser 1994).

During the warmer months, adult black sea bass are usually found inshore associated with structured habitats, including eelgrass, oyster, and mussel beds, rocky reefs, cobble and rock fields, stone coral patches, and exposed stiff clay. Man-made structures include artificial reefs, shipwrecks, bridge abutments, piers, pilings, jetties, groins, submerged pipes and culverts, navigation aids, anchorages, rip-rap barriers, fish and lobster traps, and rough bottom along the sides of navigation channels. Towed nets do not adequately sample these habitats. Richards (1963a, b) and others reported that black sea bass in Long Island Sound are usually found in structured habitats within areas of sandy sediments and rarely in muddy areas. A continual supply of shipwrecks and anthropogenic debris, and state-supervised artificial reef programs, are increasing the quantity of habitat available to this and associated species.

For adult black sea bass, bottom temperatures about 6-7.5^{o}C or above are a critical factor in habitat use and distribution (Colvocoresses and Musick 1984). In the NEFSC groundfish survey, adults were most commonly collected at water temperatures of 9-12°C in the winter and spring (Figure 6). The temperature distribution in the summer when black sea bass occurred in shallow (10-20 m) coastal areas was bimodal with peaks at about 10°C and 25°C (Figure 6). During the fall, adults were collected at 7-27°C; most fish were collected at 13-21°C with a secondary peak at about 25-27°C; fish were collected mostly in relatively shallow water (< 50 m) (Figure 6).

In the spring Massachusetts surveys, black sea bass were collected at bottom temperatures between 6-17°C and at depths < 35 m; most were in 11-14°C and very shallow, around 5 m (Figure 7). In the fall Massachusetts surveys, they were collected at bottom temperatures between 14-23°C and at depths between 5-25 m, most were at depths of < 15 m (Figure 7). In Narragansett Bay, adult black sea bass 21-41 cm TL were rarely caught in trawls (average catch of 0.036 individuals/tow). They were collected mainly in the summer and fall at bottom temperatures between 13-20°C and at depths between 6-38 m (20-110 ft) (Figure 8). Adult black sea bass dominated spring catches in central Long Island Sound; a few were collected in the fall. Black sea bass were collected at bottom temperatures of 6-18°C, from 7-47 m, and at salinities between 25-30 ppt. Black sea bass collected in the Hudson-Raritan estuary had similar temperature and depth ranges; adult black sea bass were collected at dissolved oxygen levels of > 5 mg/L (Figure 9).

GEOGRAPHICAL DISTRIBUTION

EGGS

Black sea bass eggs were collected during NEFSC MARMAP surveys in the water column across most of the continental shelf from North Carolina to Delaware, and in the New York Bight (Figure 10; Berrien and Sibunka 1999), and have been reported in Buzzards Bay (Stone *et al.* 1994). The highest egg concentrations in Buzzards Bay occurred between May and October, although they were also collected in January and April (there were no surveys during February). Eggs were collected inconsistently in Long Island Sound (Merriman and Sclar 1952; Wheatland 1956; Richards 1959) and were not collected in Delaware Bay (Wang and Kernehan 1979) or Narragansett Bay (Bourne and Govoni 1988). Eggs collected as early as January and April off Cape Hatteras were probably the result of spawning in the South Atlantic Bight and transport north by the Gulf Stream, which flows close to the coast off Cape Hatteras (Mercer 1978).

LARVAE

During the NEFSC MARMAP surveys, larvae were collected from January to November from Cape Hatteras to southern New England (Figure 11). Larvae first appeared near Cape Hatteras and were collected progressively north and shoreward mostly from June through October; a few larvae were collected in November (Kendall 1972; Able *et al.* 1995a). According to Pearson (1941), black sea bass larvae were more commonly collected by plankton nets in subsurface tows than by surface tows in June-July 1929-1930 at the mouth of and in the lower Chesapeake Bay.

Larvae are rarely reported in estuaries. Pacheco and Grant (1965) found black sea bass larvae in the Indian River estuary (Delaware) in one of three survey years; a later two-year survey found none in this estuary (Scotton 1970; Derickson and Price 1973). Larvae were not reported in Delaware Bay (Wang and Kernehan 1979), Great Bay (New Jersey) (Able and Fahay 1998), or the Hudson-Raritan estuary (Croker 1965; Dovel 1981). Few larvae were collected in Cape Cod Bay (Scherer 1984), Narragansett Bay (Herman 1962; Bourne and Govoni 1988), and other southern New England estuaries (Stone *et al.* 1994). Neither eggs nor larvae were collected in Mystic River estuary (Connecticut) (Pearcy and Richards 1962). Larvae have been reported in high salinity coastal areas of southern New England in August and September (Stone *et al.* 1994; Collette and Klein-MacPhee, in prep.). Able *et al.* (1995a), discussing Kendall's (1972) note about the absence of larvae in many estuarine surveys, believe that larval settlement occurs in nearshore marine waters, but usually not in estuaries.

JUVENILES

Recently settled juveniles occur in high salinity areas of most estuaries from North Carolina to southern Cape Cod, and occasionally into the southern Gulf of Maine, during the warmer months. Juvenile black sea bass abundance varied seasonally in the NEFSC fall groundfish surveys (Figure 12). In recent winter surveys, they were collected mostly along the outer continental shelf south of Long Island. As the continental shelf water warms in the spring, they were collected inshore in the Chesapeake Bight. There were few summer surveys, but juveniles were collected in several coastal areas mostly south of New Jersey. However, during this season many juveniles inhabit estuaries or submerged coastal reefs, wrecks, and other structures that are outside of the NEFSC survey area or are poorly sampled by trawl. In the fall, juveniles were common along the coast from southern New England to Maryland, and across the shelf off Virginia-North Carolina; this probably reflects their migration out of shallow coastal areas as these waters cooled.

Only a few juvenile black sea bass were collected in the spring in Massachusetts trawl surveys (Figure 13). They were abundant in the fall south and west of Cape Cod and a few were collected in Cape Cod Bay (Figures 12, 13). In Narragansett Bay, juvenile black sea bass were uncommon but they occurred in most areas (Figure 14); the largest mean catch (1.3 individuals/tow) came from Mount Hope Bay during the summer. Juveniles and adults were widespread in the fall in Long Island Sound (Figure 15). In the Hudson-Raritan estuary, juvenile black sea bass were collected from spring through fall (Figure 16); they were more abundant in 1997 than in the other years of the survey (1992-1997). Mansueti (1955) reported that juvenile black sea bass were common in the lower Potomac River (Maryland-Virginia).

ADULTS

The geographic distribution of the northern population of adult black sea bass is similar to the distribution of juveniles, although adults tend to prefer deeper bays and coastal waters over estuaries. Briggs (1979) suggested that once black sea bass find suitable summer habitat in New York waters, they remain until the fall migration; adult habitat fidelity is consistent with juvenile behavior (Able and Hales 1997).

Black sea bass is normally considered a reef fish. In the warmer months, they are usually closely associated with sheltering habitat in estuarine and coastal waters, generally at depths < 40 m, but they have a wider distribution in the Chesapeake Bight (Figure 12). Bigelow and Schroeder (1953) and Collette and Hartel (1988) reported occurrences of black sea bass in Massachusetts Bay at the turn of the century and occasionally since then (e.g., Figure 13), but they are rarely caught off New Hampshire and largely absent off Maine and on Georges Bank (Figure 12). At one time, they were captured by gill net over rocky bottom in Maine (Ojeda and Dearborn 1989). Adults were relatively common in the spring in the Massachusetts trawl surveys (Figure 13). In Narragansett Bay adults were rare, but they were collected from a wide range of sites from spring to fall (Figure 14). In Long Island Sound, adults were most common in the spring survey in the central sound (Figure 15). Adult black sea bass were never common in the Hudson-Raritan estuary (Figure 16).

STATUS OF THE STOCKS

The black sea bass population in the Middle Atlantic Bight is presently overexploited (National Marine Fisheries Service 1997). Recent CPUE and survey indices have been moderate to low compared to levels in the mid-1970s (Figure 17) and before 1965. Juvenile recruitment was poor in 1992-1993 and above average in 1994 (Shepherd 1998; MAFMC 1996; Northeast Fisheries Science Center 1997). Spawning stock estimates suggest that the population has been relatively stable since 1984 (Northeast Fisheries Science Center 1997). There were no apparent differences in the distributions of juvenile and adult black sea bass between periods of high (1975-1979) and low (1990-1997) abundance (Northeast Fisheries Science Center, unpublished data). Arve (1960) attributed declining black sea bass catches in the late 1950s (compared to the relatively high levels of the early 1950s) to a decline in oyster beds.

RESEARCH NEEDS

More information is needed on the use of artificial reefs by black sea bass. The following ideas were discussed in several papers in *Fisheries* (American Fisheries Society, April 1997, Volume 22, Number 4), a special issue on artificial reef management.

- What mechanisms or processes enhance black sea bass production on reefs (e.g., reducing habitat limitation, enhancing larval settlement, alleviating post-settlement demographic bottlenecks, enhancing reef and near-reef food webs)?
- How can artificial reefs and habitats be designed to enhance survival and growth of juvenile and adult black sea bass?
- Are black sea bass habitat limited such that habitat restoration or enhancement is required?

More general research needs include:

- What habitats are used during the winter on the continental shelf in the Middle Atlantic Bight? Where do 1-2 year old juveniles spend the winter? Some may remain in estuaries while others may move to coastal or inner shelf shell beds (Able *et al.* 1995a; M. Dixon, personal communication).
- What are the winter diets of juveniles? Feeding may be reduced at low temperatures.

- Clam shell beds nearshore may provide important habitat at all times of the year, but little is known of distributions of dead shells or spatial and temporal trends in shell beds.
- Do young-of-the-year black sea bass that overwinter offshore return to their natal estuary the following spring (Able and Fahay 1998)?

Adams (1993) identified the following information needs:

- Tagging studies to track seasonal migration patterns and identify habitats.
- Dietary studies to evaluate the value of specific habitats.
- The relationship between habitat structural complexity, black sea bass abundance, and fish community composition.
- Suitable habitats for juvenile black sea bass in coastal areas.
- If black sea bass are territorial.
- Spawning areas, behaviors, and feeding during spawning.

The Chesapeake Bay Program (1996) Black Sea Bass Fishery Management Plan lists the following research needs:

- Seasonal distribution and migration studies to determine size distribution and sex ratios in various areas.
- Identify spawning areas, determine spawning production, and estimate optimum size for female maximum viable egg production.
- Quantify the diet and seasonal changes in the diet [i.e., seasonal importance of blue mussels (*Mytilus*) and other reef fauna].
- Determine the optimum size of submerged aquatic vegetation beds and oyster reefs necessary for nursery and refuge grounds for juveniles.
- Investigate the transport mechanism of newly settled juveniles from the coastal zone to estuarine nurseries (Able and Fahay 1998).

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Table 1. Summary of life history and habitat characteristics for black sea bass, *Centropristis striata*. (YOY = young-of-the-year; SNE = southern New England; MAB = Middle Atlantic Bight; GOM = Gulf of Maine).

Life Stage	Time of Year	Size and Growth	Geographic Location	Habitat	Substrate
Eggs	May-Oct; appear earlier in south and later in north	0.9-1.0 mm; incubation 2-5 days	Coastal MAB; rarely in estuaries	Upper water column, shore to > 200 m depth off Virginia	Buoyant in upper water column
Larvae	May-Nov; peak June-July; appear earlier in south and later in north	Hatch at ~2.1 mm; stage lasts to ~15 mm transition	MAB, near shore, mouths of some estuaries, but rarely in them	As for eggs, < 100 m until transition to juveniles	Upper water column until transition to juveniles
Juveniles YOY	April-Dec; most settle June-Nov	~10-16 mm to 100 mm TL by Nov	MAB into GOM, inshore and into estuaries mid-late summer	Estuarine - coastal; ~1-38 m; salt marsh edges & channels; high habitat fidelity	Rough bottom, shellfish, sponge, and eelgrass beds, nearshore shell patches, man-made objects
Juveniles Winter	Dec-April	~2-12 cm; growth rate reduced	MAB: Most move offshore and south of New Jersey to warmer, deeper waters	Mostly deeper than 38 m; may prefer 90-100 m; mid and outer continental shelf and Chesapeake Bay	Nearshore shell patches and other shelter on sandy bottoms
Adults Summer	April-Dec	> 19 cm FL; growth sexually dimorphic	Coastal: MAB into GOM	~2-38 m; larger fish stay in deeper waters	Mussel beds, rock, artificial reefs, wrecks and other structures
Adults Winter	Nov-March	> 19 cm FL	Most move offshore and south of New Jersey to warmer (> 6°C) waters.	30-240 m depths; mostly 60-150 m mid/outer continental shelf; otherwise poorly known	Poorly known, possibly available shelter on offshore silty sand (e.g., pits)
Spawning Adults	May-Oct, peak in June; begins in the south and progresses north	> 19 cm FL; mature at age 1+	Inshore MAB, south to north, during migration	~20-50 m	Over sand, sand with rock, and reefs

Table 1. cont'd.

Life Stage	Temperature	Salinity	Prey	Predators	Notes
Eggs	Sensitive to extremes	Sensitive to extremes		Most planktivores where the eggs are found	Lab studies suggest eggs sensitive to high nitrate-nitrite concentrations and low pH
Larvae	11-26°C, mostly 14-23°C; sensitive to extremes	30-35 ppt; sensitive to extremes	Use yolk reserves in a few days; feeding begins on zooplankton at ~6 mm	Most planktivores where the larvae are found	Benthic settlement and transition to juvenile occurs at ~10-16 mm FL, July to October
Juveniles YOY	6-30°C, prefer 17-25°C	8-38 ppt, prefer ~18-20 ppt	Small epibenthic invertebrates, especially crustaceans and mollusks	Sharks, dogfish, skates, hakes, searobins, summer flounder, and others	Most migrate to warmer offshore or more southerly waters in winter. Hypoxia can inhibit growth
Juveniles Winter	> 5°C; sudden drops < 4°C inshore can cause mortality	12-38 ppt, prefer > 18 ppt.	Small epibenthic invertebrates, fish, but feeding may be reduced	Sharks, dogfish, skates, hakes, searobins, summer flounder, and others	Migrate inshore and northerly as waters warm > 6°C; over-wintering juveniles return to coastal estuarine areas
Adults Summer	~6-28°C, mostly 13-21°C	> 20 ppt	Benthic and near-bottom invertebrates and small fish	Sharks, dogfish, skates, hakes, searobins, summer flounder, and others	Mortality and avoidance at dissolved oxygen levels < 2 ppm
Adults Winter	> 6°C, prefer 9-12°C	~30-35 ppt	Poorly known; benthic and near-bottom invertebrates, small fish, butterfish, and squid; feeding may be reduced	Sharks, dogfish, and others	The 6-7.5°C isothermal boundary greatly influences distribution; activity and survival reduced below this temperature
Spawning Adults	> 10°C, peak at ~ 18-20°C	> 15 ppt	Poorly known; benthic and near-bottom invertebrates, small fish, butterfish, and squid; feeding may be reduced	Sharks, dogfish, and others	Spawn in coastal bays but not in estuaries; mature mostly as females, most change sex to males with growth

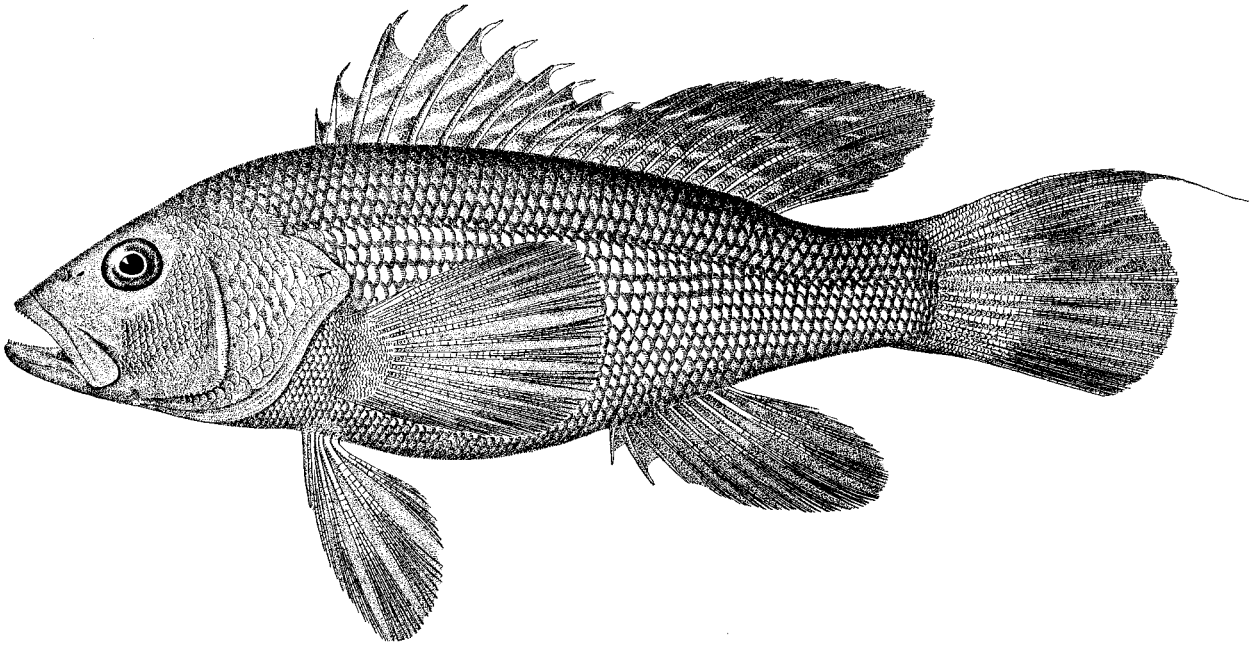


Figure 1. The black sea bass, *Centropristis striata* (from Goode 1884).

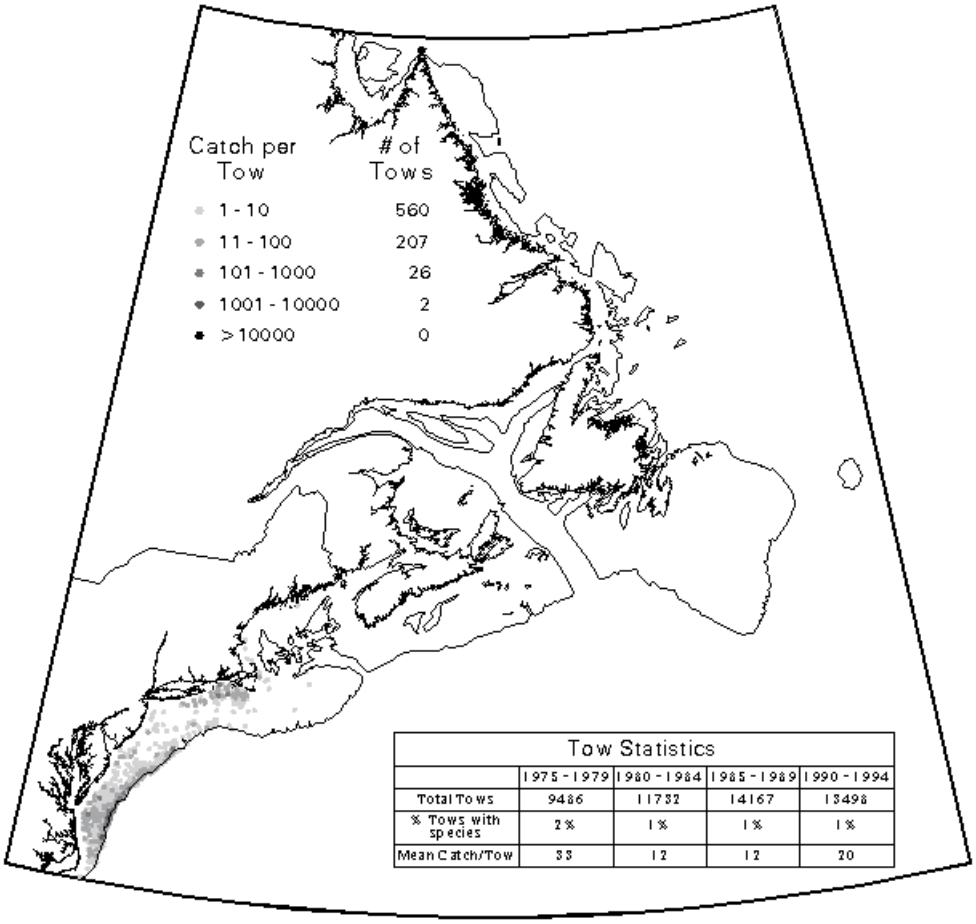


Figure 2. Distribution and abundance of black sea bass in the Northwest Atlantic during 1975-1994. Data are from the U.S. NOAA/Canada DFO East Coast of North America Strategic Assessment Project (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

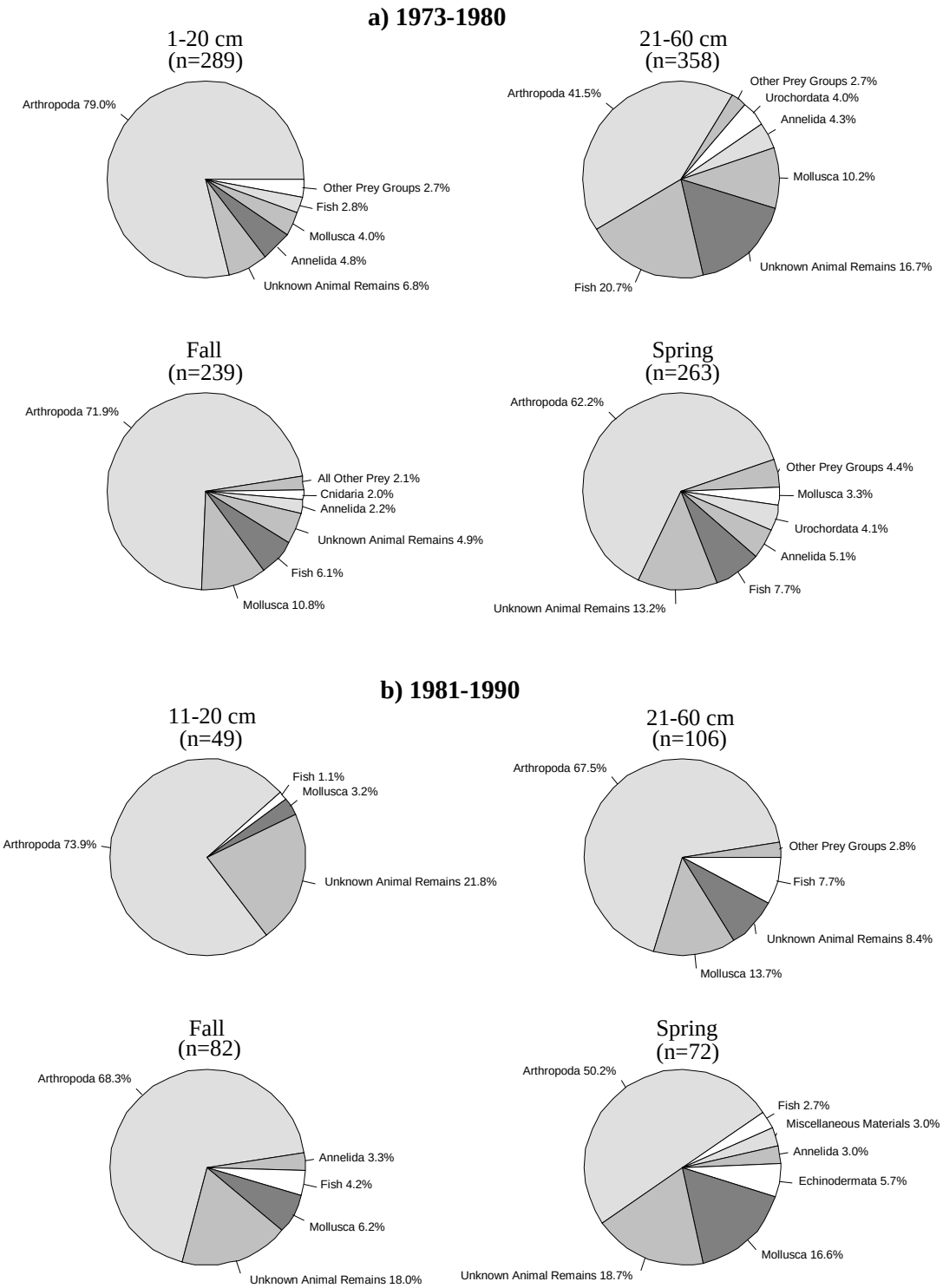


Figure 3. Abundance of the major prey items in the diets of juvenile (≤ 20 cm) and adult (> 20 cm) black sea bass collected during NEFSC bottom trawl surveys from 1973-1980 and 1981-1990. Abundance in the 1973-1980 samples is defined by mean percent prey weights, and in the 1981-1990 samples as mean percent prey volume. The category "unknown animal remains" refers to unidentifiable animal matter. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details].

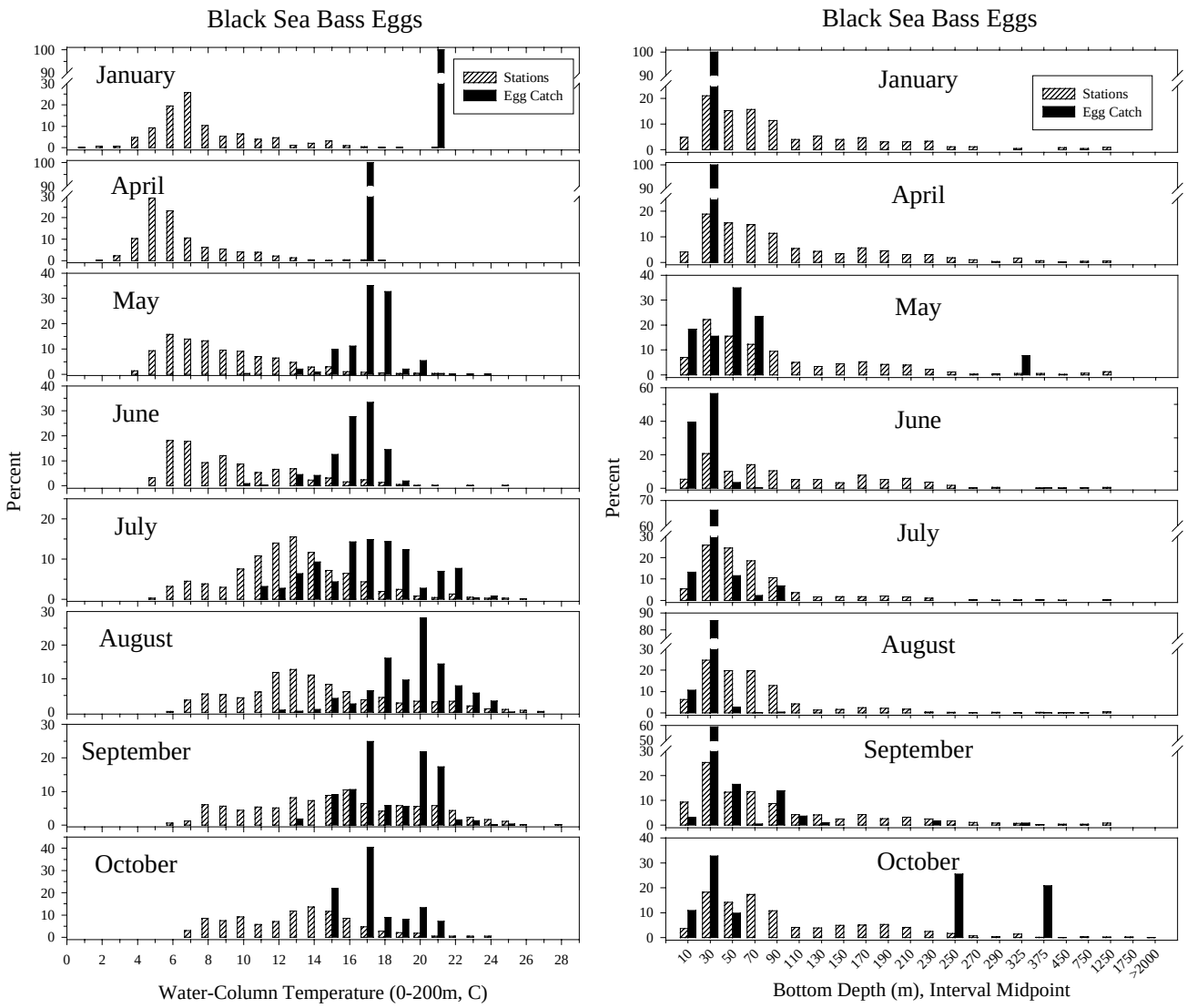


Figure 4. Abundance of black sea bass eggs relative to water column temperature (to a maximum of 200 m) and bottom depth from NEFSC MARMAP ichthyoplankton surveys (1978-1987) by month for all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

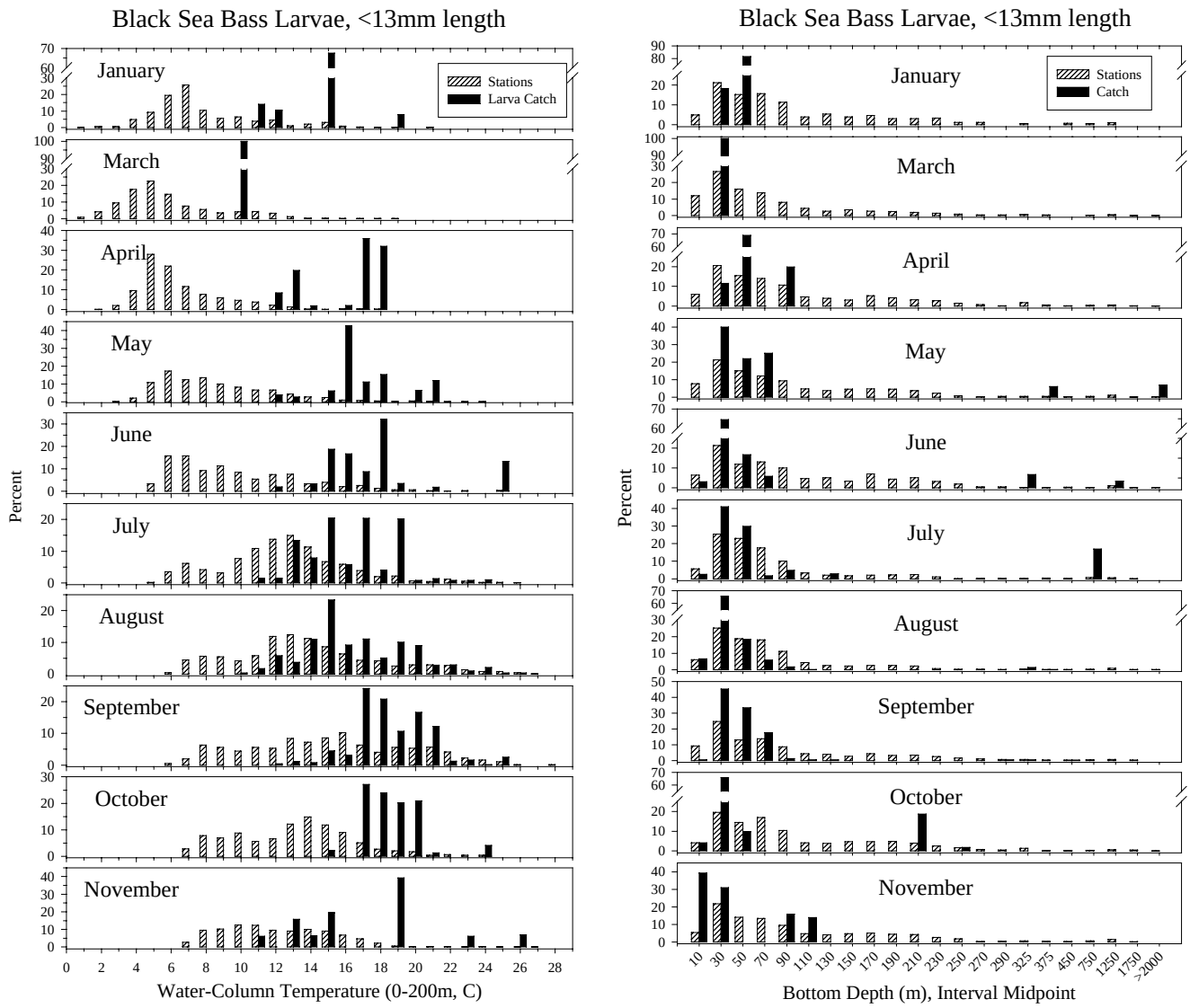


Figure 5. Abundance of black sea bass larvae relative to water column temperature (to a maximum of 200 m) and bottom depth from NEFSC MARMAP ichthyoplankton surveys (1977-1987) by month for all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

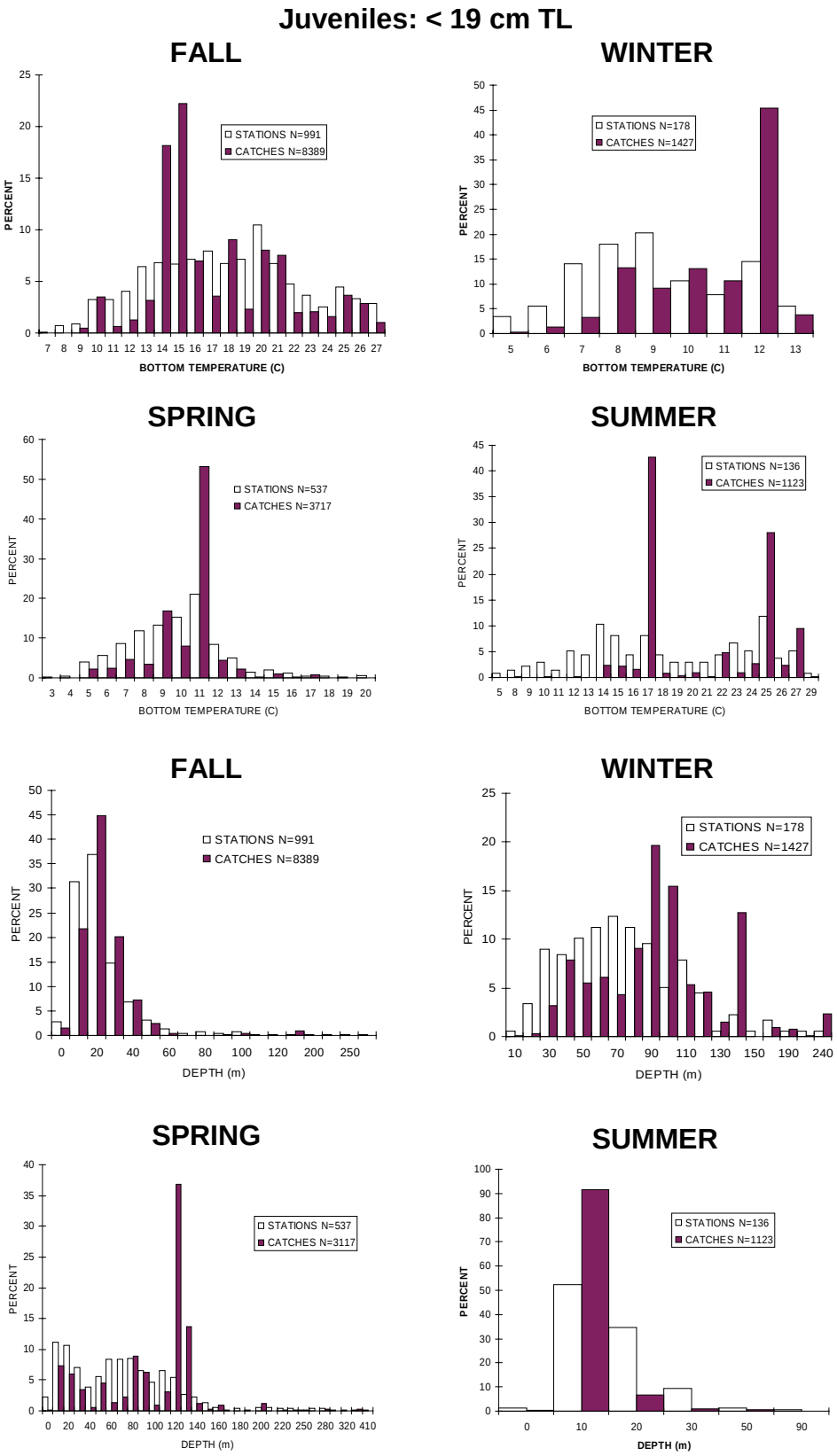


Figure 6. Seasonal abundance of juvenile (< 19 cm) and adult (≥ 20 cm) black sea bass relative to bottom water temperature and depth based on NEFSC bottom trawl surveys (1963-1997, all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

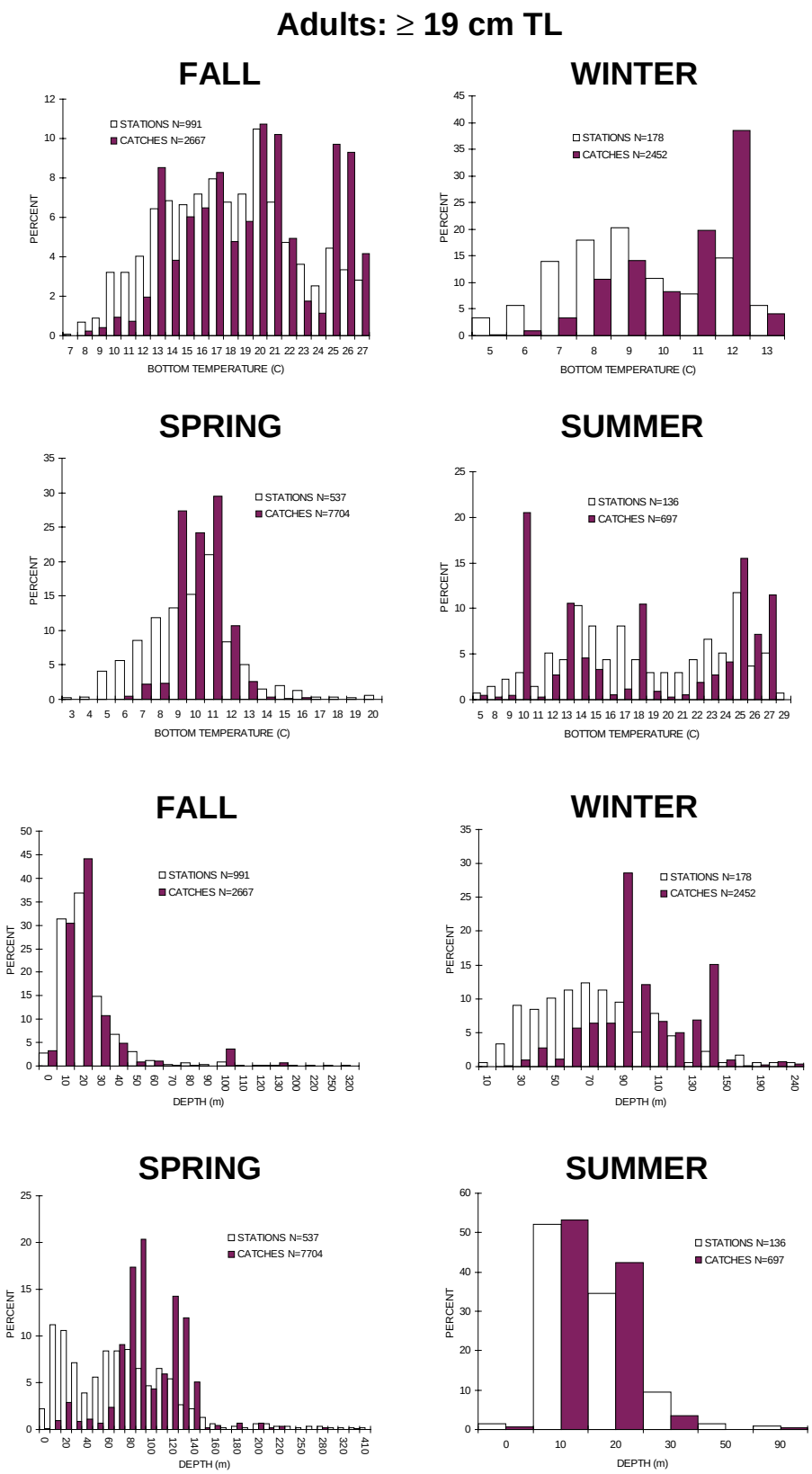


Figure 6. cont'd.

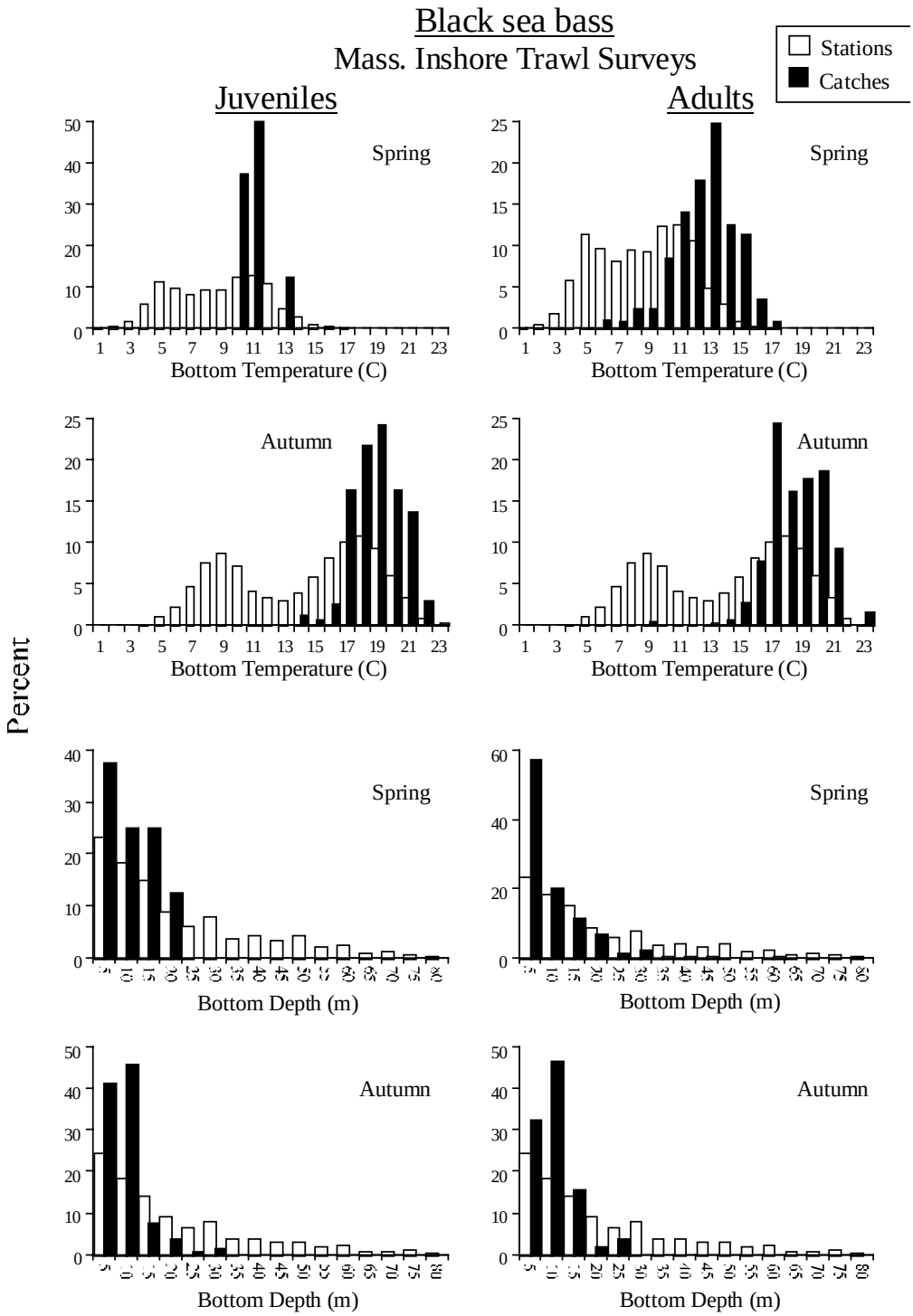


Figure 7. Abundance of juvenile and adult black sea bass relative to bottom water temperature and depth based on Massachusetts inshore bottom trawl surveys (spring and autumn 1978-1996, all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

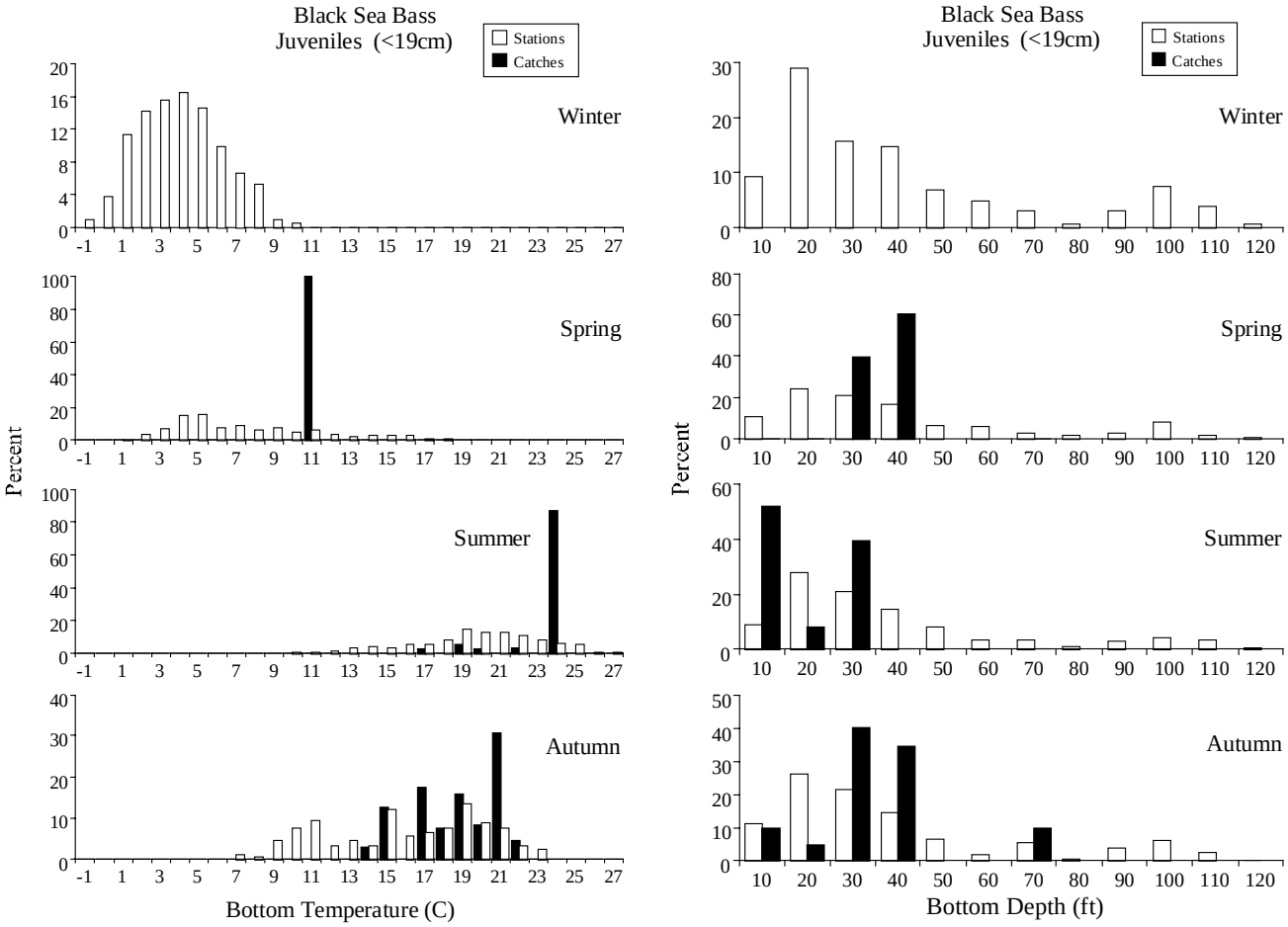


Figure 8. Seasonal abundance of juvenile and adult black sea bass relative to bottom water temperature and depth from Rhode Island Narragansett Bay trawl surveys, 1990-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

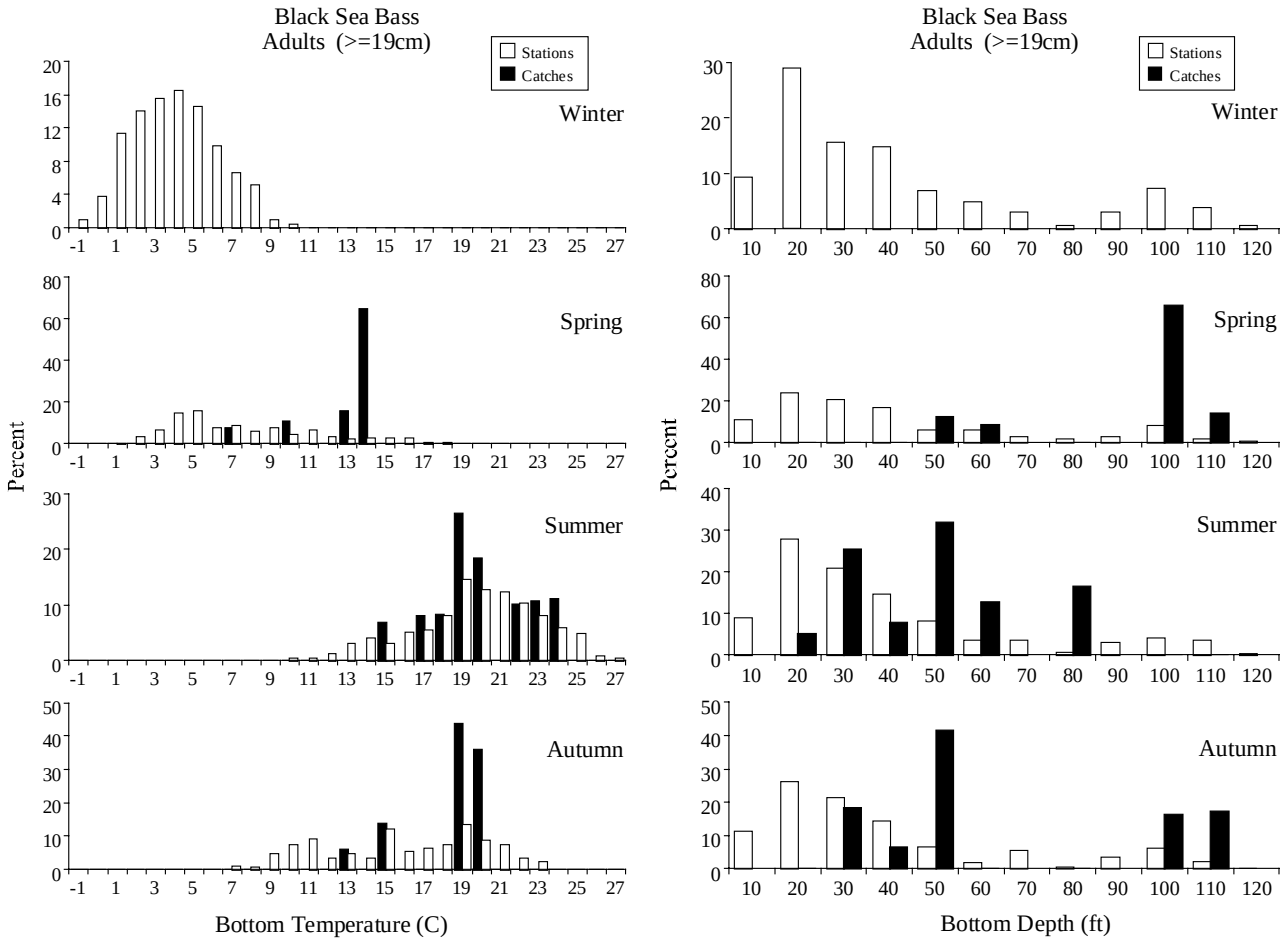


Figure 8. cont'd.

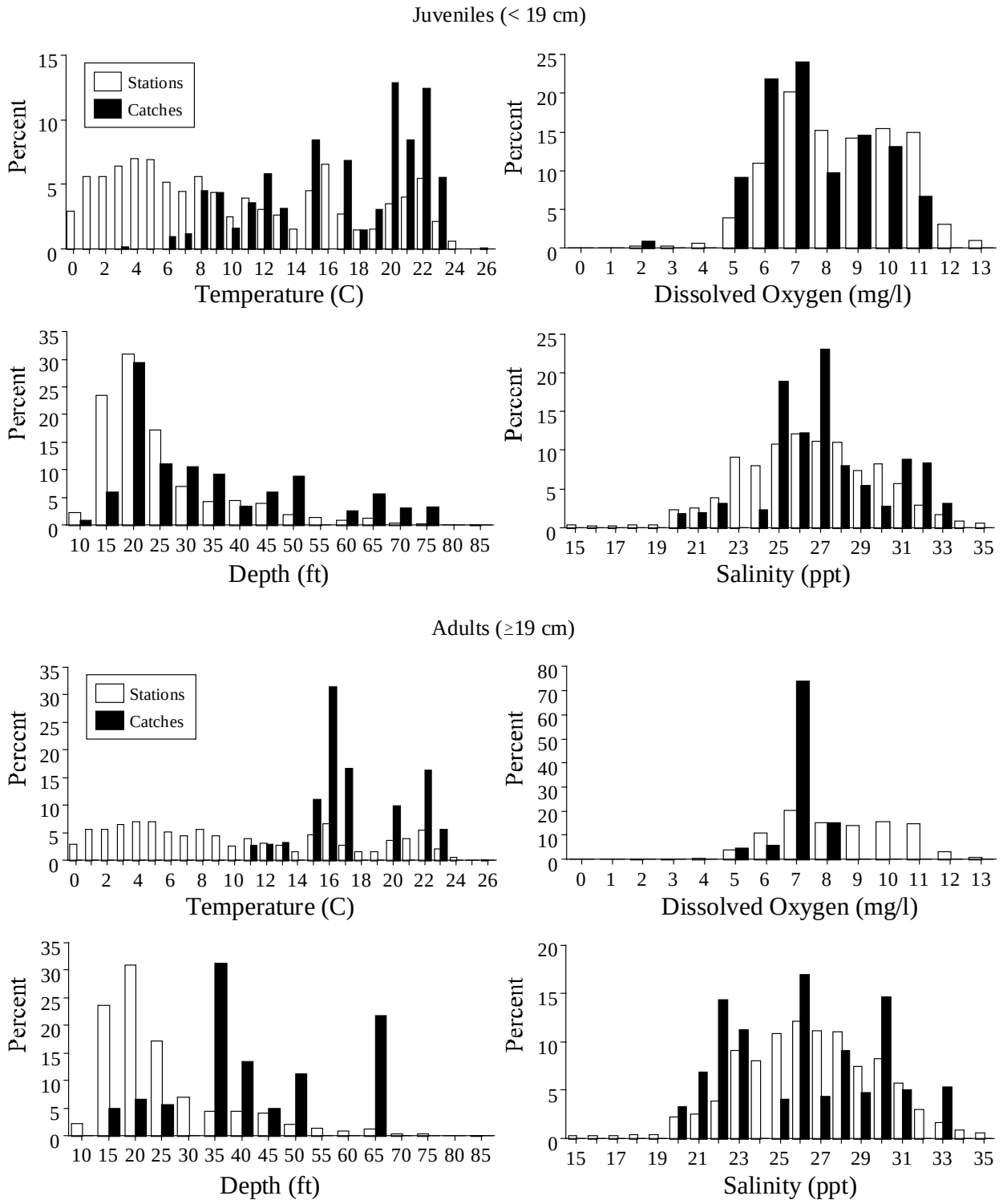


Figure 9. Abundance of juvenile and adult black sea bass relative to bottom water temperature, dissolved oxygen, depth, and salinity from Hudson-Raritan estuary trawl surveys (January 1992 - June 1997, all years combined).

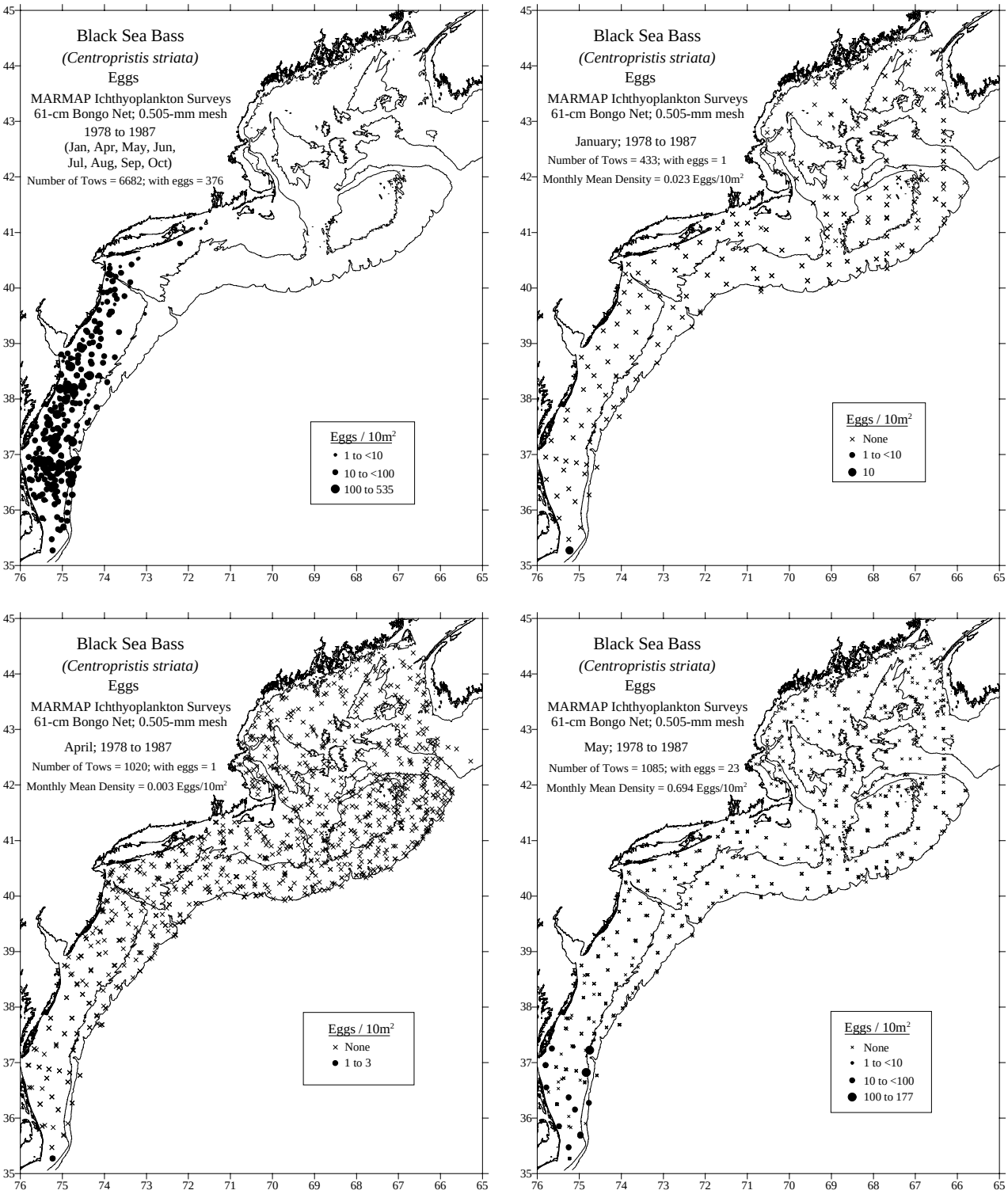
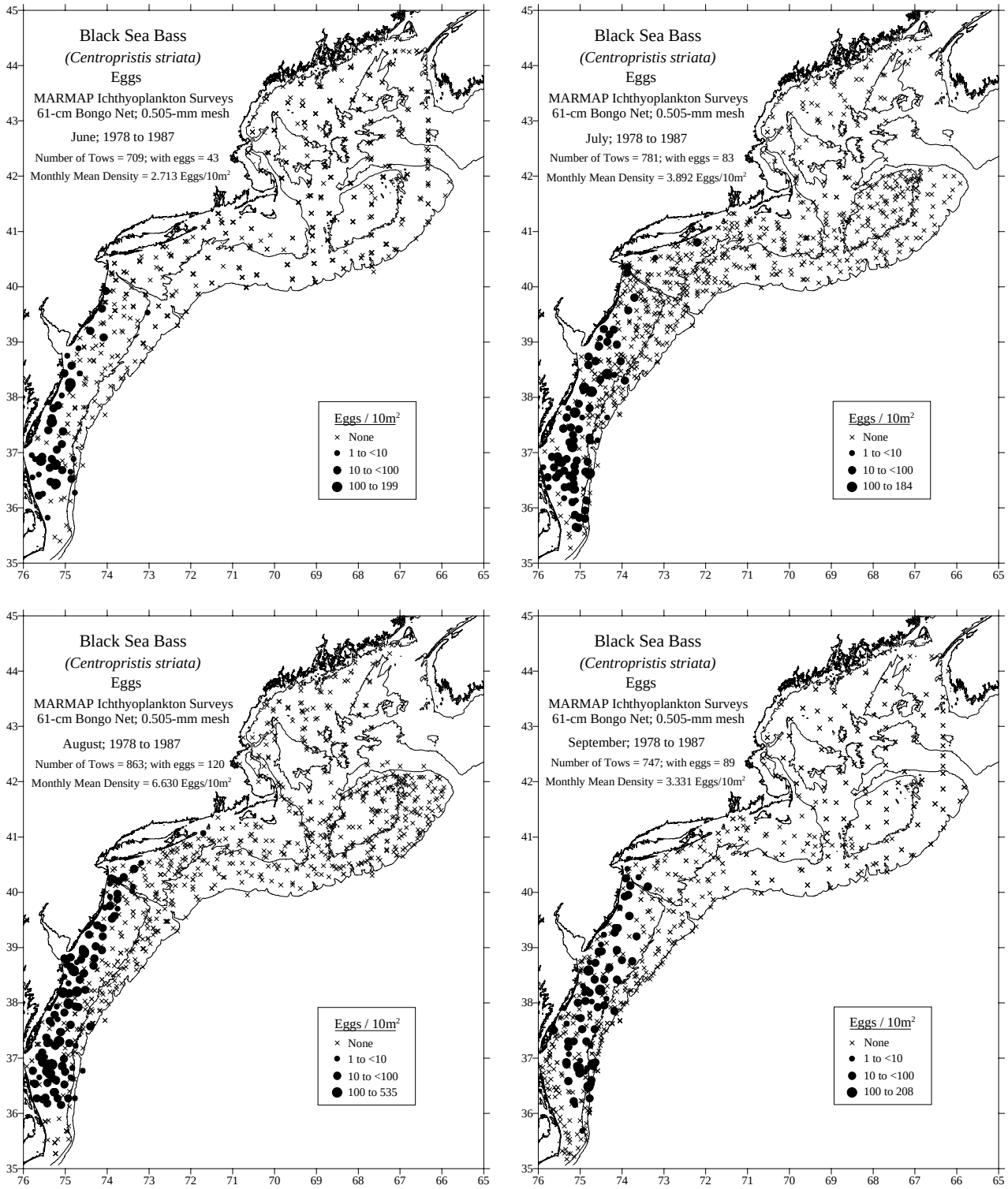


Figure 10. Distribution and abundance of black sea bass eggs collected during NEFSC MARMAP ichthyoplankton surveys, 1978-1987 [see Reid *et al.* (1999) for details]. The upper left figure is all months and all years combined, the remaining figures are individual months for all years combined.



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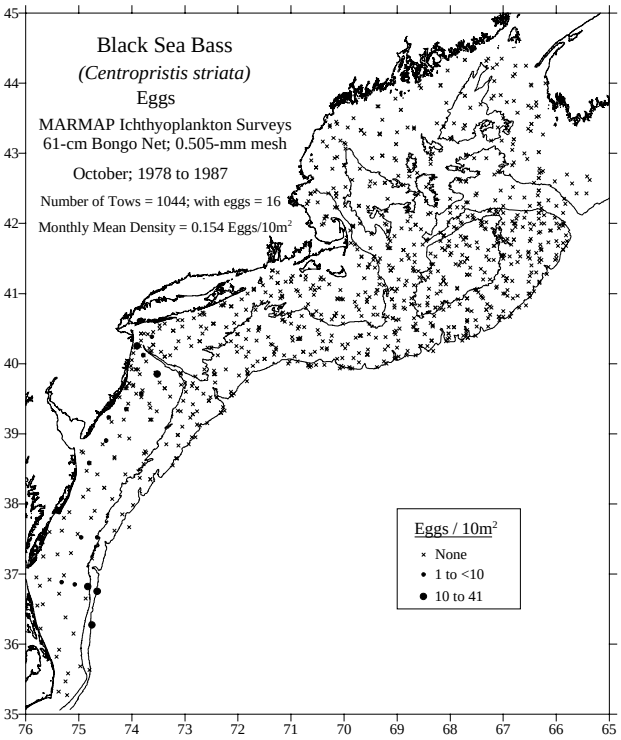

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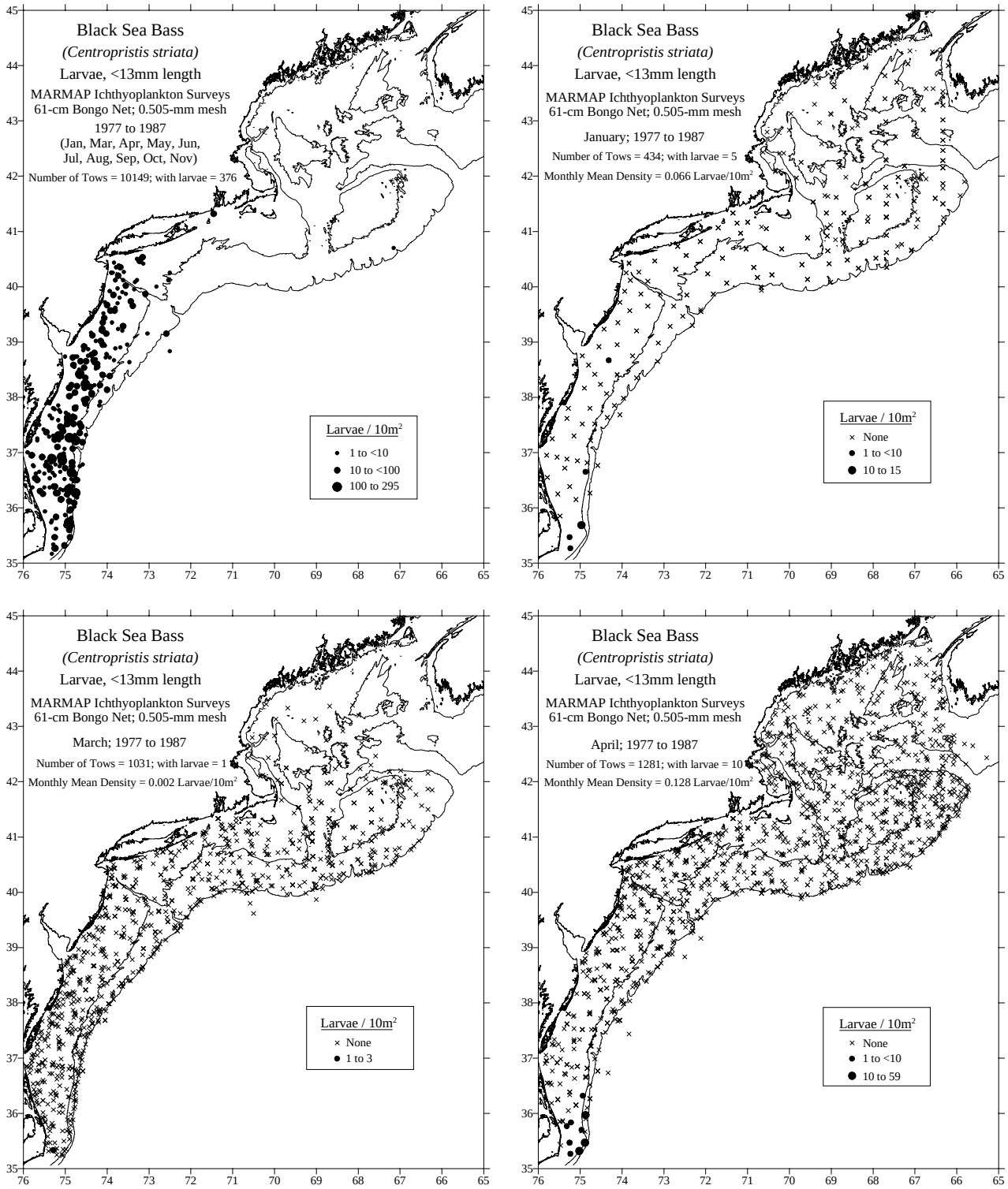

Figure 11. Distribution and abundance of black sea bass larvae (< 13 mm) collected during NEFSC MARMAP ichthyoplankton surveys, 1977-1987 [see Reid *et al.* (1999) for details]. The upper left figure is all months and all years combined, the remaining figures are individual months for all years combined.

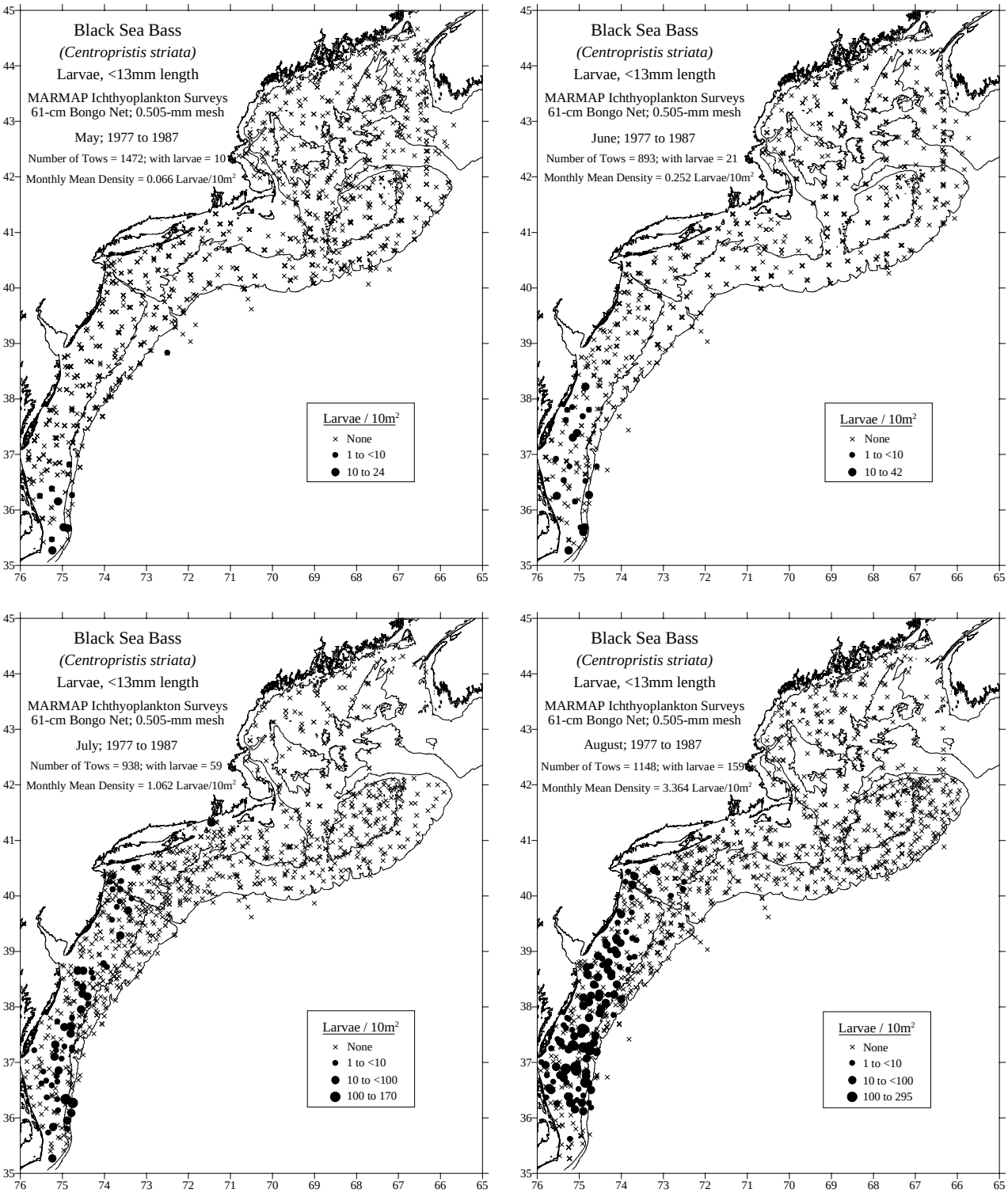

Figure 11. cont'd.

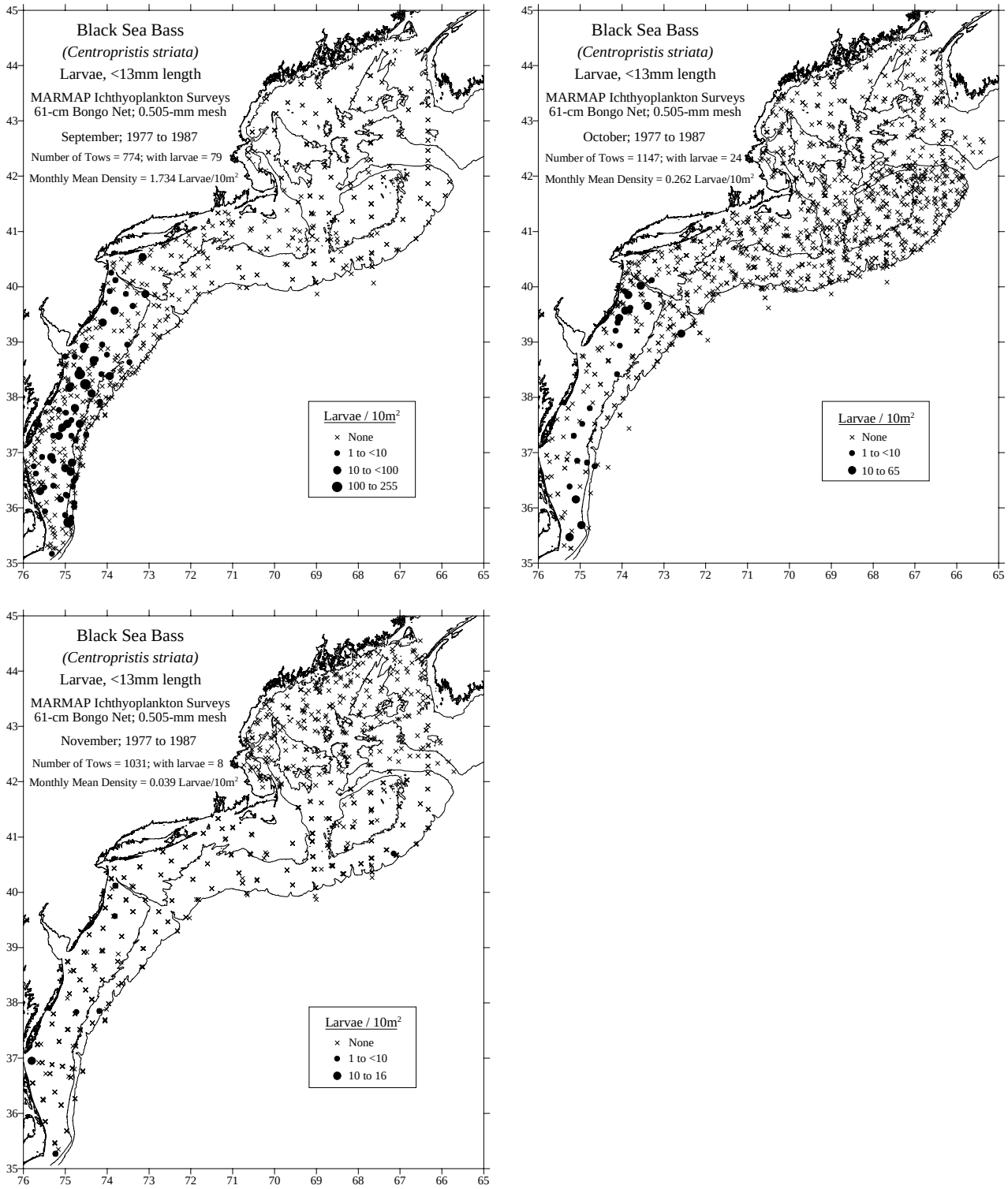

Figure 11. cont'd.

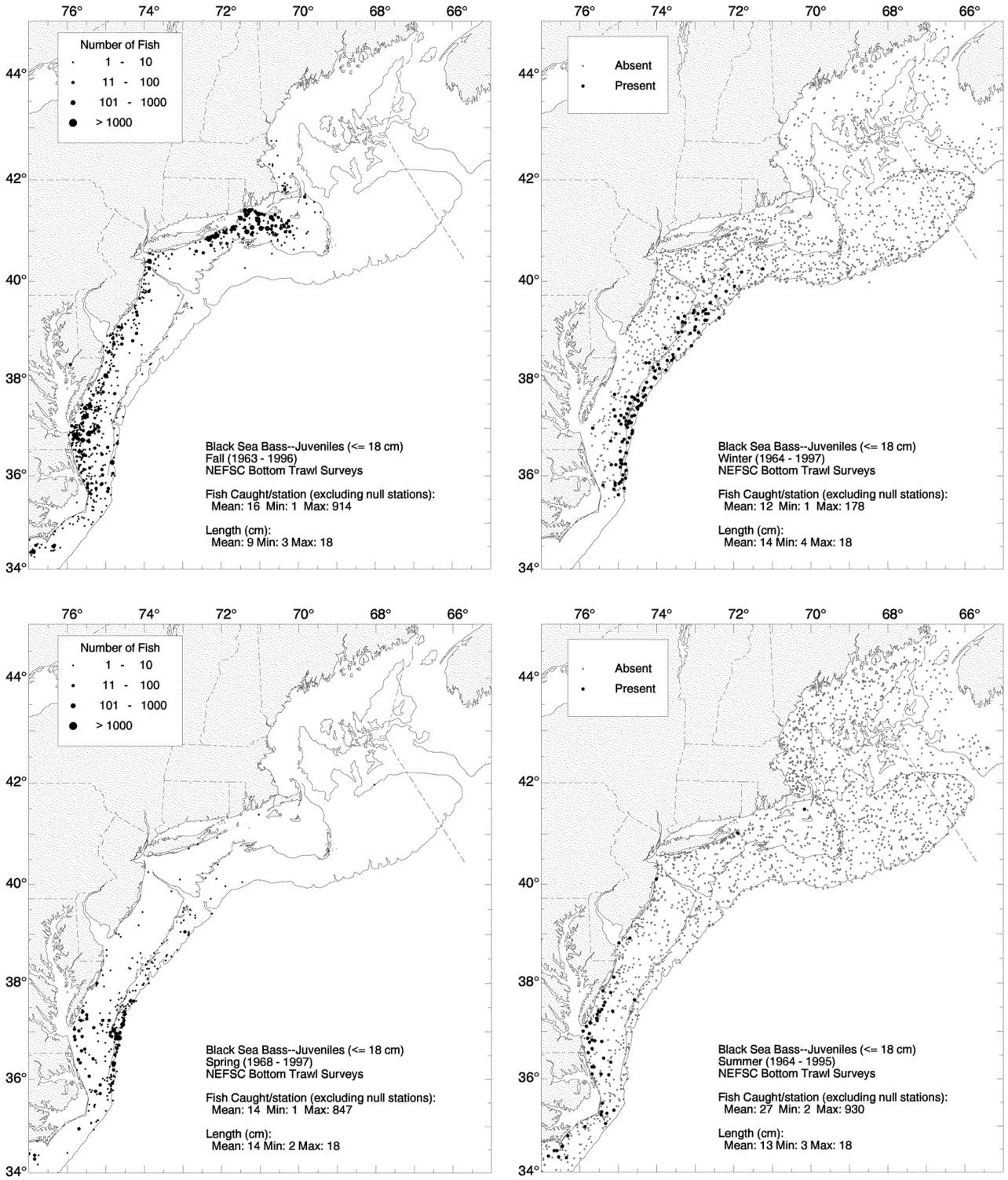

Figure 12. Seasonal distribution and abundance of juvenile and adult black sea bass collected during NEFSC bottom trawl surveys, 1963-1997 (all years combined). Densities are represented by dot size in spring and fall plots, while only presence and absence are represented in winter and summer plots [see Reid *et al.* (1999) for details].

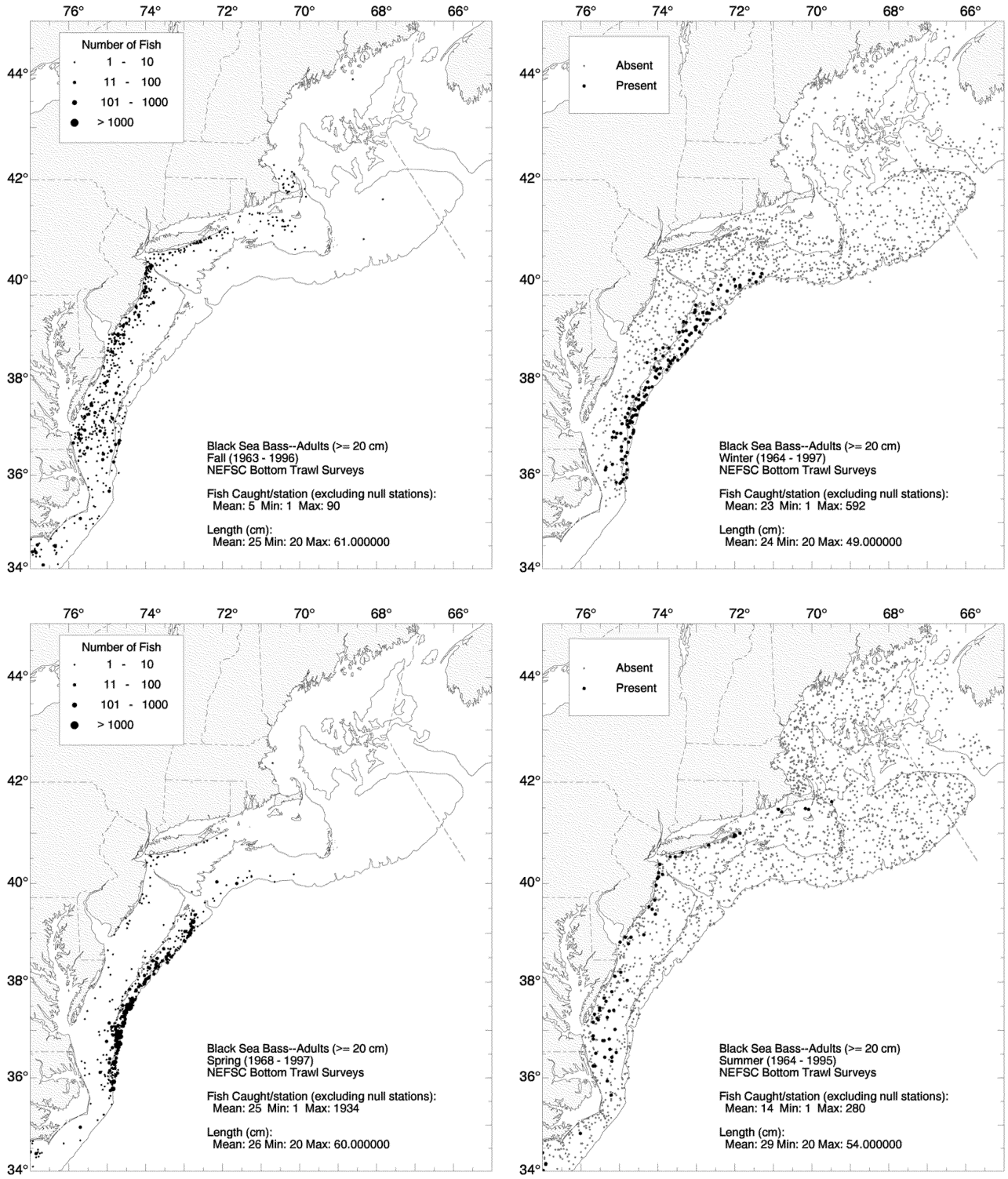

Figure 12. cont'd.

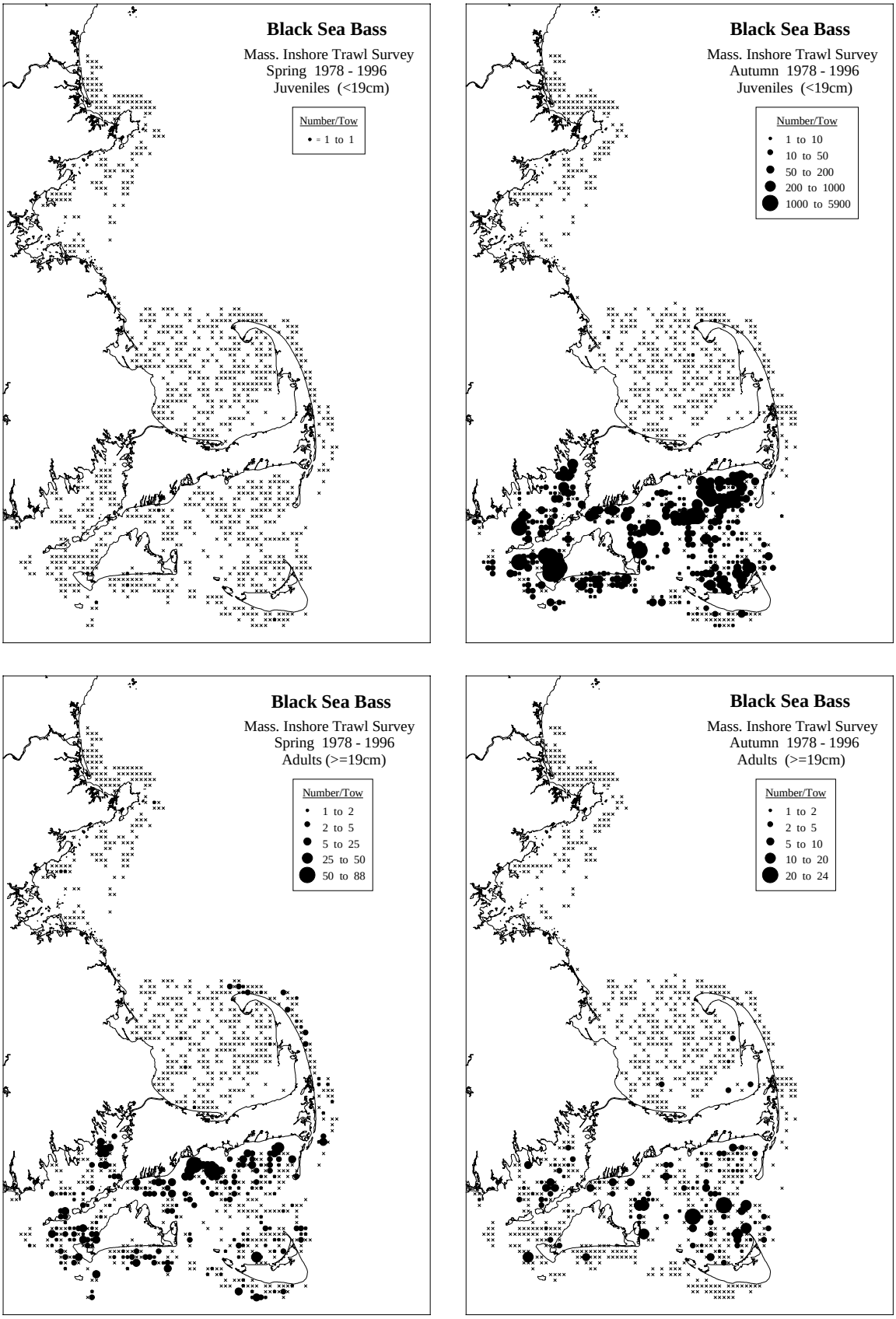

Figure 13. Distribution and abundance of juvenile and adult black sea bass collected in Massachusetts coastal waters during spring and autumn Massachusetts trawl surveys, 1978-1996 [see Reid *et al.* (1999) for details].

Black Sea Bass Juveniles (< 19 cm)

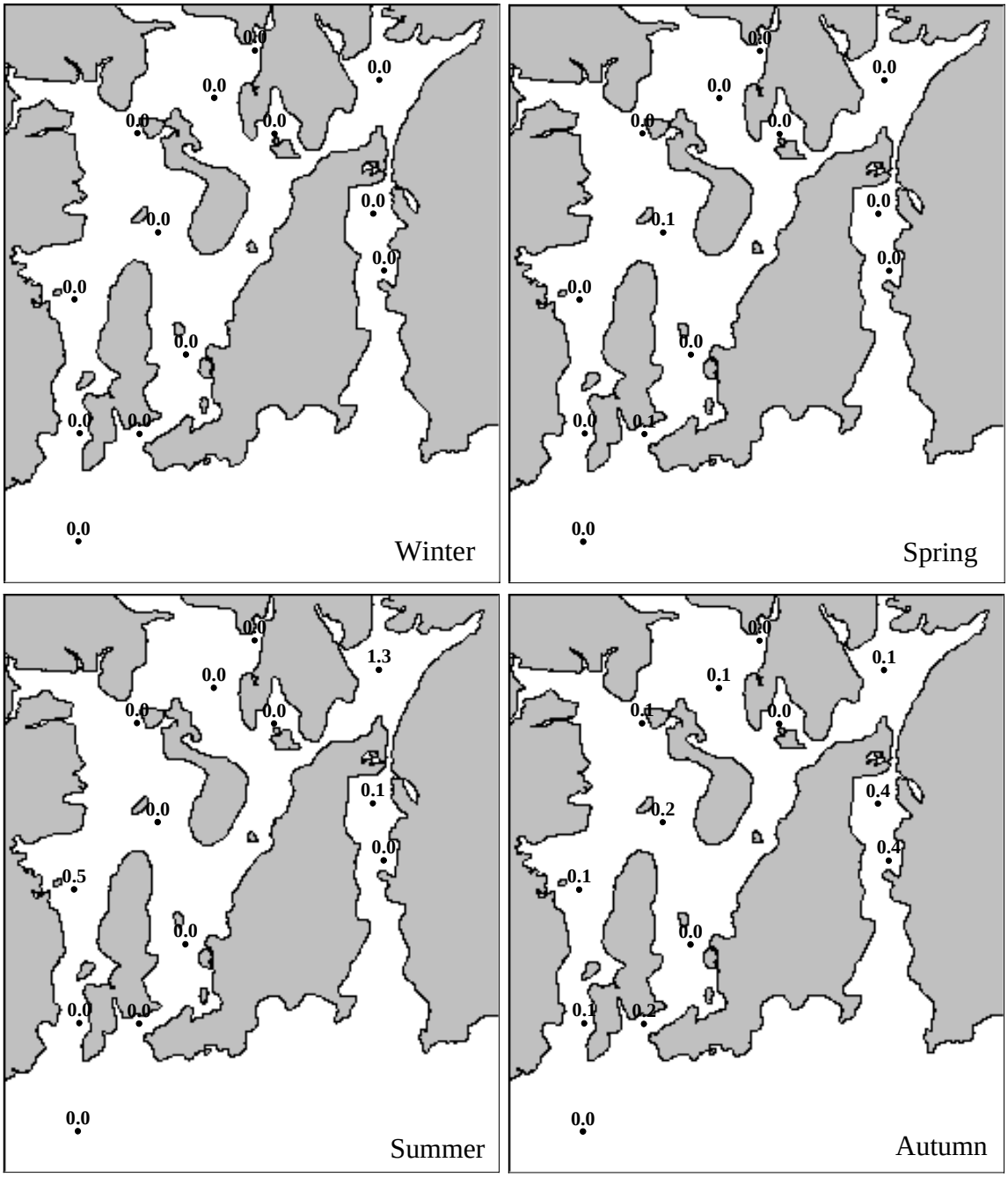

Figure 14. Distribution and abundance of juvenile and adult black sea bass collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].

Black Sea Bass Adults (>= 19 cm)

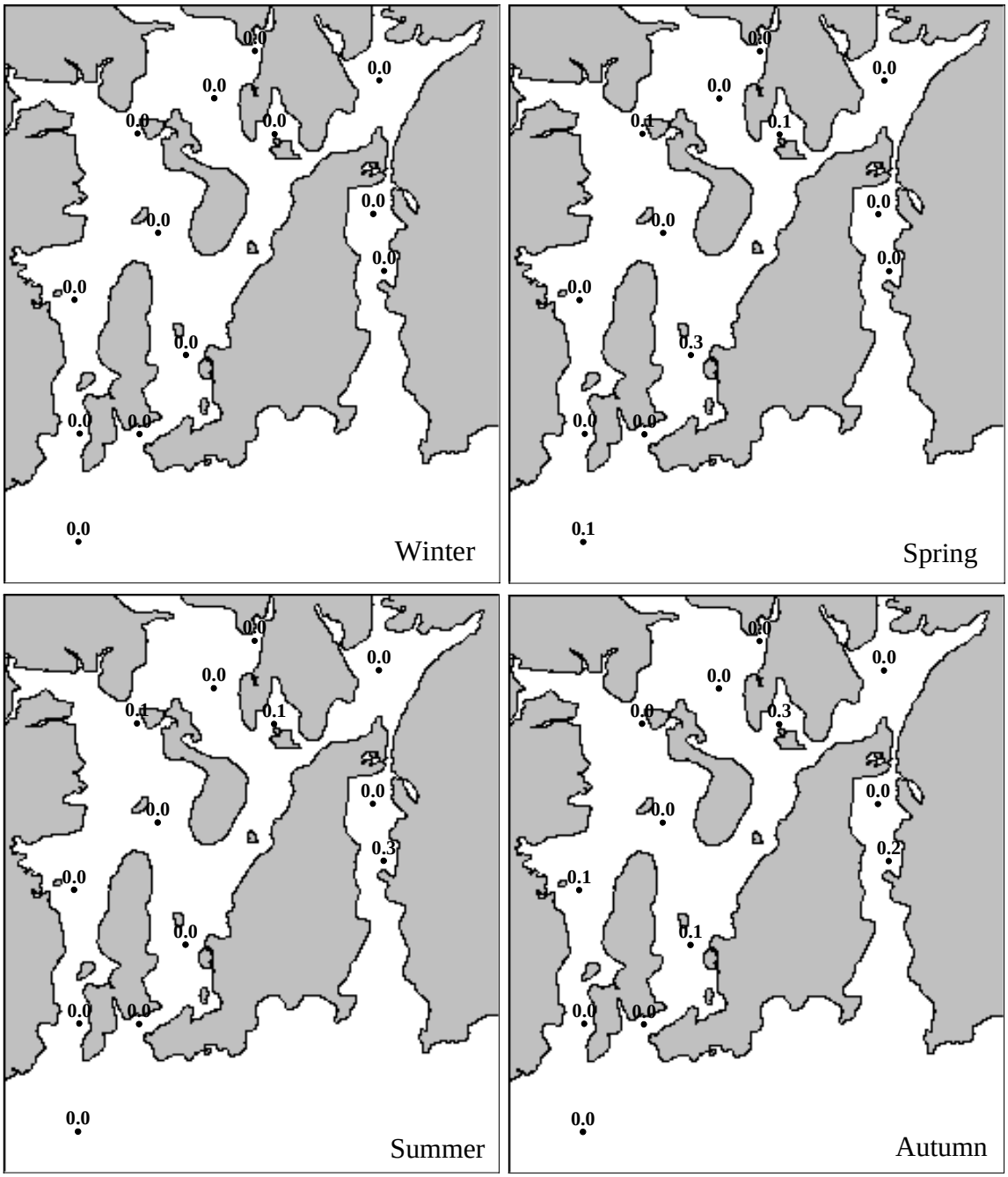

Figure 14. cont'd.

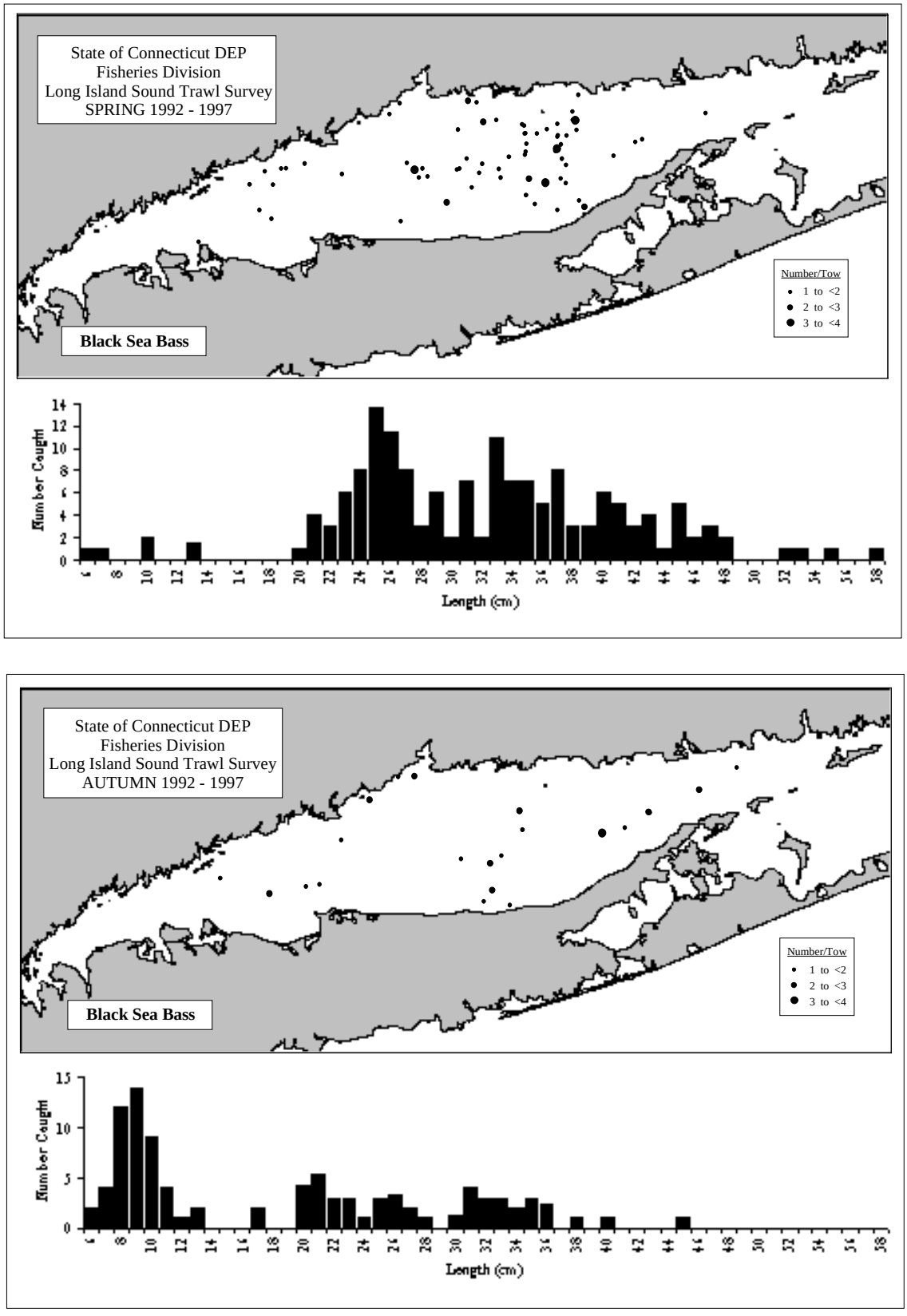

Figure 15. Distribution, abundance, and size frequency distribution of black sea bass collected in Long Island Sound during spring and autumn Connecticut bottom trawl surveys, 1992-1997 [see Reid *et al.* (1999) for details].

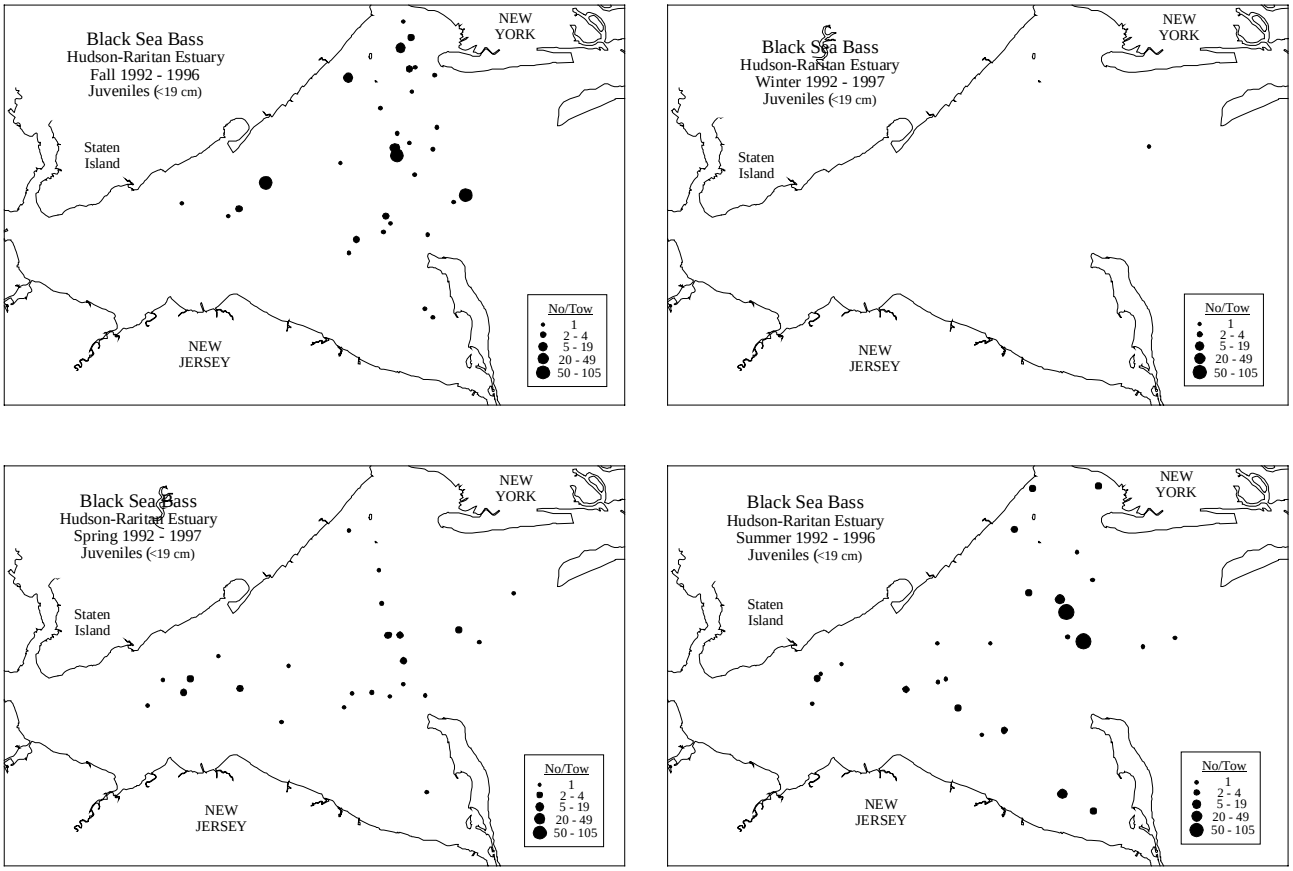

Figure 16. Seasonal distribution and abundance of juvenile and adult black sea bass in the Hudson-Raritan estuary collected during Hudson-Raritan estuary trawl surveys, 1992–1997 [see Reid *et al.* (1999) for details].

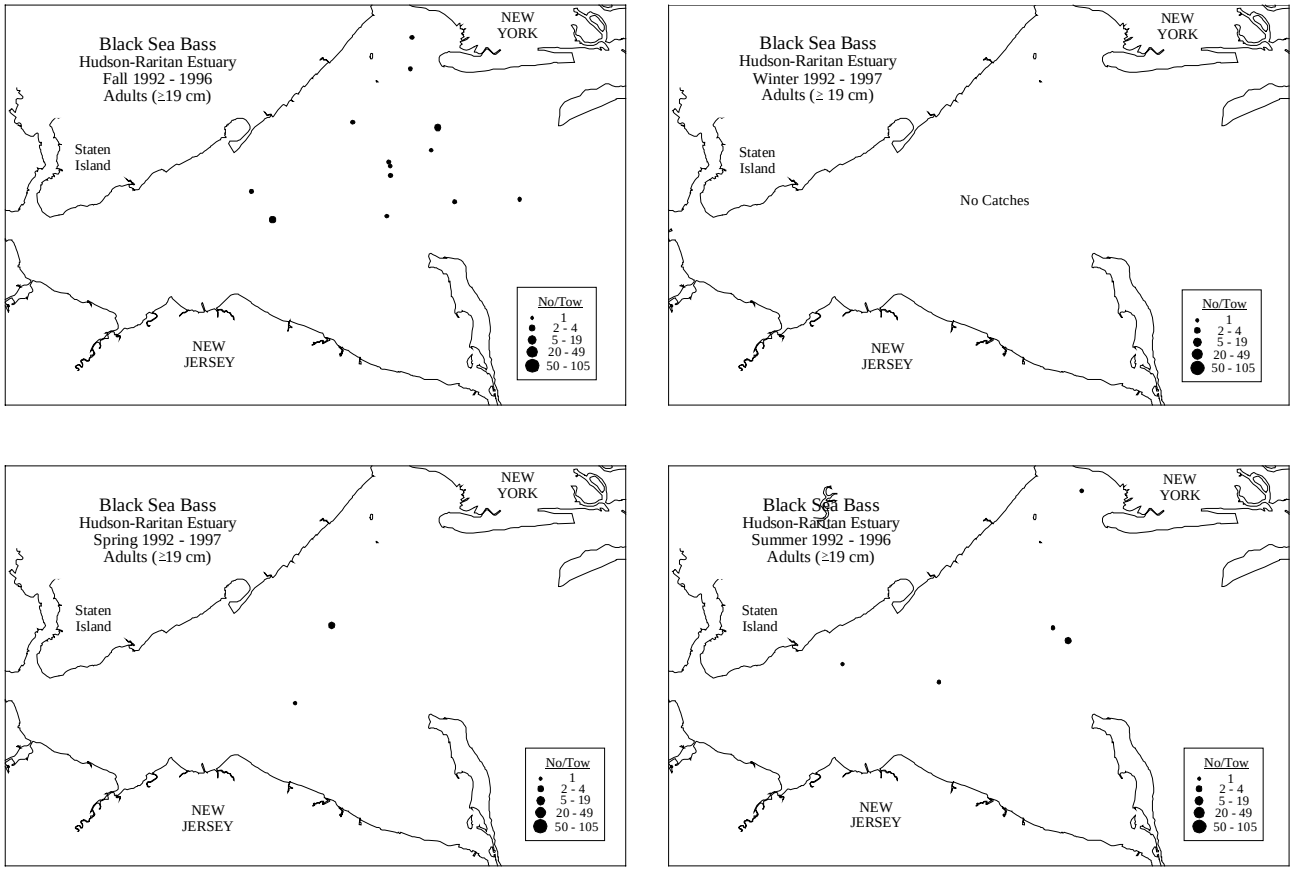

Figure 16. cont'd.

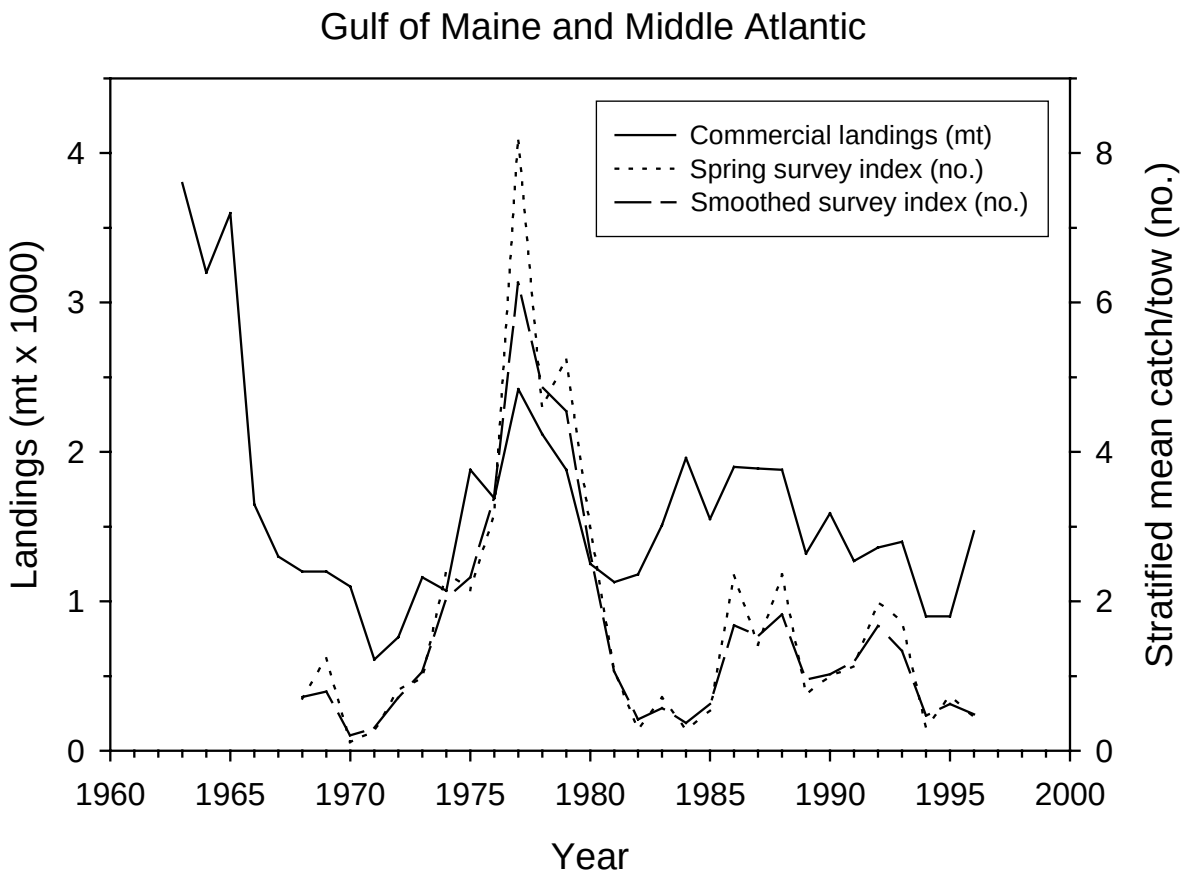

Figure 17. Commercial landings and NEFSC bottom trawl survey indices for black sea bass in the Gulf of Maine and Middle Atlantic Bight.

Publishing in *NOAA Technical Memorandum NMFS-NE*

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This series represents a secondary level of scientific publishing in the National Marine Fisheries Service (NMFS). For all issues, the series employs thorough internal scientific review, but not necessarily external scientific review. For most issues, the series employs rigorous technical and copy editing. Manuscripts that may warrant a primary level of scientific publishing should be initially submitted to one of NMFS's primary series (*i.e., Fishery Bulletin, NOAA Technical Report NMFS,* or *Marine Fisheries Review*).

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The ethics of scientific research and scientific publishing are a serious matter. All manuscripts submitted to this series are expected to adhere -- at a minimum -- to the ethical guidelines contained in Chapter 1 ("Ethical Conduct in Authorship and Publication") of the *CBE Style Manual*, fifth edition (Chicago, IL: Council of Biology Editors). Copies of the manual are available at virtually all scientific libraries.

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Organization: Manuscripts must have an abstract, table of contents, and -- if applicable -- lists of tables, figures, and acronyms. As much as possible, use traditional scientific manuscript organization for sections: "Introduction," "Study Area," "Methods & Materials," "Results," "Discussion" and/or "Conclusions," "Acknowledgments," and "References Cited."

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For spelling of scientific and common names of fishes, mollusks, and decapod crustaceans from the United States and Canada, use *Special Publications* No. 20 (fishes), 26 (mollusks), and 17 (decapod crustaceans) of the American Fisheries Society (Bethesda, MD). For spelling of scientific and common names of marine mammals, use *Special Publication* No. 4 of the Society for Marine Mammalogy (Lawrence, KS). For spelling in general, use the most recent edition of *Webster's Third New International Dictionary of the English Language Unabridged* (Springfield, MA: G.&C. Merriam).

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Tables should be prepared using all tabs or all spaces between columnar data, but not a combination of the two. Figures must be original (even if oversized) and on paper; they cannot be photocopies (*e.g.,* Xerox) unless that is all that is available, nor be on disk. Except under extraordinary circumstances, color will not be used in illustrations.

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Authors must submit one paper copy of the double-spaced manuscript, one magnetic copy on a disk, and original figures (if applicable). NEFSC authors must include a completely signed-off "NEFSC Manuscript/Abstract/Webpage Review Form." Non-NEFSC authors who are not federal employees will be required to sign a "Release of Copyright" form.

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STANDARD MAIL A

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific ournals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series includes: data reports of long-term or large area studies; synthesis reports for major resources or habitats; annual reports of assessment or monitoring programs; documentary reports of oceanographic conditions or phenomena; manuals describing field and lab techniques; literature surveys of major resource or habitat topics; findings of task forces or working groups; summary reports of scientific or technical workshops; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing. Limited free copies are available from authors or the NEFSC. Issues are also available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

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Fishermen's Report **and** ***The Shark Tagger*** -- The ***Fishermen's Report*** (FR) is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of the FR; copies are available through free subscription. ***The Shark Tagger*** (TST) is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of the TST; copies are available only to participants in the tagging program.

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NOAA Technical Memorandum NMFS-NE-144

Essential Fish Habitat Source Document:

Bluefish, *Pomatomus saltatrix*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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NOAA Technical Memorandum NMFS-NE-144

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Essential Fish Habitat Source Document:

Bluefish, *Pomatomus saltatrix*, Life History and Habitat Characteristics

Michael P. Fahay, Peter L. Berrien, Donna L. Johnson, and Wallace W. Morse

National Marine Fisheries Serv., James J. Howard Marine Sciences Lab., 74 Magruder Rd., Highlands, NJ 07732

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Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

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[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

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INTRODUCTION

The bluefish, *Pomatomus saltatrix* (Figure 1), ranges in the western North Atlantic from Nova Scotia and Bermuda to Argentina, but it is rare between southern Florida and northern South America (Robins *et al*. 1986). They travel in schools of like-sized individuals and undertake seasonal migrations, moving into the Middle Atlantic Bight (MAB) during spring and south or farther offshore during fall. Within the MAB they occur in large bays and estuaries as well as across the entire continental shelf. Juvenile stages have been recorded from all estuaries surveyed within the MAB, but eggs and larvae occur in oceanic waters (Able and Fahay 1998). Bluefish growth rates are fast and they may reach a length of 1.1 m (3.5 ft) and a weight of 12.3 kg (27 lbs) (Bigelow and Schroeder 1953). They may live to age 12.

A bimodal size distribution of young-of-the-year (YOY) bluefish during the summer in the New York Bight suggests that there are two spawning events along the east coast. Recent studies suggest that spawning is a single, continuous event, but that young are lost from the middle portion resulting in the appearance of a split season. As a result of the bimodal size distribution of juveniles, young are referred to as the *spring-spawned cohort* or *summer-spawned cohort* in the habitat discussion and distribution maps presented below.

LIFE HISTORY

EGGS

Eggs from the MAB are pelagic and spherical with a diameter of 0.95-1.00 mm. They have a smooth, transparent shell and a homogeneous yolk. The single oil globule is 0.26-0.29 mm in diameter and the perivitelline space is narrow (Fahay 1983). Incubation times depend on temperature. At 18.0-22.2^{o}C, hatching occurs after 46-48 h (Deuel *et al*. 1966). Eggs from the South Atlantic Bight (SAB) have not been described.

LARVAE AND PELAGIC-JUVENILES

Larvae are 2.0-2.4 mm long when they hatch; the eyes are unpigmented and the mouth parts are undeveloped. Characteristic pigment includes parallel lines of melanophores along the dorsal fin base, body midline, and anal fin base. Teeth are well developed at 4.3 mm and fin rays are complete at a size of about 13-14 mm (Fahay 1983). Larvae rarely occur deeper in the water column than 15 m; most are concentrated at a depth of about 4 m during the day, but they are about equally distributed between that depth and the surface at night (Kendall and Naplin 1981). The bluefish transforms from a larva to a "pelagic-juvenile" stage that is specially adapted for an oceanic, near-surface existence after completion of fin ray development (Figure 2). This specialized stage is characterized by a silvery, laterally compressed body, with dark blue counter-coloration on the dorsum. This transition occurs at an age of 18-25 d and at a size of 10-12 mm SL (Hare and Cowen 1994). Scales begin to form at about 12 mm on the posterior part of the lateral line region, then proceed forward, until the head is completely scaled at about 37 mm (Silverman 1975). Swimming ability in many fish species dramatically improves during this transformation (e.g. Hunter 1981; Stobutzki and Bellwood 1994; Leis *et al.* 1996) and this improvement presumably applies to bluefish as well. It is during this stage that bluefish arrive at nursery areas in the central part of the MAB, after advection via the Gulf Stream from spawning areas in the SAB and after crossing the Slope Sea (Hare and Cowen 1996; Hare *et al.*, in prep.) and the continental shelf (Cowen *et al.* 1993). This transport (active or passive) is crucial to the recruitment of these progeny to vital estuarine nursery areas, and therefore this life history stage might be considered a critical bottleneck.

JUVENILES (INCLUDING YOUNG-OF-THE-YEAR)

Juveniles have a usual fish shape without unusual features. The caudal fin is forked and the body is somewhat laterally compressed, with a silvery, unpatterned color. The mouth is large and oblique and all fin spines are strong. Two distinct dorsal fins touch at their bases; the second dorsal fin is about the same length as the anal fin base (Able and Fahay 1998). The *spring-spawned cohort* is 60-76 d old with a mean size of 60 mm when they recruit to estuarine habitats in the MAB in late May to mid-June (McBride and Conover 1991; Cowen *et al.* 1993). The *summer-spawned cohort* either remains in coastal nursery areas (Kendall and Walford 1979; Able and Fahay 1998) or enters estuarine nurseries in mid- to late August when they are 33-47 d old with a mean length of 46 mm (McBride and Conover 1991). Juveniles of both cohorts depart MAB estuaries and coastal areas in October and migrate to waters south of Cape Hatteras, North Carolina. At this time, members of both cohorts range from 4 to 24 cm long (Able and Fahay 1998). During most years, the *spring-spawned cohort* dominates in the emigrating young-of-the-year.

ADULTS

Adult bluefish are blue-green above, silvery below, moderately stout-bodied, and armed with stout teeth along both jaws. The snout is pointed and the mouth is large and oblique. The caudal fin is large and forked. The fin ray formulae are first dorsal: 7-9 spines; second dorsal: 1

spine and 23-26 rays; anal: 2-3 spines and 25-28 rays. Vertebrae number 26. The maximum length is about 115 cm and maximum weights are 4.5-6.8 kg, although an occasional heavier fish has been taken. The maximum age is 12 years. The sex ratio is 1:1 for all age groups (Boreman 1982), although Lassiter (1962) reported a ratio of two females per male in North Carolina and Hamer (1959) found a ratio of three females to two males in New Jersey.

REPRODUCTION

A seminal study, based largely on the distribution of eggs and larvae, concluded that there were two discrete spawning events in western Atlantic bluefish. The first occurs during March-May near the edge of the continental shelf of the SAB. The second occurs between June and August in the MAB (Kendall and Walford 1979). Recent studies have re-examined this conclusion and refined our knowledge of a complex reproductive pattern, and support the concept of a single, migratory spawning stock (Hare and Cowen 1993; Smith *et al.* 1994).

Sexual maturity and gonad ripening occur in early spring off Florida, early summer off North Carolina, and late summer off New York (Hare and Cowen 1993). In the New York Bight, gonadosomatic studies indicate that both sexes are ripe or ripening between June and September with a strong peak in July (Chiarella and Conover 1990). Larvae re-occur in the SAB in the fall (Collins and Stender 1987) and there are also indications that gonads reach a second peak in ripeness in fishes off Florida in September. Most bluefish are mature by age 2 (Deuel 1964). It is not known whether individuals spawn serially or what the contributions of individuals are to observed spawning patterns of the population. In South Africa, individuals may spawn repeatedly over a period of 5-6 months (Van der Elst 1976), but there is no comparable information for the U.S. population.

FOOD HABITS

During their oceanic larval stage, bluefish primarily consume copepods. Fishes begin to be included in their diet at sizes of 30 mm, and by 40 mm, fishes are the major diet item. Soon after this shift in diet, juveniles migrate inshore to occupy estuarine habitats (Marks and Conover 1993).

The results of several studies suggest that bluefish juveniles and adults eat whatever taxa are locally abundant (Table 1). The components of young-of-the-year bluefish diet in Sandy Hook Bay, New Jersey and the effects of those components on condition were studied over a three-year period (Friedland *et al.* 1988). Fishes dominated the diet during 1981, while crustaceans and polychaetes were more important during 1983 and 1984. Weight-length relationships indicated that weight at length was significantly greater in 1981 than in the other two years. Thus, not only does the quality of diet differ between estuaries, but the method of foraging may also differ; more benthic foraging was evident in bluefish from Sandy Hook Bay than in bluefish sampled in estuaries in Delaware (Grant 1962) and North Carolina (Lassiter 1962). Depending on age class, diets might change through a season. In Chesapeake Bay, diets of three age classes differed through the summer (Table 1), but all three concentrated on *Brevoortia tyrannus* in the fall (Hartman and Brandt 1995a, b).

PREDATION

Sharks, tunas, and billfishes are the only predators large and fast enough to prey on adult bluefish. They are a major component in the diet of shortfin mako shark, composing 77.5% of the diet by volume (Stillwell and Kohler 1982). This study estimated that this shark may consume between 4.3 and 14.5% of the bluefish resource between Georges Bank and Cape Hatteras. Bluefish also ranked fourth in number and occurrence and third in volume in swordfish diets, especially off the Carolinas (Stillwell and Kohler 1985). Blue sharks and sandbar sharks also prey on bluefish (Kohler 1988; Medved *et al.* 1985). Young-of-the-year are preyed upon by four oceanic bird species, the Atlantic puffin, Arctic tern, common tern, and roseate tern (Creaser and Perkins 1994; Safina *et al.* 1990). Cannibalism has only rarely been reported, but occurs in age 1 and older year classes in North Carolina (Lassiter 1962), and bluefish compose a minor component of the diet of larger bluefish collected during Northeast Fisheries Science Center (NEFSC) bottom trawl surveys on the continental shelf (NEFSC, unpublished data).

MIGRATIONS

Bluefish are warm water migrants and do not occur in MAB waters at temperatures < 14-16°C (Bigelow and Schroeder 1953). They generally move north in spring-summer to centers of abundance in the New York Bight and southern New England and south in autumn-winter to the waters in the SAB as far as southeastern Florida. There is a trend for larger individuals to occur farther north during the summer (Wilk 1977). Anecdotal reports suggest that larger adults truncate their southward migration and spend the winter on the outer part of the continental shelf of the MAB. One report witnessed a single fish landed from about 100 m deep off Martha's Vineyard during mid-January 1950 and several hauls of 80-640 kg from the vicinity of Hudson Canyon during early February of the same year (Bigelow and Schroeder 1953). Another study simply reported "boats engaged in

the winter trawl fishery for fluke and scup along the outer margin of the continental shelf often bring in a few bluefish" (Hamer 1959). These reports have been perpetuated since (Lund 1961; Miller 1969; Lund and Maltezos 1970; Hardy 1978). However, recent winter trawl surveys do not indicate, nor are fisheries or other data available to support, the presence of bluefish in the MAB during winter, except for a few occurrences near the shelf edge off Cape Hatteras (see Geographical Distribution).

STOCK STRUCTURE

The bluefish is presently managed as a single stock (MAFMC 1997). Although there is evidence of separate spawning events (see Reproduction), fish from these spawning groups mix extensively during their lives, and recent conclusions have ascertained that bluefish year classes are composed of seasonal cohorts (Chiarella and Conover 1990). Recent studies have re-examined this conclusion and refined our knowledge of a complex reproductive pattern, supporting the concept of a single, migratory spawning stock (Hare and Cowen 1993; Smith *et al.* 1994). A mitochondrial DNA study of *spring-* and *summer-spawned* bluefish also concluded that bluefish along the east coast of the United States comprise a single genetic stock (Graves *et al.* 1992).

HABITAT CHARACTERISTICS

The habitat characteristics for eggs, larvae, pelagic-juveniles, juveniles, and adults based on results of this compendium and pertinent published reports are presented in Table 2. Included are observations of habitat use by young-of-the-year in estuaries. When studies of juvenile abundance have been related to environmental variables, such as eelgrass presence/absence or a substrate type, they have usually been conducted with seines where catch-per-unit-of-effort is difficult to establish. Comparing the results of these studies between locations is usually not possible, and further details of essential habitats are therefore not yet available. Appendix 1 contains more complete data from various studies reported in the literature.

EGGS

In the MAB, bluefish eggs are found in the open ocean at temperatures 18-22°C and salinities > 31.0 ppt. Peak spawning occurs in the evening (Norcross *et al.* 1974). Eggs in the southern part of the MAB may be advected south and offshore (Norcross *et al.* 1974).

LARVAE AND PELAGIC-JUVENILES

Larvae in the MAB occur in open oceanic waters, near the edge of the continental shelf in the southern Bight and over mid-shelf depths farther north (Norcross *et al.* 1974; Kendall and Walford 1979). Most larvae occur in temperatures of 18-24°C and salinities of 30-32 ppt. They migrate vertically in the water column, occurring near the surface at night, but centered at about 4 m during daylight (Kendall and Naplin 1981). Larvae spawned in the SAB (*spring-spawned cohort*) are subject to advection north via the Gulf Stream (Hare and Cowen 1996; Kendall and Walford 1979), but some recruit successfully to estuaries in the SAB (Collins and Stender 1987; McBride *et al.* 1993).

The transport of pelagic-juveniles was outlined by Kendall and Walford (1979) and elaborated by Hare and Cowen (1996). Many are found in the vicinity of Cape Hatteras as early as April. In May, several have been collected on the shelf in the SAB (Fahay 1975; Kendall and Walford 1979). By June, they occur in the MAB between the shore and the shelf/slope front, actively crossing the shelf (Hare and Cowen 1996). In both the SAB and MAB, there is a strong negative correlation between fish size and depth indicating an offshore origin and onshore migration with growth.

JUVENILES (INCLUDING YOUNG-OF-THE-YEAR)

Juveniles occur in estuaries, bays, and the coastal ocean of the MAB and SAB, where they are less common. They occur in many habitats, but do not use the marsh surface. The range of physical and structural conditions in which they are found is summarized in Table 2. Juveniles begin to depart MAB estuaries in October and migrate south to spend the winter months south of Cape Hatteras.

ADULTS

Adult bluefish occur in the open ocean, large embayments, and most estuarine systems within their range. Although they occur in a wide range of hydrographic conditions, they prefer warmer temperatures and are not found in the MAB when temperatures decline below 14-16°C. See Table 2 for a summary of habitat requirements of adult bluefish.

GEOGRAPHICAL DISTRIBUTION

EGGS

Spring-spawned cohort: The spring spawning occurs near the edge of the continental shelf in the SAB.

However, bluefish eggs have not been collected or identified from this region.

Summer-spawned cohort: Eggs were collected from May to August over the MAB continental shelf during the NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) program surveys [see Reid *et al*. (1999) for methods]. Bluefish eggs were most abundant in July (Figure 3). Eggs were distributed near Cape Hatteras in May and their occurrences expanded rapidly northward during the summer. In July, eggs were distributed as far as southern New England waters with a center of abundance off Delaware Bay and New Jersey (Berrien and Sibunka 1999). Eggs were not collected after August. Bluefish eggs do not occur in estuarine waters. During the NEFSC MARMAP surveys, eggs occurred across the entire shelf, but were most concentrated in mid-shelf depths (Berrien and Sibunka 1999). In another study, most (80%) eggs collected off the Chesapeake Bay mouth were > 55 km from shore (Norcross *et al.* 1974). Most eggs were collected at surface temperatures between 17 and 23°C, and over depths of 30 to 70 m (Figure 4).

LARVAE

The distribution of all larvae collected in the MAB and SAB is shown in Figure 5. There has been a critical lack of sampling in the area immediately south of Cape Hatteras.

Spring-spawned cohort: Our understanding of the distribution of larvae in the SAB (corresponding to the *spring-spawned cohort*) is limited. The NEFSC MARMAP ichthyoplankton program sampled there from 1973 through 1980; bluefish larvae generally were collected in low densities, both in water column sampling with bongo nets (Figure 6) or Isaacs-Kidd midwater trawls (Table 3), and at the surface with two types of neuston net (Figure 7). Most larvae occurred near the 200 m depth contour, placing them close to the Gulf Stream and presumably enhancing their chances of advection to the north as proposed by Kendall and Walford (1979), Powles (1981), and Hare and Cowen (1993, 1996). The collection of bluefish eggs in April and May is consistent with back-calculated birth dates determined from estuarine recruits in the New York Bight (NYB) (see Juveniles). The densest concentrations of larvae in NEFSC MARMAP cruises in the SAB occurred over the outer half of the continental shelf during April and May. Currents there flow toward the northeast and are affected by the Gulf Stream (Lee and Atkinson 1983), while on the inner shelf, wind-driven currents are important in affecting the drift of larvae (Powles 1981; Lee and Atkinson 1983). A secondary concentration of larvae was detected during late summer/early fall of one year (1976) and may indicate the existence of an isolated spawning event (Figure 6). During 1979, all sampling was done by Isaacs-Kidd midwater trawl and was restricted to the shelf area near Charleston, South Carolina between February and August (Table 3). Larvae were collected with this gear in low densities between February and mid-May; two tows in April yielded somewhat higher densities.

Summer-spawned cohort: The distribution of larvae in the MAB is similar to that of the eggs (Figure 8). Larvae < 11 mm (the size when they become pelagic-juveniles) first occur near Cape Hatteras and along the shelf edge in the Wilmington Canyon area during May, and are present through the summer in increasing numbers throughout the southern and central parts of the MAB. Although larvae are only rarely collected in estuarine waters, they have been reported from a few large systems in the MAB, including one larva, one occurrence in Narragansett Bay (Herman 1963) and several estuaries in New York/New Jersey (Table 4). During June, peak larval abundance occurs between Cape Hatteras and Chesapeake Bay and off New Jersey. Larvae are most dense in the central part of the MAB in July and remain dense during August. Few larvae occur in the MAB during September. Larvae rarely occur deeper in the water column than 15 m and most are concentrated at a depth of about 4 m during the day, but are about equally distributed between that depth and the surface at night. Neuston sampling, therefore, is likely to drastically undersample bluefish when done during the day. In NEFSC MARMAP sampling, larvae occurred across the entire shelf but were most concentrated in mid-shelf depths. Most larvae were collected at surface temperatures between 17° and 26°C and over water depths of 30 to 70 m (Figure 9).

PELAGIC-JUVENILES (LARVAL TO JUVENILE TRANSITION)

There are no available data that adequately describe the distribution of this transformation stage in bluefish life history, however, limited observations have been made in the NYB (Shima 1989; Hare and Cowen 1996). These observations support the view that temperatures below 13-15°C impede the progress of this stage into MAB estuaries. In early June, these pelagic-juveniles mass at the shelf-slope temperature front, and resume their inshore migration when that front dissipates (Hare and Cowen 1996).

JUVENILES

It is presently unknown if bluefish are "estuarine dependant" since the distribution of juveniles over the continental shelf has not been described. The distribution and relative abundance of juveniles has been documented for estuaries along the east coast of the United States (Table 4) and for estuaries in Maine (Table 5).

A survey of juvenile bluefish published in the early 1970s (Clark 1973) noted that their distribution differed from historical observations (Figure 10). Bluefish were not observed south of Daytona Beach through the 1970s, although juveniles were reported from estuaries as far south as Palm Beach, Florida in the early part of the century (Evermann and Bean 1898; Nichols 1913). This author also suggested that the apparent high densities of juveniles in certain regions (e.g., New Jersey and South Carolina) were due to greater sampling effort. Remaining enigmatic occurrences include those in the freshwaters of the upper Chesapeake Bay (Mansueti 1955; Lund 1961), although the Chesapeake and Delaware Canal may play a role in their presence there.

Several young-of-the-year surveys (or surveys that adequately sample young stages) are conducted within MAB states (Figure 11). Several caveats pertaining to these results prevent these state data from being compared directly. Some surveys are conducted throughout the year, while others are limited in their seasonal extent, and the resultant densities are therefore unequal. Although all results are expressed as "number per tow," tow lengths and gear characteristics vary between states, and thus the basis for this number can be unequal. Finally, the definition of "juvenile" can vary between states; in some cases, it is based solely on length frequency distributions, in some cases it is based on an arbitrary length cutoff. In most states, all fish < 30 cm are considered juveniles, although in the Chesapeake Bay region, some of these could be age 1+ if they were collected early in the year (Munch 1997).

Despite these caveats, certain trends are evident in the data. There are signs of strong year classes in each state data set, but these do not necessarily match temporally. In general, abundances are greater in states between Rhode Island and New Jersey, and considerably lower in states in the southern part of the MAB, further emphasizing the importance of the former.

Massachusetts Trawl Survey

Juvenile bluefish are collected in twice-yearly otter trawl sampling in nearshore waters of Massachusetts [see Reid *et al.* (1999) for details]. Juveniles are not found during spring, but are more abundant during fall (Figure 12); most positive collections occur in embayments south of Cape Cod. In the fall, juveniles occur in the warmest bottom water temperatures and occur most commonly at the shallowest stations (Figure 13).

Rhode Island Trawl Survey, Narragansett Bay

Juveniles were collected during summer and autumn in a survey of Narragansett Bay (Figures 14, 15) [see Reid *et al.* (1999) for details]. Most were collected in depths of 6-15 m and at bottom water temperatures of 17-22°C (Figure 16).

Connecticut Trawl Survey, Long Island Sound

Young-of-the-year appear during June and by mid-August, they compose 93% of the bluefish catches in Long Island Sound (Figure 17) [see Reid *et al.* (1999) for details]. Abundance is highest during mid-summer on the Connecticut side of the sound in depths < 18 m, but adults are more widespread than juveniles (Figure 18). Peak abundance is reached during September when bluefish (94% juveniles) are found throughout the sound. Juvenile abundance is highest in depths of 9-27 m over mud bottoms in three areas: 1) the Connecticut side from New Haven to Norwalk; 2) across the Western Basin into Smithtown Bay; and 3) across the Central Basin from New Haven to Mattituck. Abundance decreases rapidly after September and juveniles appear to depart before adults.

NEFSC Hudson-Raritan Trawl Survey

Most bluefish collected in the Hudson-Raritan estuary and Sandy Hook Bay trawl survey are juveniles (< 35 cm) [see Reid *et al.* (1999) for details]. There are no occurrences during winter and only a few adults are collected during spring (Figure 19). During summer and fall, juveniles occur throughout the area in all depths sampled, at bottom temperatures between 12 and 24°C (Figure 20). The largest collections were made near navigation channels or in a basin near Graves End Bay.

SEAMAP Trawl Survey, South Atlantic Bight

The Southeast Area Monitoring and Assessment Program (SEAMAP) surveys sampled the coastal region between Cape Hatteras, North Carolina and Cape Canaveral, Florida [see Reid *et al.* (1999) for details]. After an initial several years when gear and methods were not standardized, methodology became synoptic and standardized between 1990 and 1996 (Beatty and Boylan 1997; Boylan *et al.* 1998). Bluefish collected during the latter survey period are shown in Figure 21. Length frequencies of these collections indicate most were young-of-the-year or age 1 (Figure 22). Information on distributions over the offshore portions of the SAB shelf are lacking for any size class. Monthly occurrences of these bluefish are shown in Figure 23. Occurrences decrease during spring, are at low levels during summer, and increase during October beginning in the northern

part of the bight, which suggests an influx of migrating young-of-the-year from the MAB.

ADULTS

Massachusetts Trawl Survey

Adult bluefish are collected in twice-yearly otter trawl sampling in nearshore waters of Massachusetts. During spring, a few large adults are sometimes found in the vicinity of Nantucket and Vineyard sounds, when juveniles are not found (Figure 12). Both juveniles and adults are more abundant during fall when most collections occurred in embayments south of Cape Cod (Figure 12). Adults in spring and fall occur over the warmest bottom water temperatures and most commonly in the shallowest stations (Figure 13).

Rhode Island Trawl Survey, Narragansett Bay

Adults were rarely collected during summer and autumn in a survey of Narragansett Bay (Figures 14, 15). Most were collected in depths of 6-21 m (summer) and 9-43 m (autumn) and at bottom water temperatures of 15-26°C (summer) and 17-21°C (autumn) (Figure 16).

Connecticut Trawl Survey, Long Island Sound

Bluefish adults begin to appear in Long Island Sound during May (Figure 17) when temperature preferences are 9-18°C (Figure 18). Abundance is highest during mid-summer on the Connecticut side of the sound in depths < 18 m and adults are more widespread than juveniles. Peak abundance is reached during September when bluefish (94% juveniles) are found throughout the sound. Abundance decreases rapidly after September and juveniles appear to depart before adults.

NEFSC Hudson-Raritan Trawl Survey

Most bluefish collected in Hudson-Raritan estuary and Sandy Hook Bay are juveniles (< 35 cm). There are no occurrences during winter and only a few adults are collected during spring (Figure 19). Their collections relative to bottom temperature, depth, dissolved oxygen, and salinity are shown in Figure 20.

JUVENILES AND ADULTS

NEFSC Trawl Surveys

Bluefish are migratory and their distribution varies seasonally and according to age and size of individuals composing schools. Length frequencies of trawl-collected bluefish were examined to determine age and size composition of catches in the NEFSC bottom trawl survey (Figure 24). Modes were separable into spawning cohorts and year classes based on published studies and are the bases for the distribution maps (Figures 25-32).

The distribution of all lengths during all seasons (Figure 25) indicates that bluefish occur most densely along the coast of the MAB and through the central part of Georges Bank, although these results may reflect the increased efficiency of the trawl in shallower waters. Winter occurrences are limited to the outer continental shelf near Cape Hatteras and these few occurrences are larger fish (Figures 26, 27). Spring collections include *spring-spawned* young-of-the-year off North Carolina, *spring-spawned* age 1 restricted to coastal areas south of Cape Hatteras, age 2 individuals along the continental shelf edge off North Carolina, and older year classes distributed between Cape Hatteras and the offing of the Delmarva Peninsula (Figure 28). The distributions of < 30 cm and > 30 cm bluefish relative to depths and temperatures sampled during these spring surveys are shown in Figure 29.

Summer surveys collected several age classes, including *summer-spawned* young-of-the-year in the New York Bight; *spring-spawned* young-of-the-year widely distributed along the coast between New York and Cape Hatteras; age 1 fish, especially off North Carolina, but also in the Chesapeake Bay region; and older year classes, mostly over Georges Bank (Figure 30).

Fall surveys are most important for measuring relative year-class strength. Young-of-the-year of both *spring-* and *summer-spawned cohorts* and age 1 individuals are abundant along the coast between Long Island and Cape Hatteras. Older year-classes are more abundant in southern New England and Georges Bank waters (Figure 31). When all lengths are considered, there is a trend for bluefish to occur on the warmest stations sampled (Figure 32). However, this trend is most pronounced for young-of-the-year when they are separated from older year classes. The relative occurrences of all year classes by bottom depths closely mirror the distribution of depths sampled (Figure 32).

All age classes, in combined spring and fall surveys, were collected mostly over depths < 20 m. They were collected at warmer temperatures during spring surveys, but showed little preference for temperatures during fall surveys.

STATUS OF THE STOCK

Population fluctuations have been common in the western Atlantic bluefish population since colonial times. Wide swings in abundance occurred between the 1600s and the 1950s (Bigelow and Schroeder 1953). In recent years, the total catch of bluefish (commercial landings plus recreational catches) peaked in the late 1970s and early 1980s and has declined since (Figure 33). Commercial landings decreased about 22% between 1994 and 1995. During 1982-1996, age 1 fishing mortality increased approximately fourfold, recruitment has declined from an estimated 75 million fish at age 0 to about 14 million fish, and estimates of the spawning stock biomass have decreased from about 300,000 mt to 100+ mt (Stock Assessment Review Committee, Coastal Pelagic Subcommittee 1996).

There is little difference in the distribution of adults between a period of relatively high population abundance (1980-1982) and a period of low abundance (1994-1996) (Figure 34). However, the same comparison of the distribution of young-of-the-year indicates a decline in abundance in the southern part of the MAB. Whether this is due to year-class failure in estuaries of that region, or reflects a lack of pelagic-juvenile recruitment to those estuaries, is unknown.

RESEARCH NEEDS

LIFE HISTORY AND BIOLOGY

We lack information on the reproductive biology of bluefish. Observed patterns of spawning may be based on the population level rather than on information on individual reproductive traits. We presently do not know whether individuals spawn serially, and if so, how many times they are capable of spawning in a year. We also do not know if these reproductive characteristics vary with age. It is apparent that more study of the distribution of older stages needs to be correlated with spawning events. Since bluefish school in like-sized (and supposedly like-aged) groups, we need to know what groups are where and when, and how those aggregations are associated with the observed densities of eggs. Simply describing how many spawning events are occurring can not solve the issue of the number of manageable stocks.

Our understanding of the "pelagic-juvenile" stage is limited despite its obvious importance. We need to better understand the details of transport mechanisms that provide progeny of reproduction in the SAB to nurseries in the MAB. Increased sampling of the neuston or near-surface layers of the ocean between production areas and estuarine nursery areas, associated with appropriate oceanographic observations, would provide much-needed insight into factors affecting transport and estuarine recruitment.

There has been a tight correlation between population size and the contribution of the *spring-spawned cohort* to fall trawl collections in the last three decades. Yet our knowledge of reproduction in the SAB is limited to a brief, under-sampled period in the 1970s when the population was at a relatively low level of abundance. Furthermore, larvae produced in June in the southern part of the MAB appear not to survive [unless recruits to Maine estuaries result from this output, see Creaser and Perkins (1994)], the fate of the remaining MAB summer offspring remains enigmatic, and the relative contribution of this *summer-spawned cohort* to year-class success would seem to be negligible.

There is some evidence for spawning during the fall in the Cape Canaveral region of Florida that appears to be discrete, rather than a continuation of spawning in the MAB. This evidence has been demonstrated in this document with larval occurrences and a disjunct autumn distribution of fishes between 26 and 40 cm. Hare and Cowen (1993) present gonadosomatic data that suggest the same thing. Admittedly, some of this evidence is weak and based on incomplete sampling, and should be improved to determine the origin of these spawning fish, the magnitude of spawning, and the fate of any progeny.

HABITAT REQUIREMENTS

It is obvious from a review of the literature that we lack data to address the habitat issue at Tier 3 (habitat-specific growth, reproduction, and survival rates). Assessing how characteristics of habitat might affect the quality of young-of-the-year is therefore not feasible. Results of biological sampling, in estuaries or continental shelf waters, only rarely report specific characteristics of sampling sites. Therefore, data accruing from these studies are likely to be limited to “presence/absence” value only. According to Miller (1984): “We need a reasonable schema of estuaries, emphasizing the factors that have the most significance to the fish. Unfortunately, the necessary physical data are often lacking for an accurate characterization. Many are also temporally unstable. Not even our attempts to classify estuaries recognize their dynamic nature…we need more complete descriptions of how biologically relevant abiotic factors within estuaries affect biologically relevant scales of time and space. Without this, we cannot hope to untangle the biological processes or to compare results from different estuaries. Biologists need to involve more physical oceanographers and meteorologists in our research.” Clearly, in the future, more attention to details of collecting sites needs to be paid, and habitat research supported, such that the linkages between habitat quality and year class success can be made.

There are lingering conclusions that the *summer-spawned cohort* in the MAB uses nearshore coastal zones as nurseries, more so than estuaries. To some extent, this

view may be based on the relative paucity of this cohort compared to the *spring-spawned cohort* in estuaries. Increased sampling of the near-coastal environment with appropriate gear should be encouraged to assess the relative value of this region.

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Table 1. Dietary items of bluefish from several study areas.

Source	**Life History Stage and Study Location**	**Diet Items (in order of importance)**
Texas Instruments Incorporated 1976	Young-of-the-year, Hudson River (tidal)	*Anchoa mitchilli* (dominated diet through summer), Clupeidae, *Microgadus tomcod*, *Alosa sapidissima*, *Notropis hudsonius*, Cyprinodontidae
Festa 1979	11-20 cm, Little Egg Harbor estuary, NJ	*Fundulus* spp., Atherinidae, *Anchoa* spp., *Callinectes sapidus*, *Brevoortia tyrannus*, *Crangon septemspinosa*
Friedland *et al.* 1988	Juvenile, Sandy Hook, NJ	1981: Teleosts, Crustacea, Polychaeta 1982: Crustacea, Teleostei, Polychaeta 1983: Crustacea, Teleostei, Polychaeta (weight at length significantly greater in 1981)
Hartman and Brandt 1995a, b	Age 0, Age 1, and Age 2, Chesapeake Bay (Diets of all age classes changed through season)	Age 0: *Anchoa mitchilli*, *Menidia menidia*, *Brevoortia tyrannus* Age 1: *Leiostomus xanthurus*, *A. mitchilli*, *M. menidia*, *B. tyrannus* Age 2: *Micropogonias undulatus*, *A. mitchilli*, *B. tyrannus* (*B. tyrannus* becomes important in diets of all age classes in Sep-Oct.)
Buckel and Conover 1997	Young-of-the-year, Hudson River estuary	Unidentified fish, *Anchoa mitchilli*, *Alosa* spp., *Morone saxatilis*, *Morone americana*
NEFSC, Trawl Survey Diet Data	All ages (mean size 35.6 mm FL), continental shelf, Georges Bank and Middle Atlantic Bight	1973-1980: Unidentified fishes, *Illex* spp., *Etrumeus teres*, *Loligo* spp., *Peprilus triacanthus*, Cephalopoda 1981-1990: Unidentified fishes, *Ammodytes dubius*, *Peprilus triacanthus*, *Loligo* spp., *Clupea harengus*

Table 2. Summary of life history and habitat characteristics for bluefish, *Pomatomus saltatrix*. See Appendix 1 for a more complete listing of habitat variables.

Life History Stage	Habitat (Spatial and Temporal)	Temperature	Salinity	Light/Vertical Distribution	Currents/ Circulation	Prey	Estuarine Use
Eggs [1]	*spring cohort*: unknown. *summer cohort*: occurs across continental shelf, southern New England to Cape Hatteras. Most in mid-shelf waters.	*spring cohort*: unknown. *summer cohort*: most in 18-22°C.	*spring cohort*: unknown. *summer cohort*: 31.0 ppt or more (minimum 26.0 ppt).	*spring cohort*: unknown. *summer cohort*: peak spawning in the evening (1900-2100 hrs).	*spring cohort*: unknown. *summer cohort*: in southern MAB, surface currents transport eggs south and offshore.	--	None
Larvae [2]	*spring cohort*: near edge of continental shelf, Cape Hatteras-Cape Canaveral, FL. Peak April-May. *summer cohort*: most 30-70 m depths, May-Sept, peak in July.	*spring cohort*: smallest larvae in > 24°C. *summer cohort*: near Cape Hatteras 22.1-22.4°C; in MAB 18-26°C.	*spring cohort*: smallest larvae in > 35 ppt. *summer cohort*: in MAB in 30-32 ppt.	*spring cohort*: > 4 mm strongly associate with surface. *summer cohort*: near surface at night, mostly at about 4 m during day.	*spring cohort*: subject to northward advection by Gulf Stream. Some retained in SAB by southerly counter-current. *summer cohort*: southwest winds in MAB may facilitate cross-shelf transport.	*summer cohort*: mostly copepod life history stages. Guts full during day.	None
Pelagic Juveniles [3]	*spring cohort*: smallest near 180 m contour; larger near shore. April-May. *summer cohort*: cross MAB shelf from Slope Sea to shore, early- to mid-June.	*spring cohort*: 19.0-24.0°C (or higher well offshore). *summer cohort*: in MAB 15.0-20.0°C (most > 18.0°C). As low as 13.0°C when cross shelf.	*spring cohort*: Near 180 m contour, > 35.0 ppt. *summer cohort*: During June, range 36.0-31.0 ppt.	*both cohorts*: strongly associated with the surface.	*spring cohort*: shoreward movement with growth unless advected north. *summer cohort*: move shoreward with growth. Currents important, but active swimming indicated.	--	*both cohorts*: enter estuarine nurseries during this stage
Juveniles [4] ***(summer cohort only)***	Several estuarine study areas between Narragansett Bay, RI and Delaware Bay and Delaware River.	In most studies, arrive > 20°C, remain in temperatures up to 30°C, emigrate when declines to 15°C. Can not survive below 10°C or above 34°C. Fall migration in 18-22°C on inner continental shelf.	Usually 23.0-33.0 ppt but can intrude to as low as 3.0 ppt.	Day: usually near shorelines or in tidal creeks. Night: usually in open bay or channel waters.	Can occur in surf zone or clear to turbid back-estuarine zones.	Atlantic silversides, clupeids, striped bass, bay anchovy, others.	Mostly sand, but some mud, silt, clay. Also uses *Ulva*, *Zostera* beds, and *Spartina* or *Fucus*.
Adults [5]	Generally oceanic, nearshore to well offshore over continental shelf.	Warm water, usually > 14-16°C. Can tolerate 11.8-30.4°C but are stressed at either extreme.	Oceanic salinities.	--	--	Sight feeders, prey on other fishes almost exclusively.	Not uncommon in bays, larger estuaries, as well as coastal waters.

[1] Norcross *et al.* 1974; Berrien and Sibunka 1999; Data from present report
[2] Norcross *et al.* 1974; Kendall and Walford 1979; Kendall and Naplin 1981; Powles 1981; Collins and Stender 1987; Hare and Cowen 1996; Data from present report
[3] Fahay 1975; Kendall and Walford 1979; Powles 1981; Collins and Stender 1987; Hare and Cowen 1996
[4] Lund and Maltezos 1970; Olla *et al*. 1975; Milstein *et al.* 1977; Nyman and Conover 1988; Rountree and Able 1992a, b; McBride *et al*. 1995; Able *et al.* 1996; Buckel and Conover 1997
[5] Bigelow and Schroeder 1953; Olla and Studholme 1971

Table 3. Sampling in 1979 ("Southern MARMAP") for bluefish larvae in the Charleston Bump area (32°37’N - 32°80’N x 78°42’W - 79°00’W). Isaacs Kidd MWT only.

Date	Sampling Depth	Sampling Duration	Volume Sampled	Bluefish No./10m^2
February 9	15	5	308	
“	37	27	641	
“	84	33	816	
February 28	31	26	693	0.89
“	54	25	1085	
“	110	35	1052	
March 13	30	22	580	
“	74	29	995	
March 17	114	38	1258	0.91
March 18	28	20	700	
March 27	18	20	742	1.16
“	58	27	1002	0.78
“	98	34	1261	
March 28	30	26	965	
April 6	32	25	875	0.71
“	62	25	875	41.48
“	132	40	1400	0.38
April 18	27	20	700	
“	38	21	735	2.22
“	128	33	1155	
April 19	42	22	770	1.45
April 30	28	22	770	36.99
May 1	76	27	945	21.16
“	134	38	1330	
“	50	25	875	3.97
May 16	34	22	770	2.65
“	58	25	875	9.55
“	130	35	1225	0.36
June 5	28	22	770	
“	58	31	1085	
June 30	37	26	910	
July 1	58	29	1015	
“	124	47	1645	
August 12	42	24	890	
August 13	127	31	1150	
“	50	22	816	
“	22	20	742	

Table 4. Distribution of early life history stages of bluefish, *Pomatomus saltatrix*, in estuaries from Maine to Florida. Occurrences are not quantitative and may be based on one or very few specimens. Estimates of relative abundance after Nelson and Monaco (1994), Jury *et al*. (1994), Stone *et al*. (1994). Some Middle Atlantic Bight estuaries after Able and Fahay (1998).

Estuary	**Eggs**	**Larvae**	**Juveniles**
Passamaquoddy Bay, ME	None	None	Rare
Englishman/Machias Bay, ME	None	None	Rare
Narraguagus Bay, ME	None	None	Rare
Blue Hill Bay, ME	None	None	Rare
Penobscot Bay, ME	None	None	Common
Muscongus Bay, ME	None	None	Common
Damariscotta River, ME	None	None	Common
Sheepscot River, ME	None	None	Common
Kennebec/Androscoggin Rivers, ME	None	None	Common
Casco Bay, ME	None	None	Common
Saco Bay, ME	None	None	Common
Wells Harbor, ME	None	None	Common
Great Bay, ME/NH	None	None	Common
Merrimack River, NH	None	None	Rare
Massachusetts Bay, MA	None	None	Common
Boston Harbor, MA	None	None	Common
Cape Cod Bay, MA	None	None	Common
Nauset Marsh, MA	None	None	None
Buzzards Bay, MA	None	Rare	Abundant
Narragansett Bay, RI	None	Rare/common	Abundant
Connecticut River, CT	None	None	Abundant
Long Island Sound, NY	None	None	Abundant
Gardiners Bay, NY	Rare	Rare	Abundant
Great South Bay, NY	None	None	Abundant
Hudson River, Raritan/Sandy Hook Bays, NY/NJ	Rare	Rare	Abundant
Barnegat Bay, NJ	None	Rare	Abundant
Great Bay, NJ	None	Rare	Common
Southern Inland bays, NJ	None	Rare	Abundant
Delaware Bay, NJ/DE	None	rare	Abundant
Delaware Inland bays, DE	None	None	Common
Eastern Shore, MD/VA	None	Rare	Common
Chesapeake Bay mainstem, MD/VA	None	None	Abundant
Chester River, MD	None	None	Common
Choptank River, MD	None	None	Common

Table 4. cont'd.

Estuary	Eggs	Larvae	Juveniles
Patuxent River, MD	None	None	Common
Potomac River, MD/VA	None	None	Abundant
Tangier/Pocomoke Sound, VA	None	None	Abundant
Rappahannock River, VA	None	None	Abundant
York River, VA	None	None	Abundant
James River, VA	None	None	Abundant
Albemarle Sound, NC	None	None	Common
Pamlico Sound, NC	None	None	Abundant
Pungo River, NC	None	None	Common
Neuse River, NC	None	None	Common
Bogue Sound, NC	None	None	Common
New River, NC	None	None	Common
Cape Fear River, NC	None	None	Abundant
Winyah Bay, SC	None	None	Common
Santee Rivers (N&S), SC	None	None	Common
Charleston Harbor, SC	None	None	Common
St. Helena Sound, SC	None	None	Common
Broad River, SC	None	None	Common
Savannah River, SC/GA	None	None	Common
Ossabow Sound, GA	None	None	Common
Sapelo Sound/ St. Catherine, GA	None	None	Common
Altamaha River, GA	None	None	Common
St. Andrew/St. Simon Sound, GA	None	None	Common
St. Johns River, FL	None	None	Common
Indian River, FL	None	None	Rare
Biscayne Bay, FL	None	None	Rare

Table 5. Unpublished records of juvenile bluefish in waters of coastal Maine. Collection locations are ordered from north to south (after Creaser and Perkins 1994).

Location	**Date of Collection**	**O/E[1]**	**Number Collected**	**Size (mm TL)**	**Method[2]**
Marston Pt.	August 25, 1983	O	3	100-130	HW
Seal Island	July 1991	O	1	50	AT
Matinicus Rock	July 24-30, 1991	O	4	50-60	RT
"	July 9-17, 1991	O	14	40-50	AT
"	Mid-July 1990	O	2	30-40	AT
"	July 5, 1989	O	2	85-90	AP
"	July 18, 1986	O	1	77	AP
Foot Bridge (Boothbay Harbor)	Summer 1970-1974	O	---	Juveniles (2 modes)	HS
DMR Dock	July 4, 1984	O	3	40-50	HL
"	August 25, 1978	O	1	86	DN
"	September 14, 1971	O	5	95-105	---
Townsend Gut	September 5, 1985	O	1	Juvenile	HL
Lobster Cove	August 11, 1991	O	4	162-192	HL
"	August 30, 1990	O	1	145	HL
Sheepscot River	August 2, 1989	E	1	140	HL
Sheepscot Falls	August 1967	E	---	150-200	HL
Marsh River	July 17-Sept 17, 1991	E	60	101-217	GN
"	August 1-Sept 26, 1990	E	149	89-218	GN
"	August 8-28, 1989	E	102	92-194	GN
"	August 26, 1987	E	6	129-163	GN
"	August 14, 1986	E	28	93-121	GN
The Eddy	July 9, 1991	E	3	80-85	HS
Cross River	August 8, 1991	E	1	115	HS
Berry Island	September 8, 1974	E	4	125-140	HS
"	August 29, 1973	E	2	132-141	HS
"	August 30, 1972	E	1	112	HS
Kennebec Pt.	August 10-22, 1990	O	29	39-70	HS

Table 5. cont'd.

Location	Date of Collection	O/E[1]	Number Collected	Size (mm TL)	Method[2]
Mouth of Abagadasset River	July 18, 1991	E	2	84-94	HS
"	July 3, 1991	E	6	112-115	HS
"	August 3, 1989	E	8	52-76	HS
"	September 11, 1987	E	2	142-150	HS
"	July 17, 1986	E	5	70-77	HS
Mouth of Androscoggin River	August 5, 1983	E	2	82-86	HS
Bath Bridge	Summer 1982	E	90	< 100	OT
Winnegance Bay	Summer 1988-1990	E	---	50-150	HL
Atkins Bay	Summer 1981	E	---	80-90	HS
Howard Point	August 1988	E	3	70-130	FK
Jenny Island	July 16, 1991	E	1	40	CT
Merepoint Bay	September 26, 1991	E	97	150-174	GN
Royal River	Summer 1988	E	---	Juvenile	---
SMVTI Dock	September 1986	O	---	130-150	HL
Union Wharf	September 1984	O	6	150-200	HL
Dunston, Libby, Nonesuch Rivers (confluence)	Summer 1987	E	---	Juvenile	HL
1 mi. off amusement pier, Old Orchard Beach	Summer 1961-1964	O	---	Juvenile	HL
Wells Harbor	August 1991	E	1	68	FN

[1] O = oceanic; E = estuarine
[2] Collection methods: OT = otter trawl; FN = fyke net; HL = hook and line; HS = haul seine; AP = Atlantic puffin; GN = gill net; AT = Arctic tern; DN = dip net; CT = common tern; HW = herring weir; RT = roseate tern

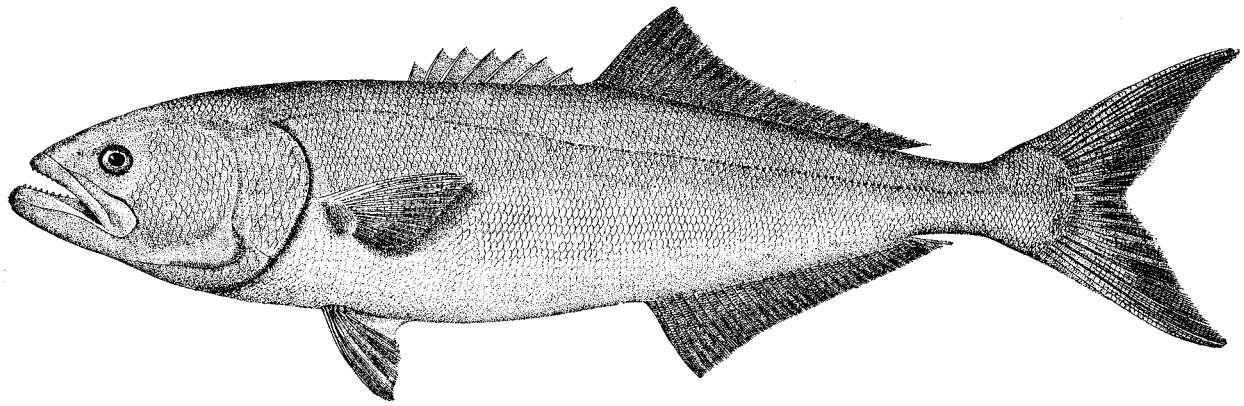


Figure 1. The adult bluefish, *Pomatomus saltatrix* (from Goode 1884).

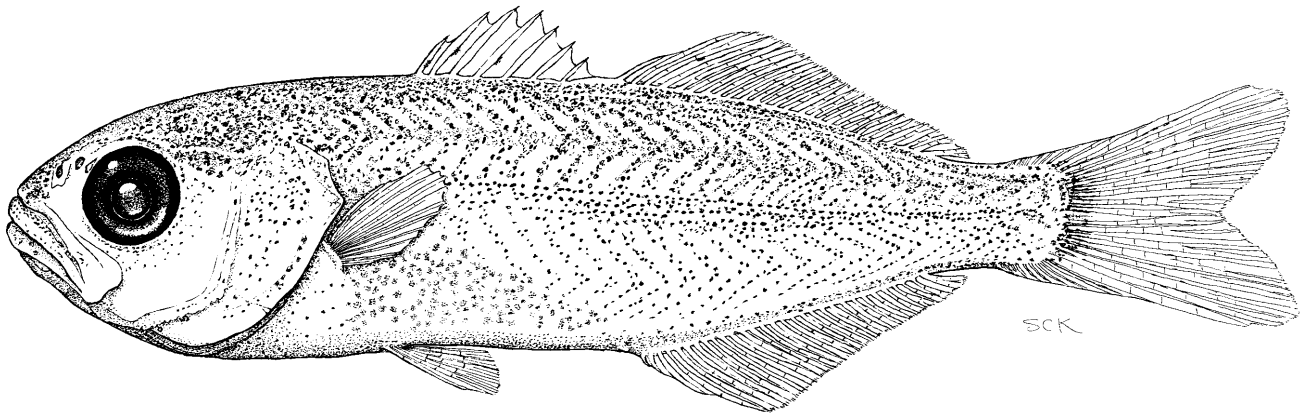


Figure 2. The pelagic juvenile bluefish, 24.3 mm SL (from Able and Fahay 1998).

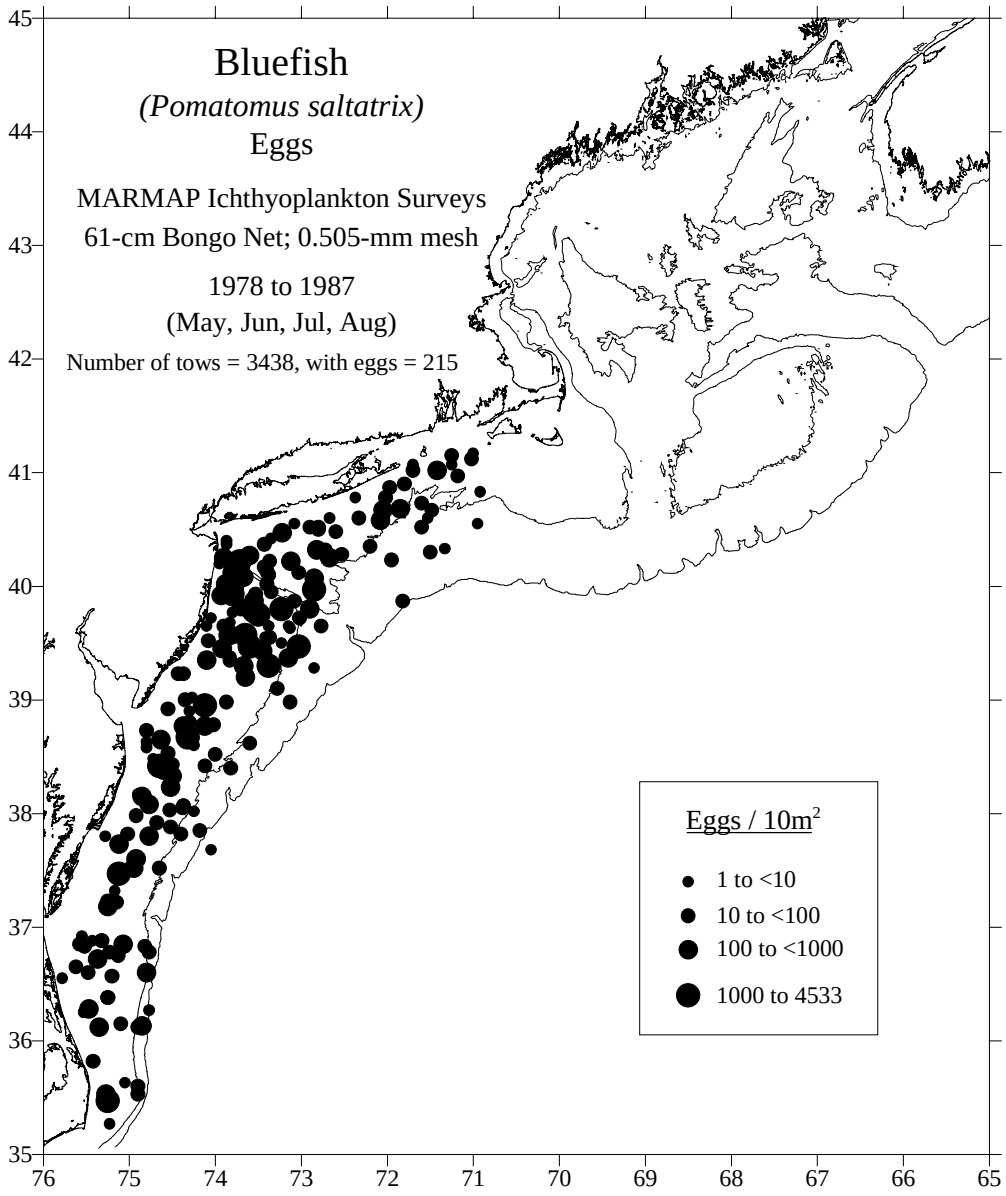


Figure 3. Distribution and abundance of bluefish eggs collected during NEFSC MARMAP ichthyoplankton surveys in the Mid-Atlantic Bight from 1978-1987 [survey also covered the Gulf of Maine and Georges Bank; see Reid *et al.* (1999) for details].

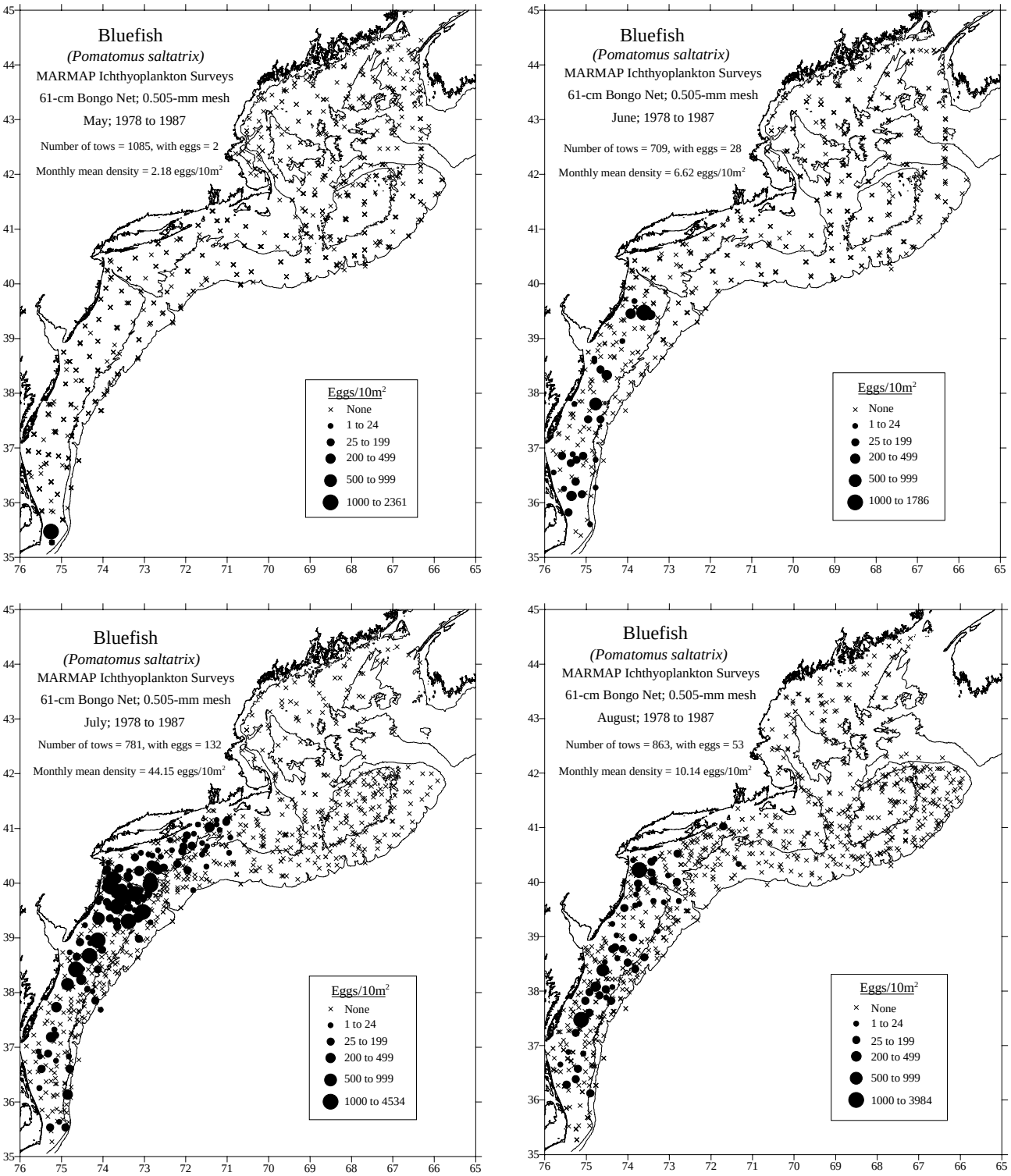


Figure 3. cont'd.

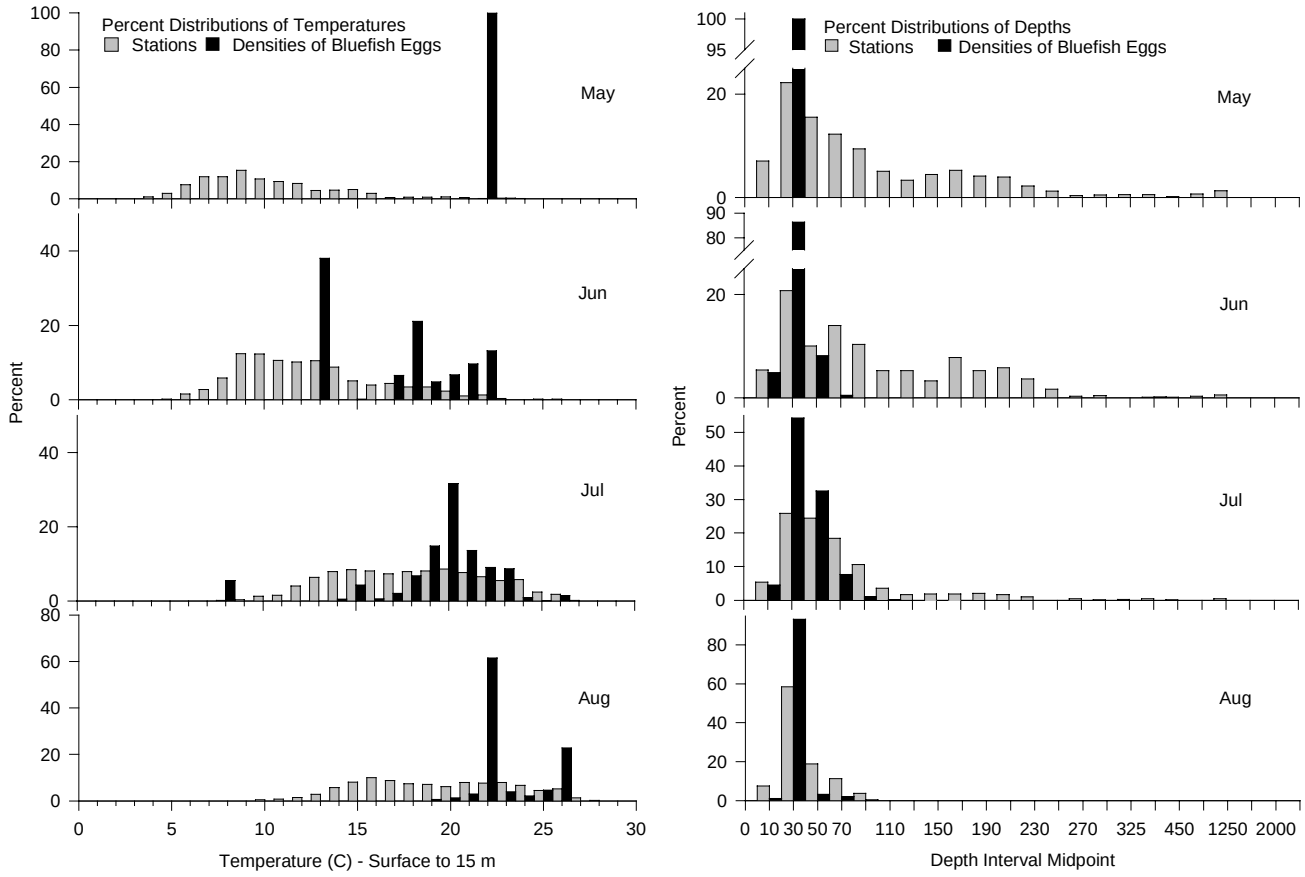


Figure 4. Abundance of bluefish eggs relative to near-surface water column temperature and depth based on NEFSC MARMAP ichthyoplankton surveys in the Mid-Atlantic Bight (May- August 1978-1987, all years combined).

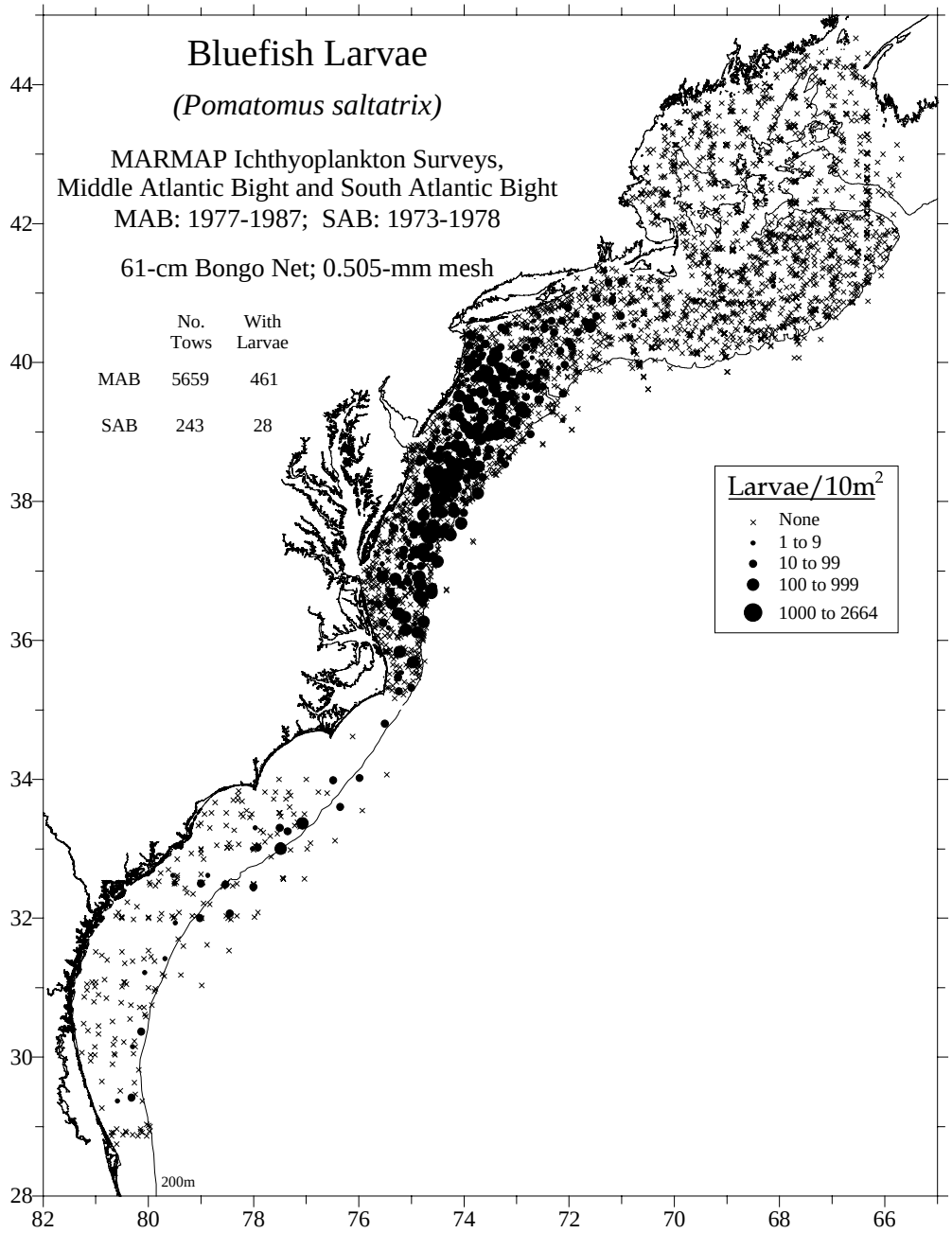


Figure 5. Distribution and abundance of bluefish larvae collected during NEFSC MARMAP ichthyoplankton surveys of both the Mid-Atlantic Bight (1977-1987) and South Atlantic Bight (1973-1978) [survey also covered the Gulf of Maine and Georges Bank; see Reid *et al.* (1999) for details].

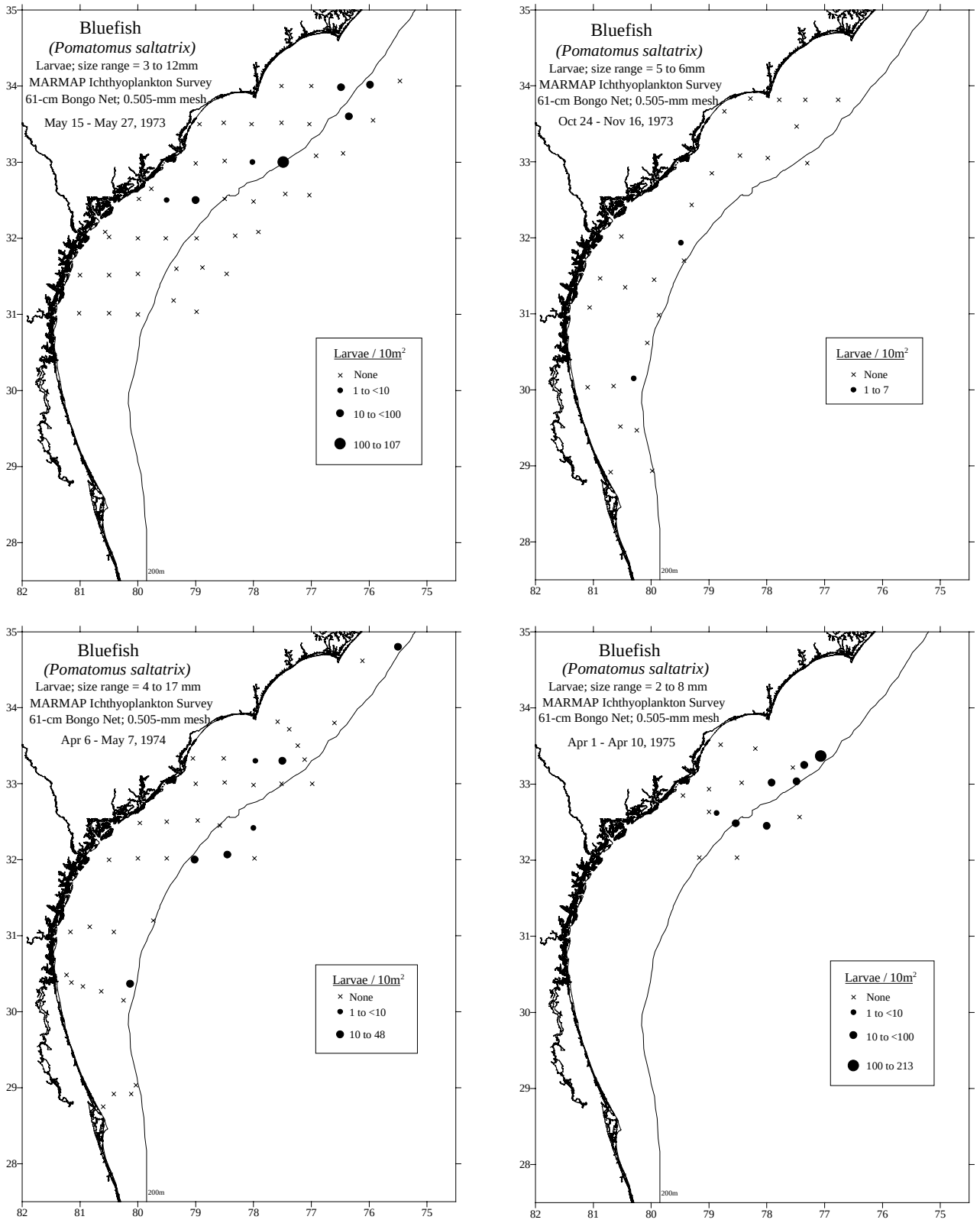
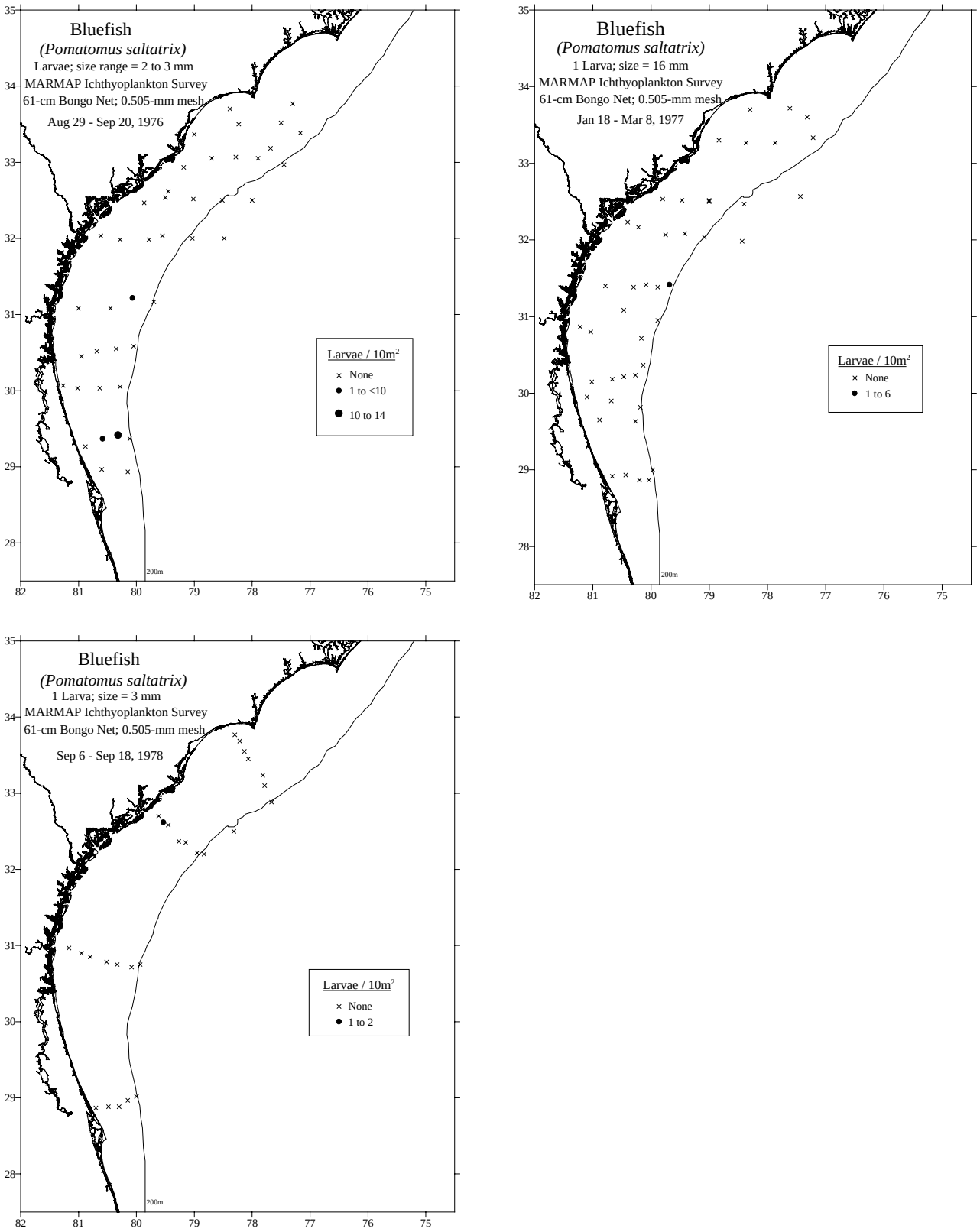


Figure 6. Distribution and abundance of bluefish larvae collected with a bongo net in the South Atlantic Bight during NEFSC MARMAP ichthyoplankton surveys [see Reid *et al.* (1999) for details].



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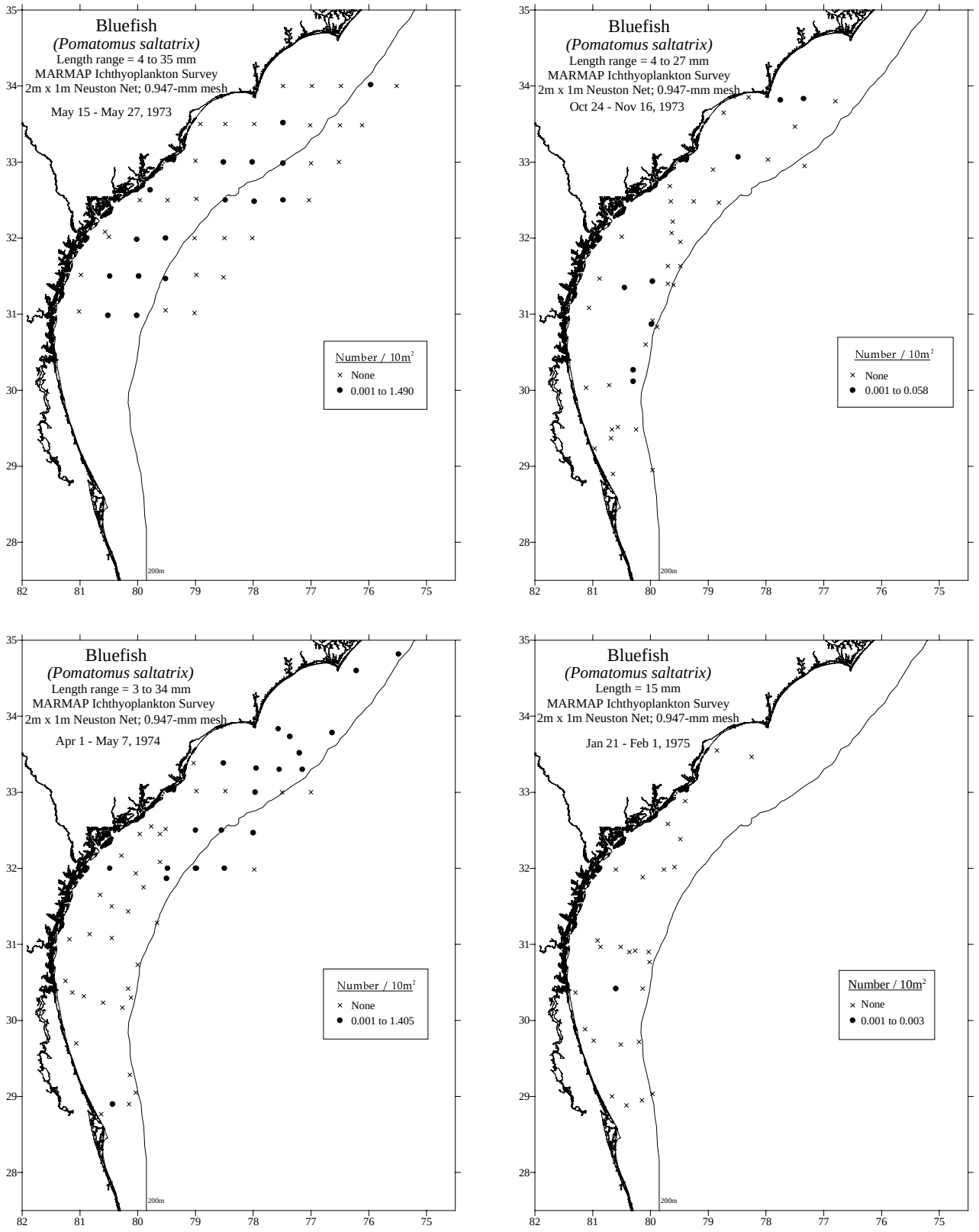


Figure 7. Distribution and abundance of bluefish larvae collected in a neuston net in the South Atlantic Bight during NEFSC MARMAP ichthyoplankton surveys [see Reid *et al.* (1999) for details].

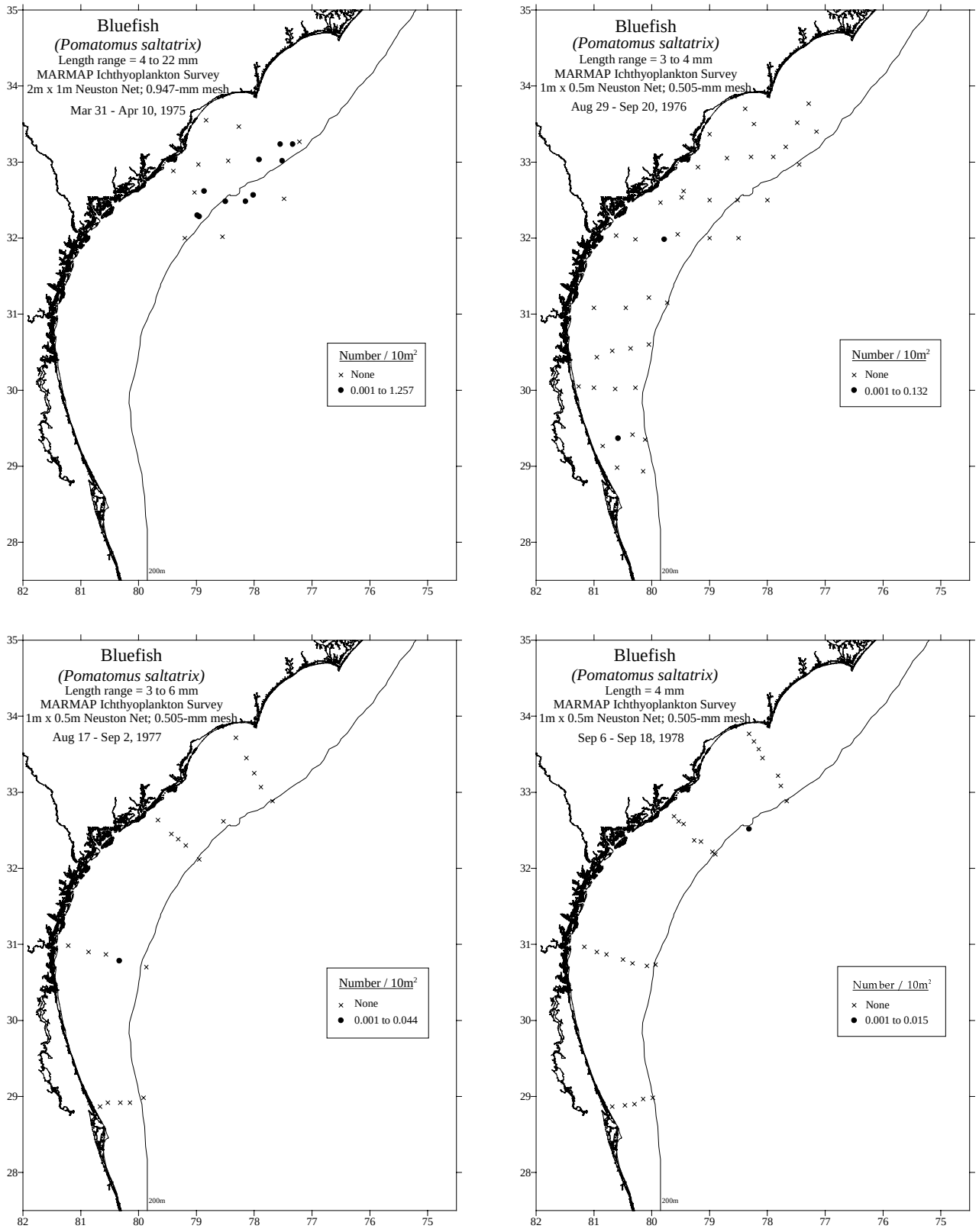


Figure 7. cont'd.

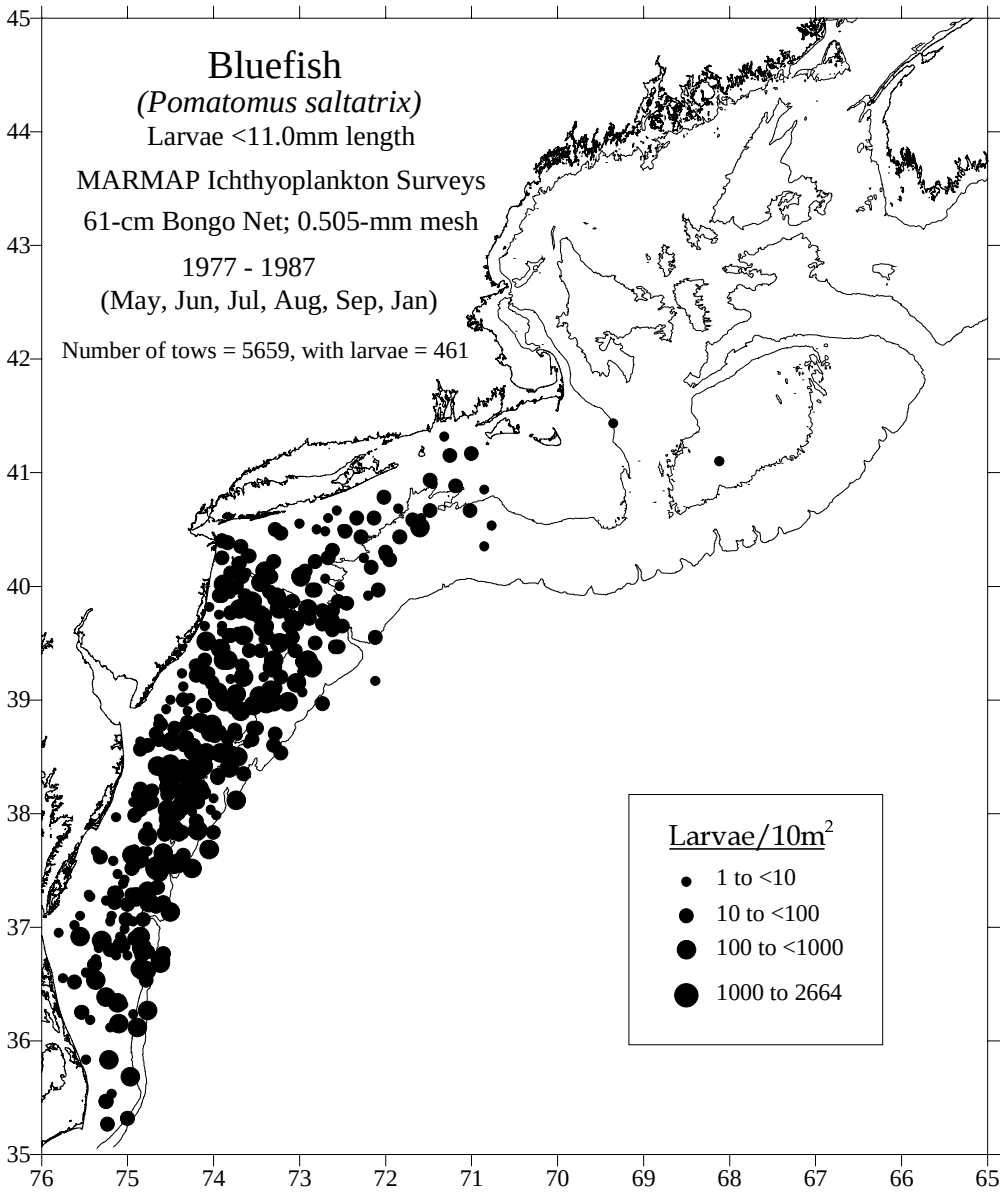
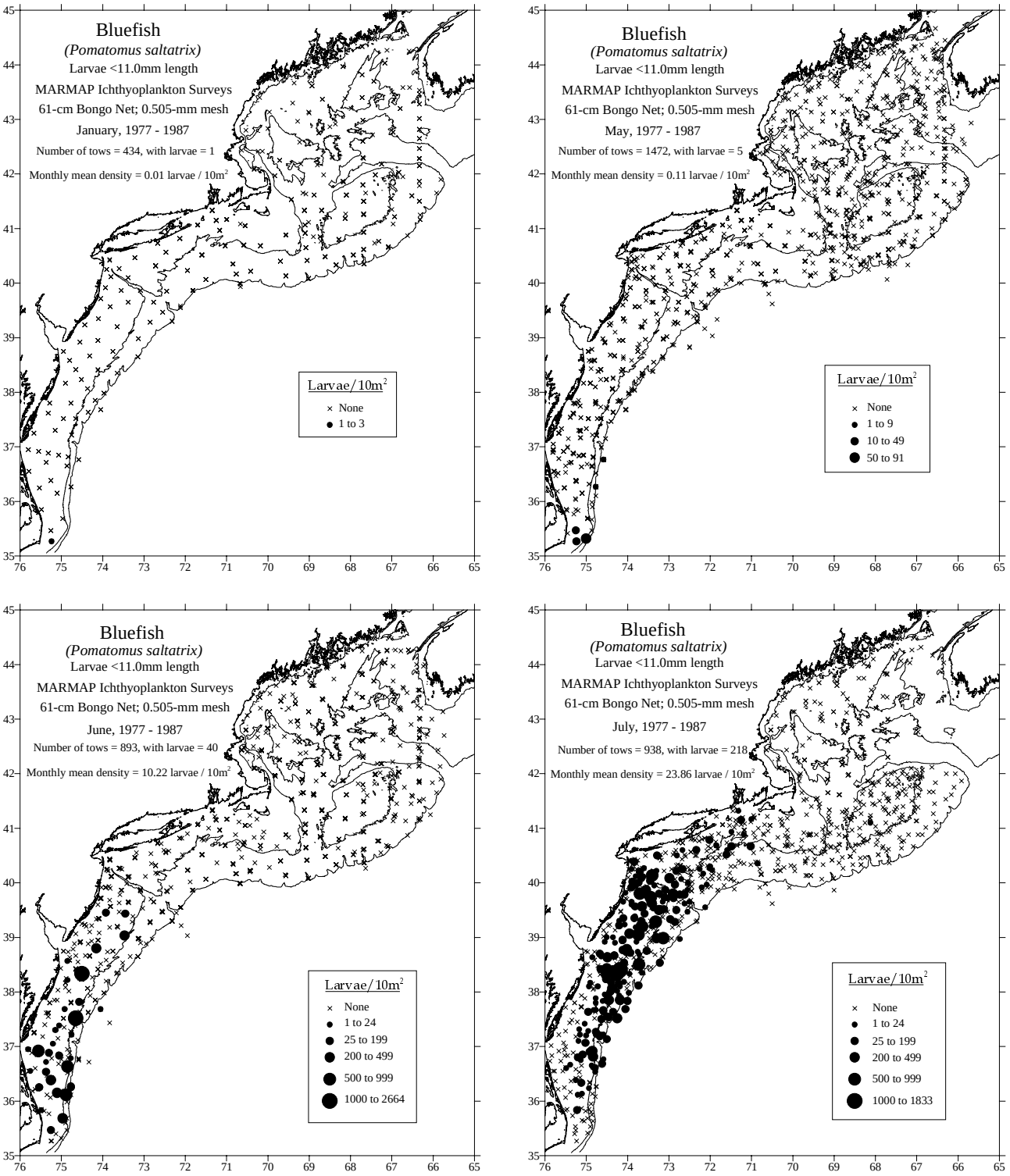


Figure 8. Distribution and abundance of bluefish larvae collected during NEFSC MARMAP ichthyoplankton surveys in the Mid-Atlantic Bight from 1977-1987 [survey also covered the Gulf of Maine and Georges Bank; see Reid *et al.* (1999) for details].



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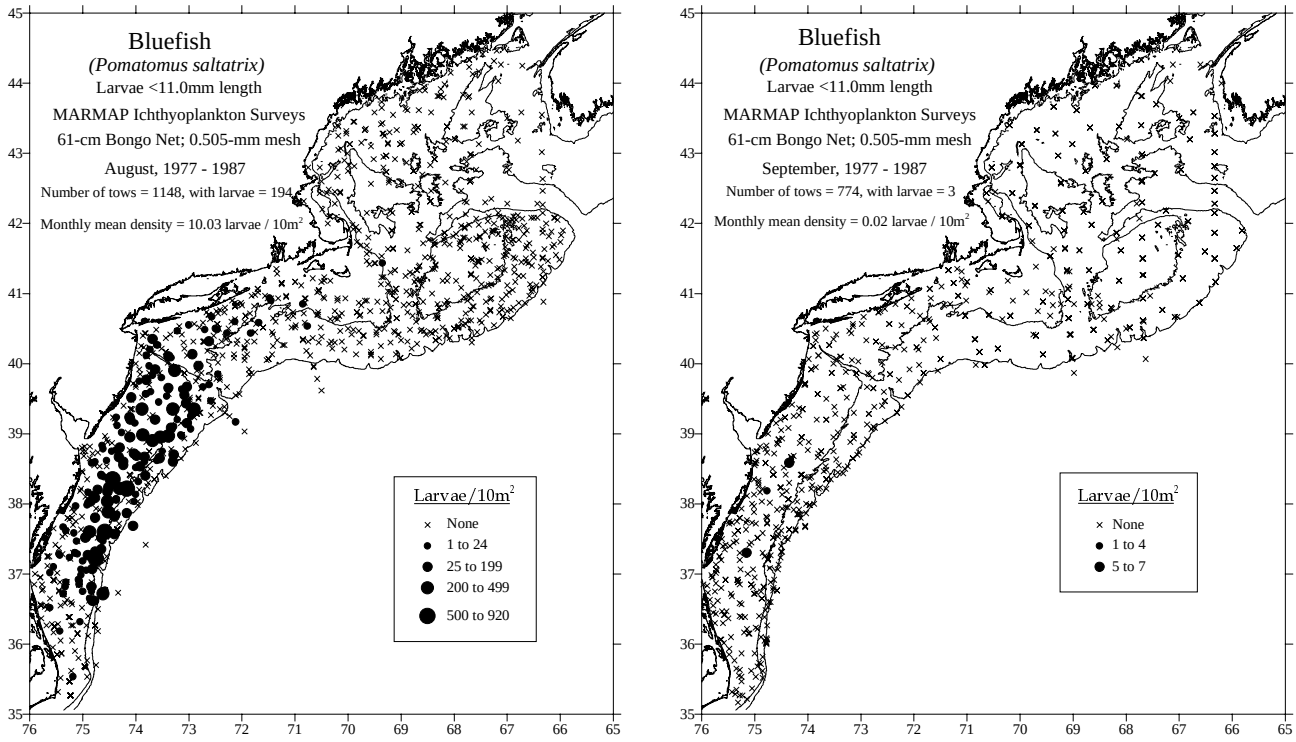

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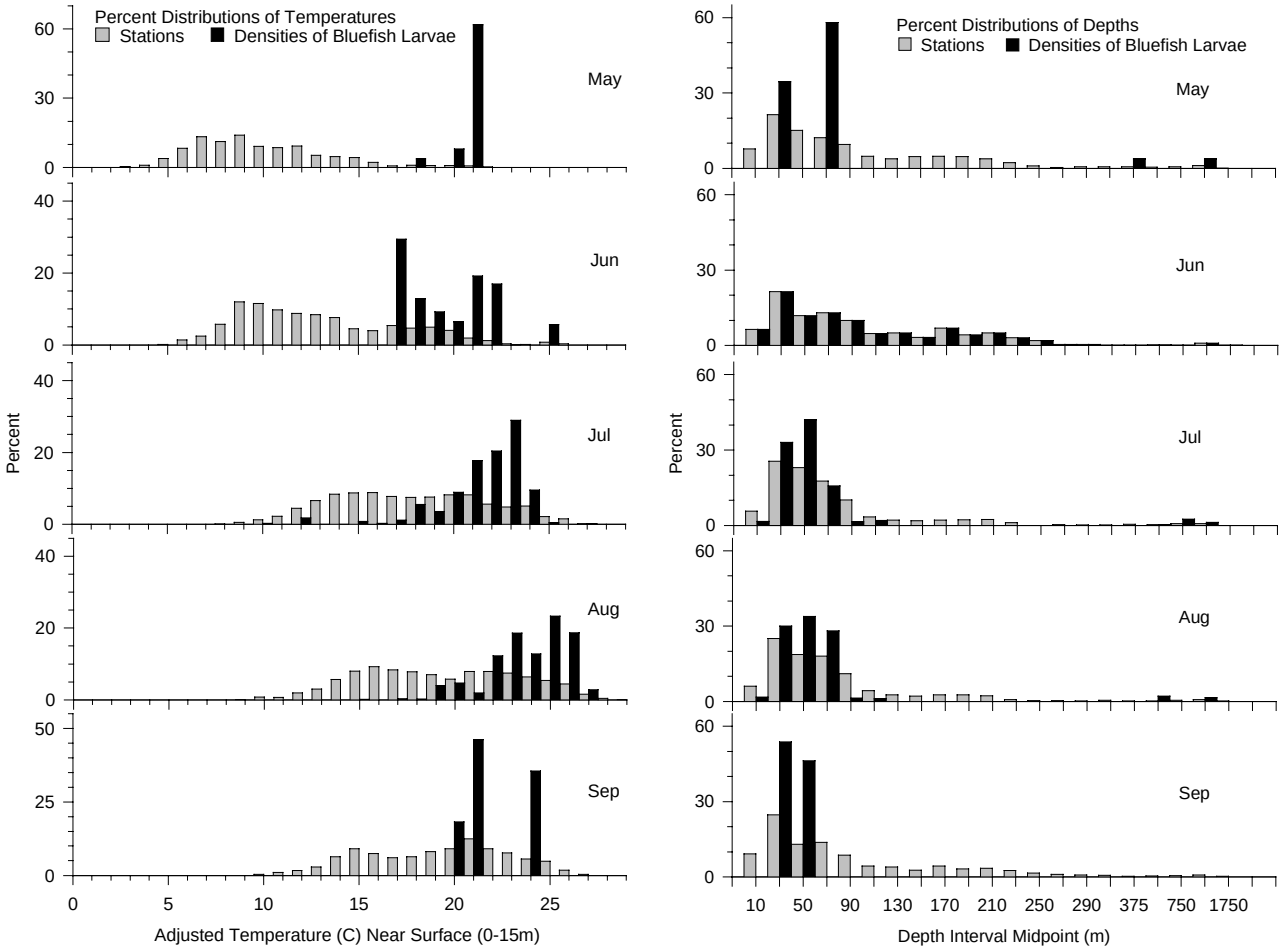


Figure 9. Abundance of bluefish larvae relative to near-surface water column temperature and depth based on NEFSC MARMAP ichthyoplankton surveys in the Mid-Atlantic Bight (May-September 1977-1987, all years combined).

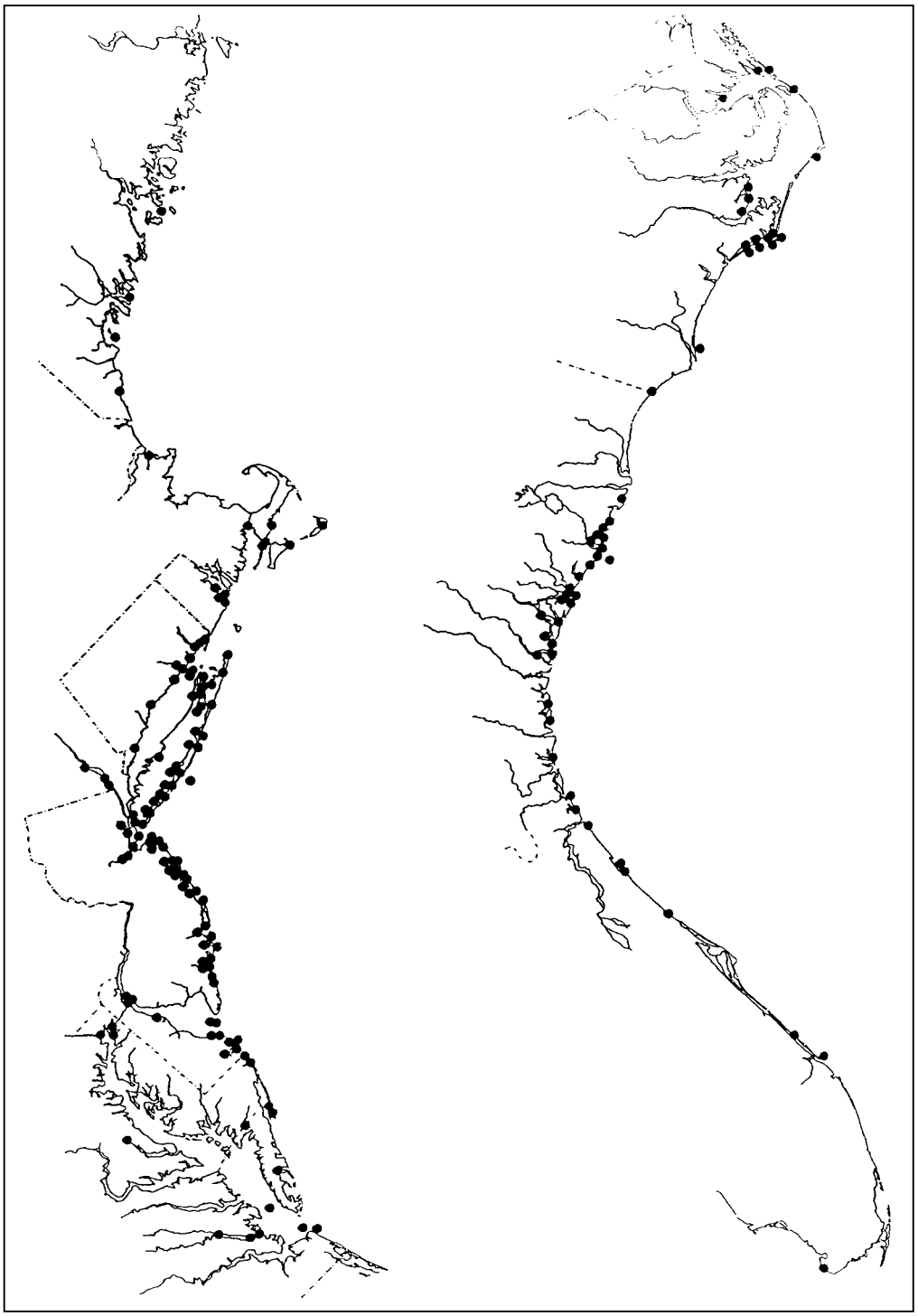


Figure 10. Reported occurrences of juvenile bluefish along the east coast of the United States (Clark 1973).

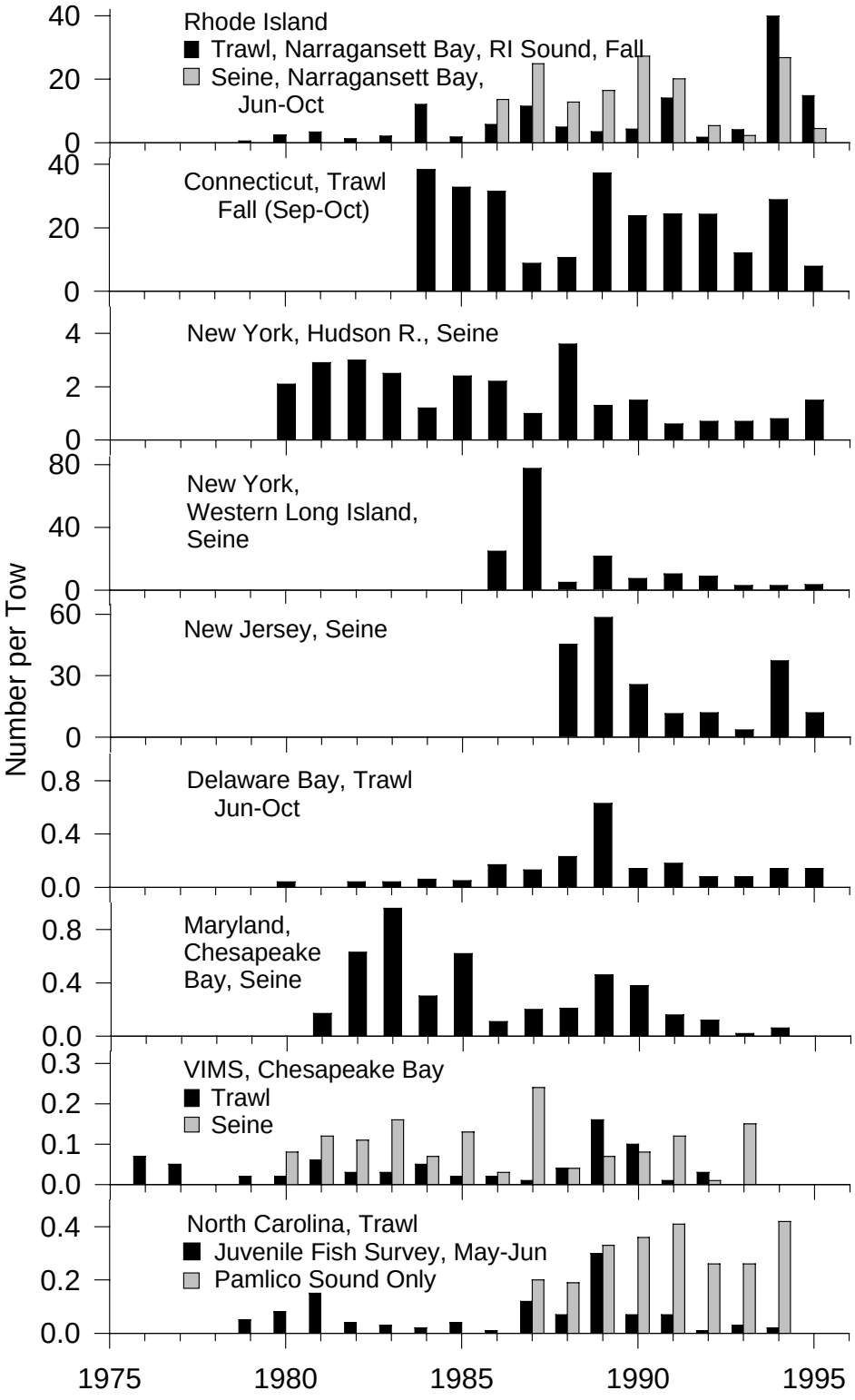


Figure 11. Abundance (number/tow) of young-of-the-year bluefish in seine and trawl surveys by state and by year.

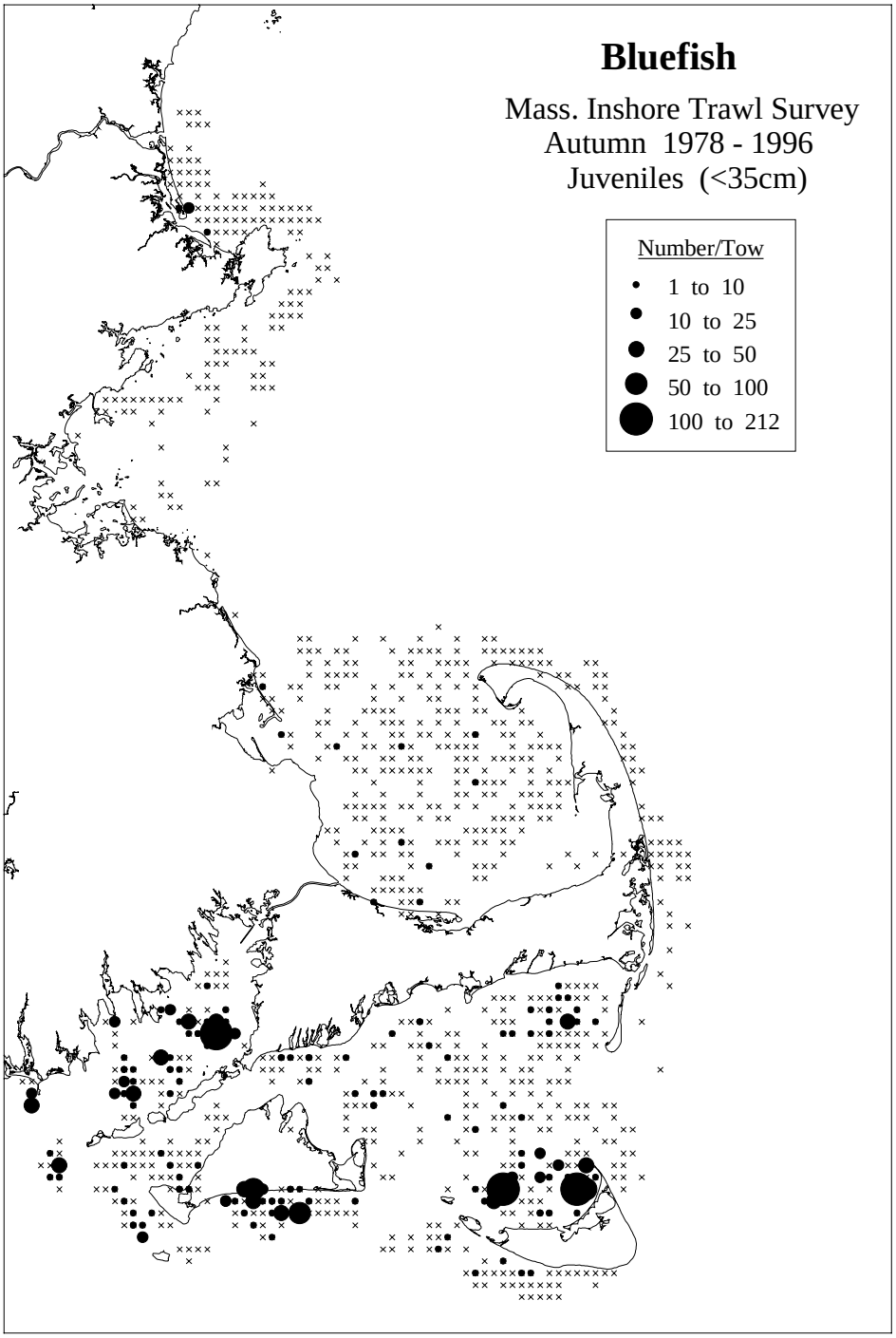
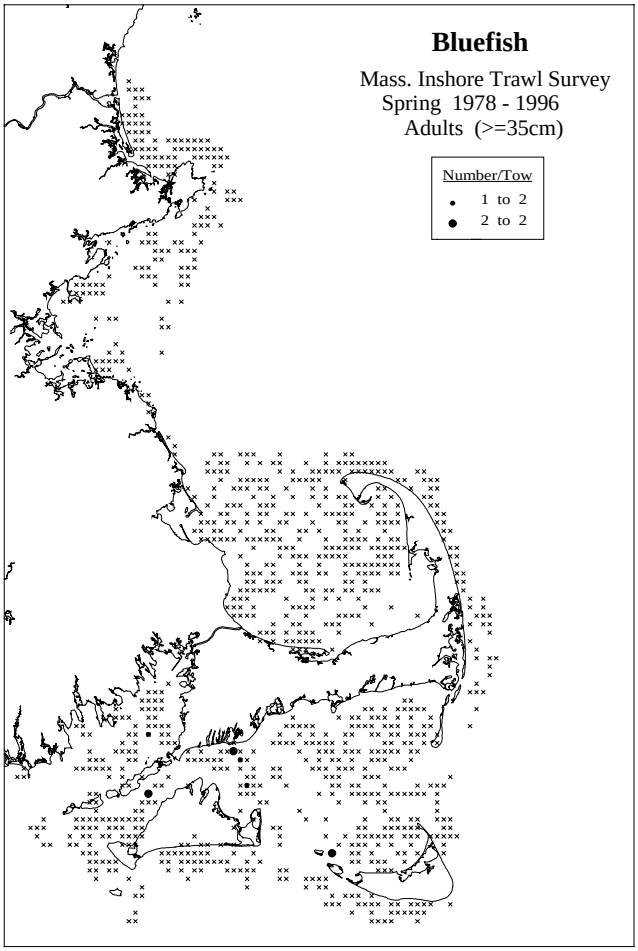
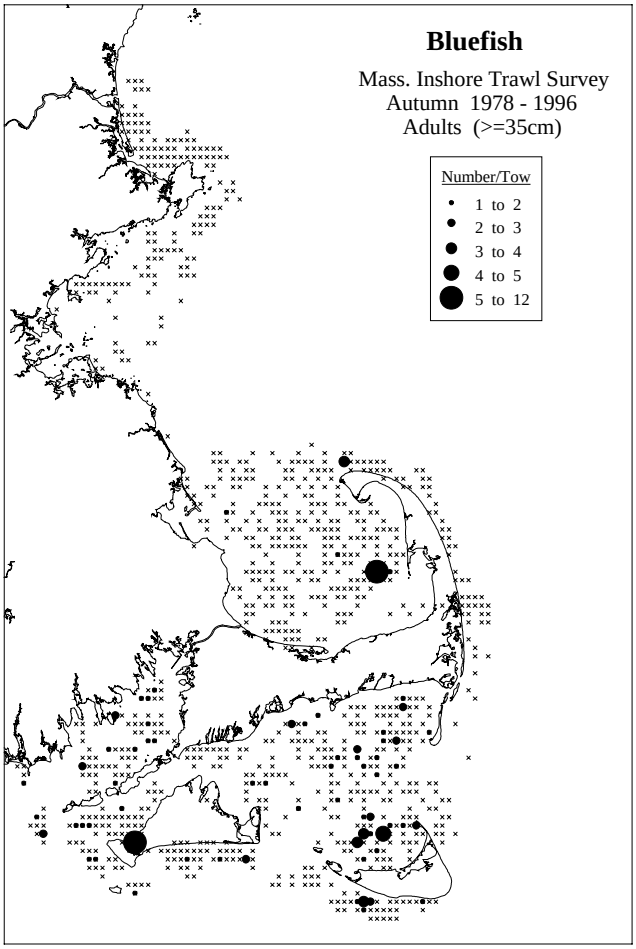


Figure 12. Distribution and abundance of juvenile and adult bluefish collected in Massachusetts coastal waters during spring (adults only) and autumn (both juveniles and adults) Massachusetts inshore trawl surveys [1978-1996, all years combined; see Reid *et al.* (1999) for details].





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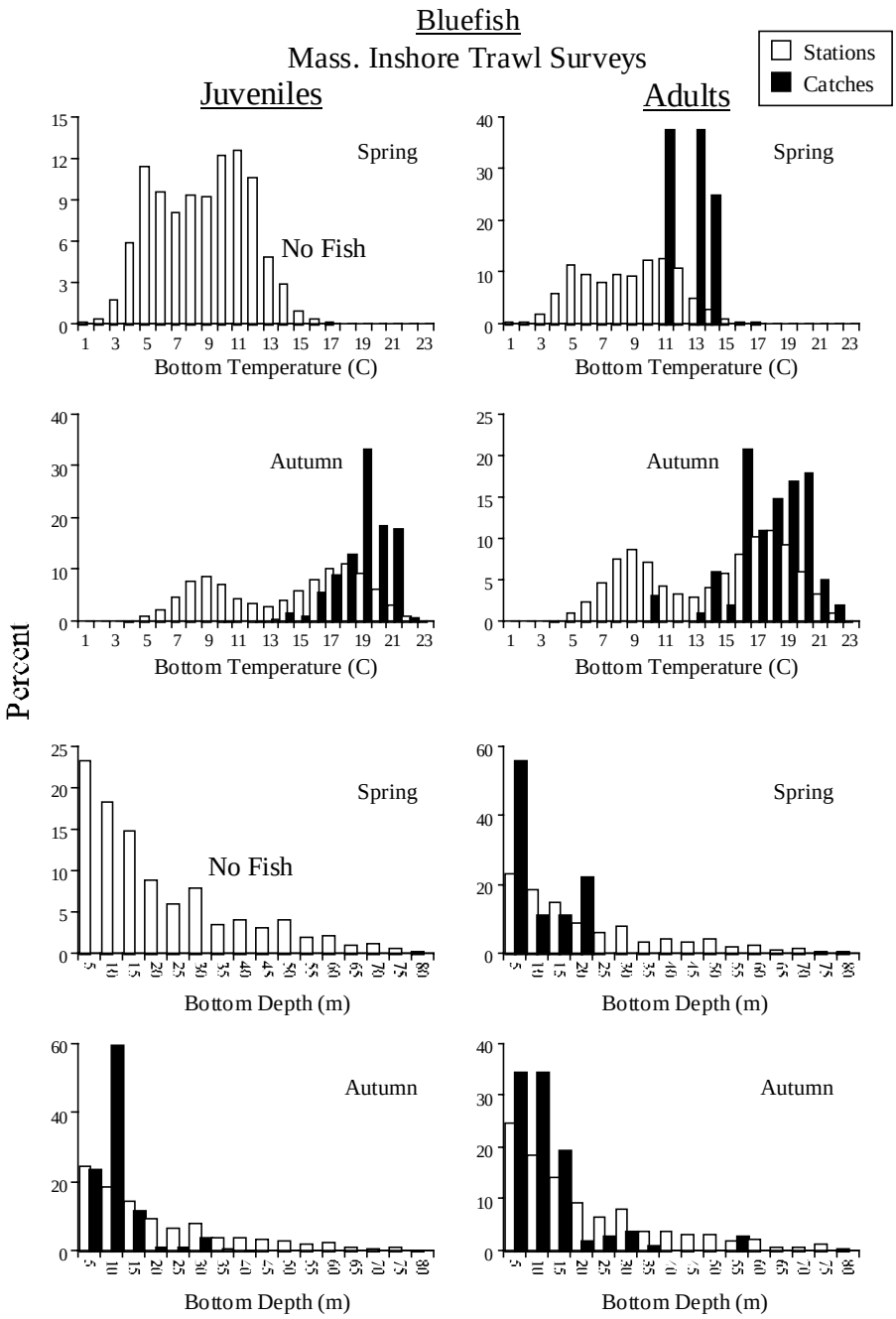


Figure 13. Abundance of juvenile and adult bluefish relative to bottom water temperature and depth based on Massachusetts inshore bottom trawl surveys (spring and autumn 1978-1996, all years combined).

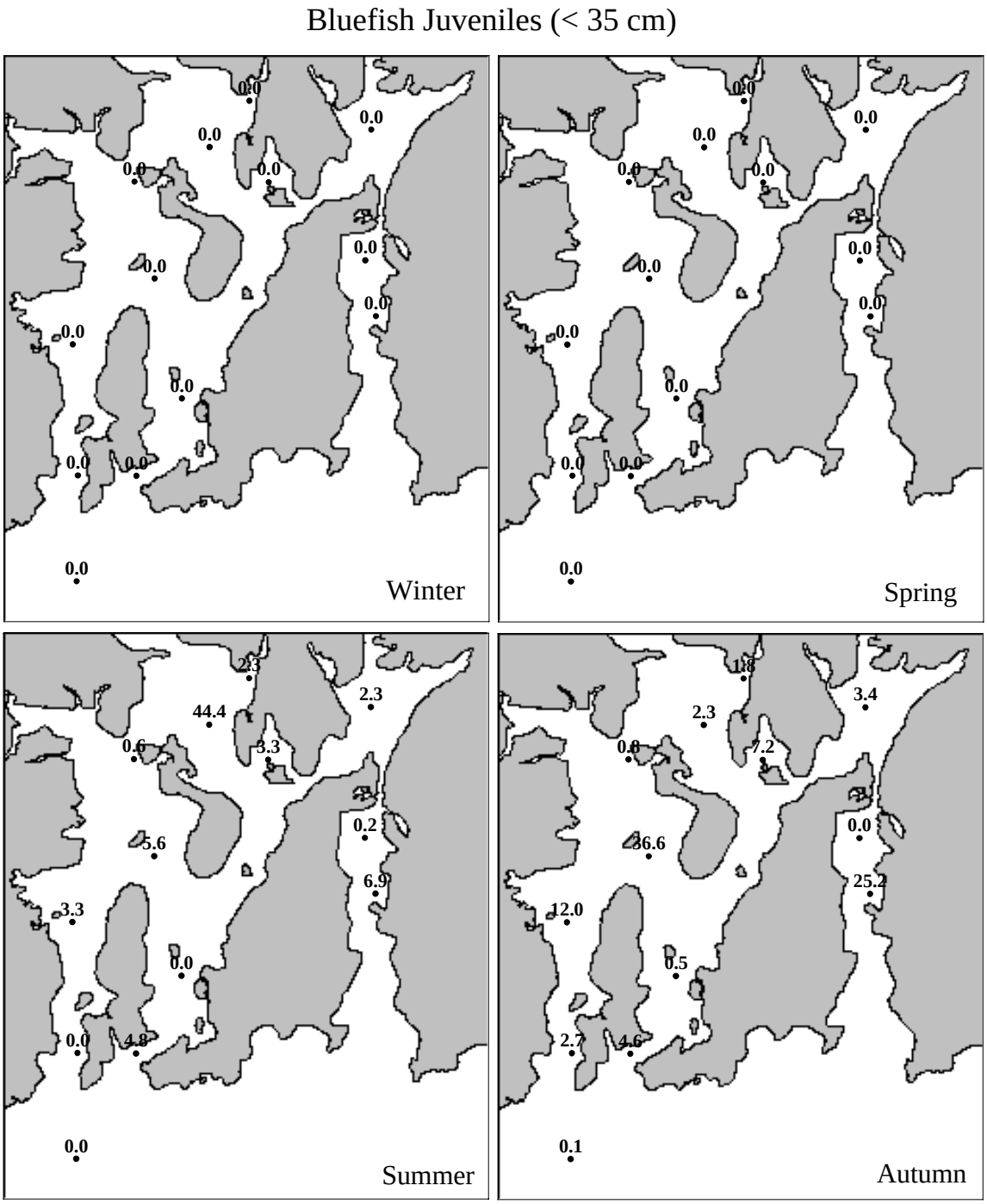
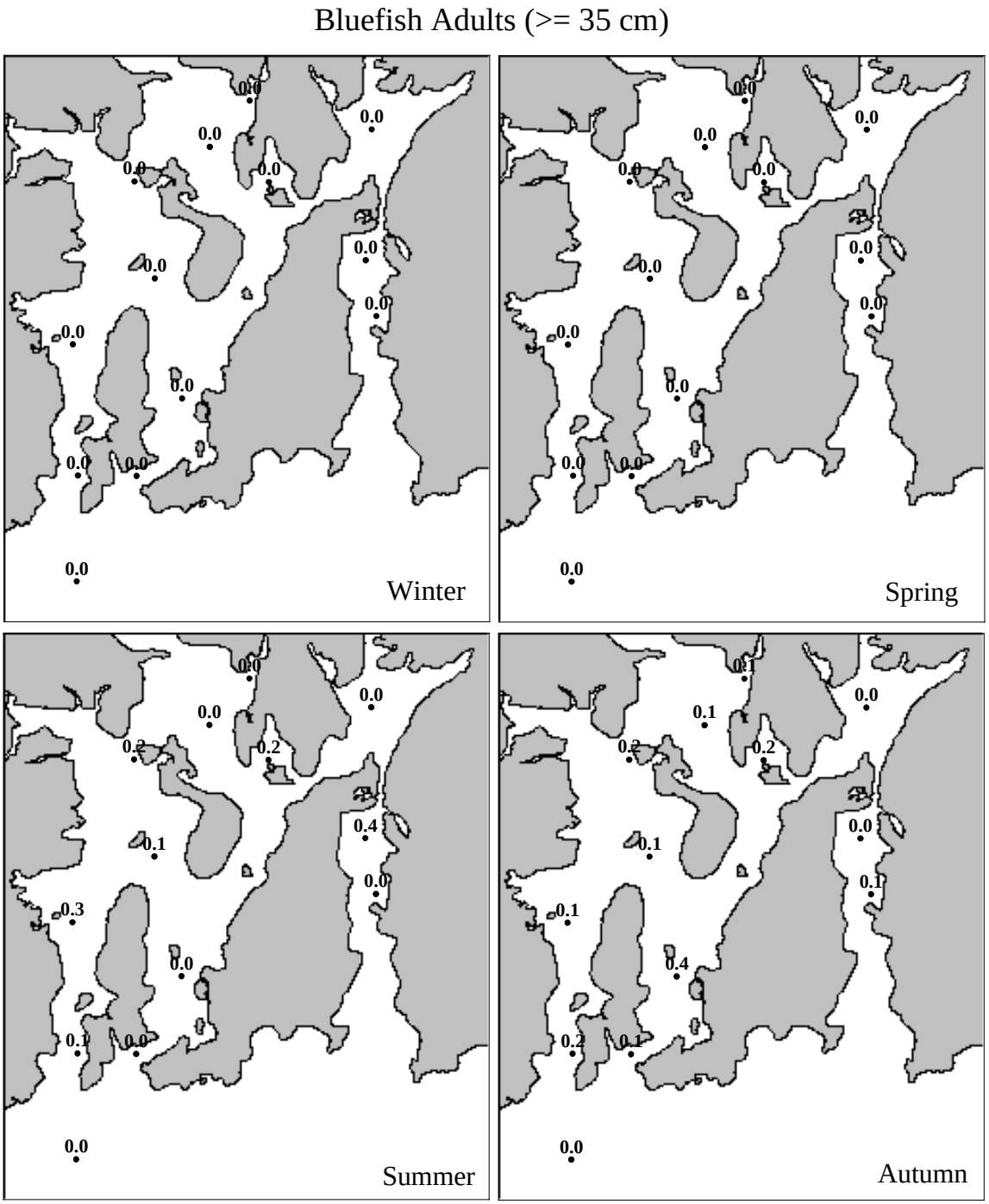


Figure 14. Distribution and abundance of juvenile and adult bluefish collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].



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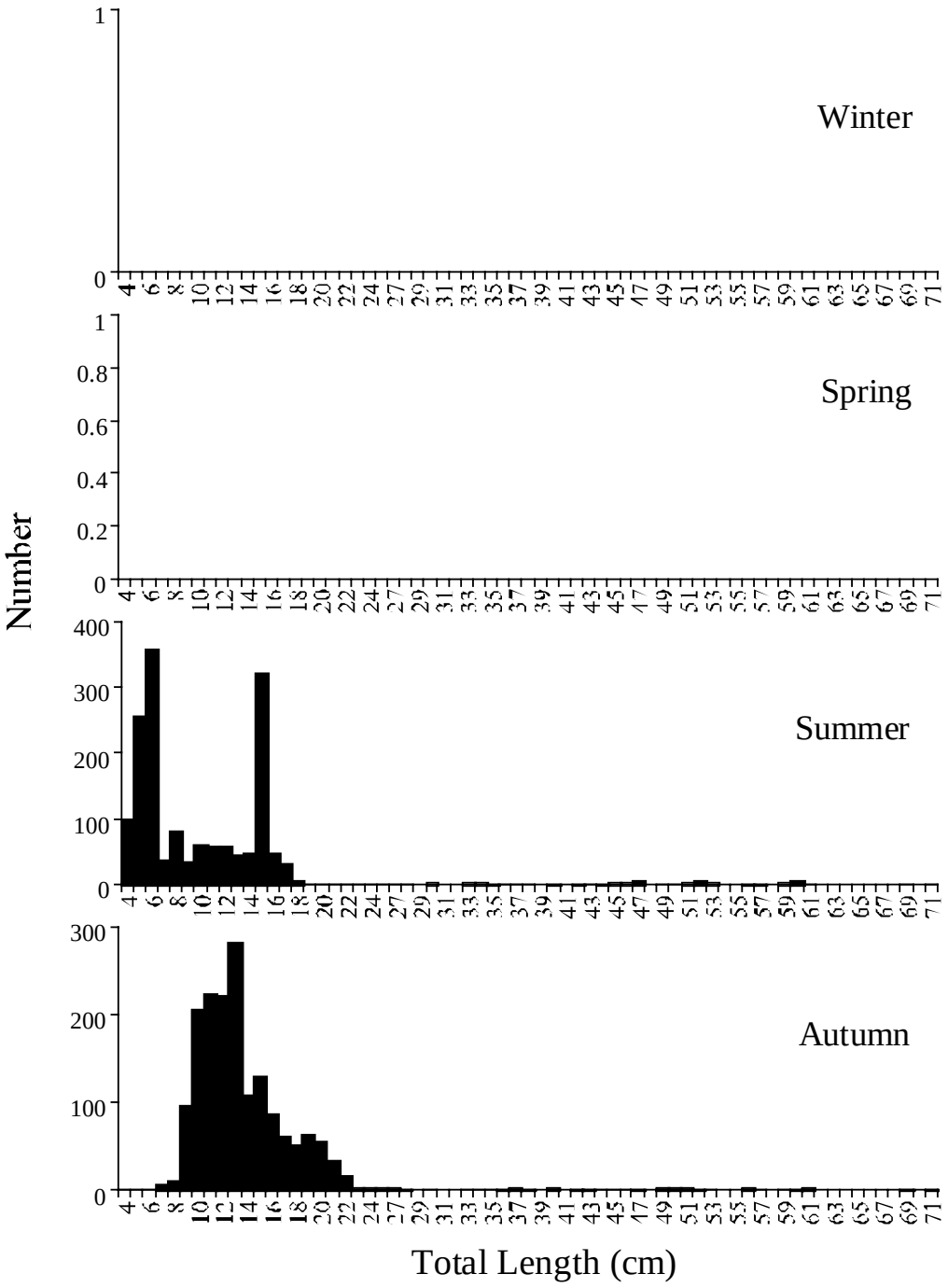


Figure 15. Seasonal length frequency distributions of bluefish collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys [all years combined; see Reid *et al.* (1999) for details].

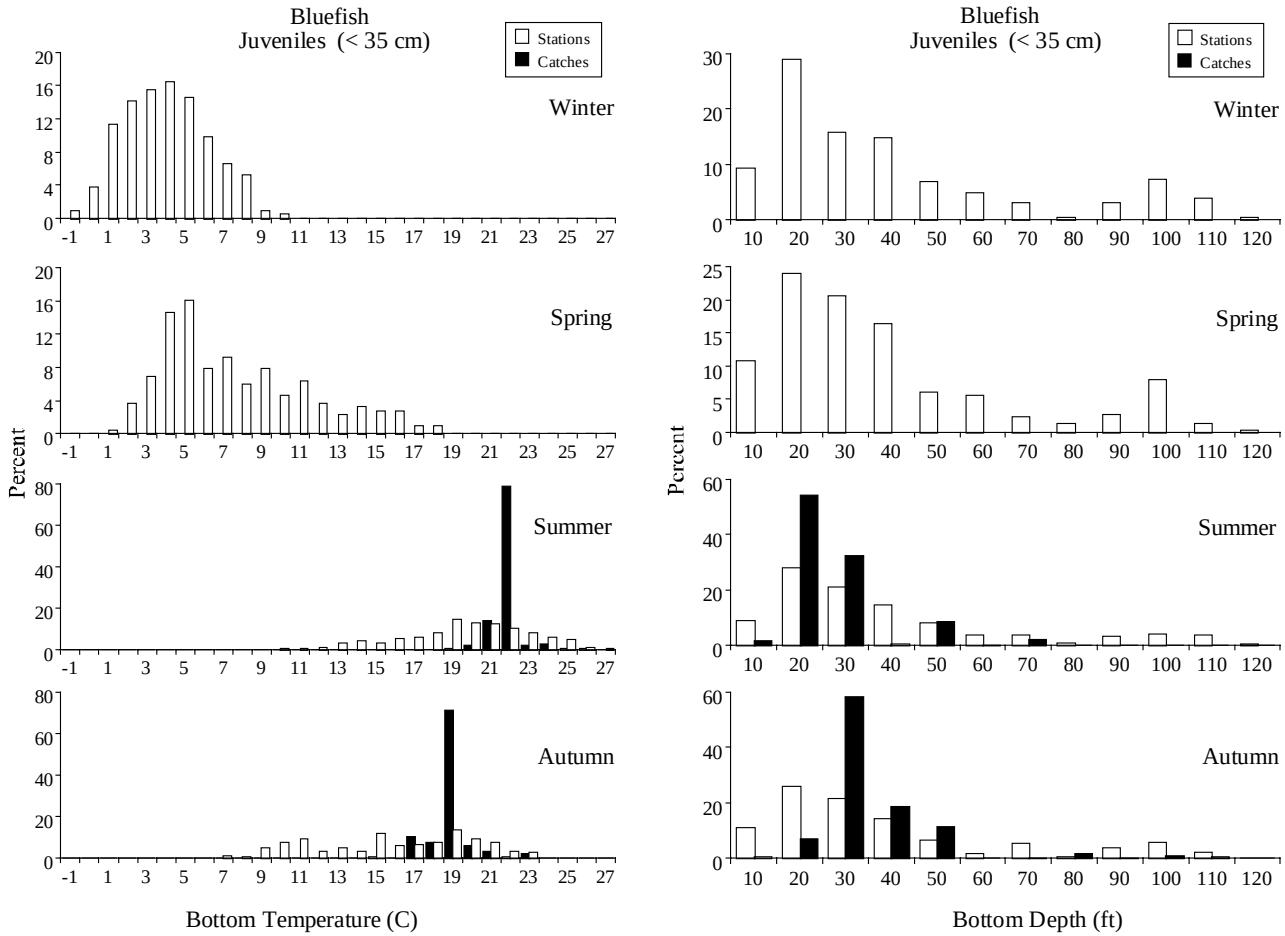


Figure 16. Seasonal abundance of juvenile and adult bluefish relative to bottom water temperature and depth based on Rhode Island Narragansett Bay trawl surveys (1990-1996, all years combined).

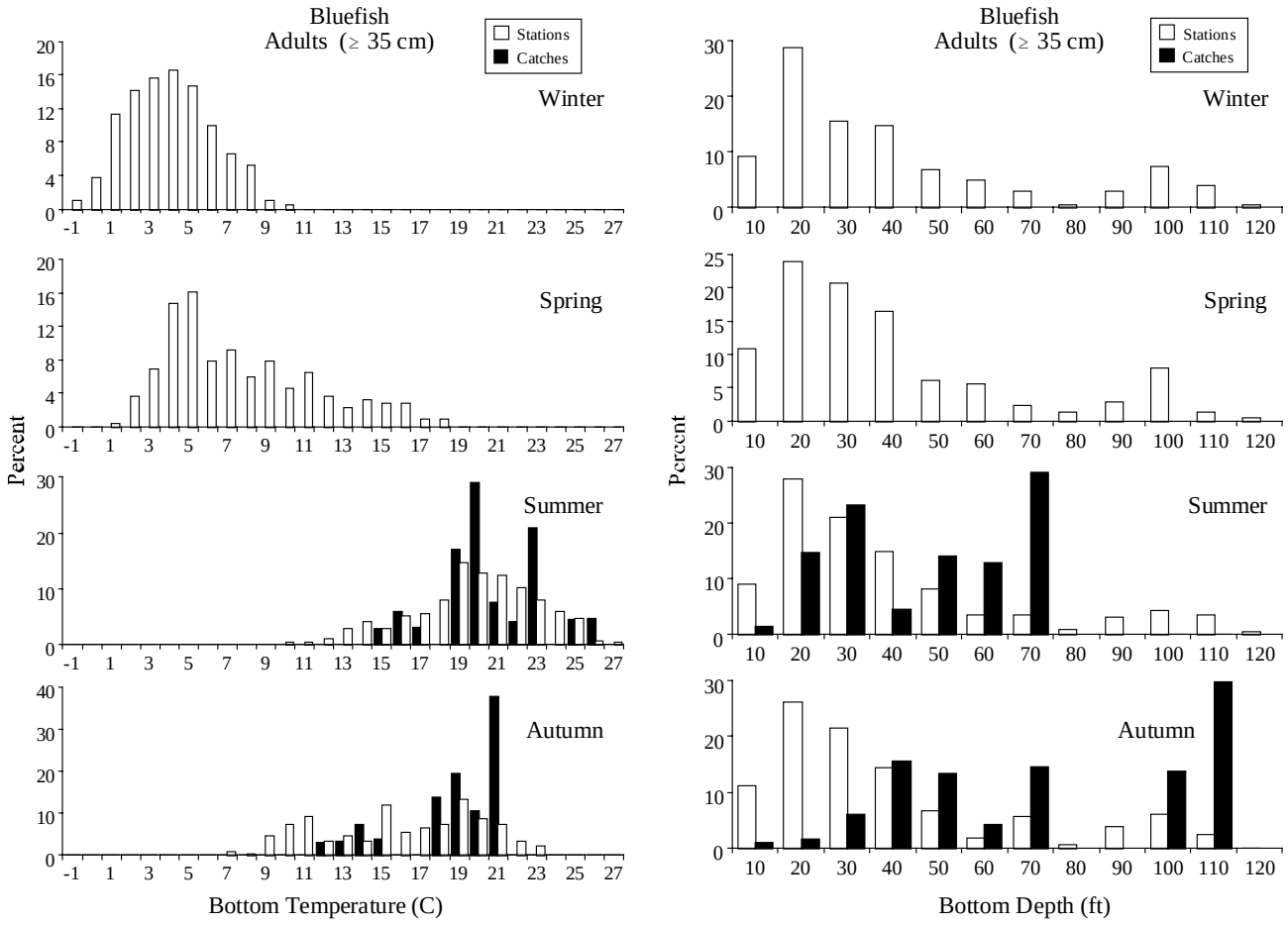
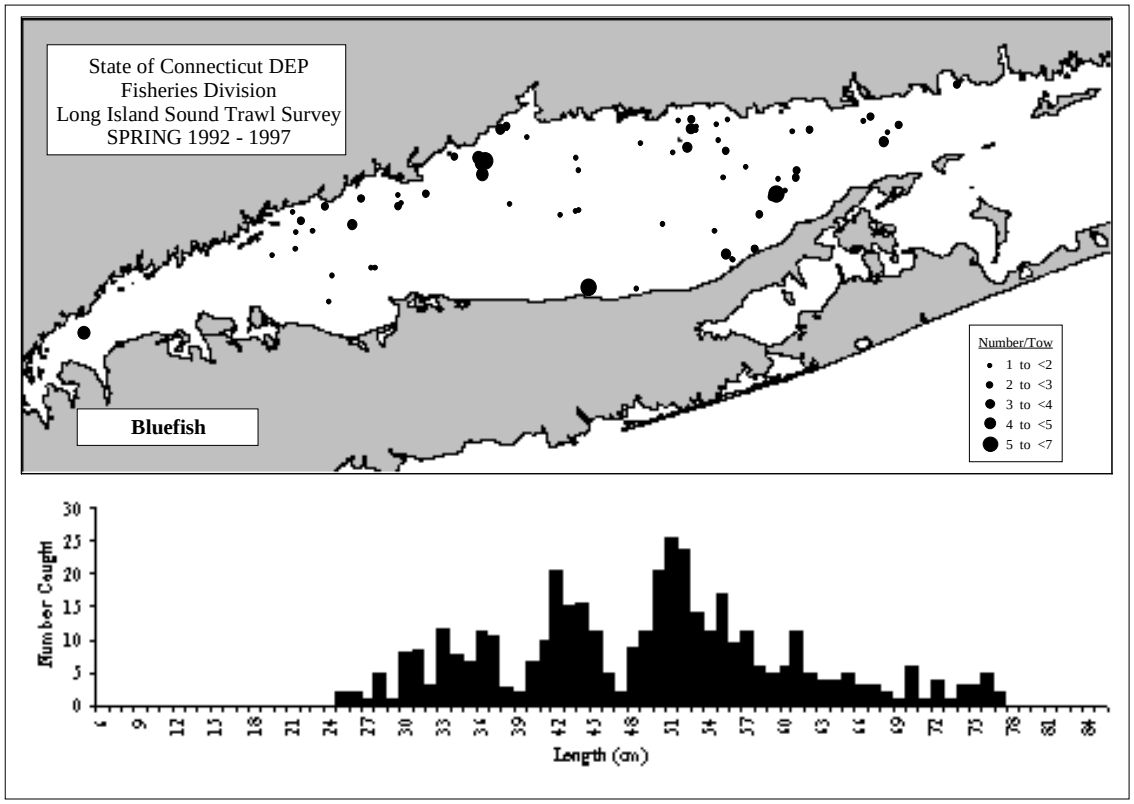


Figure 16. cont'd.



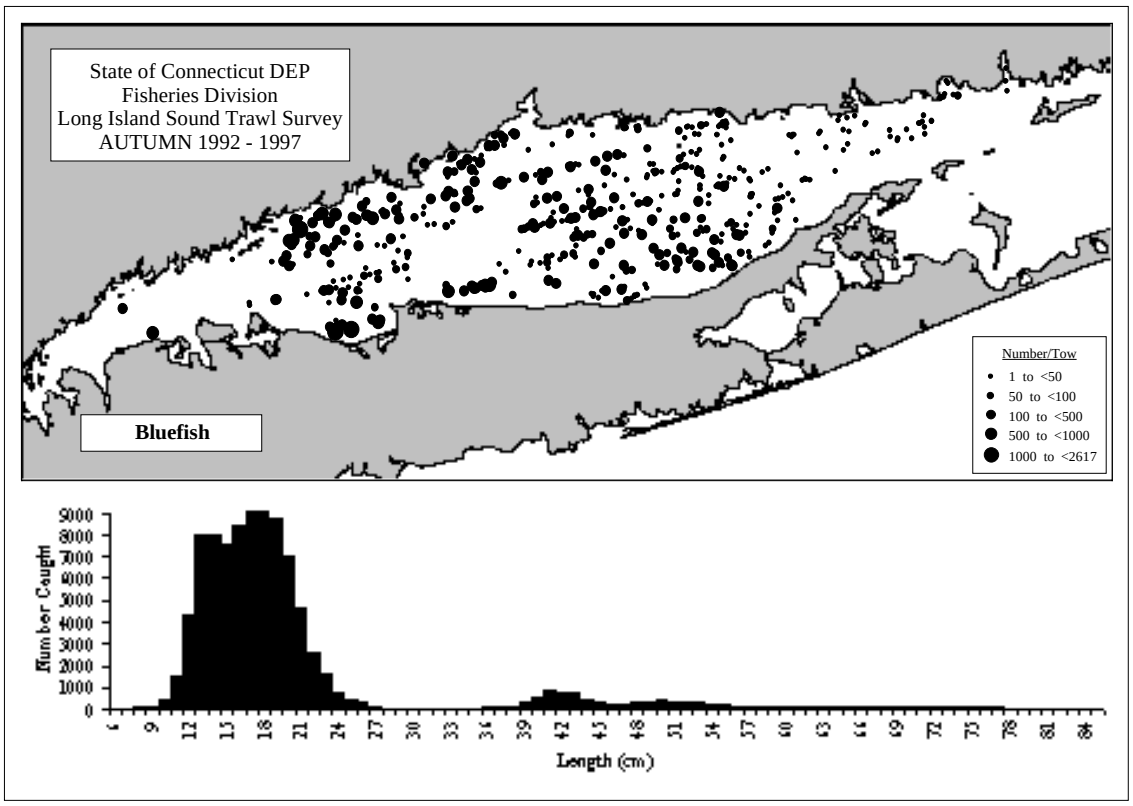
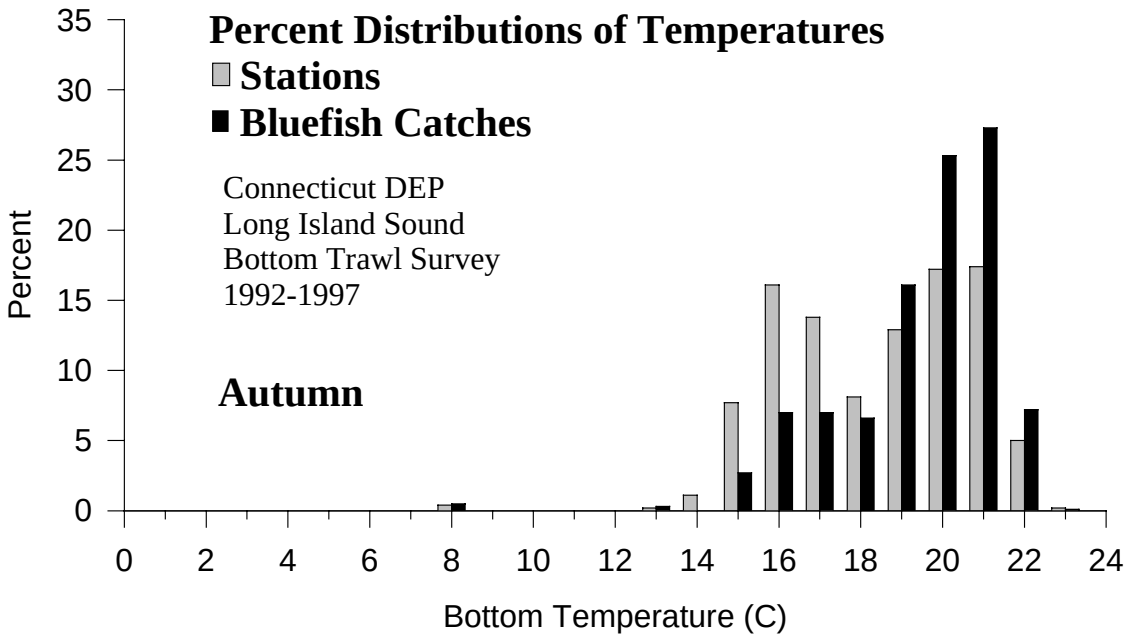


Figure 17. Distribution, abundance, and length frequency distributions of bluefish in Long Island Sound collected during spring and autumn Connecticut bottom trawl surveys [1992-1997, all years combined; see Reid *et al.* (1999) for details].



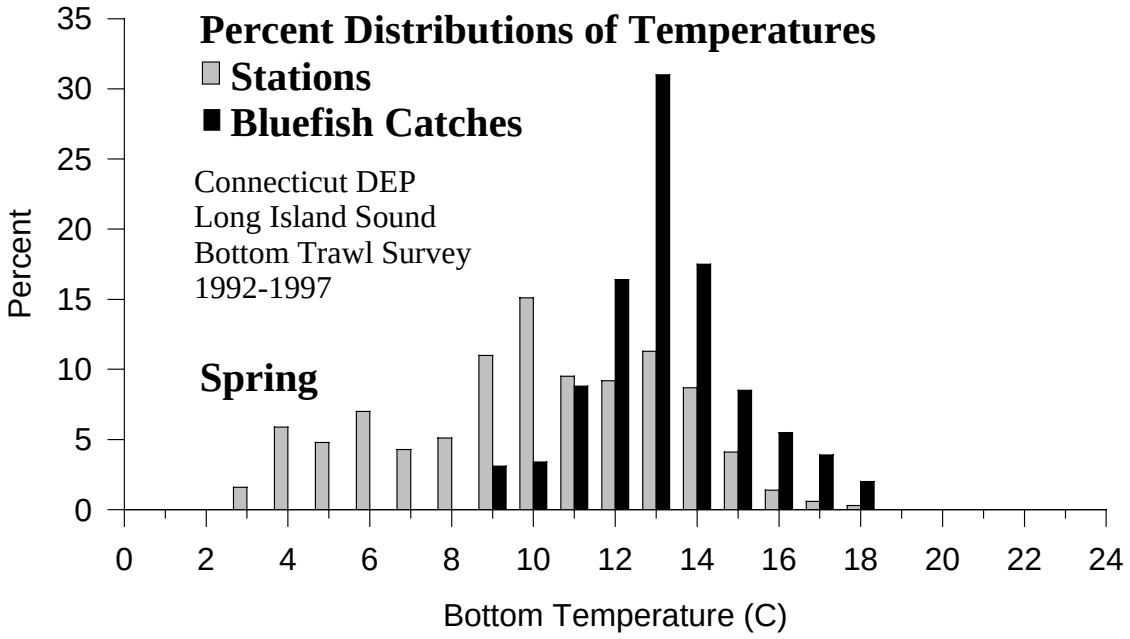


Figure 18. Abundance of bluefish relative to bottom water temperature based on spring and autumn Connecticut bottom trawl surveys in Long Island Sound (1992-1997, all years combined).

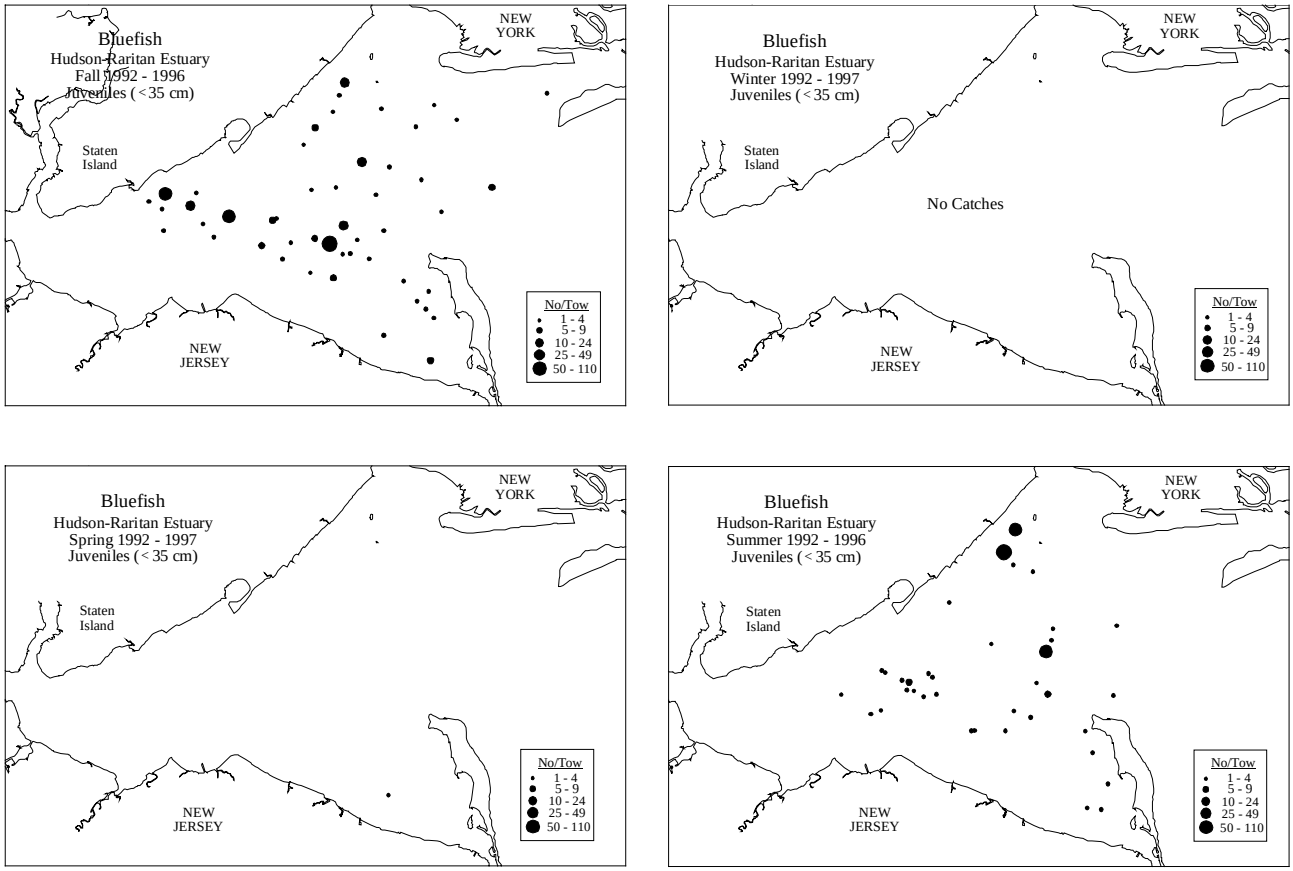


Figure 19. Seasonal distribution and abundance of juvenile and adult bluefish collected in the Hudson-Raritan estuary during Hudson-Raritan trawl surveys [1992-1997, all years combined; see Reid *et al.* (1999) for details].

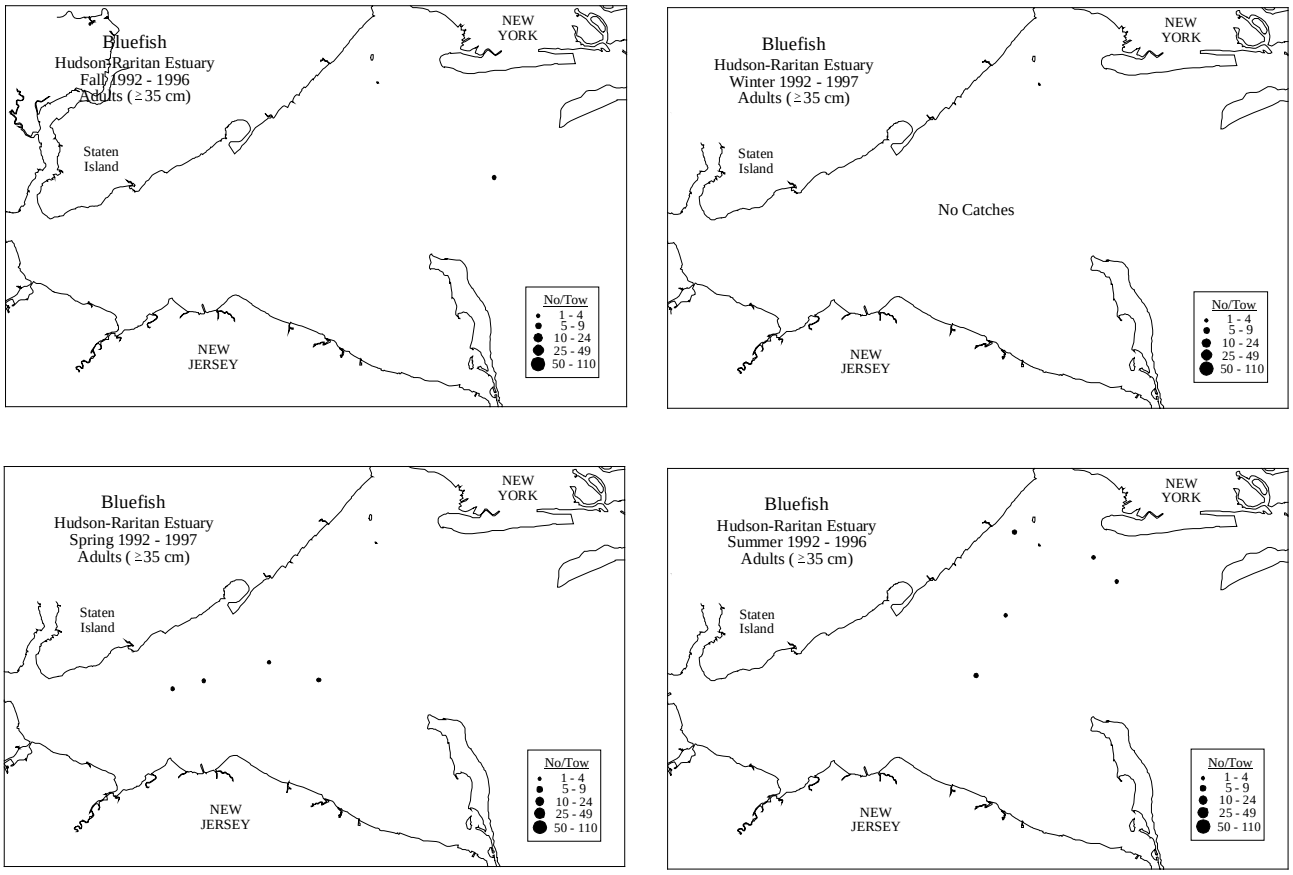


Figure 19. cont'd.

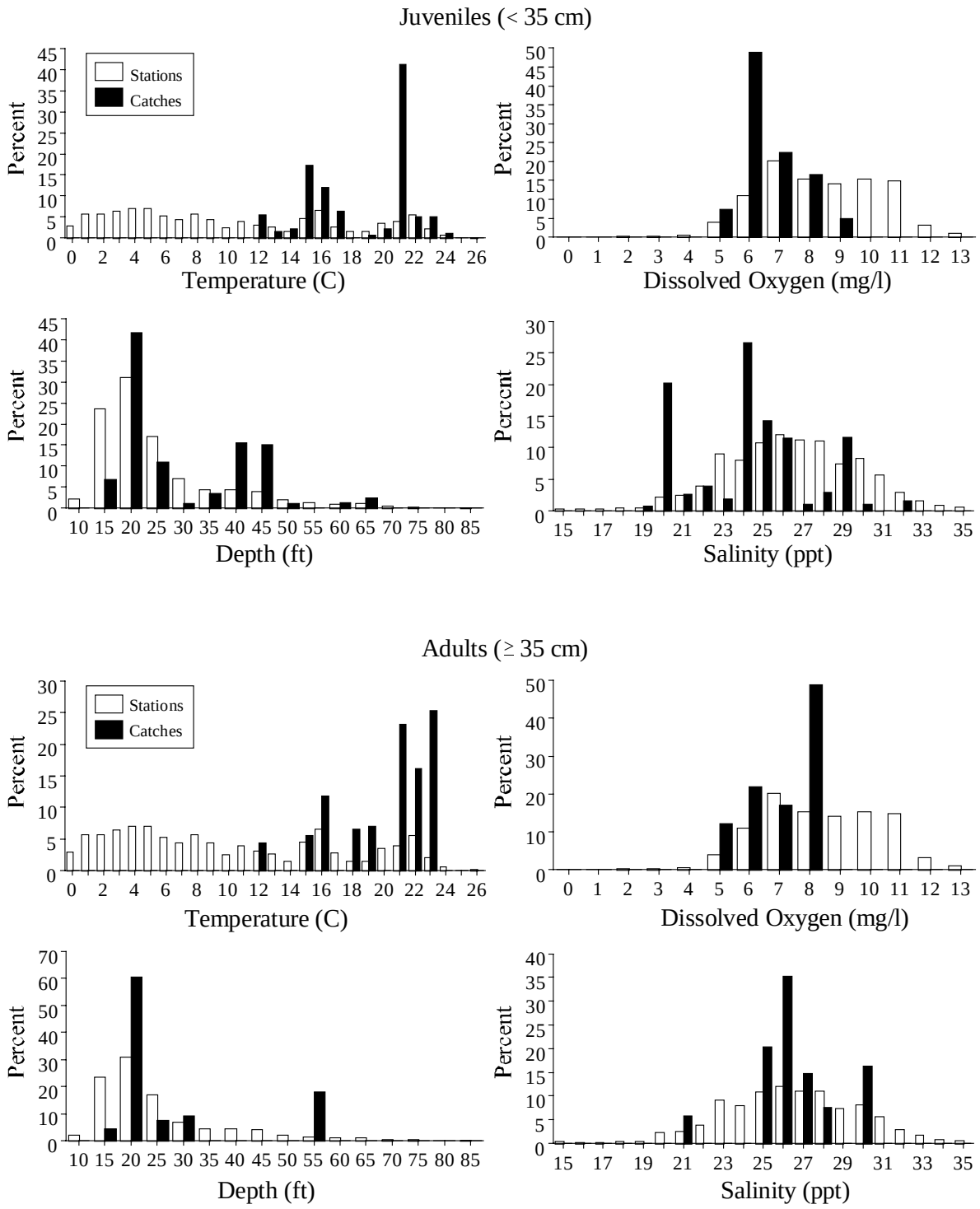


Figure 20. Abundance of juvenile and adult bluefish relative to bottom water temperature, depth, dissolved oxygen, and salinity based on Hudson-Raritan estuary trawl surveys (1992-1997, all years combined).

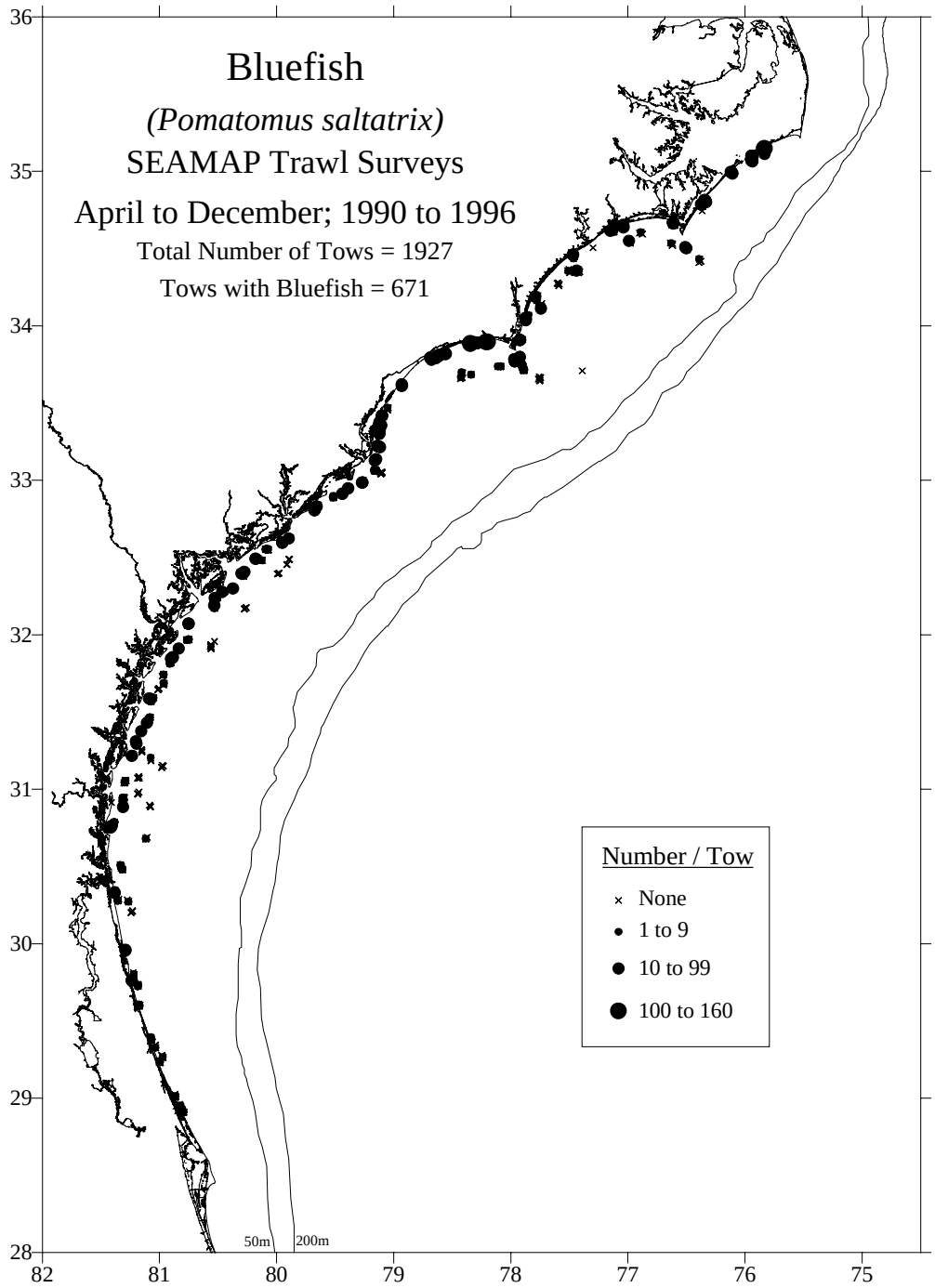


Figure 21. Distribution and abundance of bluefish in the South Atlantic Bight collected during SEAMAP bottom trawl surveys [1990-1996, all years combined; see Reid *et al.* (1999) for details].

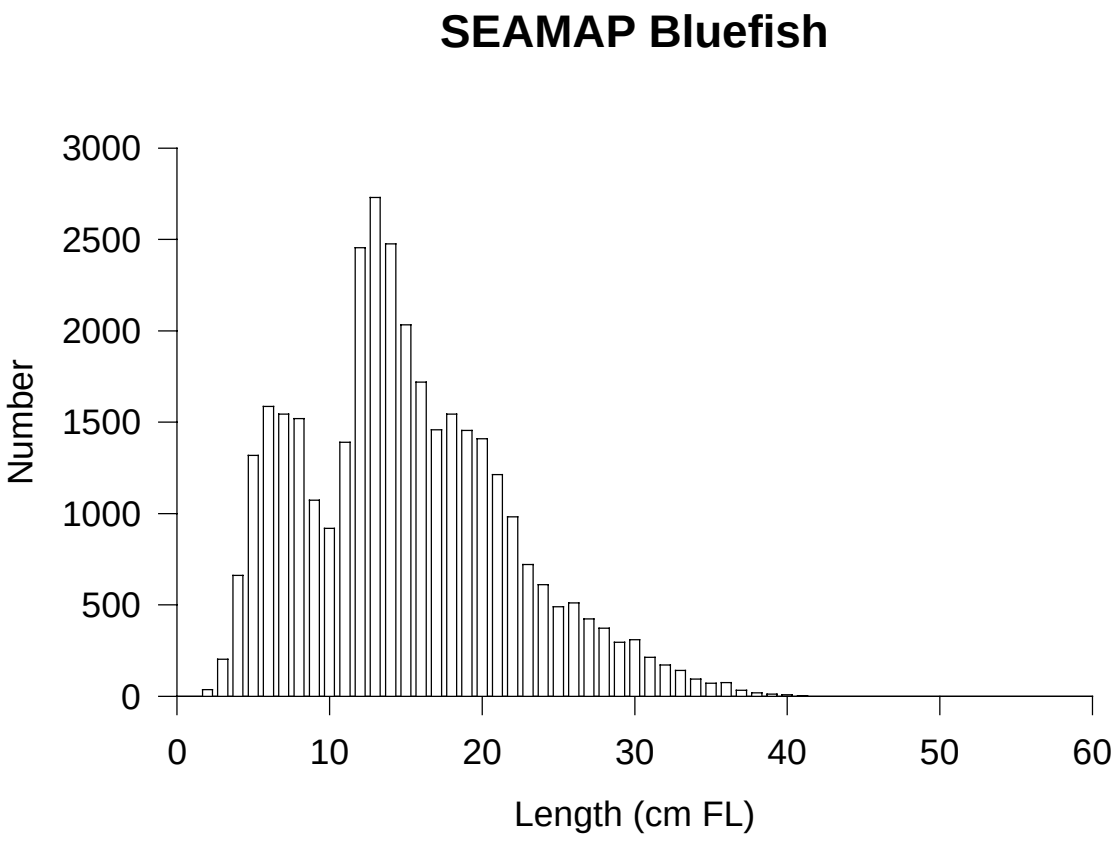


Figure 22. Length frequency distribution of bluefish in the South Atlantic Bight collected during SEAMAP bottom trawl surveys (1990-1996, all years combined).

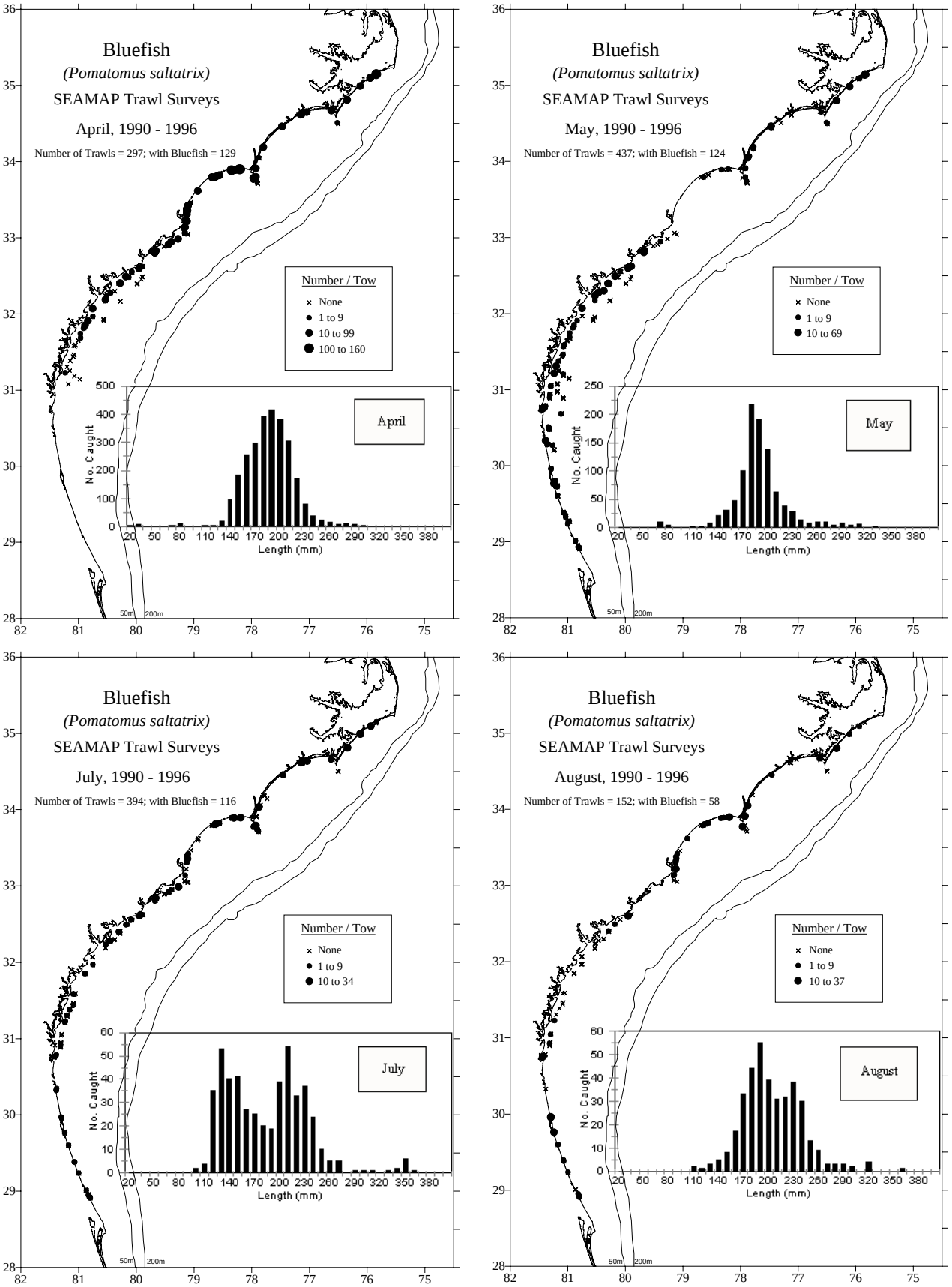
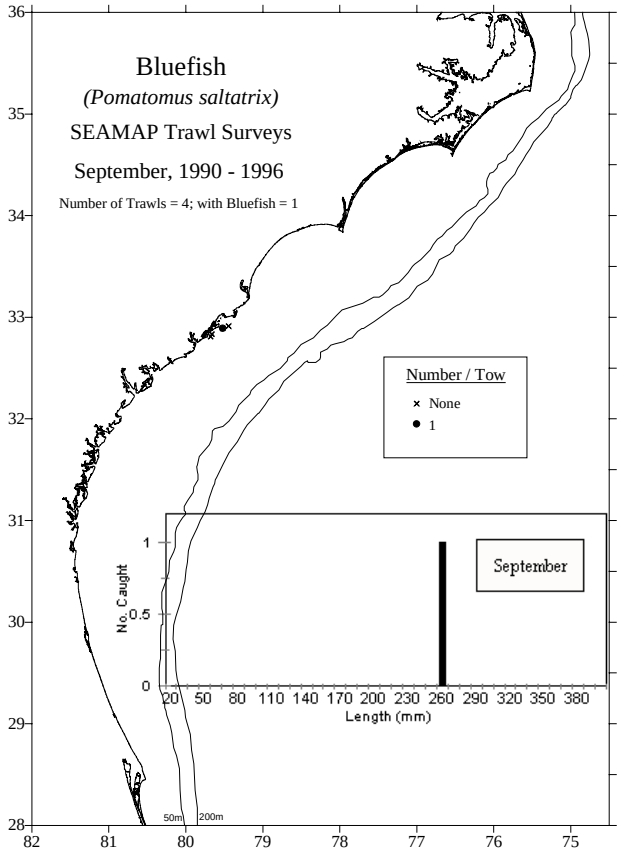
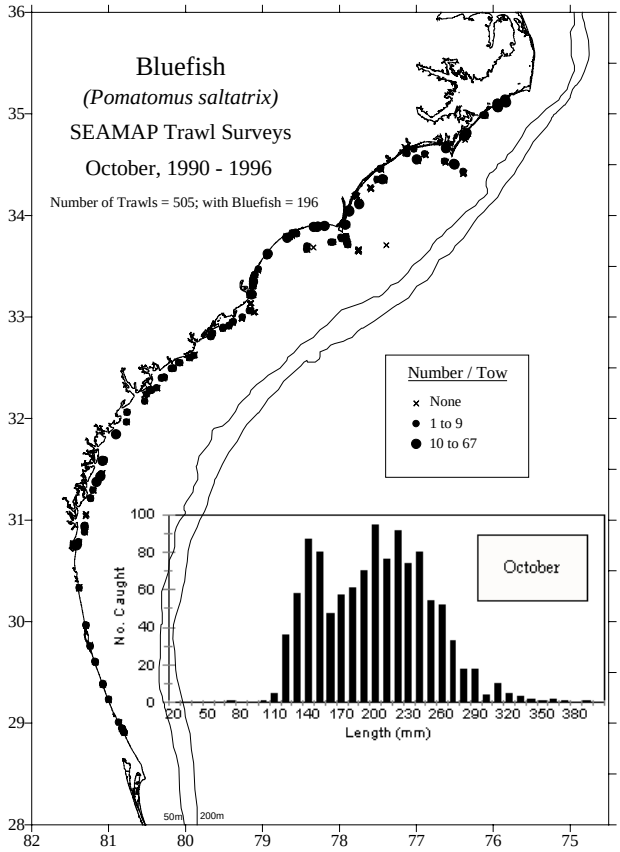


Figure 23. Monthly distribution, abundance, and length frequency distribution of bluefish in the South Atlantic Bight collected during SEAMAP bottom trawl surveys (1990-1996, all years combined).





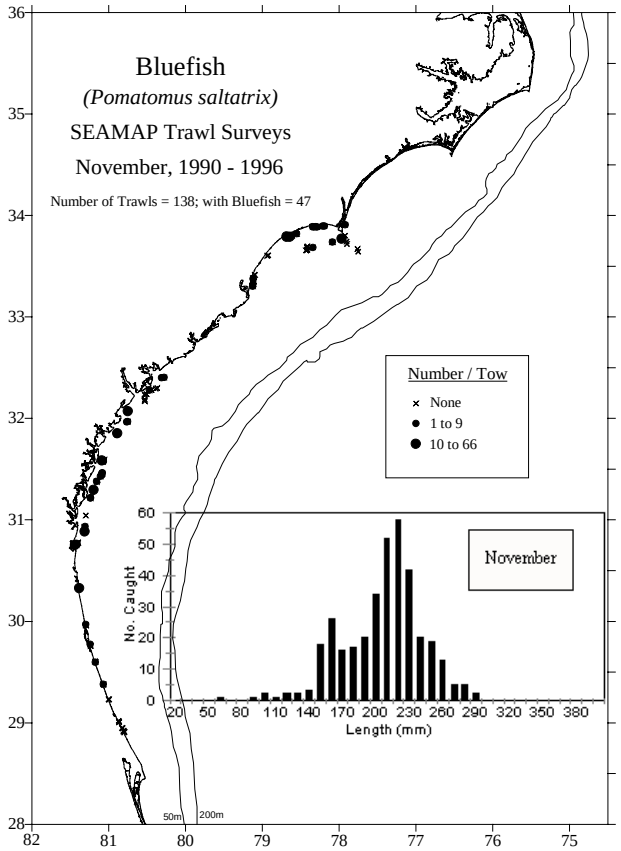


Figure 23. cont'd.

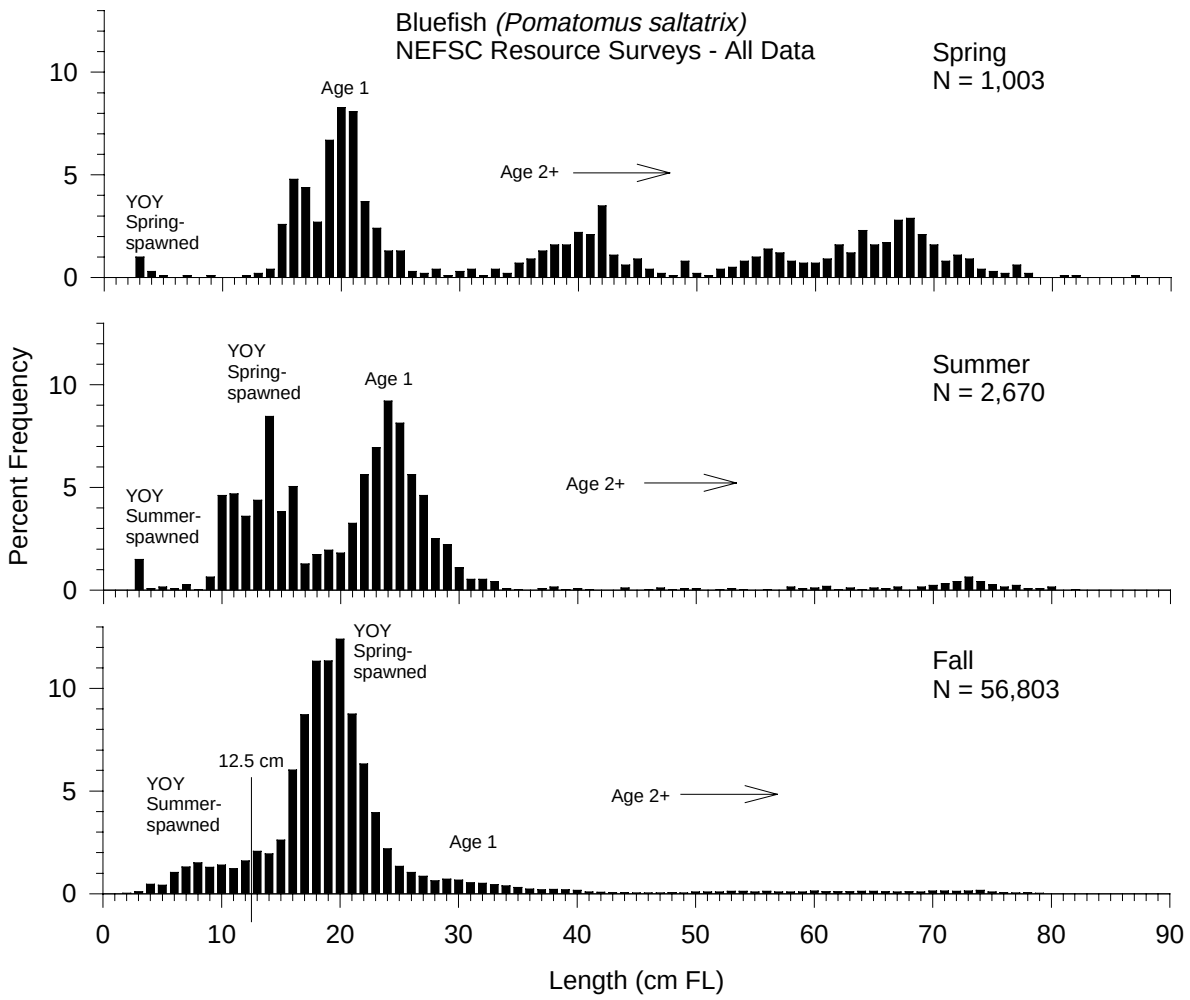


Figure 24. Seasonal length frequency distributions used to determine bluefish size and age cutoffs in NEFSC bottom trawl surveys.

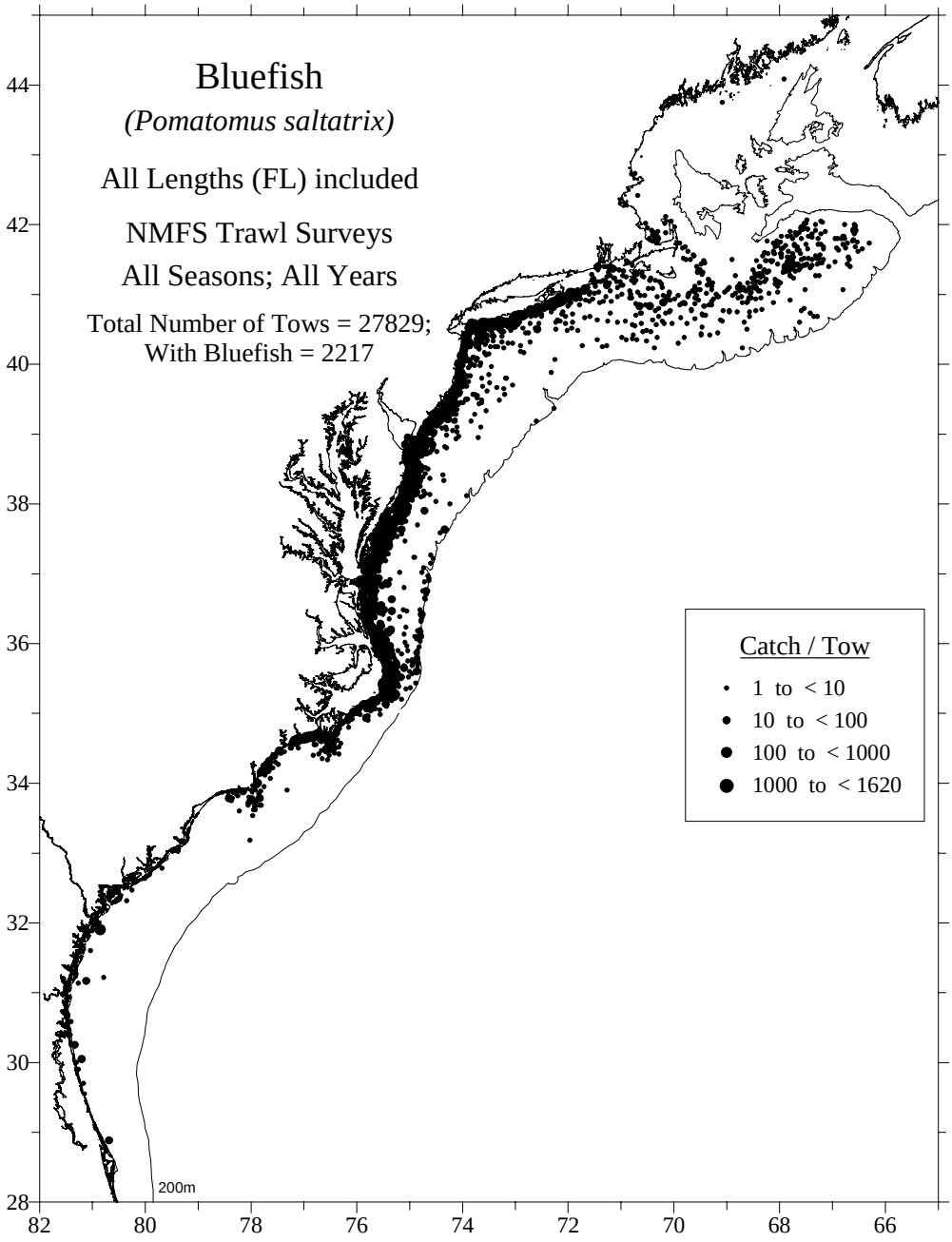


Figure 25. Distribution and abundance of bluefish (all sizes combined) collected off the east coast of the United States during NEFSC bottom trawl surveys [all years and seasons combined; see Reid *et al.* (1999) for details].

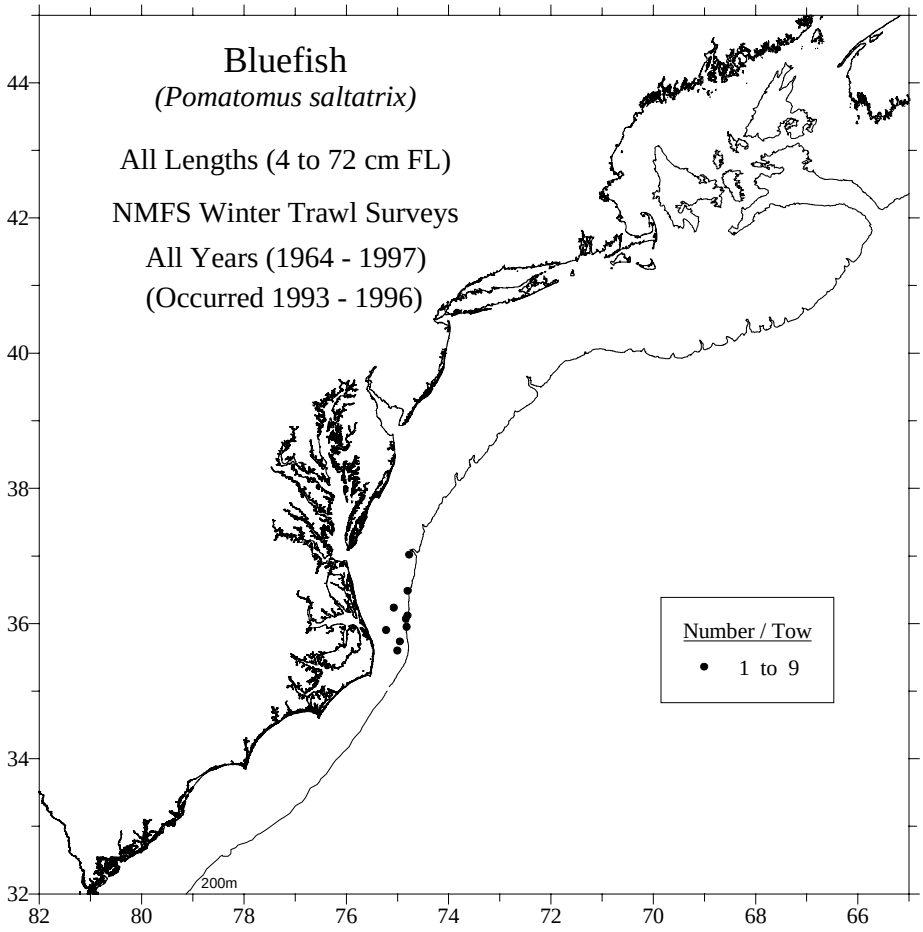


Figure 26. Distribution and abundance of bluefish (all lengths combined) collected off the east coast of the United States during winter NEFSC bottom trawl surveys [1964-1997, all years combined; see Reid *et al.* (1999) for details].

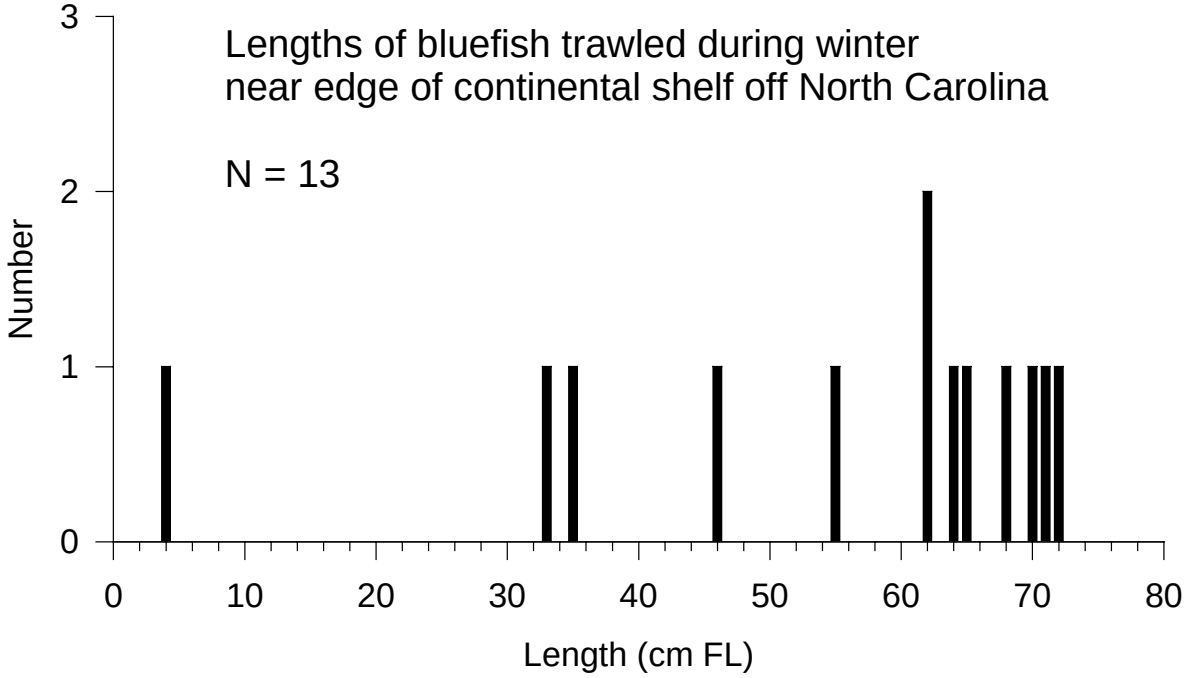


Figure 27. Length frequency distribution of bluefish caught in the winter off North Carolina during winter NEFSC bottom trawl surveys.

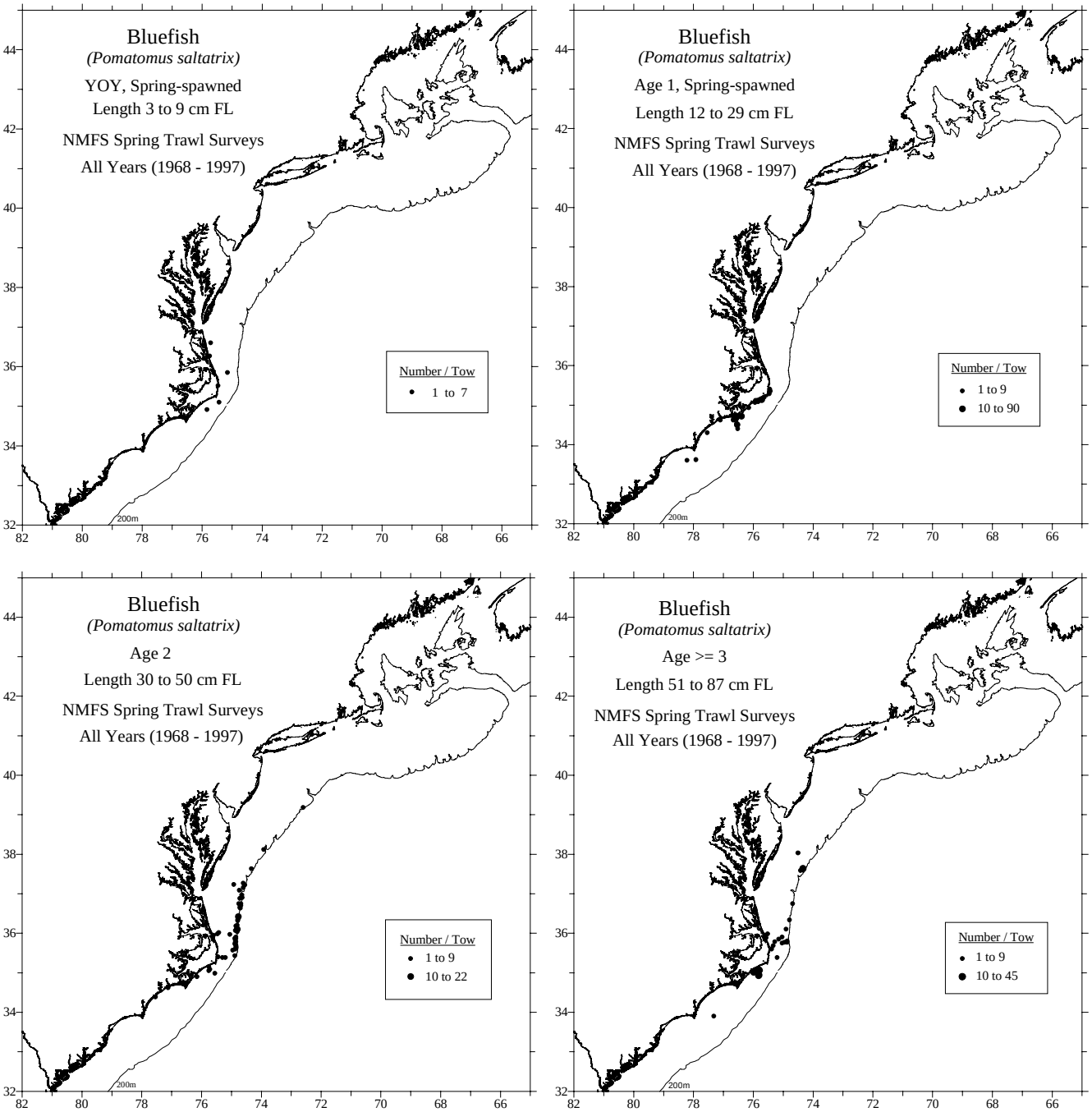


Figure 28. Distribution and abundance of four size classes of bluefish collected off the east coast of the United States during spring NEFSC bottom trawl surveys [1968-1997, all years combined; see Reid *et al.* (1999) for details].

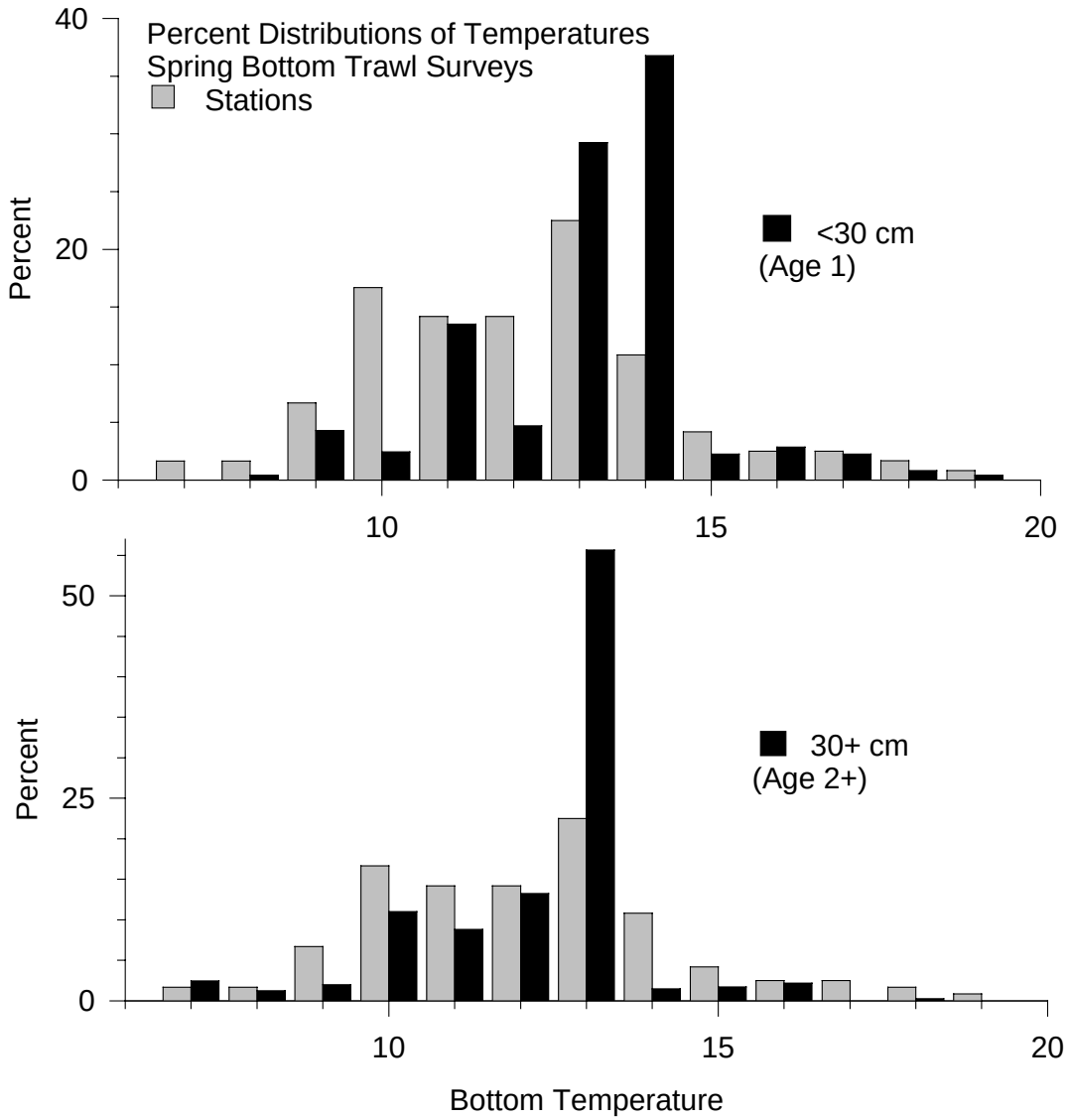


Figure 29. Abundance of large (> 30 cm) and small (< 30 cm) bluefish relative to bottom water temperature and depth based on spring east coast NEFSC bottom trawl surveys.

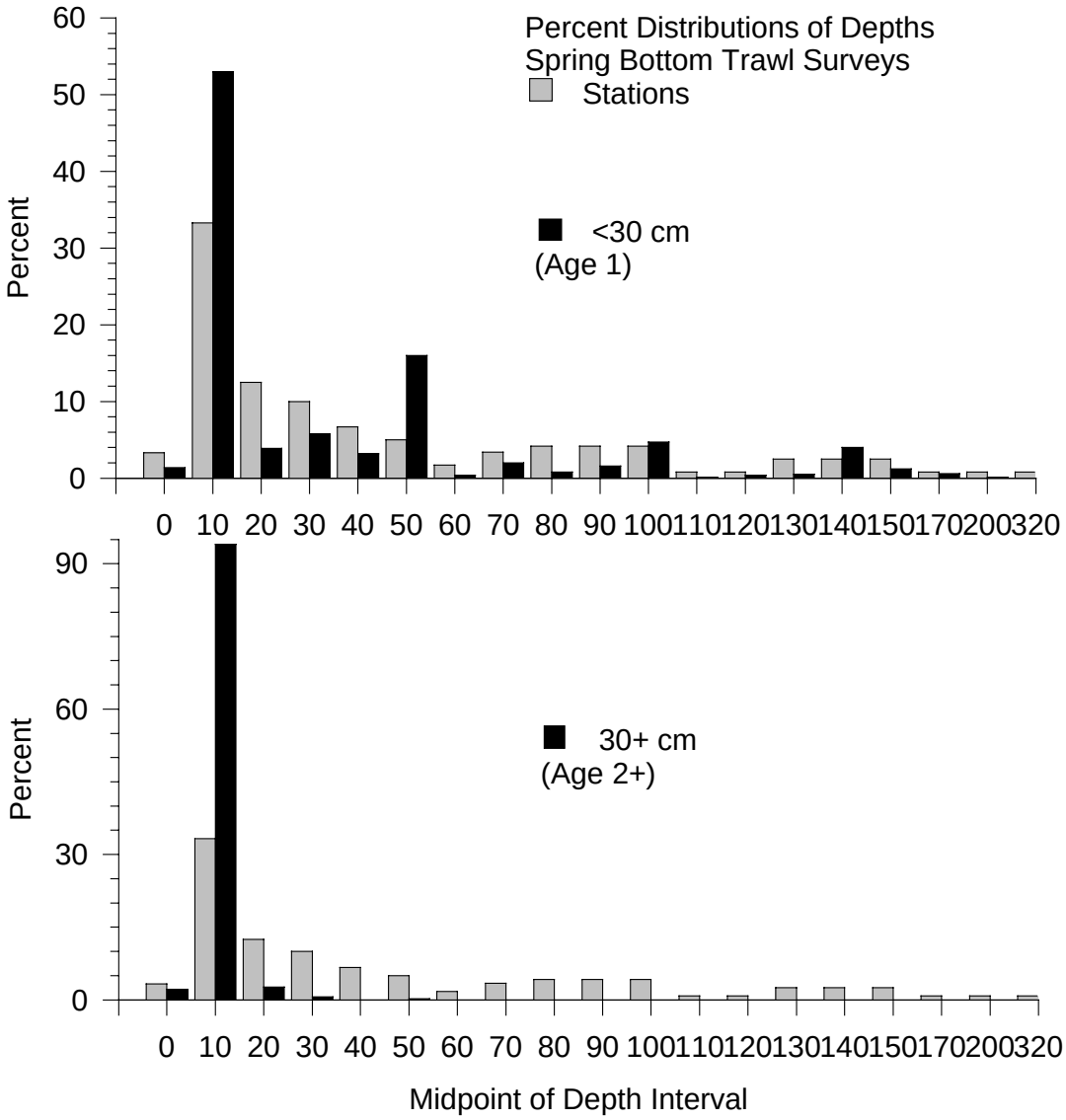


Figure 29. cont'd.

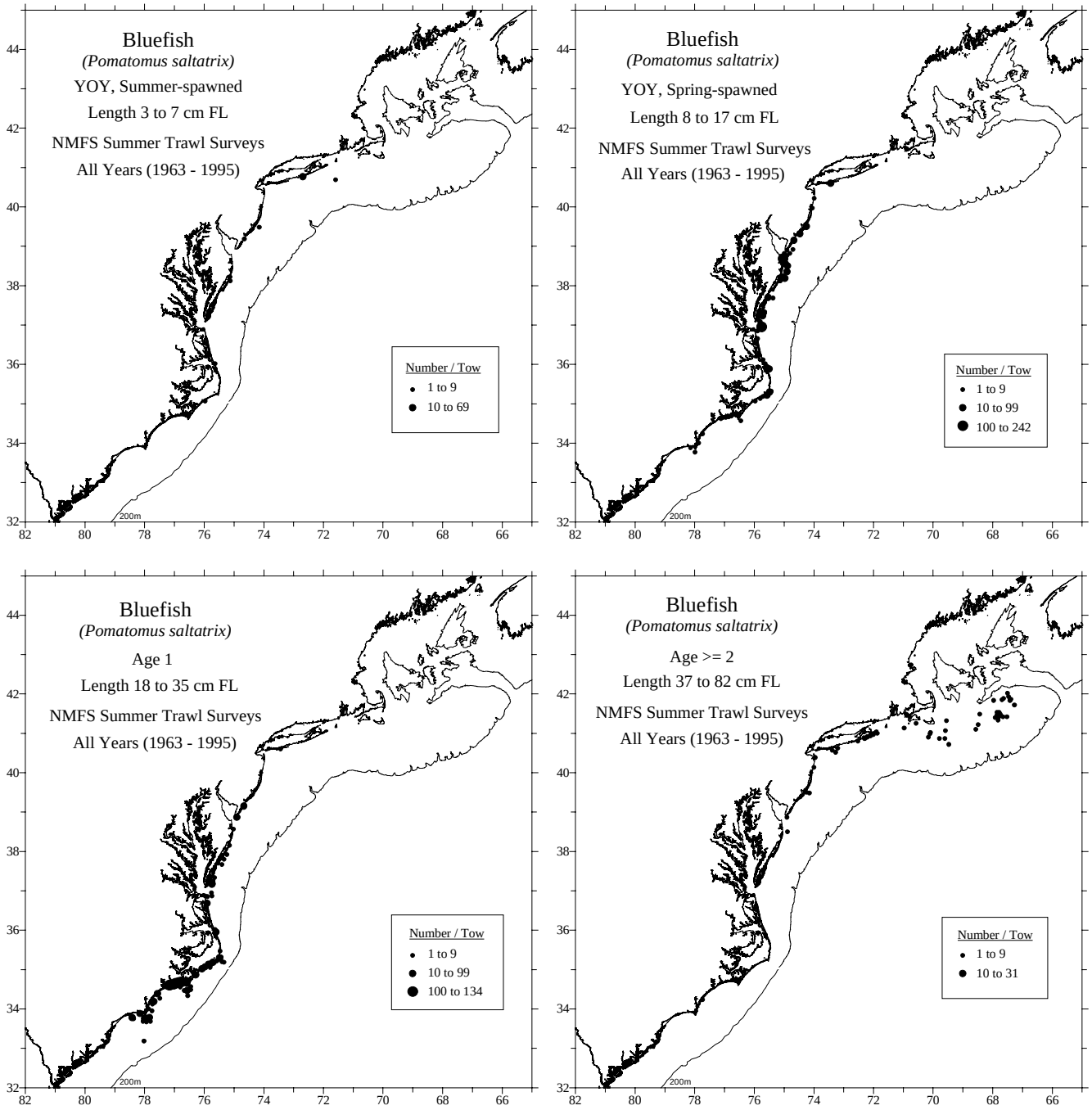


Figure 30. Distribution and abundance of four size classes of bluefish collected off the east coast of the United States during summer NEFSC bottom trawl surveys [1963-1995, all years combined; see Reid *et al.* (1999) for details].

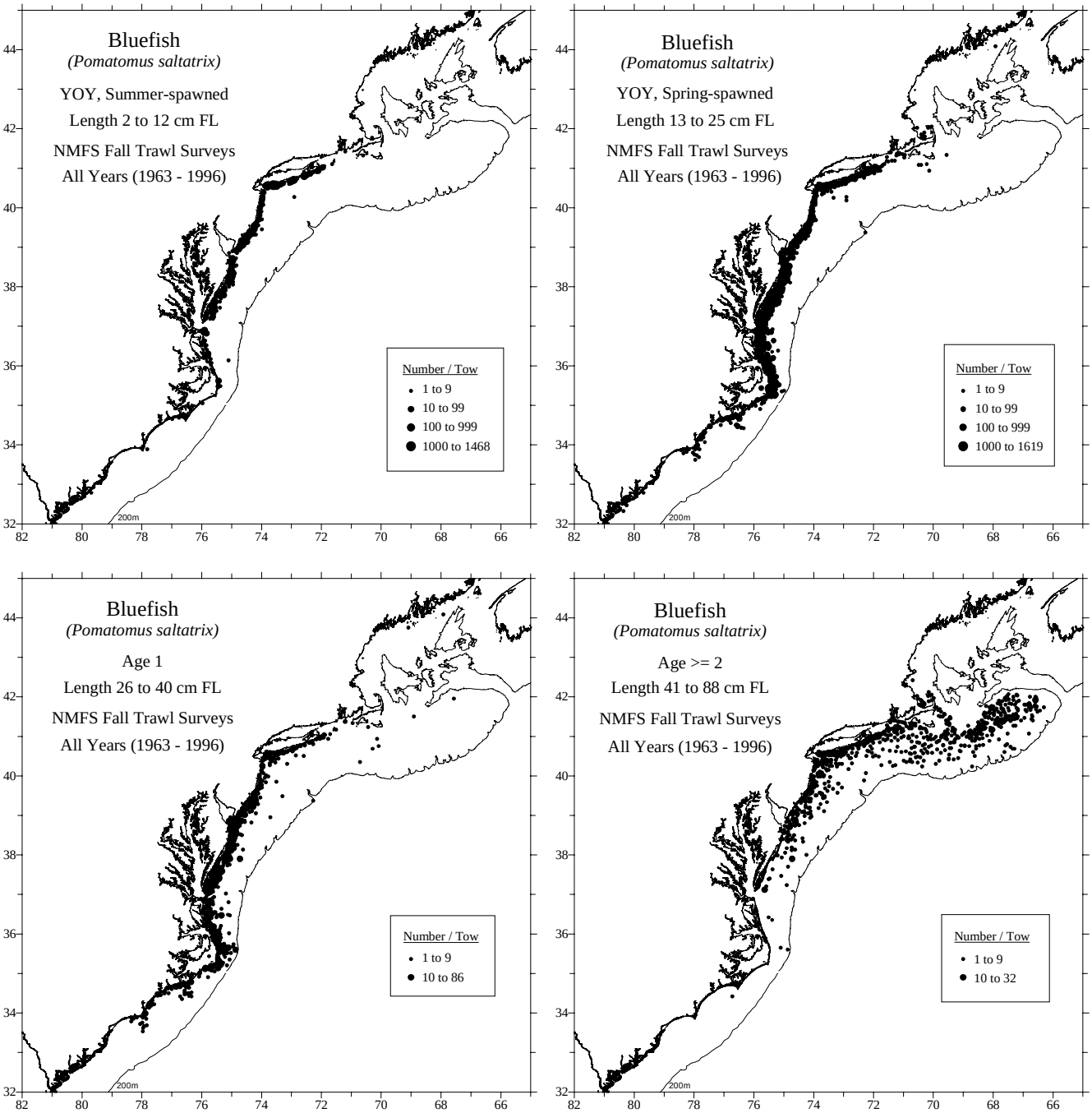


Figure 31. Distribution and abundance of four size classes of bluefish collected off the east coast of the United States during fall NEFSC bottom trawl surveys [1963-1996, all years combined; see Reid *et al.* (1999) for details].

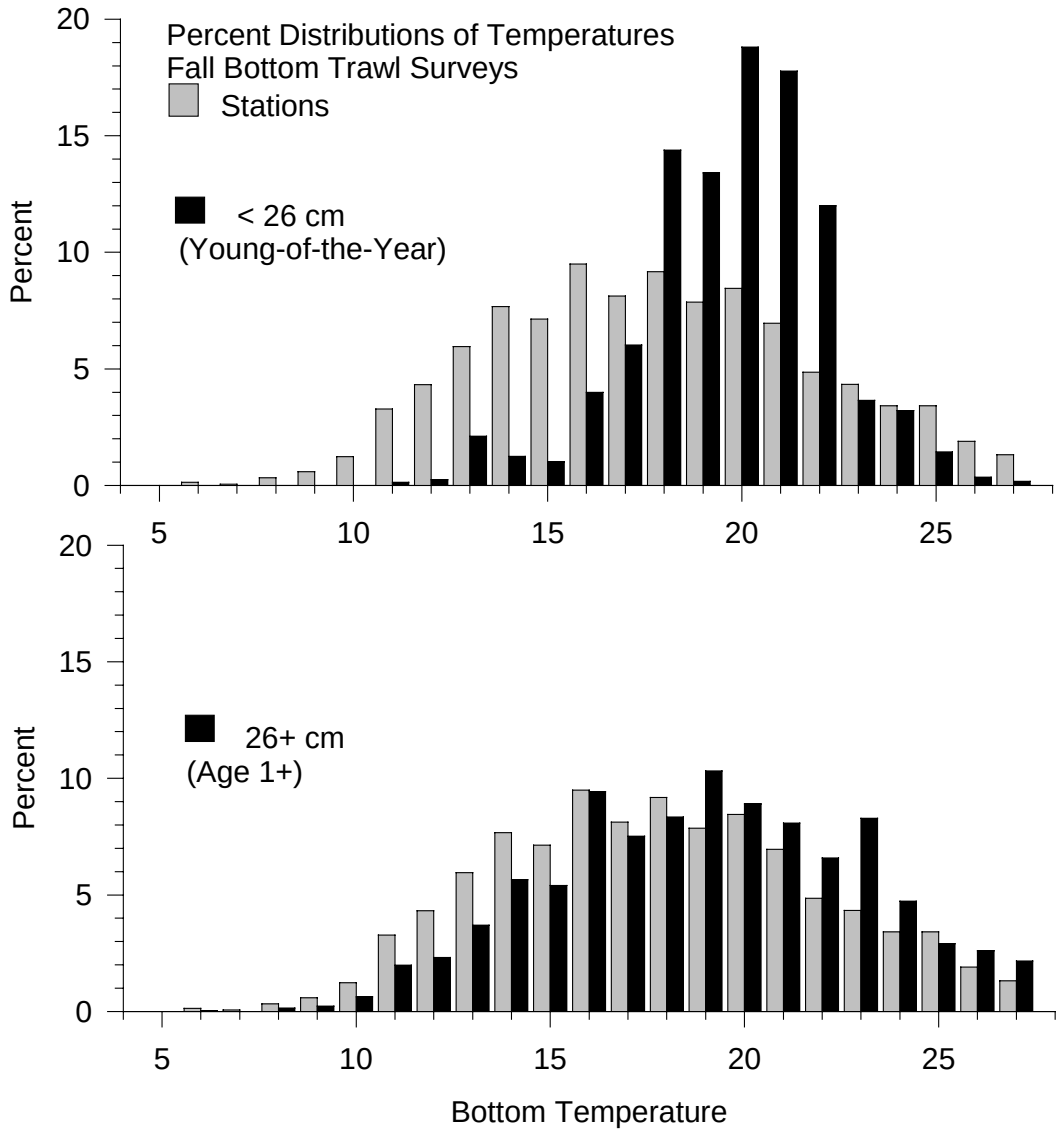


Figure 32. Abundance of young-of-the-year (YOY, < 26 cm) and age 1+ (> 26 cm) bluefish relative to bottom water temperature and depth based on fall east coast NEFSC bottom trawl surveys.

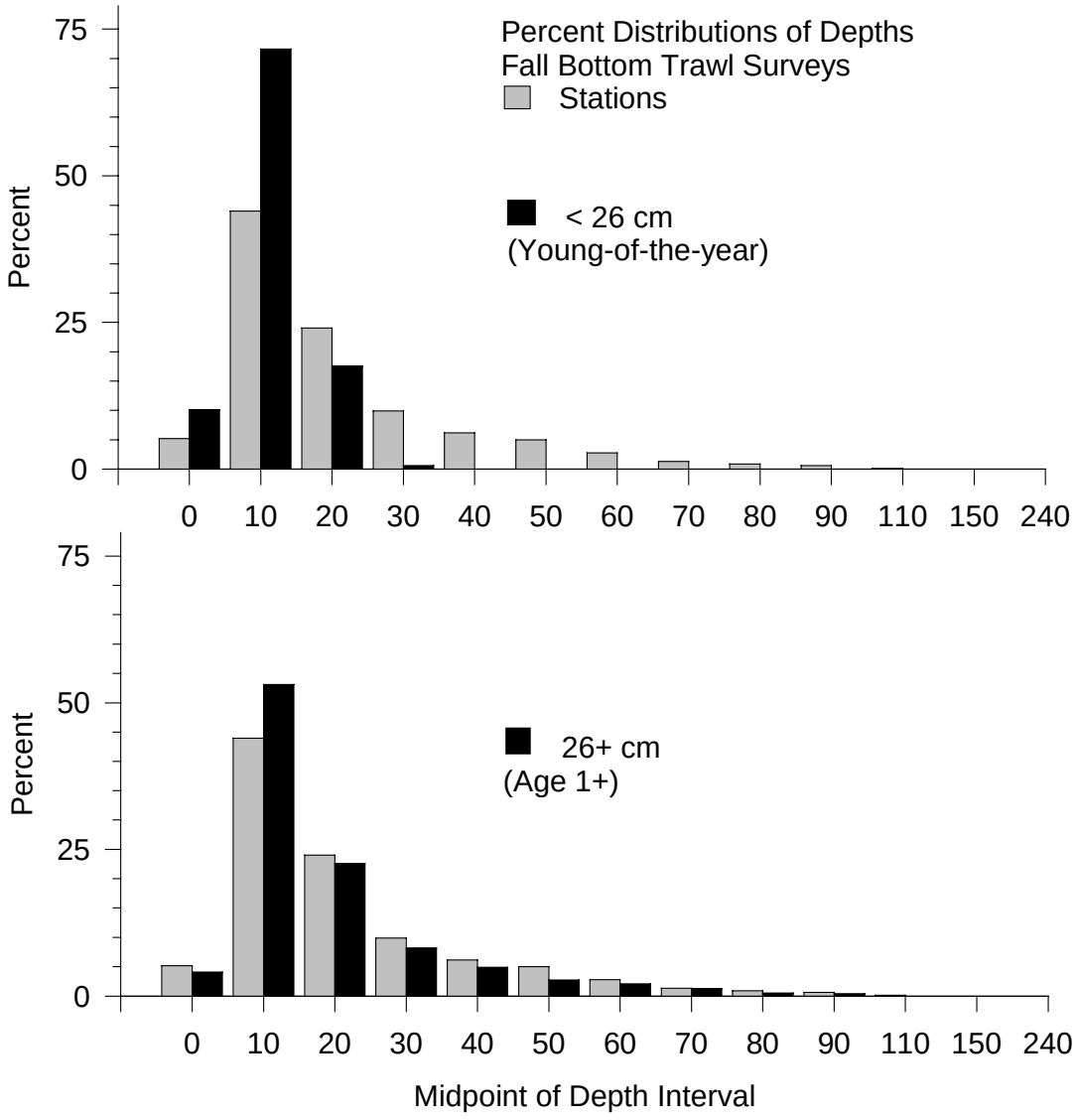


Figure 32. cont'd.

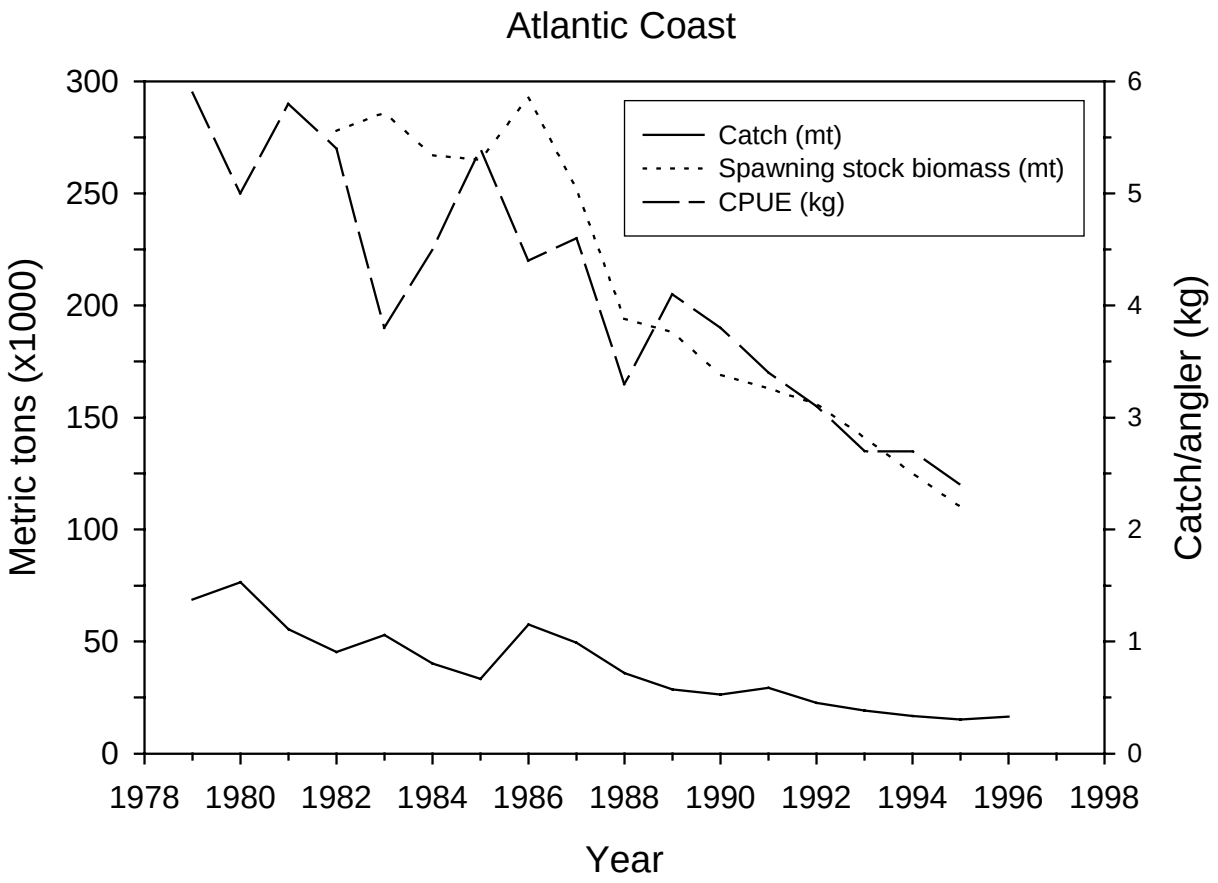


Figure 33. Commercial landings, spawning stock biomass, and catch per unit effort (CPUE) for bluefish along the east coast of the United States (NEFSC, unpublished data).

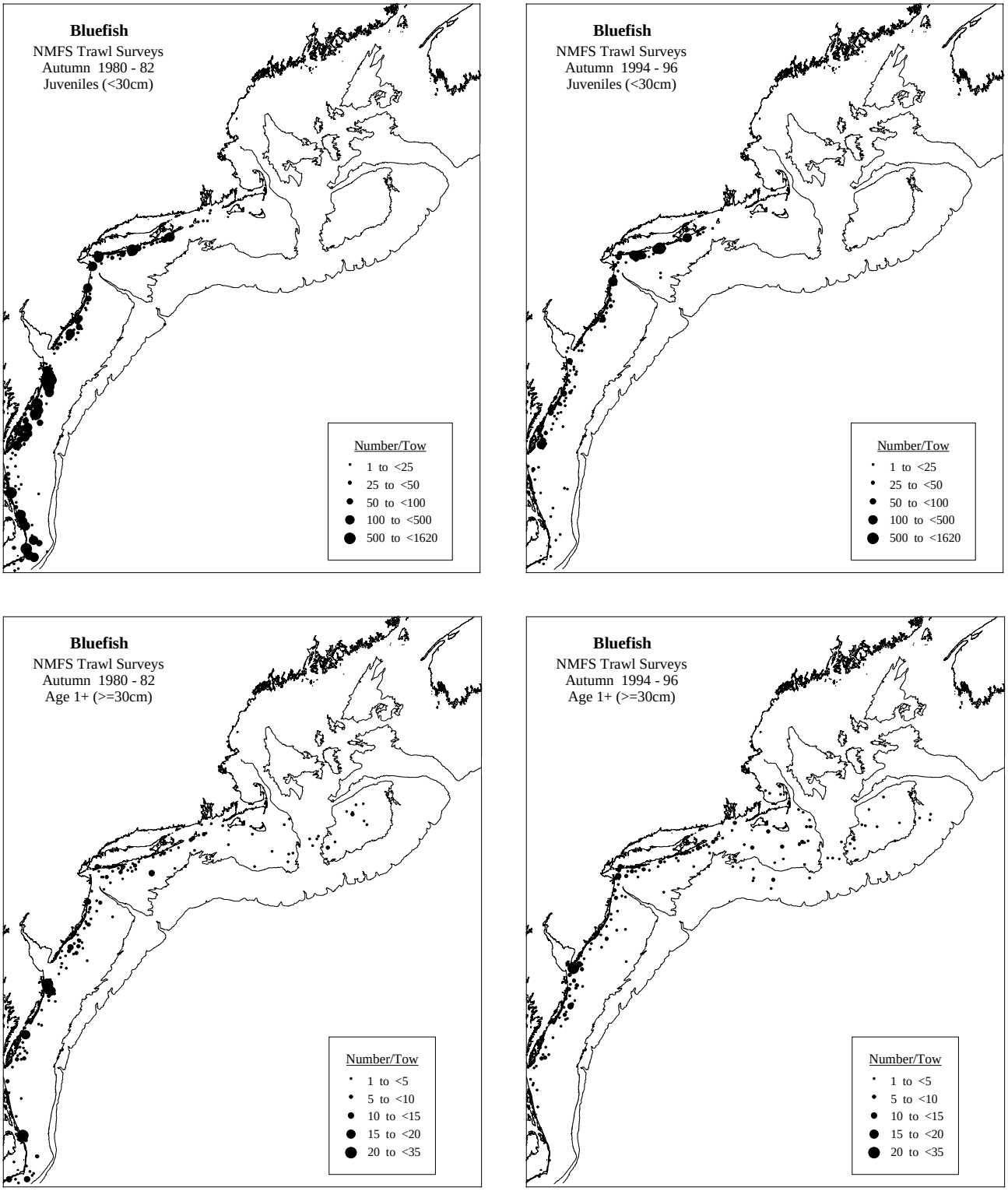


Figure 34. Distribution and abundance of juvenile (< 30 cm) and adult (≥ 30 cm) bluefish during a period of high abundance (1980-1982) and during a period of low abundance (1994-1996) based on autumn NEFSC bottom trawl surveys.

Appendix 1. Bluefish habitat characteristics. MAB = Middle Atlantic Bight; SAB = South Atlantic Bight.

Eggs

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents	Light	Prey
Berrien and Sibunka 1999	1977-1987, Continental Shelf waters, Gulf of Maine to Cape Hatteras	Occur southern New England to Cape Hatteras across entire shelf. Most in mid-shelf waters of MAB, especially off New Jersey and Delaware Bay. May-August.	---	---	---	---	---	---
Present Study	1973-1980, SAB; 1977-1987, MAB	SAB: No data; MAB: most found over depths of 20-40 m, May-August, peak in July.	SAB: No data; MAB: Most in 18-22°C	---	---	---	---	---
Norcross *et al.* 1974	1960-1962, Continental Shelf waters off Virginia	Across shelf, from nearshore to shelf edge, but most in outer half of shelf. June through August, peak July.	22°C or more. (Minimum 18°C)	31 ppt or more. (Minimum 26.6 ppt)	---	Prevailing surface currents transport eggs south and offshore.	Peak spawning evening (1900-2100 hrs.)	---

Appendix 1. cont'd.

Larvae

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents	Light/Vertical Distribution	Prey
Norcross *et al.* 1974	1960-1962, Continental Shelf waters off Virginia	Surface waters, most near edge of shelf.	---	---	---	---	---	---
Kendall and Walford 1979	1965-1967, Continental Shelf waters between Cape Cod and Palm Beach, Florida	Late April: in and near Gulf Stream off Cape Hatteras; May: near edge of shelf off Carolinas; August: mid-shelf depths off New Jersey; September: few in New York Bight; October: concentration near shelf edge off Georgia.	C. Hatteras: 22.1-22.4°C; MAB: 18-26°C SAB: 20-26°C	MAB: 30-32 ppt SAB: 35-38 ppt	---	Larvae from spring spawn advected north via Gulf Stream.	---	---
Kendall and Naplin 1981	July 1974, outer Continental Shelf off Delaware Bay	Vertical distribution study. Most larvae within 4 m of surface.	Surface 23°C	Surface 33 ppt	---	---	Near surface at night; mostly at 4 m during daylight.	Mostly copepod life history stages. Guts full during day; empty during night.
Collins and Stender 1987	1973-1980, Cape Hatteras to Cape Canaveral, Florida.	Mostly in waters > 40 m, primarily in spring, secondarily in late summer.	---	---	---	Southerly counter-current retains larvae in SAB.	> 4 mm strongly associated with surface.	---
Powles 1981	1973-1976, Cape Fear, North Carolina to Cape Canaveral, Florida	Peaked April-May; smallest near edge of shelf; larger closer to shore or advected north.	Smallest larvae > 24°C	Smallest larvae > 35 ppt	---	Ekman drift would impede inshore migration.	Predominately neustonic.	---
Present Study	SAB: 1973-1980; MAB: 1977-1987	SAB: Most April-May near edge of shelf; MAB: May-September, peak July, mostly between depths of 30-70 m.	SAB: No data MAB: Most 18-24°C	---	---	SAB: subject to northward advection by Gulf Stream.	---	---
Hare and Cowen 1996	March 1990, 1991; April 1989; June 1991; Water masses off Cape Hatteras	Larvae occurred March through June; different sizes occurred in different water masses.	March: 20-25°C; April: 18-25°C; June: 21-25°C	March: 36+ ppt; April: 34.5-36.5 ppt; June: 31-36 ppt	---	SW winds in MAB may facilitate cross-shelf transport of larvae.	---	---

Appendix 1. cont'd.

Pelagic-Juveniles

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents	Light/Vertical Distribution	Prey
Hare and Cowen 1996	1988, MAB shelf edge	Cross shelf from Slope Sea to shore early to mid-June.	13.0-15.0°C	---	---	Wind-driven flow may be important, but active swimming probably more important.	Surface oriented	---
Kendall and Walford 1979	1965-1972, East Coast U.S. (MAB and SAB Continental Shelf into Slope Sea)	April (late): many near Cape Hatteras; May: shelf in SAB, largest nearshore; June: MAB between shore and shelf/slope front; Fall: few between Delaware Bay and Cape Hatteras; Winter: few between St. Johns River and Cape Canaveral.	April-May: 22.1-24.0°C Jun: 15.0-20.0°C (most > 18.0°C) Fall: 15.0-18.0°C Winter: 13.0-15.0°C	---	---	Migrate across shelf from shelf/slope front to shore as shelf waters warm.	All collected in near-surface samplers.	---
Collins and Stender 1987	1973-1980, SAB Cape Fear-Cape Canaveral	Seaward of 40 m isobath, mostly spring, some fall occurrences.	---	---	---	Strong negative correlation of size and depth during spring, indicates shoreward movement with growth.	Strongly associated with the surface.	---
Fahay 1975	Seasonal, May 1967-Feb. 1968. SAB Continental Shelf	14 collected between North Carolina and Cape Canaveral, various depths between nearshore and shelf edge. All during May.	19.0-24.0°C	---	---	---	---	---
Powles 1981	1973-1976; SAB Cape fear-Cape Canaveral	Smallest collected near 180 m contour; larger near shore.	180 m contour: > 24.0°C	180 m contour: > 35.0 ppt	---	Weak association of size with proximity to coast. Most probably advected north.	Strongly associated with the surface.	---

Appendix 1. cont'd.

Juveniles and Older

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents/ Tide	Substrate/ Vegetation	Light/ Diel	Prey
Nyman and Conover 1988	1985-1986, both shores of Long Island, New York	Occur in embayments, between late May and October.	Arrive > 20°C; emigrate ca. 15°C	---	---	---	---	---	---
Rountree and Able 1992a, b	1988-1989, Great South Bay, New Jersey	Occur in polyhaline subtidal marsh creeks during summer.	> 20.0°C	23.0-30.0 ppt	---	---	---	Day: tidal creeks Night: open bay	*Menidia menidia*
Able *et al.* 1996	Great Bay, New Jersey	Most bluefish in subtidal creeks.	19.0-28.0°C	25.0-33.0 ppt	---	---	0.3-1.2 m depth; *Ulva lactuca*	---	---
Milstein *et al.* 1977	1972-1974, Great Bay, New Jersey	Several distinct habitats studied; bluefish most abundant in mud-sand, high salinity sites; also sandy beaches.	---	---	---	Slow to moderate, swept by waves.	Mostly sand, some gravel, silt, clay; *Ulva lactuca*, *Spartina alterniflora*, *Fucus* (sometimes).	---	---
Smith 1971	1969-1970, four low-salinity creeks, upper Delaware Bay	Six YOY occurred in two of the creeks, June and July.	24.5-30.0°C	0-5.2 ppt	4.5-7.3	Ebb/flood	Sand/gravel	Day	---
Pristas and Trent 1977	1972, St. Andrews Bay, Florida	Range of depths sampled with gill nets, 24 hrs. Bluefish most dense in shallowest zone (0.7-1.1 m).	11.4-27.0°C	25.3-34.6 ppt	---	---	> 80% sand; vegetation most dense in shallow zone.	Bluefish most abundant at night in shallowest zone.	---
McBride *et al.* 1995	Narragansett Bay, Rhode Island	June-October, shallow beaches.	18.0-28.0°C	25.0-34.0 ppt	---	---	Cobble, gravel, shell, sand; *Ulva* and some *Zostera*	Day sampling only.	---
de Sylva *et al.* 1962	1958-1960, Delaware Bay and River	July and August, mostly in shore zone of lower estuary.	---	usually high, but as low as 3.0 ppt	---	Surf zone, clear to turbid.	Sand	---	Collected with small clupeids and anchovies
Buckel and Conover 1997	1992-1993, Hudson River estuary	Mid-channel and nearshore day-night occurrence and feeding study.	---	---	---	---	---	Most abundant nearshore during daylight; mid-channel at night and twilight.	Gut fullness highest twilight and day, usually low at night. Prey: striped bass, bay anchovy, clupeids.
Present Study	1964-1997, Continental shelf MAB, south to Cape Fear, Cape Canaveral	Inner shelf (over depths < 20 m) during summer and fall.	Most 18-22°C	---	---	---	---	---	

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STANDARD MAIL A

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific ournals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series includes: data reports of long-term or large area studies; synthesis reports for major resources or habitats; annual reports of assessment or monitoring programs; documentary reports of oceanographic conditions or phenomena; manuals describing field and lab techniques; literature surveys of major resource or habitat topics; findings of task forces or working groups; summary reports of scientific or technical workshops; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing. Limited free copies are available from authors or the NEFSC. Issues are also available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series includes: data reports on field and lab observations or experiments; progress reports on continuing experiments, monitoring, and assessments; background papers for scientific or technical workshops; and simple bibliographies. Issues receive internal scientific review but no technical or copy editing. No subscriptions. Free distribution of single copies.

Fishermen's Report **and** ***The Shark Tagger*** -- The ***Fishermen's Report*** (FR) is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of the FR; copies are available through free subscription. ***The Shark Tagger*** (TST) is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of the TST; copies are available only to participants in the tagging program.

To obtain a copy of a technical memorandum or a reference document, or to subscribe to the fishermen's report, write: Research Communications Unit, Northeast Fisheries Science Center, 166 Water St., Woods Hole, MA 02543-1026. An annual list of NEFSC publications and reports is available upon request at the above address. Any use of trade names in any NEFSC publication or report does not imply endorsement.

NOAA Technical Memorandum NMFS-NE-145

Essential Fish Habitat Source Document:

Butterfish, *Peprilus triacanthus*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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NOAA Technical Memorandum NMFS-NE-145

This series represents a secondary level of scientifiic publishing. All issues employ thorough internal scientific review; some issues employ external scientific review. Reviews are -- by design -- transparent collegial reviews, not anonymous peer reviews. All issues may be cited in formal scientific communications.

Essential Fish Habitat Source Document:

Butterfish, *Peprilus triacanthus*, Life History and Habitat Characteristics

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Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

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[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, CHIEF
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INTRODUCTION

Butterfish, *Peprilus triacanthus* (Figure 1), range from Newfoundland and the Gulf of St. Lawrence to the Atlantic and Gulf coasts of Florida (Figure 2), but they are most abundant from the Gulf of Maine to Cape Hatteras (Bigelow and Schroeder 1953; Haedrich 1967; Horn 1970a; Powell *et al.* 1972; Cooley 1978; Scott and Scott 1988; Brodziak 1995; Klein-MacPhee, in review). Butterfish are fast-growing, short-lived, pelagic fishes that form loose schools, often near the surface (Schreiber 1973; Dery 1988; Brodziak 1995). They winter near the edge of the continental shelf in the Middle Atlantic Bight and migrate inshore in the spring into southern New England and Gulf of Maine waters. During the summer, butterfish occur over the entire mid-Atlantic shelf from sheltered bays and estuaries out to about 200 m. In late fall, butterfish move southward and offshore in response to falling water temperatures (Fritz 1965; Horn 1970a; Schreiber 1973; Waring 1975; Azarovitz *et al*. 1980; Klein-MacPhee, in review).

LIFE HISTORY

Butterfish are short-lived and grow rapidly; few individuals live beyond 3 years and most are sexually mature at 1-2 years of age. The maximum age reported is 3+ years (DuPaul and McEachran 1973; Waring 1975; Kawahara 1977a) and 6 years (Draganik and Zukowski 1966). Butterfish are eurythermal (4.4-21.6ºC; Fritz 1965; Schaefer 1967; Horn 1970a) and euryhaline (5-32 ppt; Musick 1972).

EGGS

Butterfish eggs are buoyant, transparent, and spherical (0.68-0.82 mm diameter; Wheatland 1956; Colton and Marak 1969; Martin and Drewry 1978; Elliott and Jiminez 1981). The incubation period is about 48 hrs at 18ºC; 50% of eggs hatched at 72 hrs at about 15ºC (Martin and Drewry 1978; Colton and Honey 1963). Eggs have been collected between 12.8-22.5ºC and 78-100% seawater (Martin and Drewry 1978). At hatching, butterfish are 1.68-1.75 mm; yolk absorption is complete by 2.48-2.64 mm (Colton and Honey 1963; Colton and Marak 1969).

LARVAE

Butterfish larvae range from 2.6 to 16 mm standard length (SL) (Martin and Drewry 1978). By 6 mm they have the thin, deep body that is characteristic of adults and by 15-16 mm they have a forked tail (Horn 1970a; Ditty and Truesdale 1983). At 10-15 mm, larvae are more nektonic than planktonic (Martin and Drewry 1978) and are caught in neuston nets (Powles and Stender 1976; Lux and Wheeler 1992). They begin to associate with jellyfish, *Sargassum*, and other flotsam at this size (Mansueti 1963; Haedrich 1967; Horn 1970b; Thomas and Milstein 1973; Lippson and Lippson 1984). Larvae may undertake diel vertical migrations; more butterfish larvae were collected between 0-4 m at night than during the day (Kendall and Naplin 1981). Metamorphosis is gradual as the larvae progressively assume juvenile characters (Able and Fahay 1998). Rotunno (1992) reported growth rates of 0.227 mm/day for fish 6.0-28.0 mm SL based on otolith analyses.

JUVENILES

Juvenile butterfish range from 16 mm to about 120 mm SL (Martin and Drewry 1978). During their first year, they grow to 76-127 mm, or about half their adult size (Hildebrand and Schroeder 1928; Klein-MacPhee, in review). Early-spawned individuals are 76-102 mm in the fall; late-spawned individuals are 51-76 mm in the fall and 76-127 mm the following spring (Martin and Drewry 1978). Young butterfish (< 30 mm) often live in the shelter of large jellyfishes during their first summer. Although this commensal association is not essential, it is a source of food and provides young butterfish some protection from their predators (Mansueti 1963; Horn 1970b, 1975).

ADULTS

Adult butterfish range from about 120 mm to 305 mm SL (Hildebrand and Schroeder 1928) with an average length of 150-230 mm (Klein-MacPhee, in review). The median length at maturity (L_{50}) for butterfish collected on the northeast shelf (1986-1989) was 12.0 cm total length (TL) for females and 11.4 cm TL for males (O'Brien *et al*. 1993), which corresponds to an age of about 1 year (Horn 1970a; DuPaul and McEachran 1973). In Chesapeake Bay, butterfish begin to mature during their second summer (age 1) and most individuals are mature by their third summer (DuPaul and McEachran 1973). In the New York Bight, ripe females 124-242 mm FL were collected in 3-145 m of water from May through August; less than 5% of the ripe females were collected in the Hudson-Raritan estuary (Wilk *et al.* 1990). At 2+ years of age, butterfish are about 17 cm and at 3+, they are about 19 cm (Waring and Murawski 1982).

REPRODUCTION

Butterfish are broadcast spawners (Horn 1970a) and spawn primarily in the evening or at night (Ferraro 1980;

Kendall and Naplin 1981), but no direct observations have been made (Klein-MacPhee, in review). Butterfish may spawn in the upper part of the water column during the evening; more eggs were collected between 0-4 m at night in the Middle Atlantic Bight than during the day (Kendall and Naplin 1981).

Butterfish are usually reported to spawn offshore (e.g., Wang and Kernehan 1979). Butterfish may spawn a few miles out to sea off Woods Hole, MA and return inshore when they are spent (Klein-MacPhee, in review). However, eggs and larvae have been collected in coastal waters and most estuaries in the northern part of the Middle Atlantic Bight (Hildebrand and Schroeder 1928; Herman 1963; Martin and Drewry 1978; Lux and Wheeler 1992; Able and Fahay 1998). Early stage eggs have been collected in Narragansett Bay and Salem Harbor (Herman 1963; Bourne and Govoni 1988; Elliott and Jiminez 1981), Raritan Bay, NJ (Croker 1965), and in the lower portions of Chesapeake Bay (Lippson and Moran 1974), but not in Delaware Bay (Wang and Kernehan 1979).

Water temperatures appear to regulate butterfish reproduction as spawning dates are progressively later in the year in the northern part of its range (Murawski *et al.* 1978; Rotunno and Cowen 1997; Able and Fahay 1998). Spawning may occur year round in the South Atlantic Bight with a peak in spring (Fahay 1975; Able and Fahay 1998). Spawning probably does not occur below 15ºC (Colton 1972).

Butterfish begin spawning in Chesapeake Bay as early as late May with a peak in activity in June and July (Hildebrand and Schroeder 1928; Pearson 1941). Spawning in the Middle Atlantic Bight occurs from May through October (Smith *et al.* 1980); the gonad weight of fish > 15 cm increases in March and April, reaches its maximum during June and July, and decreases in the fall (Kawahara 1977b). In Long Island Sound, spawning occurs from June through late August with a peak in late July; the principal spawning areas are in the eastern part of the sound (Perlmutter 1939). In Narragansett Bay, butterfish eggs are found from June to August (Herman 1963). In Massachusetts Bay, butterfish spawn from June to August (Bigelow and Schroeder 1953). In the Gulf of Maine, spawning begins in May-June, peaks in July, and ends in August (Bigelow and Schroeder 1953; Smith *et al.* 1980). On the Scotian Shelf, spawning occurs from July to October (Markle and Frost 1985).

The spawning period may be more protracted in the Middle Atlantic Bight than previously thought. Rotunno (1992) and Rotunno and Cowen (1997) estimated spawning times from a birthdate analysis of otoliths from butterfish up to about 50 mm SL collected in the Middle Atlantic and South Atlantic bights. Spawning began in February and continued through at least late July. It began in the south and progressed northward over time, which is consistent with the temporal and spatial distribution of larvae, and suggests that butterfish spawn as they migrate north and inshore on their annual migration in association with seasonal warming of waters on the northeast shelf.

FOOD HABITS

Butterfish feed mainly on planktonic prey including thaliaceans (primarily Larvacea and Hemimyaria), mollusks (primarily squids), crustaceans (copepods, amphipods, and decapods), coelenterates (primarily hydrozoans), polychaetes (primarily Tomopteridae and Goniadidae), small fishes, and ctenophores (Fritz 1965; Leim and Scott 1966; Haedrich 1967; Horn 1970a, b; Schreiber 1973; Mauer and Bowman 1975; Oviatt and Kremer 1977; Tibbets 1977; Murawski *et al.* 1978; Bowman and Michaels 1984; Klein-MacPhee, in review).

The food habits of butterfish collected during the northeast shelf during Northeast Fisheries Science Center (NEFSC) bottom trawl surveys [see Reid *et al.* (1999) for details] were similar to diets reported in the literature (Figure 3). The stomach contents were dominated by unidentifiable animal remains. Arthropods dominated the identifiable items, followed by urochordates (thaliaceans and larvaceans), unidentified plankton, annelids (probably polychaetes), chaetognaths (arrowworms), mollusks (probably squids), cnidarians (coelenterates, probably jellyfish), and fishes.

PREDATION

Butterfish are preyed on by many species including haddock, silver hake, goosefish, weakfish, bluefish, swordfish, sharks (hammerhead), and longfin inshore squid (Bigelow and Schroeder 1953; Scott and Tibbo 1968; Horn 1970a; Maurer and Bowman 1975; Tibbets 1977; Stillwell and Kohler 1985; Brodziak 1995; Klein-MacPhee, in review).

MIGRATION

North of Cape Hatteras, butterfish have a seasonal inshore-offshore north-south migration in response to changing water temperatures. There is a limited seasonal inshore-offshore migration south of Cape Hatteras (Caldwell 1961; Fritz 1965; Horn 1970a; Klein-MacPhee, in review). During the summer, butterfish move north and inshore to feed on planktonic fish, squid, crustaceans, and jellyfish, and to reproduce. They remain near the surface at depths of 22-55 m and often come close inshore; schools are frequently seen on shallow flats and in sheltered bays and estuaries (Bigelow and Schroeder 1953; Klein-MacPhee, in review).

Butterfish are common in the lower Chesapeake Bay from March through November (Geer and Austin 1997;

Murdy *et al*. 1997). They occur in Great Bay, NJ and nearby coastal waters from June through November (Able and Fahay 1998) and in the surf zone off Long Island from June through October (Schaefer 1967). They appear off Rhode Island by the last half of April and off Woods Hole, MA by mid-May, although they are not abundant there until June. Butterfish appear on Georges Bank in early June, but are not abundant until late June or early July. They occur in the Gulf of Maine from late June-early July through the fall (Bigelow and Schroeder 1953; Overholtz and Tyler 1985; Klein-MacPhee, in review). They are found in New Hampshire waters from July to October with a peak in abundance in September (MAFMC 1995). Butterfish are common along the coast of Maine and, in some years, they are common along the coast of Nova Scotia bordering the Gulf of Maine (Bigelow and Schroeder 1953).

During the winter, the stock moves south and offshore. Butterfish are found near the bottom over sand, mud, and rock bottoms. They have been caught to about 200 m deep in the northwest Atlantic (Bigelow and Schroeder 1953; Klein-MacPhee, in review) and over 350 m in the South Atlantic Bight (Barans and Burrell 1976). Butterfish are absent from nearshore waters off New Jersey from January through late April (Milstein 1974; Milstein and Hamer 1976). South of Delaware Bay, the winter offshore movement is not so extensive and some individuals move south in shallow water (Waring and Murawski 1982).

STOCK STRUCTURE

Butterfish range from Newfoundland to Florida and are considered a unit stock (Brodziak 1995; Klein-MacPhee, in review). There may be two stocks south of Cape Hatteras that are isolated by depth, although the shallow stock (< 20 m) may be a *Peprilus triacanthus*-*Peprilus burti* hybrid (Caldwell 1961; Horn 1970a; Klein-MacPhee, in review) or *P. burti*, a Gulf of Mexico species (Pershbacher *et al*. 1979).

HABITAT CHARACTERISTICS

Butterfish are pelagic fishes that form loose schools, often near the surface (Schreiber 1973; Dery 1988; Brodziak 1995). They winter near the edge of the continental shelf in the Middle Atlantic Bight and migrate inshore in the spring into southern New England and Gulf of Maine waters. During the summer, butterfish occur over the entire Mid-Atlantic shelf from sheltered bays and estuaries out to about 200 m. In late fall, butterfish move southward and offshore in response to falling water temperatures (Fritz 1965; Horn 1970a; Schreiber 1973; Waring 1975; Azarovitz *et al*. 1980; Klein-MacPhee, in review).

Table 1 summarizes the environmental conditions where butterfish eggs, larvae, juveniles, and adults have been collected based on a literature survey and analyses of several fishery-independent databases [see Reid *et al.* (1999) for survey methods and location maps].

EGGS AND LARVAE

Butterfish eggs and larvae are pelagic and occur from the outer continental shelf to the lower, high salinity parts of estuaries in Middle Atlantic Bight. Eggs have been collected between 12-23ºC and larvae have been collected between 4-28ºC; eggs and larvae occur at salinities that range from estuarine to full strength seawater (Table 1). Larvae may undertake diel vertical migrations (Kendall and Naplin 1981). Larger larvae (10-15 mm) are more nektonic than planktonic; larger larvae and pelagic juveniles (< 30 mm) often associate with jellyfish, *Sargassum*, and other flotsam (Mansueti 1963; Haedrich 1967; Horn 1970b; Thomas and Milstein 1973; Lippson and Lippson 1984).

Eggs were collected during the NEFSC Marine Resources Monitoring, Assessment and Prediction program (MARMAP) ichthyoplankton survey at water temperatures ranging from 6º to 26ºC; most eggs were collected between 11-17ºC (Figure 4). Eggs were collected in surface waters (upper 200 m or within 5 m of bottom where station depths were < 200 m) in depths ranging from 10 to 1250 m (Figure 4). Most eggs were collected in water depths < 200 m.

Larvae were collected during the MARMAP ichthyoplankton survey at water temperatures ranging from 7-26ºC; most larvae were collected at 9-19ºC (Figure 5). Larvae were collected in surface waters in depths ranging from 10 to 1750 m; most larvae were collected in water depths < 120 m (Figure 5).

Eggs and larvae are common in the high salinity zones of some estuaries in southern New England and the Middle Atlantic Bight and in the mixing zone in Chesapeake Bay (Table 2a).

JUVENILES AND ADULTS

Juvenile and adult butterfish are pelagic fishes that form loose schools, often near the surface (Schreiber 1973; Dery 1988; Brodziak 1995). They are eurythermal (4.4-21.6ºC) and euryhaline (5-32 ppt) and are frequently found over sand, mud, and mixed substrates (Table 1). In Long Island Sound, butterfish were collected less frequently at low dissolved oxygen levels (2.0-2.9ml/l) (Howell and Simpson 1994).

During the summer, butterfish occur inshore where they remain near the surface; schools are frequently seen on shallow flats and in sheltered bays, estuaries, and the surf zone (Bigelow and Schroeder 1953; Leim and Scott

1966; Schaefer 1967; Klein-MacPhee, in review). Smaller juveniles often aggregate under floating objects including the bells of coelenterates (Pearson 1941; Bigelow and Schroeder 1953; Mansueti 1963; Haedrich 1967; Horn 1970b, 1975; Lippson and Moran 1974; Milstein 1974; Scott and Scott 1988). Larger juveniles are pelagic schooling fishes that may congregate near the bottom during the day and disperse upwards at night (Waring 1975).

Juvenile and adult butterfish are common to abundant in the high salinity and mixing zones of estuaries from Massachusetts Bay to the mid-Atlantic; they are rare to uncommon in the high salinity and mixing zones of estuaries in the central and northern Gulf of Maine and in the South Atlantic Bight (Tables 2a, b). In the Gulf of Maine and Middle Atlantic Bight, butterfish move offshore during the winter; fish are found near the bottom over sand, mud, and rock substrates (Bigelow and Schroeder 1953; Klein-MacPhee, in review). The offshore migration is not as pronounced south of Delaware Bay where winter water temperatures are warmer (Waring and Murawski 1982). In the South Atlantic Bight, butterfish are present throughout most of the year in nearshore waters (Keiser 1976).

In the NEFSC bottom trawl survey (1963-1997), juvenile and adult butterfish were collected on the continental shelf from 10 m of water nearshore out to about 360 m of water offshore; most juveniles and adults were collected in water depths < 180 m (Figure 6). Adults were distributed somewhat deeper than juveniles in all seasons. Bottom-water temperatures where juveniles and adults were captured ranged from 3º to 28ºC; most fish were collected between 7-20ºC (Figure 6). Modal water temperatures during spring and fall surveys were 10-14ºC for juveniles and adults.

In the Massachusetts trawl survey (1978-1996), juvenile and adult butterfish were collected at depths ranging from 5 to 80 m; most juveniles were collected between 10-35 m and most adults between 10-50 m (Figure 7). Bottom water temperatures ranged from 9-15ºC in the spring and 7-22ºC in the fall (Figure 7). Adults were caught deeper than juveniles in the fall when water temperatures were lower.

In the Rhode Island Narragansett Bay/Coastal trawl survey, juvenile and adult butterfish were collected at depths between 10-120 ft (3-37 m); most juveniles and adults were collected between 30-110 ft (10-34 m). Bottom water temperatures for juveniles and adults at the time of collection ranged from 9-24ºC in the summer and fall and 5-15ºC in the winter and spring.

In the Connecticut Long Island Sound trawl survey, juvenile and adult butterfish were collected at depths between 6-60 m; most fish were collected between 10-30 m. Bottom water temperatures for juveniles and adults at the time of collection ranged from 7-18ºC in the spring and 8-23ºC in the fall; most fish were captured at 9-15ºC in the spring and 16-21ºC in the fall. Bottom water salinities at the time of collection ranged from 18-32 ppt; most fish were captured at 26-29 ppt.

In the Hudson-Raritan trawl survey, juvenile and adult butterfish were collected at depths ranging from 10-75 ft (3-23 m) (Figure 8). Bottom water temperatures ranged from 8-26ºC, salinities ranged from 19-32 ppt, and dissolved oxygen ranged from 3-10 mg/l (Figure 8).

GEOGRAPHICAL DISTRIBUTION

Butterfish range from Newfoundland and the Gulf of St. Lawrence to the Atlantic and Gulf coasts of Florida (Figure 2), but they are most abundant from the Gulf of Maine to Cape Hatteras (Haedrich 1967; Horn 1970a; Powell *et al*. 1972; Cooley 1978; Scott and Scott 1988; Brodziak 1995; Klein-MacPhee, in review). Butterfish spend the winter near the edge of the continental shelf in the Middle Atlantic Bight and migrate inshore in spring to waters off southern New England and into the Gulf of Maine. During the summer, butterfish range from the Gulf of Maine to the South Atlantic Bight where they are found from sheltered bays and estuaries (Table 3) across the shelf to depths of 200 m and greater. In late fall, butterfish move southward and offshore in response to falling water temperatures (Fritz 1965; Horn 1970a; Schreiber 1973; Waring 1975; Azarovitz *et al*. 1980; Klein-MacPhee, in review). During the winter, they are largely absent from bays and estuaries in the Middle Atlantic Bight and Gulf of Maine (Table 3).

EGGS

Butterfish eggs have been reported in the Gulf of Maine, on Georges Bank, in the Middle Atlantic Bight, and off North Carolina (Smith *et al.* 1980; Rotunno 1992; MAFMC 1995; Rotunno and Cowen 1997). They have also been collected in Salem Harbor, MA and Narragansett Bay, RI (Herman 1963; Bourne and Govoni 1988; Elliott and Jiminez 1981), Block Island Sound (Merriman and Sclar 1952), Long Island Sound (Wheatland 1956), Peconic Bay, NY (Ferraro 1980), Raritan Bay, NJ (Croker 1965), and Chesapeake Bay (Lippson and Moran 1974).

During the MARMAP ichthyoplankton survey, butterfish eggs were collected from Cape Hatteras to the northern Gulf of Maine from April through September (Figure 9). Eggs first appeared in ichthyoplankton collections in April; by May, eggs were distributed along the edge of the continental shelf between Cape Hatteras and Georges Bank and inshore in the southern and middle Mid-Atlantic Bight. As water temperatures increased on the shelf, eggs were found progressively closer to the coast from south to north. Eggs were most abundant and most frequently encountered in July; they were most abundant in the Gulf of Maine in August. By September,

egg abundance declined dramatically; no eggs were collected from October to March.

In coastal bays and estuaries, butterfish eggs were recorded as far north as Penobscot Bay and as far south as Chesapeake Bay (Stone *et al.* 1994). Eggs were abundant in Narragansett Bay and common in Massachusetts Bay, Cape Cod Bay, Waquoit Bay, Buzzards Bay, Long Island Sound, Gardiners Bay, Great South Bay, and Chesapeake Bay (Table 2a).

LARVAE

Butterfish larvae have been reported from the New York Bight and Georges Bank (Smith *et al*. 1980; Wilk *et al*. 1990; Rotunno 1992; MAFMC 1995; Rotunno and Cowen 1997), in Buzzards Bay, MA (Lux and Wheeler 1992), Narragansett Bay, RI (Herman 1963; Bourne and Govoni 1988; Elliott and Jiminez 1981), Raritan Bay, NJ (Croker 1965), Great Bay, NJ (Able and Fahay 1998), Chesapeake Bay (Lippson and Moran 1974), and in the South Atlantic Bight as far south as Cape Kennedy, FL (Fahay 1975; Powles and Stender 1976; Rotunno 1992; Rotunno and Cowen 1997). Larvae were not abundant in the South Atlantic Bight (< 0.5% of total ichthyoplankton) and did not occur frequently (< 10% of stations in a survey of 73 coastal stations) (Fahay 1975).

During the MARMAP ichthyoplankton survey, butterfish larvae were collected from Cape Hatteras into the Gulf of Maine in every month except December (Figure 10). Larvae first appeared in ichthyoplankton collections in January. From January through April, larvae were collected primarily off Cape Hatteras. In May and June, larvae began to appear along the edge of the continental shelf between Cape Hatteras and Georges Bank and inshore in the southern portion of the Middle Atlantic Bight. As water temperatures increased on the shelf, larvae were found progressively closer to the coast from south to north. Larvae were most abundant and most frequently encountered in July and August across the continental shelf in the Middle Atlantic Bight northward to Georges Bank. The abundance of larvae declined sharply from September through November.

In the coastal bays and estuaries of New England and the mid-Atlantic, butterfish larvae were recorded as far north as Penobscot Bay and as far south as Chesapeake Bay (Stone *et al.* 1994). Larvae were common in Boston Harbor, Waquoit Bay, Buzzards Bay, Narragansett Bay, Long Island Sound, Gardiners Bay, Great South Bay, Great South Bay, and Chesapeake Bay (Table 2a).

JUVENILES

Juvenile butterfish occur from Nova Scotia to the Atlantic and Gulf coasts of Florida, but they are most abundant from the Gulf of Maine to Cape Hatteras (Bigelow and Schroeder 1953; Haedrich 1967; Horn 1970a; Powell *et al.* 1972; Cooley 1978; Scott and Scott 1988; Brodziak 1995; Klein-MacPhee, in review). They occur in the high salinity and mixed salinity zones of most estuaries from the Gulf of Maine to Florida (Table 2a) (Jury *et al.* 1994; Stone *et al.* 1994; Geer and Austin 1997; Murdy *et al*. 1997).

During the NEFSC Bottom trawl survey, juvenile butterfish were collected from the northern Gulf of Maine south to Cape Lookout, South Carolina (Figure 11). During the winter and spring, juveniles were collected along the outer continental shelf from southern New England to Cape Hatteras and along the coast near Cape Hatteras. During the summer, juvenile butterfish were collected near the coast throughout the Middle Atlantic Bight and on Georges Bank. During the fall, they were abundant across the shelf throughout the Middle Atlantic Bight and on Georges Bank.

Juvenile butterfish were collected in spring and fall by the Massachusetts Trawl Survey, but catches were 1-2 orders of magnitude greater in the fall (Figure 12). During the Southeast Area Monitoring and Assessment Program-South Atlantic (SEAMAP-SA) bottom trawl survey, juvenile butterfish were collected from Cape Lookout, South Carolina to Cape Kennedy, Florida (Figure 13). Catches were smallest during the winter and largest during the summer.

In the coastal bays and estuaries of New England and the mid-Atlantic, juvenile butterfish were recorded from Passamaquoddy Bay, Maine south to the James River in Virginia (Table 2a) (Stone *et al.* 1994). South of Cape Hatteras, juveniles occurred in bays and estuaries in South Carolina, Georgia, and Florida (Table 2a). Juveniles were abundant in Buzzards Bay, Narragansett Bay, and Long Island Sound, and common in most of the remaining bays and estuaries between Massachusetts Bay and Chesapeake Bay.

In Narragansett Bay, juvenile butterfish were collected in all seasons, but they were rare in winter and spring; they were most abundant in summer when they occurred throughout the bay (Figure 14). In Long Island Sound, butterfish appeared in May; abundance peaked in September-October and declined in November (Figure 15). Juveniles composed 17% of all butterfish caught in May, 91% in September-October, and 73% in November. Juveniles appear in surf zone off Long Island in July and are common from August through October (Schaefer 1967). In the Hudson-Raritan estuary, juveniles were caught in trawls from spring through fall (Figure 16).

ADULTS

Adult butterfish have been reported from Newfoundland to the Atlantic and Gulf coasts of Florida, but they are most abundant from the Gulf of Maine to Cape Hatteras (Bigelow and Schroeder 1953; Haedrich

1967; Horn 1970a; Powell *et al.* 1972; Cooley 1978; Scott and Scott 1988; Brodziak 1995; Klein-MacPhee, in review). They have been collected in high salinity and mixed salinity zones of most estuaries from the Gulf of Maine to Florida (Tables 2a, b) (Hildebrand and Schroeder 1928; DuPaul and McEachran 1973; Wilk and Silverman 1976b; Jury *et al.* 1994; Stone *et al.* 1994; Geer and Austin 1997; Murdy *et al.* 1997).

During the NEFSC bottom trawl survey, adult butterfish were collected from the northern Gulf of Maine south to below Cape Lookout, South Carolina (Figure 11). During the winter and spring, they were distributed along the outer continental shelf from southern New England to Cape Hatteras; they occurred along the coast from Cape Hatteras to Maryland. During the summer, adult butterfish were collected across the shelf throughout the Middle Atlantic Bight, on Georges Bank, and in the coastal Gulf of Maine. During the fall, they were abundant on the shelf throughout the Middle Atlantic Bight, on Georges Bank, and in Massachusetts Bay.

In the Massachusetts Trawl Survey, adult butterfish were collected in the spring primarily south of Cape Cod and in Buzzards Bay, and in the fall primarily in Buzzards Bay, Massachusetts Bay, and around Cape Ann (Figure 12). During the SEAMAP-SA bottom trawl survey, adult butterfish were collected from Cape Lookout, South Carolina to Cape Kennedy, Florida (Figure 13). The size of the catches was similar throughout the year. Butterfish are present in nearshore waters off South Carolina throughout most of the year (Keiser 1976).

In the coastal bays and estuaries of New England and the mid-Atlantic, adult butterfish were recorded from Passamaquoddy Bay in Maine south to the James River in Virginia (Jury *et al.* 1994; Stone *et al.* 1994). South of Cape Hatteras, adults occurred in bays and estuaries in South Carolina, Georgia, and Florida (Table 2a, b). Adults were abundant in Buzzards Bay, Narragansett Bay, and Long Island Sound, and common in most of the remaining bays and estuaries between Massachusetts Bay and Chesapeake Bay (Table 2b). Spawning adults were recorded from Massachusetts Bay south to the Chesapeake Bay, but were common only in Long Island Sound, Gardiners Bay, Great South Bay, and Chesapeake Bay (Table 2b).

In Narragansett Bay, adult butterfish were collected in all seasons, but they were rare in winter and spring; they were most abundant in summer when they occurred throughout the bay (Figure 14). In Long Island Sound, butterfish appeared in May; abundance peaked in September-October and declined in November (Figure 15; Wheatland 1956). Adults composed 83% of all butterfish caught in May, 9% in September-October, and 27% in November. Adults appear in the surf zone off Long Island in May and are common from June through October (Schaefer 1967). Butterfish were among the most abundant species in both of these Long Island surveys. In the Hudson-Raritan estuary, adults were caught from spring through fall (Figure 16).

STATUS OF THE STOCKS

A fishery for butterfish has existed since the late 1800s (Murawski and Waring 1979); from 1920 to 1962, the average annual landings in US waters were 3,000 mt (Waring 1975). In 1963, distant water fleets from Japan, Poland, and the USSR began targeting butterfish from late autumn through early spring when the fish were concentrated offshore (Murawski and Waring 1979; MAFMC 1995). Annual landings increased to a record 19,500 mt in 1973 (Figure 17) (Brodziak 1995). Restrictions were placed on the foreign fisheries and landings subsequently decreased to an average of 6,100 mt from 1977 to 1987. Directed foreign fishing was halted in 1987 and landings continued to decline to an average 2,500 mt in the domestic fishery from 1987 to 1992 (Brodziak 1995; MAFMC 1995). The domestic fishery targeted butterfish from late spring through fall in inshore areas (Murawski and Waring 1979). Butterfish landings totaled 4,500 mt in 1993 and came primarily from southern New England (79% in Rhode Island ports) and the New York Bight. These landings were 60% higher than landings in 1992 and were comparable with record domestic catches in 1987 (Brodziak 1995).

Butterfish biomass estimated from the Northeast Fisheries Science Center bottom trawl surveys has made several record lows and near record highs in the last decade (Figure 17). Despite seasonal increases in biomass and pre-recruit indices, butterfish stock size has decreased and commercial landings remain low (Northeast Fisheries Science Center 1994). Although the demand for butterfish has declined in recent years, the capacity for increased landings remains in an under-exploited fishery (Brodziak 1995). The butterfish stock is not overfished nor approaching an overfished condition (National Marine Fisheries Service 1997).

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Table 1. Summary of life history and habitat characteristics for butterfish, *Peprilus triacanthus.* *

Life Stage	Geographic Location	Habitat	Substrate	Temperature	Salinity
Eggs (0.68-0.82 mm diameter)	Cape Sable, Nova Scotia to Florida; in spring along edge of continental shelf from Georges Bank to Cape Hatteras; found progressively closer to coast from south to north as water temperatures increase. Commonly occur in the saline parts of bays and estuaries from MA to NY and Chesapeake Bay in spring and summer.	Surface waters from continental shelf into estuaries and bays; collected to about 60 m deep in shelf waters. Common in high salinity zone of estuaries and bays from MA through VA. MARMAP Survey: collected in surface waters in 10-1250 m of water.		Literature: 12.8-22.5ºC; MARMAP Survey: 6-26ºC; most eggs collected between 11-17ºC	Estuarine to full seawater; about 25-33 ppt
Larvae (2.6-16 mm SL)	Cape Sable, Nova Scotia to Cape Kennedy, FL; most abundant in central Middle Atlantic Bight in summer, but absent in the winter. Commonly occur in bays and estuaries from MA to NY and Chesapeake Bay in summer and fall.	Surface waters from continental shelf into estuaries and bays; collected to about 60 m deep in shelf waters; common in high salinity zone of estuaries and bays; may spend day deeper in the water column and migrate to the surface at night. MARMAP Survey: collected in surface waters in water 10-1750 m deep.		Literature: 4.4-27.9ºC. MARMAP Survey: 7-26ºC; most eggs collected between 9-19ºC	6.4-37.4 ppt
Juveniles (16 mm SL-120 mm FL)	Cape Sable, Nova Scotia to Florida; most abundant in Middle Atlantic Bight in summer and near the edge of continental shelf in winter. Commonly occur in bays and estuaries from MA to VA from spring through fall; less abundant in bays and estuaries in the Gulf of Maine and in the South Atlantic Bight.	From surface waters to depth on continental shelf; into coastal bays and estuaries; common in inshore areas, including the surf zone, and in high salinity and mixed salinity zones of bays and estuaries. NEFSC Trawl Survey: collected on continental shelf in 10-330 m of water; most collected in < 120 m	Larger individuals found over sandy and muddy substrates.	4.4-29.7ºC; survival reduced below 10ºC	3.0-37.4 ppt
Adults (> 120 mm FL)	Cape Sable, Nova Scotia to Florida; most abundant inshore in Middle Atlantic Bight in summer and near the edge of continental shelf in winter; most abundant north of Cape Cod in summer and fall; commonly occur in bays and estuaries from MA to VA from spring through fall; less abundant in bays and estuaries in the Gulf of Maine and in the South Atlantic Bight; do not migrate far offshore in South Atlantic Bight.	From surface waters to depths of 270-420 m on continental shelf; into coastal bays and estuaries; common in inshore areas, including the surf zone, and in high salinity and mixed salinity zones of bays and estuaries. NEFSC Trawl Survey: collected on continental shelf in 10-360 m of water; most collected in < 180 m.	Schools found over sandy, sandy-silt, and muddy substrates.	4.4-26.0ºC; survival reduced below 10ºC	3.8-33.0 ppt
Spawning Adults	At least the Gulf of Maine to the South Atlantic Bight (SAB); most abundant in Middle Atlantic Bight; in SAB between Cape Hatteras and Cape Kennedy. Common in Long Island Sound, some Long Island bays, and Chesapeake Bay in spring and summer. In NY Bight, caught from May-August.	Spawning occurs on continental shelf, inshore areas, and in bays and estuaries (rarely in bays and estuaries north of Cape Cod). Spawning adults common in Long Island Sound and bays and estuaries of Long Island. In NY Bight, caught between 3-145 m.		Spawning does not occur at < 15ºC	

Table 1. cont'd.

Life Stage	Dissolved Oxygen	Light	Currents	Prey	Predators	Notes
Eggs (0.68-0.82 mm diameter)						Incubation period 2-3 days. Salinity range based on 78-100% seawater (Martin and Drewry, 1978) assuming seawater at 33 ppt.
Larvae (2.6-16 mm SL)						More nektonic than planktonic by 10-15 mm.
Juveniles (16 mm SL-120 mm FL)	Hudson-Raritan Bay: 3-9 mg/l; most 5-8 mg/l	Larger juveniles are pelagic schoolers; may congregate near bottom during day and disperse upward at night.		Feed mainly on planktonic prey, including thaliaceans, squids, copepods, amphipods, decapods, coelenterates, polychaetes, small fishes, and ctenophores.	Preyed on by haddock, silver hake, bluefish, swordfish, weakfish, goosefish, sharks, and long-finned squid	Smaller juveniles may associate with floating objects including jellyfish and inanimate objects.
Adults (> 120 mm FL)	Abundance declines in Long Island Sound at 2.0-2.9 mg/l. Hudson-Raritan Bay: 3-10 mg/l; most 6-9 mg/l.			Feed mainly on planktonic prey, including thaliaceans, squids, copepods, amphipods, decapods, coelenterates, polychaetes, small fishes, and ctenophores.	Preyed on by haddock, silver hake, bluefish, swordfish, weakfish, goosefish, sharks, skates, and long-finned squid	Median size of sexual maturity 120 mm FL based on O'Brien *et al.* (1993).
Spawning Adults						Spawning occurs July-October on Scotian Shelf, May-August in Gulf of Maine, May-October in Middle Atlantic Bight (peak June-August), January-April off Cape Hatteras (peak in March), and year round in South Atlantic Bight (peak in spring).

*In addition to the citations mentioned in the text, the following references were used to compile Table 1: Austin 1973, 1976; Berrien *et al*. 1978; Colton *et al*. 1979; Edwards *et al*. 1962; Lang 1974; Lessard 1974; Obenchain 1981; Wilk and Silverman 1976a; Wilk *et al.* 1977.

Table 2a. Relative abundance of eggs, larvae, and juvenile butterfish (*Peprilus triacanthus*) in New England and Mid-Atlantic estuaries by salinity zone [based on Estuarine Living Marine Resources (ELMR) data in Stone *et al.* 1994]. Salinity zone: T = tidal fresh, M = mixing zone, S = seawater, • = salinity zone not present. Relative abundance: H = highly abundant, A = abundant, C = common, R = rare, blank = not present, na = no data available.

	Eggs			**Larvae**			**Juveniles**		
	T	**M**	**S**	**T**	**M**	**S**	**T**	**M**	**S**
Passamaquoddy Bay		na	na		na	na		R	R
Englishman/Machias Bays								R	R
Narraguagus Bay								R	R
Blue Hill Bay								R	R
Penobscot Bay		R	R		R	R		R	R
Muscongus Bay								R	R
Damariscotta River								R	R
Sheepscot River								R	R
Kennebec/Androscoggin Rivers								R	R
Casco Bay								R	R
Saco Bay								R	R
Wells Harbor	•			•			•		
Great Bay		R	R		R	R		R	R
Merrimack River		R	•		R	•		R	•
Massachusetts Bay	•	•	C	•	•	R	•	•	C
Boston Harbor	•		C	•		C	•		R
Cape Cod Bay	•		C	•		R	•	C	C
Waquoit Bay		R	C		R	C		R	C
Buzzards Bay		R	C		R	C		C	H
Narragansett Bay		R	H		R	C		C	H
Long Island Sound			C			C	R	H	A
Connecticut River								C	
Gardiners Bay			C			C			C
Great South Bay, NY			C			C		R	C
Hudson River/Raritan Bay			R	R	C	R	R	C	C
Barnegat Bay, NJ						R		C	C
New Jersey Inland Bays						R		C	C

Table 2a cont'd.

	Eggs			Larvae			Juveniles		
	T	**M**	**S**	**T**	**M**	**S**	**T**	**M**	**S**
Delaware Bay			R			C		C	C
Delaware Inland Bays									C
Chincoteague Bay									
Chesapeake Bay Mainstream		C	C		C	C		C	C
Chester River									
Coptank River								R	
Patuxent River								R	
Potomac River								R	
Tangier/Pocomoke Sound								R	
Rappahannock River								R	
York River, VA								C	
James River, VA								C	
South Atlantic estuaries – see below									

Butterfish occur in estuaries between North Carolina and Florida, but this species was not included in the ELMR survey of the southeast estuaries (Nelson *et al.* 1991). Information on their occurrence in South Atlantic estuaries is presented below.

North Carolina

- Cape Fear River estuary: butterfish < 0.05% of all fishes caught (Schwartz *et al.* 1979)

South Carolina

- Winyah Bay estuary: butterfish (50-110 mm TL) collected in lower and middle estuary; < 1% of all fishes caught (Wenner *et al*. 1981)
- Charleston Harbor estuary system: occur in Charleston Harbor and lower reaches of Ashley, Cooper, and Wando rivers; < 0.05% of all fishes collected (Stender and Martore 1990)

Georgia

- Sapelo Sound: butterfish collected "occasionally" on ocean beaches and in the lower and middle reaches of estuary; did not occur at salinities < 19.5 ppt (Dahlberg 1972).

Florida

- Pensacola Bay: juveniles present in winter, spring, summer; rare to uncommon (Cooley 1978).
- Santa Rosa Sound: juveniles collected in winter, spring, summer; rare to uncommon (Cooley 1978).
- Escambia Bay: juveniles collected in winter, spring, fall; rare to uncommon (Cooley 1978).
- Butterfish recorded from ocean beaches on Atlantic and Gulf coasts (to Mississippi) and in Tampa Bay (Powell *et al*. 1972).

Table 2b. Relative abundance of spawning adult and adult butterfish (*Peprilus triacanthus*) in New England and Mid-Atlantic estuaries by salinity zone [based on Estuarine Living Marine Resources (ELMR) data in Stone *et al.* 1994]. Salinity zone: T = tidal fresh, M = mixing zone, S = seawater, • = salinity zone not present. Relative abundance: H = highly abundant, A = abundant, C = common, R = rare, blank = not present, na = no data available.

	Spawning Adults			**Adults**		
	T	**M**	**S**	**T**	**M**	**S**
Passamaquoddy Bay					R	R
Englishman/Machias Bays					R	R
Narraguagus Bay					R	R
Blue Hill Bay					R	R
Penobscot Bay					R	R
Muscongus Bay					R	R
Damariscotta River					R	R
Sheepscot River					R	R
Kennebec/Androscoggin Rivers					R	R
Casco Bay					R	R
Saco Bay					R	R
Wells Harbor	•			•		
Great Bay					R	R
Merrimack River	•			•	R	
Massachusetts Bay	•	•	R	•	•	C
Boston Harbor	•			•	R	R
Cape Cod Bay	•			•	C	C
Waquoit Bay	•		R	•	R	C
Buzzards Bay	•		R	•	C	H
Narragansett Bay			R		C	A
Long Island Sound			C		A	H
Connecticut River			•		C	•
Gardiners Bay	•		C	•	C	C
Great South Bay, NY	•		C	•	R	C
Hudson River/Raritan Bay					C	C
Barnegat Bay, NJ					R	R
New Jersey Inland Bays						R

Table 2b cont'd.

	Spawning Adults			Adults		
	T	**M**	**S**	**T**	**M**	**S**
Delaware Bay			R		R	C
Delaware Inland Bays	•			•		C
Chincoteague Bay	•	•		•	•	
Chesapeake Bay Mainstream		C	C		C	C
Chester River			•			•
Coptank River			•		R	•
Patuxent River			•		R	•
Potomac River			•		R	•
Tangier/Pocomoke Sound	•		•	•	R	•
Rappahannock River			•		R	•
York River, VA			•		C	•
James River, VA			•		C	•
South Atlantic estuaries[1]						

[1]See note at bottom of Table 2a.

Table 3. Abundance of butterfish eggs, larvae, juveniles, adults, and spawning adults in New England and Mid-Atlantic estuaries by month summarized across salinity zones [based on Estuarine Living Marine Resources (ELMR) data in Stone *et al.* 1994]. Maximum abundance: A = abundant, C = common, R = rare, blank = not present.

	Eggs		**Larvae**		**Juveniles**		**Adults**		**Spawning Adults**	
Estuary	months present	max. abun.	months present	max. abun.	months present	max. abun.	months present	max. abun.	months present	max. abun.
Passamaquoddy Bay	----------		----------		-----JJASO--	R	-----JJASO--	R	----------	
Englishman/Machias Bays	----------		----------		-----JJASO--	R	-----JJASO--	R	----------	
Narraguagus Bay	----------		----------		-----JJASO--	R	-----JJASO--	R	----------	
Blue Hill Bay	----------		----------		-----JJASO--	R	-----JJASO--	R	----------	
Penobscot Bay	------JAS---	R	------JAS---	R	-----JJASO--	R	-----JJASO--	R	----------	
Muscongus Bay	----------		----------		-----JJASO--	R	-----JJASO--	R	----------	
Damariscotta River	----------		----------		-----JJASO--	R	-----JJASO--	R	----------	
Sheepscot River	----------		----------		-----JJASO--	R	-----JJASO--	R	----------	
Kennebec/Androscoggin Rivers	----------		----------		-----JJASO--	R	-----JJASO--	R	----------	
Casco Bay	----------		----------		-----JJASO--	R	-----JJASO--	R	----------	
Saco Bay	----------		----------		-----JJASO--	R	-----JJASO--	R	----------	
Wells Harbor	----------		----------		----------		----------		----------	
Great Bay	-----JJAS---	R	-----JJAS---	R	-----JJASO--	R	-----JJASO--	R	----------	
Merrimack River	-----JJA----	R	-----JJA----	R	-----JJAS---	R	-----JJAS---	R	----------	
Massachusetts Bay	-----JJAS---	C	-----JJAS---	R	-----JJASO--	C	-----JJASO--	C	-----JJAS---	R
Boston Harbor	-----JJAS---	C	------JAS---	C	-----JJASO--	R	-----JJASO--	R	----------	
Cape Cod Bay	-----JJASO--	C	------JASO--	R	-----JJASO--	C	-----JJASO--	C	----------	
Waquoit Bay	----MJJA----	C	-----JJASO--	C	----MJJASO--	C	----MJJASO--	C	----MJJAS---	R
Buzzards Bay	----MJJAS---	C	-----JJASO--	C	---AMJJASOND	A	---AMJJASOND	A	-----JJAS---	R
Narragansett Bay	----MJJA----	A	-----JJASO--	C	---AMJJASOND	A	---AMJJASOND	A	----MJJA----	R
Gardiners Bay	----MJJ-----	C	----MJJ-----	C	----MJJASOND	C	----MJJASOND	C	----MJJ-----	C
Long Island Sound	-----JJAS---	C	-----JJASON-	C	----MJJASOND	A	----MJJASOND	A	-----JJAS---	C
Connecticut River	----------		----------		----MJJASOND	C	----MJJASOND	C	----------	
Great South Bay	----MJJ-----	C	----MJJA----	C	----MJJASOND	C	----MJJASOND	C	----MJJ-----	C
Hudson River/Raritan Bay	-----JJA----	R	----MJJASON-	C	---AMJJASON-	C	---AMJJASON-	C	----------	
Barnegat Bay	----------		-----JJA----	R	-----JJASO--	C	----MJJASO--	R	----------	
New Jersey Inland Bays	----------		-----JJA----	R	-----JJASO--	C	------JAS---	R	----------	
Delaware Bay	----MJJ-----	R	----MJJ-----	C	------JASOND	C	----MJJASO--	C	----MJJ-----	R
Delaware Inland Bays	----------		----------		----MJJASON-	C	----MJJASON-	C	----------	
Chincoteague Bay	----------		----------		----------		----------		----------	
Chesapeake Bay	----MJJ-----	C	-----JJA----	C	------JASO--	C	---AMJJASON-	C	----MJJ-----	C
Potomac River	----------		----------		-----JJASO--	R	----MJJASO--	R	----------	
Rappahannock River	----------		----------		------JASON-	R	---AMJJASON-	R	----------	
York River	----------		----------		------JASON-	C	---AMJJASON-	C	----------	
James River	----------		----------		------JASON-	C	---AMJJASON-	C	----------	
Patuxent River	----------		----------		------JAS---	R	-----JJAS---	R	----------	
Chester River	----------		----------		----------		----------		----------	
Choptank River	----------		----------		------JAS---	R	-----JJAS---	R	----------	
Tangier/Pocomoke Sound	----------		----------		------JASO--	R	----MJJASO--	R	----------	

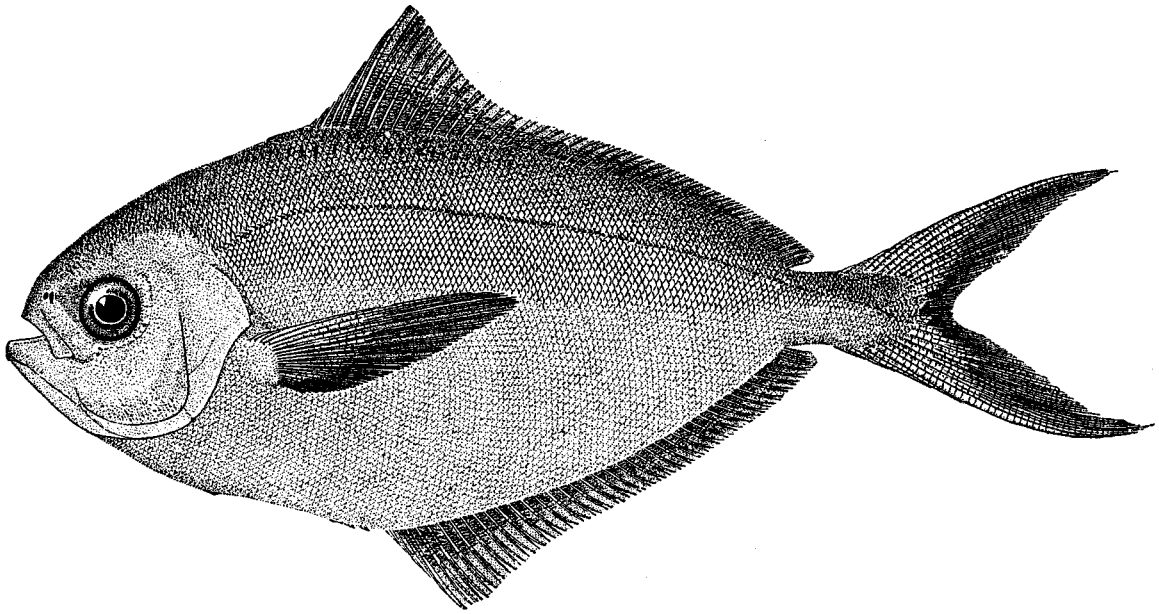
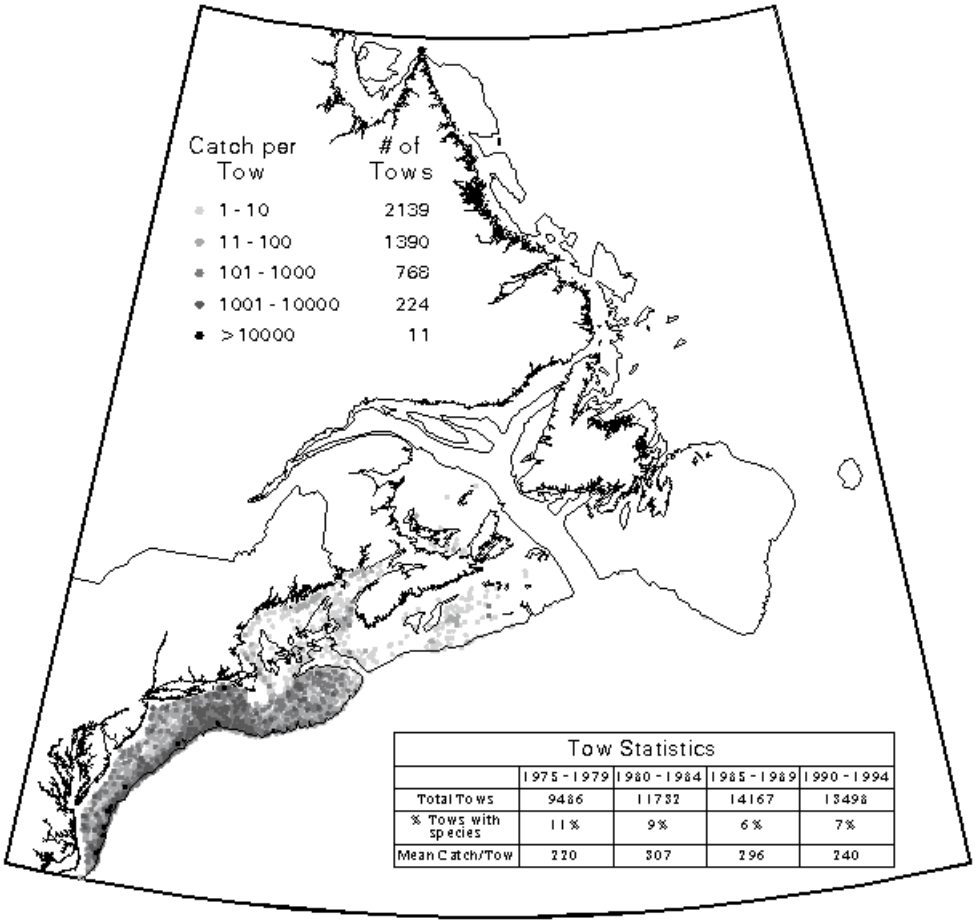


Figure 1. The adult butterfish, *Peprilus triacanthus* (from Goode 1884).



Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	11%	9%	6%	7%
Mean Catch/Tow	220	307	296	240

Figure 2. The distribution of butterfish from Newfoundland to Cape Hatteras. Data are from the U.S. NOAA/Canada DFO East Coast of North America Strategic Assessment Project (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

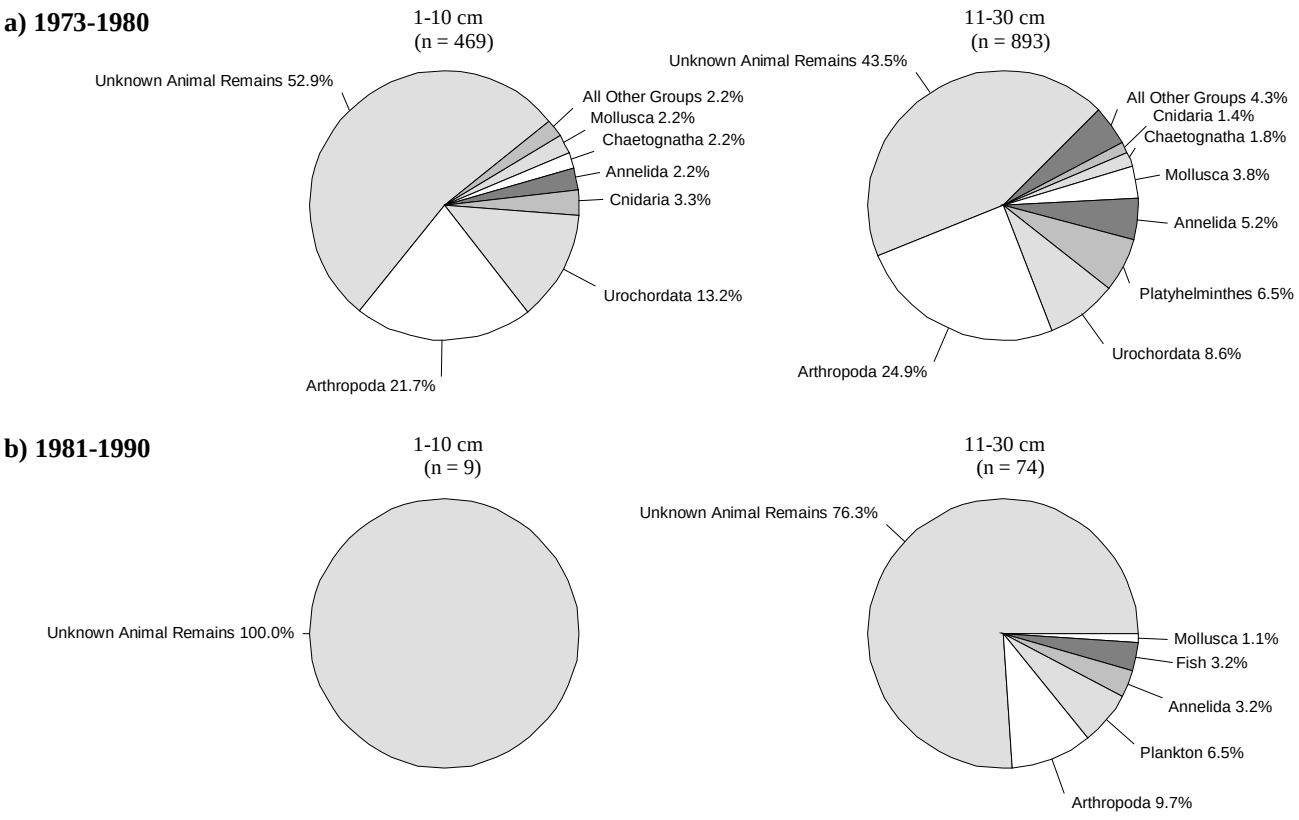


Figure 3. Abundance (percent occurrence) of the major prey items of butterfish collected during NEFSC bottom trawl surveys from 1973-1980 and 1981-1990. The 1-10 cm size range corresponds, at least roughly, to juveniles, and the 11-30 cm size class corresponds to adults. The category "animal remains" refers to unidentifiable animal matter. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details].

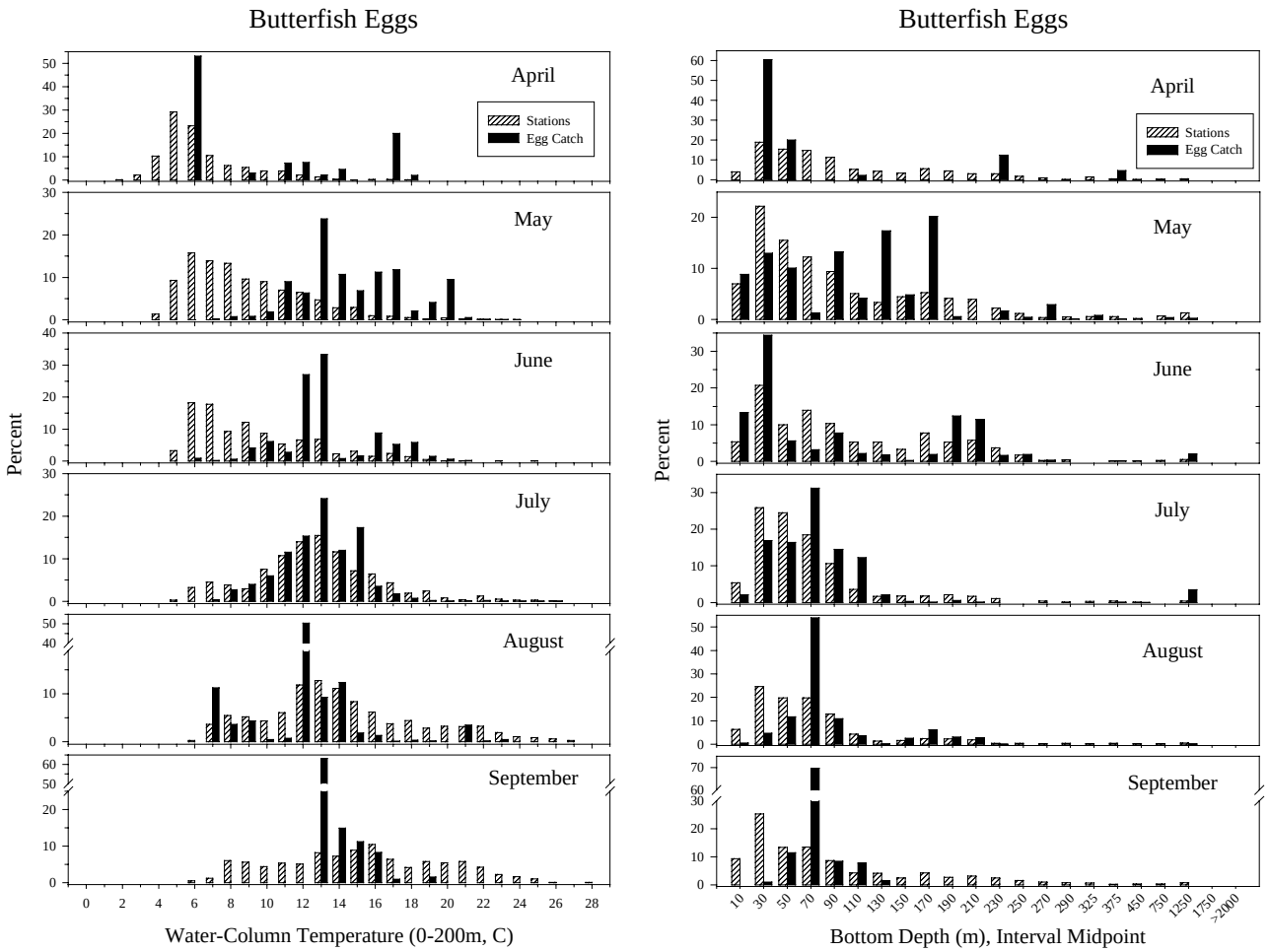


Figure 4. Abundance of butterfish eggs relative to water column temperature (to a maximum of 200 m) and bottom depth from NEFSC MARMAP ichthyoplankton surveys (1978-1987) by month for all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

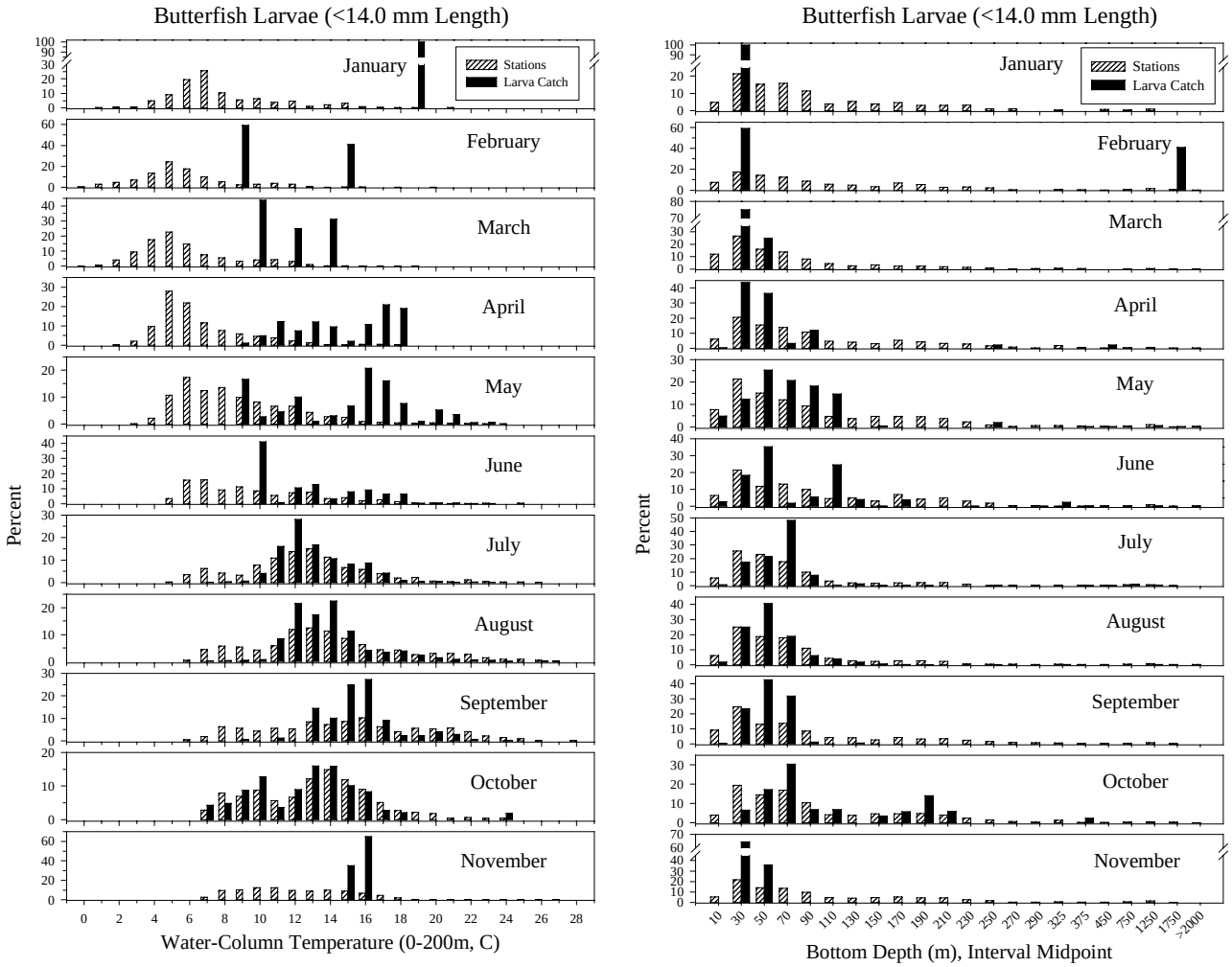


Figure 5. Abundance of butterfish larvae (< 14 mm) relative to water column temperature (to a maximum of 200 m) and bottom depth from NEFSC MARMAP ichthyoplankton surveys (1977-1987) by month for all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

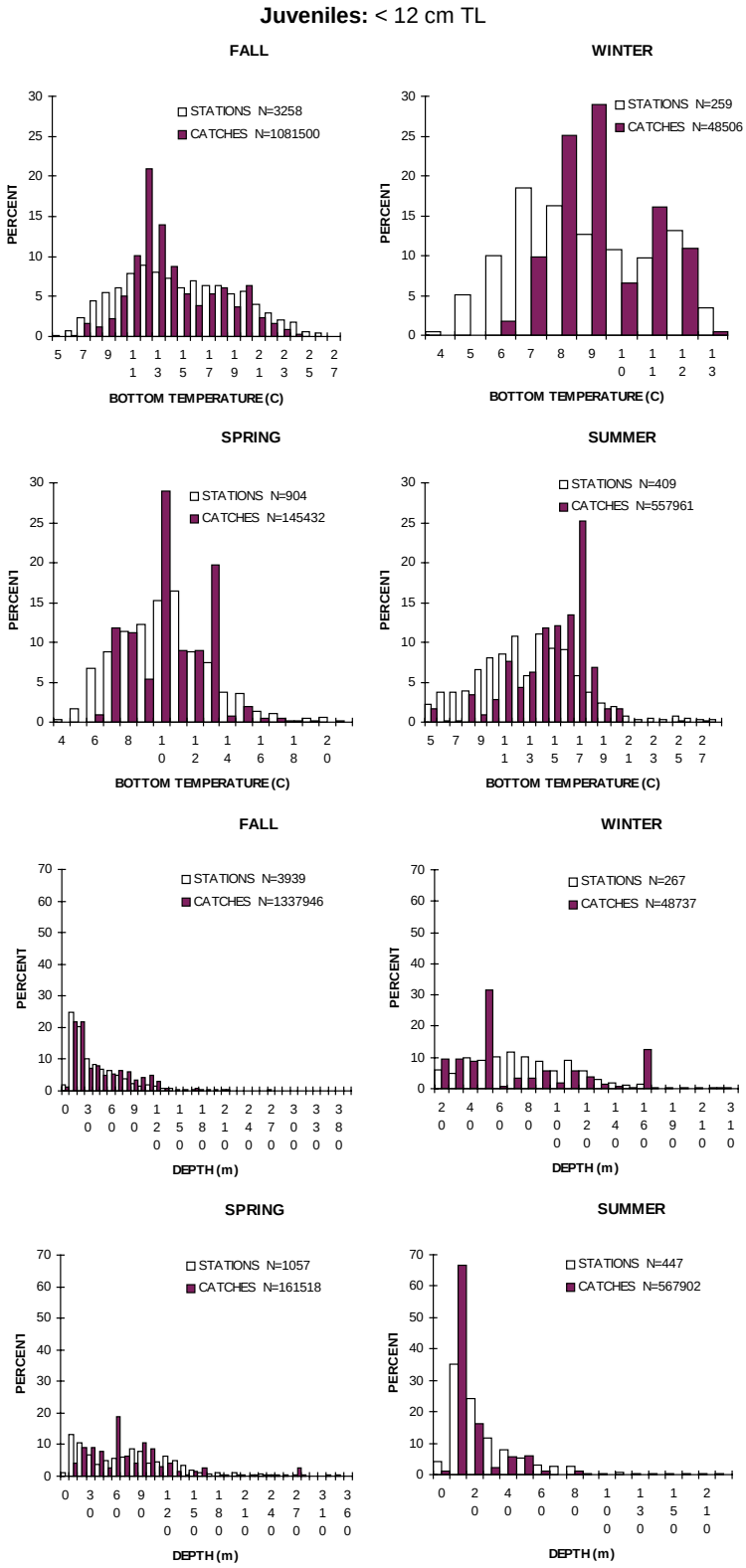


Figure 6. Abundance of juvenile (< 12 cm) and adult (≥ 12 cm) butterfish relative to bottom water temperature and depth based on NEFSC bottom trawl surveys (1963-1997) by season for all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

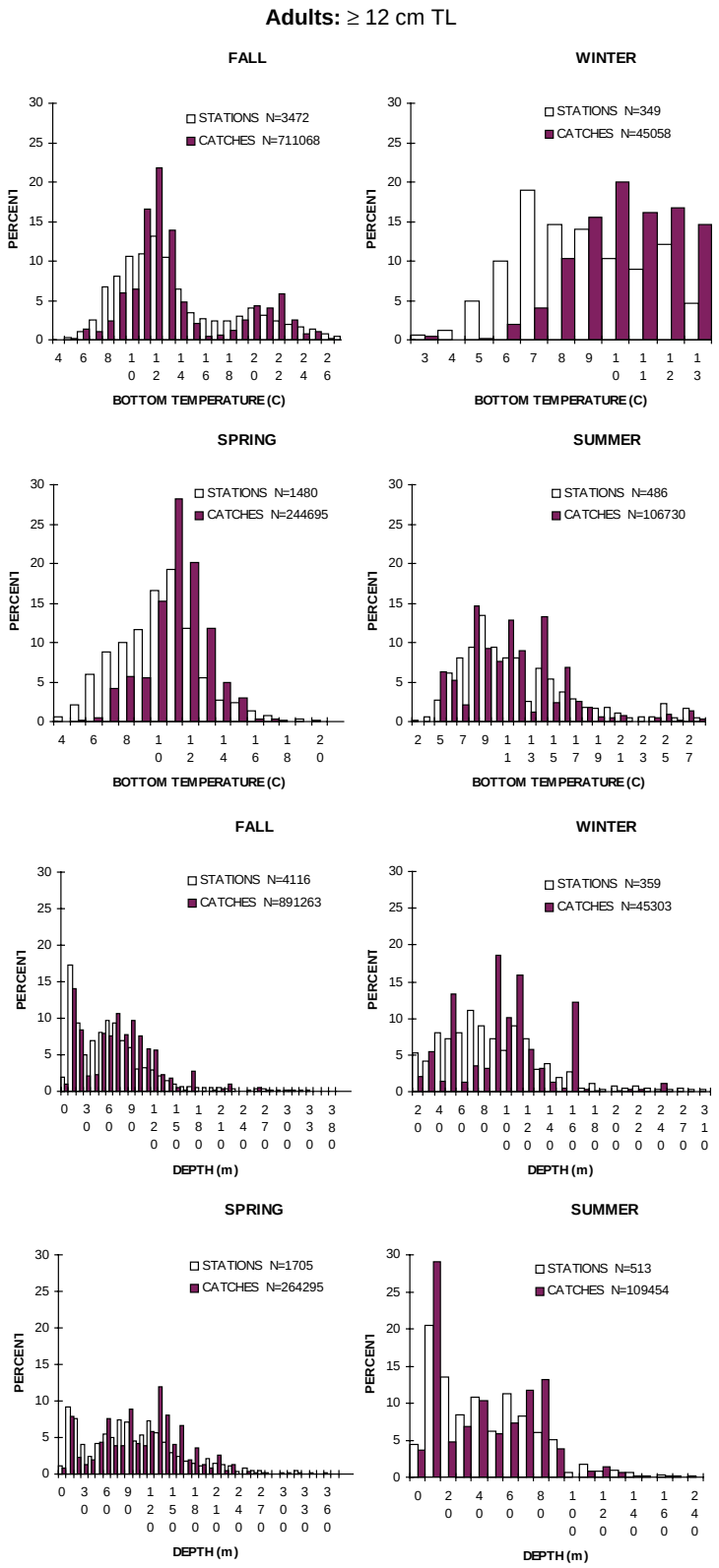


Figure 6. cont'd.

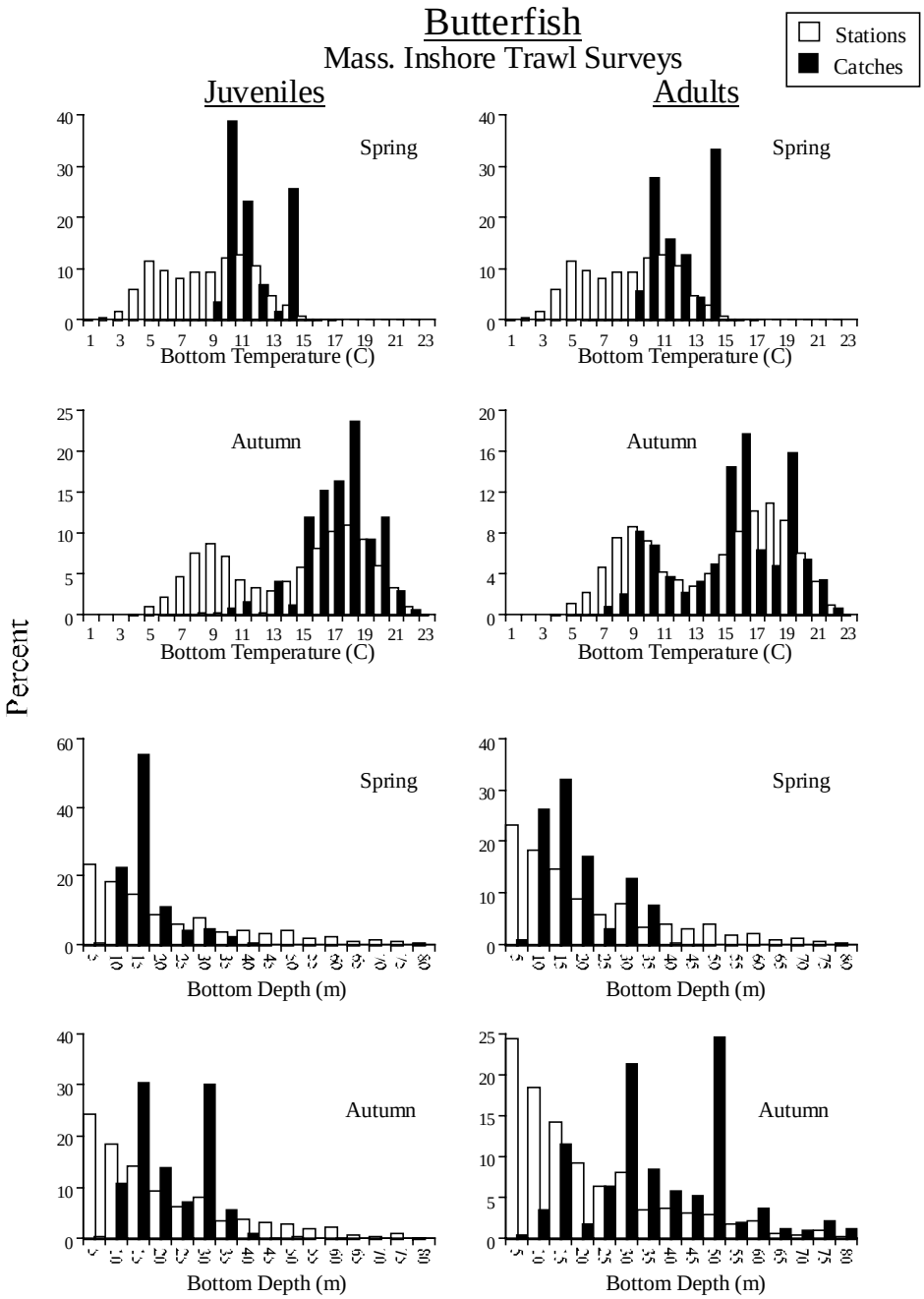


Figure 7. Abundance of juvenile and adult butterfish relative to bottom water temperature and depth based on Massachusetts inshore bottom trawl surveys (spring and autumn 1978-1996, all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

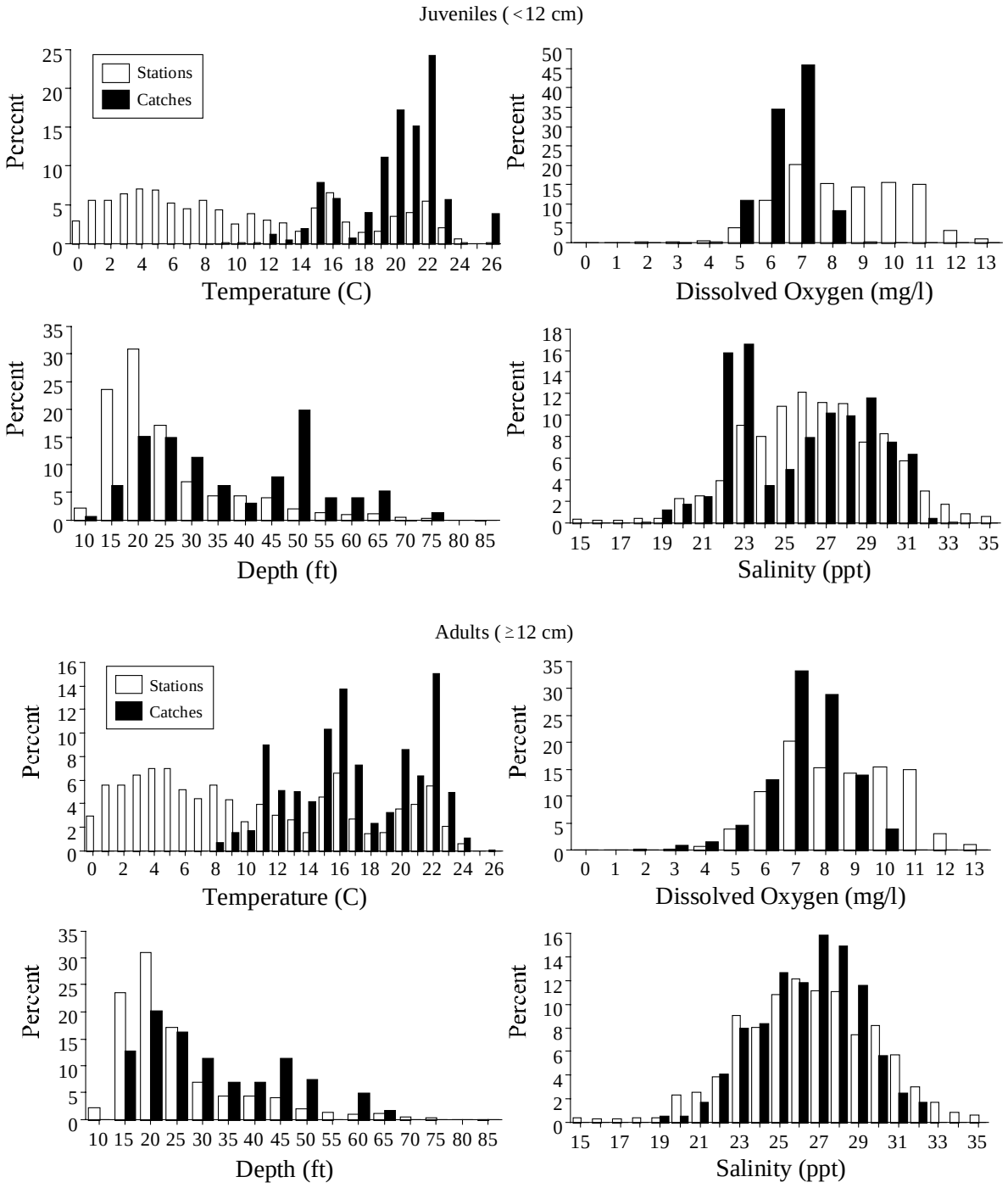


Figure 8. Abundance of juvenile and adult butterfish relative to bottom water temperature, depth, dissolved oxygen and salinity from Hudson-Raritan estuary trawl surveys (1992-1997) for all years combined.

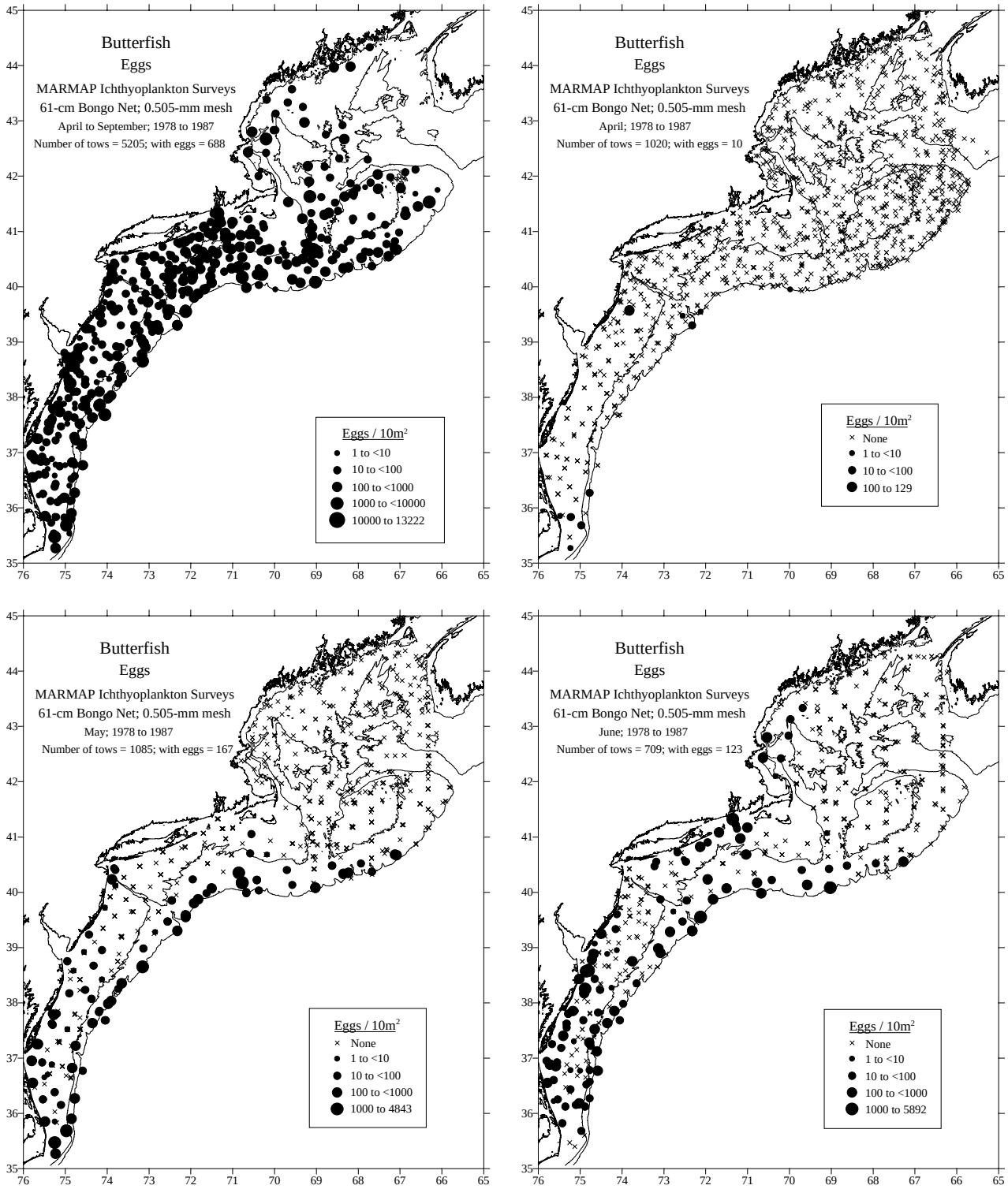
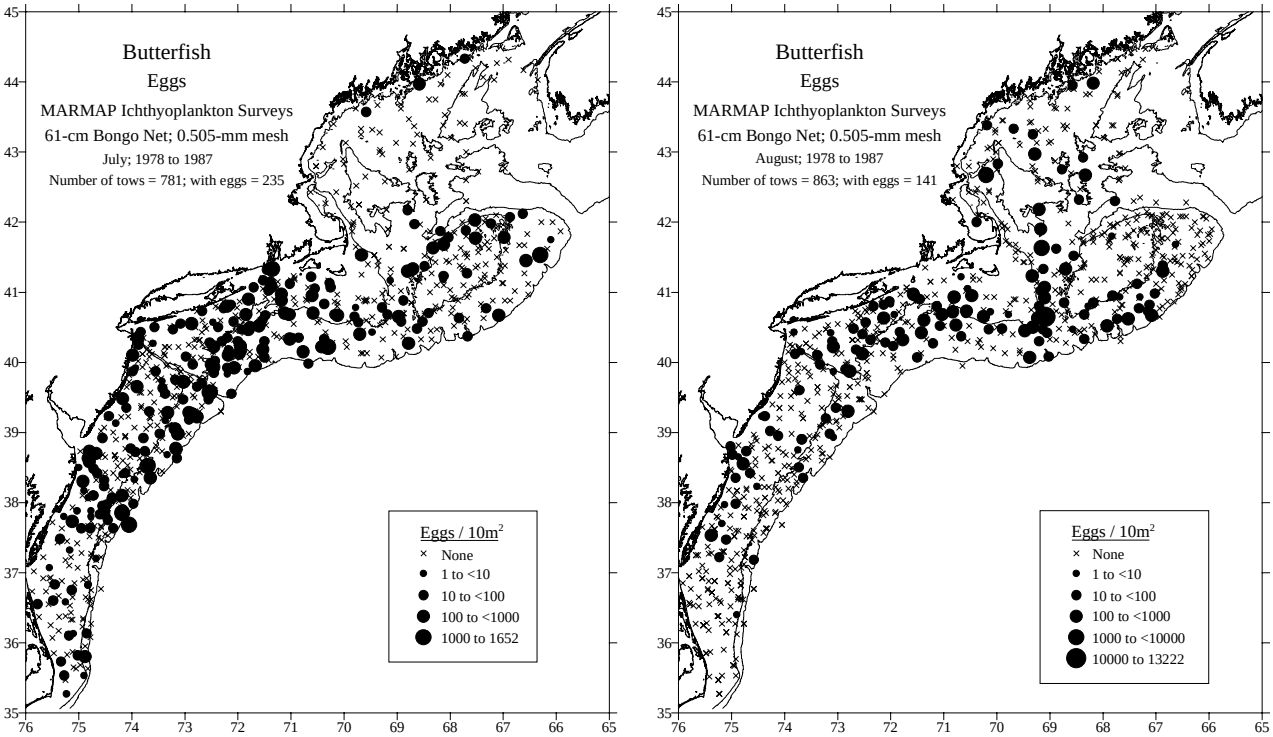
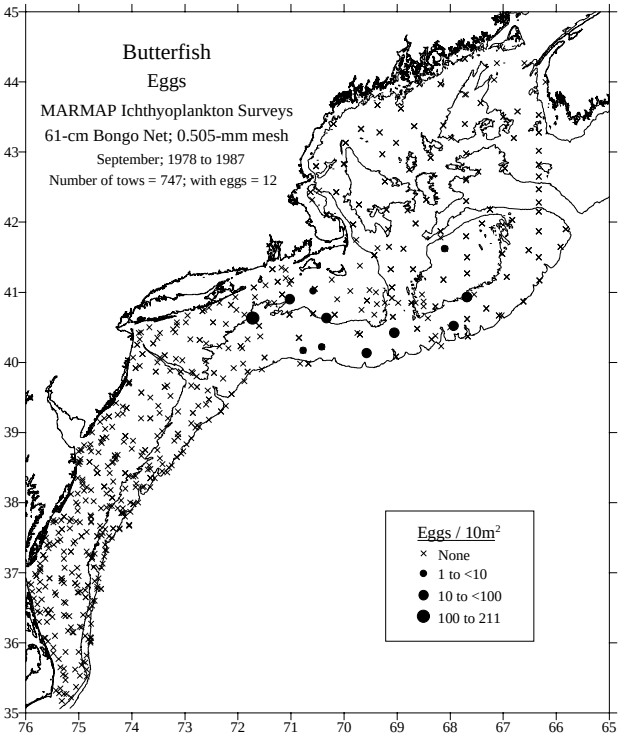


Figure 9. Distribution of butterfish eggs based on NEFSC MARMAP ichthyoplankton surveys from April to September, 1978-1987 [see Reid *et al.* (1999) for details].





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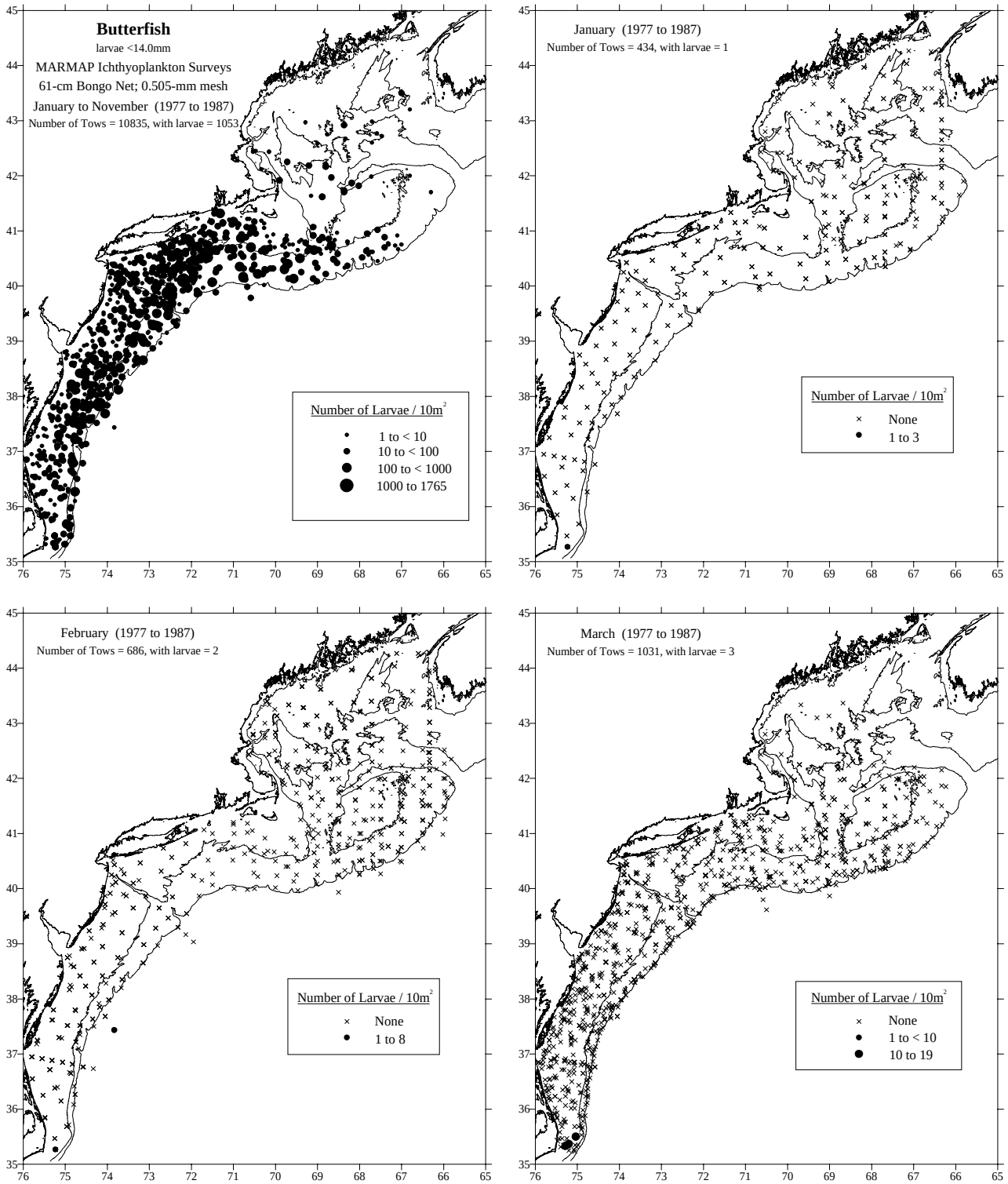
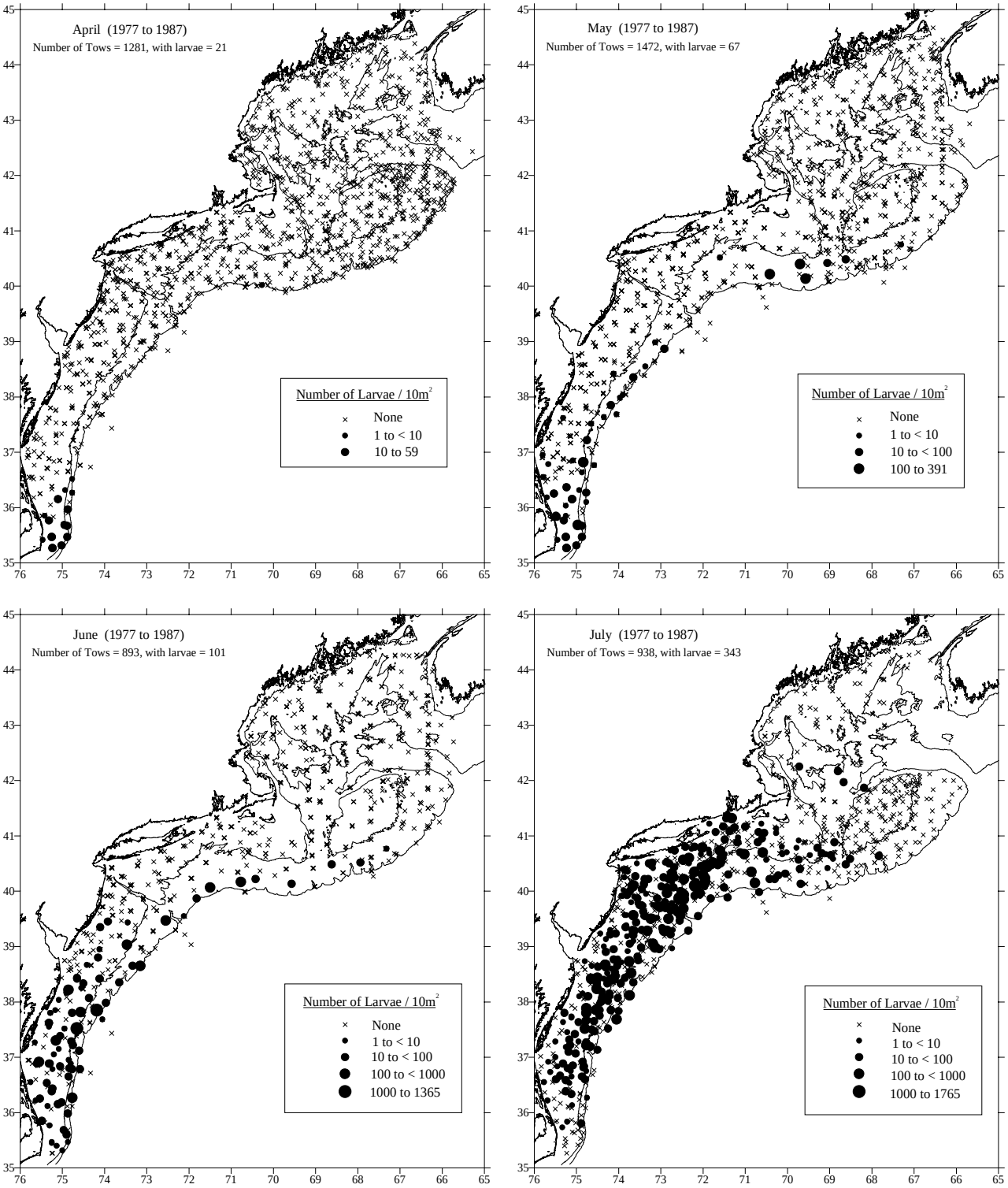


Figure 10. Distribution of butterfish larvae (< 14 mm) collected during NEFSC MARMAP ichthyoplankton surveys from January through November, 1977-1987 [see Reid *et al.* (1999) for details].



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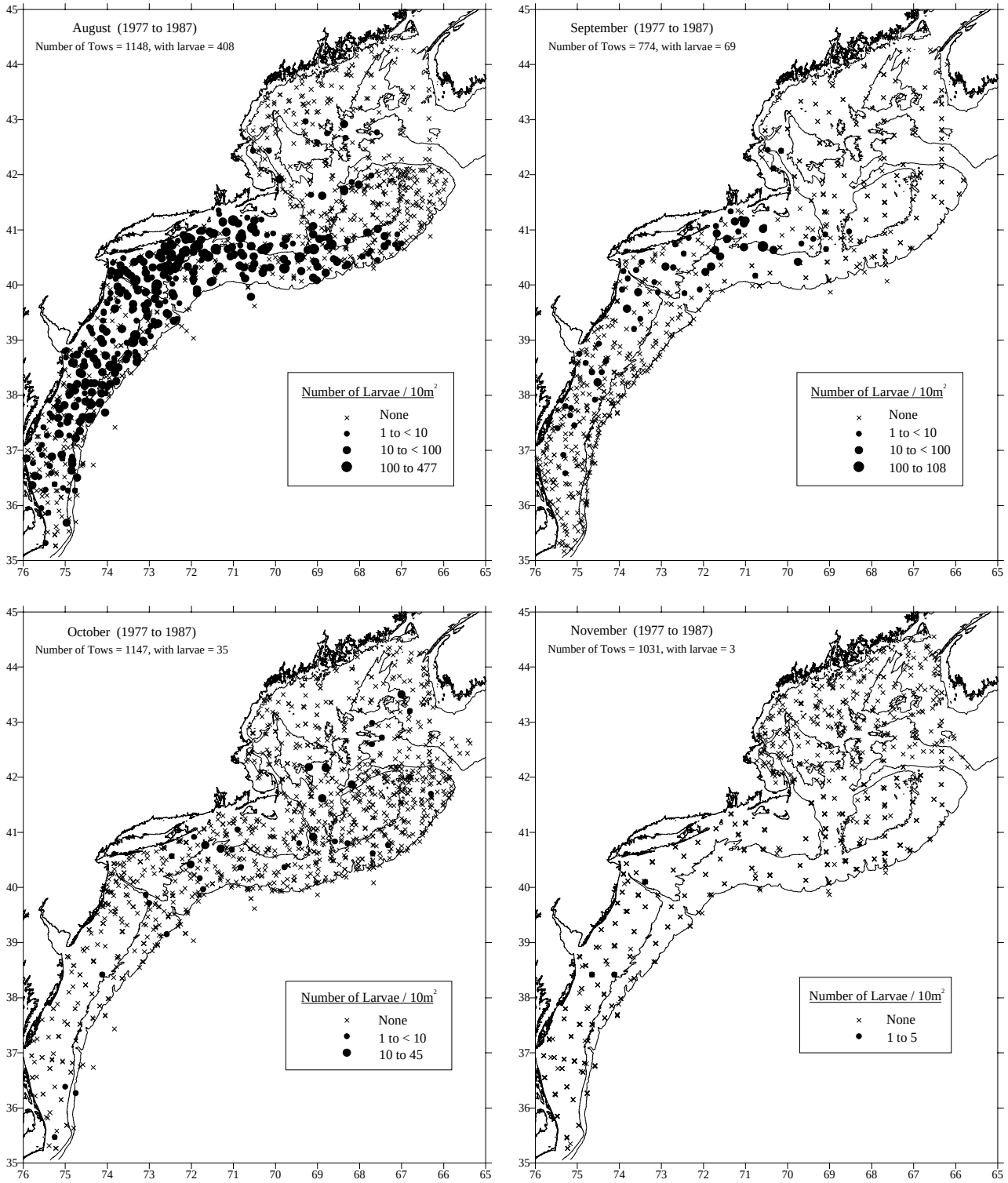

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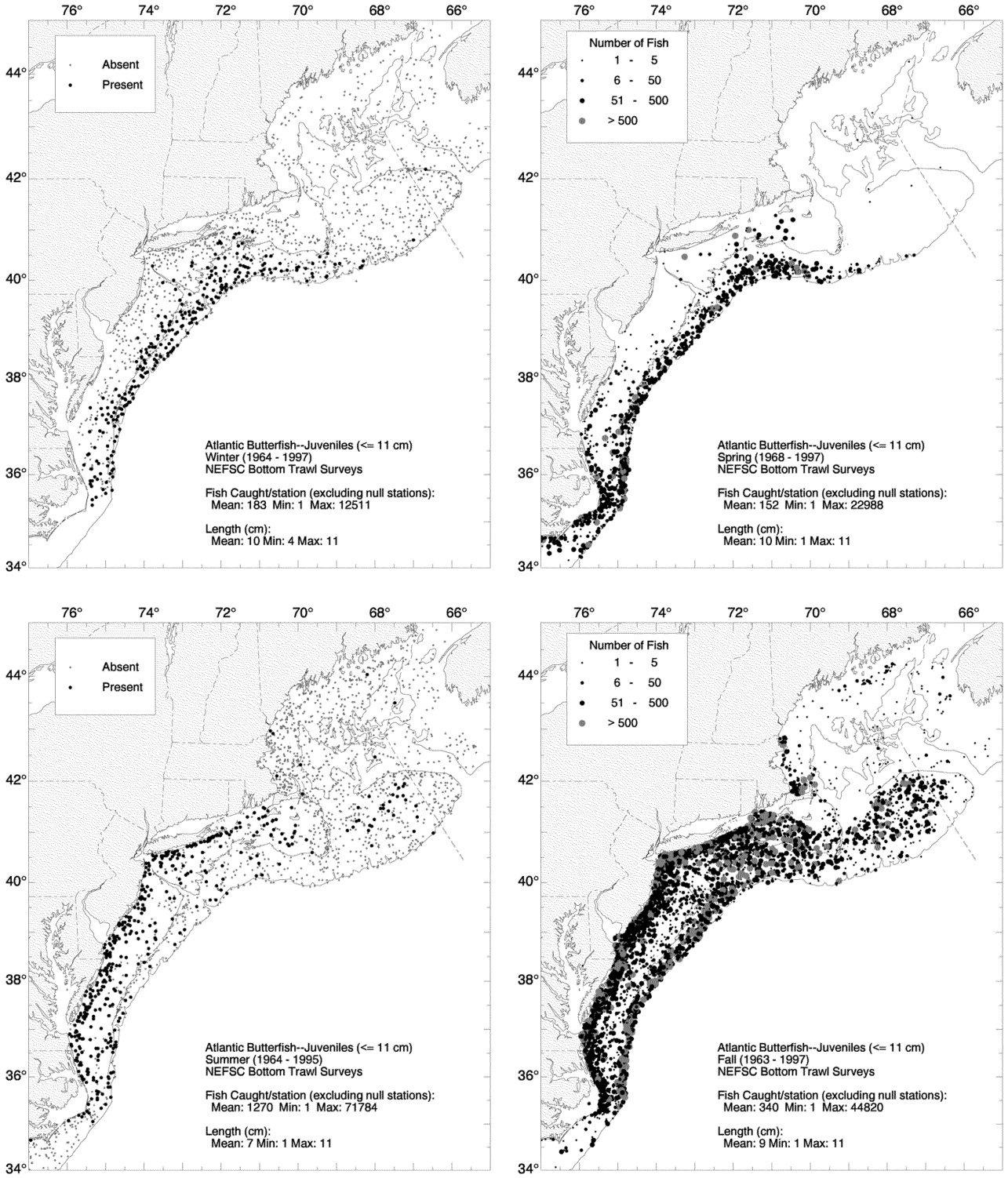


Figure 11. Distribution of juvenile and adult butterfish collected during NEFSC bottom trawl surveys during all seasons during 1963-1997. Densities are represented by dot size in spring and fall plots, while only presence and absence are represented in winter and summer plots [see Reid *et al.* (1999) for details].

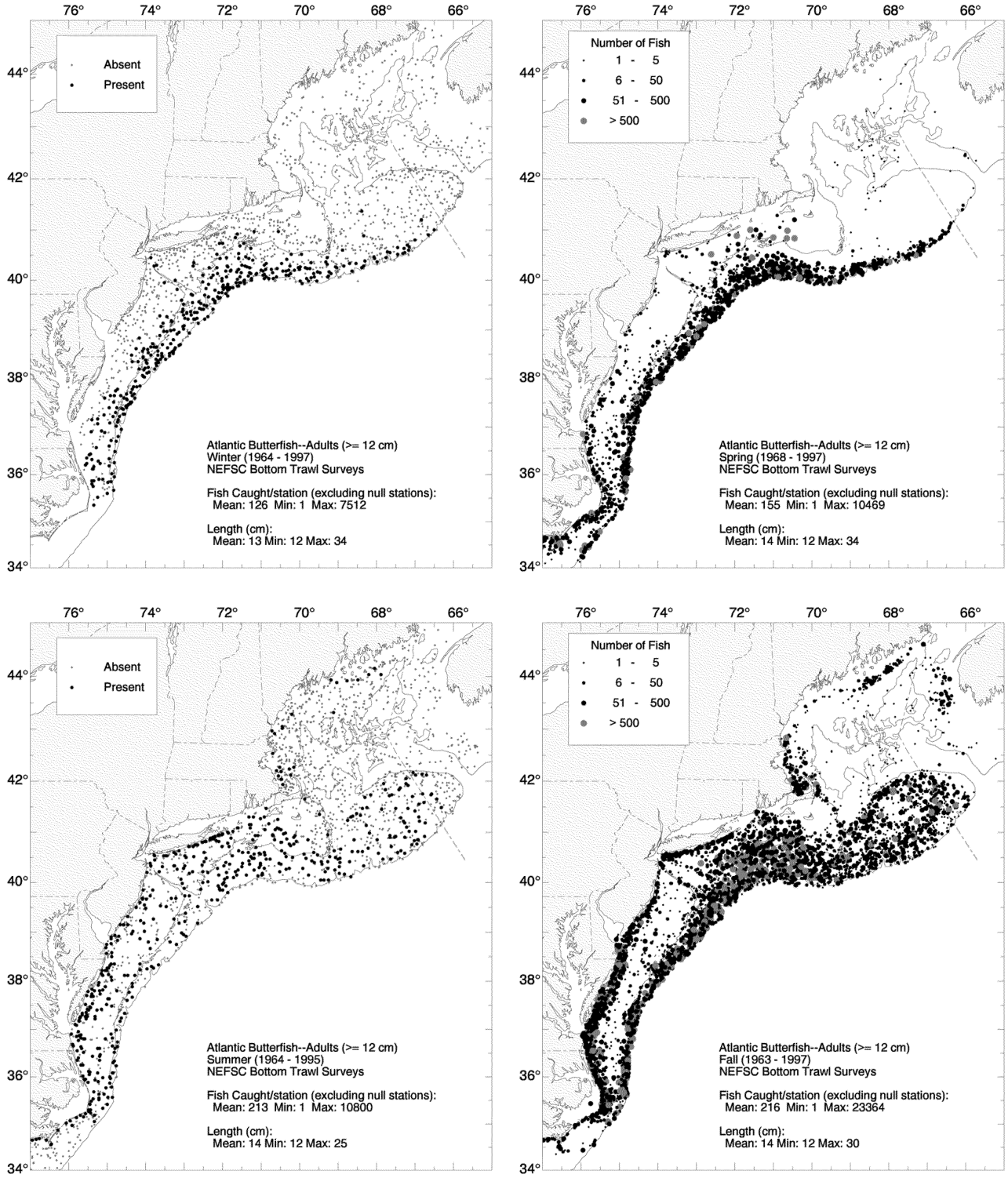


Figure 11. cont'd.

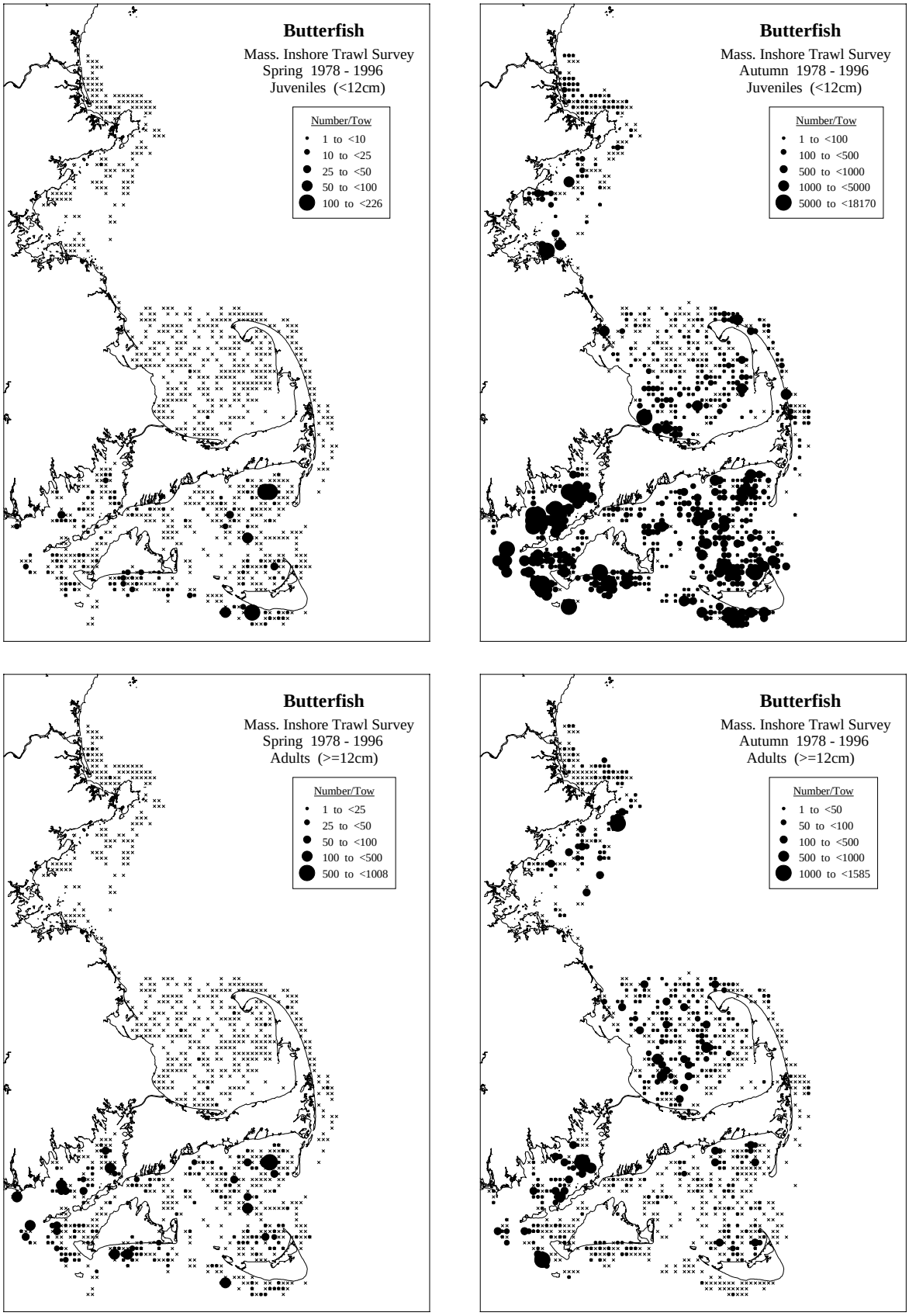


Figure 12. Distribution of juvenile and adult butterfish in Massachusetts coastal waters during spring and autumn Massachusetts trawl surveys, 1978-1996 [see Reid *et al.* (1999) for details].

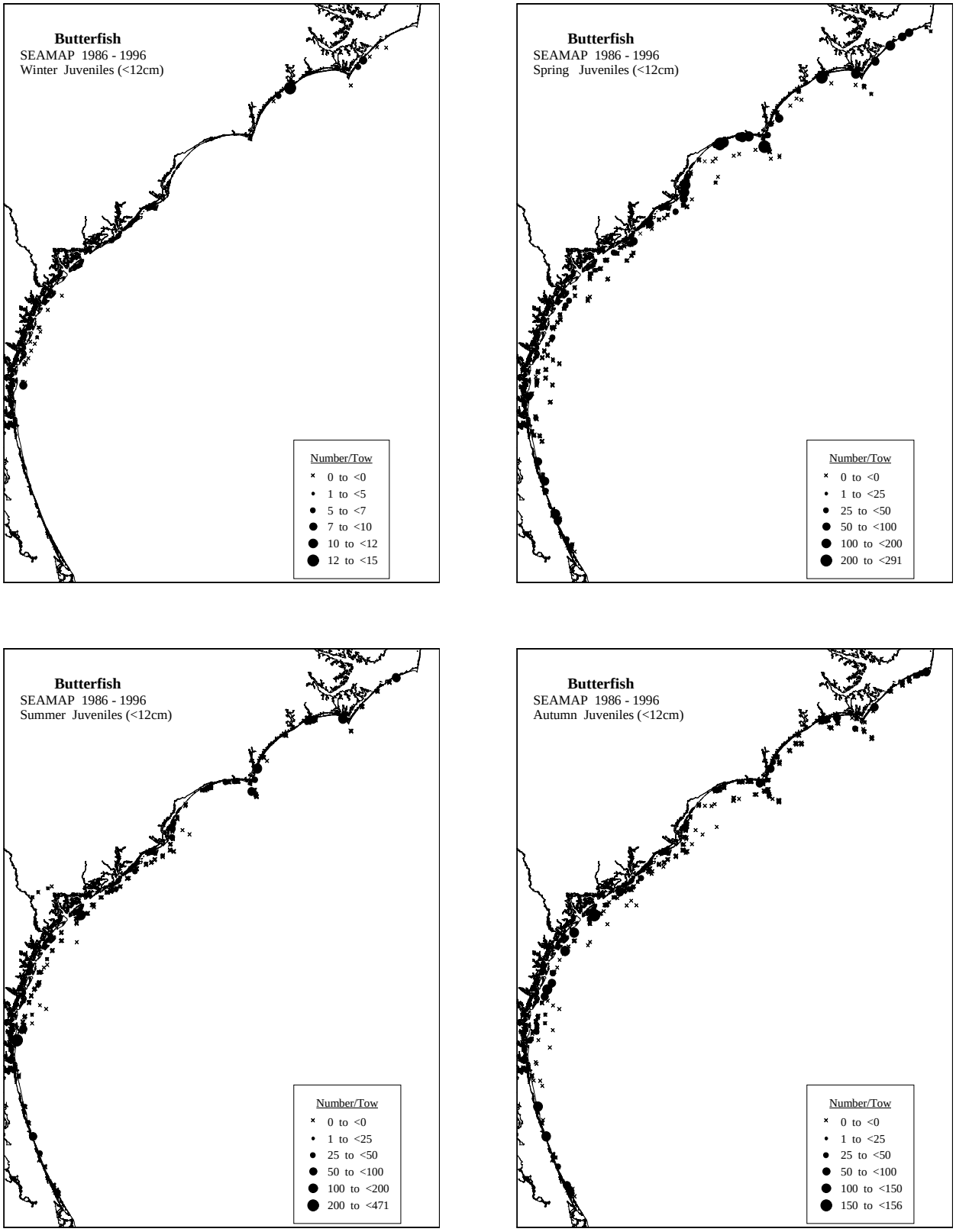
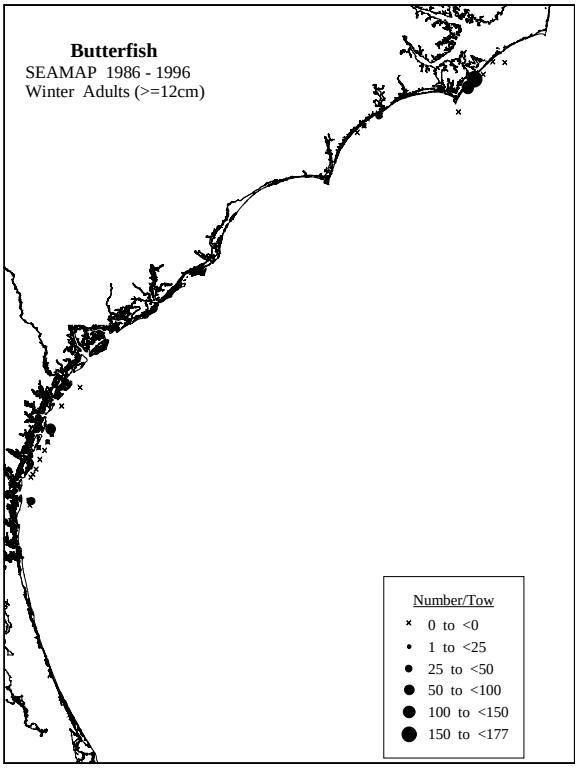
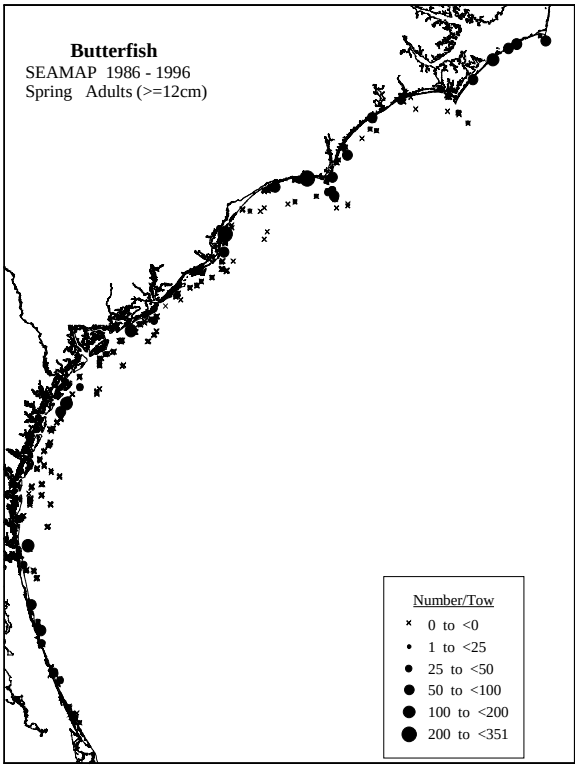
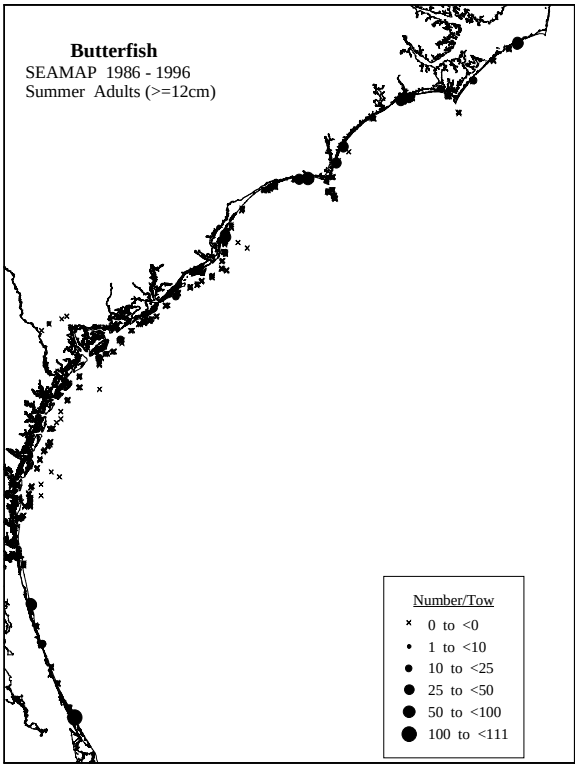


Figure 13. Distribution of juvenile and adult butterfish in the SEAMAP bottom trawl surveys in all seasons for all years combined (1986-1996).







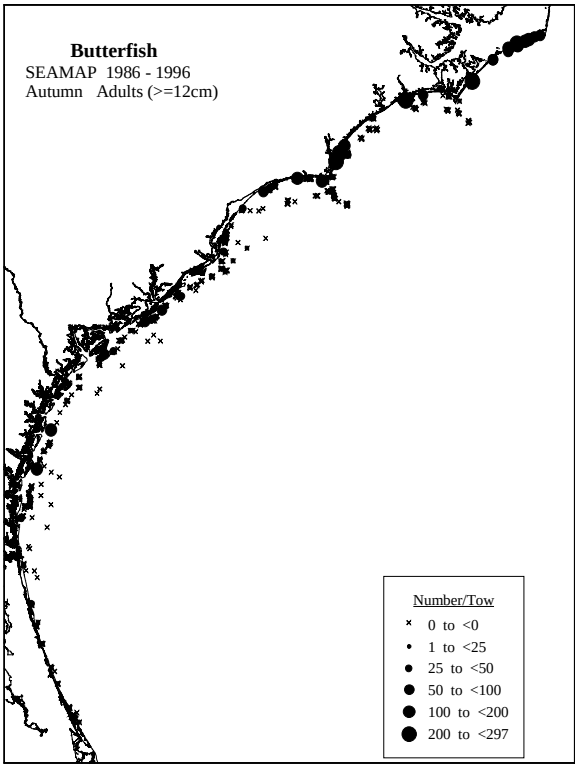


Figure 13. cont'd.

Butterfish Juveniles (< 12 cm)

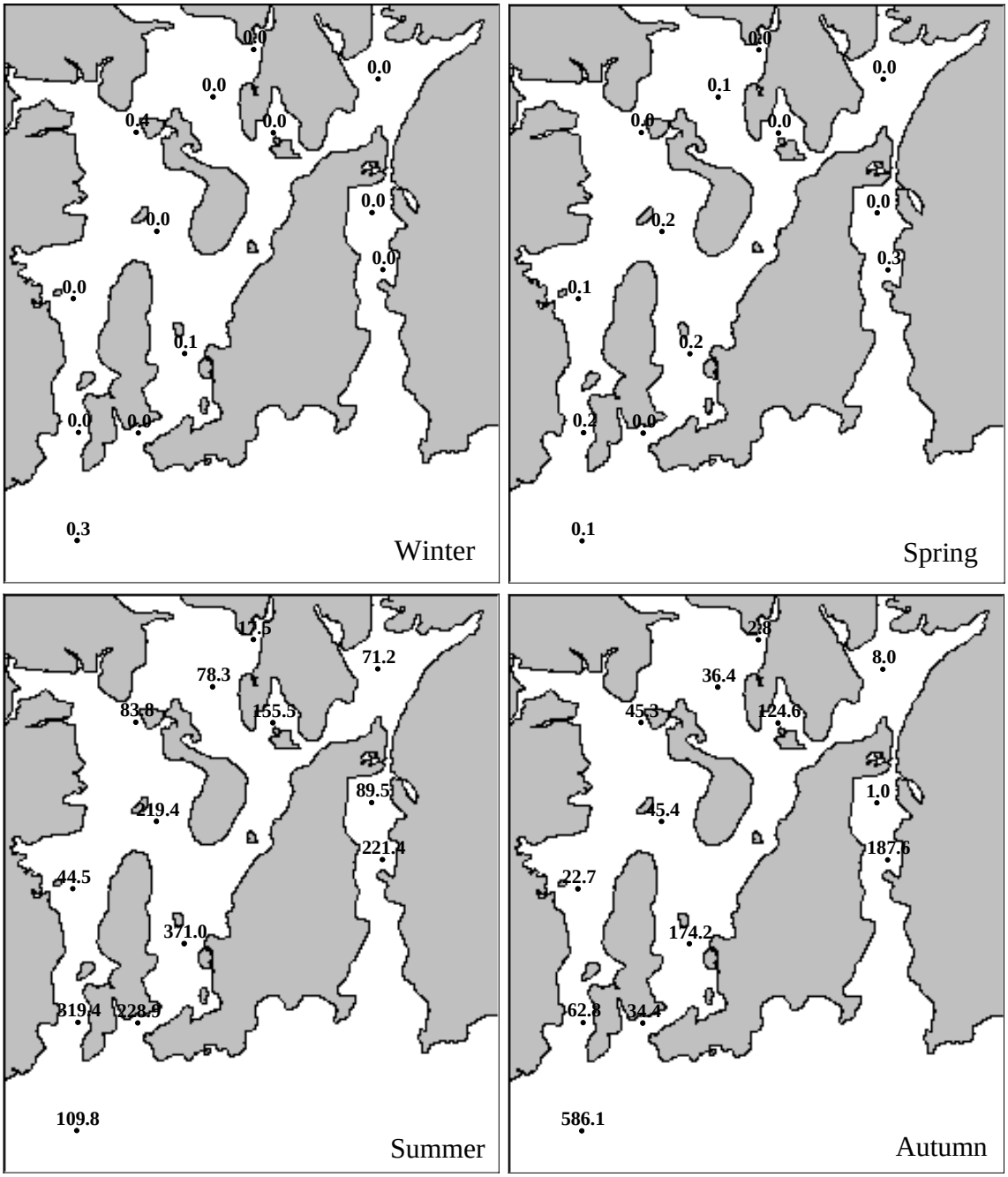
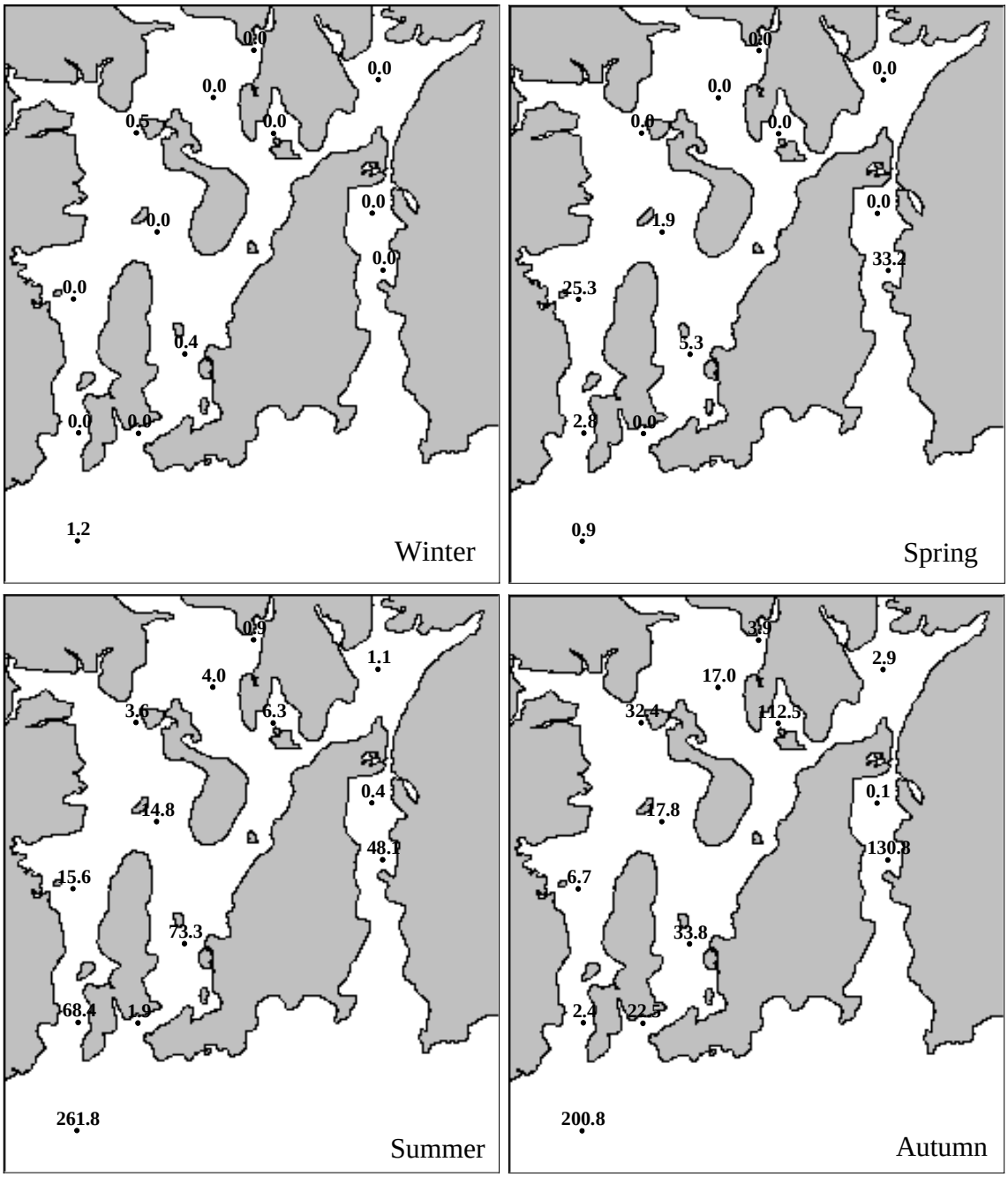


Figure 14. Distribution of juvenile and adult butterfish collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].

Butterfish Adults (>= 12 cm)



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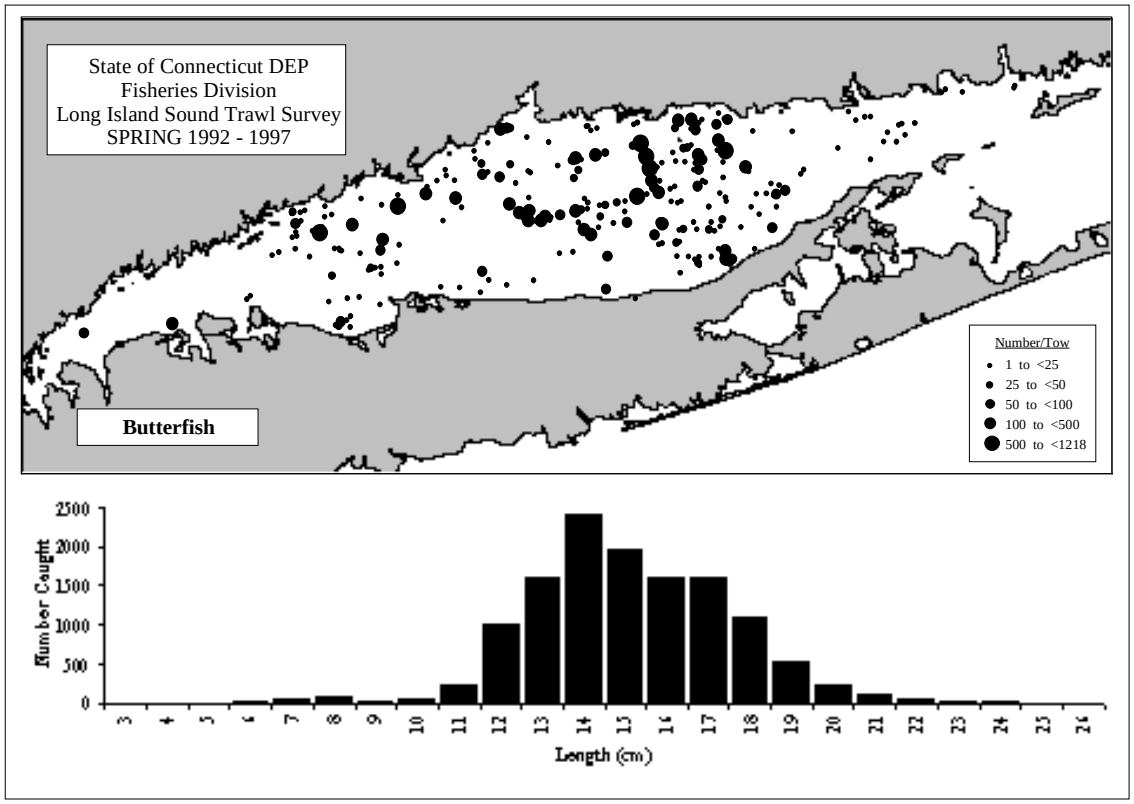

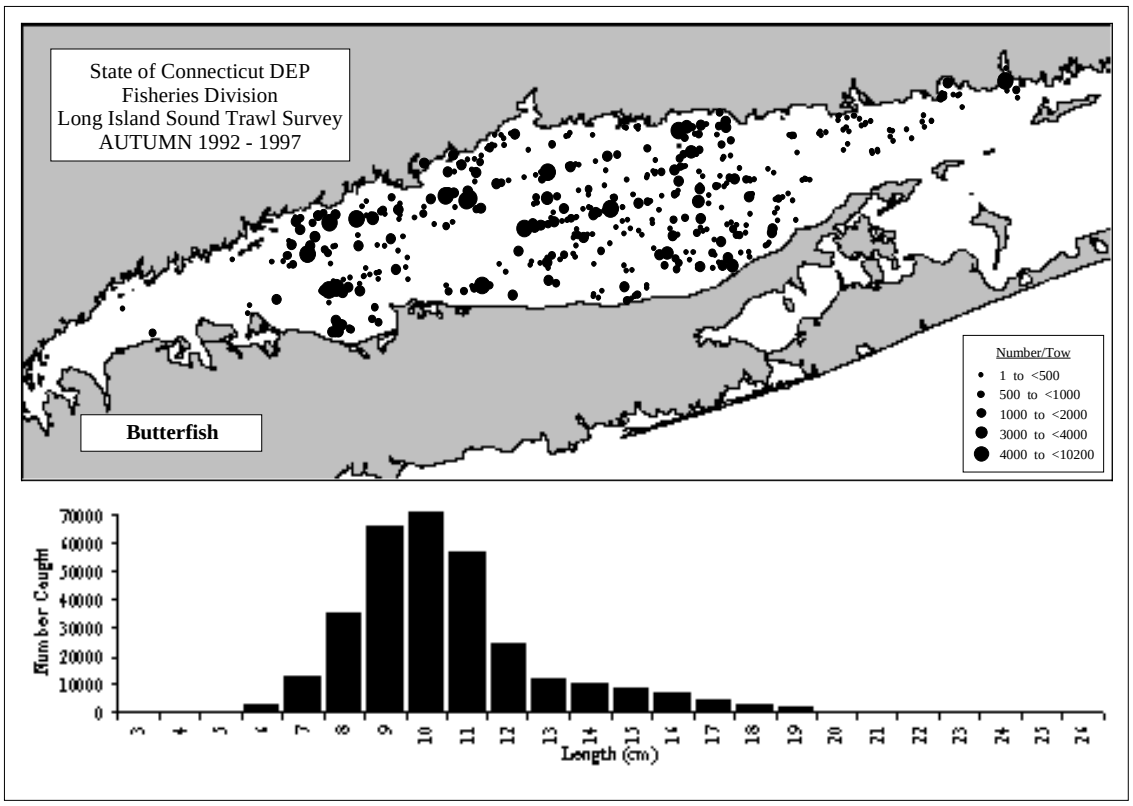

Figure 15. Distribution of juvenile and adult butterfish in Long Island Sound in spring and autumn, from the Connecticut bottom trawl surveys, 1992-1997 [see Reid *et al.* (1999) for details].

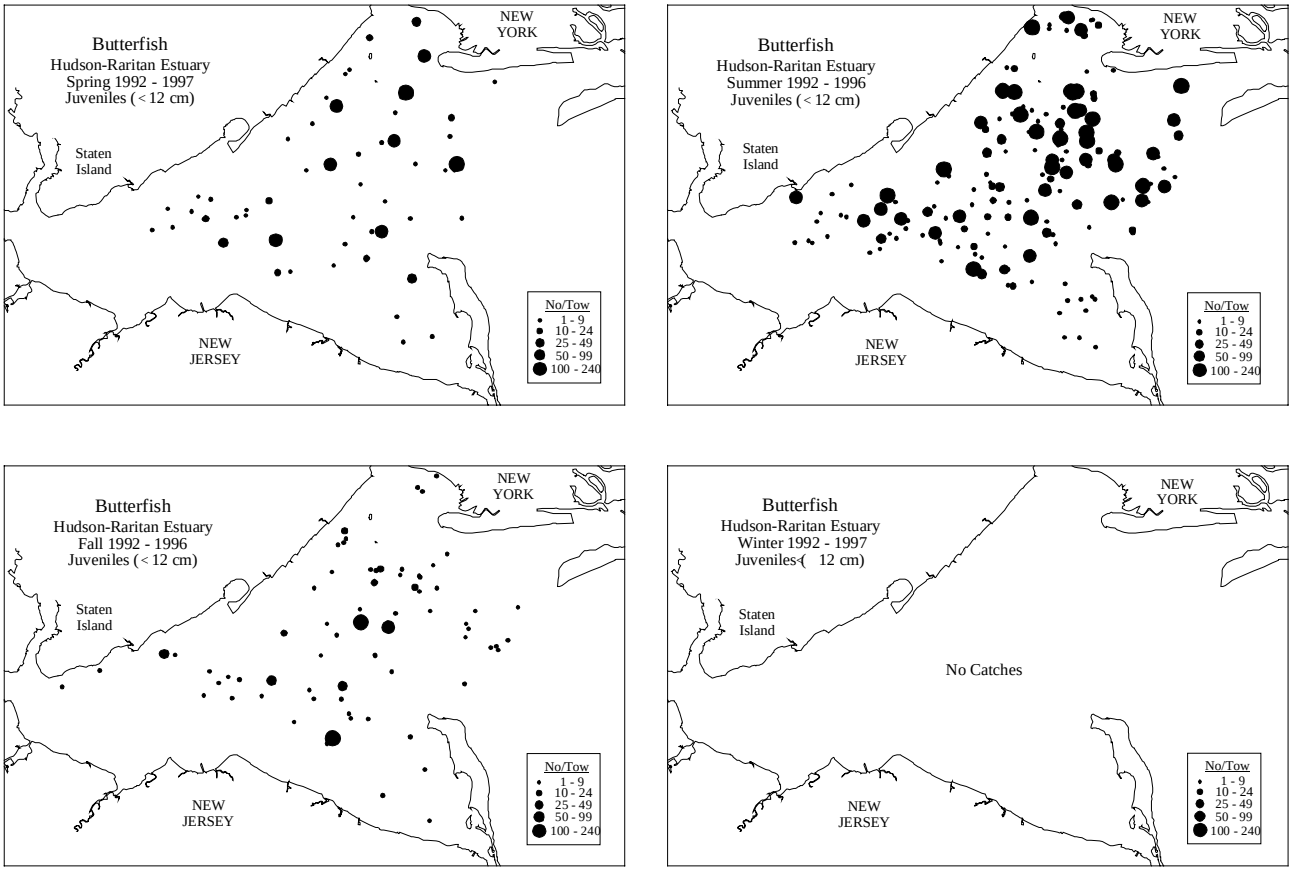

Figure 16. Distribution of juvenile and adult butterfish in the Hudson-Raritan estuary based on Hudson-Raritan trawl surveys, 1992-1997 [see Reid *et al.* (1999) for details].

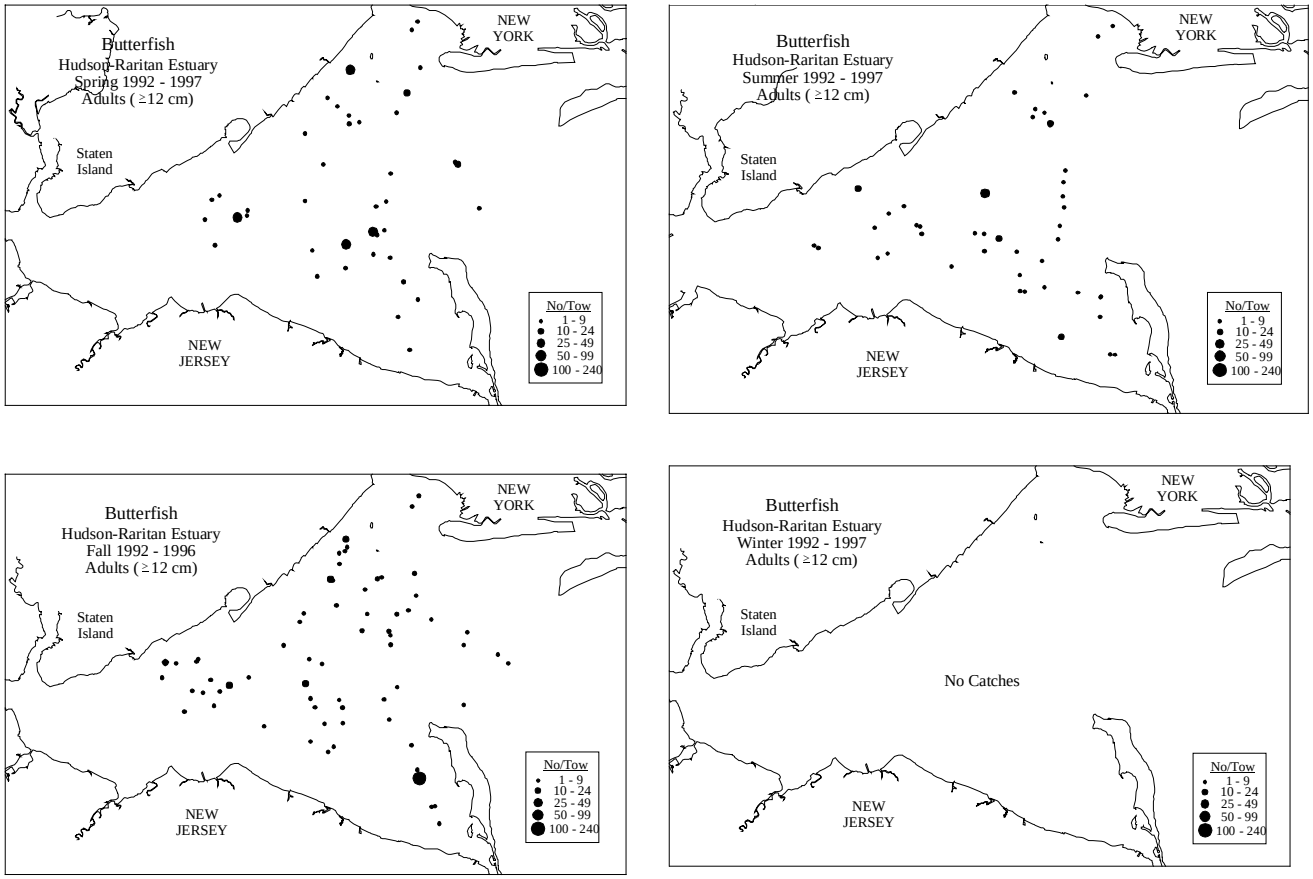

Figure 16. cont'd.

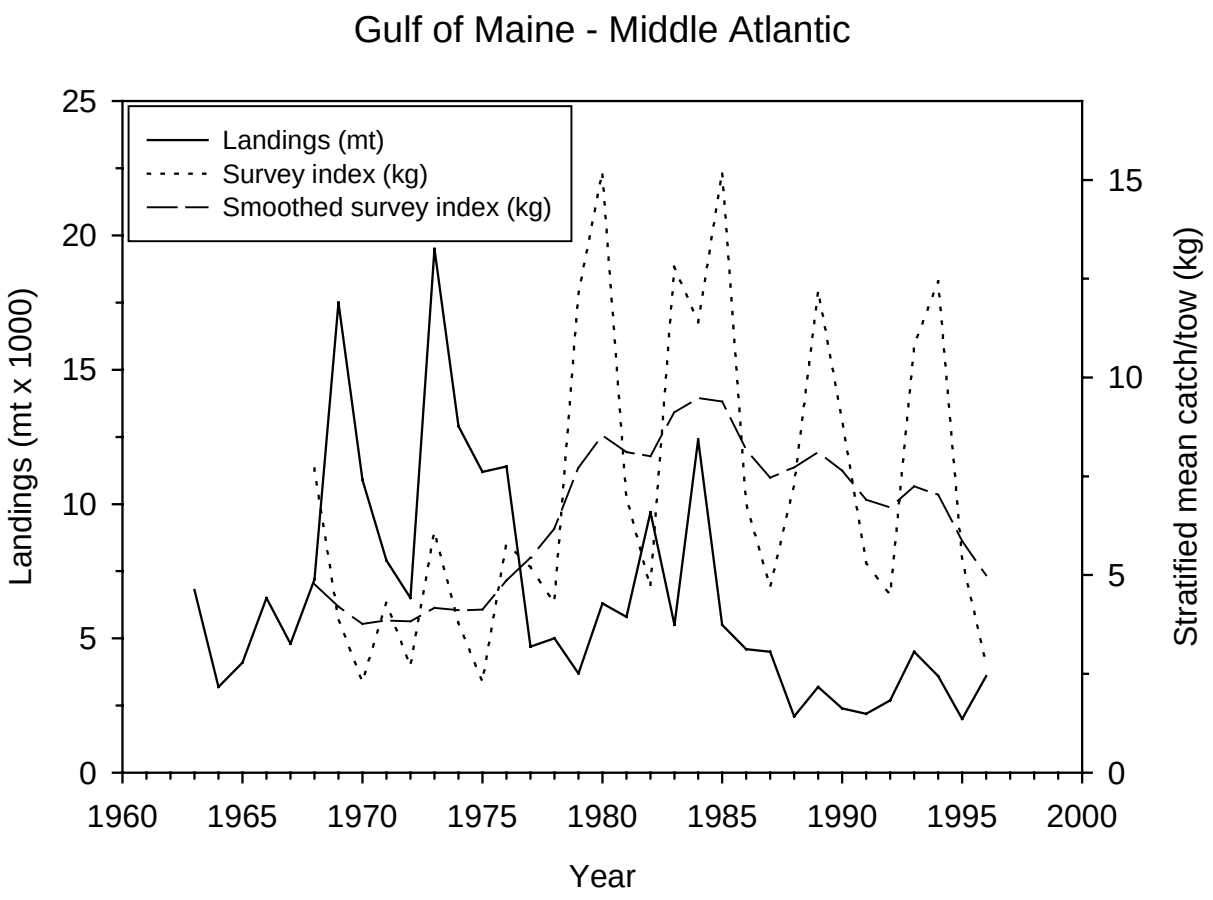

Figure 17. Commercial landings and abundance indices (from the NEFSC bottom trawl surveys) for butterfish from the Gulf of Maine to the Middle Atlantic.

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NOAA Technical Memorandum NMFS-NE-146

Essential Fish Habitat Source Document:

Longfin Inshore Squid, *Loligo pealeii*, Life History and Habitat Characteristics

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September 1999

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NOAA Technical Memorandum NMFS-NE-146

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Essential Fish Habitat Source Document:

Longfin Inshore Squid, *Loligo pealeii*, Life History and Habitat Characteristics

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Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

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[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, CHIEF
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INTRODUCTION

The longfin inshore squid, *Loligo pealeii*, is a pelagic schooling species of the molluscan family Loliginidae (Figure 1). It is distributed in continental shelf and slope waters from Newfoundland to the Gulf of Venezuela; it occurs in commercial abundance from southern Georges Bank to Cape Hatteras. Exploitation of the species is currently managed by the Mid-Atlantic Fishery Management Council under the Atlantic Mackerel, Squid and Butterfish Fishery Management Plan (MAFMC 1996). Within the range of commercial exploitation, the population is considered to be a single stock unit. This Essential Fish Habitat Source Document provides information on the life history and habitat characteristics of longfin inshore squid inhabiting the Gulf of Maine, Georges Bank, and the Middle Atlantic Bight.

LIFE HISTORY

A brief synopsis of the life history characteristics of the longfin inshore squid is provided by Brodziak (1995) and Amendment #6 to the Fishery Management Plan for the Atlantic Mackerel, Squid and Butterfish Fisheries (MAFMC 1996). More detailed information is provided here.

EGGS AND LARVAE

The 1 mm x 1.6 mm eggs are encased in a gelatinous capsule as they pass through the female oviduct during mating. Each capsule contains 150-200 eggs (Arnold *et al.* 1974; Gosner 1978; MAFMC 1996) and is about 50-80 mm long and 1 cm in diameter (Gosner 1978; Lange 1982; MAFMC 1996). During spawning, the male cements bundles of spermatophores into the mantle cavity of the female; as the capsule of eggs passes out through the oviduct, the jelly is penetrated by the sperm (Black *et al.* 1987). The egg capsules are laid on the bottom in clusters 50-60 cm wide composed of hundreds of capsules (Gosner 1978; Griswold and Prezioso 1981). Each female lays 20-30 capsules (Lange 1982). The number of eggs spawned per female has been reported as 950-8,500 (Haefner 1959), 3,500-6,000 (Summers 1971), 2,500-15,900 (Vovk 1972b), and 3,000-6,000 (MAFMC 1996). Development time varies from 257 to 642 hrs depending on water temperature; 26.7 days to hatching at 12-18°C, 18.5 days at 15.5-21.3^{o}C, and 10.7 days at 15.5-23.0^{o}C (Summers 1971).

Little is known about the larval stages of the longfin inshore squid (MAFMC 1996) because they are not often found in the spawning areas. Larvae are pelagic in near surface waters (McMahon and Summers 1971) and are referred to as paralarvae (Young and Harman 1988). Larvae 2-4 mm in length have been caught in the Gulf of Maine (Bigelow 1924).

JUVENILES AND SUBADULTS

There are two juvenile stages; ‘juvenile’ is the stage after the paralarval stage and before the subadult stage; ‘subadult’ is the stage before maturity when the morphological characteristics of adults are attained (Young and Harman 1988). The shift from inhabiting surface waters to a demersal lifestyle occurs at 45 mm (Vecchione 1981). Off Martha’s Vineyard, the juvenile life stage lasts about 1 month; by November subadults migrate to the outer shelf areas where they remain until March (Summers 1968a, b). Subadults are thought to overwinter in deeper waters along the edge of the continental shelf (Black *et al.* 1987). Young-of-the-year (subadults) are found with adults in mid-summer trawls (Summers 1968a, b). Sexual maturity is first reached at 8-12 cm, although most mature individuals are > 10 cm (Macy 1980; Brodziak and Hendrickson 1999). The length at which 50% of individuals are sexually mature (L_{50}) is 16 cm (Brodziak 1995).

ADULTS

Historically, the lifespan of longfin inshore squid was believed to be 1-2 years (Summers 1971; Lange 1982). However, recent studies using statolith aging demonstrated exponential growth and a lifespan of less than 1 year (Brodziak and Macy 1996).

Longfin inshore squid reach sizes greater than 40-50 cm mantle length (ML), although most are less than 30 cm (Vecchione *et al.* 1989; Brodziak 1995). They are sexually dimorphic – males grow more rapidly and reach larger size at age than females (Brodziak 1995). Longfin inshore squid migrate offshore during late autumn and overwinter in warmer waters along the edge of the continental shelf; they return inshore during the spring and early summer (MAFMC 1996). Mature individuals enter inshore waters before immature ones (Macy 1982). Off Massachusetts, larger individuals migrate inshore in April-May while smaller individuals move inshore in the summer (Lange 1982). Longfin inshore squid form large schools based on size prior to feeding (Macy 1980) and make diurnal vertical migrations up into the water column at night (MAFMC 1996). This movement may be associated with the pursuit of food organisms such as euphausiids.

REPRODUCTION

Historically, longfin inshore squid were believed to

spawn from summer to early fall (Lange and Sissenwine 1980), although this varied among years and geographic areas. Brodziak and Macy (1996), however, recently reported that longfin inshore squid can spawn year round. Most eggs are spawned in May and hatching occurs in July (Summers 1971). Spawning has been reported from August to September in the Bay of Fundy (Stevenson 1934), from May to August in New England waters (Macy 1980; Summers 1971), and from late spring to early summer in the Middle Atlantic (Lange and Sissenwine 1983; Black *et al.* 1987). Mesnil (1977) reported that spawning on the Scotian Shelf and Georges Bank occurs during early spring and late summer.

Spawning has been reported in the Gulf of Maine in Cobequid Bay and Massachusetts Bay (Bigelow 1924), the Bay of Fundy (Stevenson 1934), Minas Basin (Cohen 1976), along the eastern coast of Nova Scotia in St. Margaret's and Terrence bays (Dawe *et al.* 1990), on Georges Bank (Mesnil 1977), and in the Middle Atlantic in Narragansett and Delaware bays (Haefner 1959; Griswold and Prezioso 1981).

FOOD HABITS

The diet of the longfin inshore squid changes with size; small immature individuals feed on planktonic organisms (Vovk 1972b; Tibbetts 1977) while larger individuals feed on crustaceans and small fish (Vinogradov and Noskov 1979). Cannibalism is observed in individuals larger than 5 cm (Whitacker 1978). Studies by Vovk and Khvichiya (1980) and Vovk (1985) showed that juveniles 4.1-6 cm long fed on euphausiids and arrow worms, while those 6.1-10 cm fed mostly on small crabs, but also on polychaetes and shrimp. Adults 12.1-16 cm long fed on fish (clupeids, myctophids) and squid larvae/juveniles, and those > 16 cm fed on fish and squid (Vovk and Khvichiya 1980; Vovk 1985). Fish species preyed on by longfin inshore squid include silver hake, mackerel, herring, menhaden (Langton and Bowman 1977), sand lance, bay anchovy, menhaden, weakfish, and silversides (Kier 1982). Maurer and Bowman (1985) demonstrated the following seasonal and inshore/offshore differences in diet: in offshore waters in the spring, the diet is composed of crustaceans (mainly euphausiids) and fish; in inshore waters in the fall, the diet is composed almost exclusively of fish; and in offshore waters in the fall, the diet is composed of fish and squid.

The Northeast Fisheries Science Center (NEFSC) bottom trawl survey data on food habits [see Reid *et al.* (1999) for details] show a similar ontogenetic shift in the diet of longfin inshore squid (Figure 2). During 1973-1980, the diet of squid 1-10 cm was composed primarily of crustaceans (23%), while fish were the most important prey item in the diet of squid 11-40 cm. During 1981-1990, the diet of squid 1-10 cm was composed of 42% cephalopods (i.e., squid), 26% fish, and 21% crustaceans, while the diet of squid 11-40 cm was dominated by fish (39%) and cephalopods (22%).

PREDATION

Juvenile and adult longfin inshore squid are preyed upon by many pelagic and demersal fish species, as well as marine mammals and diving birds (Lange and Sissenwine 1980; Vovk and Khvichiya 1980; Summers 1983). Marine mammal predators include longfin pilot whale, *Globicephala melas*, and common dolphin, *Delphinus delphis* (Waring *et al.* 1990; Overholtz and Waring 1991; Gannon *et al.* 1997). Fish predators include bluefish, sea bass, mackerel, cod, haddock, pollock, silver hake, red hake, sea raven, spiny dogfish, angel shark, goosefish, dogfish, and flounder (Maurer 1975; Langton and Bowman 1977; Gosner 1978; Lange 1980).

HABITAT CHARACTERISTICS

The terms pre-recruit and recruit are used here in the description of the habitat characteristics and geographical distributions. These terms refer to the exploited and unexploited portions of the stock. Longfin inshore squid are exploited at a minimum mantle length of 9 cm; thus, pre-recruits are ≤ 8 cm and recruits are ≥ 9 cm. Information on the habitat characteristics and preferences of the longfin inshore squid is summarized in Table 1.

EGGS AND LARVAE

Egg masses are commonly found attached to rocks and small boulders on sandy/muddy bottom and on aquatic vegetation, such as *Fucus* sp., *Ulva lactuca*, *Laminaria* sp. and *Porphyra* sp. (Arnold *et al.* 1974; Griswold and Prezioso, 1981; Summers 1983). The eggs are demersal, are generally laid in waters < 50 m deep (Bigelow 1924; Griswold and Prezioso 1981; Lange 1982), and are found at temperatures of 10-23°C (McMahon and Summers 1971) and salinities of 30-32 ppt (McMahon and Summers 1971).

The larvae are pelagic near the surface (McMahon and Summers 1971; McConathy *et al.* 1980) and occur at temperatures of 10-26°C and salinities of 31.5-34.0 ppt (Vecchione 1981). Surface waters are important to hatchlings and larvae move deeper as they grow older (Vecchione 1981).

JUVENILES

Juveniles inhabit the upper 10 m of the water column over water 50-150 m deep (Mercer 1969; Vovk and

Khvichiya 1980; Brodziak and Hendrickson 1999). They are found at surface water temperatures of 10-26°C (Vecchione 1981; Brodziak and Hendrickson 1999) and salinities of 31.5-34.0 ppt (Vecchione 1981).

Longfin inshore squid pre-recruits (≤ 8 cm ML) caught during NEFSC trawl surveys were taken at depths ranging from 0-210 m (Figure 4). However, depth of occurrence varied seasonally in accordance with known inshore-offshore migrations. Most pre-recruits were taken at 70-120 m and 8-12°C in winter, 20-130 m and 10-13°C in spring, 10 m and 13-18°C in summer, and 10-40 m and 11-17°C in winter.

Off Massachusetts, most pre-recruits were found in 10-15 m of water at temperatures of 10-13°C in spring and 15-20°C in autumn (Figure 6). In Narragansett Bay, pre-recruits were found at depths of 3-34 m (27 m in winter, 6-12 m in spring, 30-34 m and summer, and 30 m in autumn) and temperatures of 9-25°C (10°C in winter, 9-16°C in spring, 11-25°C with most at 19°C in summer, and 13-23°C with most at 20°C in autumn) (Figure 8). In the Hudson-Raritan estuary, most pre-recruits were found at temperatures of 16-20°C, depths of 30 and 45-50 ft (~9 and 14-15 m), salinities of 30 ppt, and dissolved oxygen levels of 7-8 mg/L (Figure 10).

ADULTS

Adult longfin inshore squid inhabit the continental shelf and upper continental slope to depths of 400 m (Vecchione *et al.* 1989), but depth varies seasonally. In spring they occur at depths of 110-200 m (Serchuk and Rathjen 1974; Lange and Sissenwine 1980), in summer and autumn they inhabit inshore waters as shallow as 6-28 m (Summers 1968a, b; Serchuk and Rathjen 1974; Gosner 1978; Howell and Simpson 1994), and in winter they inhabit offshore waters to depths of 365 m (Lange 1982). They are found on mud or sand/mud substrate (Howell and Simpson 1994), at surface temperatures ranging from 9-21°C, and bottom temperatures ranging from 8-16°C (Summers 1969; Lux *et al.* 1974; Serchuck and Rathjen 1974; Lange and Sissenwine 1980; Macy 1980; Brodziak and Hendrickson 1999).

Longfin inshore squid recruits (≥ 9 cm) caught during NEFSC trawl surveys were taken at depths ranging from 0-300 m. However, depth of occurrence varied seasonally in accordance with known inshore-offshore migrations. Most recruits were collected at 50-120 m and 7-12°C in winter, 100-150 m and 10-12°C in spring, 10-20 m and 11-16°C in summer, and 20-70 m and 10-14°C in fall (Figure 4).

Off Massachusetts, most recruits were collected at 10-15 m and 10-13°C in spring, and 10-30 m and 16-20°C in autumn (Figure 6). In Narragansett Bay, recruits were found at depths of 3-37 m. Seasonally, in winter they were found at 27-30 m, in spring and summer at 3-37 m with most at 30-34 m, and in autumn 27-30 m. They were also found at temperatures of 7-26°C. Seasonally, in winter they were found at 7-10°C, in spring 9-16°C with most at 11°C, in summer 9-26°C with most at 17-21°C, and in autumn 11-23°C with most at 15°C (Figure 8). In the Hudson-Raritan estuary, most recruits were found at temperatures of 16-17°C, depths of 50 and 60 ft (15 and 18 m), salinities of 30 ppt, and dissolved oxygen levels of 7-8 mg/L (Figure 10).

GEOGRAPHICAL DISTRIBUTION

Longfin inshore squid occur from Newfoundland to the Gulf of Venezuela, however, the principal concentrations occur from Georges Bank to Cape Hatteras (Brodziak 1995). Longfin inshore squid are generally found at water temperatures of at least 9°C (Lange and Sissenwine 1980). The population makes seasonal migrations that appear to be related to bottom water temperatures; they move offshore during late autumn to overwinter along the edge of the continental shelf and return inshore during the spring and early summer (MAFMC 1996). During winter and early spring when inshore waters are coldest, the population concentrates along the outer edge of the continental shelf where waters are 9-13°C. The inshore movement to the shelf areas takes place when water temperatures are rising (Black *et al.* 1987) and begins in the south and proceeds north along the coast (MAFMC 1996). A northerly extension of the range has been noted in summer (Black *et al.* 1987).

EGGS AND LARVAE

The egg and larval stages of longfin inshore squid were not sampled by the NEFSC Marine Resources Monitoring, Assessment and Prediction program (MARMAP) offshore ichthyoplankton surveys.

PRE-RECRUITS

NEFSC Bottom Trawl Surveys

The NEFSC bottom trawl surveys [see Reid *et al.* (1999) for details] captured longfin inshore squid pre-recruits (≤ 8 cm ML) during all seasons (Figure 3). In winter, pre-recruits were captured from Cape Hatteras to Nantucket Shoals, although most were found south of Long Island. They were generally found offshore of the 55 m (30 f) depth contour, with highest concentrations in the vicinity of the 183 m (100 f) contour. They were distributed farther inshore in the southern part of the range, presumably due to warmer water temperatures. In the spring, the distribution extended farther to the south, with high concentrations south of Cape Hatteras, and

farther to the north, with catches on Georges Bank and the Scotian Shelf. Although the highest concentrations were still found near the 183 m contour, concentrations inshore of the 55 m contour were much higher than in winter, indicating that the spring inshore migration had commenced. In summer, the highest concentrations occurred nearshore; a number of extremely dense schools (> 10,000 squid/tow) were found nearshore from the Delmarva Peninsula to Buzzards Bay, Massachusetts. Very few were caught on Georges Bank and in the Gulf of Maine. In autumn, longfin inshore squid were distributed throughout the continental shelf from the shore to the 183 m contour, although the highest concentrations were found nearshore. This presumably indicates the beginning of the offshore migration.

Pre-recruits were caught at a wide range of temperatures (Figure 4). In winter, they were found at 5-13°C, although most were caught at 8-12°C. In spring, they were at 6-20°C, with most caught at 10-13°C. In summer, they were found at 7-26°C, but most were caught at 13-18°C, with the highest catch at 18°C. In autumn, temperatures ranged from 7-27°C, with most caught at 11-17°C.

Pre-recruits were caught at depths ranging from 0-210 m, although this varied seasonally and in accordance with inshore-offshore migrations (Figure 4). In winter, depths ranged from 20-200 m, but most were caught between 70-120 m. In spring, depths ranged from 10-210 m, although most were caught at 20-130 m, and the highest catch was at 40 m. In summer, depths were much less variable, ranging from 0-110 m, and 70% were found at 10 m. In autumn, depths ranged from 10-150 m, but most were caught at 10-40 m, with the highest catch at 20 m.

Massachusetts Inshore Trawl Survey

Pre-recruits were collected in greater abundance in autumn than in spring in waters off Massachusetts (Figure 5). In the spring, high concentrations occurred in Buzzards Bay and around Martha's Vineyard and Nantucket islands. Low numbers were found in and around Cape Cod Bay, and none were captured north of Cape Cod. In the autumn, high concentrations were found in Buzzards Bay, around Martha's Vineyard and Nantucket, throughout Cape Cod Bay, in Massachusetts Bay, and north and south of Cape Ann. The lower numbers of pre-recruits in inshore waters in the spring was most likely due to the survey occurring prior to the main part of the inshore migration.

Pre-recruits were found at warmer temperatures in autumn than in spring (Figure 6). In spring, most were found at 10-13°C while in autumn most were found at 15-20°C. There was little difference in depth distribution in spring and autumn, with most found at 10-15 m (Figure 6). However, pre-recruits inhabited a wider range of temperatures in autumn.

Rhode Island Trawl Survey

Longfin inshore squid pre-recruits (≤ 8 cm ML) were caught during all seasons in Narragansett Bay (Figure 7). Catches were low in winter, increased slightly in spring, and were highest during summer and autumn. This pattern corresponds to inshore migrations beginning in early spring. Pre-recruits were found at depths ranging from 10 to 110 feet (3 to 34 m) (Figure 8). In winter the few pre-recruits caught were taken at 90 feet (27 m), in summer and spring most were caught at 20-40 feet (6-12 m) and 100-110 feet (30-34 m), and in autumn most were caught at 100 feet (30 m). Pre-recruits were collected at temperatures ranging from 9-25°C. They were collected at temperatures of 10°C in winter, from 9-16°C in spring, from 11-25°C with most at 19°C in summer, and from 13-23°C with most at 20°C in autumn.

Hudson-Raritan Estuary Trawl Survey

Longfin inshore squid pre-recruits (≤ 8 cm ML) were captured in the Hudson-Raritan estuary during spring, summer, and fall (Figure 9). They were found almost exclusively in the eastern portion of the bay and were collected in the highest numbers in the summer and autumn. Pre-recruits were collected at temperatures ranging from 9-24°C, but most were taken at 16-20°C. They were also collected at depths of 15-75 ft (~5-23 m), with most at 45-50 ft (~14-15 m), and salinities of 20-33 ppt, with the highest catch at 30 ppt. They were found at dissolved oxygen levels of 5-10 mg/L, with most at 7-8 mg/L (Figure 10). Longfin inshore squid require oxygen concentrations greater than 4 mg/L (Howell and Simpson 1994).

RECRUITS

NEFSC Bottom Trawl Surveys

The NEFSC bottom trawl surveys [see Reid *et al*. (1999) for details] captured longfin inshore squid recruits (≥ 9 cm ML) during all seasons. Their seasonal distributions are identical to that of pre-recruits and illustrate the spring and summer inshore and the autumn offshore migrations (Figure 3).

Recruits were caught at a wide range of temperatures (Figure 4). In winter, they were found at 4-13°C, although most were at 7-12°C. In spring, they were found at 5-17°C, with > 60% found at 10-12°C. In summer, they were caught at 6-26°C, but most were at 11-16°C, with the highest catch at 16°C. In autumn, temperatures ranged from 7-27°C, with most at 10-14°C.

Recruits were caught at depths ranging from 0-300 m, although this varied seasonally and in accordance with

inshore-offshore migrations (Figure 4). In winter, depths ranged from 20-290 m, although most were caught between 50-120 m. In spring, depths ranged from 0-270 m, but most were caught at 100-150 m, and the highest catch was at 120 m. In summer, depths were less variable, ranging from 0-110 m, and > 80% were caught at 10-20 m. In autumn, depths ranged from 10-300 m, but most were caught between 20-70 m.

Massachusetts Inshore Trawl Survey

The distribution of longfin inshore squid recruits (≥ 9 cm) in waters off Massachusetts was almost identical to that of pre-recruits, although the overall number of recruits was much lower (Figure 5). Recruits were also found at similar temperatures and depths as pre-recruits (Figure 6). Most were found at 10-13°C and 10-15 m in spring and 16-20°C and 10-30 m in autumn.

Rhode Island Trawl Survey

Longfin inshore squid recruits (≥ 9 cm) were caught during all seasons in Narragansett Bay (Figure 7). Catches were low in winter, increased somewhat in spring, and were highest during summer and autumn. This pattern corresponds to inshore migrations beginning in spring. Recruits were found at depths ranging from 10 to 120 feet (3-37 m) (Figure 8). In winter the few recruits caught were taken at 90-100 feet (27-30 m). In summer and spring they were taken at depths ranging from 10-120 feet (3-37 m), but most were caught at 100-110 feet (30-34 m). In autumn most were caught at 90-100 feet (27-30 m). Recruits were taken at temperatures ranging from 7-26°C (Figure 8). Seasonally they were collected at 7-10°C in winter, from 9-16°C with most at 11°C in spring, from 9-26°C with most at 17-21°C in summer, and from 11-23°C with most at 15°C in autumn.

Connecticut Trawl Survey

Longfin inshore squid were captured from throughout Long Island Sound in surveys conducted from 1992-1997 (Figure 11). A total of 70,930 were captured in all seasons, although they were much less abundant in winter and spring than in summer and autumn. The highest catches occurred in September-October; these were dominated by small squid ranging from about 2 to 12 cm (Gottschall *et al.*, in review). By November, abundance dropped dramatically, most likely due to the migration to offshore overwintering areas.

Squid taken in the surveys ranged from 2-40 cm ML. Recruits dominated the catches in winter and spring and pre-recruits were caught in high numbers in summer and fall (Figure 11). The largest squid were present in May and June when 65% were adults; by September, most ranged from 4 to 9 cm, and only 1% were 16 cm or greater (Gottschall *et al.*, in review).

Hudson-Raritan Estuary Survey

Longfin inshore squid recruits (≥ 8 cm ML) were captured in the Hudson-Raritan estuary during spring, summer, and fall (Figure 9). They were found mostly in the eastern portion of the bay; the highest catches occurred in summer and autumn. Recruits were collected at temperatures ranging from 9-24°C, but most were at 16-17°C. They were also collected at depths of 15-75 ft (~5-23 m), with most at 50-60 ft (~15-18 m), and salinities of 20-33 ppt, with the highest catch at 30 ppt. They were found at dissolved oxygen levels of 5-10 mg/L, with most at 7-8 mg/L (Figure 10). Longfin inshore squid require oxygen concentrations greater than 4 mg/L (Howell and Simpson 1994).

STATUS OF THE STOCKS

The northwest Atlantic (Cape Hatteras to the Gulf of Maine) commercial landings of longfin inshore squid, *Loligo pealeii*, were 12,459 metric tons (mt) in 1996, a 33% decrease over the 1995 landings of 18,500 mt, and a 45% decrease from the 1994 landings of 22,500 mt (Figure 12; Northeast Fisheries Science Center 1996). Of the 1993 landings of 22,300 mt, 56% were caught in the Middle Atlantic Bight between Hudson Canyon and Baltimore Canyon and 50% were caught in the winter from January through March (Northeast Fisheries Science Center 1996).

Annual landings of *Loligo pealeii* from North Carolina to Maine by the distant water fleet were highest from 1972-1976 with a peak of 37,600 mt in 1973 (Lange 1982). Foreign fishing regulations were enforced in 1977 (MAFMC 1996); during the following three years, landings decreased to an average of 15,000 mt, then increased slightly in 1980-1984, but fell again to 15,000 mt in 1985-1987 (Northeast Fisheries Science Center 1996). Directed foreign fishing was eliminated in 1987 and commercial landings continued to fluctuate throughout the late 1980s and early 1990s. Annual domestic landings of *Loligo* averaged 17,800 mt in 1987-1992 (Brodziak 1995) and were taken primarily in the winter fishery in offshore waters of the New York Bight (Northeast Fisheries Science Center 1996).

Long-term data from the Northeast Fisheries Science Center fall and spring bottom trawl surveys indicate fluctuations in seasonal biomass as well. In the fall, 1973-1976, *Loligo pealeii* stock biomass averaged 62,000 mt (Northeast Fisheries Science Center 1996). The peak of 37,600 mt was landed in the commercial fisheries during this period. Stock biomass in the spring, 1972-1976, was

also above average with estimates of 22,000 mt. However, biomass decreased in the spring and fall, 1977-1982, to 10,000 and 33,000 mt, respectively, and during this time, commercial landings also declined (Northeast Fisheries Science Center 1996). During the next nine years, spring and fall biomass levels remained relatively above average with few periods of low abundance. Throughout 1992-1994, biomass decreased to considerably lower levels than during 1989-1991. Average biomass levels in 1992-1994 were 12,000 mt in spring and 45,000 mt in autumn; the spring 1994 level was almost a record low (Northeast Fisheries Science Center 1996). Stock biomass levels in the fall of 1992 and spring of 1993 were estimated to be 35-50% below the historical average even though the number of pre-recruits per tow was the highest ever in the fall of 1992 (Brodziak 1995). The *Loligo pealeii* stock in the northwest Atlantic from Cape Hatteras to the Gulf of Maine has a medium biomass level that is almost fully exploited (Northeast Fisheries Science Center 1996).

RESEARCH NEEDS

- There is little biological information on the egg and larval stages. There is a need for more information on the location of spawning beds and the movement of larvae.
- More information on growth rates and maturity are needed. For example, Brodziak and Macy (1996) demonstrated that growth rates are exponential, lifespans are less than one year, and spawning occurs throughout the year. More data from geographically and temporally diverse studies are needed to confirm these findings.
- The commercially exploited population from Cape Hatteras to Georges Bank is considered a single stock unit. More information is needed on stock structure, including gene flow and levels of genetic differentiation among geographic areas.

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Table 1. Summary of life history and habitat characteristics for longfin inshore squid, *Loligo pealeii*.

Life Stage	Size and Growth	Habitat	Substrate	Temperature	Salinity
Eggs [1]	Incubation time varies with temperature: 26.7 d at 12-18°C, 18.5 d at 15.5-21.3°C, and 10.7 d at 15.5-23.0°C.	Eggs generally in shallow waters, < 50 m.	Egg masses are commonly found on sandy/mud bottom; usually attached to rocks/boulders, pilings, or algae such as *Fucus*, *Ulva lactuca*, *Laminaria* and *Porphyra* sp.	Eggs found in waters 10-23°C; usually > 8°C. Optimal development at 12°C.	Found at 30-32 ppt.
Larvae [2]	Paralarvae range in size from 1.4-15 mm ML (mantle length). Growth rates slower for winter-hatched animals than spring-hatched.	Found in coastal, surface waters in spring, summer and fall. Hatchlings found in surface waters day and night. Move deeper in water column as they grow larger.		Found at 10-26°C (at lower temperatures found at higher salinities).	Found at 31.5-34.0 ppt.
Juveniles [3]	Size ranges from approx. 15 mm - 8 cm. At 6-8 cm sexual size dimorphism is evident, before offshore migrations occur. Growth rates of young-of-the-year are 12-38 mm/month.	Inhabit upper 10 m at depths of 50-100 m on continental shelf. Found in coastal inshore waters in spring/fall, offshore in winter. Migrate to surface at night. Ontogenetic descent: at 45 mm, chromatophores are concentrated on dorsal rather than ventral surface, indicating a change from inhabiting surface waters to demersal lifestyle.		Found at 10-26°C (at lower temperatures found at higher salinities). Juveniles prefer warmer bottom temperatures and shallower depths in fall than adults.	Found at 31.5-34.0 ppt.
Adults [4]	Smallest size at maturity 8 cm ML; most are > 10 cm ML. Males grow faster than females and attain larger sizes; larger sizes at higher latitudes. Growth is rapid, faster in warm months (1.5-2.0 cm/month) than in cold months (0.4-0.6 cm/month). Life span is < 1 year. Maximum size and age are ~50 cm ML, 3 yrs.	Range from Newfoundland south to Cape Hatteras, on continental shelf and upper slope. Most abundant from Gulf of Maine to Hatteras. Mar-Oct: inshore, shallow waters up to 180 m. Winter: offshore deeper waters, up to 400 m on shelf edge. Most abundant at bottom during the day; move upwards at night. Generally found at greater depths and cooler bottom temperatures in the fall than juveniles.	Mud or sandy mud.	Found at surface temperatures ranging from 9-21°C and bottom temperatures ranging from 8-16°C.	

[1] Bigelow (1924), McMahon and Summers (1971), Arnold *et al.* (1974), Griswold and Prezioso (1981), Lange (1982), Summers (1983), Dawe *et al.* (1990)
[2] McMahon and Summers (1971), McConathy *et al.* (1980), Vecchione (1981), Nesis (1982), Vovk (1983), Young and Hartman (1988)
[3] Summers (1968a, b), Mercer (1969), Macy (1980), Vovk and Khvichiya (1980), Vecchione (1981), Young and Hartman (1988), Brodziak and Henderson (1999)
[4] Haefner (1964), Summers (1968a, b, 1969, 1971, 1983), Rathjen (1973), Lux *et al.* (1974), Serchuk and Rathjen (1974), Cohen (1976), Mesnil (1977), Gosner (1978), Sissenwine and Bowman (1978), Lange (1980, 1982), Lange and Sissenwine (1980), Macy (1980), Nesis (1982), Vecchione *et al.* (1989), Dawe *et al.* (1990), Howell and Simpson (1994), Brodziak and Macy (1996), Brodziak and Henderson (1999)

Table 1. cont'd.

Life Stage	Prey	Predators	Spawning	Notes
Eggs [1]	N/A		Most eggs are spawned in May, hatching occurs in July. Fecundity ranges from 950-15,900 eggs per female.	Eggs are demersal. Enclosed in a gelatinous capsule containing up to 200 eggs. Each female lays 20-30 capsules. Laid in masses made up of hundreds of egg capsules from different females.
Larvae [2]	Primary prey are copepods.			"Paralarvae" defined as stage after hatching when cephalopods are pelagic. Tentacles are non-functional at ≤ 15 mm.
Juveniles [3]	Primary prey varies with size: < 4.0 cm: plankton, copepods; 4.1-6.0 cm: euphausiids, arrow worms; 6.1-10.0 cm: crabs, polychaetes, shrimp. Cannibalism observed in specimens larger than 5 cm ML (small *Illex illecebrosus* were found in 49 of 322 *Loligo* stomachs).	Many pelagic and demersal fish species as well as marine mammals and birds.		Changes in habitat as the squid grows are indicated by changes in the diet.
Adults [4]	Fish prey includes silver hake, mackerel, herring, menhaden, sand lance, bay anchovy, menhaden, weakfish and silversides. Invertebrate prey include crustaceans (*Crangon*, *Palaeomonetes* sp.) and squid. 15 cm adults can eat fish up to half their mantle length. At 16-25 cm, consume more fish and less crustaceans as growth increases; > 25 cm, more squid than fish eaten; and > 30 cm, almost exclusively squid.	Predators include many fishes (bluefish, sea bass, mackerel, cod, haddock, pollock, hakes, sea raven, goosefish, flounder, dogfish, angel sharks, skates), pilot whale (*Globicephala melas*) and common dolphin (*Delphinus delphis*), and diving birds.	Spawning occurs on Scotian Shelf, Georges Bank, Gulf of Maine and from Nantucket Shoals to Cape Hatteras in shallow waters, 10-90 m, from April-Nov (New England: May-Aug; Bay of Fundy: Aug-Sept). Georges Bank: two broods - early spring and late summer. Spring spawn: hatch in June, mature over winter. Summer spawn: hatch in fall, mature in 2nd winter. Mating occurs during inshore migration in spring. Mortality occurs after first spawning.	*Loligo* form schools according to size class prior to feeding. Oxygen requirement > 4 ml/l. Larger individuals migrate earlier (April-May) than smaller ones.

[1] Haefner (1959), Summers (1971), Vovk (1972b), Arnold *et al.* (1974), Gosner (1978), Griswold and Prezioso (1981), Lange (1982), Nesis (1982), Lange and Sissenwine (1983)
[2] Vecchione (1981), Vovk (1983), Young and Hartman (1988)
[3] Vovk (1972b, 1985), Tibbetts (1977), Whitaker (1978), Vinogradov and Noskov (1979), Vovk and Khvichiya (1980), Vecchione (1981)
[4] Stevenson (1934), Summers (1969, 1971), Vovk (1972a, 1985), Rathjen (1973), Maurer (1975), Cohen (1976), Langton and Bowman (1977), Mesnil (1977), Tibbetts (1977), Gosner (1978), Vinogradov and Noskov (1979), Lange (1980, 1982), Lange and Sissenwine (1980, 1983), Macy (1980), Griswold and Prezioso (1981), Kier (1982), Summers (1983), Maurer and Bowman (1985), Dawe *et al.* (1990), Waring *et al.* (1990), Overholtz and Waring (1991), Howell and Simpson (1994), Brodziak and Macy (1996), Gannon *et al.* (1997)

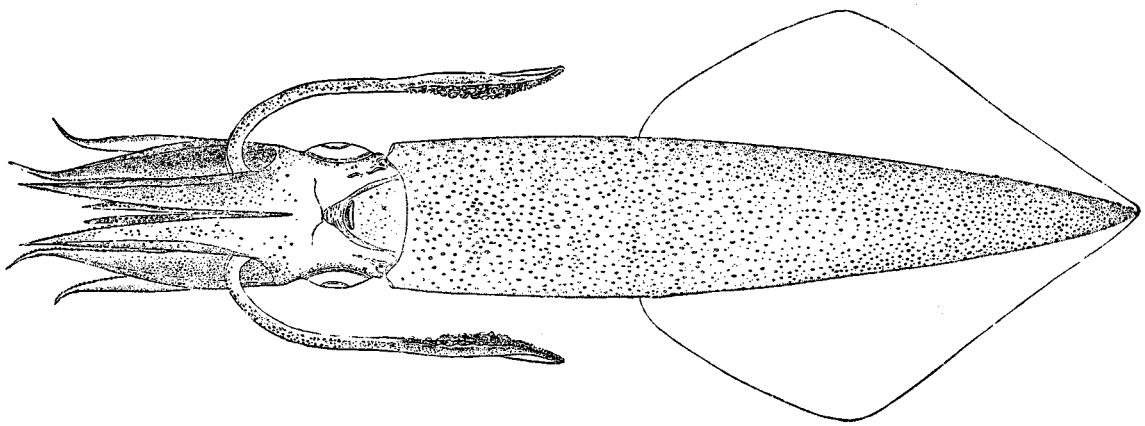


Figure 1. The longfin inshore squid, *Loligo pealeii* (from Goode 1884).

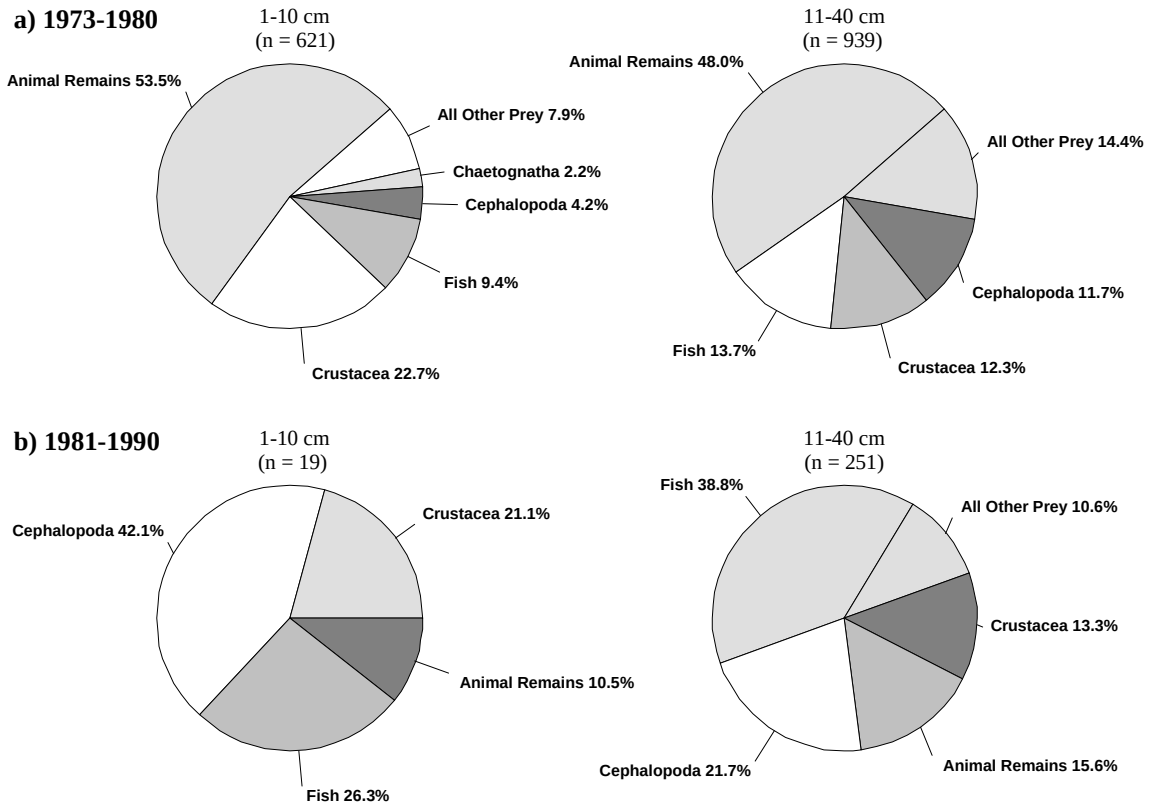


Figure 2. Abundance (percent occurrence) of the major prey items in the diet of longfin inshore squid collected during 1973-1980 and 1981-1990 NEFSC bottom trawl surveys. The 1-10 cm size range corresponds, at least roughly, to pre-recruits or juveniles, and the 11-30 cm size class corresponds to recruits or adults. The category “animal remains” refers to unidentifiable animal matter. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details].

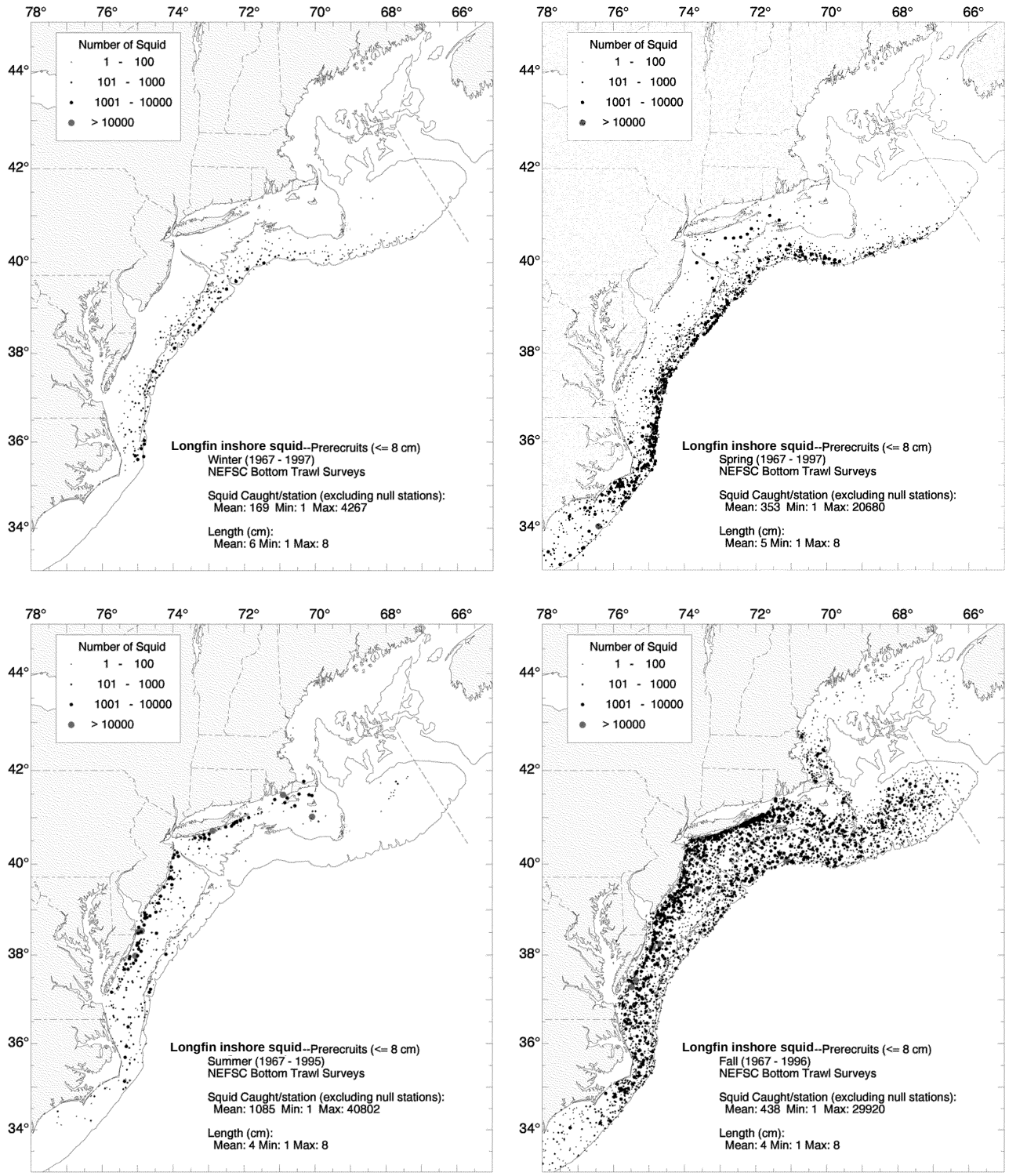


Figure 3. Distribution and abundance of longfin inshore squid pre-recruits (≤ 8 cm) and recruits (≥ 9 cm) collected during NEFSC bottom trawl surveys in winter (1967-1997), spring (1967-1997), summer (1967-1995) and autumn (1967-1996). Densities (number per tow) are represented by dot size [see Reid *et al.* (1999) for details].

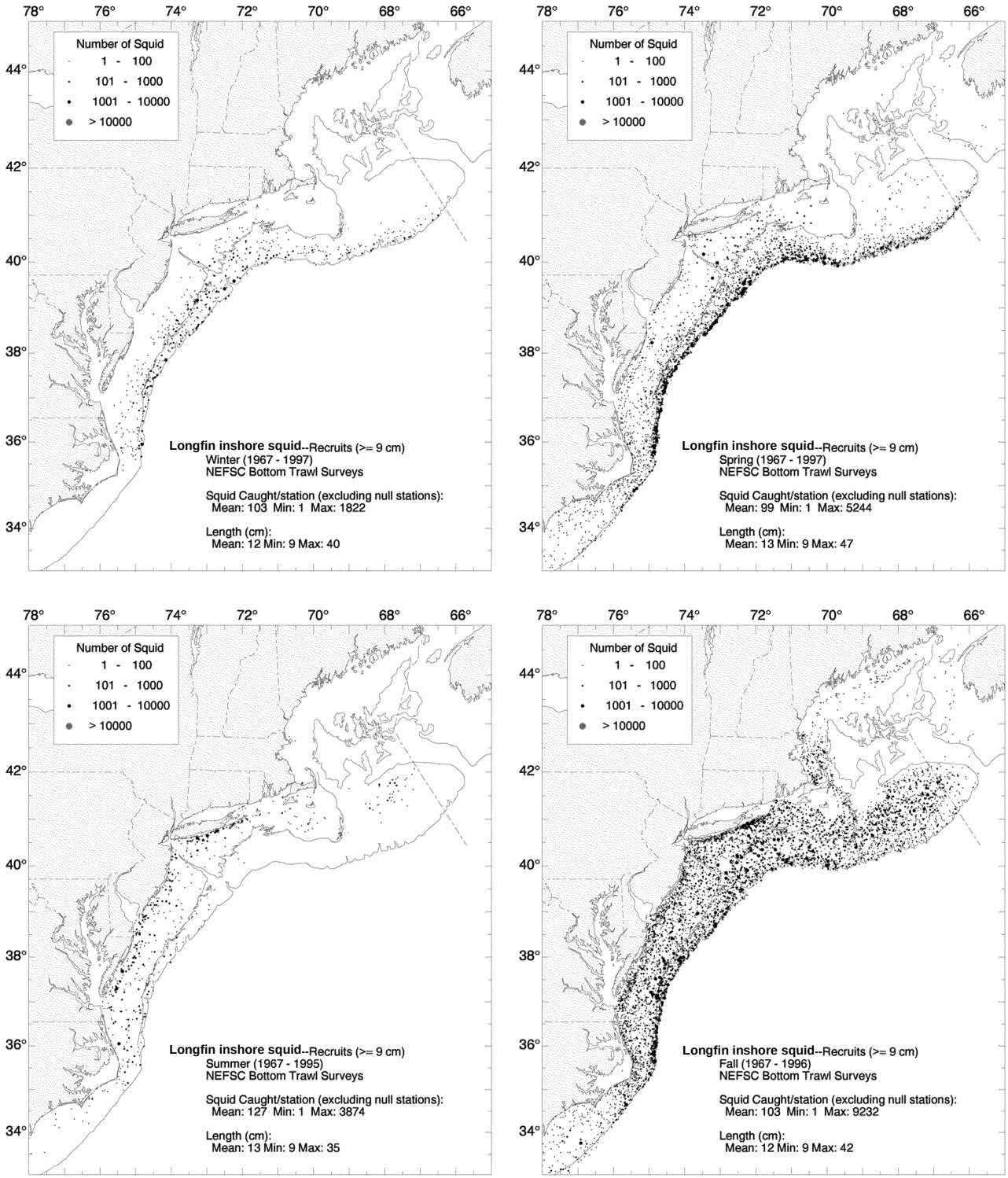


Figure 3. cont'd.

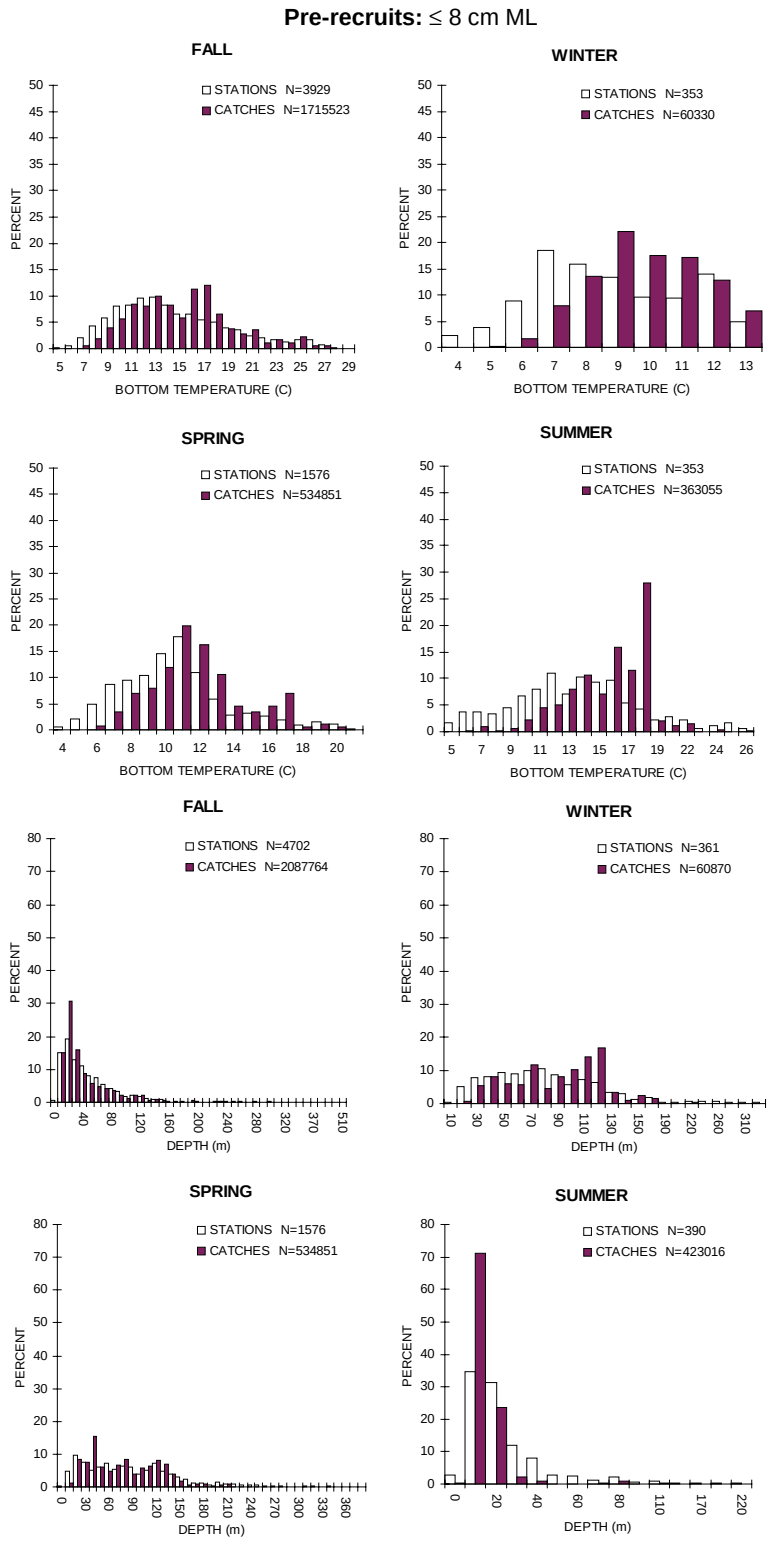
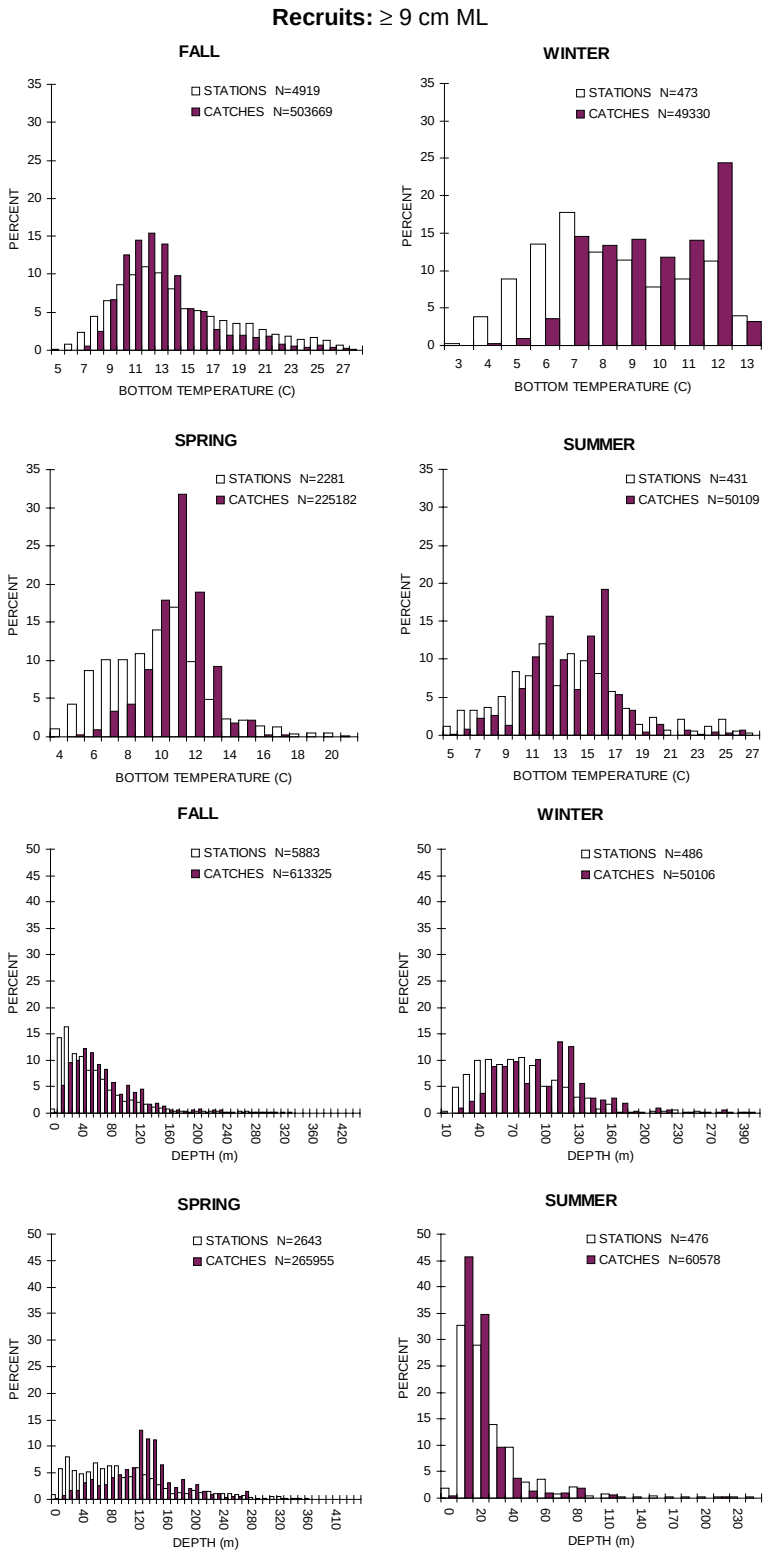


Figure 4. Seasonal abundance of longfin inshore squid pre-recruits (≤ 8 cm) and recruits (≥ 9 cm) relative to bottom water temperature and depth based on NEFSC bottom trawl surveys, all years combined. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).



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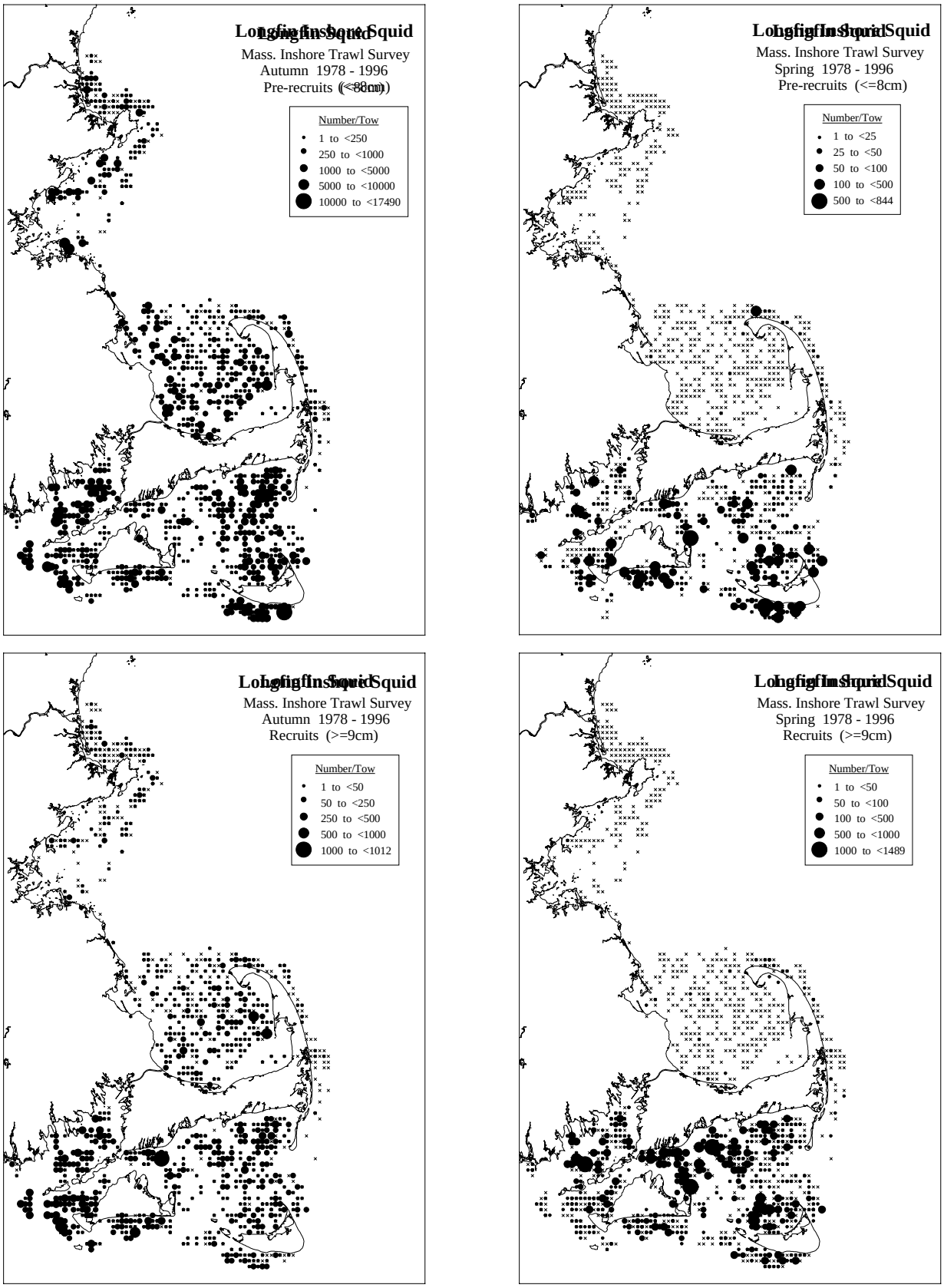


Figure 5. Distribution and abundance of longfin inshore squid pre-recruits (≤ 8 cm) and recruits (≥ 9 cm) in Massachusetts coastal waters during spring and autumn Massachusetts trawl surveys, 1978-1996 [see Reid *et al.* (1999) for details].

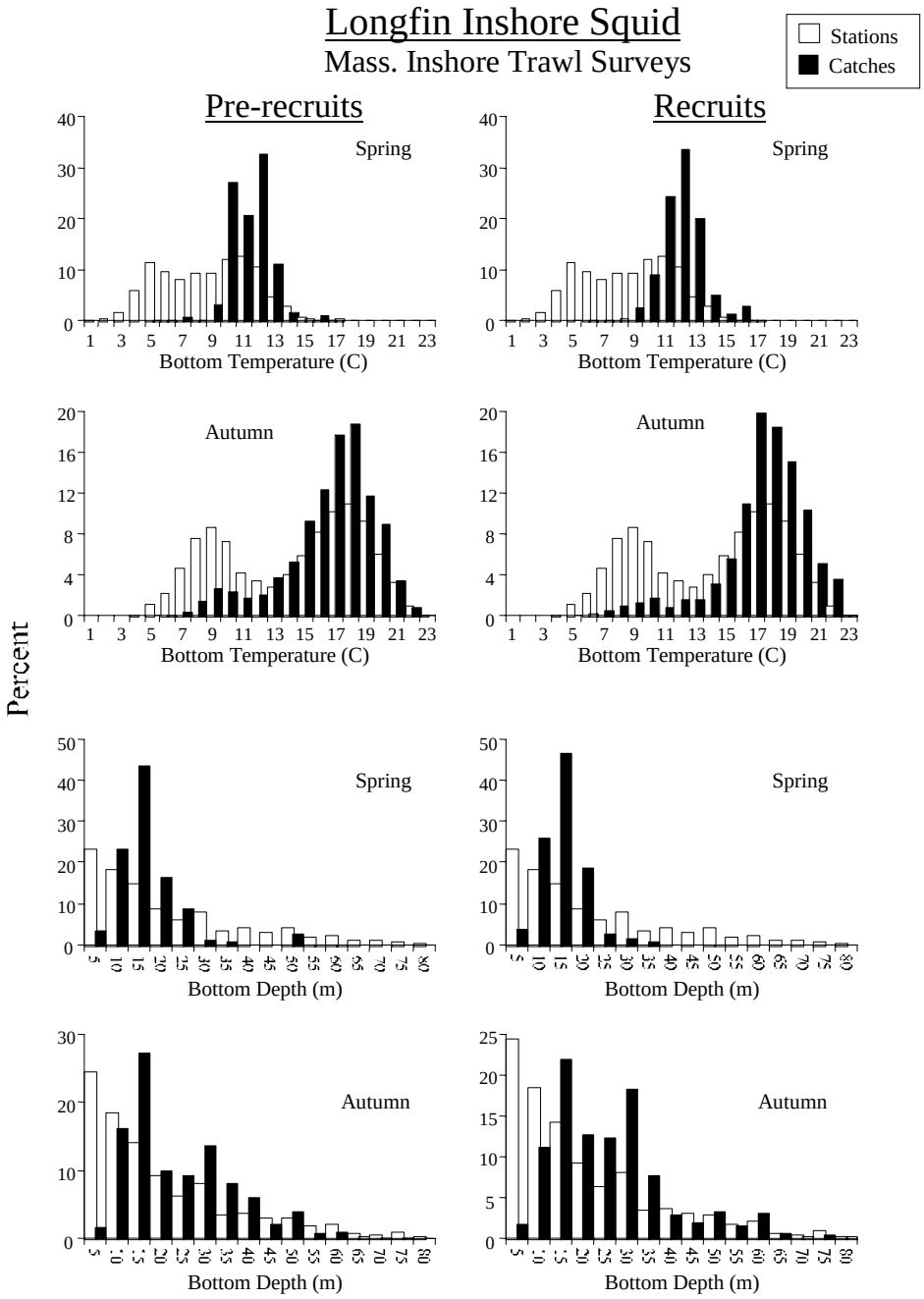


Figure 6. Abundance of longfin inshore squid pre-recruits and recruits relative to bottom water temperature and depth based on Massachusetts inshore bottom trawl surveys (spring and autumn 1978-1996, all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

Longfin Inshore Squid Pre-recruits (≤ 8 cm)

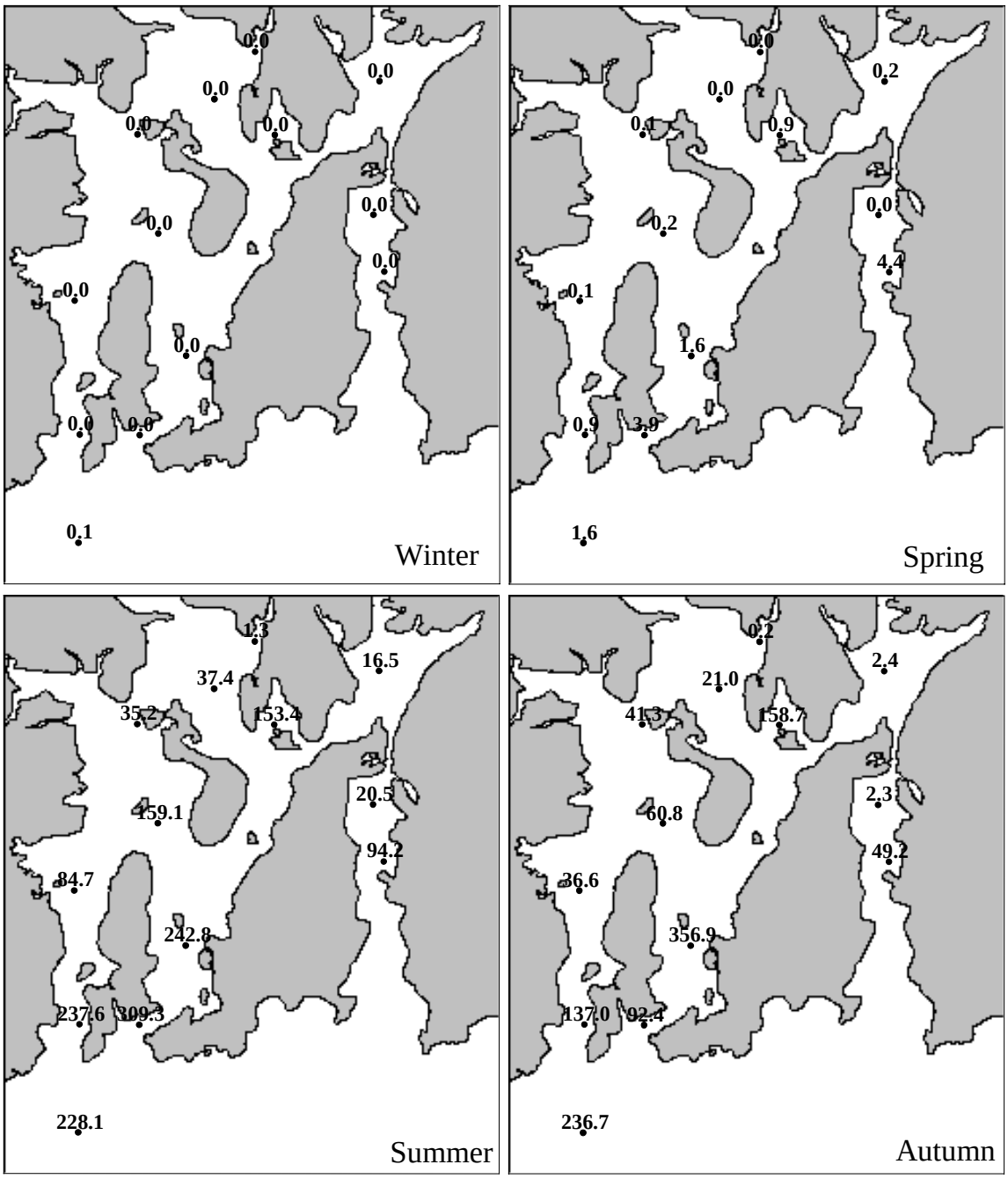
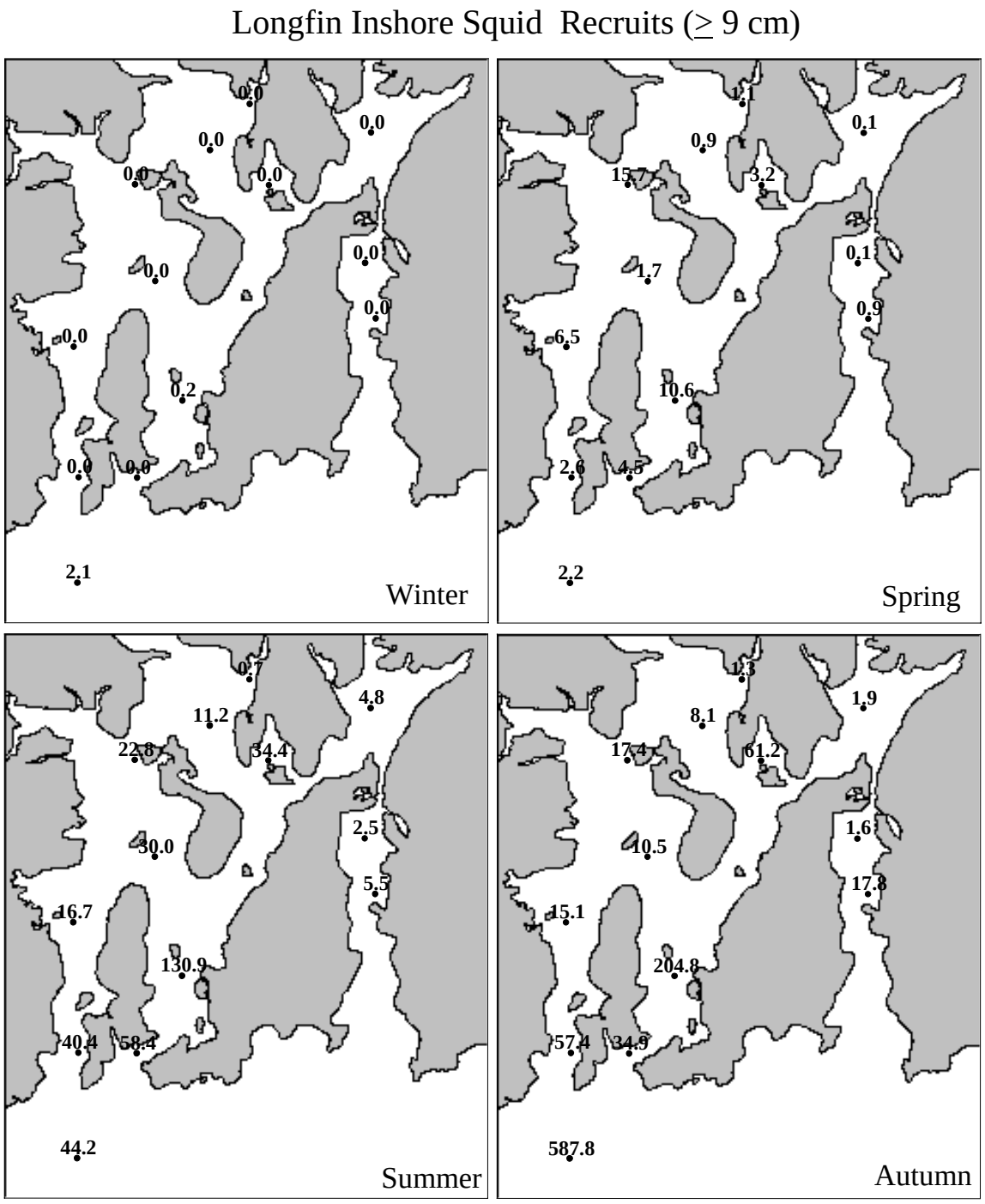


Figure 7. Distribution and abundance of longfin inshore squid pre-recruits (≤ 8 cm) and recruits (≥ 9 cm) in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].



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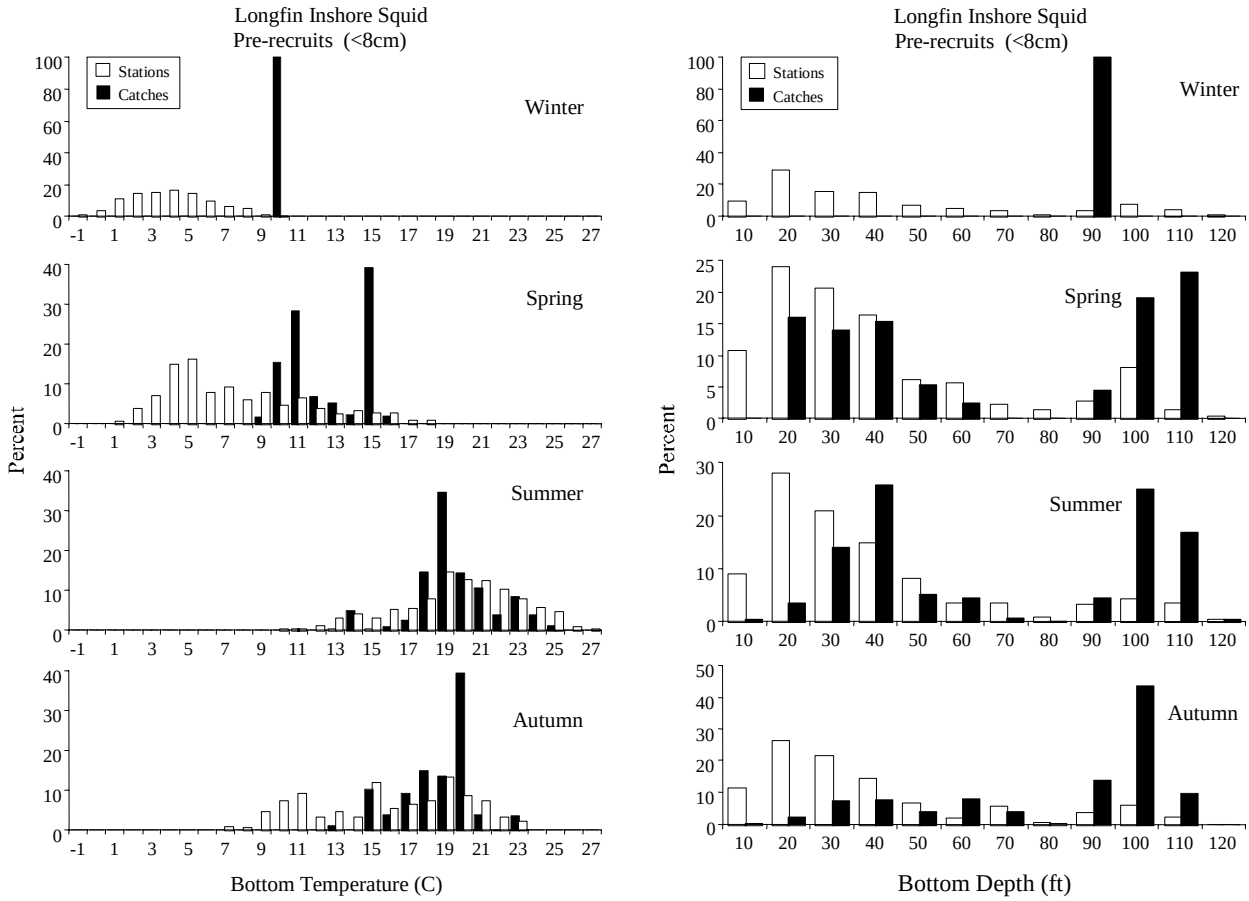


Figure 8. Seasonal abundance of longfin inshore squid pre-recruits (≤ 8 cm) and recruits (≥ 9 cm) relative to mean bottom water temperature and bottom depth from Rhode Island Narragansett Bay trawl surveys, 1990-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

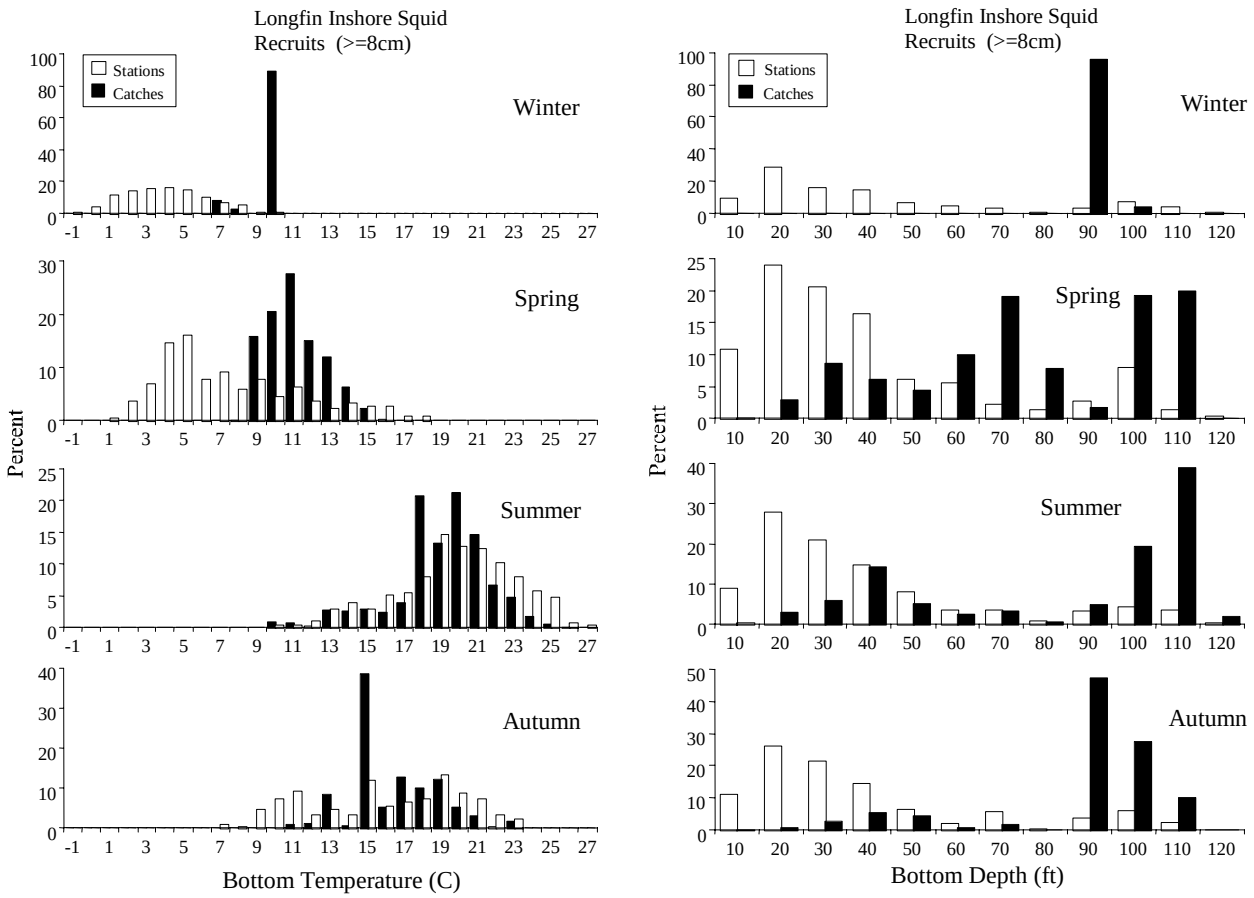


Figure 8. cont'd.

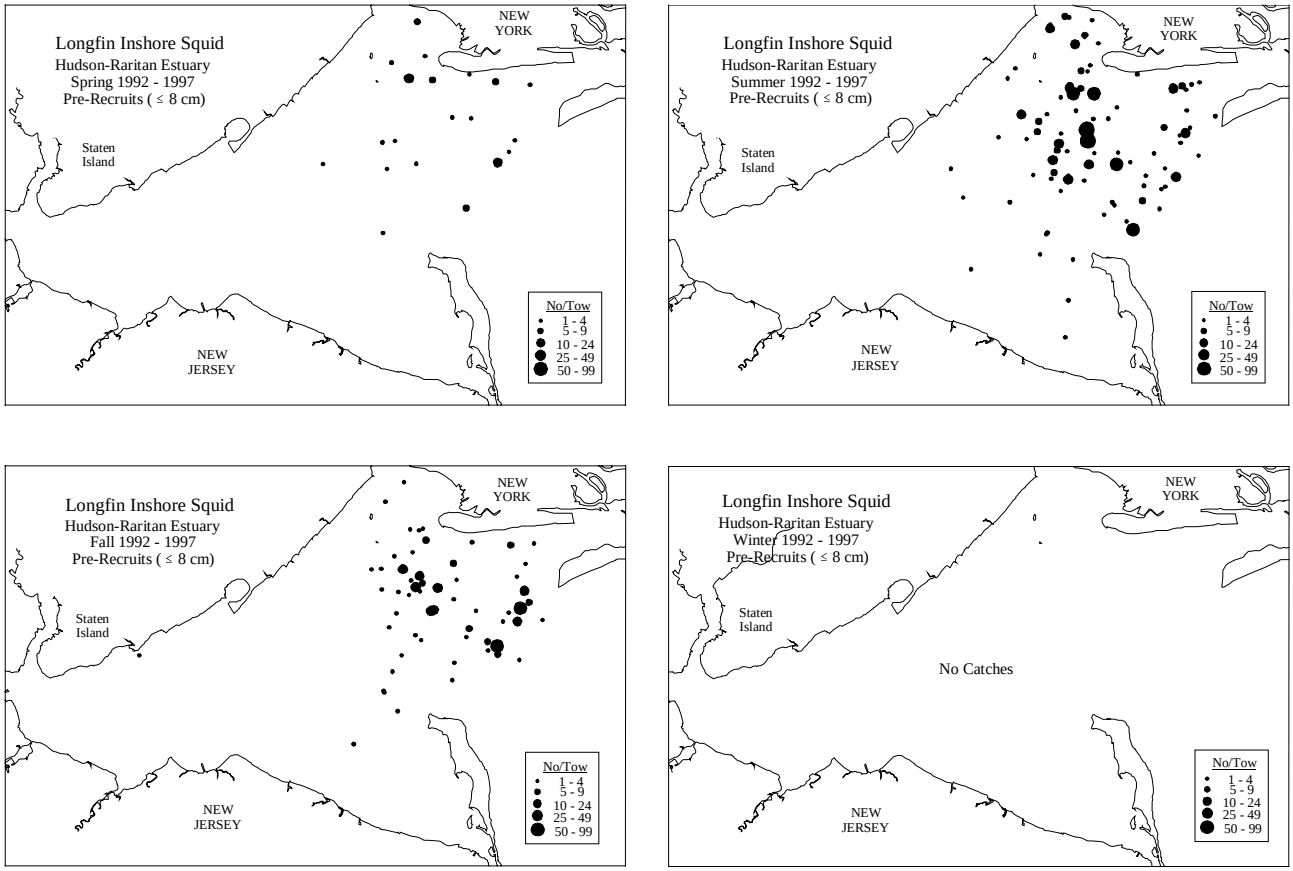
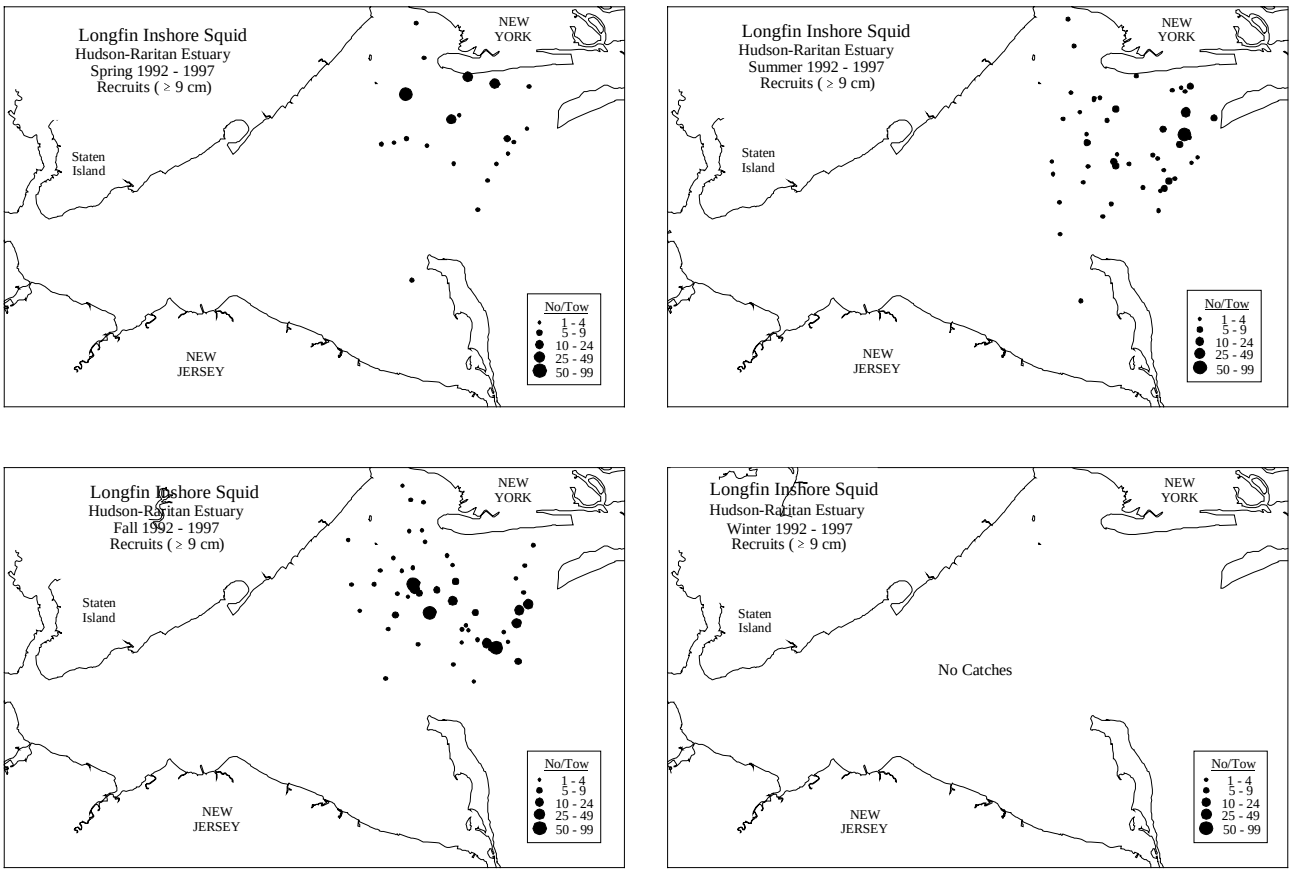


Figure 9. Seasonal distribution and abundance of longfin inshore squid pre-recruits (≤ 8 cm) and recruits (≥ 9 cm) collected in the Hudson-Raritan estuary during NEFSC Hudson-Raritan trawl surveys, 1992 – 1997 [see Reid *et al.* (1999) for details].



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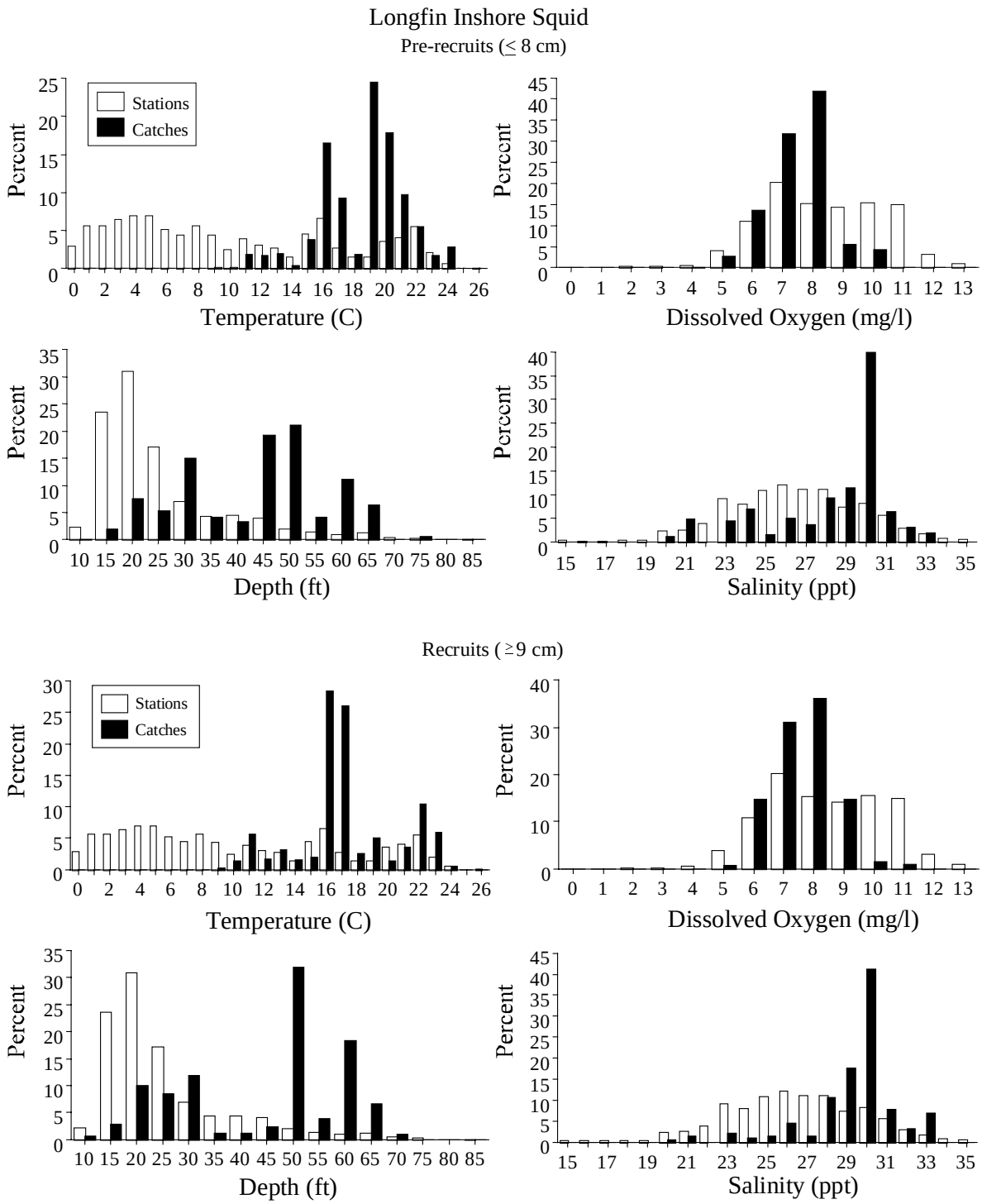
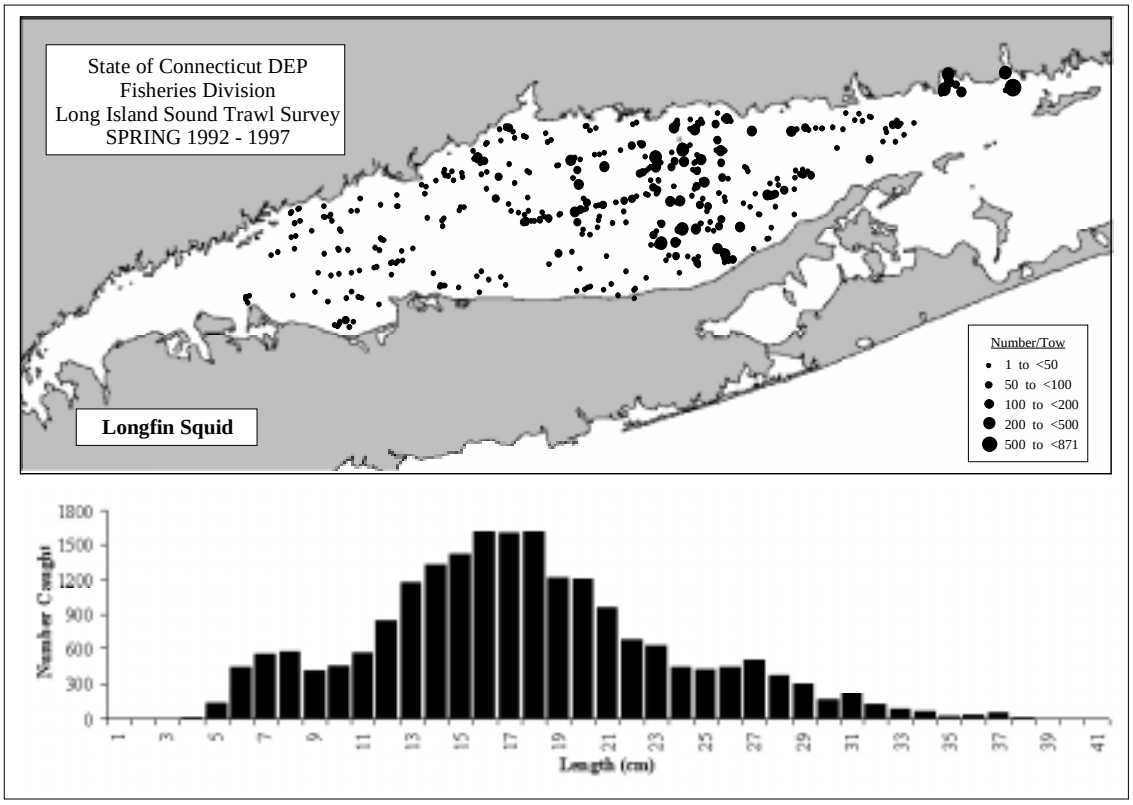


Figure 10. Abundance of longfin inshore squid pre-recruits (≤ 8 cm) and recruits (≥ 9 cm) relative to bottom water temperature, depth, dissolved oxygen, and salinity based on Hudson-Raritan estuary trawl surveys, 1992 – 1997, all seasons and years combined. Open bars represent the proportion of all stations surveyed, solid bars represent the proportion of the sum of all standardized catches.



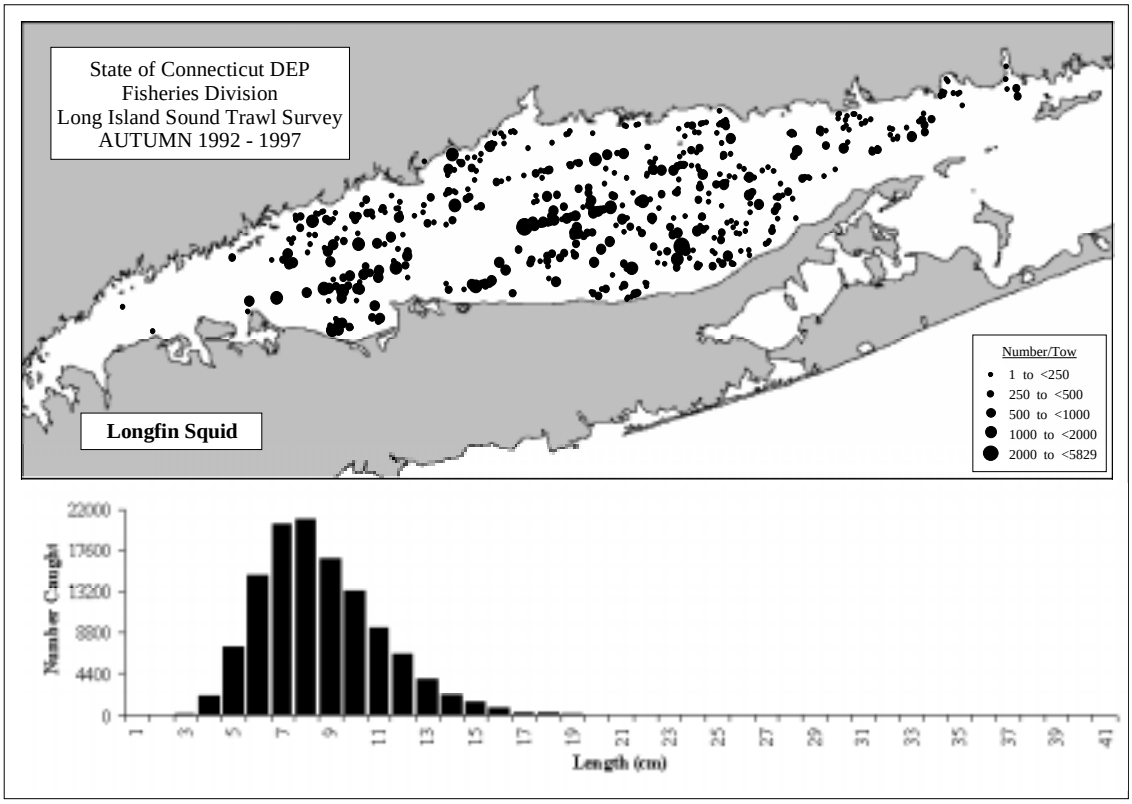


Figure 11. Distribution, abundance, and size frequency distribution of longfin inshore squid captured in Long Island Sound during spring and autumn Connecticut bottom trawl surveys, 1992-1997 [see Reid *et al.* (1999) for details].

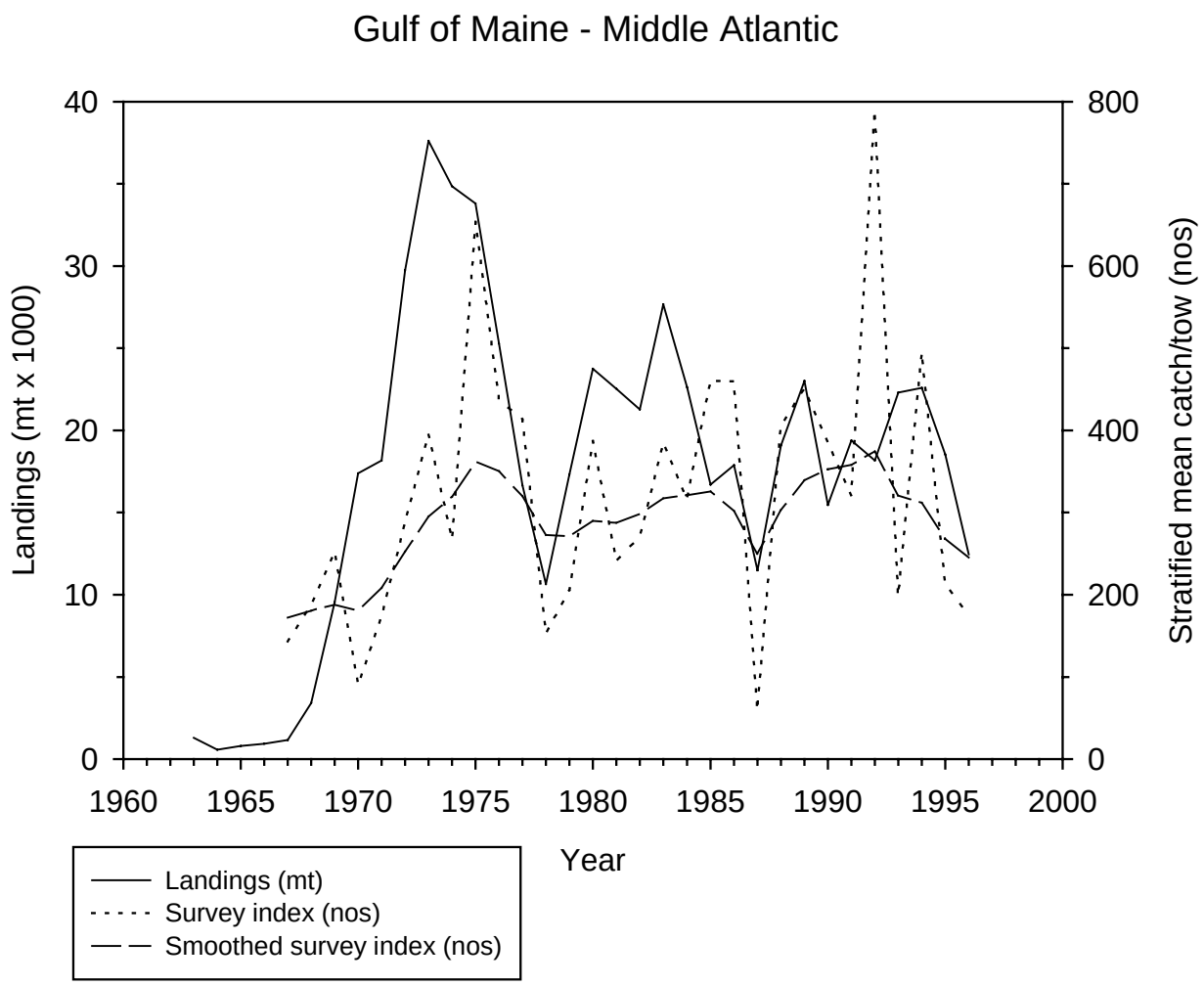


Figure 12. Commercial landings and population abundance indices (from the NEFSC bottom trawl surveys) for longfin inshore squid in the Gulf of Maine and Middle Atlantic Bight, 1963-1996.

Publishing in *NOAA Technical Memorandum NMFS-NE*

Manuscript Qualification

This series represents a secondary level of scientific publishing in the National Marine Fisheries Service (NMFS). For all issues, the series employs thorough internal scientific review, but not necessarily external scientific review. For most issues, the series employs rigorous technical and copy editing. Manuscripts that may warrant a primary level of scientific publishing should be initially submitted to one of NMFS's primary series (*i.e., Fishery Bulletin, NOAA Technical Report NMFS,* or *Marine Fisheries Review*).

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Organization: Manuscripts must have an abstract, table of contents, and -- if applicable -- lists of tables, figures, and acronyms. As much as possible, use traditional scientific manuscript organization for sections: "Introduction," "Study Area," "Methods & Materials," "Results," "Discussion" and/or "Conclusions," "Acknowledgments," and "References Cited."

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For spelling of scientific and common names of fishes, mollusks, and decapod crustaceans from the United States and Canada, use *Special Publications* No. 20 (fishes), 26 (mollusks), and 17 (decapod crustaceans) of the American Fisheries Society (Bethesda, MD). For spelling of scientific and common names of marine mammals, use *Special Publication* No. 4 of the Society for Marine Mammalogy (Lawrence, KS). For spelling in general, use the most recent edition of *Webster's Third New International Dictionary of the English Language Unabridged* (Springfield, MA: G.&C. Merriam).

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Tables should be prepared using all tabs or all spaces between columnar data, but not a combination of the two. Figures must be original (even if oversized) and on paper; they cannot be photocopies (*e.g.,* Xerox) unless that is all that is available, nor be on disk. Except under extraordinary circumstances, color will not be used in illustrations.

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STANDARD MAIL A

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific ournals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

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Fishermen's Report **and** ***The Shark Tagger*** -- The ***Fishermen's Report*** (FR) is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of the FR; copies are available through free subscription. ***The Shark Tagger*** (TST) is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of the TST; copies are available only to participants in the tagging program.

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NOAA Technical Memorandum NMFS-NE-149

Essential Fish Habitat Source Document:

Scup, *Stenotomus chrysops*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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NOAA Technical Memorandum NMFS-NE-149

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Essential Fish Habitat Source Document:

Scup, *Stenotomus chrysops*, Life History and Habitat Characteristics

Frank W. Steimle, Christine A. Zetlin, Peter L. Berrien, Donna L. Johnson, and Sukwoo Chang

National Marine Fisheries Serv., James J. Howard Marine Sciences Lab., 74 Magruder Rd., Highlands, NJ 07732

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Woods Hole, Massachusetts

September 1999

Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

---

[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

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INTRODUCTION

Scup (*Stenotomus chrysops* Linnaeus 1766) (Figure 1), is a temperate species that occurs primarily from Massachusetts to South Carolina, although it has been reported as far north as the Bay of Fundy and Sable Island Bank, Canada (Bigelow and Schroeder 1953; Fritz 1965; Scott and Scott 1988) and as far south as Florida (Morse 1978; Manooch 1984).

The 'southern porgy' (*S. aculeatus*) is referred to in a number of South Atlantic Bight studies and reviews (e.g., Morse 1978; Powles and Barans 1980; Sedberry and Van Dolah 1984), but is not considered a separate species by the American Fisheries Society (Robins *et al.* 1991) leading to some taxonomic confusion (T. Munroe, National Systematics Laboratory, Smithsonian Institution, Washington, DC, personal communication). For example, Miller and Richards (1980) list *S. chrysops* and *S. aculeatus* as reef dwellers in the South Atlantic Bight.

Although there can be some mixing of the Middle and South Atlantic Bight scup populations off North Carolina, the Middle Atlantic Bight population is treated separately here, because only this population appears to make extensive seasonal migrations and few fish tagged off New England or New York have been caught south of Cape Hatteras (Nesbit and Neville 1935; Finkelstein 1971). Scup in the Middle Atlantic Bight population are commonly found during the summer in larger estuaries and in coastal waters; during the winter, they occur along the outer continental shelf to about 200 m (656 ft) and occasionally deeper. Beebe and Tee-Van (1933) reported that scup were introduced to Bermuda, but the status of that introduction is unknown and probably unsuccessful (B. Collette, National Systematics Laboratory, Smithsonian Institution, Washington, DC, personal communication). Archeological evidence suggests scup have been common in southern New England waters for several thousand years and were used as food by native Americans (Waters 1967).

The scup population in the Middle Atlantic Bight spawns along the inner continental shelf off southern New England from May through August with a peak in June to July. Larvae occur in coastal waters during the warmer seasons, feed upon small zooplankton, and are prey to a variety of planktivores, including medusae, crustaceans and fish. Larvae settle to the seafloor in coastal and estuarine waters when they are about 25 mm total length (TL), but this event is poorly documented. During the summer and early fall, juveniles and adults are common in most larger estuaries and coastal areas in open and structured habitats where they feed on a variety of small benthic invertebrates. Scup begin to mature at 2 years of age (Finkelstein 1969b) at about 15.5 cm fork length (FL) (O'Brien *et al.* 1993). Most fish are mature at 3 years and at 21 cm FL (Gabriel 1998). In the last century, scup ≥ 45 cm FL were reported (Baird 1873) living to about 20 years and weighing about 2 kg (Bigelow and Schroeder 1953). Currently, the population in the Middle Atlantic Bight is composed primarily of fish ≤ 7 years and ≤ 33 cm FL (Northeast Fisheries Science Center 1997). Since the 1930s, there has been a significant decline in the average size of scup; small scup have slightly different habitat and prey requirements than larger scup (Smith and Norcross 1968).

LIFE HISTORY

The life history of scup is typical of most demersal fishes, with pelagic eggs and larvae, and a gradual transition to the demersal adult stage. As a temperate species, scup is at the northern limits of its range in the northeastern United States and migrates south in the winter to warmer waters south of New Jersey.

EGGS

Scup eggs are small, 0.8-1.0 mm in diameter, and buoyant (Kuntz and Radcliffe 1918; Wheatland 1956). They require two to three days (40-75 hrs) to hatch depending on temperature (Griswold and McKenney 1984). Little else is known of this ephemeral stage.

LARVAE

The newly hatched larvae are about 2.0 mm TL, pelagic, and depend on their yolk for about three days until they are about 2.8 mm TL (Bigelow and Schroeder 1953) when active feeding begins. After reaching 15-30 mm TL in early July, the larvae become demersal in shoal waters (Lux and Nichy 1971; Johnson 1978; MAFMC 1996; Able and Fahay 1998). Griswold and McKenney (1984) considered the larvae as juveniles when they grow to about 18-19 mm TL. There is no information available on habitat use or requirements during this transition period.

JUVENILES

Able and Fahay (1998) noted that the smallest, young-of-the-year (YOY) individuals appeared in estuaries in June. In southern New England, juvenile scup grew to 5 to 10 cm FL by November (Bigelow and Schroeder 1953; Gottschall *et al.*, in review). Returning juveniles in the spring were about 10-13 cm FL (Michelman 1988; Able and Fahay 1998). Growth of YOY scup is considered relatively slow (Able and Fahay 1998). Michelman (1988) estimated daily growth of juveniles to be 0.84% of its dry wt/day using a length frequency method and 0.93% of its dry wt/day using a bioenergetics method. The growth production rates were

between 0.15 and 0.40 g of its dry wt/m^2 with a growth efficiency of about 24%. Growth rates and curves for juvenile scup were reported in several studies, see MAFMC (1996).

ADULTS

Adult scup are common residents in the Middle Atlantic Bight from spring to fall and are generally found in schools on a variety of habitats, from open sandy bottom to structured habitats such as mussel beds, reefs or rough bottom. Smaller-sized adult scup are common in larger bays and estuaries but larger sizes tend to be in deeper waters. Schools are reported to be size-structured (Morse 1978). Scup mature at about 2 years of age and 50% of both sexes are reported to be mature when they achieve a length of 15.5 cm FL (O'Brien *et al.* 1993). Examining growth of male and female scup from the New York Bight (the continental shelf bounded by southern Long Island and the New Jersey coast), Wilk *et al.* (1978) found no significant difference in the length-weight relationships between sexes within the 113-361 mm FL range. The relationship for a larger sample of unsexed fish, 27-380 mm FL, was log W = log (-5.022) + 3.169 log FL, where W is weight in grams and fork length (FL) is in mm; similar relationships have been reported in MAFMC (1996). Growth in length is curvilinear between 10-38 cm FL corresponding to ages of about 1 to 13 years; growth is relatively rapid at 10-15 cm FL and declines with increasing size (Penttila *et al.* 1989).

Scup are members of an offshore-wintering guild of fishes whose movements, habitats, and food habits generally coincide (Musick and Mercer 1977; Colvocoresses and Musick 1984; Austen *et al.* 1994; Brown *et al.* 1996). This guild includes summer flounder (*Paralichthys dentatus*), black sea bass (*Centropristis striata*), northern searobin (*Prionotus carolinus*), and smooth dogfish (*Mustelus canis*) (Gabriel 1992; Shepherd and Terceiro 1994). Although biological interactions among guild members can occur, slight differences exist in their environmental tolerances and habitat preferences (Neville and Talbot 1964).

REPRODUCTION

The mean fecundity of scup, 17.5-23.0 cm FL, is about 7,000 (±4,860 SD) eggs per female (Gray 1990). Scup spawn once a year beginning in the spring during the inshore migration (Kendall 1973) when water temperatures are >10°C. In eastern Long Island bays (New York) and Raritan Bay (New York-New Jersey), spawning occurs in May and June (Breder 1922; Finkelstein 1969a). Along coastal Rhode Island, spawning peaks in June (O'Brien *et al.* 1993) and extends to August at temperatures of about 24°C (Herman 1963). In southern Massachusetts, spawning fish occur in shoal waters < 10 m deep until late June, when they move into deeper waters (MAFMC 1996). Most spawning occurs in southern New England from Massachusetts Bay south to the New York Bight, including eastern Long Island Sound, Peconic and Gardiners Bays, and Raritan Bay (Goode 1884; Kuntz and Radcliffe 1918; Breder 1922; Nichols and Breder 1927; Permutter 1939; Bigelow and Schroeder 1953; Wheatland 1956; Richards 1959; Finkelstein 1969a; Sisson 1974; Morse 1978; Clayton *et al.* 1978).

Able and Fahay (1998) noted that there has been no reported evidence of spawning in Block Island Sound (Rhode Island), Great South Bay (New York), the Hudson River estuary, and Great Bay (New Jersey). Although Breder (1922) reported ripe scup in the Hudson-Raritan estuary, more recent studies do not report the collection of scup eggs or larvae (Croker 1965; Berg and Levinton 1985). Esser's (1982) note on scup spawning in the estuary was not referenced and is probably based on Breder (1922).

Spawning has not been reported south of New Jersey (Morse 1982); e.g., off Chesapeake Bay (Hildebrand and Schroeder 1928; Pearson 1932). However, Berrien and Sibunka (1999) found eggs in this area between 1978 and 1987, although they were not abundant or widespread. Although scup are common in the spring off Maryland and Virginia, Eklund and Targett (1990) did not observe spawning over hard-bottom reef habitat. The scup they observed appeared to be migrants since few remained as summer residents in the study area.

Ferraro (1980) suggested that scup spawn in the morning in Peconic Bay, Long Island, unlike most fish that generally spawn in the evening or at night. Scup usually spawn over weedy or sandy areas and fertilization is external with no parental care (Morse 1978). Scup appear to refrain from feeding during spawning (Baird 1873; Bigelow and Schroeder 1953; Morse 1978).

Spawning can fail in some years, e.g., 1958 (Edwards *et al.* 1962), even though, based on landings data, spawning stocks are near peak abundance (MAFMC 1996). The relationship of this apparent spawning failure to environmental or habitat variables is unknown. Scup spawning coincides temporally with that of several other fish, including weakfish (*Cynoscion regalis*), tautog (*Tautoga onitis*), and northern searobin (Morse 1978).

FOOD HABITS

Although food habits data for scup larvae are not available, rearing experiments suggest that the larvae feed on small zooplankton (Griswold and McKenney 1984).

In Long Island Sound, juvenile scup feed during the day, principally on polychaetes (e.g., maldanids, nephthids, nereids, and flabelligerids), epibenthic amphipods and other small crustaceans, mollusks, and

fish eggs and larvae (Bowman *et al.* 1987). Copepods and mysids are important to post-larvae and early juveniles, while bivalve mollusks are more commonly eaten by larger fish (Richards 1963b; Bowman *et al.* 1987; Michelman 1988). Allen *et al.* (1978) reported amphipods, polychaetes, copepods, and other small crustaceans were eaten by a small sample of juvenile scup in southern New Jersey, which is consistent with Northeast Fisheries Science Center (NEFSC) data [Figure 2; see Reid *et al.* (1999) for a discussion of NEFSC food habitats data]. Michelman (1988) reported that scup only eat when they are in a school and the relative importance of major prey taxa varies seasonally. Baird (1873) reported prey were "rooted out of the sand or mud." Juvenile and adult scup near an artificial reef in lower Delaware Bay ate a mix of hard-surface epifauna and sand bottom infaunal prey, including amphipods (caprellids and others), razor clams (*Ensis directus*), hydroids, blue mussels (*Mytilus edulis*), anemones, and mysids (F. Steimle, unpublished data). In Raritan Bay, scup 9-12 cm FL ate a variety of benthic infaunal and epifaunal invertebrates including polychaetes, copepods, small mollusks, and hydroids; dietary composition varied among areas within the bay (Steimle *et al*., in review). Michelman (1988) estimated that juvenile scup in Narragansett Bay (Rhode Island) consumed 0.6-1.7 g dry wt/m^2 of benthic prey between June 1 and September 30. The daily food ration of juvenile scup was 3.49-3.99% of dry body weight (depending on method used), or about 5% of their body weight per day.

Adult scup are also benthic feeders and forage on a variety of prey, including small crustaceans (including zooplankton), polychaetes, mollusks, small squid, vegetable detritus, insect larvae, hydroids, sand dollars, and small fish (Goode 1884; Nichols and Breder 1927; Hildebrand and Schroeder 1928; Bigelow and Schroeder 1953; Oviatt and Nixon 1973; Maurer and Bowman 1975; Morse 1978; Sedberry 1983; Figure 2). As scup grow, their diets include larger prey. Bowman *et al.* (1976) found that polychaetes were more important in the diets of scup off southern New England and anthozoans were more important in the Middle Atlantic Bight. Sedberry (1983) reported that during the fall migration off New Jersey scup fed mainly on amphipods, polychaetes, and to a lesser extent on decapod crustaceans, copepods, snails, and other small invertebrates. Adults also prey on small benthic invertebrates, although feeding and growth appear to be reduced during the winter.

At times and in certain areas, scup diets overlap those of red hake (*Urophycis chuss*) and, depending on scup size, those of silver hake (*Merluccius bilinearis*) and Gulf Stream flounder (*Citharichthys arctifrons*) (Sedberry 1983). Langton (1982) found that although the diets of scup overlapped those of several other demersal species, there was little prey overlap with cod (*Gadus morhua*) or silver hake off New England, even though they have similar benthic diets. Jeffries and Terceiro (1985) hypothesized that an expanding scup population in Narragansett Bay seemed to replace the winter flounder (*Pseudopleuronectes americanus*) because both species have similar diets; if abundance of winter flounder were reduced, more prey could be available for benthic-feeding species such as scup. This dietary similarity was also found in a recent fish food habit study in Hudson-Raritan Bay (Steimle *et al*., in review).

During inshore residency, scup gradually accumulate food reserves from the spring into the fall. The mean caloric content increases from 24.2 kj/g ash-free dry weight of whole scup in the spring to 28.1 kj/g ash-free dry weight in the fall (Steimle and Terranova 1985). This stored energy can support the extra demands of migration, reduced feeding in winter, and gonadal development. Feeding may be minimal during the winter because there is so little growth (Bigelow and Schroeder 1953).

PREDATION AND MORTALITY

Larvae are probably preyed on by a variety of planktivores, including medusae, crustaceans, and fishes. Small or juvenile scup are heavily preyed on by bluefish (*Pomatomus saltatrix)*, Atlantic halibut (*Hippoglossus hippoglossus*), cod, various sharks, striped bass (*Morone saxitilus*), weakfish, goosefish (*Lophius americanus*), silver hake, and other coastal fish predators (Baird 1873; Smith 1898; Jensen and Fritz 1960; Schaefer 1970; Morse 1978; Sedberry 1983). Baird (1873) reported that cod ate large numbers of small scup on Nantucket Shoals in late November. Wading and diving shorebirds are also potential predators during the summer.

The NEFSC bottom trawl survey data on food habits lists the following species as predators of scup: dusky shark (*Carcharhinus obscurus*), sandbar shark (*C. plumbeus*), smooth dogfish, spiny dogfish (*Squalus acanthias*), Atlantic sharpnose shark (*Rhizoprionodon terraenovae*), Atlantic angel shark (*Squatina dumeril*), Atlantic torpedo (*Torpedo nobiliana*), bluntnose stingray (*Dasyatis say*), silver hake, bluefish, summer flounder, black sea bass, weakfish, northern stargazer (*Astroscopus guttatus*), goosefish, inshore lizardfish (*Synodus foetens*), and king mackerel (*Scomberomorus cavalla*).

Another potential source of mortality is disease. Disease can be initiated by direct epidermal exposure or through feeding on contaminated prey. Scup had fin rot in the degraded inner New York Bight and Hudson-Raritan estuary (Mahoney *et al.* 1975). Benthic invertebrate prey commonly eaten in the New York Bight were contaminated with several toxic heavy metals (Steimle *et al.* 1994).

MIGRATION

As inshore water temperatures decline to < 8-9°C in

the winter, scup leave inshore waters and move to warmer waters on the outer continental shelf south of the Hudson Canyon off New Jersey and along the coast from south of Long Island to North Carolina in depths ranging from 75-185 m (Morse 1978; Bowman *et al.* 1987). Juveniles follow adults to wintering areas on the mid to outer continental shelf south of Long Island, although some remain in larger and deeper estuaries during warmer winters. During migration, scup move south along the coast (within the 18 m isobath) and offshore (Hamer 1970) as coastal bottom water temperature declines below 10°C. Phoel (1985) reported that scup migrated south of Cape Hatteras to about Cape Fear (North Carolina) in the winter and spring (he assumed one species and no population mixing).

With rising water temperatures in the spring, scup return inshore. Larger fish arrive first followed by schools of subadults, which have been reported to appear off southern New England slightly later (Sisson 1974). The fish reach Chesapeake Bay by April (Hildebrand and Schroeder 1928) and southern New England by early May (Baird 1873; Perlmutter 1939; Neville and Talbot 1964; Finkelstein 1971). It has been suggested that the population moves in schools of similarly-sized individuals during migration and perhaps at other times as well (Baird 1873; Hildebrand and Schroeder 1928; Neville and Talbot 1964; Sisson 1974; Morse 1978). Fish that arrive inshore early can be caught in pockets of residual cold water and can become inactive or dormant (Kessler 1966).

STOCK STRUCTURE

Although the Middle Atlantic Bight population was once considered to be two stocks, i.e., southern New England and New Jersey (Edwards *et al.* 1962; Neville and Talbot 1964; Hamer 1970; Morse 1978). More recent analysis found that the evidence for this segregation was weak. Pierce (1981) suggested that the apparent segregation of two stocks in the Middle Atlantic Bight could be an artifact of the temporary location of separate winter water masses containing temperatures acceptable to scup; in most years this water mass separation is lacking or less influential. Scup is presently considered a single stock in the Middle Atlantic Bight (Pierce 1981; Mayo 1982).

HABITAT CHARACTERISTICS

Scup are a temperate, demersal species that use several benthic habitats from open water to structured areas for feeding and possibly for shelter (Table 1). Their distribution changes seasonally as fish migrate from estuaries to the edge of the continental shelf as water temperatures decline in the winter and return from the edge of the continental shelf to inshore areas as water temperatures rise in the spring. Some reports on scup habitat use and distribution may be biased by the type of collection gear used and the habitats in which they can be deployed effectively. For example, most surveys use towed nets that are appropriate for open bottom but not for rough, structured habitats that scup are known to use such as mussel beds, rock rubble, or reefs.

EGGS

Scup eggs are commonly found in larger bodies of coastal waters such as bays and sounds in and near southern New England during spring and summer. Lebida (1969) reported eggs were relatively abundant in Buzzards Bay (Massachusetts) from May through June at water temperatures of 8.5° to 23.7°C, which is similar to their distribution in Connecticut and Rhode Island estuaries (Herman 1963). Eggs hatched in about 70-75 hrs at 18°C and 40-54 hrs at 21-22°C (Griswold and McKenney 1984); they may not develop normally at temperatures below 10°C (Bigelow and Schroeder 1953).

Few scup eggs were collected in the NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) ichthyoplankton survey [see Reid *et al.* (1999) for survey methods]. The few survey tows that collected eggs were made during May-August when integrated water column temperatures were between 11° and 23°C (Figure 3). Their occurrence at 23°C probably represents eggs collected off Maryland-Virginia during the summer. Most eggs were collected in generally < 50 m (Figure 3).

LARVAE

Larval scup are pelagic and occur in coastal waters during warmer months. Larvae were collected in the more saline parts of Long Island Sound and eastern Long Island bays, Narragansett Bay, Buzzards Bay, Vineyard Sound, and Cape Cod Bay from May through September at water temperatures of 14-22°C; the greatest densities occurred at 15-20°C (Fish 1925; Wheatland 1956; Pearcy and Richards 1962; Herman 1963; Scherer 1984; MAFMC 1996). Herman (1963) found larvae when water temperatures were 20.0-23.5°C. The optimum for rearing larvae in the laboratory is 18°C (Lawrence 1979). The NEFSC MARMAP larval data indicate a peak in abundance at 17°C at depths < 50 m (Figure 4).

JUVENILES

During warmer months, juvenile scup live inshore in a variety of coastal habitats and can dominate the overall fish population in most larger estuarine areas during that period. In Rhode Island, YOY scup have been collected

in intertidal and subtidal habitats, over sand, silty-sand, shell, mud, mussel beds and eelgrass (*Zosteria marina*) (Baird 1873). Although Gottschall *et al.* (in review) noted that 1 year old scup were found on various types of sediment during warmer months in Long Island Sound, Richards (1963a) reported collecting more juvenile scup in a sandy habitat 9 m deep than at a 17 m deep muddy area of the sound. Scup were also collected in the smaller coastal bays of Delaware (Derickson and Price 1973). However, scup were not common in shoreline seine or throw-trap surveys in vegetated and unvegetated habitats in Chesapeake Bay, Long Island Sound, or New Jersey estuaries (Greeley 1939; Warfel and Merriman 1944; Briggs and O'Connor 1971; Himchak 1982; Weinstein and Brooks 1983; Sogard 1989; Sogard and Able 1991).

While little is known about the specific habitats occupied in winter when juvenile scup reside offshore, their winter-spring distributions indicate that they occur in habitats ranging from relatively flat, open, sandy-silty bottoms to the head of submarine canyons, and other areas with topographical relief and varying sediments (Wigley and Theroux 1981).

The presence of structure can be important to scup. Gray (1990) and Auster *et al.* (1991, 1995) noted that juveniles use biogenic depressions in the sediments off southern New England in the fall; the size of the depression was directly related to the size of the fish. Juveniles can use biogenic depressions, sand wave troughs, and possibly mollusk shell fields for shelter in winter. Their poor growth during colder months (Bigelow and Schroeder 1953) suggests inactivity and possibly an increased need for shelter.

Juvenile scup have been collected at water temperatures ranging from 5-27°C [Figures 5-8; see Reid *et al.* (1999) for survey methods]. This is slightly below the thermal maximum of 30.2-35.6^{o}C (depending on acclimation) reported by Everich and Gonzalez (1977). The modes of highest relative abundance shift from about 10°C in the spring to peaks at 16°C and 22°C from summer to fall, except in Narragansett Bay (Figure 8) and Long Island Sound where the bimodality was unclear. In Long Island Sound, where juveniles dominate the population, they were collected at bottom temperatures of 7-18°C in the spring and 15-22°C in the fall at salinities of 25-31 ppt. Subadults, which usually follow the migrations of adults south during the fall, have been killed by sudden cold spells in shallow New England bays (Baird 1873; Sherwood and Edwards 1902; Morse 1978). However, from 1971 to 1975, juveniles over-wintered in Long Island Sound (Thomson *et al.* 1978). In the Hudson-Raritan estuary, juveniles were collected at temperatures ranging from 9° to 26°C, at salinities ranging from 18 to 33 ppt, and dissolved oxygen (DO) levels > 4 mg/l (Figure 6).

From summer through fall, YOY and age 1+ scup were found in many tidal bays, sounds, and coastal areas primarily north of Maryland at depths within the 38 m (< 125 ft) contour (Morse 1978; Figures 6-8). In Raritan Bay, juvenile scup were most commonly collected at depths between about 5 and 12 m (15 to 35 ft) (Figure 6).

ADULTS

Adult habitats are similar to those used by juveniles, including soft, sandy bottoms, on or near structures, such as rocky ledges, wrecks, artificial reefs, and mussel beds in euryhaline areas (Briggs 1975a; Eklund 1988; MAFMC 1996). In Long Island Sound, scup exhibit a strong preference for mixed sand and mud sediments (Gottschall *et al.*, in review), which are probably rich in small benthic prey (Reid *et al.* 1979). Similar to juveniles, the specific habitats used by adult scup during the winter or during migration are not known. The areas in which they have been found can include a variety of habitat types that differ in sediment composition, availability of food, and structure or relief (Wigley and Theroux 1981; Steimle 1990).

Adult scup also occurred at bottom water temperatures of 6-27°C (Figures 5-8). Their winter distribution appears to be mostly limited by the 7°C isotherm, their lower preferred limit (Neville and Talbot 1964). Magnuson *et al.* (1981) reported that scup may aggregate north of transient Gulf Stream frontal boundaries off Cape Hatteras, at least in the fall when the temperature differential was about 8°C (25.6^{o} vs. 17.1^{o}C). However, there are taxonomic uncertainties about the species of *Stenotomus* involved.

Although scup are considered a demersal species, they have been observed at the water surface (Bigelow and Schroeder 1953). Off Massachusetts (Figure 7) and in Narragansett Bay (Figure 8), most adults were collected in spring through fall at depths < 30 m (100 ft). In New Jersey, they were reported to aggregate within the 20 m depth coastal zone as they began their offshore southerly movements (MAFMC 1996).

Adult scup in the Hudson-Raritan estuary were collected at salinities ranging primarily from 20 to 31 ppt (Figure 6), which is consistent with salinity associations in Long Island Sound (Gottschall *et al.*, in review). Similar to juveniles in the Hudson-Raritan estuary, most adults were collected at DO levels ≥ 4mg/l (Figure 6).

GEOGRAPHICAL DISTRIBUTION

Scup is a temperate species and north of Cape Hatteras the population is restricted to water temperatures above 6°C (Figure 9). Postlarval scup migrate to stay within acceptable thermal limits as bottom water temperatures in the northeast decline in winter.

EGGS

Scup eggs have been collected primarily in coastal waters off southern New England where abundance can range up to 1000 eggs/10 m^2 of sea surface (Berrien and Sibunka 1999) but samples containing > 100 eggs/10 m^2 were rare during the NEFSC MARMAP survey (Figure 10) when stock abundance was relatively low (MAFMC 1996). Eggs were collected primarily during June and July from inshore waters off southern New England; few eggs were collected on the continental shelf from May to August (Berrien and Sibunka 1999). Patchy occurrences were recorded from mid-shelf in the Chesapeake Bight from May through August (Figure 10).

Since the NEFSC MARMAP surveys did not sample waters < 10 m and excluded most coastal bays, it is probable that eggs are more abundant and widely distributed in nearshore areas. Wheatland (1956) reported that in eastern Long Island Sound and nearby bays, eggs were variably abundant from year to year from May to August with peaks in June and July. According to Stone *et al.* (1994), scup eggs were common or abundant in the saline parts of coastal bays from southern Cape Cod to Long Island Sound, eastern Long Island, and the Hudson-Raritan estuary. In contrast, Merriman and Sclar (1952) did not find eggs in Block Island Sound, along the south shore of Long Island, or in coastal waters or bays to the south. Interestingly, Able and Fahay (1998) note that there has not been a verified collection of scup eggs within southern New England estuaries since Sisson (1974).

North of Cape Cod, scup eggs have been recorded in southern Cape Cod Bay from June to August (1974-1976), possibly transported from Buzzards Bay through the Cape Cod Canal (Scherer 1984). There have been other reports of eggs in Massachusetts Bay suggesting that spawning occurs there (MAFMC 1996).

LARVAE

Larval distribution is also limited and even more conjectural than for eggs. Although Kendall (1973) noted the offshore occurrence of larvae from Virginia to Cape Cod and in estuaries from Delaware Bay to Buzzards Bay, the NEFSC MARMAP surveys collected < 5 larvae/tow, mostly inshore (about 30 m) off Rhode Island in July (Figure 11). However, larvae can be more abundant in shallow, nearshore waters since Stone *et al.* (1994) reported them in the same areas as eggs; i.e., from southern Cape Cod to Long Island Sound and in the Hudson-Raritan estuary.

Despite these reports, Able and Fahay (1998) noted that like the eggs there has been no verified collection of scup larvae in southern New England estuaries since Sisson (1974). Cowen *et al.* (1993) did not collect scup larvae in coastal or shelf waters of the New York Bight during July and August 1988, nor were they common in bays or estuaries south of Long Island (Pearson 1932; Massman *et al.* 1961; de Sylva *et al.* 1962; Dovel 1967, 1981; Scotton 1970; Pacheco and Grant 1973; Himchak 1982; Morse 1982; Olney 1983; Berg and Levinton 1985; Monteleone 1992; Stone *et al.* 1994) or in the surf zone (D. Clark, U.S. Army Corps Engineers, Vicksburg, MS, personal communication). This is surprising since some of these areas; e.g., Delaware Bay, are important juvenile nurseries (de Sylva *et al.* 1962).

Clayton *et al.* (1978) reported the occurrence of larvae in Rocky Point in northwestern Cape Cod Bay, which, as with eggs, could have been transported through the Cape Cod Canal from Buzzards Bay (Scherer 1984). Based on the presence of eggs and larvae, there is a possibility that scup can spawn in Massachusetts Bay (MAFMC 1996).

JUVENILES

In contrast with the conflicting reports and uncertainty in the spatial extent and abundance of scup eggs and larvae, juveniles have been collected inshore and offshore from New England to the Chesapeake Bay area. In fact, the saline areas of Narragansett Bay, Long Island Sound, Raritan Bay, and Delaware Bay are important nursery areas (Richards 1963a; Abbe 1967; Oviatt and Nixon 1973; Werme *et al.* 1983; Michelman 1988; Gray 1990; MAFMC 1996; Wilk *et al.* 1997; Gottschall *et al.*, in review).

Reports of the coastal occurrence of juvenile scup date back to the last century. Smith (1894) reported that they were abundant from Hyannis, Massachusetts to Barnegat, New Jersey in 1891 and Moore (1894) indicated they were common only as far south as New Jersey. More recent reports indicate that during warmer months, juvenile scup were common from the intertidal zone to about 30 m in more saline (> 15 ppt) portions of bays and estuaries and along the inner continental shelf of the Middle Atlantic Bight from about May to November (Smith 1898; Breder 1922; Kendall 1973; Werme *et al.* 1983; Bowman *et al.* 1987; Szedlmayer and Able 1996; Gottschall *et al.*, in review).

The changes in seasonal distribution are reflected in the results of the NEFSC bottom trawl surveys in which juveniles occurred offshore in winter and spring, inshore in summer, and were concentrated in near-coastal waters through fall (Figure 12). Young-of-the-year fish are locally abundant north of Cape Cod (Clayton *et al.* 1978), especially in the fall (Lux and Kelly 1982). However, this is not reflected in the Massachusetts trawl survey that indicated higher concentrations south of the Cape in spring and fall (Figure 13). Juveniles were common in Narragansett Bay (Figure 14) and Long Island Sound (Figure 16) in summer and fall. Zawacki and Briggs (1976) routinely seined juveniles on the north shore of

Long Island from July through October. Gottschall *et al.* (in review) reported that YOY scup (approximately 4 cm FL) were first collected in Long Island Sound in August and became numerically dominant in the catch by September; 1 year old juveniles were collected in April. However, other surveys of Long Island estuaries or surf zones did not support these findings (Schaefer 1967; Briggs 1975b).

The occurrence of juveniles in coastal bays and estuaries south of Long Island is temporally and spatially variable. In Raritan Bay, juveniles were abundant in spring and summer; a few were collected in the fall and were not collected in winter (Figure 17). While juveniles occur in the larger bays; e.g., Raritan and Delaware Bays (de Sylva *et al.* 1962; Werme *et al.* 1983), they seldom occur in smaller coastal lagoons such as Barnegat Bay (New Jersey), tributaries of the Hudson-Raritan estuary, or the ocean surf zone (Marcellus 1972; Howells and Brundage III 1977; Vouglitois 1983; Wilk *et al.* 1997; D. Clark, personal communication).

Varying numbers have been collected in New Jersey estuaries south of Barnegat Bay; i.e. within Hereford Inlet (Allen *et al.* 1978). Although formerly relatively abundant, juvenile scup have not occurred in large numbers in vegetated sites in lower Chesapeake Bay (Orth and Heck 1980; MAFMC 1996). However, in fall they are still collected in relatively large numbers by the NEFSC trawl surveys at the mouth of the bay (Figure 12). While juveniles do not occur to any great extent in seaside bays of Maryland and Virginia (Arve 1960; Schwartz 1961, 1964), Richards and Castagna (1970) did find them in their survey of Virginia's seaside bays.

The NEFSC groundfish surveys (1963-1997) mostly post-date the last period of high scup abundance, approximately 1950-1965 (Northeast Fisheries Science Center 1997). The NEFSC bottom trawl survey results for 1963-1964 (not shown) indicated that juveniles were widespread and distribution was similar to the present. The only apparent change in this general coastal distribution pattern was in the late 1960s (during the period of relatively low abundance) when the largest collections of juveniles were clustered off southern New England, Virginia, and North Carolina. This distribution pattern raised the question of whether there were two stocks in the Middle Atlantic Bight (Hamer 1970).

ADULTS

Adults have been reported as far north as the Bay of Fundy, southern Nova Scotia, and Sable Island Bank (east of Nova Scotia) as summer visitors (Scott and Scott 1988) and at least as far south as Cape Hatteras. As part of a temperate, migrant guild, scup have even been collected occasionally on the southern Grand Banks (Brown *et al.* 1996).

Scup occur primarily in the Middle Atlantic Bight. They migrate from offshore winter habitats into coastal waters from Chesapeake Bay to southern New England where they reside from spring to fall (Bigelow and Schroeder 1953; Richards 1963a; Scott and Scott 1988; Morse 1978; Chang 1990). These migration patterns are reflected in the results of the NEFSC bottom trawl surveys (Figure 12) and in the Massachusetts inshore survey (Figure 13). During warm months, larger scup occur in or near the mouths of larger bays, such as Narragansett Bay (Figures 14, 15) and Long Island Sound (Figure 16), and along the coast within the 38 m contour (Morse 1978).

Distribution and abundance of adult scup off New England is temperature dependent (Mayo 1982; Gabriel 1992). Smaller fish are found in more saline (> 15 ppt) shallow bays and parts of estuaries including the Hudson-Raritan estuary and Hereford Inlet (New Jersey) (Figures 6, 17; Allen *et al.* 1978; Morse 1978; Werme *et al.* 1983; Wilk *et al.* 1997). However, they may not be abundant in all bays; e.g., they have not been reported in Barnegat Bay (Marcellus 1972; Vouglitois 1983; Tatham *et al.* 1984), Maryland bays (MAFMC 1996), or in New York Harbor (Stoecker *et al.* 1992; Will and Houston 1992).

Adult scup usually arrive offshore in December and winter in deeper water from Nantucket Shoals to Cape Hatteras to depths of about 240 m (Figures 5 and 12; Pearson 1932; Neville and Talbot 1964; Morse 1978). Scup density and distribution during the winter are related to the location of the 7°C bottom isotherm, their lower preferred limit (Neville and Talbot 1964). Nesbit and Neville (1935) indicated that this band of warmer, outer continental shelf water is influenced mainly by the Gulf Stream just off the shelf. During warm winters, scup can be found across most of the continental shelf south of New Jersey (Nesbit and Neville 1935). As coastal waters warm above the 7°C threshold in spring, scup return inshore and to the north.

STATUS OF THE STOCKS

Commercial landings of scup in the Middle Atlantic Bight have declined substantially since peak landings in the 1950s and early 1960s; although there was a minor peak in landings in the early 1980s (Figure 18; Northeast Fisheries Science Center 1997). Recreational landings have also declined (MAFMC 1996).

Groundfish surveys by the NEFSC indicated cycles in abundance of scup of about 3-4 years and an overall decline since the 1950-1960s (Figure 18; Gabriel 1998). Currently, the stock is composed primarily of fish < 3 years old and the age distribution is truncated (MAFMC 1996). The abundance of scup eggs off southern New England has been low recently (Gray 1990; Able and Fahay 1998). According to Jeffries and Terceiro (1985), slightly warmer average summer temperatures (+1°C) in coastal waters off southern New England are related to an

increase in scup abundance.

The Middle Atlantic Bight stock is currently considered overfished because the stock is near record low abundance levels and catches exceed F_{max} (Gabriel 1998; National Marine Fisheries Service 1997; Northeast Fisheries Science Center 1997).

RESEARCH NEEDS

- The taxonomic status of scup and "southern porgy" should be resolved.
- The degree of mixing between populations in the Middle Atlantic and South Atlantic Bights across Cape Hatteras should be determined.
- Better characterization of spawning sites and egg and larval habitats is needed.
- Offshore winter habitats in the Middle Atlantic Bight need to be identified and described.
- The relative importance of larger estuaries (e.g., Chesapeake, Delaware, and Raritan Bays, Long Island Sound) compared to smaller estuaries and inshore areas (e.g., Barnegat Bay, seaside bays from Maryland to Virginia) as primary nurseries should be examined.
- Determine whether the patchy, inconsistent occurrence of juveniles results from inadequate monitoring or highly variable recruitment.
- The habitat factors that result in the patchy distributions of juvenile and adult scup in space and time need to be identified.
- The role of natural and artificial structured habitats in the life history, productivity, and fishery management of scup should be determined.
- Research should be conducted on the trophic relationships of scup, including the factors that control the production and distribution of their prey (Kline 1997).
- The effects of altering the population age structure on habitat requirements should be examined.
- The effects of the winter trawl fishery in the southern Middle Atlantic Bight on spawning stock, juvenile survival, and habitat should be determined.
- Information is needed on the direct and indirect effects of degraded environments on feeding, growth, fecundity, survival, and distribution of scup; indirect effects should include food web alterations.
- The long-term, synergistic effects of combinations of environmental variables (e.g., pH and toxins) on survival, reproduction, and genetic changes should be investigated (Kline 1997).

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Table 1. Summary of life history and habitat characteristics for scup, *Stenotomus chrysops*. MAB = Middle Atlantic Bight, SNE = southern New England, GOM = Gulf of Maine.

Life Stage	Time of Year	Size and Growth	Geographic Location	Habitat	Substrate	Temperature
Eggs	May-Aug, south to north progression	0.8-1.0 mm	Coastal Virginia - SNE, southern GOM	Water column, < 30 m in depth	Buoyant in water column	11-23°C; most common 12-14°C
Larvae	May-Sept, south to north	Hatch at ~2.0 mm; stage lasts to ~15-30 mm	MAB and southern GOM, near shore; mostly SNE	Water column, < 20 m until juvenile transition	In water column until transition	14-22°C; peak densities at 15-20°C
YOY and older juveniles	May-Nov, south to north	YOY: 15-30 mm to 10 cm by Nov; juveniles: to 16 cm by end of 1+ yr	MAB-GOM; in estuaries spring to fall	Estuarine and coastal; from intertidal to about 38 m	Sand, mud, mussel, and eel grass beds	Greater than ~9-27°C; mostly 16-22°C
Winter juveniles	Nov-Apr/ May	~10-13 cm; growth rate reduced	Most move offshore and south of New Jersey to warmer, deeper waters; some overwinter in Long Island Sound	Mostly > 38 m depth; mid and outer continental shelf; sometime in deep estuaries	Poorly known, found over various sand substrates	Greater than ~7°C
Summer adults	Apr-Dec	> 15.5 cm FL	Coastal from Delaware to GOM	~2-38 m	Fine to silty-sand, mud, mussel beds, rock, artificial reefs, wrecks, and other structures	~7-25°C; can acclimate to 35.6°C
Winter adults	Jan-Mar	> 15.5 cm FL	Most move offshore and south of New Jersey to warmer, deeper waters.	Mostly 38-185 m depths; mid/outer continental shelf.	Poorly known, found over various sands.	> 7°C
Spawning adults	May-Aug, peak in June	> 15.5 cm FL; mature at about age 2	Inshore from Delaware Bay north to SNE; mostly in SNE	< 30 m, during inshore migration	Weedy to sandy	> 9-24°C

Table 1. cont'd.

Life Stage	Salinity	Prey	Predators	Notes
Eggs	> 15 ppt		Most planktivores where the eggs are found.	Eggs hatch in 70-75 hrs at 18°C, and in 40-54 hrs at 21°C
Larvae	> 15 ppt	Can use yolk for ~3 days; at ~2.8 mm feeding on zooplankton must begin	Most planktivores where the larvae are found.	Benthic settlement and juvenile transition occurs at ~15-30 mm FL
YOY and older juveniles	> 15 ppt	Small benthic invertebrates, fish eggs and larvae	Bluefish, cod, hake, summer flounder, weakfish, striped bass, and others	Diurnal schooling feeders. Most migrate to deeper/warmer waters to the south in winter
Winter juveniles	Mostly > 30 ppt, except in estuaries	Poorly known; possibly small benthic invertebrates, but feeding may be reduced	Cod during SNE migration	Migrate offshore as temperatures fall below 8-9°C and inshore and north as water warms to > 7°C; early arrivals can be affected by late cold spell
Summer adults	> 15 ppt	Benthic and near bottom invertebrates, and small fish	Sharks, stingrays, dogfish, bluefish, silver hake, black sea bass, and others	Usually found in schools of similarly sized individuals. Possibly tolerant or avoid hypoxic conditions
Winter adults	> 30 ppt	Poorly known, but feeding may be reduced	Sharks, stingrays, dogfish, bluefish, silver hake, black sea bass, and others	7°C isotherm greatly influences distribution
Spawning adults	> 15 ppt	Poorly known, but feeding may be reduced	Sharks, stingrays, dogfish, bluefish, silver hake, black sea bass, and others	Spawning is often in AM; fish may avoid hypoxic areas

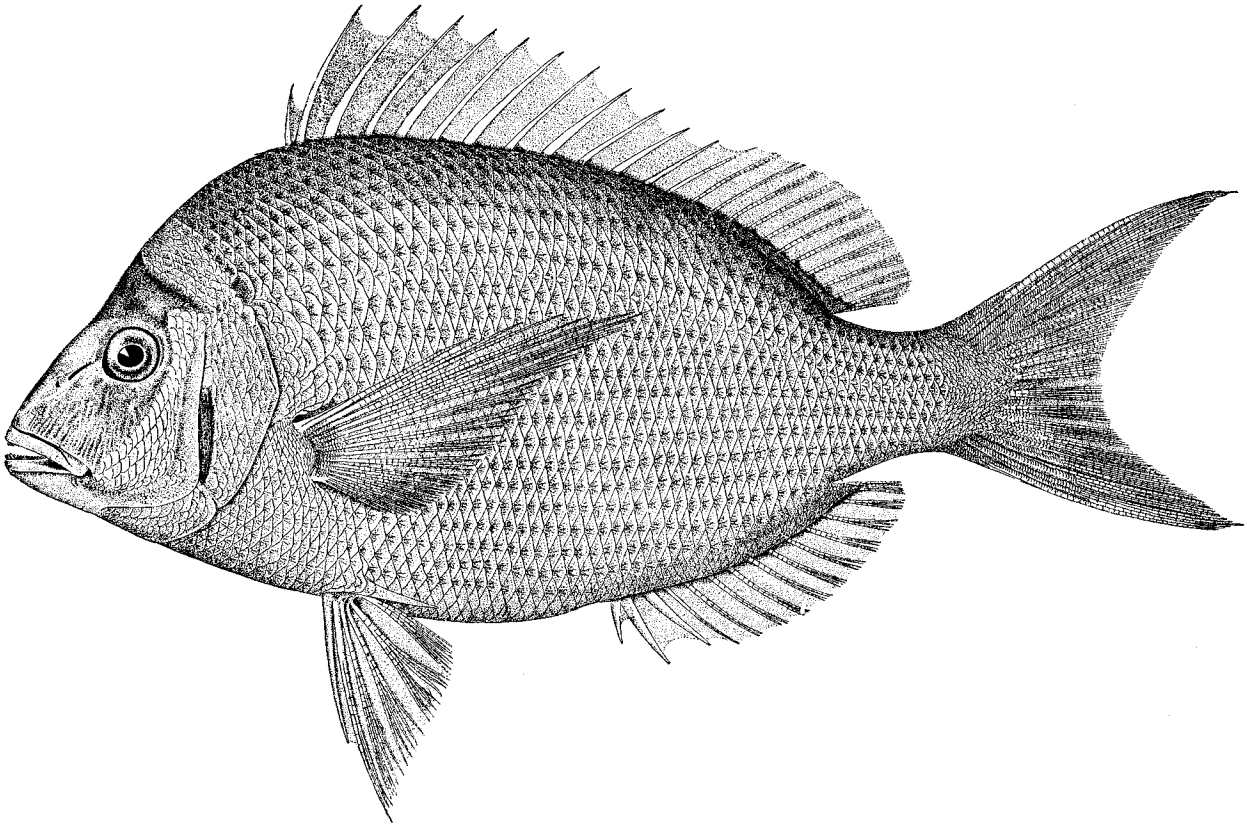


Figure 1. The scup, *Stenotomus chrysops* (from Goode 1884).

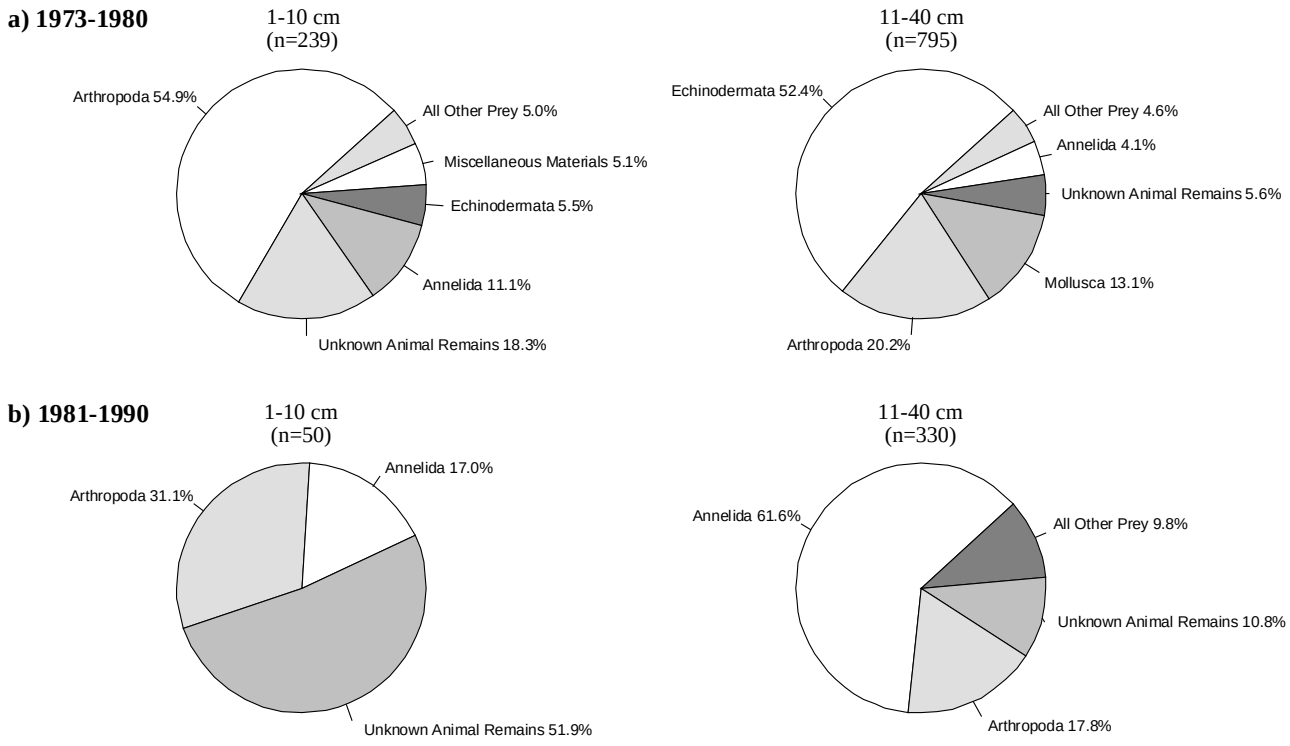


Figure 2. Abundance of the major items in the diet of juvenile (1-10 cm) and adult (11-40 cm) scup collected during NEFSC bottom trawl surveys from 1973-1980 and 1981-1990. Abundance in the 1973-1980 samples is defined by mean percent prey weights, and in the 1981-1990 samples as mean percent prey volume. The "Arthropoda" are almost entirely crustacea; see text for discussion of specific taxa involved. The category "animal remains" refers to unidentifiable animal matter. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details].

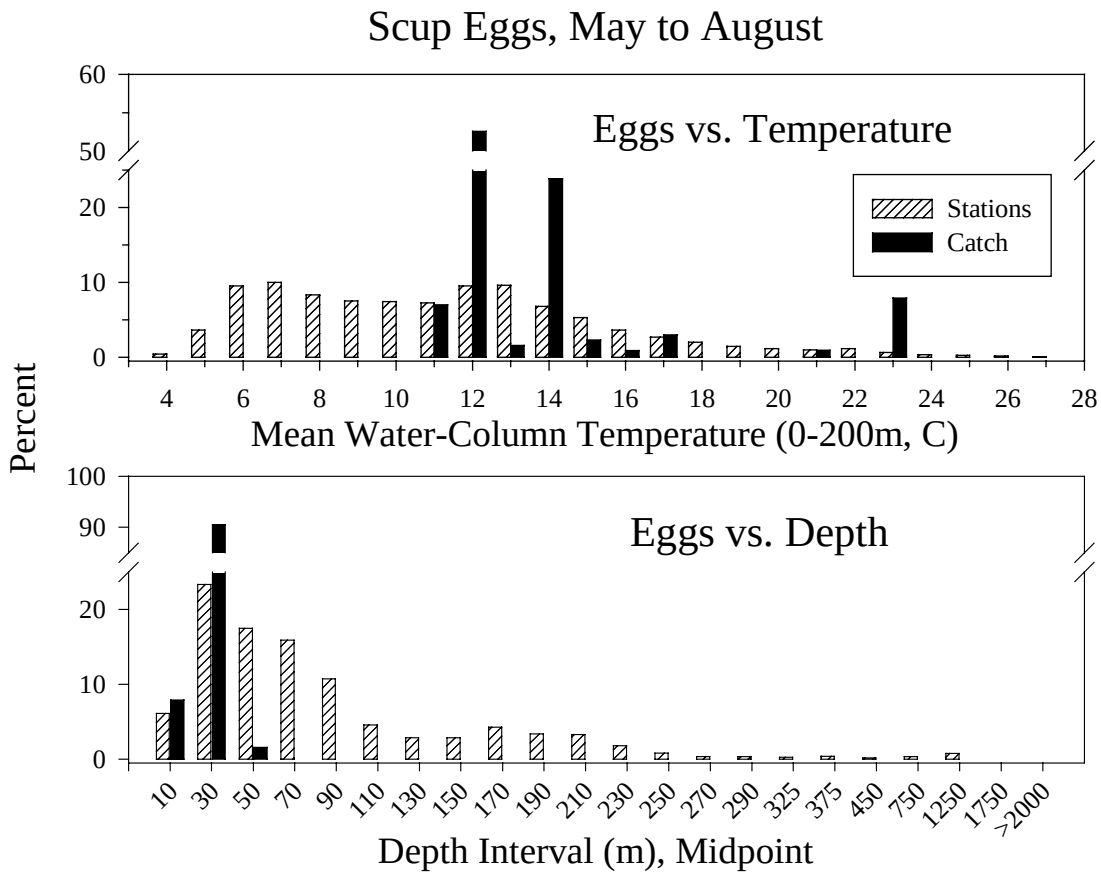


Figure 3. Abundance of scup eggs relative to water column temperature (to a maximum of 200 m) and bottom depth from NEFSC MARMAP ichthyoplankton surveys (May to August 1978-1987, all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

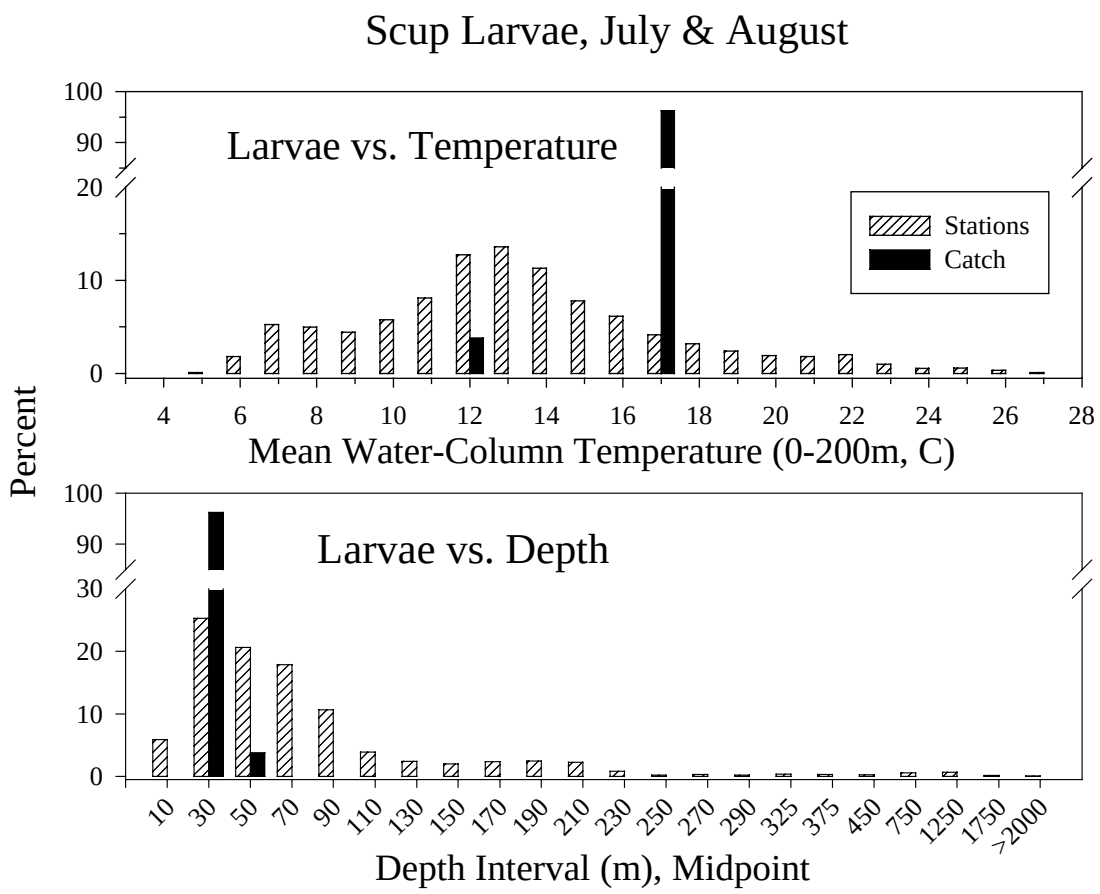


Figure 4. Abundance of scup larvae relative to water column temperature (to a maximum of 200 m) and bottom depth from NEFSC MARMAP ichthyoplankton surveys (July and August 1977-1987, all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

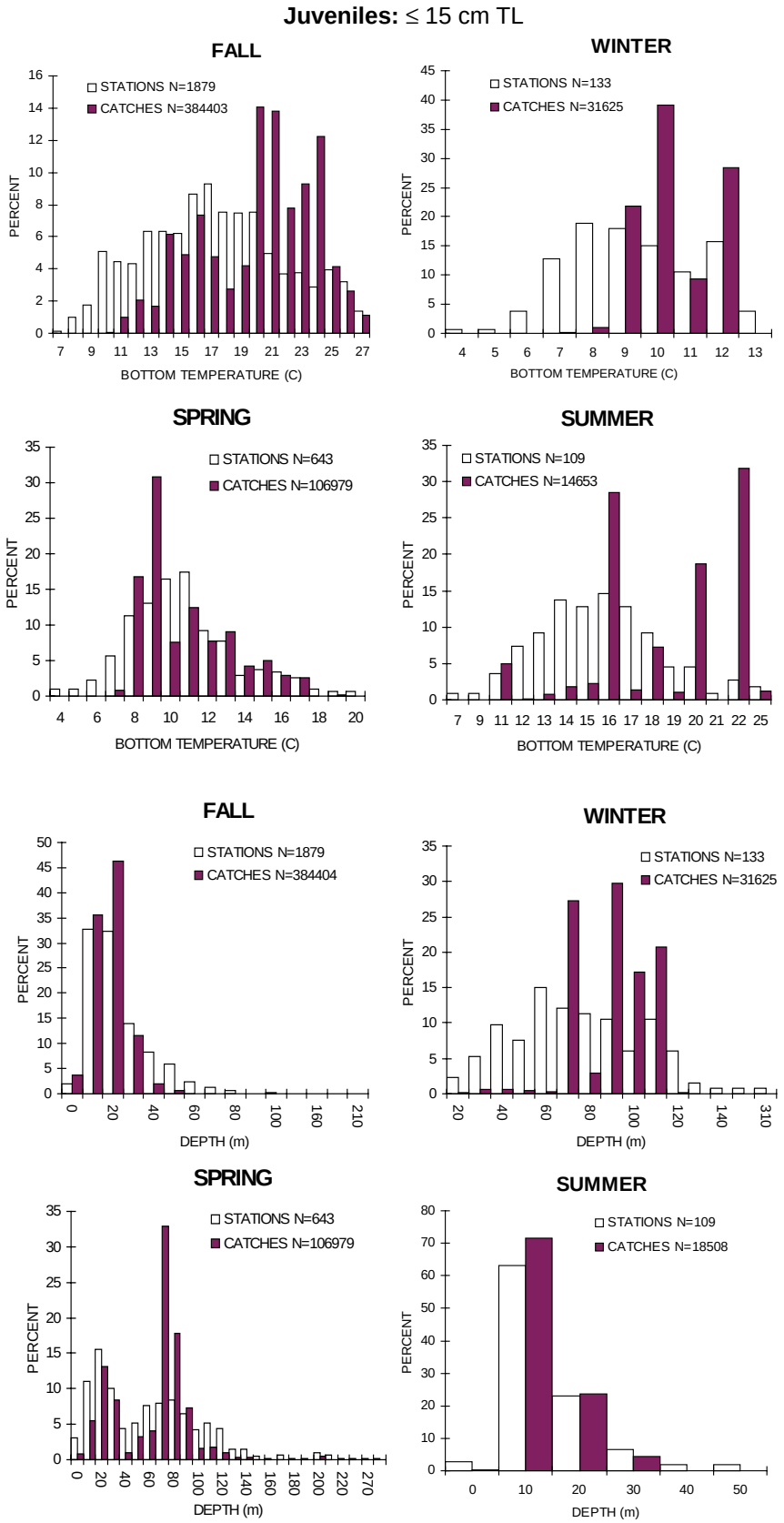
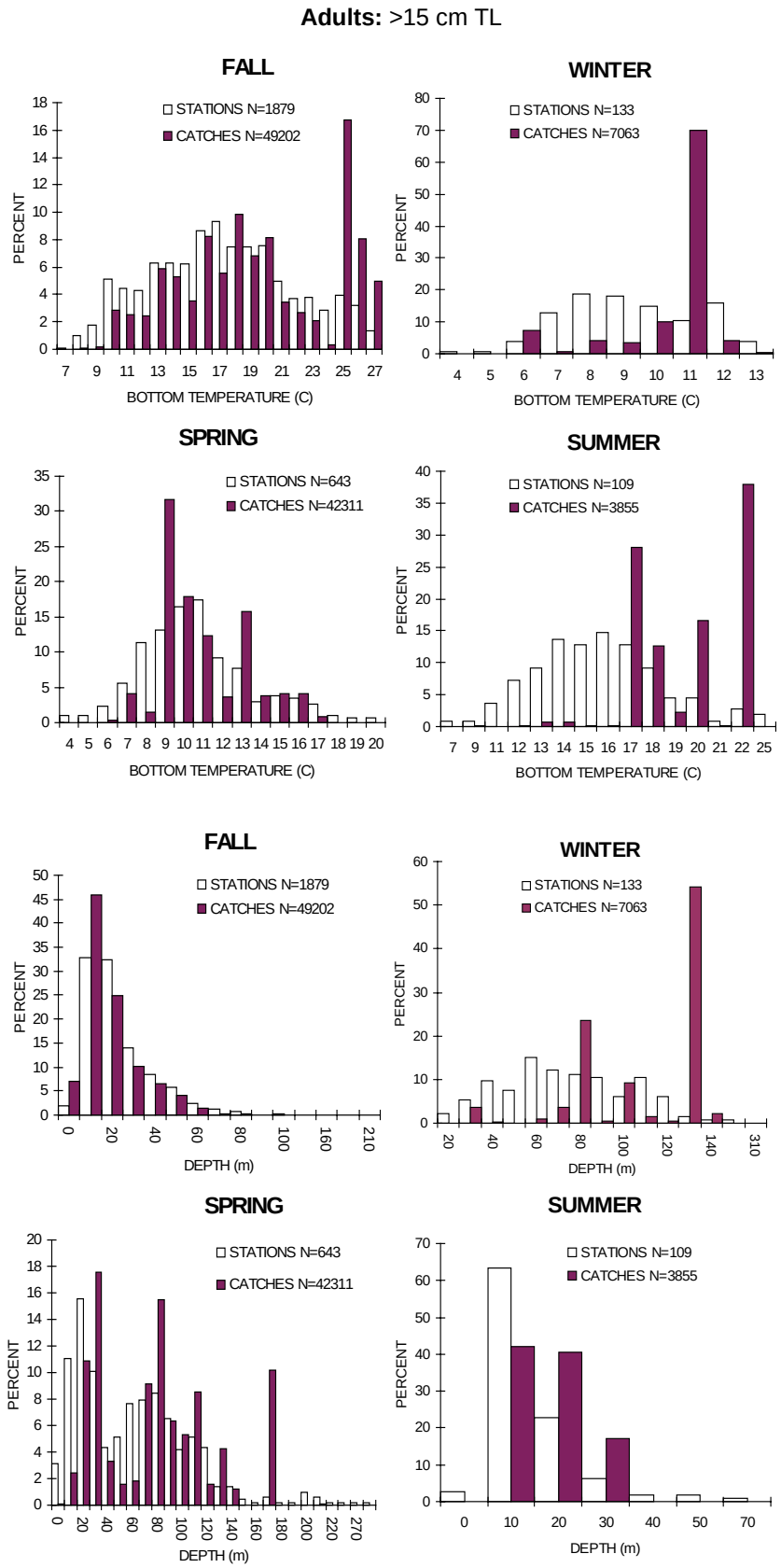


Figure 5. Seasonal abundance of juvenile and adult scup relative to bottom water temperature and depth based on NEFSC bottom trawl surveys (1963-1997, all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).



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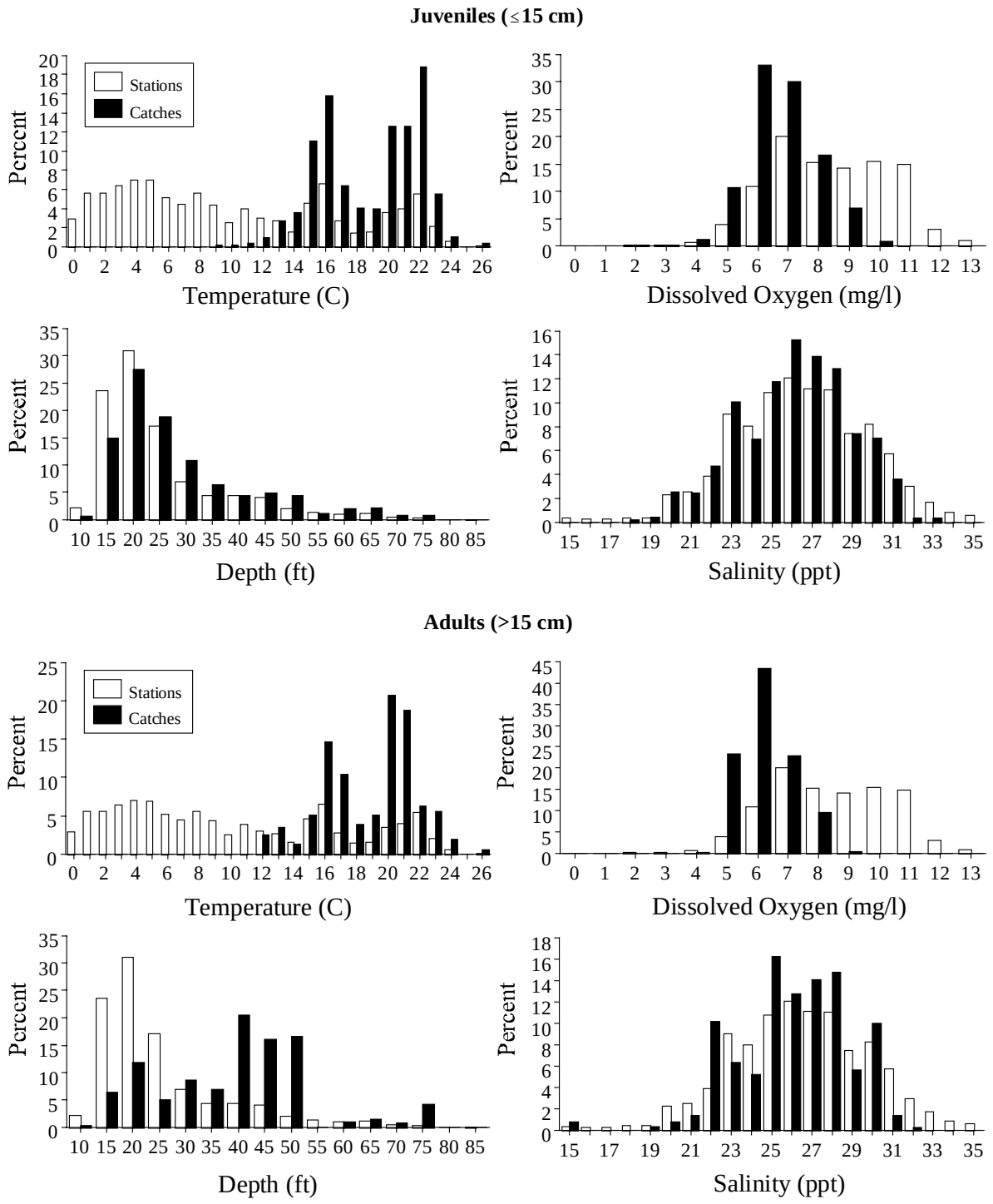


Figure 6. Abundance of juvenile and adult scup relative to bottom water temperature, depth, dissolved oxygen, and salinity based on Hudson-Raritan estuary trawl surveys (1992–1997, all years combined).

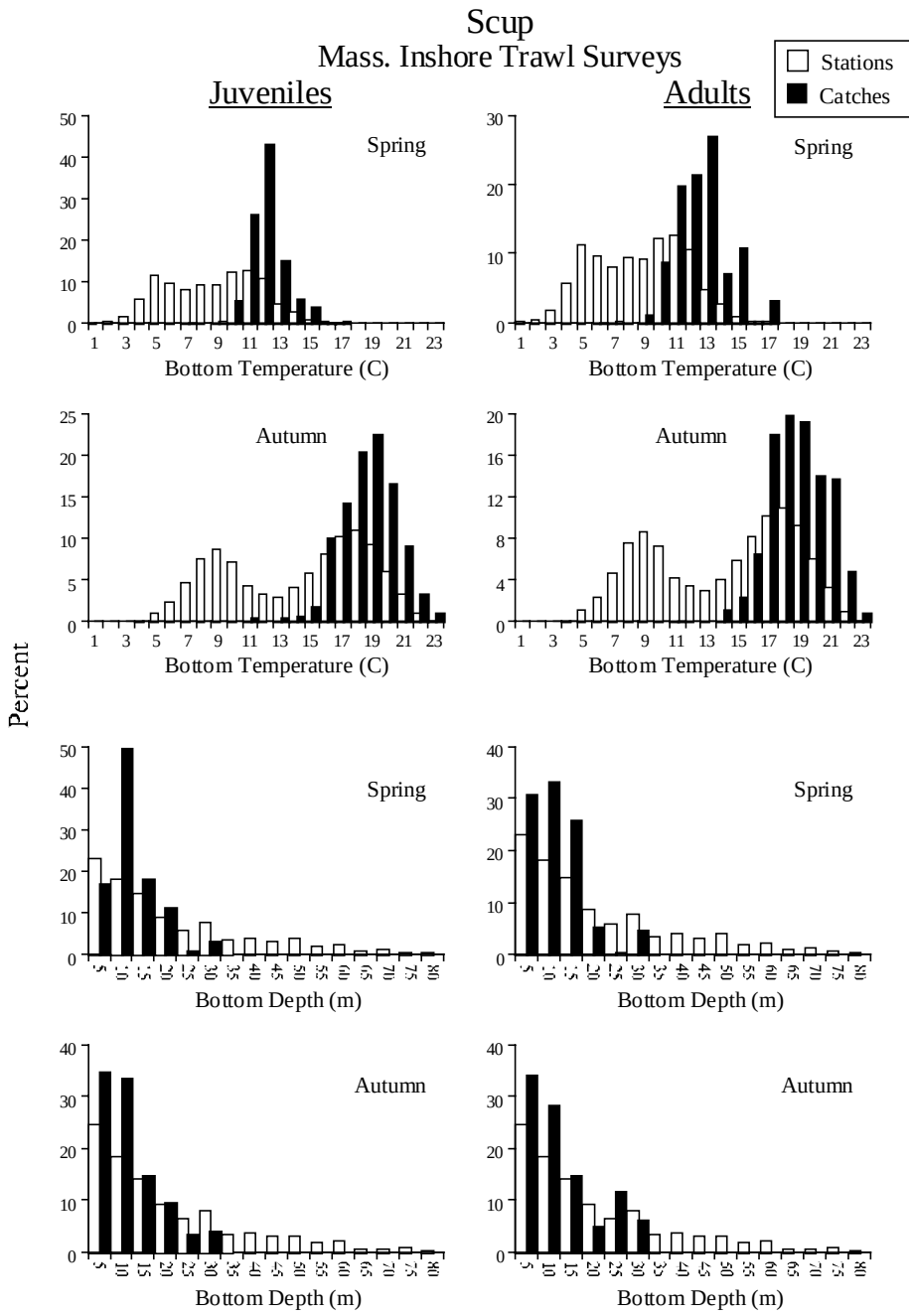


Figure 7. Abundance of juvenile and adult scup relative to bottom water temperature and depth based on Massachusetts inshore bottom trawl surveys (spring and autumn 1978-1996, all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

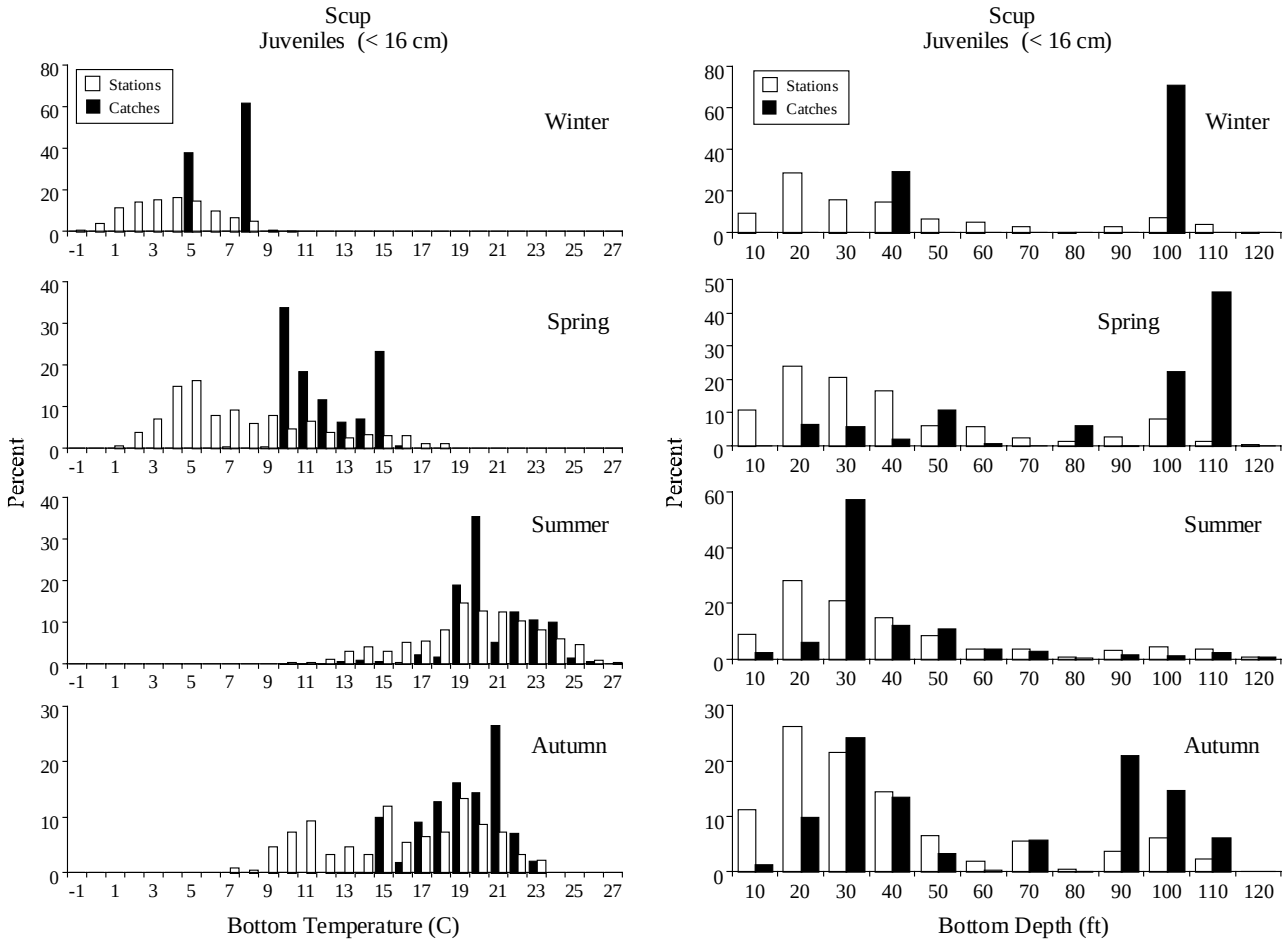
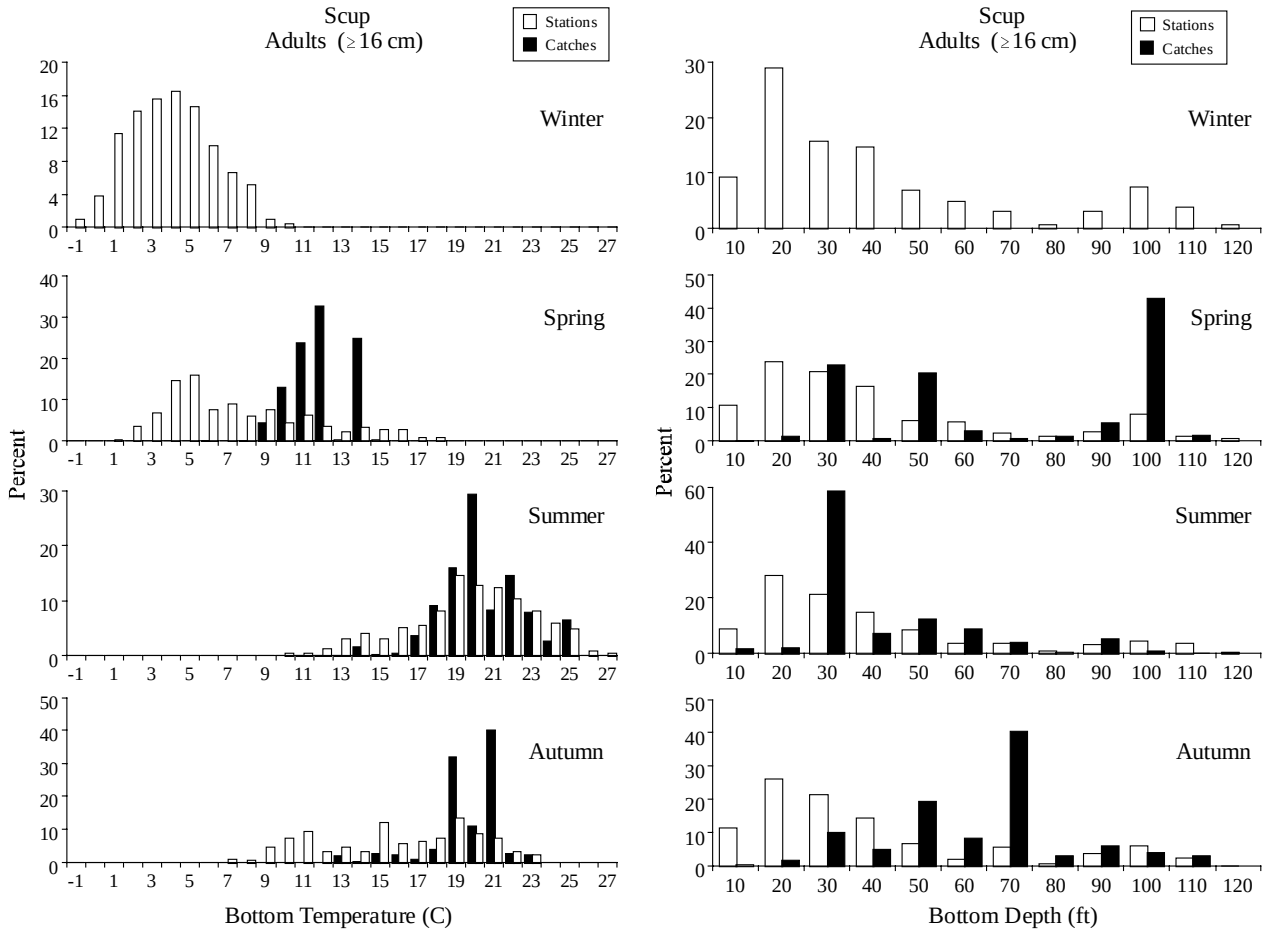


Figure 8. Seasonal abundance of juvenile and adult scup relative to mean bottom water temperature and bottom depth from Rhode Island Narragansett Bay trawl surveys, 1990-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.



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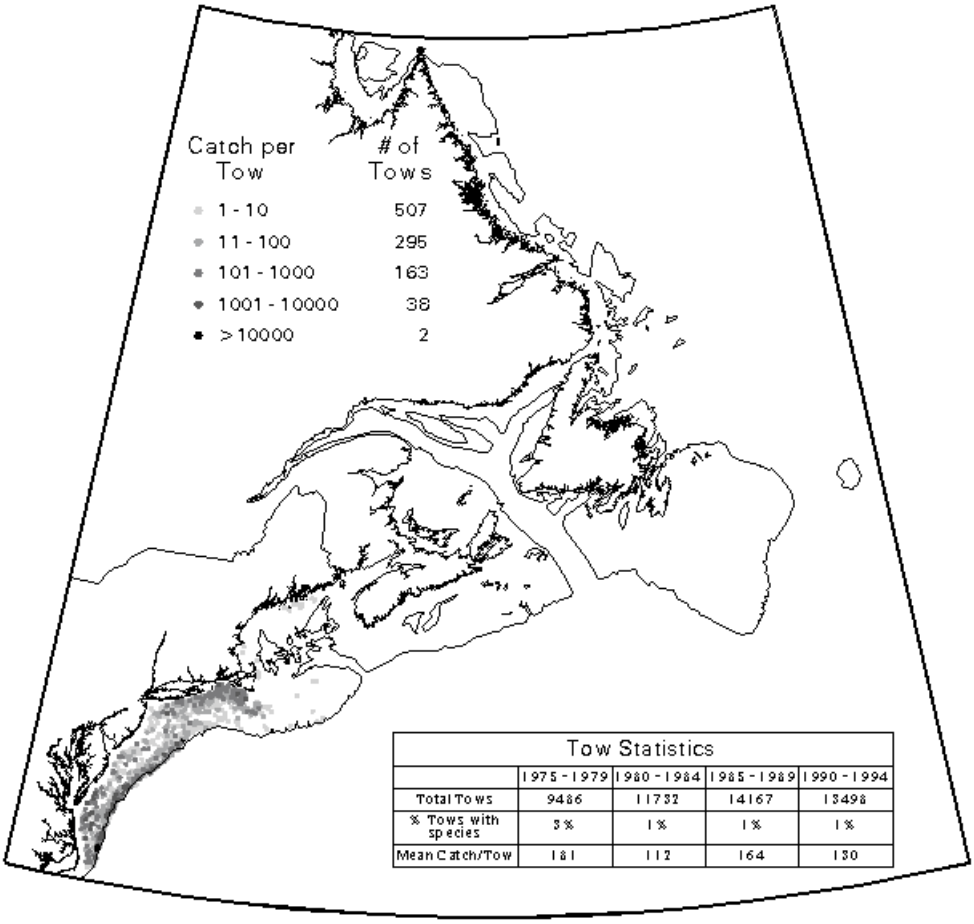


Figure 9. The distribution of scup from Newfoundland to Cape Hatteras. Data are from the U.S. NOAA/Canada DFO East Coast of North America Strategic Assessment Project (http//:www-orca.nos.noaa.gov/projects/ecnasap/ ecnasap_table1. html).

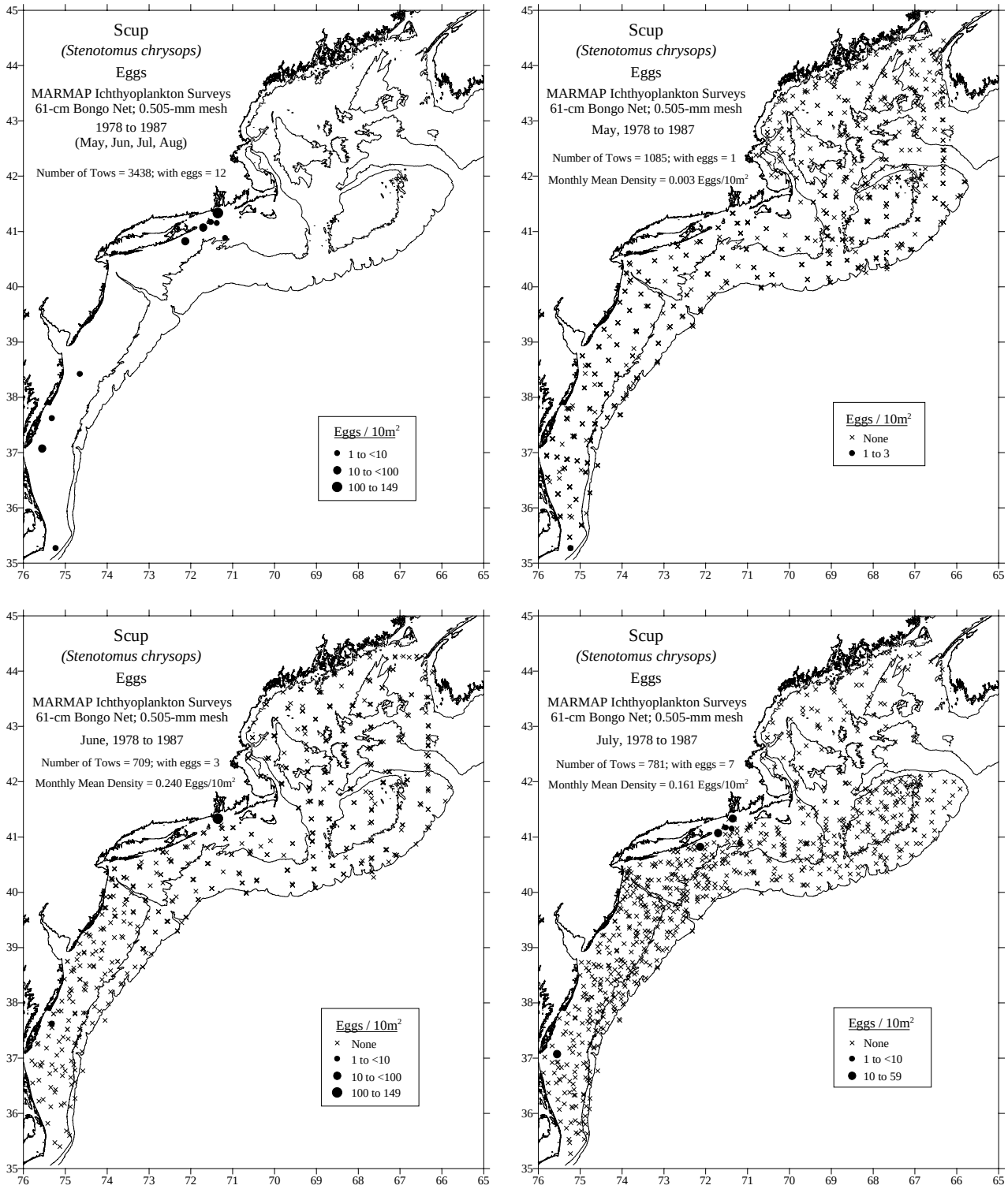
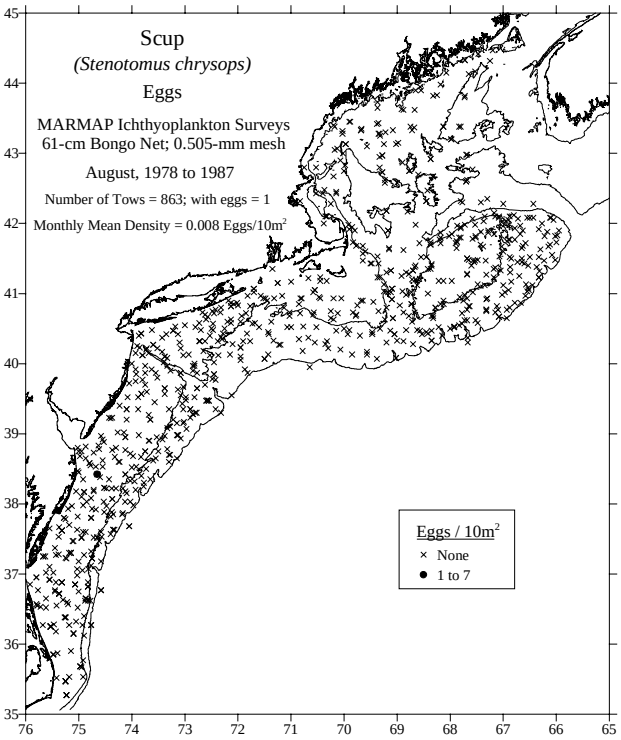


Figure 10. Distribution and abundance of scup eggs collected during NEFSC MARMAP ichthyoplankton surveys, 1978-1987 [see Reid *et al.* (1999) for details]. The upper left figure is a summary of all months and years; the remaining figures are by individual month (May, June, July and August) for all years combined.



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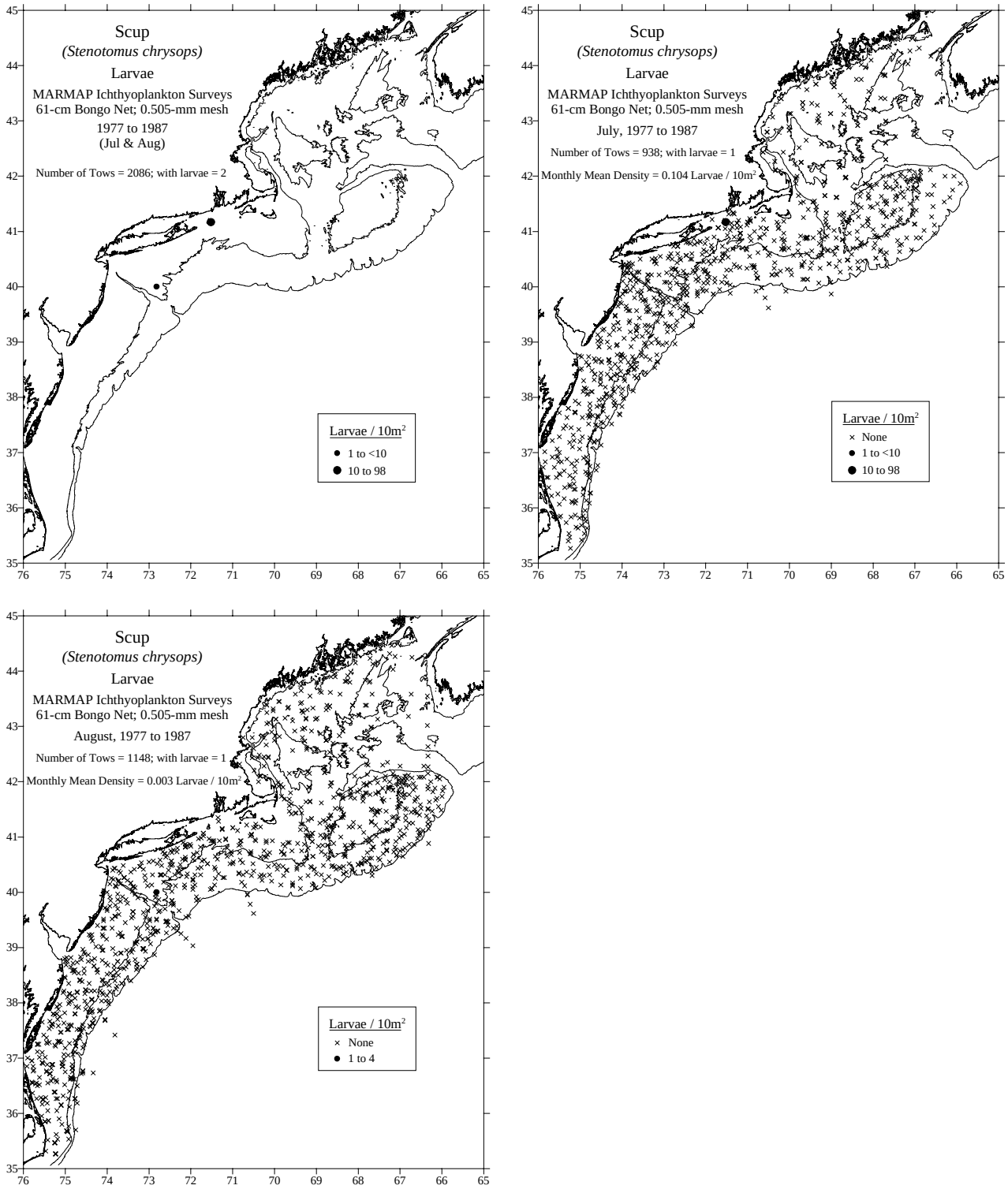


Figure 11. Distribution and abundance of scup larvae collected during NEFSC MARMAP ichthyoplankton surveys, 1977-1987 [see Reid *et al.* (1999) for details]. The upper left figure is a summary of all months and years; the remaining figures are by individual month (July and August) for all years combined.

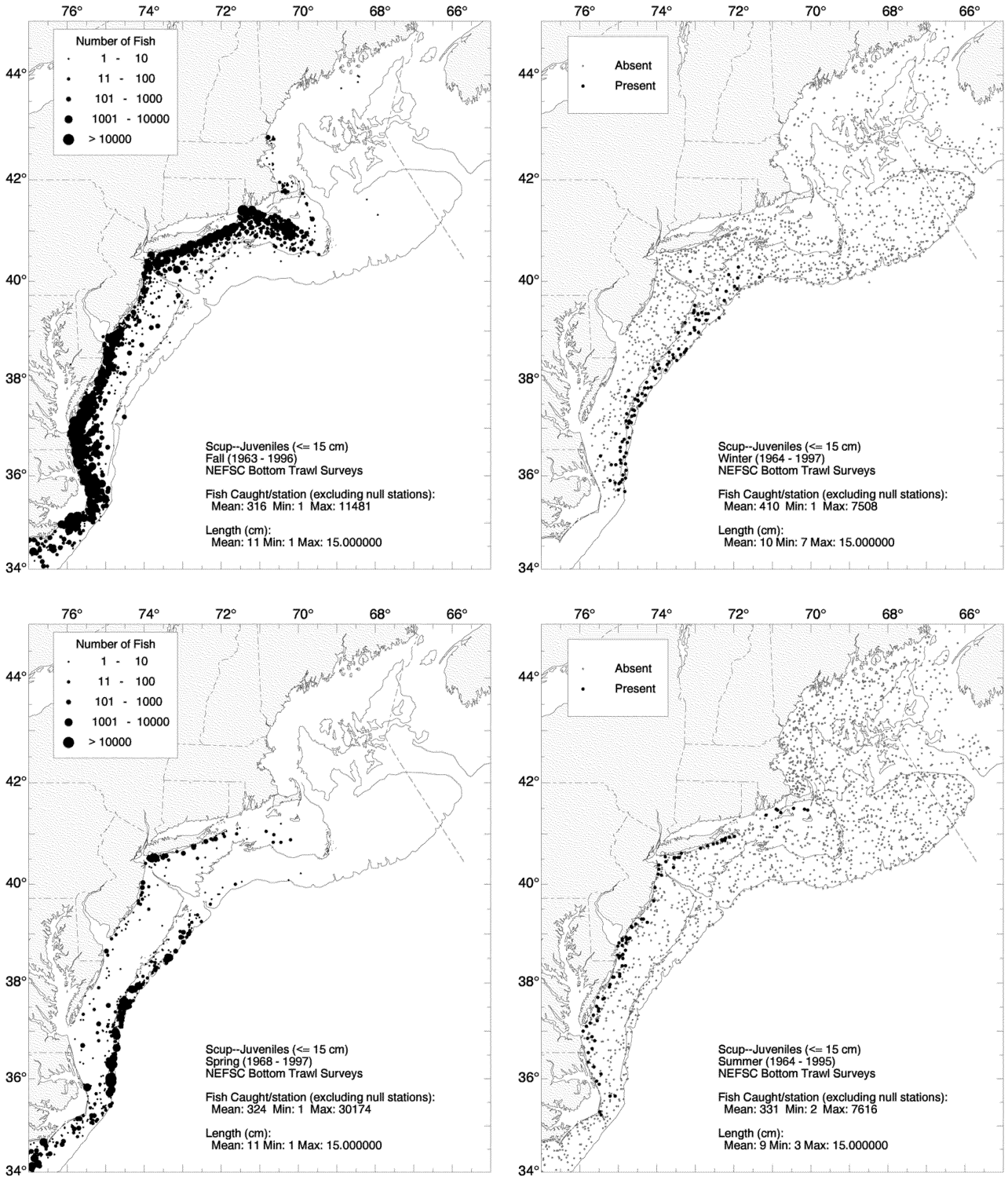
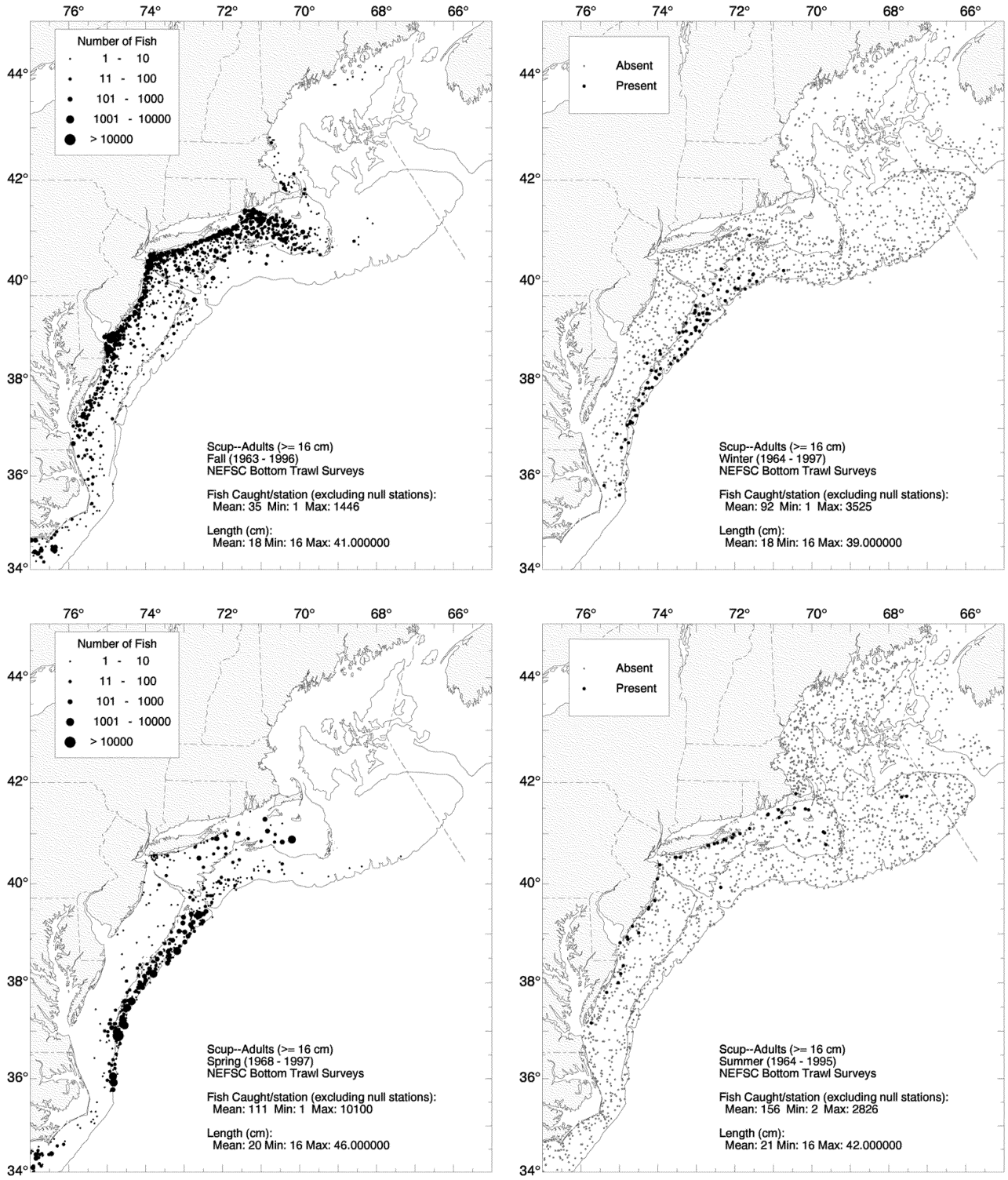


Figure 12. Distribution and abundance of juvenile and adult scup collected during NEFSC bottom trawl surveys (1963-1997, all years combined). Densities are represented by dot size in spring and fall plots, while only presence and absence are represented in winter and summer plots [see Reid *et al.* (1999) for details].



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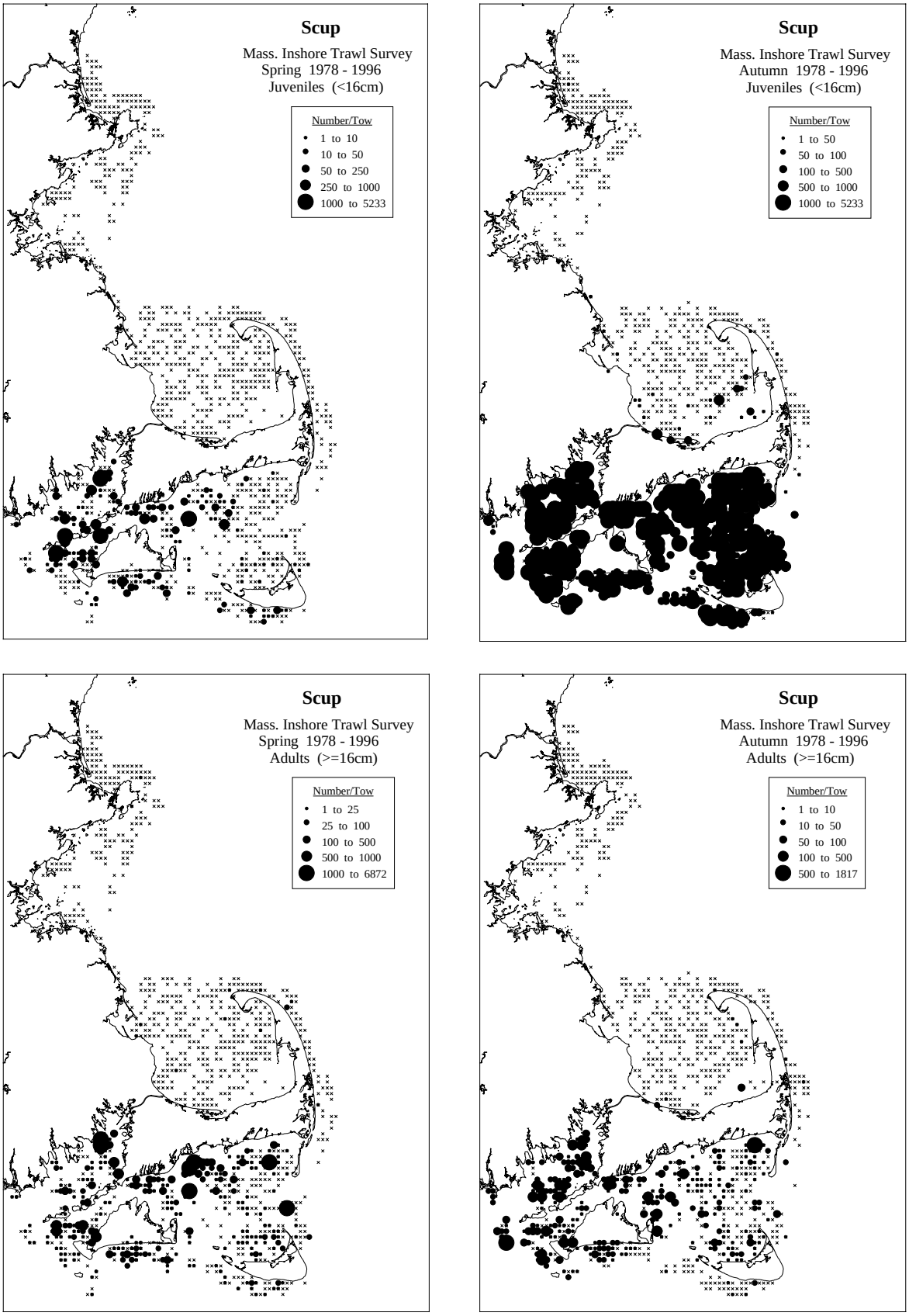


Figure 13. Distribution and abundance of juvenile and adult scup in Massachusetts coastal waters collected during spring and autumn Massachusetts inshore bottom trawl surveys, 1978-1996 [see Reid *et al.* (1999) for details].

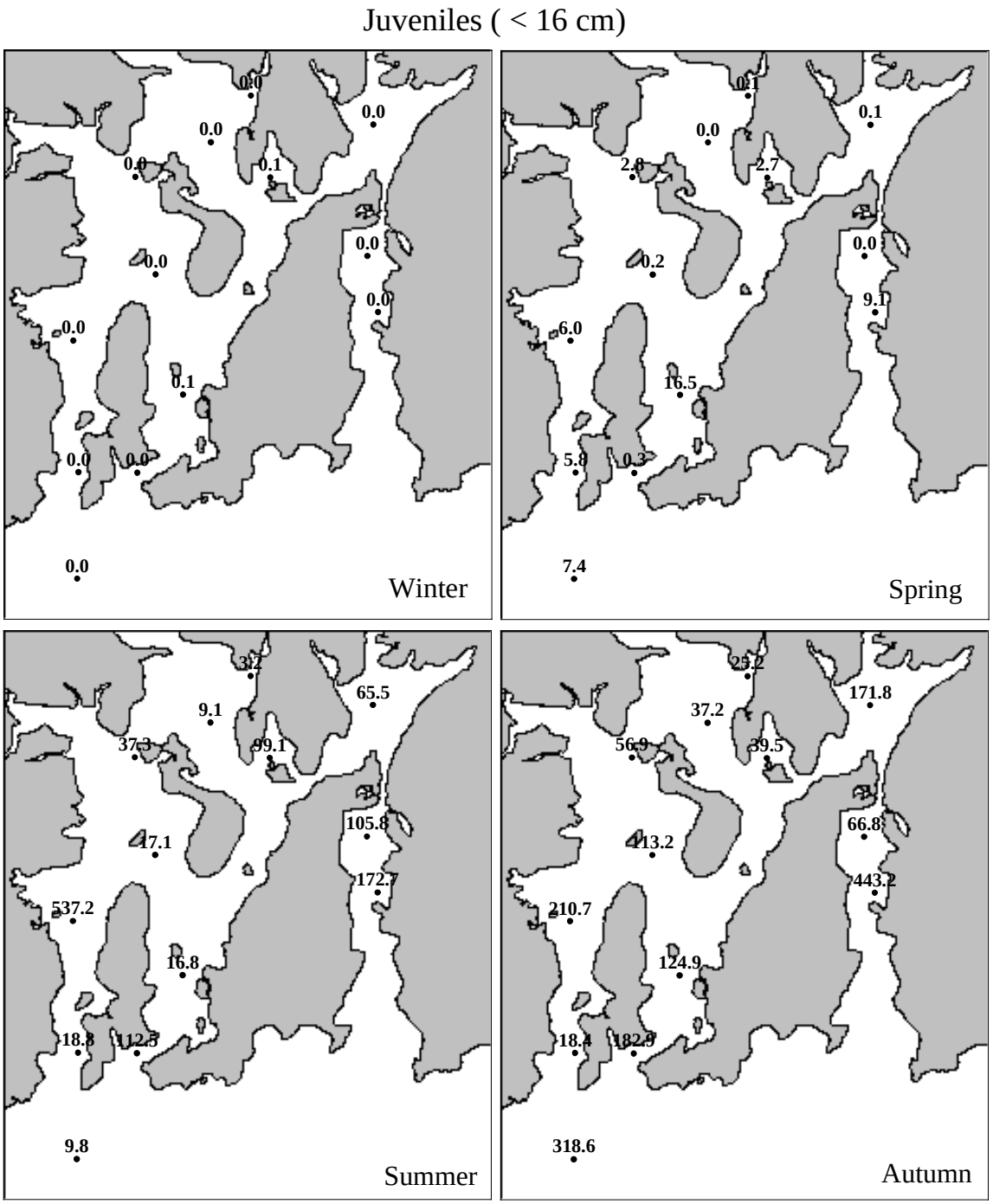
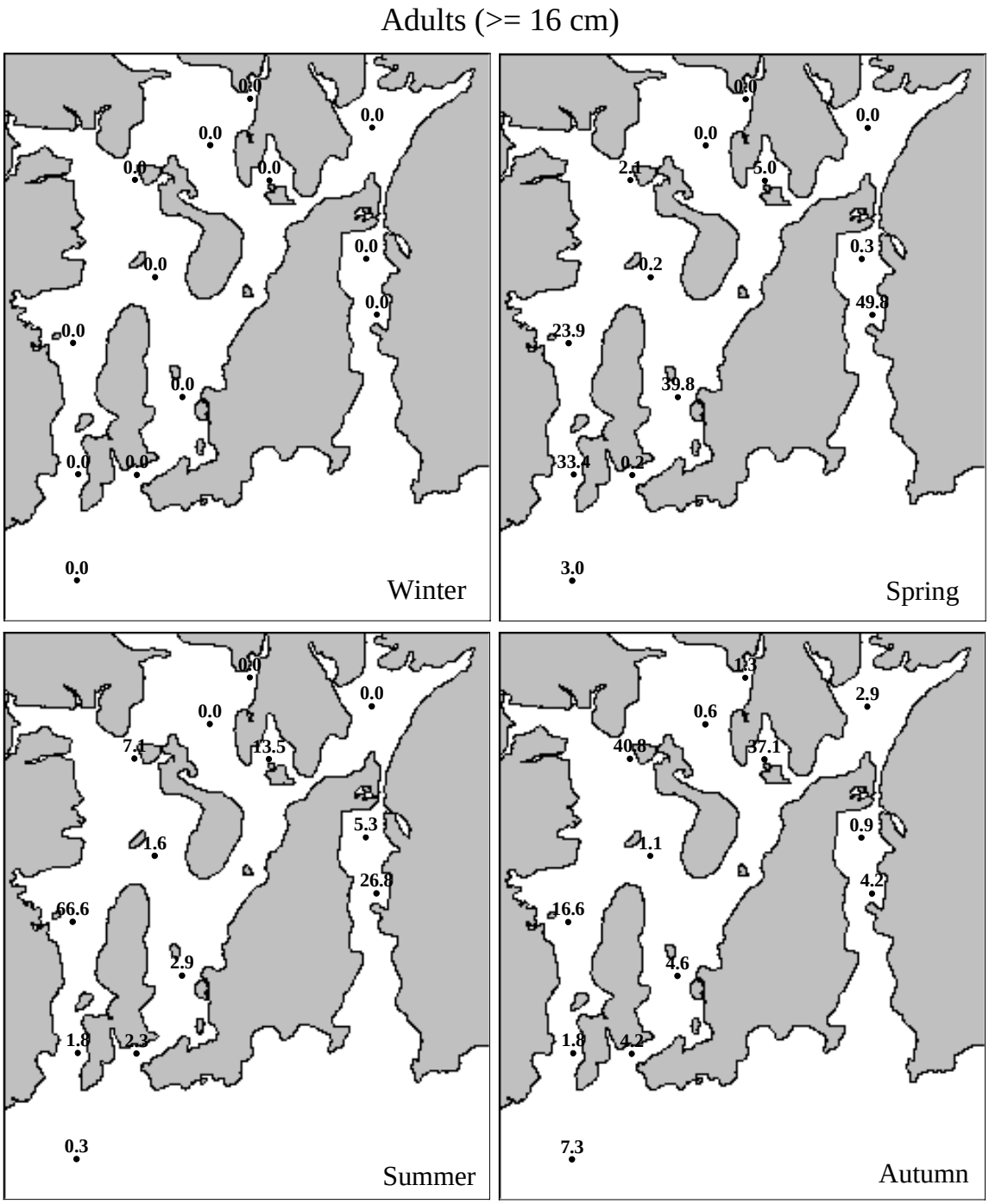


Figure 14. Seasonal distribution and abundance of juvenile and adult scup collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].



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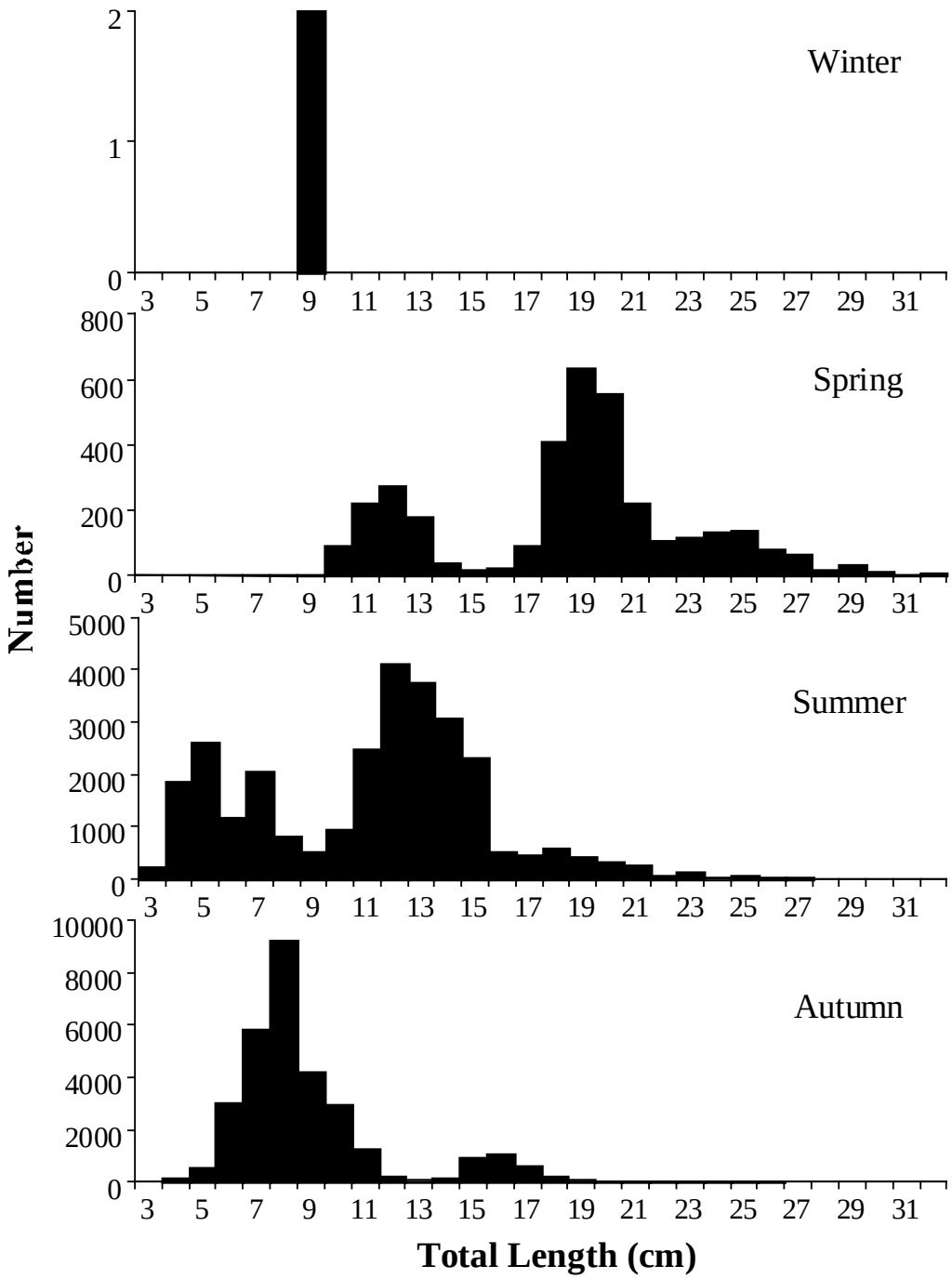
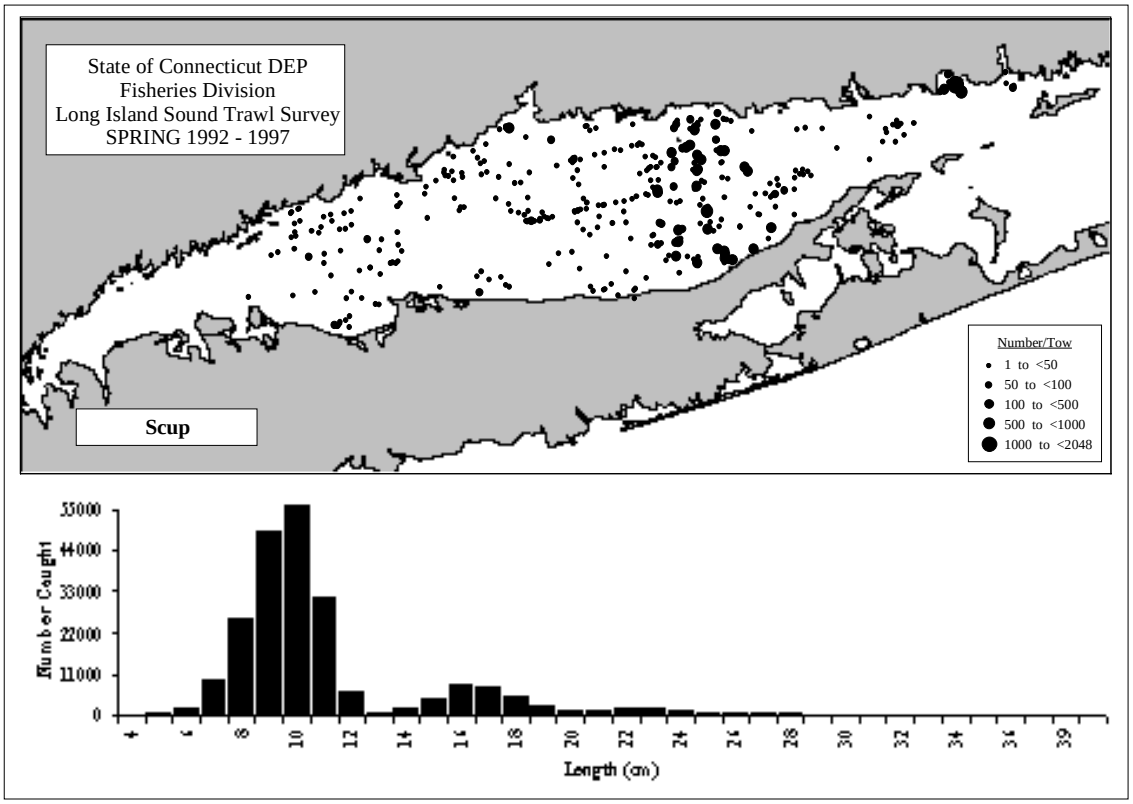


Figure 15. Size frequency distribution of scup collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys.



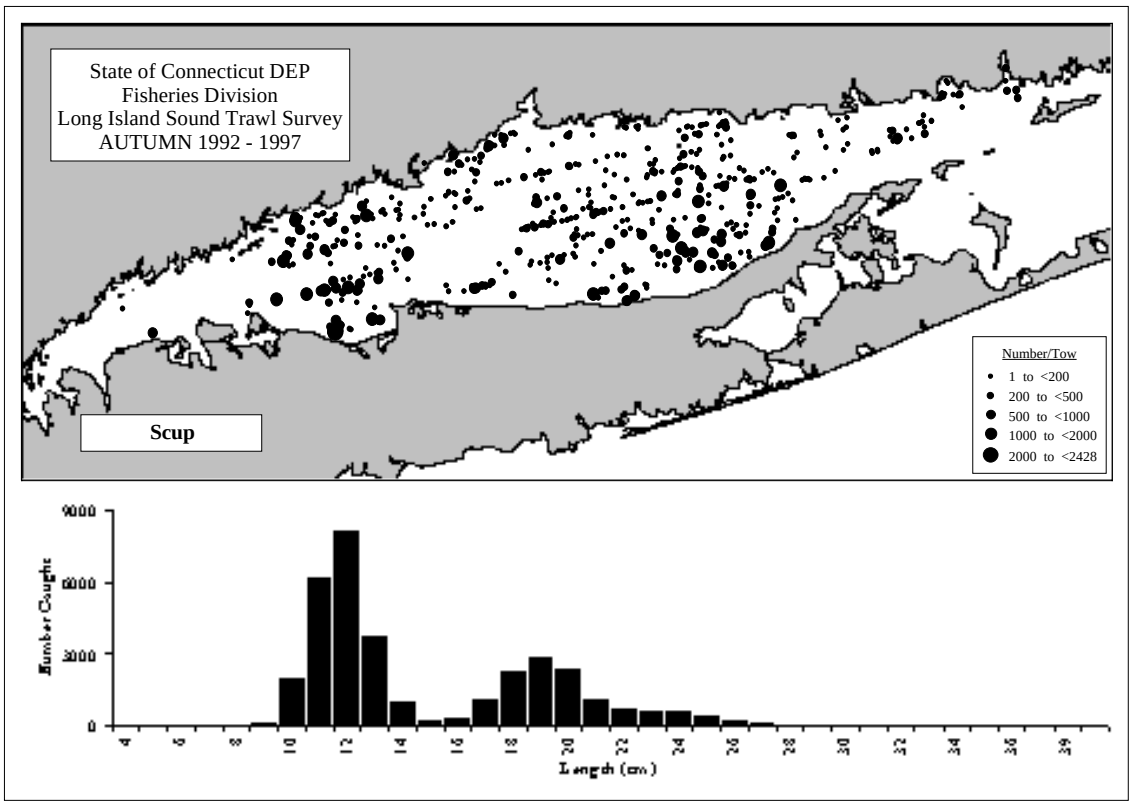


Figure 16. Distribution, abundance, and size frequency of scup in Long Island Sound in spring and autumn, from the Connecticut bottom trawl surveys, 1992-1997 [see Reid *et al.* (1999) for details].

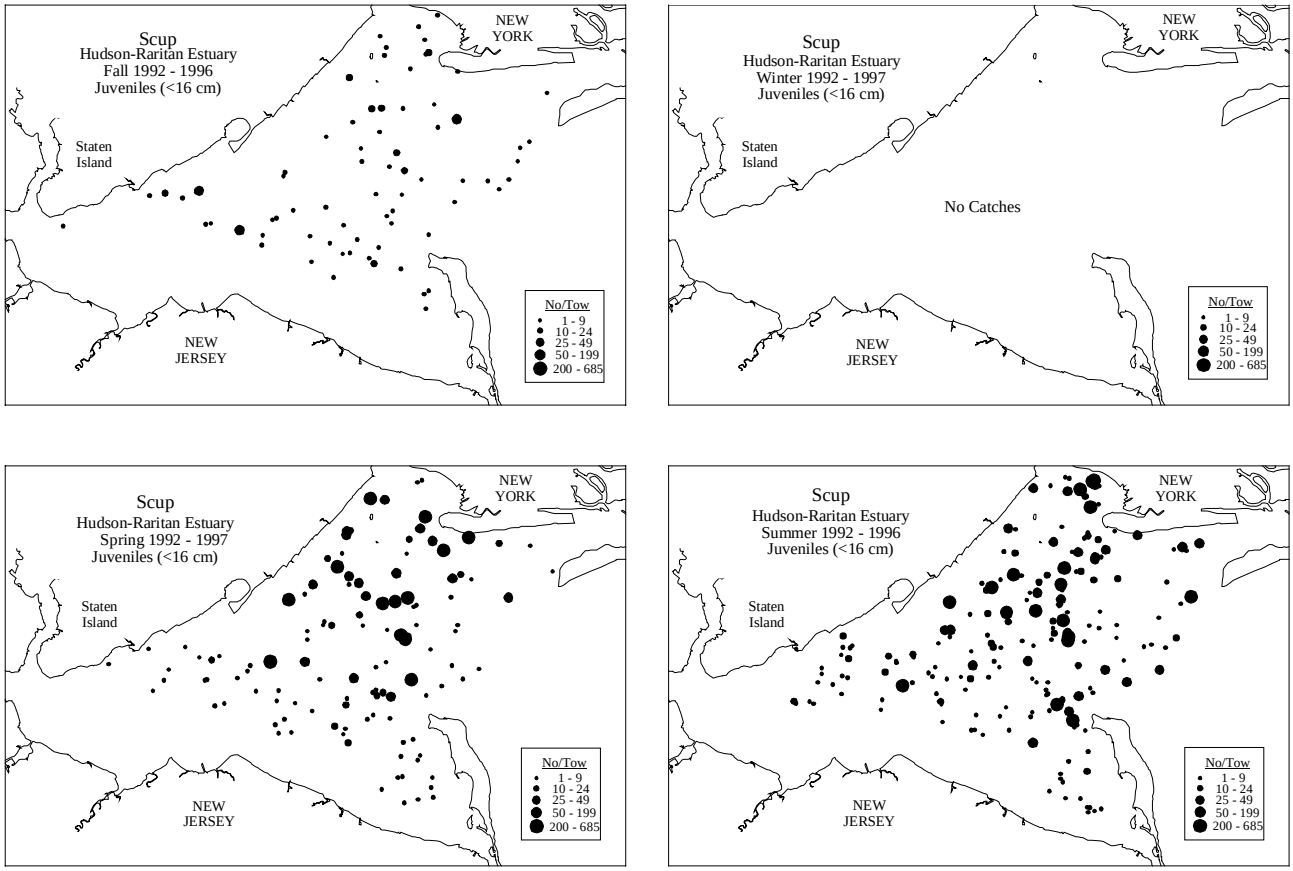
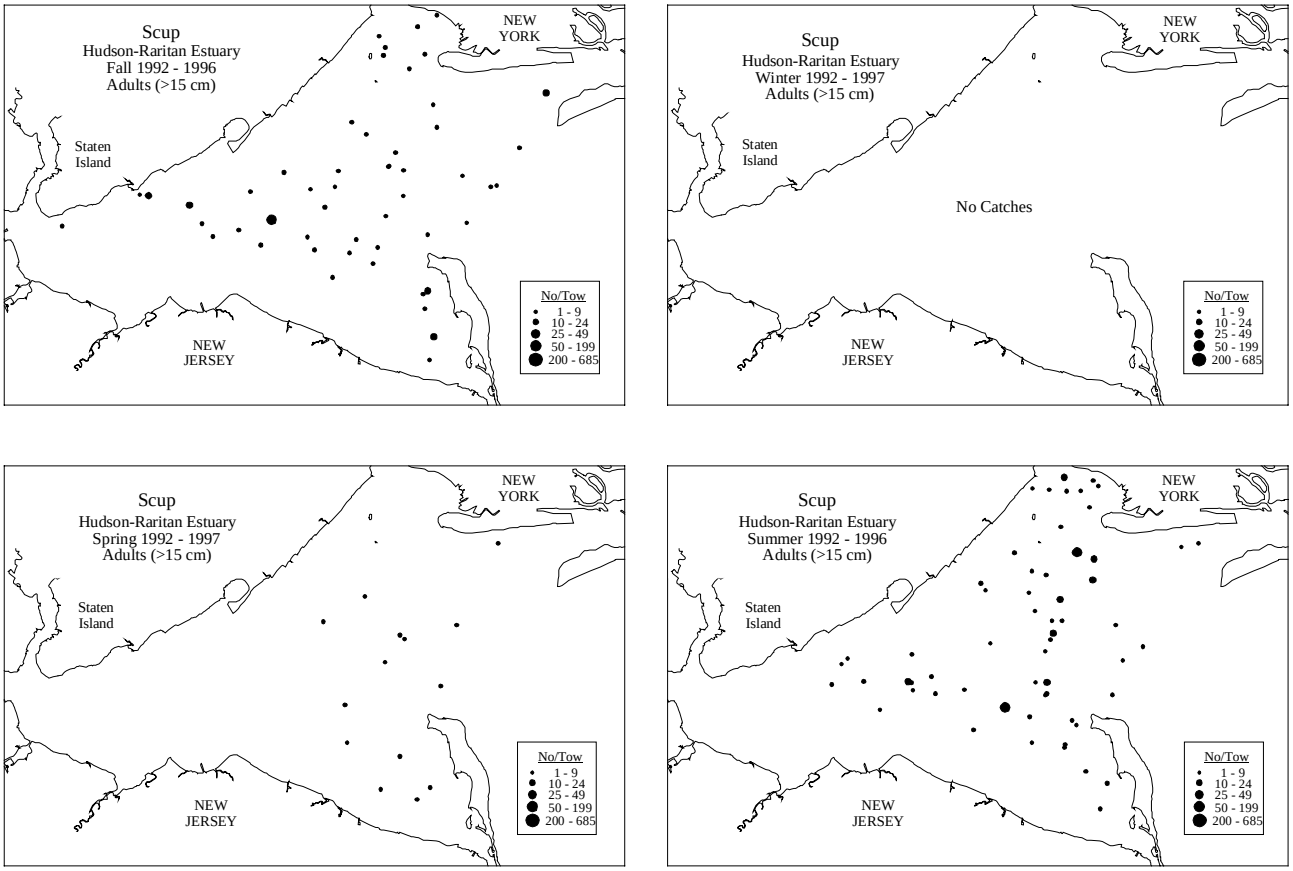


Figure 17. Seasonal distribution and abundance of juvenile and adult scup in the Hudson-Raritan estuary collected during Hudson-Raritan estuary trawl surveys, 1992–1997 [see Reid *et al.* (1999) for details].



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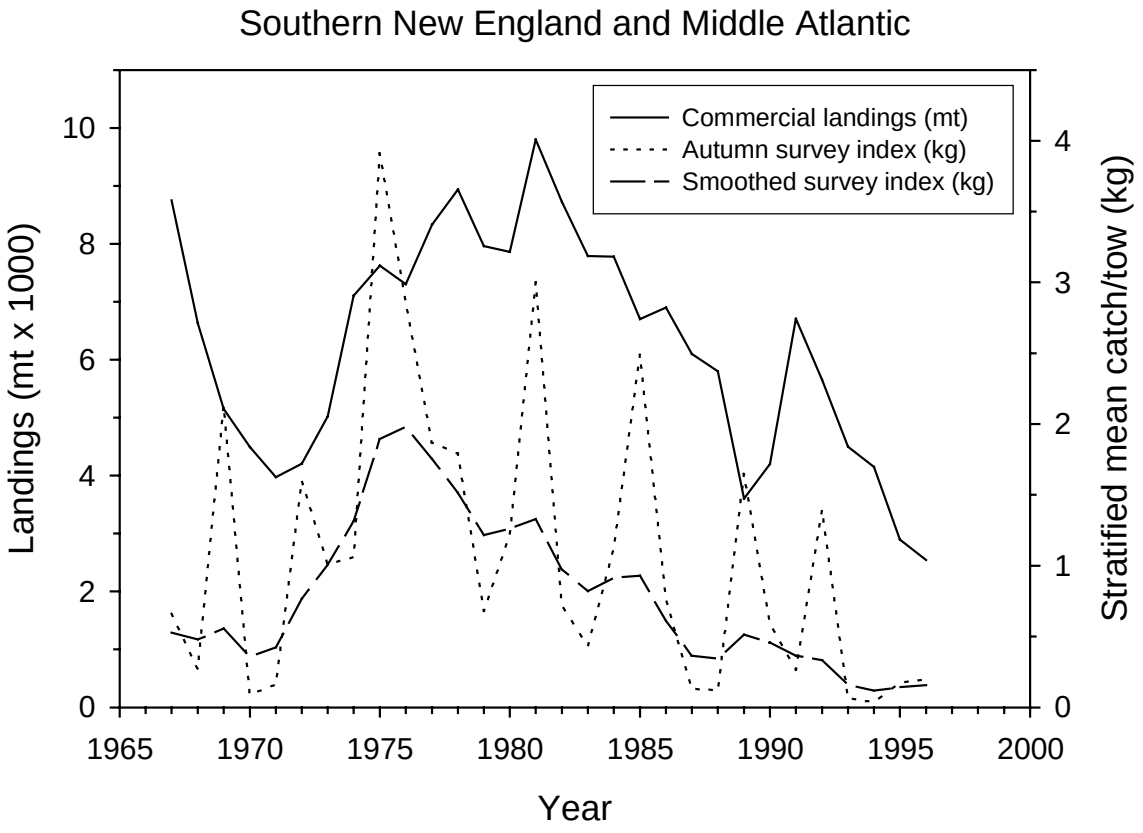

Figure 18. Commercial landings (metric tons, mt) and NEFSC bottom trawl survey indices (stratified mean catch per tow, kg) for scup in southern New England and the Middle Atlantic Bight.

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This series represents a secondary level of scientific publishing in the National Marine Fisheries Service (NMFS). For all issues, the series employs thorough internal scientific review, but not necessarily external scientific review. For most issues, the series employs rigorous technical and copy editing. Manuscripts that may warrant a primary level of scientific publishing should be initially submitted to one of NMFS's primary series (*i.e., Fishery Bulletin, NOAA Technical Report NMFS,* or *Marine Fisheries Review*).

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STANDARD MAIL A

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific ournals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

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Fishermen's Report **and** ***The Shark Tagger*** -- The ***Fishermen's Report*** (FR) is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of the FR; copies are available through free subscription. ***The Shark Tagger*** (TST) is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of the TST; copies are available only to participants in the tagging program.

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NOAA Technical Memorandum NMFS-NE-151

Essential Fish Habitat Source Document:

Summer Flounder, *Paralichthys dentatus*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1999

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Essential Fish Habitat Source Document:

Summer Flounder, *Paralichthys dentatus*, Life History and Habitat Characteristics

David B. Packer, Sara J. Griesbach, Peter L. Berrien, Christine A. Zetlin, Donna L. Johnson, and Wallace W. Morse

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Woods Hole, Massachusetts

September 1999

Editorial Notes on Issues 122-152 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the authors and acknowledgees of each issue, as well as those noted below in "Special Acknowledgments."

Special Acknowledgments

David B. Packer, Sara J. Griesbach, and Luca M. Cargnelli coordinated virtually all aspects of the preprinting editorial production, as well as performed virtually all technical and copy editing, type composition, and page layout, of Issues 122-152. Rande R. Cross, Claire L. Steimle, and Judy D. Berrien conducted the literature searching, citation checking, and bibliographic styling for Issues 122-152. Joseph J. Vitaliano produced all of the food habits figures in Issues 122-152.

Internet Availability

Issues 122-152 are being copublished, *i.e.*, both as paper copies and as web postings. All web postings are, or will soon be, available at: *www.nefsc.nmfs.gov/nefsc/habitat/efh*. Also, all web postings will be in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152 must be updated at least every five years. All official updates will appear in the web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]).

---

[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 30 EFH species reports (plus one consolidated methods report). The EFH species reports comprise a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and have understandably begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 30 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, CHIEF
ECOSYSTEMS PROCESSES DIVISION
NORTHEAST FISHERIES SCIENCE CENTER

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INTRODUCTION

The geographical range of the summer flounder or fluke, *Paralichthys dentatus* (Figure 1), encompasses the shallow estuarine waters and outer continental shelf from Nova Scotia to Florida (Ginsburg 1952; Bigelow and Schroeder 1953; Anderson and Gehringer 1965; Leim and Scott 1966; Gutherz 1967; Gilbert 1986; Grimes *et al*. 1989), although Briggs (1958) gives their southern range as extending into the northern Gulf of Mexico. The center of its abundance lies within the Middle Atlantic Bight from Cape Cod, Massachusetts, to Cape Hatteras, North Carolina (Figure 2; Hildebrand and Schroeder 1928). North of Cape Cod and south of Cape Fear, North Carolina, summer flounder numbers begin to diminish rapidly (Grosslein and Azarovitz 1982). South of Virginia, two closely related species, the southern flounder (*Paralichthys lethostigma*) and the gulf flounder (*Paralichthys albigutta*) occur and sometimes are not distinguished from summer flounder (Hildebrand and Cable 1930; Byrne and Azarovitz 1982). For more detailed discussions of the summer flounder's distribution on the shelf and in the various estuaries, see the Life History and Geographical Distribution section.

Summer flounder exhibit strong seasonal inshore-offshore movements, although their movements are often not as extensive as compared to other highly migratory species. Adult and juvenile summer flounder normally inhabit shallow coastal and estuarine waters during the warmer months of the year and remain offshore during the fall and winter (Figure 3). Complete descriptions of the inshore-offshore migratory patterns of the summer flounder are in the Life History and Geographical Distribution section of this paper.

LIFE HISTORY AND GEOGRAPHICAL DISTRIBUTION

STOCK STRUCTURE

Several stocks of summer flounder may exist throughout its range, and numerous attempts have been made to identify them. Since a genetically distinct stock can have unique rates of recruitment, growth, and mortality (Cushing 1981), identification of the various stocks or subpopulations of summer flounder and their stock-specific biological traits, as well as their habitat distribution and overlap, is necessary for proper management. Previous stock identification studies suggested that significant differences exist between summer flounder north and south of Cape Hatteras; i.e., between those in the Mid-Atlantic Bight and South Atlantic Bight (Wilk *et al*. 1980; Fogarty *et al*. 1983; Able *et al*. 1990; Wenner *et al*. 1990a). Summer flounder north and south of the Cape were statistically separable on the basis of morphometric characters, with apparent intermixing of northern and southern contingents in the vicinity of Cape Hatteras [tagging studies by Desfosse (1995) also indicated that there was some exchange of summer flounder between the north and south of Cape Hatteras during winter]. Thus, it was suggested that the Cape Hatteras region may form a zoogeographical barrier between the Middle and South Atlantic Bights which results in the reproductive isolation of the adjacent stocks of summer flounder (Wilk *et al*. 1980; Fogarty *et al*. 1983). This was also suggested by tagging studies in the nearshore waters and sounds north of North Carolina which showed that fish tagged north of Cape Hatteras moved northward, while fish tagged south of Hatteras moved southward (Monaghan 1992, 1996). An alternative hypothesis by Wenner *et al*. (1990a) suggested that, rather than two separate populations, the South Atlantic Bight may serve as a nursery area for summer flounder in the Mid-Atlantic Bight.

However, Jones and Quattro (1999) analyzed the genetic diversity revealed in the mitochondrial DNA (mtDNA) in samples of juveniles and adult summer flounder collected from coastal sites from Buzzard's Bay, Massachusetts to Charleston, South Carolina during 1992 to 1996. In contrast to the previous morphological studies, analyses of mtDNA variation revealed no significant population subdivision centered around Cape Hatteras; i.e., summer flounder populations are not genetically different north and south of Cape Hatteras. Jones and Quattro (1999) suggest that the phenotypic divergence seen among geographic samples of summer flounder (Wilk *et al*. 1980; Fogarty *et al*. 1983) may reflect differential environmental influences.

Within the Middle Atlantic Bight, Fogarty *et al*. (1983) reported that a summer flounder discrimination workshop was unable to examine adequately the hypothesis of multiple stocks. Although Smith (1973) identified concentrations of summer flounder eggs off Long Island, Delaware-Virginia, and North Carolina, the workshop concluded that the distribution of summer flounder eggs and larvae was continuous throughout the Middle Atlantic Bight and that the apparent concentrations identified by Smith (1973) were not the result of multiple stocks, but may have been due to sampling variability. However, Jones and Quattro (1999) did detect population genetic structure in their samples of summer flounder from the northern portion of its range; i.e., a small but significant portion of the total genetic variance could be attributed to differences between their Massachusetts and Rhode Island samples and all the other samples. Furthermore, tagging studies by Desfosse *et al*. (1988) and Desfosse (1995) indicate that there may be two subpopulations of summer flounder in Virginia inshore waters, and studies by Van Housen (1984), Delaney (1986), and Holland (1991), as well as such supplemental observations as by Ross *et al*. (1990) off of North Carolina, suggest that inshore populations from Virginia to North Carolina may form a separate population from those to the north and offshore (a trans-Hatteras stock). Further studies from these regions will be necessary to confirm these observations.

Nonetheless, it is important to note that throughout the

U.S. EEZ, summer flounder is managed and assessed as a single stock by the Mid-Atlantic Fishery Management Council (NMFS 1997).

ADULTS

As stated above, summer flounder exhibit strong seasonal inshore-offshore movements (Figure 3). Adult flounder normally inhabit shallow coastal and estuarine waters during the warmer months of the year and remain offshore during the colder months on the outer continental shelf at depths down to 150 m (Figure 4; Bigelow and Schroeder 1953; Grosslein and Azarovitz 1982). Some evidence suggests that older adults may remain offshore all year (Festa 1977). However, due to overfishing, most of the adults are ≤ 3 years of age and they return to the inner continental shelf and estuaries during the summer [Able and Kaiser 1994; Terceiro 1995; Northeast Fisheries Science Center 1997; in addition, Desfosse's (1995) study in Virginia waters notes that the majority of fish sampled from 1987-1989 were from 0-3 years of age, and over 90% of the summer flounder survey catch in Delaware Bay for 1996 was also less than age 3 (Michels 1997)]. The southern population may undertake less extensive offshore migrations (Fogarty *et al*. 1983). Tagging studies indicate that fish which spend their summer in a particular bay tend largely to return to the same bay in the subsequent year or to move to the north and east (Westman and Neville 1946; Hamer and Lux 1962; Poole 1962; Murawski 1970; Lux and Nichy 1981; Monaghan 1992; Desfosse 1995). For example, tagging studies indicate that the majority of summer flounder from inshore New Jersey return to inshore New Jersey the following year. This homing is also evident in summer flounder which return to New York waters, with some movement to waters off Connecticut, Rhode Island and Massachusetts (Poole 1962). Once inshore during the summer months, there appears to be very little movement of inshore fish to offshore waters (Westman and Neville 1946; Poole 1962; Desfosse 1995).

Tagging studies conducted by Poole (1962) and Lux and Nichy (1981) on flounder released off Long Island and southern New England revealed that fish usually began seaward migrations in September or October. Their wintering grounds are located primarily between Norfolk and Veatch Canyons east of Virginia and Rhode Island, respectively, although they are known to migrate as far northeastward as Georges Bank. Fish that move as far north as the wintering grounds north of Hudson Canyon may become rather permanent residents of the northern segment of the Mid-Atlantic Bight (Lux and Nichy 1981). New York and New Jersey fish may move farther south in the winter months and generally may not move as far north in the summer as New England flounder (Poole 1962).

The presence, distribution, and abundance of the adults nearshore and in the estuaries has been documented by both fishery dependent and independent data and each States' flounder experts (Table 1). For example, summer flounder in Massachusetts migrate inshore in early May and occur along the entire shoal area south of Cape Cod and Buzzards Bay, Vineyard Sound, Nantucket Sound, and the coastal waters around Martha's Vineyard (Figure 5; Howe *et al*. 1997). They also occur in the shoal waters in Cape Cod Bay (A.B. Howe, Massachusetts Div. of Mar. Fish., Sandwich, MA, personal communication). In some years summer flounder are found along the eastern side of Cape Cod and as far north as Provincetown by early May. The Massachusetts Division of Marine Fisheries considers the shoal waters of Cape Cod Bay and the region east and south of Cape Cod, including all estuaries, bays and harbors thereof, as critically important habitat (Howe, personal communication). Summer flounder begin moving offshore in late September and October and Howe (personal communication) believes that spawning occurs within territorial waters south of Cape Cod because occasional ripe and running fish have been taken there. Summer flounder are regularly taken in southern Massachusetts waters as late as December, presumably as fish are dispersing to offshore wintering grounds, which, in most years are well out on the continental shelf from approximately Veatch Canyon to Baltimore Canyon.

T.R. Lynch (Rhode Island Dept. of Environ. Mgmt., Wickford, RI, personal communication) states that the coastal waters of Rhode Island, the immediate waters surrounding Block Island, and the waters of Little Narragansett Bay and all of Narragansett Bay are habitat for both adults and juveniles. Based on collections from the 1990-1996 Rhode Island Narragansett Bay survey, adults were distributed throughout the Bay and captured in all seasons except winter and most were caught in summer and autumn (Figure 6). The length frequencies show that similar sizes were captured in each season and lengths ranged from about 25-71 cm with most occurring from 30-50 cm (Figure 7). Abundance in relation to bottom depth shows a preference for depths greater than 12.2-15.2 m (40-50 ft) and that few were captured in depths less than 9.1 m (30 ft) (Figure 8).

In Connecticut, E. Smith (Connecticut Dept. of Environ. Prot., Hartford, CT, personal communication) states that the flounder migrate to inshore waters in late April and early May, and are present in Long Island Sound throughout the April-November trawl survey period, and probably occur in limited numbers in winter as well (Figure 9 -- these figures include juveniles and adults, see Figure 10). August through October are often the months of highest relative abundance (Simpson *et al*. 1990a, b, 1991; Gottschall *et al*., in review). Although they occur on all bottom types, their abundance does vary by area and depth (Gottschall *et al*., in review). In April, abundance is similar at all depths, but from May through August abundance is highest in shallow water, especially in depths less than 9 m along the Connecticut shore from New Haven to Niantic Bay, and near Mattituck, New York (Figure 9; Gottschall *et al*., in review). In September, when abundance peaks,

summer flounder are again distributed in all depths throughout the sound. After September, their abundance decreases, and the remaining fish are more common in deeper water. Abundance is highest in depths between 18-27 m in October and depths > 27 m in November (Gottschall *et al*., in review). Abundance indices within the Sound are generally highest in the central Sound (Connecticut to Housatonic Rivers) and lowest west of the Housatonic River (Simpson *et al*. 1990a, b, 1991). Salinity range appears to be at least 15 ppt and greater. The trawl survey usually takes 400-700 fish in 320 tows per year. In 1989, only 47 fish were taken (D.G. Simpson, Connecticut Dept. of Environ. Prot., Waterford, CT, personal communication). From the Marine Angler Survey, about two-thirds of the sport flounder catch is from east of the Connecticut River, while the trawl survey catches indicate that the greater New Haven area is also important.

In the Hudson-Raritan estuary, New York and New Jersey, summer flounder was the 13th most abundant species in the Wilk *et al*. (1977) survey and it occurred in 21% of all trawls and had a mean annual density in the Lower Bay complex of 1.2/15 min tow (see also reviews by Gaertner 1976 and Berg and Levinton 1985). The 1992-1997 Hudson-Raritan surveys show the adults to be present in moderate numbers throughout the estuary in all seasons except winter (Figure 11). In the fall, they tend to be found in greater numbers in the deeper waters of the Raritan Channel (Figure 11). In the spring, the greatest numbers occurred in Sandy Hook Bay. The greatest densities of summer flounder adults occurred in the summer, particularly in the deeper Raritan and Chapel Hill channels and Raritan and Sandy Hook Bays. This species was not reported in any trawls in the Arthur Kill-Hackensack River estuary. However, it has been collected in Newark Bay from April-October (Wilk *et al*. 1997; Figure 12). Great South Bay, on the south shore of Long Island, supports an important recreational fishery, particularly around Fire Island inlet (Neville *et al*. 1939; Schreiber 1973).

Tagging studies by Murawski (1970) provided recaptured summer flounder from the entire New Jersey coastline. Summer flounder overwinter offshore of New Jersey in 30-183 m of water. Allen *et al*. (1978) collected both adult and juvenile summer flounder in Hereford Inlet near Cape May. They occurred in all of the major waterways, but were more abundant in the upper embayment from May to July and in the lower embayment from August to October. The majority were 200-400 mm and were caught on the slopes of the channels. In Barnegat Bay, an ichthyofauna survey by Vouglitois (1983) from 1976-1980 found a wide range of sizes of summer flounder, but in low numbers. This study was conducted along the western shoreline of the Bay, where muddy sediments predominate, and Vouglitois (1983) suggests that the scarcity of summer flounder is due to their apparent preference for sandy substrates. A hard sandy bottom does predominate in the eastern portion of the Bay and this is where most summer flounder have been caught.

Delaware Bay is an important nursery and summering area for adults as well as a nursery area for juveniles (R. Smith, Delaware Dept. of Nat. Res. and Environ. Control, Dover, DE, personal communication). They are abundant in the lower and middle portions of the estuary, and rare in the upper estuary (Ichthyological Associates, Inc. 1980; Seagraves 1981; Weisberg *et al*. 1996; Michels 1997). Smith and Daiber (1977) caught adults from the shoreline to a maximum depth of 25 m, mostly from May through September, while R. Smith (personal communication) states that adults have been captured in Delaware Bay during all months of the year, but appear to be most common from April to November. The Delaware Bay Coastal Finfish Assessment Survey for 1996 found adults throughout the April to December sampling period, with the highest catch rate in April and greatest occurrences at mid-bay stations (Michels 1997). Delaware's coastal bays are also used by summer flounder as nursery and summering areas [e.g., Indian River and Rehobeth Bays (Michels 1997)].

In Virginia adult flounder use the Eastern Shore seaside lagoons and inlets and the lower Chesapeake Bay as summer feeding areas (Schwartz 1961; J.A. Musick, Virginia Inst. Mar. Sci., Gloucester Point, VA, personal communication). These fish usually concentrate in shallow warm water at the upper reaches of the channels and larger tidal creeks on the Eastern Shore in April, then move toward the inlets as spring and summer progress. They are most abundant in the ocean near inlets by July and August. Tagging studies by Desfosse (1995) revealed that fall migration begins out of Chesapeake Bay in October and is completed by December where most recaptures of fish were from the nearshore fishery from Cape Henry south to Cape Hatteras. The majority of tagged returns during January through March came from offshore from the Cigar north to Wilmington Canyon, and were concentrated east of Cape Henry from the Cigar to Norfolk Canyon. A second group came from inshore waters near Oregon Inlet, south to Cape Hatteras. Movement inshore started in March or perhaps as early as February, and continued from April till June.

Virginia's artificial reefs also provide additional habitat for summer flounder (J. Travelstead, Virginia Mar. Res. Comm., Hampton, VA, personal communication; see also Lucy and Barr 1994). Reef materials include discarded vessels, automobile tires, and fabricated concrete structures.

Both adults and juveniles occur in Pamlico Sound and adjacent estuaries (Figure 13), although it appears that juveniles are usually the more abundant, confirming the significant role of these estuaries as a nursery area for this species (Powell and Schwartz 1977). They occur in areas of intermediate or high salinities, often close to inlets, and prefer a sandy or sand/shell substrate (Powell and Schwartz 1977).

Several surveys have shown that both adult and juvenile summer flounder occur in small numbers in the waters of South Carolina (e.g., Bearden and Farmer 1972; Hicks 1972; Wenner *et al*. 1981, 1986; Stender and Martore 1990; Wenner *et al*. 1990a, b). Artificial reefs also provide habitat

for summer flounder off of South Carolina (Parker *et al*. 1979).

Dahlberg (1972) surveyed the North and South Newport Rivers, Sapelo Sound, and the St. Catherines Sound estuarine complex in Georgia. Adult and juvenile summer flounder were most abundant in the lower reaches of the estuaries and were rarely trawled in the middle reaches.

REPRODUCTION

In the Middle Atlantic Bight, Morse (1981) estimated the length at which 50% of the fish are mature (L_{50}) is 24.6 cm for males and 32.2 cm for females. The smallest mature male was 19.1 cm and the largest immature male was 39.9 cm. Females began maturing at 24.9 cm and the largest immature female was 43.9 cm. The range of L_{50} for males and females indicates sexual maturity is attained by age 2 (Morse 1981; however see below). Adult females are 60 mm total length (TL) longer on average than males at first attainment of sexual maturity. The L_{50} also varied during the six years of Morse's (1981) study. No consistent general trend in L_{50} was evident as males and females appeared to exhibit independent changes. Murawski and Festa (1976) reported that the minimum size at maturity of female summer flounder sampled from off New Jersey during 1963-1964 was 37.0 cm TL, while Smith and Daiber (1977) reported that the minimum size at maturity of fish from Delaware Bay was 30.5 cm and 36.0 cm TL for males and females, respectively. Desfosse (1995) reported the minimum size at maturity of fish sampled from 1987-1989 in Virginia waters was 22-23 cm TL for males and 23-24 cm TL for females. The L_{50} for males was 26.1-27.0 cm TL and 36.1-37.0 cm TL for females. Powell (1974) noted that the minimum size at maturity of summer flounder from Pamlico Sound, North Carolina was 35.0 cm TL. In the South Atlantic Bight, Wenner *et al*. (1990a) estimated the L_{50} to be 28.9 cm TL for males and 30.7 cm TL for females, corresponding to fish approaching age 2. Based on the study by O'Brien *et al*. (1993) on the L_{50} of summer flounder sampled from 1985-1989 from Nova Scotia to Cape Hatteras, this report will use the female size of 28 cm (age 2.5) as the divide between all juvenile and adult individuals. The median length at maturity for males in the O'Brien *et al*. (1993) study was 24.9 cm (age 2). However, as O'Brien *et al*. (1993) notes, a revision to aging convention (Smith *et al*. 1981; Almeida *et al*. 1992) has resulted in median lengths being attained a year earlier than those reported above; thus, for example, the ages of O'Brien *et al*. (1993) are also off by a year (i.e., the age 2.5 female fish are now age 1.5). These conclusions have been supported by more recent growth studies (Able *et al*. 1990; Szedlmayer *et al*. 1992).

Fecundity and length exhibit a curvilinear relationship, but with logarithmic transformations, Morse (1981) expressed the relationship as:

$$\log_{10} \text{Fecundity} = \log_{10} a + b\,(\log_{10} \text{length})$$

where the intercept (a) = -3.098 and the slope (b) = 3.402. The relationship between fecundity and weight and ovary weight were expressed by Morse (1981) as:

$$\text{Fecundity} = a + bX$$

where the intercept (a_{weight}) = -101,865.5 and the slope (b_{weight}) = 908.864, and the intercept ($a_{ovary\ weight}$) = 52,515.161 and the slope ($b_{ovary\ weight}$) = 10,998.048.

Powell (1974) estimated that females ranging from 50.6-68.2 cm TL have 1.67-1.70 million ova per fish, while Morse (1981) reported fish between 36.6 and 68.0 cm TL have 0.46-4.19 million ova. The relative fecundity, number of eggs produced per gram of total weight of spawning female, ranged from 1,077-1,265 in Morse's (1981) study. The increase in variability in fecundity estimates as weight increases tends to obscure the true relationship. The high egg production to body weight is maintained by serial spawning. In fact, the weight of annual egg production, assuming an average egg diameter of 0.98 mm and 1.0 specific gravity, equals approximately 40-50% of the biomass of spawning females (Morse 1981).

Morse (1981) calculated the percent of ovary weight to total fish weight as an index for maturity. The mean maturity index increased rapidly from August to September, peaked in October-November, then gradually decreased to a low in July. The wide range in the maturity indices during the spawning season indicates nonsynchronous maturation of females and a relatively extended spawning season. The length and peak spawning time as indicated by the maturity index agree with results determined by egg and larval occurrence (Herman 1963; Smith 1973).

Spawning occurs over the open ocean areas of the shelf (Figure 14). Summer flounder spawn during the fall and winter while the fish are moving offshore or onto their wintering grounds; the offshore migration is presumably keyed to declining water temperature and decreasing photoperiod during the autumn. The spawning migration begins near the peak of the summer flounder`s gonadal development cycle, with the oldest and largest fish migrating first each year (Smith 1973).

The seasonal migratory/spawning pattern varies with latitude (Smith 1973); i.e., gonadal development, spawning and offshore movements occur earlier in the northern part of their range (Rogers and Van Den Avyle 1983). For example, in Delaware Bay, gonads of summer flounder appear to ripen from mid-August through November (Smith and Daiber 1977), while peak gonadal development occurs during December and January for fish around Cape Hatteras (Powell 1974). Spawning begins in September in the inshore waters of southern New England and the Mid-Atlantic. As the season progresses, spawning moves onto Georges Bank as well as southward and eastward into deeper waters across the entire breadth of the shelf (Berrien and Sibunka 1999).

Spawning continues through December in the northern sections of the Middle Atlantic Bight, and through February/March in the southern sections (Smith 1973; Morse 1981; Almeida *et al*. 1992). Spawning peaks in October north of Chesapeake Bay and November south of the Bay (Smith 1973; Able *et al*. 1990; note that the latter statement on spawning south of the Bay in November appears to contradict the published information above concerning peak gonadal development occurring December-January near Cape Hatteras). The half year spawning season reduces larval crowding and decreases the impact of predators and adverse environmental conditions on egg and larval survival (Morse 1981). In the South Atlantic Bight, maturity observations by Wenner *et al*. (1990a) suggest that spawning begins as early as October, and may continue through February and possibly early March.

EGGS

Eggs of summer flounder are pelagic and buoyant. They are spherical with a transparent, rigid shell; yolk occupies about 95% of the egg volume. Mean diameter of mature unfertilized eggs is 0.98 mm.

Eggs are most abundant between Cape Cod/Long Island and Cape Hatteras (Figures 14 and 15); the heaviest concentrations have been reported within 45 km of shore off New Jersey and New York during 1965-1966 (Smith 1973), and from New York to Massachusetts during 1980-1986 (Able *et al*. 1990). Able *et al*. (1990) discovered that the highest frequency of occurrence and greatest abundances of eggs in the northwest Atlantic occurs in October and November (Figure 15), although, due to limited sampling in December south of New England, December could be under represented. Festa (1974) also notes an October-November spawning period off New Jersey. Keller *et al*. (1999) found eggs (maximum density 19.5/100 m^3) from February to June in Narragansett Bay during a December 1989 to November 1990 sampling period. In southern areas, eggs have been collected as late as January-May (Figure 14; Smith 1973; Able *et al*. 1990).

The eggs have been collected mostly at depths of 30-70 m in the fall, as far down as 110 m in the winter, and from 10-30 m in the spring (Figure 16).

LARVAE

Planktonic larvae (2-13 mm) are often most abundant 19-83 km from shore at depths of around 10-70 m, and are found in the northern part of the Middle Atlantic Bight from September to February, and in the southern part from November to May, with peak abundances occurring in November (Smith 1973; Able *et al*. 1990; Figures 17, 18, 19). The smallest larvae (< 6 mm) were most abundant in the Mid-Atlantic Bight from October-December, while the largest larvae (≥ 11 mm) were abundant November-May with peaks in November-December and March-May (Able *et al*. 1990). Off eastern Long Island and Georges Bank, the earliest spawning and subsequent larval development occurs as early as September (Able and Kaiser 1994). By October, the larvae are primarily found on the inner continental shelf between Chesapeake Bay and Georges Bank. During November and December they are evenly distributed over both the inner and outer portions of the shelf. By January and February the remaining larvae are primarily found on the middle and outer portions of the shelf. By April, the remaining larvae are concentrated off North Carolina (Able and Kaiser 1994).

From October to May larvae and postlarvae migrate inshore, entering coastal and estuarine nursery areas to complete transformation (Table 1; Merriman and Sclar 1952; Olney 1983; Olney and Boehlert 1988; Able *et al*. 1990; Szedlmayer *et al*. 1992). Larval to juvenile metamorphosis, which involves the migration of the right eye across the top of the head, occurs over the approximate range of 8-18 mm SL (Burke *et al*. 1991; Keefe and Able 1993; Able and Kaiser 1994; Figure 20). They then leave the water column and settle to the bottom where they begin to bury in the sediment and complete development to the juvenile stage, although they may not exhibit complete burial behavior until mid-late metamorphosis when eye migration is complete, often at sizes as large as 27 mm SL (Keefe and Able 1993, 1994). However, burying behavior of metamorphic summer flounder is also significantly affected by substrate type, water temperature, time of day, tide, salinity, and presence and types of predators and prey (Keefe and Able 1994).

Keller *et al*. (1999) found larvae (maximum density 1.4/100 m^3) from September to December in Narragansett Bay during a December 1989 to November 1990 sampling period. Able *et al*. (1990) and Keefe and Able (1993) discovered that some transforming larvae (10-16 mm) entered New Jersey estuaries primarily during October-December, with continued ingress through April; Allen *et al*. (1978) collected larvae (12-15 mm) in February and April in Hereford Inlet near Cape May. Dovel (1981) recorded 9 larvae in the lower Hudson River estuary, New York in 1972. In North Carolina, the highest densities of larvae are found in Oregon Inlet in April, while farther south in Ocracoke Inlet, the highest densities occur in February (Hettler and Barker 1993). J.P. Monaghan, Jr. (North Carolina Dept. of Nat. Res. and Commer. Dev., Morehead City, NC, personal communication) mentions that for the years 1986-1988, peak immigration periods of larvae through Beaufort Inlet and into North Carolina estuaries were from late February through March. In the Cape Fear River Estuary, North Carolina, it has been reported that postlarvae first enter the marshes in March and April and are 9-16 mm SL during peak recruitment (Weinstein 1979; Weinstein *et al*. 1980b). Schwartz *et al*. (1979a, b) also notes that age 0 flounder appear in the Cape Fear River between March and May, depending on the year. Warlen and Burke (1990) found larvae (mean 13.1 mm SL) in the

Newport River estuary just inside Beaufort Inlet from February-April, 1986, with peak abundance in early March. Powell and Robbins (1998) reported larval summer flounder adjacent to live-bottom habitats (rock outcroppings containing rich invertebrate communities and many species of tropical and subtropical fishes) in Onslow Bay (near Cape Lookout) in November (at stations of 17-22 m depth), February (28-30 m depth), and May (14-16 m and 17-22 m depth). Burke *et al*. (1998) conducted night-time sampling for transforming larvae and juveniles in Onslow Bay, Beaufort Inlet, and the Newport River estuary in February-March 1995. Although flounders were captured both in Onslow Bay and in the surf zone during the immigration period, densities were low and all were transforming larvae (7-15 mm SL). After the immigration period, flounders were absent, as juveniles were not caught. Within the Newport River estuary, flounders were locally very abundant as compared to within Onslow Bay and initial settlement was concentrated in the intertidal zone. During February most were transforming larvae, in March some were completely settled juveniles (11-21 mm SL). In South Carolina, Burns (1974) captured summer flounder larvae (14.9-17.5 mm) in New Bridge Creek, North Inlet estuary in February-March, while Bearden and Farmer (1972) recorded larvae and postlarvae in Port Royal Sound estuary from January-March. During 1986-1988, Wenner *et al.* (1990a) found that ingress of recently transformed larval and juvenile summer flounder (10-20 mm TL) into Charleston Harbor, South Carolina estuarine marsh creeks began in January and continued through April (Figure 21). Larvae and postlarvae were also found during this period in the Chainey Creek area (Wenner *et al.* 1986).

JUVENILES

As stated above, juveniles are distributed inshore (e.g., Figure 22) and in many estuaries throughout the range of the species during spring, summer, and fall (Table 1; Deubler 1958; Pearcy and Richards 1962; Poole 1966; Miller and Jorgenson 1969; Powell and Schwartz 1977; Fogarty 1981; Rountree and Able 1992a, b, 1997; Able and Kaiser 1994; Walsh *et al*. 1999). During the colder months in the north there is some movement to deeper waters offshore with the adults (Figure 3; Figure 23), although many juvenile summer flounder will remain inshore through the winter months while some juveniles in southern waters may generally overwinter in bays and sounds (Smith and Daiber 1977; Wilk *et al*. 1977; Able and Kaiser 1994). In estuaries north of Chesapeake Bay, some juveniles remain in their estuarine habitat for about 10 to 12 months before migrating offshore their second fall and winter; in North Carolina sounds, they often remain for 18 to 20 months (Powell and Schwartz 1977). The offshore juveniles return to the coast and bays in the spring and generally stay the entire summer.

Fogarty (1981) examined the distribution patterns of prerecruit (≤ 30.5 cm) summer flounder caught during the 1968-1979 spring surveys and found a striking absence of small fish in northern areas. Both spring and autumn bottom trawl survey data indicated that the concentration of young-of-year summer flounder was south of 39° latitude. The importance of the Chesapeake Bight to this species is demonstrated by the fact that almost all of the young-of-year caught during those spring surveys were from this area.

In Mid-Atlantic estuaries, first year summer flounder can grow rapidly and attain lengths of up to at least 30.0 cm (Poole 1961; Almeida *et al*. 1992; Szedlmayer *et al*. 1992). Young-of-the-year summer flounder in New Jersey marsh creeks have average growth rates of 1.3-1.9 mm/d, and increase from about 16.0 cm TL at first appearance in late July to around 26.0 cm by September (Rountree and Able 1992b; Szedlmayer *et al*. 1992). First year fish from Pamlico Sound, North Carolina obtained mean lengths of 16.7 cm for males and 17.1 cm for females (Powell 1982). In Charleston Harbor and other South Carolina estuaries from 1986-1988, Wenner *et al*. (1990a) found transforming larvae were recruited into the estuarine creeks when 1-2 cm TL. Growth accelerated in May and June when they reached modal sizes of 8 and 14 cm TL, respectively. By September, modal size was 16 cm TL and reached from 23-25 cm TL through October and November. Modal lengths of yearlings ranged from 23-25 cm in January through June and generally reached 28 cm by October. In Georgia, lab studies by Reichert and van der Veer (1991) found that juveniles from Duplin River of 28-46 mm SL had a maximum growth rate of about 1.3-1.4 mm/d at laboratory temperatures of 23.7-24.8°C.

Juvenile summer flounder make use of several different estuarine habitats. Estuarine marsh creeks are important as nursery habitat, as has been shown in New Jersey (Rountree and Able 1992b, 1997; Szedlmayer *et al*. 1992; Szedlmayer and Able 1993), Delaware (Malloy and Targett 1991), Virginia (Wyanski 1990), North Carolina (Burke *et al*. 1991) and South Carolina (Bozeman and Dean 1980; McGovern and Wenner 1990; Wenner *et al*. 1990a, b). Other portions of the estuary that are used include seagrass beds, mud flats and open bay areas (Lascara 1981; Wyanski 1990; Szedlmayer *et al*. 1992; Walsh *et al*. 1999).

Patterns of estuarine use by the juveniles can vary with latitude. In New Jersey, nursery habitat includes estuaries and marsh creeks from Sandy Hook to Delaware Bay (Allen *et al*. 1978; Rountree and Able 1992a, b, 1997; Szedlmayer *et al*. 1992; Szedlmayer and Able 1993; B.L. Freeman, New Jersey Dept. of Environ. Prot., Trenton, NJ, personal communication). The juveniles often make extensive use of creek mouths (Szedlmayer *et al*. 1992; Szedlmayer and Able 1993; Rountree and Able 1997). In the Hudson-Raritan estuary, New York and New Jersey, 1992-1997 surveys show the juveniles to be present in small numbers throughout the estuary in all seasons, with slightly higher numbers seen in the spring (Figure 24). In Great Bay, young-of-the-year stay for most of the summer, leaving as early as August and continuing until November-December (Able *et al*. 1990; Rountree and Able 1992a; Szedlmayer

and Able 1992; Szedlmayer *et al*. 1992). As stated previously, Allen *et al*. (1978) collected both adult and juvenile summer flounder (200-400 mm) in Hereford Inlet near Cape May where they occurred in all of the major waterways, but were more abundant in the upper embayment from May to July and in the lower embayment from August to October. Most were caught on the channel slopes.

Smith and Daiber (1977) report that in Delaware Bay, most summer flounder were collected May through September but a few juveniles have been caught in the deeper parts of the Bay in every winter month. The Delaware Bay Coastal Finfish Assessment Survey for 1996 found juveniles throughout their April to October sampling period (Michels 1997).

In Maryland, J.F. Casey (Maryland Dept. of Nat. Res., Ocean City, MD, personal communication) indicated that although the coastal bays are excellent habitat for both adults and juveniles (Schwartz 1961), in areas of significant pollution, a lack of proper food sources precludes the presence of summer flounder. Other areas which lack sufficient water circulation also appear to have considerably reduced populations. Shore-side development and resultant runoff also appear to have reduced some local populations (Casey, personal communication). Since the 1970's, Maryland has been conducting trawl and seine surveys around Ocean City inlet. Casey (personal communication) reported sharp declines in young-of-the-year flounder in the coastal bay trawl samples. The majority of the summer flounder taken in this sampling were between 76 and 102 mm, with larger fish basically absent. Summer flounder were also sometimes found in Maryland's portion of the Chesapeake Bay with the majority of these fish in the 200-300 mm range.

In Virginia, Musick (personal communication) states that the most important nursery areas for summer flounder appear to be in the lagoon system behind the barrier islands on the seaside of the Eastern Shore (Schwartz 1961), and the shoal water flat areas of higher salinity (> 18 ppt) in lower Chesapeake Bay. Young-of-the-year enter these nursery areas in early spring (March and April) and remain there until fall when water temperatures drop. Then these yearlings move into the deeper channel areas and down to the lower Bay and coastal areas. In most winters these age 1+ fish migrate out in the ocean but in warmer winters some may remain in deep water in lower Chesapeake Bay (Musick, personal communication). However, the Virginia Institute of Marine Science juvenile finfish survey for 1995 shows juvenile (as well as some adult) flounder occurring throughout most of the main stem of Chesapeake Bay and the major Virginia tributaries (Rappahannock, York, and James Rivers) over most of the year (Geer and Austin 1996; Figure 25; see also Wagner and Austin 1999). Lower numbers occurred from December-March (Figure 26). Wyanski (1990) found recruitment to occur from November to April on both sides of Virginia's Eastern Shore and from February to April on the western side of Chesapeake Bay. Peak recruitment occurred in November-December on the Eastern Shore, compared to March-April on the western side of the Bay. Wyanski (1990) and Norcross and Wyanski (1988) also found that young-of-the-year occur in a variety of habitats, including shallow, mud bottomed marsh creeks, shallow sand substrates (including seagrass beds), deep sand substrate, and deep fine-sand substrates.

Tagged summer flounder have been recaptured from inshore areas to the northeast of their release sites in subsequent summers, leading to the hypothesis that their major nursery areas are the inshore waters of Virginia and North Carolina, and as they grow older and larger, they would return inshore to areas farther north and east of these nursery grounds (Poole 1966; Murawski 1970; Lux and Nichy 1981). However, tagging studies by Desfosse (1995) indicate that it is not the older and larger fish, but rather the smaller fish (length at tagging) which return to inshore areas north of Virginia. Summer flounder that were recaptured north of their release site in subsequent years were smaller (length at tagging) than those recaptured at their release sites, or to the south, in later years. Desfosse (1995) suggests that while Virginia waters do indeed form part of the nursery grounds for fish which move north in subsequent years, they are primarily a nursery area for fish which will return to these same waters as they grow older and larger.

The estuarine waters of North Carolina, particularly those west and northwest of Cape Hatteras (Monaghan 1996) and in high salinity bays and tidal creeks of Core Sound (Noble and Monroe 1991), provide substantial habitat and serve as significant nursery areas for juvenile Mid-Atlantic Bight summer flounder. Powell and Schwartz (1977) found that juvenile summer flounder were most abundant in the relatively high salinities of the eastern and central parts of Pamlico Sound, all of Croatan Sound (Figure 13), and around inlets. Young-of-the-year disappeared from the catch during late summer, suggesting that the fish are leaving the estuaries at that time (Powell and Schwartz 1977). Upon leaving the estuaries, the juveniles enter the north-south, inshore-offshore migration of Mid-Atlantic Bight summer flounder (Monaghan 1996). Although North Carolina also provides habitat for summer flounder from the South Atlantic Bight, these fish do not exhibit the same inshore-offshore and north-south migration patterns as do Mid-Atlantic Bight fish (Monaghan 1996). Summer flounder > 30 cm are rarely found in the estuaries of North Carolina, although larger fish are found around inlets and along coastal beaches. Powell and Schwartz (1977) also noted that juvenile summer flounder were most abundant in areas with a predominantly sandy or sand/shell substrate, or where there was a transition from fine sand to silt and clay.

Surveys by Hoffman (1991) in marsh creeks in Charleston Harbor, South Carolina showed that recently settled summer flounder were abundant over a wide variety of substrates including mud, sand, shell hash, and oyster bars.

HABITAT CHARACTERISTICS

EGGS

Temperature

Smith (1973) found that eggs were most abundant in the water column where bottom temperatures were between 12 and 19°C; however, eggs were found in temperatures as cold as 9°C and as warm as 23°C. The Northeast Fisheries Science Center (NEFSC) Marine Resources Monitoring, Assessment, and Prediction (MARMAP) ichthyoplankton data from 1978-1987 also shows that the eggs occur at water column temperatures around 11-23°C with peak abundances in the fall at temperatures of around 14-17°C (Figure 27). A temperature increase of 20°C above an acclimation temperature of about 15°C caused no mortality in early embryo stage eggs, but an increase of 16°C for 16 minutes or an increase of 18°C for 2 minutes caused mortality in late embryo stage eggs (Itzkowitz *et al*. 1983). The rate of development is dependent on temperature, with development rate increasing as temperature increases. Embryos held at 16°C developed slower than those at 21°C (Johns and Howell 1980). The incubation period from fertilization to hatching was estimated by Smith (1973) and Smith and Fahay (1970) to vary with temperature as follows: about 142 hours at 9°C; 72-75 hours at 18°C; and 56 hours at 23°C. Other incubation times under experimental conditions were 48-72 hours at 16-21°C and 216 hours at 5°C (Johns and Howell 1980; Johns *et al*. 1981). In another study, summer flounder eggs required 72-96 hours to hatch while incubated at temperatures ranging from 15-18°C (Smigielski 1975). Eggs from Narragansett Bay and Long Island Sound broodstocks incubated at 12.5°C started hatching 85 hours after fertilization, while those incubated at 21°C hatched 60 hours after fertilization (Bisbal and Bengtson 1995c).

Watanabe *et al*. (1999) studied the combined effects of temperature and salinity on eggs from captive summer flounder broodstock in the laboratory, and also showed that higher temperatures and salinities accelerated the rate of embryonic development through hatching. At 16°C and 20°C, the hatching rate was moderate to high at all experimental salinities (22, 27, and 33 ppt). At a higher temperature of 24 °C, hatching rate was high at 33 ppt, but at lower salinities of 22 and 27 ppt, embryonic development and hatching was impaired, indicating a high-temperature–low-salinity inhibition.

Salinity

The studies of Watanabe *et al*. (1998, 1999; see also previous section) suggest that whereas temperature produces marked differences in developmental rates and median hatching time of summer flounder embryos, the effects of salinity on median hatching time are relatively small.

Dissolved Oxygen

No information is available.

Light

Watanabe *et al*. (1998) studied the effects of light on eggs from captive summer flounder broodstock in the laboratory. Although the rate of embryonic development appeared to be faster at higher light intensities, hatching rate was not influenced by light intensity within the range of 0-2,000 lx.

Water Currents

No information is available.

Predation

No information is available.

LARVAE/JUVENILES

Temperature

Larvae have been found in temperatures ranging from 0-23°C, but are most abundant between 9 and 18°C. NEFSC MARMAP ichthyoplankton data from 1977-1987 shows a seasonal shift in offshore larval occurrence with water column temperatures (Figure 28): most larvae are caught at temperatures ≥ 12°C in the fall, from 4-10°C in the winter and from 9-14°C in the spring. Sissenwine *et al*. (1979) found prerecruit summer flounder in the Mid-Atlantic Bight are often most abundant at temperatures in excess of 15°C during the spring, summer and fall, and usually at depths of 40-60 m. Larval flounder have been collected inshore earlier in years with mild winters than in years with severe winters (Cain and Dean 1976; Bozeman and Dean 1980). In the estuaries, transforming larvae (11-17 mm TL) have been collected over a temperature range from -2.0-14°C in Great Bay/Little Egg Harbor in New Jersey (Szedlmayer *et al*. 1992; Able and Kaiser 1994); from 2.1-17.6°C in the lower Chesapeake and Eastern Shore, Virginia (Wyanski 1990); from 2-22°C in North Carolina (Williams and Deubler 1968b); and from 8.4-23.4°C in South Carolina (McGovern and Wenner 1990). Hettler *et al*. (1997) also reported an increase in summer larval abundance with increasing temperatures (7-18°C) in Beaufort Inlet, North Carolina; however, they suggest that unknown factors are probably more important in causing peaks in the abundances of immigrating larvae (see also Hettler and Hare 1998).

Johns and Howell (1980) and Johns *et al*. (1981)

performed experiments on yolk utilization and growth to yolk-sac absorption in summer flounder embryos and larvae. Notochord lengths at hatching were 2.83-3.16 mm SL, with yolk-sac absorption completed at about 3.6 mm SL. For embryos and larvae reared at 21°C, total yolk-sac absorption was complete by 120 h post-fertilization, at 16°C, complete absorption did not occur until 168-182 h, while at 11°C absorption did not occur until 287 h post-fertilization; these development times are similar to those reported by Watanabe *et al*. (1998) for larvae at 19°C. After hatching, total yolk-absorption at 21°C was complete in 67 h, at 16°C it took 105 h, and at 11°C it took 137 h. Larvae reared in cyclic temperature regimes exhibited development rates intermediate to those at temperature extremes of the cycle. All larvae reared at 5°C and in the 5-11°C cycle regime died prior to total yolk-sac absorption. Although incubation temperature had a significant effect on the larval length at hatching, there were no significant differences in the notochord length or yolk utilization efficiency of the larvae at the time of yolk-sac absorption. The similarity in growth and yolk utilization efficiency for larvae reared under these temperature regimes suggests that the physiological mechanisms involved are able to compensate for temperature changes encountered in nature. Larvae are able to acclimate to new temperatures in less than one day (Clements and Hoss 1977).

Watanabe *et al*. (1999), using larvae hatched from eggs obtained from captive broodstock in the laboratory, also showed that development of yolk-sac larvae through first feeding was accelerated by higher temperatures within the range of 16-24°C, consistent with what was previously reported by Johns and Howell (1980) and Johns *et al.* (1981). In all three studies the rate of yolk disappearance (yolk utilization efficiency) was faster at higher temperatures. Watanabe *et al*. (1999) showed that the average time from the first-feeding to when 97% of the yolk-sac was absorbed in unfed larvae ranged from 2.4 to 4.3 times longer at 16°C (18.3 h) than at 20°C (4.3 h) or 24°C (7.7 h). Thus, larvae in 16°C waters may have considerably more time to initiate exogenous feeding before yolk reserves are exhausted [see also the discussion of the Bisbal and Bengtson's (1995c) study, below].

However, contrary to the Johns and Howell (1980) and Johns *et al.* (1981) studies, lower temperatures in the Watanabe *et al*. (1999) study produced larger larvae at the first-feeding and 97% yolk-sac absorption stages. Watanabe *et al*. (1999) state that these dissimilar results are attributable to the modifying influence of salinity, which differed between these studies (see the Salinity section, below). In their study, Watanabe *et al*. (1999) noted a high-temperature–low-salinity inhibition on growth and yolk utilization efficiency, but at a salinity of 33 ppt, there were no temperature-related differences in yolk utilization efficiency. Watanabe *et al*. (1999) suggest this may be consistent with what was observed in the Johns and Howell (1980) and Johns *et al.* (1981) studies, which used seawater of an unspecified salinity.

Further interactions of temperature and salinity in the Watanabe *et al*. (1999) study will be discussed in the Salinity section, below.

Bisbal and Bengtson (1995c) show the interdependence of temperature and food availability (i.e., delay of initial feeding) and their effects on survival and growth of summer flounder larvae hatched from Narragansett Bay and Long Island Sound broodstock. Their laboratory observations occurred from the time of hatching throughout the period of feeding on rotifers. The larvae withstood starvation for longer times at lower temperatures. They possessed sufficient reserves to survive starvation for 11 to 12 days when temperatures were maintained close to the experimentally determined lower tolerance limit (12.5°C; Johns *et al*. 1981). At temperatures close to the highest thermal limit reported to occur in their environment (21°C; Smith 1973), larvae only survived for 6 to 7 days. At either temperature, best survival occurred when the larvae began to feed at the time of mouth opening, thus survival is also significantly affected by the time at which they first have access to exogenous food. At 12.5°C, every treatment group was represented by a low number of survivors which did not grow significantly from the initial figures at mouth opening. Growth of the larvae at 21°C was inversely proportional to the duration of early starvation; the size distribution of the survivors of the 21°C experiment showed an increase in mean size and weight when the initial feeding delay was shorter.

The prevailing temperature conditions influence the duration of metamorphosis of pelagic larvae, with increasing temperatures resulting in a shorter metamorphic period. For example, Keefe and Able (1993) found the time to completion of metamorphosis in wild-caught New Jersey flounder maintained in the laboratory was clearly temperature dependent. While laboratory-reared summer flounder averaged 24.5 days (range 20-32 days) to complete metamorphosis (stage F- to stage I) at ambient spring temperatures of around 16.6°C, wild-caught flounder held in heated water (daily average 14.5°C) advanced metamorphosis over controls kept at ambient winter temperatures (daily average 6.6°C). Total time required to complete metamorphosis in the heated water averaged 46.5 days (range 31-62 days); ambient winter temperature treatments resulted in delayed metamorphosis such that partial metamorphosis (stage H- to stage I) required as much as 92.9 days (range 67-99 days). Burke (1991) found that settling behavior of fish raised at 18-20°C occurred 28 days after hatching, although some took as long as 70 days.

Keefe and Able (1993) also found that mortality during metamorphosis in the laboratory ranged from 17-83% among treatment groups, and was significantly greater in flounder maintained at approximately 4°C relative to those maintained at ambient New Jersey estuarine temperatures of around 10.1°C. They found no apparent effect of starvation on either mortality or time to completion of metamorphosis at cool water temperatures (< 10°C). Szedlmayer *et al.* (1992) examined the temperature-induced mortality of

young-of-the-year, early postmetamorphic (11-15 mm TL) summer flounder collected in New Jersey estuaries from November to May over a temperature range of 0-13°C. Survival of metamorphosing larvae in the laboratory decreased drastically relative to controls when temperatures dropped below 2°C. In trial 1, temperatures dropped steadily from 15-1°C over a 14-day period. Relatively little mortality (2%) occurred up to day 12. However, on days 13 and 14, temperatures dropped below 2°C causing 58% mortality. Temperatures then increased and fluctuated around 5°C but did not drop below 3°C, and during this period, mortality was lower (14%), for a total ambient temperature mortality of 74%. Only 3% total mortality occurred due to rearing environment in the control group, heated to 15°C. During trial 2, in which controls were absent and ambient temperatures did not drop below 2°C, overall mortalities were lower (31% total) and these occurred sporadically.

Malloy and Targett (1991) conducted laboratory experiments on juvenile summer flounder (41-80 mm TL) collected from Delaware to determine low temperature tolerance (2-3°C) and to measure feeding rate, assimilation efficiency, growth rate and growth efficiency at various temperatures. Above 3°C, all the juveniles survived. Mortality was 42% after 16 days at 2-3°C, and was highest in fish < 50 mm TL (1g). Mean specific growth rates were not significantly different between 2 and 10°C, and these rates were not significantly different from zero. Additional mortality probably resulted from low growth rates caused by sub-optimal temperatures (< 10°C). Malloy and Targett (1994a) also demonstrate that mortality of juveniles depends more on the rate of temperature decline than on the final exposure temperature: increased rate of temperature decline leads to decreased survival (lower LT_{50}'s). Their study showed that juveniles from Delaware had greater tolerances for low temperatures (1-4°C) than juveniles from North Carolina.

Malloy and Targett (1994a) showed that under maximum-feeding conditions, juvenile summer flounder (18-80 mm TL) from both Delaware and North Carolina do not exhibit positive growth rates at temperatures < 7-9°C. [They consider this a more precise estimate of maintenance temperature than that reported in their earlier study (Malloy and Targett 1991).] Similarly, Peters and Angelovic (1971) in their laboratory studies of North Carolina juveniles reported predicted growth rates of close to zero at 10°C. Growth rates of juvenile flounder at temperatures above 10°C are similar in studies on Delaware fish by Malloy and Targett (1991) and on North Carolina fish by Peters and Angelovic (1971). Malloy and Targett (1991) showed that mean growth rate increased to 2.4% per day at 14°C and 3.8% per day at 18°C and Peters and Angelovic (1971) demonstrated that specific growth rates of North Carolina juveniles were 5% and 10% per day, at 15 and 20°C, respectively. Both studies showed that feeding rates increased with temperature, ranging from 1.04% body weight per day at 2°C to 23-24% body weight per day at 18°C. Peters and Angelovic (1971) reported an increase in feeding and growth efficiency rates with increasing temperatures to an optimum; beyond that optimum increasing temperatures are detrimental. The optimal temperature in their experiments was 21°C. Mean assimilation efficiency (60.1%) was not affected by temperature in the Malloy and Targett (1991) study. Mean growth efficiency (K_1) for Delaware juveniles was significantly lower at 6°C (-23.1%) than at 14 and 18°C (18.4 and 22.1% respectively) and was highly variable. Malloy and Targett (1994a, b) conclude that North Carolina juveniles had higher maximum growth rates and gross growth efficiencies than Delaware juveniles at temperatures between 6 and 18°C. Growth efficiency accounted for most of these differences in growth rates, because there were no differences in feeding rate or assimilation efficiency. Newly settled juveniles likely remain at settlement sizes for up to 6 months until temperatures are conducive for positive growth (Able *et al*. 1990; Malloy and Targett 1991, 1994b).

Malloy and Targett (1994a) also reported that juveniles from North Carolina and Delaware can survive at least 14 d without food at the 10-16°C temperatures typically found after settlement. However, growth rates are dependent on feeding rate at all temperatures they examined. Growth rates under starvation conditions and maintenance rations do not change between 10-16°C; however, scope for growth increases with temperature. Scope for growth of the North Carolina juveniles was higher than that of the Delaware juveniles between 10-16°C. In another study, Malloy and Targett (1994b) showed that juveniles (18-80 mm TL) from both Delaware and a North Carolina sandy marsh were severely growth limited (< 20% of maximum growth) in May and June when temperatures were 13-20°C. Malloy and Targett (1994a, b) conclude that prey availability is very important to the growth and condition of early juveniles during the months immediately following settlement, and changes in prey abundance may explain the patterns in growth limitation.

Mortality resulting from acute exposure to low temperatures in Mid-Atlantic Bight estuaries probably occurs during a 2 to 4 week period each winter. Szedlmayer *et al*. (1992) hypothesized that year class strength may be affected by winter temperature in New Jersey estuaries, as has been suggested for juveniles by Malloy and Targett (1991) for the Mid-Atlantic Bight as a whole. Recruitment success may be lower in years with late winter cold periods (i.e., March vs. December) due to increased numbers of fish inshore at that time of the year being exposed to lethal low temperatures (Malloy and Targett 1991). Thus, the timing of ingress is critical. However, because Malloy and Targett (1991) found that there was 100% survival at temperatures above 3°C, juveniles are probably able to survive most winter water temperatures encountered throughout Mid-Atlantic Bight estuaries. However, Malloy and Targett (1994a) state that the magnitude of the variability in low temperatures may also be more important to prerecruit mortality than the magnitude of the temperature itself. The

low feeding rates observed at low temperatures in the laboratory and the apparent lack of a starvation effect on low-temperature tolerance suggest that food limitation during winter is less important than the magnitude and variability of temperature minima. They conclude that although low temperatures may contribute to prerecruit mortality south of Cape Hatteras, they are probably more important in more northern nurseries because they persist longer there. In New Jersey, the most probable factors affecting survival of metamorphic summer flounder are the prevailing environmental conditions, especially the timing of ingress relative to estuarine water temperatures and predation (Szedlmayer *et al*. 1992; Keefe and Able 1993; Witting and Able 1993).

Tracking studies by Szedlmayer and Able (1993) in Schooner Creek, near Great Bay and Little Egg Inlet, New Jersey, suggest that tidal movements of juveniles (210-254 mm TL) may be in response to a preferred range of environmental parameters. Although they were collected in a wide range of habitats during their first year (Szedlmayer *et al*. 1992), during the August to September study period, they were found within a narrow range of water temperature (mean 23.5^{o}C) and also dissolved oxygen. Small changes in these parameters may force the fish to move.

Several studies indicate that juvenile summer flounder in Chesapeake Bay may succumb to infections of the hemoflagellate *Trypanoplasma bullocki* at low temperatures (Burreson and Zwerner 1982, 1984; Sypek and Burreson 1983). Effective immune response to the parasite was not noted in natural infections below 10°C (Sypek and Burreson 1983). Therefore, because *T. bullocki* causes mortality of juvenile summer flounder during winter, suggesting that this mortality is temperature dependent, and since no fish with symptoms of the disease have been observed south of Cape Hatteras, Burreson and Zwerner (1984) hypothesize that the presence of the symptoms of this disease in juvenile summer flounder can be used as a measure of mortality north of Cape Hatteras. In addition, increased antibody production in early spring eliminates the infection in the flounder and the recovered fish are immune for at least one year, even if challenged at temperatures as low as 9°C (Burreson and Frizzell 1986).

NEFSC groundfish data shows a seasonal shift in offshore juvenile summer flounder occurrence with bottom temperatures (Figure 29): most juveniles are caught over a range of temperatures from 10-27°C in the fall, from 3-13°C in the winter, from 3-17°C in the spring, and from 10-27°C in the summer. Massachusetts inshore trawl survey data also shows a seasonal shift in juvenile occurrence with bottom temperature (Figure 30). In the spring, most juveniles occur at a range of temperatures from 9-14°C, while in the fall they occur at temperatures from 15-21°C.

Salinity

Watanabe *et al*. (1998) studied the effects of salinity and light intensity on yolk-sac larvae hatched from captive summer flounder broodstock in the laboratory. Significant effects of both salinity and light intensity on larval size were evident at hatching: larvae hatched under 500 lx and salinities of approximately 35 ppt showed maximum values, a trend observed at the first feeding stage. However, in a later study by Watanabe *et al*. (1999), salinity did not influence development and growth rates of yolk sac larvae through the first feeding stage. Watanabe *et al*. (1998) suggest that the differences among the two studies may be attributed to the lower salinity range (22-33 ppt) used in this later study.

Also in the Watanabe *et al*. (1999) study, a high temperature of 24°C, although not greatly influencing larval survival at 33 ppt, markedly impaired survival at the 97% yolk-sac absorption stage when salinities were at 22 and 27 ppt, indicating high-temperature–low-salinity inhibition. Conversely, a low temperature of 16°C enhanced larval survival at these reduced salinities, indicating a low-temperature–low salinity synergistic effect. Watanabe *et al*. (1999) therefore hypothesize that moderate to high survival under all salinities at 16°C reflects an adaptability of the yolk sac larvae to inshore movement during the pelagic larval phase, whereas simultaneous exposure to higher temperatures and reduced salinities may increase mortality and affect year-class strength.

Transforming larvae and juveniles are most often captured in the higher salinity portions of estuaries. In New Jersey, Festa (1974) captured larval summer flounder in salinities of 26.6-35.6 ppt, while in two marsh creeks, larvae occurred at salinities ranging from 20-33 ppt (Able and Kaiser 1994). In the lower Chesapeake Bay, Virginia, young-of-the-year were common in creeks with salinities > 15 ppt and were most abundant at the highest salinities, but were absent in a small tributary of the Poropotank River with salinities 3-11 ppt (Able and Kaiser 1994). In North Carolina, Williams and Deubler (1968a) found postlarval summer flounder in waters ranging from 0.02-35 ppt, with optimal conditions at 18 ppt. In addition, postlarval summer flounder (10-18 mm SL) were captured most frequently at salinities exceeding 7.4 ppt in the Cape Fear River Estuary, North Carolina (Weinstein *et al*. 1980b). However, Turner and Johnson (1973) reported that summer flounder of all ages occurred in the Newport River, North Carolina, at salinities of 3-33 ppt. Data from 1987-1991 trawl surveys from Pamlico Sound show that almost all individuals were collected in the sound while few were found in the adjacent subestuaries with lower salinities such as the Pamlico and Neuse Rivers (Able and Kaiser 1994). M. Street (North Carolina Dept. of Nat. Res. and Commer. Dev., Morehead City, NC, personal communication) mentioned that summer flounder distribution in Pamlico Sound varied in response to salinity changes. In dry years the area of higher salinity

greatly expands in Pamlico Sound, and nursery areas similarly expand. In South Carolina, larvae have been collected at salinities from 0-24.7 ppt (McGovern and Wenner 1990). Recently settled individuals (< 50 cm TL) in the Charleston Harbor estuary occur at both very low and very high salinities from February to March (Figure 31). However by May, individuals 20-100 mm TL are found at higher salinities of > 10 ppt. This suggests that as the flounder disperse in this estuary, they may move up into nearly fresh water, but as they grow they concentrate in the higher salinities of the lower estuary (Wenner *et al*. 1990a; Hoffman 1991; Able and Kaiser 1994).

In an estuarine complex in Georgia, Dahlberg (1972) noted that adult and juvenile summer flounder were most abundant in the higher salinity zones.

Malloy and Targett (1991) found that salinities of 10-30 ppt had no significant effect on feeding, growth, or survival of juvenile summer flounder (41-80 mm TL) in Delaware. However, there was a slight interaction of temperature and salinity on growth rate, suggesting that fish have higher growth rates at high salinities and at high temperatures. This agrees with other laboratory studies which show that larval and juvenile growth rate and growth efficiency are greatest at salinities > 10 ppt (Deubler and White 1962; Peters and Angelovic 1971; Watanabe *et al*. 1998, 1999), although Malloy and Targett (1991) suggest that there appears to be no significant physiological advantage or greater capacity for growth in waters of higher salinities, except at high temperatures. In other laboratory experiments, however, summer flounder grew best at higher salinities and more moderate temperatures, typical of habitats close to the mouths of estuaries (Peters 1971). This could explain why Powell and Schwartz (1977) captured juveniles in the central portions and around inlets of North Carolina estuaries at intermediate to high salinities of 12-35 ppt. Burke (1991) and Burke *et al*. (1991) also found newly settled summer flounder concentrated on tidal flats in the middle reaches of a North Carolina estuary. In the spring, older juveniles moved to high salinity salt marsh habitats. Young-of-the-year in spring were also significantly correlated with salinity (around 22-23 ppt) in eelgrass (*Zostera marina*) beds in the shallow water (1.2 m), high salinity area near Hog Island in Pamlico Sound (Ross and Epperly 1985; it is unclear if this applies to the larger juveniles and adults caught in the study with sizes up to 320 mm). Walsh *et al*. (1999), sampling in the Newport River and Back Sound estuaries adjacent to Beaufort Inlet from April-October 1994, also found that during the spring, larger juveniles (e.g.; 57, 60, 78 mm mean SL) occurred in the high salinities of the lower estuary on sand flats and in channels and along marsh edges.

But Burke (1991) and Burke *et al*. (1991) make it clear that the summer flounder's distribution is due to substrate preference and is not affected by salinity. Malloy and Targett (1991) also suggest that reported distributions of juvenile summer flounder at salinities > 12 ppt are probably the result of substrate and prey availability. In addition, the data of Walsh *et al*. (1999) from the Newport River and Back Sound estuaries suggest that temperature, salinity, turbidity, and substrate type are related to juvenile summer flounder distribution and area of settlement, though they were unable to separate the independent effect of these variables.

Dissolved Oxygen

Klein-MacPhee (1979) measured oxygen consumption rhythms in juvenile summer flounder over a 24 hour period in a flow-through metabolic chamber. The flounder showed a standard metabolic rate cycle, as manifested by oxygen consumption, with maximum consumption occurring between the hours of 2300 and 0100, and a minimum between 1130 and 1300. Oxygen consumption varied inversely with the size of the fish. Mean oxygen consumption was 33.5 mg/kg body weight per hour for 120 g fish; 31.1 mg/kg body weight per hour for 165 g fish; and 22.9 mg/kg per hour for 250 g fish. Comparisons of metabolic rate cycles with activity cycles showed that the pattern was the same (high activity, high oxygen consumption in the dark) but the peaks of the two cycles did not always coincide, and there was less day to day variation in the oxygen consumption cycle.

As reported previously under the temperature section, tracking studies by Szedlmayer and Able (1993) in Schooner Creek, near Great Bay and Little Egg Inlet, New Jersey suggest that tidal movements of juveniles (210-254 mm TL) may be in response to a preferred range of environmental parameters. They were found within a narrow range of water temperature and dissolved oxygen (mean 6.4 ppm), and small changes in these parameters may force the fish to move.

Postlarvae of the closely related southern flounder (*Paralichthys lethostigma*) responded negatively to water with dissolved oxygen concentrations < 3.7 ml/l (or 5.3 mg/l) (Deubler and Posner 1963). The southern flounders also showed no difference in sensitivity to oxygen depletion when subjected to temperatures of 6.1, 14.4 and 25.3^{o}C. Growth rates of young-of-the-year winter flounder (*Pseudopleuronectes americanus*) were significantly reduced for fish exposed to low (2.3 ppm) and diurnally fluctuating (2.5-6.5 ppm; avg. 5.1 ppm) levels of dissolved oxygen (Bejda *et al*. 1992).

Light

As stated previously, Watanabe *et al.* (1998) studied the effects of light intensity and salinity on yolk-sac larvae hatched from captive summer flounder broodstock in the laboratory. Significant effects of both salinity and light intensity on larval size were evident at hatching: larvae hatched under 500 lx and salinities of approximately 35 ppt showed maximum values, a trend observed at the first

feeding stage. Shorter notochord lengths of larvae grown under a light intensity of 2,000 lx compared with 0-1,000 lx is presumably related to higher light-induced activity and energy metabolism. 500 lx appears to be the optimal intensity for culture of eggs and yolk-sac larvae.

Hettler *et al*. (1997) found that larvae inside Beaufort Inlet, North Carolina were more abundant in catches made later in the night, suggesting that they disperse into the water column from the edges and bottom. Night-time sampling by Rountree and Able (1997) at the mouths of marsh creeks in Little Egg Harbor estuary, New Jersey, suggests that young-of-the-year (range 138-390 mm SL) summer flounder make extensive use of these shallow habitats during night-time hours.

White and Stickney (1973) found that late larval and early postlarval summer flounder reared in the laboratory feed well with a surface light intensity of 300-500 foot candles (1 foot candle = 10.76 meter candles). Other laboratory studies by Keefe and Able (1994) in New Jersey suggest that metamorphic flounder exhibit a diel pattern in burying behavior with a higher incidence of burying occurring during the day, with swimming in the water column at night. Klein-MacPhee (1979) showed that, under 12 h light/12 h dark photoperiods, maximum activity by juveniles occurred in the dark and had a bimodal distribution. Peaks occurred at 1900 and 0400 h. Under constant dark regimes, peak activity occurred at 2000 and 0100 with a minor peak at 1200. The free running period was 26 hours. In natural light, major activity occurred at 0300 with minor peaks at 1200 and 1800 h. In constant light, activity was reduced and found to be acyclic. Activity patterns of laboratory juveniles were different from wild adults, the latter being light active. Laboratory studies by Lascara (1981) on juveniles and adults from lower Chesapeake Bay showed that peak feeding activity (search-pursuits/unit time) generally occurred during daylight hours between 0800 and 1200.

Grover (1998) studied the incidence of feeding of oceanic larval summer flounder collected north and east of Hudson Canyon. The incidence of feeding was defined as the percentage of frequency of larvae with prey in their guts, in relation to the total number of specimens examined in a time block. Pelagic larvae began feeding near sunrise; the presence of prey in the guts reached its lowest point at 0400-0599, then dramatically increased at 0600-0759. At 0800-0959, the incidence of feeding was 100%, and throughout daylight remained high until 2000. Full guts were not observed until 1200-1359. Maximum gut fullness was at 1200-1559 and 2000-2159. The only time block in which all larvae contained prey in their guts was at 0800-0959. These observations confirm the visual nature of oceanic larval feeding. The incidence of feeding in estuarine larvae was significantly lower than oceanic larvae at 1800-1959 and 2000-2159.

Surveys in the lower Chesapeake Bay, Virginia (Orth and Heck 1980; see also Lascara 1981) and near Beaufort Inlet, North Carolina (Adams 1976a) show that during daylight hours, juveniles tend to occupy areas in the estuaries that have submerged aquatic vegetation.

Water Currents

Smith (1973) found that larvae did not drift far from spawning areas, and were taken near the eggs. Williams and Deubler (1968a) stated that larvae shorter than 7 mm SL depend on currents for dispersal; however, there are no data that describe relationships between recruitment to nursery areas and wind-driven (Ekman) transport or prevailing directions of water flow. Greater densities of young fish were found in or near inlets, and greater numbers were captured during periods of the full moon (Williams and Deubler 1968a). Young-of-the-year summer flounder have been found in high concentrations around the mouths of tidal creeks (Szedlmayer *et al*. 1992; Szedlmayer and Able 1993; Rountree and Able 1997). This could serve to maximize energy efficiency, as the creek mouths are often areas of reduced current speed.

Laboratory experiments by Keefe and Able (1994) in New Jersey indicated an increase in burying behavior by early metamorphic summer flounder on a flood tide. Although this may represent a mechanism that allows the flounder to remain in favorable habitats, field studies by Burke *et al*. (1998) showed that during flood tides in Beaufort Inlet, North Carolina, the highest densities of transforming larvae occurred at mid-depths within the water column, while during ebb tide, the highest densities were at the bottom. Their position in the water column was dependent on tidal stage, and there was a shift in their distribution and abundance which was associated with the shift in tidal stage. However, the increase in the numbers of flounders in the water column occurred around slack tide, and preceded the rise in salinity which followed the onset of flood tide (Burke *et al*. 1998).

Dispersal in areas having strong tidal currents may be accomplished by diel vertical migrations that result in tidal transport (Weinstein *et al*. 1980a; Burke 1991; Burke *et al*. 1991; Burke *et al*. 1998). The shift in vertical distribution with tidal stage observed by Burke *et al*. (1998) in Beaufort Inlet indicates that flounders in Onslow Bay enter the estuary by tidal stream transport. In the laboratory, Burke *et al*. (1998) discovered that wild-caught G-H stage larvae had a regular pattern of activity correlated with the tidal cycle, and peak activity was associated with the time of ebb tide. Interestingly, laboratory-reared flounder had no clear pattern of activity. The observed tidal rhythm of activity of the wild-caught flounder, coupled with field observations that they appear to make the vertical shift into the water column during slack tide (see previous paragraph) when current velocities are low, suggests that there is a behavioral component to their tidal stream transport (Burke *et al*. 1998). The high activity during ebb tide seen in the laboratory suggests that the most active behavioral component of tidal stream transport involves avoidance of

advection by the ebbing tide rather than movement into the water column and transport by the flood tide (Burke *et al*. 1998). Burke *et al*. (1998) also hypothesize that a change in behavior necessary for development of a tidal rhythm occurs during the eye migration phase of metamorphosis. The lack of a tidal activity pattern seen in laboratory-reared flounder suggests that development of a tidal rhythm is dependent on exposure to physical variables that are correlated with the tide.

Tidal transport of young-of-year summer flounder has also been shown to occur in a New Jersey marsh creek (Szedlmayer and Able 1993). Fish moved up the creek on flood tides and down the creek with ebb tides. Rountree and Able (1992b) and Szedlmayer and Able (1993) hypothesize that tidal movements of summer flounder in marsh creeks are the result of both foraging behavior and behavioral homeostasis (e.g., behavioral thermoregulation). Stomach fullness of fish captured leaving the creeks on ebb tides was significantly greater than that of fish captured entering the creeks on flood tides, suggesting that summer flounder undergo tidal movements to take advantage of high concentrations of prey available in the creeks. Although the flounder were found in a wide range of temperatures, salinities and dissolved oxygen concentrations, they generally stayed within narrow limits of these parameters. Thus, movements may be related to the avoidance of environmental extremes.

Substrate/Shelter

Powell and Schwartz (1977) state that benthic substrate appears to influence juvenile summer flounder and southern flounder distributions in Pamlico Sound and adjacent estuaries, North Carolina. Summer flounder were dominant in sandy substrates or where there was a transition from fine sand to silt and clay, while southern flounder were dominant in muddy substrates. Turner and Johnson (1973) also note juvenile summer flounder occur more frequently over sandy substrates than mud or silt bottoms in Pamlico Sound. Burke (1991) and Burke *et al*. (1991) demonstrated in their North Carolina study that it is salinity which affects the distribution of southern flounder while the most important factor affecting the distribution of summer flounder is substrate type. Their data indicated that the highest probability of encountering juvenile summer flounder occurred on mixed to sandy substrates.

Walsh *et al*. (1999), who collected juveniles only during the spring and summer in estuaries adjacent to Beaufort Inlet from April-October 1994, also noted the same species-specific preferences in the type of marsh edge habitat occupied. Juvenile southern flounder were more abundant in the low salinity upper estuary on muddier substrates, while summer flounder juveniles were more abundant at higher salinities and on sandier substrates. However, regarding juvenile summer flounder abundances alone, they found no significant differences across the various habitat types within the estuaries. Indeed, during both seasons, but particularly in the spring, higher abundances of recently recruited juveniles were found along marsh edges in mud substrate. Lower numbers were found on sand flats and channels in the lower estuary. There was, however, evidence of size-specific habitat segregation during the spring, with the larger juveniles (e.g.; 57, 60, 78 mm mean SL) occurring in those sand flats and channels in the lower estuary. As stated above, although the data of Walsh *et al*. (1999) suggest substrate type, along with temperature, salinity, and turbidity are related to juvenile distribution and area of settlement, they were unable to separate the independent effect of these variables.

Juveniles make extensive use of marsh creeks (Wyanski 1990; Burke *et al.* 1991; Malloy and Targett 1991; Rountree and Able 1992b, 1997; Szedlmayer *et al*. 1992; Szedlmayer and Able 1993) as well as other estuarine habitats. For example, as stated previously, surveys by Hoffman (1991) in marsh creeks in Charleston Harbor, South Carolina also showed that recently settled summer flounder were abundant over a wide variety of substrates including mud, sand, shell hash, and oyster bars. In Virginia, Wyanski (1990) and Norcross and Wyanski (1988) found newly recruited juvenile summer flounder in shallow, mud bottomed marsh creek habitat until they were 60-80 mm TL in late spring, at which time they were on shallow sand substrates (including seagrass beds), deep sand substrate, and deep fine-sand substrates. Although Keefe and Able (1994) found that metamorphic and juvenile summer flounder collected from Great Bay-Little Egg Harbor estuary in southern New Jersey showed a preference for sandy substrates in the laboratory, studies by Szedlmayer *et al*. (1992) and Rountree and Able (1992a, 1997) show that in southern New Jersey they also occur abundantly in marsh creeks with soft mud bottoms and shell hash.

Substrate preferences of metamorphic and juvenile summer flounder, as well as burying behavior, may be correlated to the presence and types of predators and prey (Keefe and Able 1994). For example, in North Carolina estuaries, Burke (1991) suggests the preferred habitat of summer flounder appears to be in the mid-estuary, which also appears to correspond to high densities of their principal prey. This in spite of the fact that Burke (1991) also demonstrated that metamorphosing larvae raised in the lab exhibit substrate preferences that correspond to the habitat of older flounders in the wild, preferring sand whether benthic prey species were present or excluded from test substrates. Timmons (1995) also reported a preference for sand by juvenile (7.6-24.9 cm TL) summer flounder from the south shores of Rehobeth and Indian River Bays, Delaware, but in addition the flounder were captured near large aggregations of the macroalgae *Agardhiella tenera* only when large numbers of their principal prey, the grass shrimp *Palaemonetes vulgaris*, were present. Timmons (1995) suggests that the summer flounder are attracted to the algae because of the presence of the shrimp, but remain near the sand to avoid predation ("edge effect"). Indeed, in her

laboratory experiments, the juvenile summer flounder did not show a preference for the macroalgae, and in caging experiments, blue crabs were least able to prey on the flounder in cages with sand bottoms only, but had an advantage in capturing the flounder in cages containing macroalgae. Similar results have been reported in laboratory experiments by Lascara (1981) on larger juveniles and adults from lower Chesapeake Bay. Flounder appeared to utilize submerged aquatic vegetation (eelgrass) as a "blind", they lie-in-wait along the vegetative perimeter, effectively capturing prey (in this case, juvenile spot, *Leiostomus xanthurus*) which moved from within the grass. In the absence of the eelgrass, the spot visually detected and avoided the flounder; the flounder therefore consumed fewer spot on average in the non-vegetated treatment than in the vegetated treatments. Therefore, Lascara (1981) concludes that the ambush tactics of summer flounder are especially effective when the flounder are in patchy habitats where they remain in the bare substrate (sand) between eelgrass patches. Lascara (1981) also noted that if flounder remained within densely vegetated areas, they would probably be conspicuous to prey. As the flounder moved through the vegetation in his laboratory experiments, the grass blades were matted down and essentially "traced out" their body shape. The flounder might also be conspicuous to potential predators as well, again suggesting the "edge effect" hypothesis of Timmons (1995). Thus, flounder remain near the sand to both avoid predation and conceal themselves from prey.

Other studies have shown that summer flounder use vegetated habitats. Adams (1976a) reported the occurrence of juvenile summer flounder in eelgrass meadows near Beaufort, North Carolina during the summer; YOY juveniles in spring also appeared to favor the eelgrass beds in the shallow water (1.2 m), high salinity (means 22-28 ppt) area near Hog Island in Pamlico Sound (Ross and Epperly 1985). *Paralichthys* spp. in the eelgrass communities near Beaufort, North Carolina collectively accounted for about 1% of the annual production and respiration of the fish assemblage (Thayer and Adams 1975; Adams 1976b). Hettler (1989) also reported juveniles in North Carolina salt marsh cordgrass habitat during flood tides. Orth and Heck (1980) and Heck and Thoman (1984) indicated that summer flounder used similar shallow vegetated areas during daylight in Chesapeake Bay; Lascara (1981) reports that juvenile and adult flounder entered and fed in these same areas. In a Virginia tidal marsh creek prior to late summer, juveniles were randomly distributed, but in late summer and early fall, they were more abundant in the adjacent seagrass beds (Weinstein and Brooks 1983). These data indicate that grass bed habitats are important to summer flounder, and any loss of these areas along the Atlantic seaboard may affect flounder stocks (Rogers and Van Den Avyle 1983). In the inland bays of Delaware, Timmons (1995) suggests that macroalgal systems appear to act as ecological surrogates to seagrass beds and seagrass/macroalgal systems as described by various authors. As with seagrass systems that attract juveniles when the submerged aquatic vegetation (SAV) increases from June to September, so does the macroalgae attract summer flounder, because, as stated previously, the macroalgae attracts their prey. This may also be true for Great Bay and Little Egg Harbor in southern New Jersey. Szedlmayer and Able (1996) report that juvenile and adult summer flounder (140-416 mm SL) were associated with the station considered to be a sea lettuce (*Ulva lactuca*) macroalgae habitat.

Conversely, also in Great Bay-Little Egg Harbor, Keefe and Able (1992) determined habitat quality as measured by relative growth of juvenile summer flounder (17-41 mm SL). Growth did not appear to be related to the habitats tested, including eelgrass and adjacent unvegetated substrate, macroalgae (*Ulva*) and adjacent unvegetated substrate, and marsh creek. The fastest growth occurred in shallow bays and marsh creeks. However, Malloy and Targett (1994b) suggest that juvenile growth is related to substrate or habitat in the Newport River estuary, North Carolina because of the presence of specific prey items. The growth limitation of juveniles (18-80 mm TL) in one sandy-marsh habitat could be explained by the low abundance of mysids from May into summer, while the increasing abundance of other prey (polychaetes and amphipods) during that same month at a muddier site may account for favorable growth seen there. Other diet studies in this estuary (Burke 1991, 1995; Burke *et al*. 1991) suggest that polychaetes are actually the preferred prey for juveniles of this size (see the Food Habits section below).

Food Habits

The timing of peak spawning in October/November coincides with the breakdown of thermal stratification on the continental shelf and the maximum production of autumn plankton which is characteristic of temperate ocean waters of the northern hemisphere, thus assuring a high probability of adequate larval food supply (Morse 1981).

Initiation of feeding is a function of the rate and efficiency at which yolk-sac material is consumed, which in turn is dependent on incubation temperature. As reported previously by Johns and Howell (1980) and Johns *et al*. (1981), total yolk-absorption was complete in 67 h and 105 h at 21°C and 16°C, respectively. Within those 3 to 4 days from hatching, summer flounder larvae complete the morphological differentiation of the digestive tract, jaw suspension, and accessory organs necessary for independent exogeneous feeding (Bisbal and Bengtson 1995b).

To repeat the results of the Bisbal and Bengtson (1995c) study: they show the interdependence of temperature and food availability (i.e., delay of initial feeding) and their effects on survival and growth of summer flounder larvae hatched from Narragansett Bay and Long Island Sound broodstock. Their laboratory observations occurred from the time of hatching throughout the period of feeding on rotifers. The larvae withstood starvation for

longer times at lower temperatures. They possessed sufficient reserves to survive starvation for 11 to 12 days when temperatures were maintained close to the experimentally determined lower tolerance limit (12.5°C; Johns *et al*. 1981). At temperatures close to the highest thermal limit reported to occur in their environment (21°C; Smith 1973), larvae only survived for 6 to 7 days. At either temperature, best survival occurred when the larvae began to feed at the time of mouth opening, thus survival is also significantly affected by the time at which they first have access to exogenous food. At 12.5°C, every treatment group was represented by a low number of survivors which did not grow significantly from the initial figures at mouth opening. Growth of the larvae at 21°C was inversely proportional to the duration of early starvation; the size distribution of the survivors of the 21°C experiment showed an increase in mean size and weight when the initial feeding delay was shorter.

Bisbal and Bengtson (1995a) also determined the nutritional status of lab raised larvae and juveniles from the same areas. Mortality due to starvation occurs later in the older ontogenetic states; i.e., 60 h in 6 day old larvae, 72 h in 16 day old larvae, 8 d in 33 day old larvae, and 10 d in 60 day old juveniles at a temperature of around 19°C.

In the laboratory, Peters and Angelovic (1971) reared postlarvae on a diet of zooplankton (mostly copepods) and *Artemia* nauplii; Buckley and Dillmann (1982) also used *Artemia* for their larval feeding experiments. The larvae exhibited an exponential increase in daily ration with age and a linear increase with weight (Buckley and Dillmann 1982). Other investigators have raised larvae on rotifers (e.g., Bisbal and Bengtson 1995c).

Previous studies have inferred that larval and postlarval summer flounder initially feed on zooplankton and small crustaceans (Peters and Angelovic 1971; Powell 1974; Morse 1981; Timmons 1995). Grover (1998) studied the food habits of oceanic larval flounder collected north and east of Hudson Canyon. The diets of all stages of larvae were dominated by immature copepodites. The size of other prey was directly related to larval size. Preflexion larvae (1.9-6.9 mm SL) fed on, in order of importance: immature copepodites, copepod nauplii, and tintinnids, as well as bivalve larvae and copepod eggs. Flexion larvae (3.7-7.2 mm SL) fed on immature copepodites (mostly calanoids) and adult calanoid copepods. Premetamorphic (4.8-7.6 mm SL) and metamorphic (5.8-9.0 mm SL) larvae also fed on immature copepodites, but adult calanoid copepods (mostly *Centropages typicus*) and appendicularians were also prey items.

Studies on the food habits of late larval and juvenile estuarine summer flounder reveal that while they are opportunistic feeders and differences in diet are often related to the availability of prey, there also appears to be ontogenetic changes in diet. Smaller flounder (usually < 100 mm) seem to focus on crustaceans and polychaetes while fish become a little more important in the diets of the larger juveniles. In Great Bay-Little Egg Harbor estuary, New Jersey, Grover (1998) found that the primary prey of metamorphic (8.1-14.6 mm SL) summer flounder was the calanoid copepod *Temora longicornis*, indicating pelagic feeding. Evidence of benthic feeding was observed only in late-stage metamorphic flounder (H+ and I), where the prey included polychaete tentacles, harpacticoid copepods, and a mysid. Incidence of feeding, defined as the percentage of frequency of larvae with prey in their guts, in relation to the total number of specimens examined in a time block, declined as metamorphosis progressed, from 19.1% at stage G to 2.9% at stage I. Rountree and Able (1992b) also discovered that young-of-year summer flounder in Great Bay-Little Egg Harbor marsh creeks preyed on creek fauna in order of abundance (Rountree and Able 1992a): Atlantic silversides (*Menidia menidia*), mummichogs (*Fundulus heteroclitus*), grass shrimp (*Palaemonetes vulgaris*), and sand shrimp (*Crangon septemspinosa*) contributed most importantly to their diets. Seasonal shifts in diet reflected seasonal changes in creek faunal composition, and Rountree and Able (1992a) note that the maximum abundance of young-of-year summer flounder in August coincided with the peak in Atlantic silverside abundances. In Little Egg Harbor estuary, New Jersey, Festa (1979) reported that fish, including anchovies, sticklebacks and Atlantic silversides, comprised 32.6% of the diet volume of 6-24 cm summer flounder. The fish component was supplemented by mysid and caridean shrimp, of which the sand shrimp *Crangon septemspinosa* was of somewhat more importance.

Timmons (1995) reported that juvenile (7.6-24.9 cm TL) summer flounder from Rehobeth Bay, Delaware, fed mostly on the shrimp *Palaemonetes vulgaris* as well as porturid and blue crabs. Flounder from Indian River Bay fed mostly on mysids.

Postlarvae (10.5-14.2 mm SL) in Chesapeake Bay have been found with guts full of the mysid *Neomysis americana* (Olney 1983). In Magothy Bay, Virginia, small summer flounder (4.2-19.8 cm) also fed mainly on *Neomysis americana*, but in addition, consumed larger proportions of amphipods, small fishes, small gastropod mollusks, and plant material than the larger fish (Kimmel 1973). Wyanski (1990) found that mysids were also the dominant prey of 100-200 mm TL summer flounder in the lower Chesapeake Bay and Eastern Shore of Virginia. Lascara (1981) reported that larger juveniles and adults (avg. length 27.4 cm SL) from lower Chesapeake Bay fed on juvenile spot (*Leiostomus xanthurus*), pipefish (*Syngnathus fuscus*), the mysid *Neomysis americana*, and shrimps (*P. vulgaris*, *C. septemspinosa*).

Burke (1991, 1995) in his North Carolina field surveys in the Newport and North Rivers discovered that late larval and early juvenile summer flounder are active infaunal predators. Prey of summer flounder during the immigration period (11-22 mm SL) consisted of common estuarine crustaceans including harpactacoid copepods, polychaetes, and parts of infaunal animals such as polychaete tentacles (primarily from the dominant spionid *Streblospio benedicti*) gills and clam siphons (Figure 32). The appendages of

benthic animals appear to be the most important prey item for postlarval flounders. The increasing importance of polychaetes and clam siphons was suggested with development, while feeding on harpactacoid copepods and amphipods was independent of stage. For juveniles 20-60 mm SL, polychaetes, primarily spionids (*S. benedicti*), were the most important part of the diet (Figure 32). Burke (1991, 1995) suggests that the distribution of these dominant polychaetes may influence the distribution of summer flounder in this estuary and could explain the movement of juvenile summer flounder into marsh habitat [Burke *et al*. 1991; note the Malloy and Targett (1994b) study mentioned in the Substrate section, above]. Other prey items for this size class of summer flounder included invertebrate parts, primarily clam siphons; shrimp, consisting of the mysids *Neomysis americana* and palmonid shrimp; calanoid copepods, primarily *Paracalanus*; amphipods of the genus *Gammarus*; crabs, primarily *Callinectes sapidus*; and fish. Powell and Schwartz (1979) reported that larger juvenile (100-200 mm TL) summer flounder feed mainly on mysids (mostly *Neomysis americana*) and fishes throughout the year in Pamlico Sound, North Carolina (Figure 33). Mysids were found in relatively greater quantities in the smaller flounder, but as their size increased, the diet consisted of shrimps and fishes in similar quantities.

In South Carolina, Wenner *et al*. (1990a) reported that juveniles between 50-125 mm TL consumed only mysids and caridean shrimps (*Palaemonetes* sp., *P. pugio*, *P. vulgaris*). The importance of fish (mostly bay anchovy, *Anchoa mitchilli*, and mummichogs) in the diet increased as summer flounder size increased.

In Georgia, Reichert and van der Veer (1991) found that juveniles from the Duplin River of around < 40 mm SL fed principally on harpacticoid copepods; they also report that *Paralichthys* species > 25 mm fed on increasing numbers of other crustaceans including mysids, crabs, *Palaemonetes*, as well as polychaetes. Summer flounder > 100 mm also fed on fish.

Co-occurring Species and Predation

In Great Bay-Little Egg Harbor estuary in southern New Jersey, a survey by Witting *et al*. (1999) from 1989-1994 showed that the fall larval fish assemblage was more diverse than any of the other seasonal assemblages, with strong representation by summer flounder, Atlantic menhaden (*Brevoortia tyrannus*), Atlantic croaker (*Micropogonias undulatus*), bay anchovy, and a few other species.

Larval and juvenile summer flounder undoubtedly are preyed upon until they grow large enough to fend for themselves. Results of food habit studies by NEFSC from 1969-1972 showed that Pleuronectiformes occurred in the stomachs of the following piscivores: spiny dogfish, goosefish, cod, silver hake, red hake, spotted hake, sea raven, longhorn sculpin, and fourspot flounder (Bowman *et al*. 1976). These data do not indicate the proportion of summer flounder among the flatfish prey taken, but it is likely that they are represented.

Following a thermal shock of 10°C above an acclimation temperature of 15°C, larvae were actually less susceptible to predation by striped killifish (*Fundulus majalis*) than control larvae (Deacutis 1978).

Witting and Able (1993), working in the laboratory with 11-16 mm TL transforming larvae from Great Bay-Little Egg Harbor, New Jersey, suggest that these small summer flounder are vulnerable to predation by a large size range of *Crangon septemspinosa* (around 10-50 mm TL) in New Jersey's estuaries. Laboratory experiments by Keefe and Able (1994) in New Jersey demonstrated that predation on metamorphic summer flounder influences burying behavior and perhaps substrate preference. The type and abundance of predators could determine whether a metamorphic summer flounder stays in the substrate or the water column. For example, Keefe and Able's (1994) experiments showed that buried *C. septemspinosa* may reduce burying by the flounder, while pelagic mummichogs may cause more burying by the flounder during the day.

Timmons (1995) reports a preference for sand by juvenile (7.6-24.9 cm TL) summer flounder from the south shores of Rehobeth Bay and Indian River Bay, Delaware. In her study, the flounder were captured near large aggregations of the macroalgae *Agardhiella tenera* only when large numbers of their principal prey, the shrimp *Palaemonetes vulgaris*, were present. Timmons (1995) suggests that the summer flounder are attracted to the algae because of the presence of the shrimp, but the flounder remain near the sand to avoid predation ("edge effect"). Indeed, in her laboratory experiments, the juvenile summer flounder did not show a preference for the macroalgae, and in caging experiments, blue crabs were least able to prey on the flounder in cages with sand bottoms only, but had an advantage in capturing the flounder in cages containing macroalgae. Laboratory studies by Lascara (1981) on flounder from lower Chesapeake Bay also suggest that in patchy seagrass/sand habitats, the flounder may avoid predation by staying in the sand near the seagrass beds, rather than in the grass beds themselves.

Lab studies in Georgia by Reichert and van der Veer (1991) on juveniles from the Duplin River found potential predators to be blue crabs (*Callinectes* spp.) and sea robins (*Prionotus* spp.).

ADULTS

Temperature

NEFSC groundfish data shows a seasonal shift in offshore adult summer flounder occurrence with bottom temperatures (Figure 34): most adults are caught over a range of temperatures from 9-26°C in the fall, from 4-13°C

in the winter, from 2-20°C in the spring, and from 9-27°C in the summer. Massachusetts inshore trawl survey data also shows a seasonal shift in adult occurrence with bottom temperature (Figure 30). In the spring, most adults occur at a range of temperatures from 6-17°C, while in the fall they occur at temperatures from 14-21°C. Prior to 1979, Sissenwine *et al*. (1979) reported that NEFSC trawl surveys on the continental shelf showed that the distribution of summer flounder by depth was related to their temperature distribution. During spring they were distributed widely over the continental shelf, from 0-360 m depth (compare with Figure 4), and primarily in waters between 8-16°C. During summer the flounder were primarily captured in depths of less than 100 m, and in waters between 15-28°C. The autumn distribution was also at depths of less than 100 m and temperatures between 12-28°C. During winter, they generally were found at depths greater than 70 m, and at temperatures between 5-11°C (Sissenwine *et al*. 1979).

Based on collections from the 1990-1996 Rhode Island Narragansett Bay survey, adults were distributed throughout the Bay and captured in all seasons except winter; in spring they were found in bottom temperatures above 6°C and below 15°C in autumn (Figure 35). By summer the adults occurred at nearly all temperatures and in autumn they were concentrated where temperatures exceeded 17°C.

In the Mid-Atlantic Bight north of Chesapeake Bay, spawning and the offshore limits of migration coincide with the inshore edge of the mass of cold bottom water that disappears along with the thermocline in November (Smith 1973).

A study by Stolen *et al*. (1984a) compared the effect of temperature on the humoral antibody formation in the summer and winter flounder at 8, 12 and 17°C during the same time of the year. Summer flounder showed only a delay in the appearance of circulating antibody at lower temperatures while winter flounder showed both a delay and a marked suppression at lower temperatures. Summer flounder produced a high titered antibody that persisted over a long period of time and over a wide temperature range, while in winter flounder antibody levels began decreasing after one month.

A similar study on the kinetics of the primary immune response in summer flounder was also studied by Stolen *et al*. (1984b). The flounder produced antibody over a wide range of environmental temperatures ranging from 7.5-27°C. At the lower environmental temperatures, a corresponding delay in the appearance of circulation antibody occurred, although the magnitude and duration of the response was not appreciably affected. After immunizing at 12°C, lowering the environmental temperature gradually to 8°C did not appear to inhibit an ongoing primary response. Typical secondary responses were seen in fishes kept at warmer temperatures, but when the temperature was lowered to 8°C, no anamnestic response was seen. Individual variation was most noticeable at middle temperature ranges.

Salinity

Adult summer flounder return inshore to coastal waters in April through June, and are often found in the high salinity portions of estuaries [e.g., Abbe (1967) in Delaware, Tagatz and Dudley (1961) and Powell and Schwartz (1977) in North Carolina; Dahlberg (1972) in Georgia]. However, the adult summer flounder's distribution may be due more to substrate preference than salinity preference.

Dissolved Oxygen

Effects of dissolved oxygen concentration on summer flounder adults has not been investigated (Rogers and Van Den Avyle 1983). Festa (1977) reported that the high variability in catch rates of summer flounder off of New Jersey in the summer of 1976 appeared to be directly related to the movement of an anoxic water mass present that year. Large numbers of summer flounder were forced into inlets and bays where they were more concentrated and vulnerable to the sport fishery (Freeman and Turner 1977).

Light

Laboratory studies (Olla *et al*. 1972; Lascara 1981) and field collections (Orth and Heck 1980) indicate that adult summer flounder are active primarily during daylight hours. To repeat what was stated above for juveniles: laboratory studies by Lascara (1981) on juveniles and adults from lower Chesapeake Bay showed that peak feeding activity (search-pursuits/unit time) generally occurred during daylight hours between 0800 and 1200.

Water Currents

No information is available.

Substrate/Shelter

Adults have often been reported as preferring sandy habitats (Bigelow and Schroeder 1953; Schwartz 1964; Smith 1969). For example, in Pamlico Sound, North Carolina, Powell and Schwartz (1977) found that summer flounder were most abundant at stations where quartz sand or coarse sand and shell predominated. In Barnegat Bay, New Jersey, Vouglitois (1983) suggests that both juvenile and adult summer flounder are found in greater numbers in the eastern portion of the Bay, where sandy sediments predominate. However, adults can camouflage themselves via pigment changes to reflect the substrate (Mast 1916). Thus, they can be found in a variety of habitats with both mud and sand substrates, including marsh creeks, seagrass

beds, and sand flats (Bigelow and Schroeder 1953; Dahlberg 1972; Orth and Heck 1980; Lascara 1981; Rountree and Able 1992a).

As previously explained above in the Section on juveniles, laboratory experiments by Lascara (1981) on larger juveniles and adults from lower Chesapeake Bay found that flounders appear to utilize eelgrass beds as 'blinds'; i.e., they lie-in-wait along the vegetative perimeter, effectively capturing prey which move from within the grass. Lascara (1981) concludes that the ambush tactics of summer flounder are especially effective when the flounder are in patchy habitats where they remain in the bare substrate (sand) between eelgrass patches. Lascara (1981) also noted that if flounder remained within densely vegetated areas, they would probably be conspicuous to prey because, in his laboratory experiments, as the flounder moved through the vegetation, the grass blades were matted down and essentially "traced out" their body shape. The flounder might also be conspicuous to potential predators as well, suggesting the "edge effect" hypothesis of Timmons (1995). Thus, the flounder remain near the sand to both avoid predation and conceal themselves from prey.

Food Habits

Adult summer flounder are opportunistic feeders with fish and crustaceans making up a significant portion of their diet (Figure 36). Differences in diet between habitats or locations may be due to prey availability. The flounder are most active during daylight hours and may be found well up in the water column as well as on the bottom (Olla *et al*. 1972). Included in their diet are: windowpane (Carlson 1991), winter flounder, northern pipefish, Atlantic menhaden, bay anchovy, red hake, silver hake, scup, Atlantic silverside, American sand lance, bluefish, weakfish, mummichog, rock crabs, squids, shrimps, small bivalve and gastropod mollusks, small crustaceans, marine worms and sand dollars (Hildebrand and Schroeder 1928; Ginsburg 1952; Bigelow and Schroeder 1953; Poole 1964; Smith and Daiber 1977; Allen *et al*., 1978; Langton and Bowman 1981; Curran and Able 1998).

In Little Egg Harbor estuary, New Jersey, Festa (1979) reports that at least seven species of fish occurred in the stomachs of 25-65 cm summer flounder. These included Atlantic silversides, anchovies, sticklebacks, silver perch, sea robins, winter flounder and pipefish. Fish remains comprised 74.3% of the diet volume. Brachyuran crabs, primarily *Callinectes*, were of secondary importance in the diet. In Hereford Inlet near Cape May, New Jersey, Allen *et al*. (1978) found that adult and juvenile summer flounder (200-400 mm) fed mostly on *Crangon septemspinosa*, mysids and fish.

Smith and Daiber (1977) reported that Delaware Bay adults < 45 cm TL fed on invertebrates, while those > 45 cm TL ate more fish. Food items found, in order of percent frequency of occurrence, included decapod shrimp (*Crangon septemspinosa*), weakfish (*Cynoscion regalis*), mysids (*Neomysis americana)*, anchovies (*Anchoa* sp.*)*, squids (*Loligo* sp.*)*, Atlantic silversides (*Menidia menidia*), herrings (*Alosa* sp.), hermit crabs (*Pagurus longicarpus*), and isopods (*Olencira praegustator*).

In Magothy Bay, Virginia, large summer flounder (20.1-47.6 cm) fed mainly on *Neomysis americana*, as well as large crustaceans such as *Squilla empusa*, xanthid crabs, and squids. The fish from this area are not mainly piscivorous, but the larger specimens (> 40.0 cm) did contain a higher percentage of fishes than did the smaller ones (Kimmel 1973). Lascara (1981) reports that larger juveniles and adults (avg. length 27.4 cm SL) from lower Chesapeake Bay fed on juvenile spot (*Leiostomus xanthurus*), pipefish (*Syngnathus fuscus*), the mysid *Neomysis americana*, and shrimps (*P. vulgaris*, *C. septemspinosa*).

In South Carolina, Wenner *et al*. (1990a) showed that flounder 50-313 mm TL consumed mostly decapod crustaceans, especially caridean shrimps (*Palaemonetes* sp., *P. pugio*, *P. vulgaris*). The importance of fish (mostly bay anchovy, *Anchoa mitchilli*, and mummichogs) in the diet increased as summer flounder size increased.

Co-Occurring Species and Predation

Spatial co-occurrence and dietary overlap among summer flounder, scup, and black sea bass have been previously documented (Musick and Mercer 1977; Gabriel 1989; Shepherd and Terceiro 1994). For example, the composition and distribution of fish assemblages in the Middle Atlantic Bight was described by Colvocoresses and Musick (1979) by subjecting NEFSC bottom trawl survey data to the statistical technique of cluster analyses. Summer flounder, scup, northern sea robin, and black sea bass, all warm temperate species, were regularly classified in the same group during spring and fall. In the spring this group was distributed in the warmer waters on the southern shelf and along the shelf break at depths of approximately 152 m. During the fall this group was distributed primarily on the inner shelf at depths of less than 61 m where they were often joined by smooth dogfish.

All of the natural predators of adult summer flounder are not fully documented, but larger predators such as large sharks, rays, and goosefish probably include summer flounder in their diets.

Laboratory studies by Lascara (1981) on flounder from lower Chesapeake Bay suggest that in patchy seagrass/sand habitats, the flounder may avoid predation by staying in the sand near the seagrass beds, rather than in the grass beds themselves.

INSHORE SUMMER FLOUNDER HABITAT CHARACTERISTICS

Habitat information is meaningful because habitat differences can be important in determining local abundances of summer flounder (Cadrin *et al*. 1995). Because most of the summer flounder habitat research occurs inshore, Tables 2-4 present the inshore habitat parameters or requirements for summer flounder found in nearshore New Jersey, Delaware, and North Carolina, respectively. Those States were chosen because of the amount of the high quality, habitat related research on summer flounder occurring there [by highest quality we mean Level 3 information as defined in the EFH Technical Manual (National Marine Fisheries Service, Office of Habitat Conservation 1998) and Interim Final Rule (Department of Commerce, National Oceanic and Atmospheric Administration 1997)]. Thus, we have also chosen to concentrate on studies (experimental or otherwise) which focus on the habitat parameter preferences, and are from published, peer-reviewed literature sources, rather than on information that merely attempts to correlate environmental variables with fish densities, such as that which often appears in general fisheries surveys. We heed the advice of Hettler *et al*. (1997), who suggest caution when interpreting correlations of environmental variables with fish abundances. For example, they reported an increase in summer flounder larval abundance with increasing temperatures in Beaufort Inlet, North Carolina. This could be caused by winter spawning and the larvae arriving at the inlet after a two to three month cross-shelf transport time, resulting in a higher larval abundance corresponding with rising temperatures. Their statistical analyses suggest that unknown factors are probably more important in causing peaks in the abundances of immigrating larvae (see also Hettler and Hare 1998).

Table 5 is a summation and synthesis of Tables 2-4, and should provide an overall, yet more succinct view of current habitat requirements information on inshore summer flounder. The habitat parameter headings for all the tables are based upon those used in the Habitat Characteristics section, above.

STATUS OF THE STOCKS

The following section is based on Terceiro (1995) and the Northeast Fisheries Science Center (1997). The coverage is from New England to Cape Hatteras.

The stock is at a medium level of historical (1968-1996) abundance and is over-exploited. The age structure of the spawning stock has begun to expand, with 34% of the biomass at ages 2 and older in 1996, although under equilibrium conditions about 85% of the spawning stock biomass would be expected to be ages 2 and older. The 1995 year class is about average (1982-1996), but the 1996 year class is estimated to be the smallest since the poor year class of 1988.

Commercial landings of summer flounder averaged 13,200 mt during 1980-1988, reaching a high of 17,100 mt in 1984 (Figure 37). The recreational fishery for summer flounder harvests a significant proportion of the total catch, and in some years recreational landings have exceeded the commercial landings. Recreational landings have historically constituted about 40% of the total landings. Recreational landings averaged 9,800 mt during 1980-1988, and peaked in 1983 at 12,700 mt. During the late 1980s and into 1990, landings declined dramatically, reaching 4,200 mt in the commercial fishery in 1990 and 1,400 mt in the recreational fishery in 1989 (Table 6). Reported 1996 landings in the commercial fishery used in the assessment were 5,770 mt and estimated 1996 landings in the recreational fishery were 4,704 mt (Table 6).

Spawning stock biomass declined 72% from 1983 to 1989 (18,900 mt to 5,200 mt), but has since increased with improved recruitment to 17,400 mt in 1996 (Figure 37**;** Table 6). The age structure of the stock is improving, with 34% of the spawning biomass in 1996 composed of fish of ages 2 and older, compared to only 17% in 1992.

Figure 38 shows the contrast between the distribution of summer flounder from periods of high abundances in the past (1974-1978) to recent periods of low abundances (1989-1993), for both adults and juveniles in the fall and spring.

RESEARCH NEEDS

Obviously, there are many gaps in our understanding of the autecology of summer flounder. Because it is such a highly migratory species and occurs everywhere throughout its range, knowledge of its life history and habitat requirements can vary regionally, and what affects them in one area can easily cause repercussions in the population in another area. Even though summer flounder is managed and assessed as one stock throughout the U.S. EEZ, the question of multiple stocks, particularly in the Mid-Atlantic Bight, still needs to be settled from a scientific standpoint. There is a lack of knowledge concerning the habitat requirements for all life history stages, especially the offshore eggs and larvae, but even for the adults within our own estuaries, since much of the current habitat research has focused on estuarine larvae and juveniles (note Tables 2-5). Of course, more habitat information is needed on the inshore transforming larval and early juvenile stages, especially because their health affects the future growth and survival of the population. Finally, critical habitat preferences must be defined. For example, while it is likely that temperature may drive the seasonal movements of juveniles and adults in and out of the estuaries, it may have less effect on their choice of specific habitats within those estuaries, where substrate, salinity, etc. may be the overriding factors. Once their habitat preferences are defined, their critical habitats can be more thoroughly delineated and mapped.

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Table 1. Presence of summer flounder inshore, by State, as documented by authors cited in the text and personal communications from each States' flounder experts.

Author	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Notes
	MA													
Howe personal communication	shoals s. of Cape Cod & Cape Cod Bay					**A** II				EE	EEEEEEE	EEEEEEE	EEEEEEE	
	CT													
Smith personal communication	Long Island Sound	**A**			III	II				**A: peak**				
	NY													
Poole 62	Great South Bay, Long Island									**A** EEEEEEE	EEEEEEE			mean length 38cm
	NJ													
Szedlmayer *et al*. 92	Great Bay, Little Egg Harbor	TL IIIIIIIIIII	IIIIIIIIIII	IIIIIIIIIII	IIIIIIIIIII	IIIIIIIIIII	**J**			EE		TL IIIIIIIIIII	IIIIIIIIIII	TL: 11-17mm, J: YOY, 60-326mm
Allen *et al*. 78	Hereford Inlet, near Cape May		**TL**			**J, A**								TL: 12-15mm J/ A: 200-400m
Murawski 70	Sandy Hook & Cape May				**A** IIIIIIIIIII	IIIIIIIIIII				EEEEEEE				A: 230-700mm
Festa 74	NJ estuaries; Sandy Hook to Great Bay	L/TL *IIIIIIIIIII*	IIIIIIIIIII	IIIIIIIIIII							**L/TL** *IIIIIIIIIII*	*IIIIIIIIIII*	*IIIIIIIIIII*	L/TL 5-21mm; enter est. early Oct-late Jan most yrs, as late as March
Keefe and Able 93	NJ estuaries	**TL** IIIIIIIIIII	IIIIIIIIIII	IIIIIIIIIII	IIIIIIIIIII						**TL** *IIIIIIIIIII*	*IIIIIIIIIII*	*IIIIIIIIIII*	TL: 10-15mm, most abundant Oct-Dec
Able *et al*. 90	NJ estuaries							**J: peak**	EEEEEEE	EEEEEEE	EEEEEEE	EEEEEEE	EEEEEEE	J: YOY, 160-320mm TL

———	presence	**L**	larvae
═══	peak abundance	**TL**	transforming larvae
- - -	limited numbers	**J**	juveniles
IIIIIIIIIII	peak ingress	**A**	adults
IIIIIIIIIII	ingress		
EEEEEE	egress		

Table 1. cont'd.

Author	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Notes
	DE													
Smith personal communication	Delaware Bay	**A**			**A: peak**									some adults present all year
Smith and Daiber 77	Delaware Bay					**J/A: peak**								some juveniles present in deep parts of bay every winter month
	VA													
Musick personal communication	Eastern Shore & lower Chesapeake Bay	**J**		IIIIIIIIIIII	IIIIIIIIIIII						EEEEEEE	EEEEEEE		In milder winters some age 1+ fish remain in bay
	Eastern Shore, seaside inlets/lagoons				**A** IIIIIIIIIIII				EEEEEEE					
	lower Chesapeake Bay				**A** IIIIIII					EEE	EEE			
Wyanski 90	both sides of Eastern Shore	**J** IIIIIIIIIIII	IIIIIIIIIIII	IIIIIIIIIIII	IIIIIIIIIIII							*IIIIIIIIIII*	*IIIIIIIIIII*	peak recruitment Nov-Dec
	western Chesapeake Bay		**J** IIIIIIIIIIII	*IIIIIIIIIII*	*IIIIIIIIIII*									peak recruitment March-April

———	presence	**L**	larvae
═══	peak abundance	**TL**	transforming larvae
- - -	limited numbers	**J**	juveniles
IIIIIIIIII	peak ingress	**A**	adults
IIIIIIIIIII	ingress		
EEEEEE	egress		

Table 1. cont'd.

Author	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Notes
	NC													
Hettler and Barker 93	Oregon Inlet, Ocracoke Inlet		TL IIIIIIIIIIII		IIIIIIIIIIII TL									TL: peak ingress
Powell and Schwartz 77	Pamlico sound	J II IIIIIIII							*E					J=YOY, present ~18-20 mos. from mid winter recruitment to ~Aug of 2nd yr. *
Burke *et al.* 91	Newport River, North River estuaries	TL IIIIIIIIIIII	IIIIIIIIIIII	IIIIIIIIIIII	IIIIIIIIIIII									TL = 11-17mm SL
Monaghan personal communication	Beaufort Inlet		TL III	IIIIIIIIIIII										TL: peak ingress
Tagatz and Dudley 61	Beaufort Inlet			TL/J										TL/J = 11-180mm
Weinstein 79	Cape Fear River			TL IIIIIIIIIIII	IIIIIIIIIIII									TL = 9-16mm SL
	SC													
Wenner *et al.* 90a	Charleston Harbor & vicinity	TL/J IIIIIIIIIIII	IIIIIIIIIIII	IIIIIIIIIIII	IIIIIIIIIIII									TL/J = 10-20mm TL

———	presence	L	larvae
═══	peak abundance	TL	transforming larvae
- - - -	limited numbers	J	juveniles
IIIIIIIIII	peak ingress	A	adults
IIIIIIIIII	ingress		
EEEEEE	egress		

Table 2. Habitat parameters for summer flounder, *Paralichthys dentatus*: inshore New Jersey.

Life Stage	Authors	Size Range	Geographic Location	Time Period	Habitat	Substrate	Temperature
TRANSFORMING LARVAE	Grover 1998	8.1-14.6 mm SL (metamorphic)	Great Bay, Little Egg Harbor	Fall, winter, spring 89-95	Little Sheepshead Creek		
	Keefe and Able 1993, 1994	10-15.6 mm SL, mean 12.8 (metamorphic)	Great Bay, Little Egg Harbor	Nov 90-Nov 91 Nov 90-Mar 91	Little Sheepshead Creek	Sand preference by both metamorphs and juveniles. [1]	Increased temps. = shorter metamorphic period. Greater mortality at 4°C. No effect of starvation on mortality or time to completion of metamorphosis at temps. < 10°C. [1]
	Szedlmayer *et al*. 1992	11-17 mm TL (metamorphic)	Great Bay, Little Egg Harbor	Nov 88-Apr 89			0-13°C, mortality < 2°C [1]
	Witting and Able 1993	11-16 mm TL (metamorphic)	Great Bay, Little Egg Harbor	Jan-Feb 90			9-12°C [1]
JUVENILES	Rountree and Able 1992a	mean 132 mm SL (YOY), range ca. 16-245 mm	Great Bay, Little Egg Harbor	Apr-Nov 88 Apr-Oct 89	Schooner, New, Foxboro creeks	mud	mean 19°C
	Rountree and Able 1992b	mean 238 mm TL (YOY), range 156-312 mm	Great Bay, Little Egg Harbor	1987-1990	Schooner, New, Foxboro, Stoney creeks	mud	mean 22°C, range 15-27°C
	Rountree and Able 1997	mean 192 mm SL, range 138-390 mm, mostly YOY	Little Egg Harbor	May/July-Nov 90	Foxboro, Stonely Island creeks. Marsh creeks and deeper (4-9 m) bay shoals.	mud	
	Szedlmayer *et al*. 1992	60-326 mm TL (YOY)	Great Bay, Little Egg Harbor	June-Sept 89	**June**: mesohaline subtidal creeks **July**: shallow mudflats/dredged channels **Aug-Sep**t: marsh creeks	subtidal creeks 90-98% mud	
	Szedlmayer and Able 1993	210-254 mm TL (age 0)	Great Bay, Little Egg Harbor	Aug-Sept 90	Schooner Creek		mean 23.5°C (optimum?)

[1] Laboratory study
Adults: no pertinent information

Table 2. cont'd.

Life Stage	Authors	Salinity	Dissolved Oxygen	Light	Currents	Prey	Predators	Notes
TRANSFORMING LARVAE	Grover 1998					Primary prey: calanoid copepod *Temora longicornis*, indicating pelagic feeding. Evidence of benthic feeding observed only in late-stage metamorphs (stage H+ and I), where prey included polychaete tentacles, harpacticoid copepods.		
	Keefe and Able 1993, 1994			Prefer burying during daylight. [1]	Increased burial at flood tide. [1]		Less burying in presence of decapod shrimp *Crangon*, increased burying in presence of mummichog *Fundulus*. [1]	Time to completion of metamorphosis temperature dependent.
	Szedlmayer *et al*. 1992							
	Witting and Able 1993						11-16 mm TL transforming larvae are vulnerable to predation by a large size range of shrimp (*Crangon septemspinosa*, ~ 10-50 mm TL) in NJ estuaries. [1]	
JUVENILES	Rountree and Able 1992a	mean 29 ppt						Found mostly during summer. Abundance varied significantly between years. Maximum abundance of fluke during peak in *Menidia menidia* abundances.
	Rountree and 1992b	mean 27ppt, range 23.5-30 ppt			Moving with the tides. Tidal movements associated with foraging - stomachs fuller on ebb tide.	In order of abundance: Atlantic silversides *Menidia menidia*, mummichogs *Fundulus heteroclitus*, shrimps *Palaemonetes vulgaris* and *Crangon septemspinosa*.		Creeks are foraging habitat. Prey composition exhibits a seasonal influence. Frequency of *Menidia* declines during Aug, Sept, Oct while *Crangon* rises.
	Rountree and Able 1997	range 22-33 ppt		Nocturnal sampling: extensive use of shallow habitats during night-time.	Mostly caught on ebb tides (sampling during night hours).			Preference for creek mouths and tidal creeks rather than bay shoals. Peak catch in late July/Oct.
	Szedlmayer *et al*. 1992	subtidal creeks avg. 20 ppt						High use of creek mouths.
	Szedlmayer and Able 1993	mean 29 ppt (optimum?)	mean 6.4 ppm (optimum?)		selective tidal stream transport			Selective tidal transport, feeding, optimal environmental conditions cause movement. High use of creek mouths.

[1] Laboratory study
Adults: no pertinent information

Table 3. Habitat parameters for summer flounder, *Paralichthys dentatus*: inshore Delaware.

Life Stage	Authors	Size Range	Geographic Location	Time Period	Habitat	Substrate
JUVENILES	Malloy and Targett 1991	Collected 41-80 mm TL for experiment.	Roosevelt Inlet and Indian River Bay	Inlet: Nov 89-Apr 90 Bay: Feb-June 89-90	Estuarine marsh creeks 0.5-1.5 m in depth.	
	Malloy and Targett 1994a	18-80 mm TL	Indian River Bay	Jan-June 91/92		
	Malloy and Targett 1994b	18-80 mm TL	Indian River Bay	Jan-June 92	Protected beach close to muddy channel.	Intermediate size grains with ephemeral macroalgal cover.
	Timmons 1995	7.6-24.9 cm TL	Rehoboth Bay, Indian River Bay	June 92, Aug 92, Nov 92, Mar 93	Attracted to the algae *Agardhiella tenera* because of the presence of prey, but remain in nearby sand to avoid predation. Collected in water depths between 0.5-5.5 m.	Prefer sand to shell rubble or algae. [1] Captured in sand and mud.
ADULTS	Smith and Daiber 1977	> ~ 28 cm TL	Delaware Bay	Aug 66-Nov 71. Most captured May-Sept, a few [juveniles] have been caught in the deeper parts of the Bay in every winter month.	Captured from the shoreline to 25 m deep.	

[1] Laboratory study
Transforming larvae: no pertinent information
D.O., Currents, Light: no pertinent information

Table 3. cont'd.

Life Stage	Authors	Temperature	Salinity	Prey	Predator	Notes
JUVENILES	Malloy and Targett 1991	Mortality was 42% after 16 days at 2-3°C; > 3°C, all fish survived. Mortality highest in fish < 50 mm TL in < 3°C water; all fish > 65 mm survived < 2.5°C for 2 weeks. Growth rates were the same between 2 and 10°C. Mean growth rate increased to 2.4% per day at 14°C and 3.8% per day at 18°C. [1]	Collected at 24-30 ppt. Experimental salinity variation (10-30 ppt) had no effect on feeding, growth or survival. [1]	Fed locally caught mysid shrimp *Neomysis americana* in experiment. [1]	The extended period of time spent at small sizes may increase vulnerability to predation.	Juveniles that arrive in northern Mid-Atlantic Bight estuaries in the fall, in advance of winter temperature minima, may be able to grow past a lower critical size, thus increasing survival.
	Malloy and Targett 1994a	Mortality of juveniles depends more on rate of temperature decline than on final exposure temperature. No growth at temperatures < 9°C. DE fish more tolerant of low temperatures (1-4°C) than NC fish. [1]		Can survive 14 days with no food at 10-16°C (typical temperature at settlement). Prey availability is important to growth. Fed locally caught mysid shrimp *N. americana* in experiment. [1]		
	Malloy and Targett 1994b	2.6-20°C		Low densities of mysids (one of the dominant prey items) until June.	Extended period of time spent at small sizes (13-25mm TL) could increase vulnerability to predation.	< 50% maximum growth in May/early June.
	Timmons 1995	June: 22-28°C, August: 17-25°C, November: 7-12°C, March: 9-13°C	Range: 12-28 ppt. Salinities were constantly lower in Indian River Bay compared to Rehoboth Bay.	Rehoboth flounder fed on shrimp *Paleomonetes vulgaris*, plus porturid and blue crabs. Indian River fish fed on mysids.	In caging experiments, blue crabs were least able to prey on the flounder in cages with sand bottoms only, but had an advantage in capturing the flounder in cages containing macroalgae.[1]	Suggests that macroalgal systems appear to act as an ecological surrogate to seagrass beds and seagrass/macro-algal systems.
ADULTS	Smith and Daiber 1977			< 45 cm fed on invertebrates, > 45 cm TL ate more fish. In order of % frequency of occurrence: shrimp (*C. septemspinosa*), weakfish, mysids (*N. americana*), anchovies, squids, Atlantic silversides, herrings, hermit crabs (*P. longicarpus*), isopods (*O. praegusta*).		Appear to migrate little and may be permanent residents.

[1] Laboratory study
Transforming larvae: no pertinent information
D.O., Currents, Light: no pertinent information

Table 4. Habitat parameters for summer flounder, *Paralichthys dentatus*: inshore North Carolina.

Life Stage	Authors	Size Range	Geographic Location	Time Period	Habitat	Substrate	Temperature
TRANS-FORMING LARVAE	Burke 1991	mean 14.7 mm SL	Newport River Estuary	Feb-Mar 87-89		Wild caught and lab reared larvae: preferred sand over mud even when prey not present. Implies search for food to some extent restricted to sandy substrate in settling fish. [1]	6-20°C[1]
	Burke 1995	11-20 mm SL	Newport and North River	Jan-Apr 88	Tidal flats, channels.		10-13°C
	Burke *et al*. 1991	11-17 mm SL	Newport and North Rivers	Nov-Apr 86-89	Larvae concentrate on shallow tidal flats (< 1 m), middle reaches of estuary. Fewer catches in 1.5-3 m. In spring juveniles migrate to higher salinity salt marsh.	Substrate type can affect distribution. Higher probability on sand than mud.	
	Burke *et al*. 1998	Onslow Bay: 9-15 mm SL, transforming larvae. Beaufort Inlet: 11-15 mm SL, all at stages G - I_2. Newport River estuary: 11-21 mm SL.	Onslow Bay, includes nearshore waters; Beaufort Inlet and Newport River estuary.	Feb/Mar 1995	Onslow Bay: concentrate in estuarine areas. Outside the estuary in the surf zone and in deeper habitats of the Bay, larvae were present only during the immigration season. Within the Newport estuary initial settlement appears to be concentrated in the intertidal zone rather than in adjacent deeper areas.		
	Deubler and White 1962	12-15 mm SL	Bogue Sound	Feb-61			
	Hettler *et al*. 1997	12-15 mm SL	Beaufort Inlet	Nov 91-Apr 92, nightly	Tidal channel, 6m deep.		7-18°C, higher abundance with increased temperatures.
	Weinstein *et al*. 1980a	7-34 mm SL	Cape Fear River Estuary	Mar-Apr	Tidal salt marsh and creeks, shallow open water.		
	Weinstein *et al*. 1980b	mean 13.6 mm	Cape Fear River Estuary	Sept 77-Aug 78	Tidal creeks, shallow marsh.	Grain size variation among sites: fine sand (58-93%), medium sand (7-41%), mud (1-14%).	16.8-21.1°C
	Williams and Deubler 1968b		Pamlico Sound, Neuse River	1957-1966, biweekly, at night			2-22°C, most abundant at 8-16°C.

[1] Laboratory study
Adults: no pertinent information
D.O.: no pertinent information

Table 4. cont'd.

Life Stage	Authors	Size Range	Geographic Location	Time Period	Habitat	Substrate	Temperature
JUVENILES	Burke 1991, 1995	20-60 mm SL	Newport and North Rivers	Jan-Apr 88	Tidal flats and channels, juveniles migrate to salt marsh. Shallow: < 1 m mean low tide.		10-13°C
	Malloy and Targett 1994a	18-80 mm TL	lower Newport River	Jan-June 91-92			2-20°C: Increase in temperature = increase in feeding rate, maximum growth rate, gross growth efficiencies. Increased rate of temperature decline = decreased survival. < 7-9°C no positive growth rates. [1]
	Malloy and Targett 1994b	18-80 mm TL	Newport River Estuary	Jan-June 92	Sandy salt marsh (adjacent to *Spartina alterniflora* marshes) and muddy beach.	Predicted growth rates higher at muddy beach site in May. [1]	8-23°C (Feb-June)
	Peters and Angelovic 1971						10-30°C, increase in temperature = increase in ad libitum feeding rate and growth efficiency. Little growth at low temperatures, fastest growth rate at 20-25°C. Specific growth rate = 5% at 15°C, 10% at 20°C.[1]
	Powell 1982	18-224 mm TL, mean at end of 1st yr: males 167 mm, females 171 mm TL	Pamlico Sound	May 71-July 72			Migration to estuary in February: body weight increases 5%/day. After February increase in temperature = a decrease in growth rates. Late fall growth negligible. June: 2% increase body weight /day, August: 1%.
	Powell and Schwartz 1977	Range 70-250 mm TL. 8-16 mm when entering estuary, 90-100 mm at first spring, 1st yr. juveniles 170 mm by Dec.	Pamlico Sound	Aug 71-July 72	Most abundant in eastern and central Pamlico Sound (relatively high salinity), close to inlets.	Greater abundance with sand, or sand/shell, scarce where mud predominates.	Warm temperatures and intermediate/high salinities = increased growth rate.
	Powell and Schwartz 1979	100-400 mm TL (84% of captures 100-200 mm TL)	Pamlico Sound and adjacent estuary	Aug 71-July 72, monthly, daylight sampling	Dominant in lower estuary.		Increased temperatures = increased food consumption for overwintering juveniles.
	Ross and Epperly 1985	21-320 mm SL	Pamlico Sound	Mar 81-Nov 82	YOY on seagrass bed.	fine sand	

[1] Laboratory study
Adults: no pertinent information
D.O.: no pertinent information

Table 4. cont'd.

Life Stage	Authors	Salinity	Light	Currents	Prey	Predators	Notes
TRANS-FORMING LARVAE	Burke 1991	16-34 ppt [1]					Sand preference of metamorphosing larvae in laboratory corresponds to older fish in wild.
	Burke 1995	21-32 ppt			Polychaete tentacles most important, plus polychaetes and harpactacoid copepods. Increasing importance of polychaetes and clam siphons with increasing development.		
	Burke *et al*. 1991	19-31 ppt				Predator avoidance by burying in sandy substrate.	
	Burke *et al*. 1998	~31-34 ppt		During flood tides, highest larval densities at mid-depths within water column; during ebb tide, highest densities at bottom. Position in water column dependent on tidal stage; shift in distribution/abundance associated with shift in tidal stage, indicating flounders enter Onslow Bay by tidal stream transport. Wild-caught larvae had regular pattern of activity correlated with tidal cycle; peak activity associated with ebb tide[1]. Lab-reared flounder: no clear pattern of activity[1].			Observations of tidal rhythm of activity of wild-caught flounder[1] and vertical shift into water column during slack tide suggests behavioral component to tidal stream transport. High activity during ebb tide[1] suggests most active behavioral component of TST involves avoidance of advection by ebbing tide rather than movement into water column and transport by flood tide. Lack of tidal activity pattern in lab-reared flounder[1] suggests development of tidal rhythm dependent on exposure to physical variables that are correlated with the tide.
	Deubler and White 1962	10-30 ppt: increase in salinity = increase in body wt; 40 ppt = decrease in body wt. [1]					Salinities commonly found in lower estuary allows optimal growth.
	Hettler *et al*. 1997	24-36 ppt	More abundant in catches later at night.				mean density = 2 larvae/100m^3 (Dec 31-Apr 15)
	Weinstein *et al*. 1980a		Night catches > day catches. At night concentration at surface > concentration at other depths.	Marsh migration aided by surface movement on flood tides at night, settle to bottom on ebb.			Despite intensive tidal flows maintain preferred position in estuary by specific behavioral responses.
	Weinstein *et al*. 1980b	1.7-24.9 ppt; greater occurrence in mid/higher salinities.					Distribution influenced by salinity gradients and to lesser extent by substrate characteristics.
	Williams and Deubler 1968a	.02-35 ppt, 18 ppt optimum					

[1] Laboratory study
Adults: no pertinent information
D.O.: no pertinent information

Table 4. cont'd.

Life Stage	Authors	Salinity	Light	Currents	Prey	Predators	Notes
JUVENILES	Burke 1991, 1995	21-32 ppt	Visual predators. Feeding largely restricted to daylight.		Active predator; ate primarily infaunal crustaceans, polychaetes, invertebrate parts. Polychaetes (primarily spionids) most important.		Diets of summer and southern flounder similar during settlement when distributions overlapped. Diets diverged prior to segregated distribution. Spionid prey *Streblospio benedicti* abundant in marsh; may explain juvenile migration to marsh.
	Malloy and Targett 1994a	30 ppt			Winter food limitation less important than variability of temperature minima.		NC juveniles higher maximum growth rates and growth efficiencies than DE fish at temperatures from 6-18°C. NC fish less tolerant of low temperatures (1-4°C) than DE fish. [1]
	Malloy and Targett 1994b				Low abundance of NC mysids from May into summer might explain growth limitation in marsh juveniles during May. Increasing abundance of other prey (polychaetes, amphipods) may account for favorable juvenile growth in muddier site during May.		Predicted growth rates = 2-5%/d Feb-April. Marsh juveniles severely growth limited after April with temperatures 18-20°C.
	Peters and Angelovic 1971	5-35 ppt; relatively little effect on ad libitum feeding rate. [1]					Maximum caloric growth efficiency predicted at 21°C, 24 ppt salinity and 78% ad libitum feeding. All body processes including feeding increases with temperature to an optimum; > optimum, increasing temperature becomes detrimental.
	Powell 1982						Decrease in growth with increase in temperature probably due to intrinsic (not environmental) factors.
	Powell and Schwartz 1977	Most abundant moderate/high salinities 18-35 ppt. Spatial segregation with southern flounder: increase in salinity = increase in summer flounder abundance.		Shallow waters near inlets (fast flowing).			Juveniles overwinter in estuary (adults migrate to ocean). Distribution governed primarily by benthic substrate and salinity. Pamlico Sound unusual: solar-lunar tides immeasurable; salinities uniform in much of sound.
	Powell and Schwartz 1979	Dominant in higher salinities.			Young flounder fed mostly on mysids and fishes throughout the year. As size increases diet consisted of shrimps and fishes in similar quantities. Feeding rate decreases in winter.		Southern flounder diet compared: reverse importance was found - fishes, then mysids.
	Ross and Epperly 1985	Distribution significantly correlated with salinity, range 22-28 ppt, optimal 22-23 ppt.					

[1] Laboratory study
Adults: no pertinent information
D.O.: no pertinent information

Table 5. Summary of life history and habitat parameters for summer flounder, *Paralichthys dentatus*: inshore New Jersey, Delaware and North Carolina.

Life Stage	Size	Geographic Location	Habitat	Substrate	Temperature
TRANSFORMING LARVAE (No pertinent information for DE)	~ > 8 - < 18 mm SL	**NJ**: Great Bay, Little Egg Harbor; **NC**: Pamlico Sound and Cape Fear estuaries.	Shallow tidal flats and marsh creeks.	Sand preference [1]	Time to completion of metamorphosis temperature dependent. Increased temperatures = shorter metamorphosis. Mortality from < 2-4°C. No effect of starvation on mortality or time to completion of metamorphosis at temperatures < 10°C.[1]
JUVENILES	~ > 20 mm - ~ < 28 cm TL	**NJ**: Great Bay, Little Egg Harbor; **DE**: Delaware and Indian Rivers, Rehobeth Bays; **NC**: Pamlico Sound, Cape Fear, and adjacent estuaries.	Lower estuary: flats, channels, salt marsh creeks, eelgrass beds. Possible preference for creek mouths **(NJ)** and inlets **(NC)**. Creeks are foraging habitat. **DE**: Attracted to macroalgae because of the presence of prey, but remain in nearby sand to avoid predation.	**NJ**: found on muddy bottoms. **NC**: often greater abundances on sand or mixed substrates. Scarcer on mud. **DE**: Sand preference.[1] Captured on sand and mud. Substrate preference possibly overrides salinity preference.	**DE**: > 3°C, all fish survived. **NC**: Feeding rate, growth rate and efficiencies increase with increasing temperatures. < 7-9°C = no positive growth rates (both **DE**, **NC** fish); 20-25°C = fastest growth rates. **NC** fish higher maximum growth rates/growth efficiencies at 6-18°C than **DE** fish.[1] **DE** juveniles show greater tolerances for low temperatures than **NC** juveniles. Mortality of juveniles depends more on rate of temperature decline than on final exposure temperatures.[1]
ADULTS (No pertinent information for NJ, NC)	~ > 28 cm TL	Delaware Bay	Captured from the shoreline to 25 m.		

[1] Laboratory study
D.O.: no pertinent information

References
New Jersey: Rountree and Able (1992a,b, 1997), Szedlmayer *et al.* (1992), Keefe and Able (1993, 1994), Szedlmayer and Able (1993), Witting and Able (1993), Grover (1998)
Delaware: Smith and Daiber (1977), Malloy and Targett (1991), Malloy and Targett (1994a,b), Timmons (1995)
North Carolina: Deubler and White (1962), Williams and Deubler (1968b), Peters and Angelovic (1971), Powell and Schwartz (1977, 1979), Weinstein *et al.* (1980a,b), Powell (1982), Ross and Epperly (1985), Burke (1991), Burke *et al.* (1991, 1998), Malloy and Targett (1994a,b), Burke (1995), Hettler *et al.* (1997), Walsh *et al.* (1999)

Table 5. cont'd.

Life Stage	Salinity	Light	Currents	Prey	Predators
TRANSFORMING LARVAE (No pertinent information for DE)	Salinities found in lower estuaries optimal for growth: 10-30 ppt.; Increasing salinity = increased body weight [Weinstein *et al*. 80b: Distribution possibly influenced more by salinity than by substrate.]	Prefer burying during daylight.[1] Night active.	**NJ**: Increased burial at flood tide;[1] however, **NC**: possible surface or mid-depth movement on flood, settlement on ebb. Position in water column dependent on tidal stage, flounders utilize tidal stream transport (behavioral component suggested). Peak activity associated with ebb tide[1].	Calanoid copepod *Temora longicornis* -- indicates pelagic feeding. Benthic feeding in late-stage metamorphs, prey includes polychaete tentacles, harpactacoid copepods, polychaetes.	Burying behavior determined by presence of particular predator.[1] **NJ**: 11-16 mm transforming larvae vulnerable to predation by large size range of shrimp *C. septemspinosa* (~ 11-50 mm TL) [1]
JUVENILES	More abundant in higher salinities of 18-35 ppt. Possible preference, but interactions with substrate preferences. **DE**: Experimental salinity variation (10-30 ppt) had no effect on feeding, growth or survival.[1]	Visual predators, feeding restricted to daylight, but **NJ** study (Rountree and Able 97) shows increased night-time catches in marsh creeks. **DE**: No pertinent information.	Selective tidal stream transport. Feeding, optimal environmental conditions cause movement. **DE**: No pertinent information.	Smaller juveniles: infauna (e.g., polychaetes). Larger juveniles (~ > 100 mm TL): fish, shrimps, crabs; often tied to abundance in environment.	**DE**: In caging experiments, blue crabs were least able to prey on the flounder in cages with sand bottoms only, but had an advantage in capturing the flounder in cages containing macroalgae.[1] **NJ, NC**: No pertinent information.
ADULTS (No pertinent information for NJ, NC)				< 45 cm fed on invertebrates, > 45 cm TL ate more fish. In order of % frequency of occurrence: shrimp (*C. septemspinosa*), weakfish, mysids (*N. americana*), anchovies, squids, Atlantic silversides, herrings, hermit crabs (*P. longicarpus*), isopods (*O. praegusta*).	

[1] Laboratory study
D.O.: no pertinent information

References
New Jersey: Rountree and Able (1992a,b, 1997), Szedlmayer *et al.* (1992), Keefe and Able (1993,1994), Szedlmayer and Able (1993), Witting and Able (1993), Grover (1998)
Delaware: Smith and Daiber (1977), Malloy and Targett (1991), Malloy and Targett (1994a,b), Timmons (1995)
North Carolina: Deubler and White (1962), Williams and Deubler (1968b), Peters and Angelovic (1971), Powell and Schwartz (1977, 1979), Weinstein *et al.* (1980a,b), Powell (1982), Ross and Epperly (1985), Burke (1991), Burke *et al.* (1991, 1998), Malloy and Targett (1994a,b), Burke (1995), Hettler *et al.* (1997), Walsh *et al.* (1999)

Table 6. Summer flounder catch and status (weights in '000 mt, recruitment in millions, arithmetic means).

Year	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**Max[2]**	**Min[2]**	**Mean[2]**
Commercial landings	8.1	4.2	6.2	7.6	5.7	6.6	7.0	5.8	17.1	4.2	9.7
Commercial discards	0.7	1.2	1.1	0.7	0.8	0.9	0.3	0.5	1.2	0.3	0.8
Recreational landings	1.4	2.3	3.6	3.2	3.5	4.1	2.5	4.7	12.7	1.4	5.4
Recreational discards	0.1	0.6	1.1	0.9	1.8	1.4	1.8	1.6	1.8	0.1	1.1
Catch used in assessment	10.4	8.3	12.0	12.3	11.9	13.0	9.5	10.5	27.0	8.3	16.6
Spawning stock biomass[1]	5.2	7.5	5.8	7.3	9.3	12.4	17.3	17.4	18.9	5.2	12.4

[1]At the peak of the spawning season (i.e., November 1). [2]Over period 1982-1996.

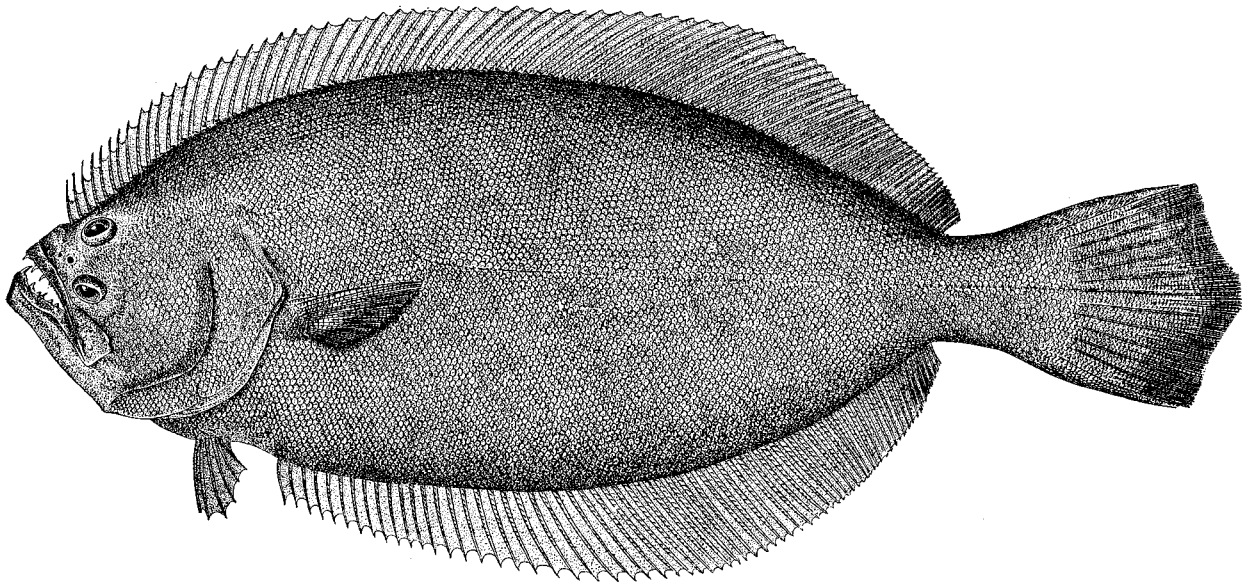


Figure 1. The summer flounder, *Paralichthys dentatus* (from Goode 1884).

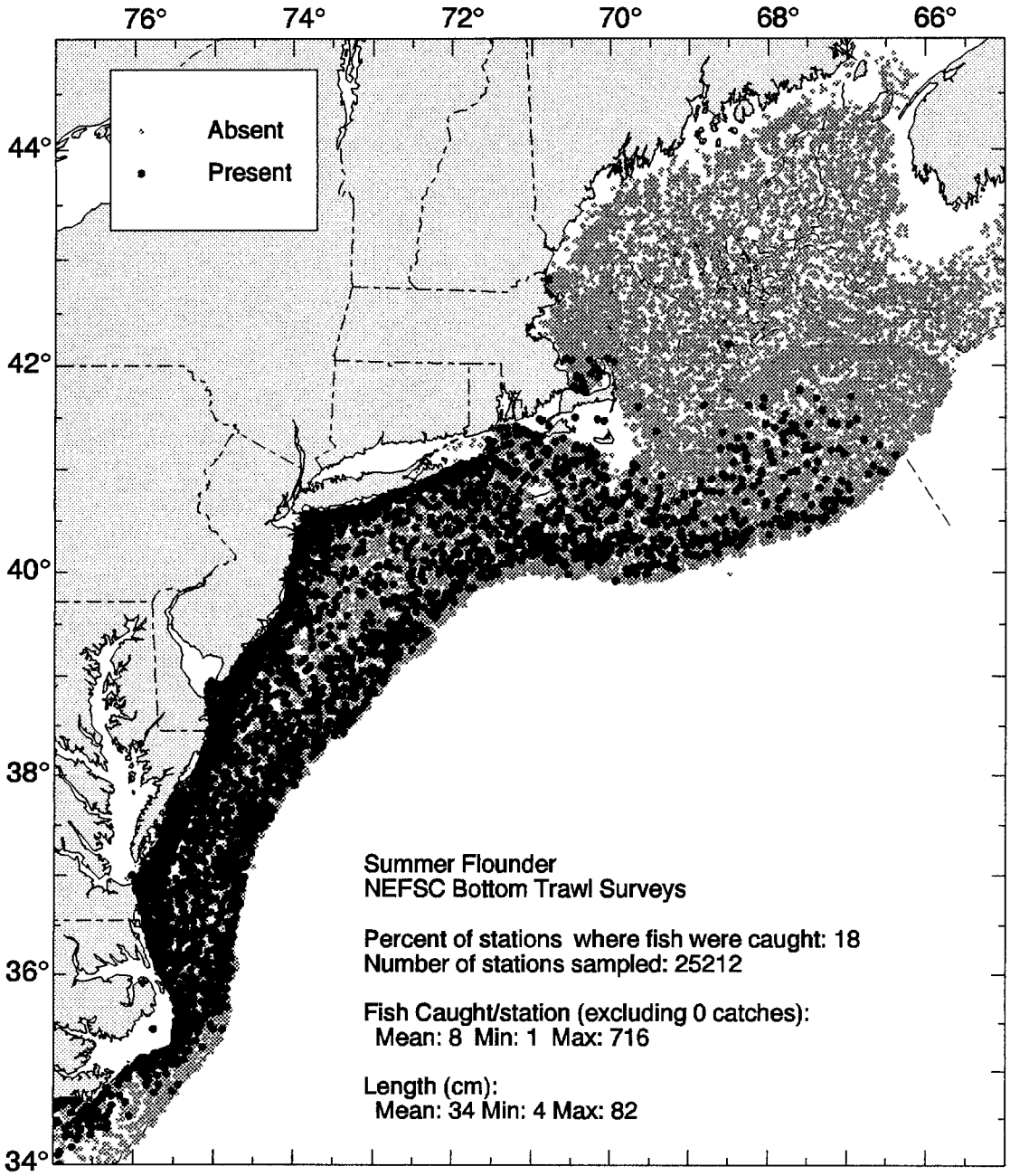


Figure 2. Overall distribution of adult and juvenile summer flounder in NEFSC bottom trawl surveys in autumn (1963-1996), winter (1964-1997), spring (1968-1997), and summer (1964-1995) [see Reid *et al.* (1999) for details].

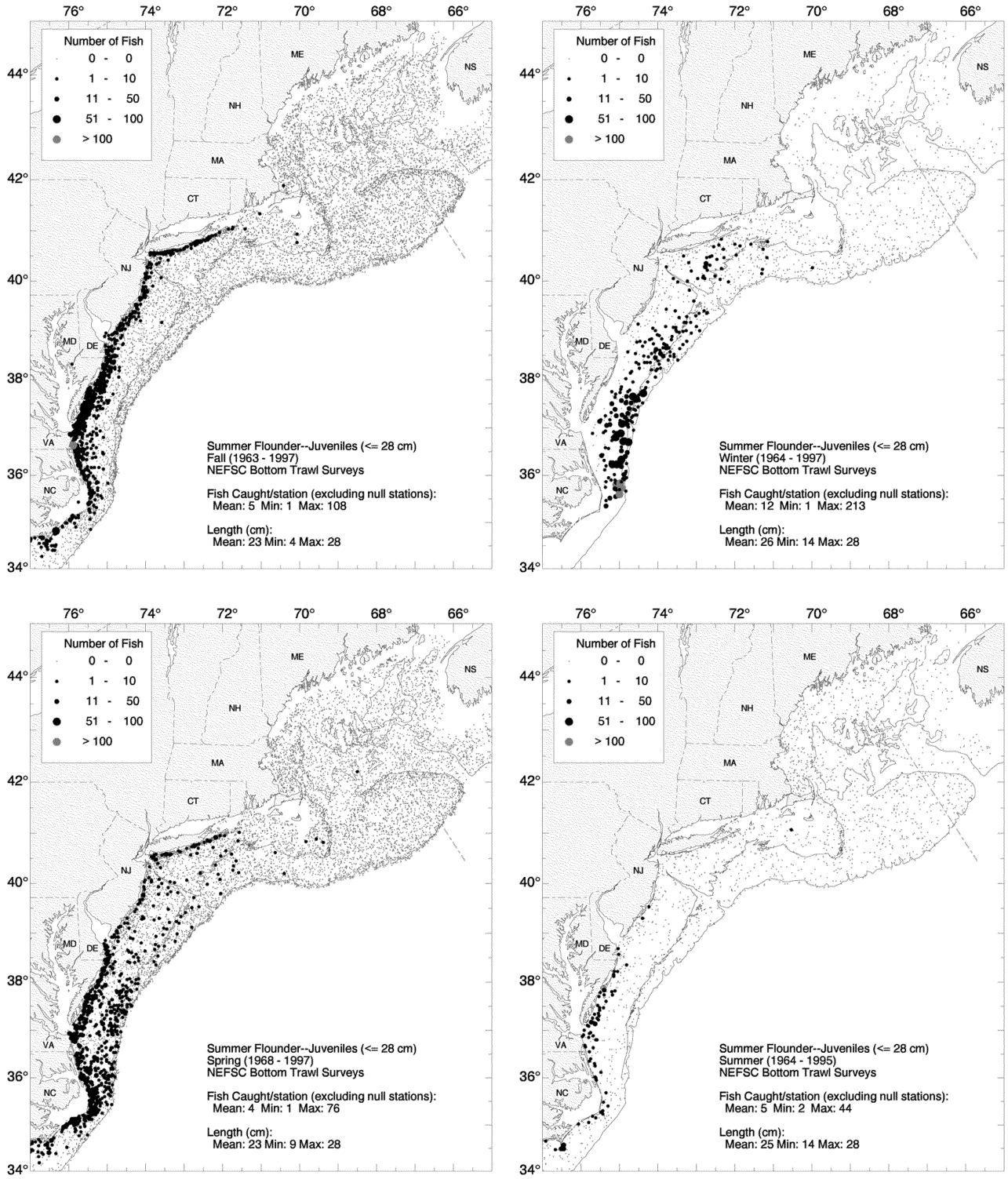


Figure 3. Distribution and abundance of juvenile (≤ 28 cm TL) and adult (> 28 cm TL) summer flounder by season, collected during NEFSC bottom trawl surveys during autumn (1963-1996), winter (1964-1997), spring (1968-1997) and summer (1964-1995) [see Reid *et al.* (1999) for details].

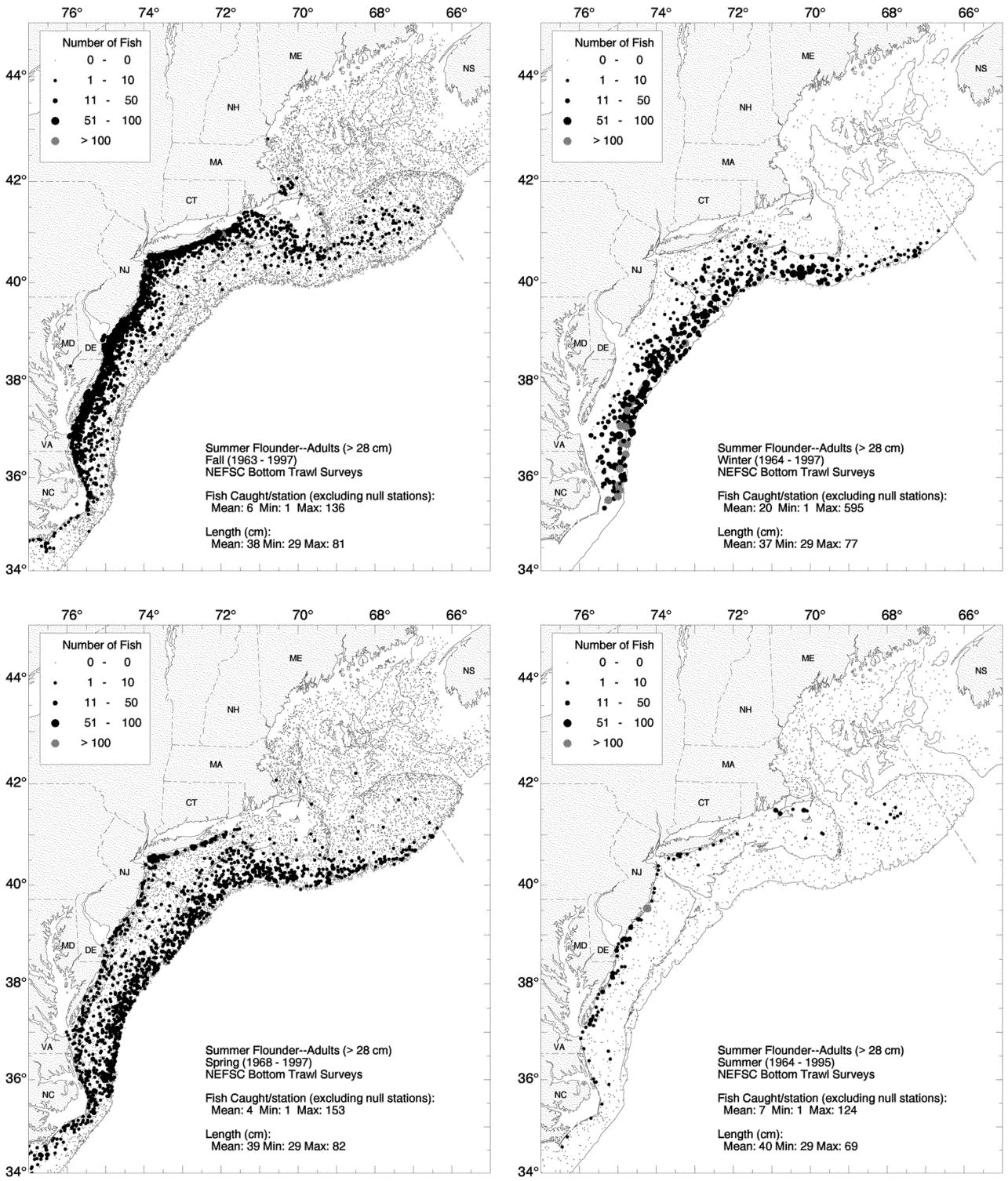


Figure 3. cont'd.

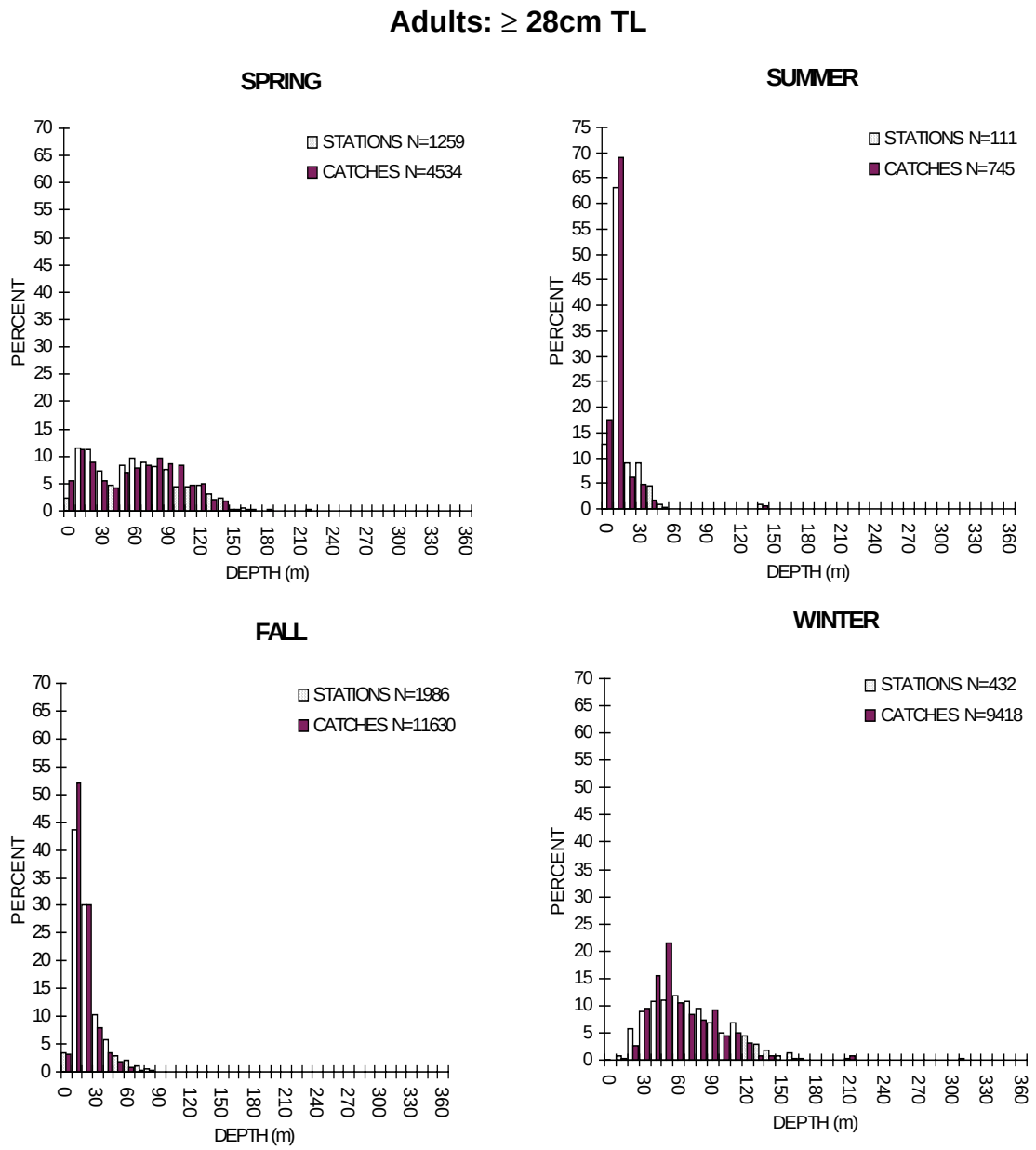


Figure 4. Seasonal abundance of adult summer flounder relative to water depth based on NEFSC bottom trawl surveys [1963-1997, all years combined; see Reid *et al.* (1999) for details]. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

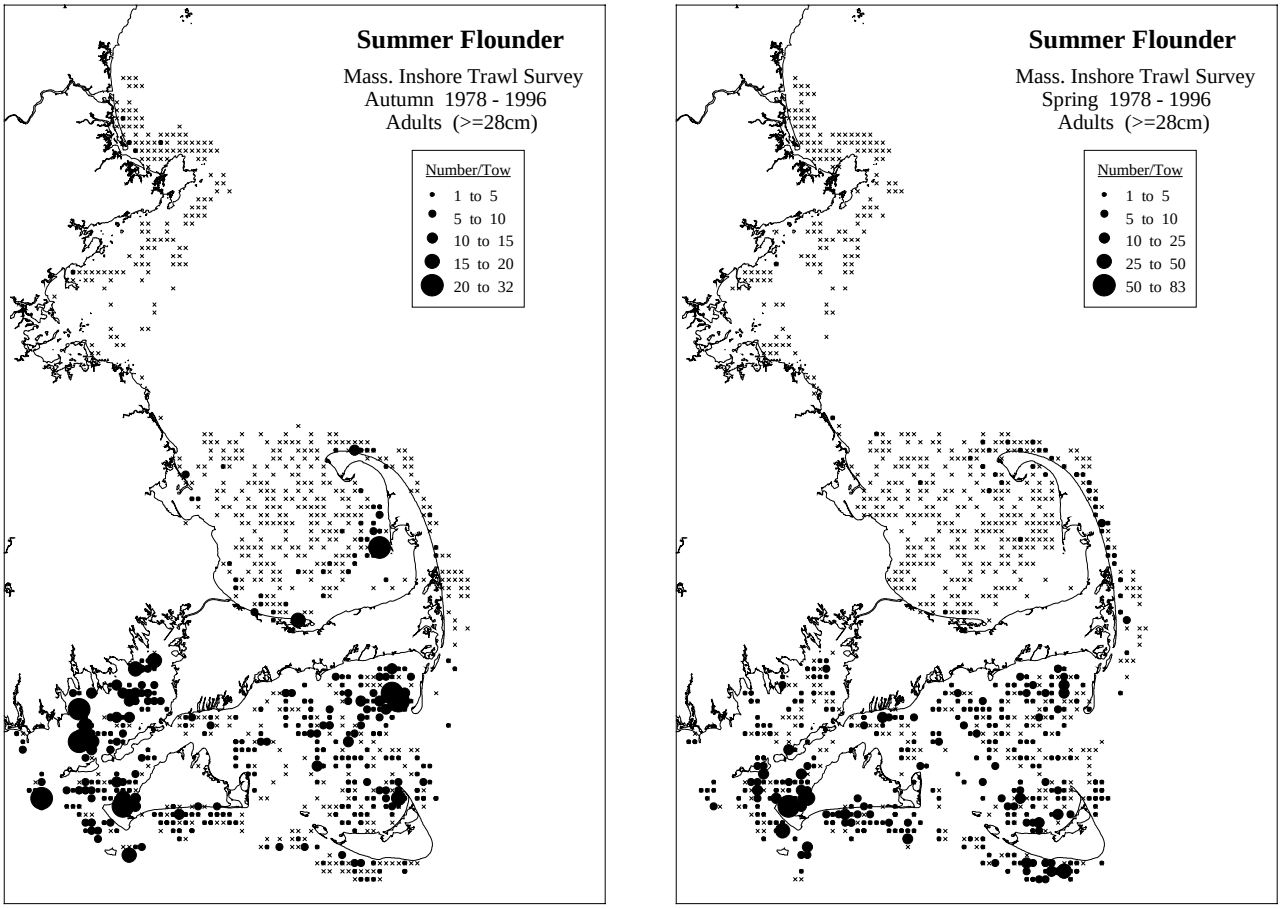


Figure 5. Distribution and abundance of adult summer flounder in Massachusetts coastal waters from shore out to 3 miles during fall (typically September) and spring (typically May), based on bottom trawl surveys by the Massachusetts Division of Marine Fisheries from 1978-1996 (Howe *et al.* 1997; Reid *et al.* 1999). Collections where no adults were caught are shown as small x's.

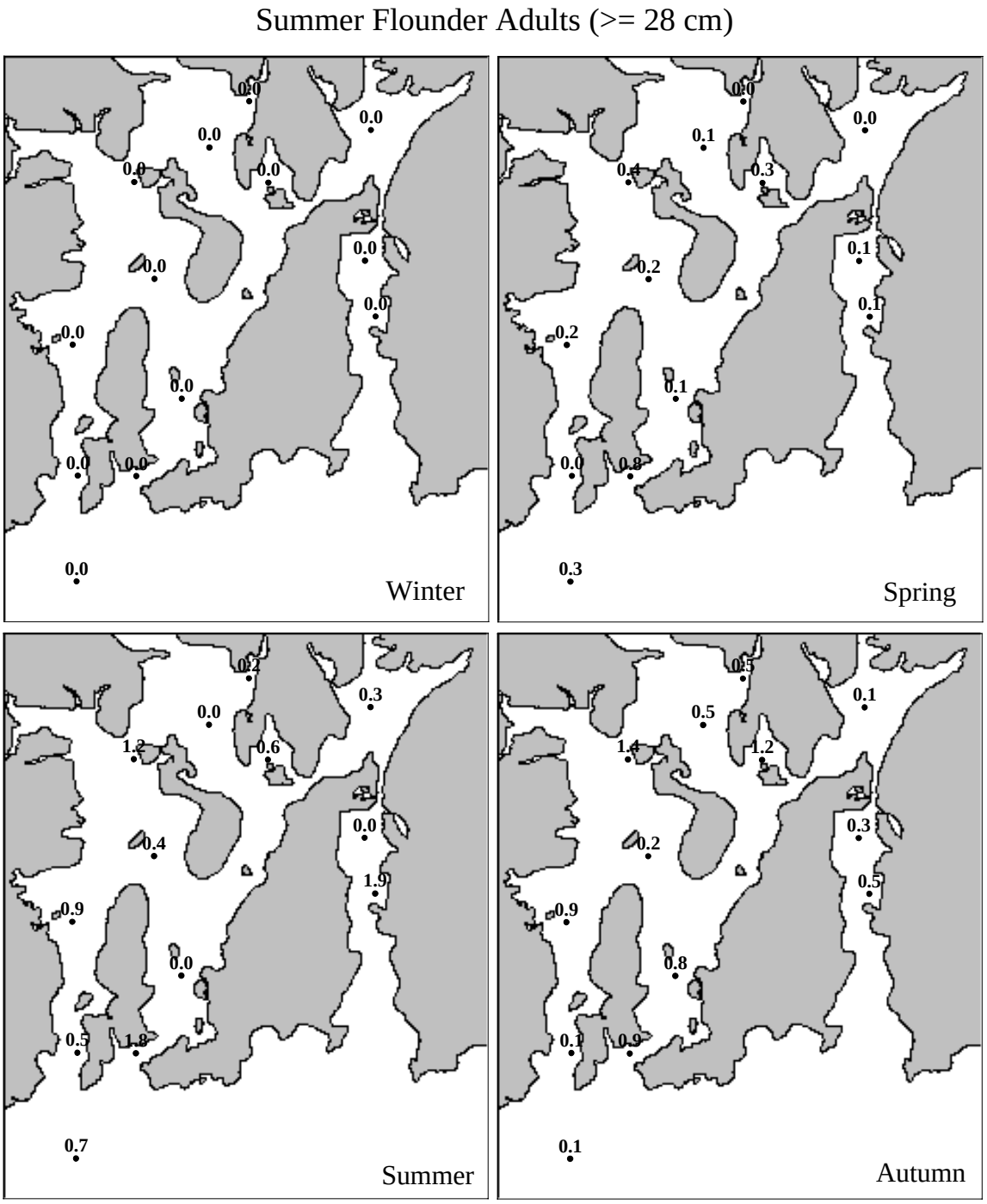


Figure 6. Seasonal distribution and relative abundance of adult summer flounder collected in Narragansett Bay during 1990-1996 Rhode Island Division of Fish and Wildlife bottom trawl surveys of Narragansett Bay. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].

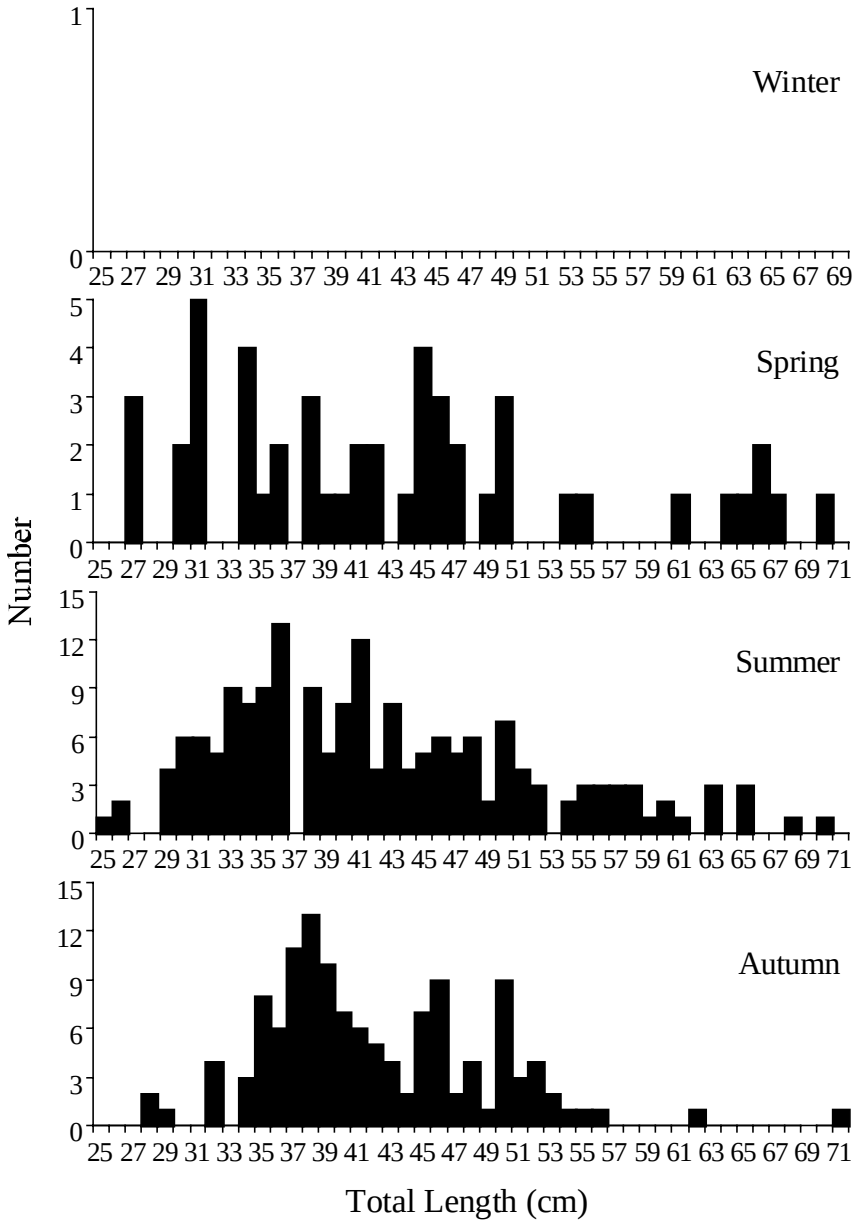


Figure 7. Seasonal length frequencies of summer flounder caught in Narragansett Bay during 1990-1996, from the Rhode Island Division of Fish and Wildlife Narragansett Bay bottom trawl surveys of 1990-1996.

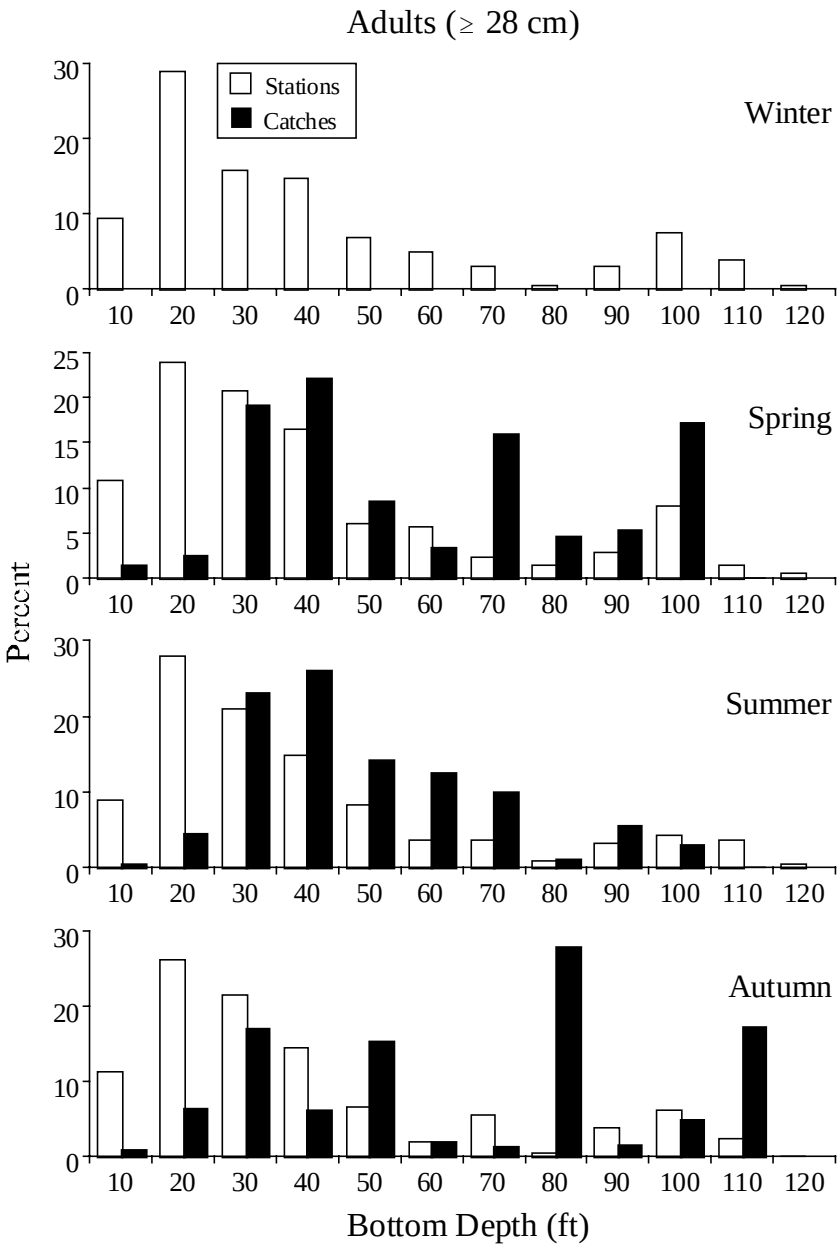


Figure 8. Seasonal abundance of adult summer flounder relative to bottom depth based on Rhode Island Division of Fish and Wildlife bottom trawl surveys of Narragansett Bay, 1990-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

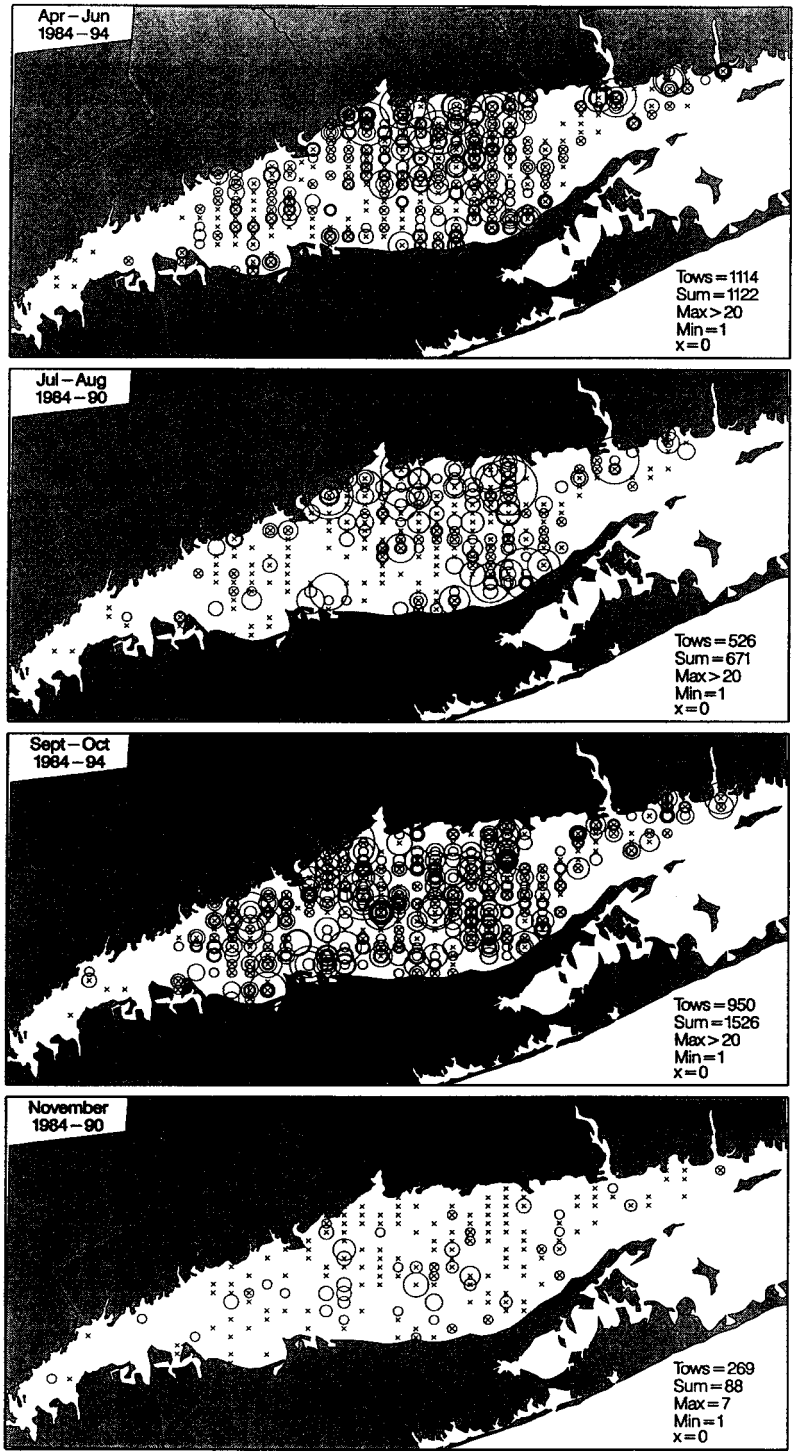


Figure 9. Distribution and abundance of juvenile and adult summer flounder (12-76 cm TL) collected in Long Island Sound, based on the finfish surveys of the Connecticut Fisheries Division, 1984-1994 (from Gottschall *et al.*, in review). Circle diameter is proportional to the number of fish caught, and is scaled to the maximum catch (indicated by "max=" or "max>"). Collections were made with a 14 m otter trawl at about 40 stations chosen by stratified random design.

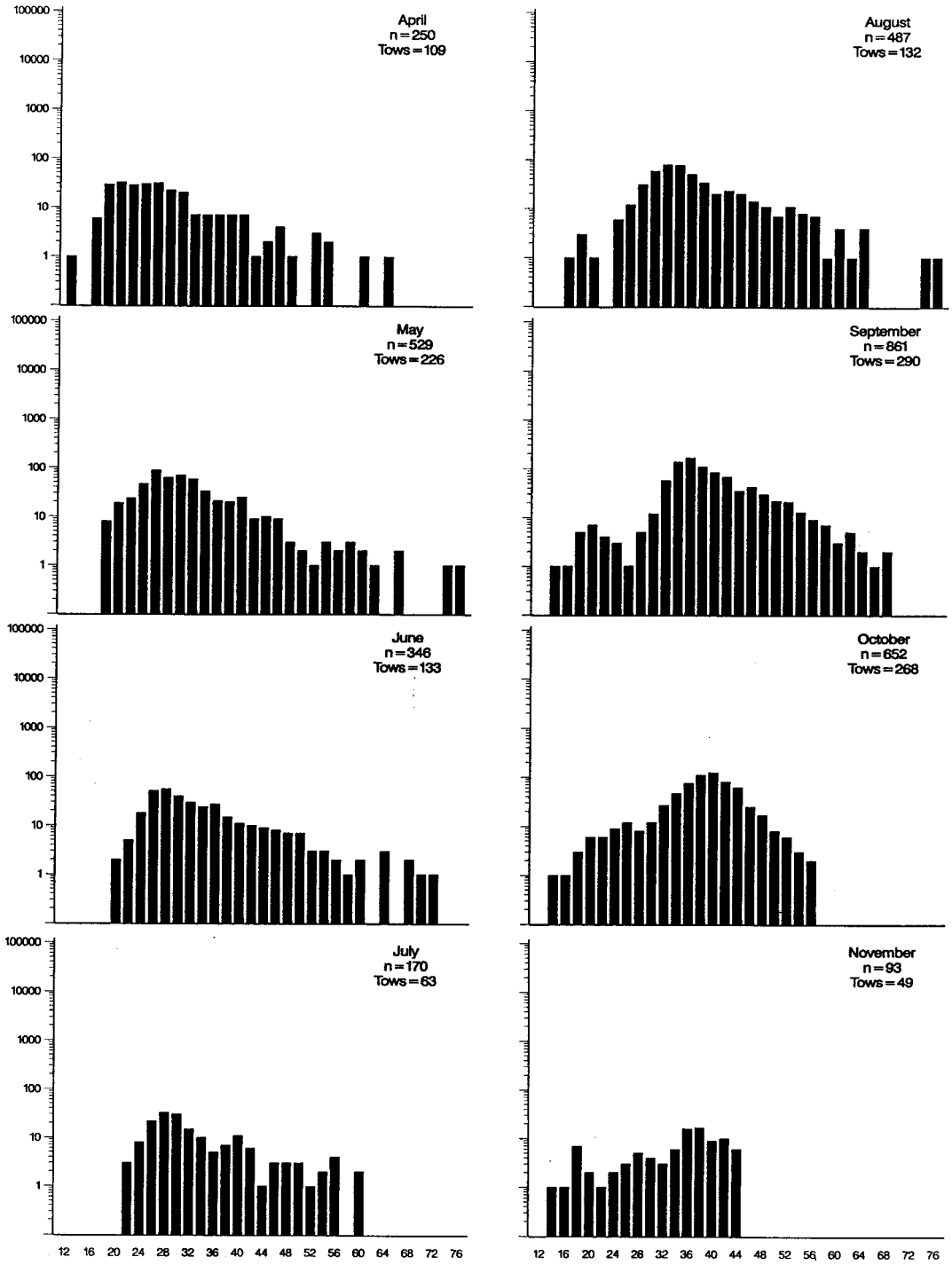


Figure 10. Length frequency distribution (cm) of juvenile and adult summer flounder collected in Long Island Sound, based on the finfish surveys of the Connecticut Fisheries Division, 1984-1994 (from Gottschall *et al.*, in review).

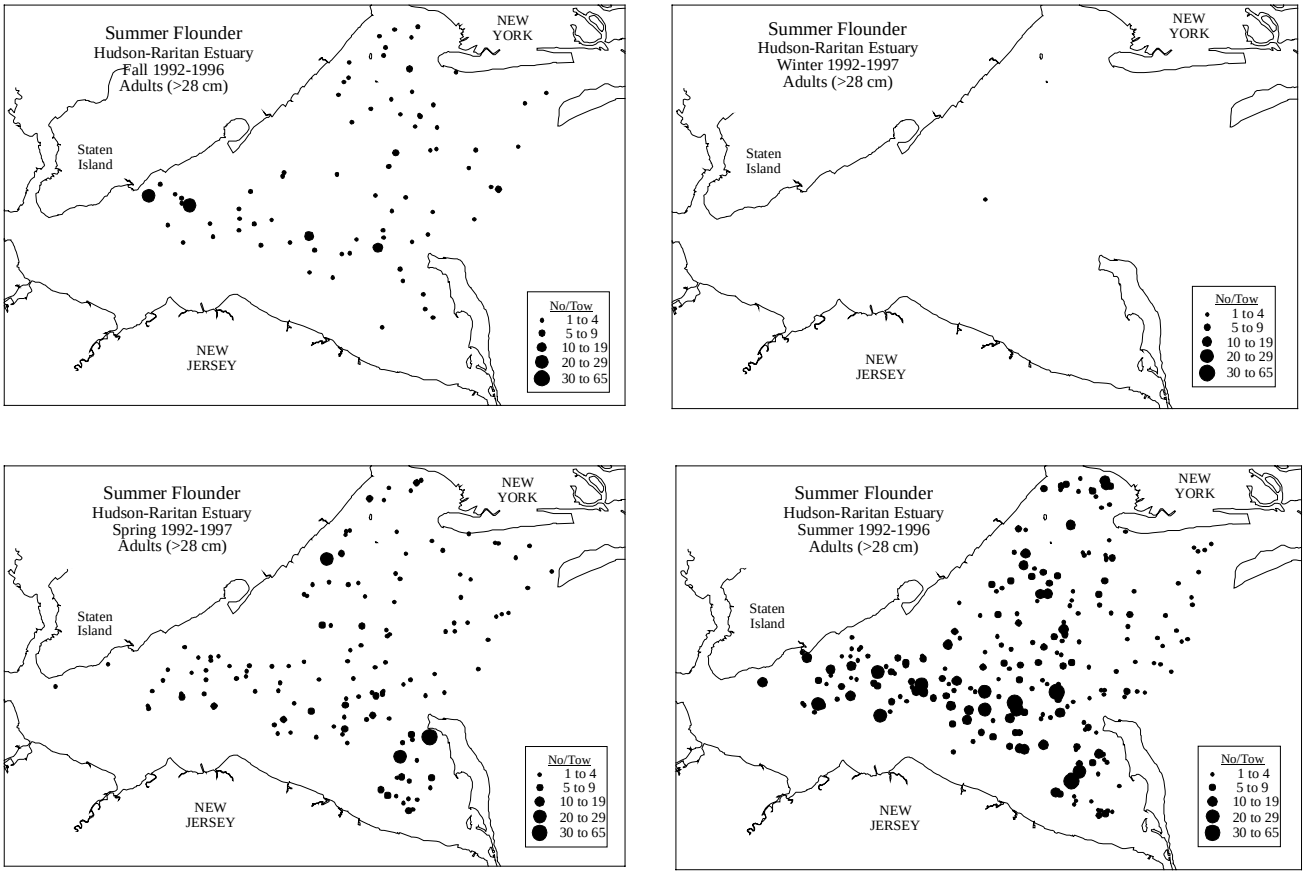


Figure 11. Distribution and relative abundance of adult summer flounder collected in the Hudson-Raritan estuary during Hudson-Raritan trawl surveys in fall (October-December, 1992-1996), winter (January-March, 1992-1997), spring (April and June, 1992-1996), and summer (July and August, 1992-1996) [see Reid *et al.* (1999) for details].

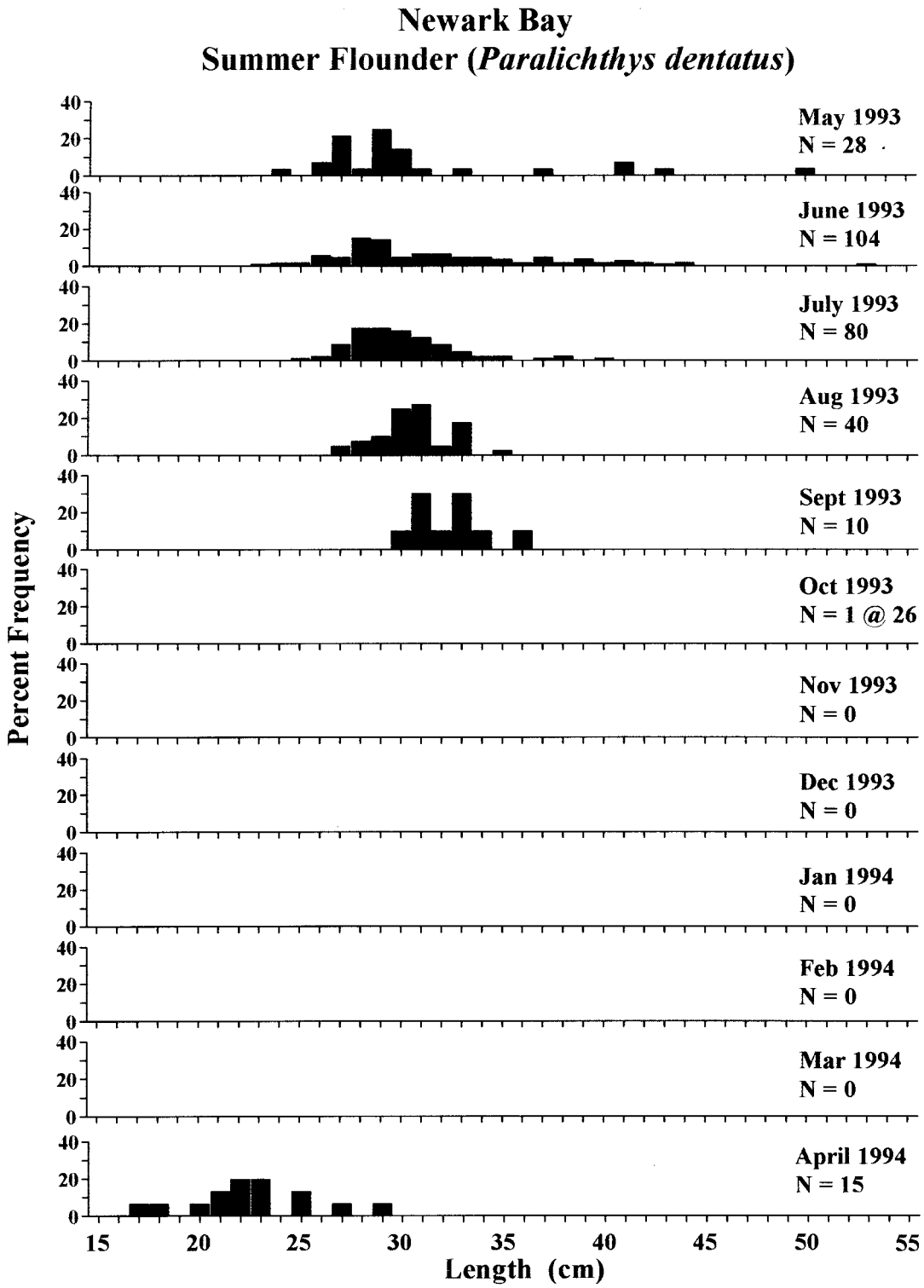


Figure 12. Length-frequency distributions of juvenile and adult summer flounder from Newark Bay, New Jersey. Collected using an 8.5 m otter trawl from May 1993-April 1994 (Wilk *et al*. 1997).

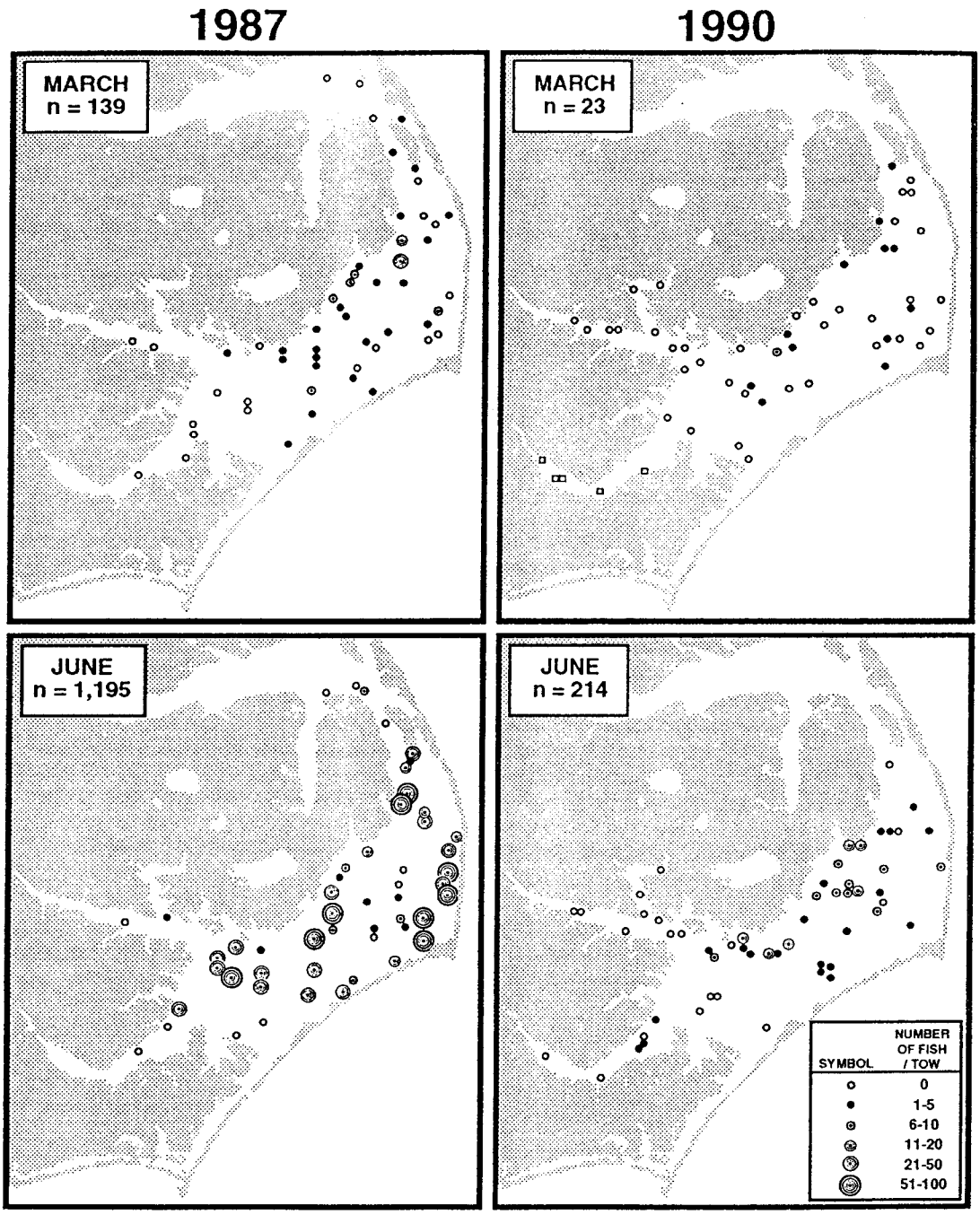


Figure 13. Distribution and abundance of juvenile and adult summer flounder in Pamlico Sound, North Carolina and adjacent estuaries during years of high (1987) and low (1990) abundance. Collections were made by Mongoose trawl at stations chosen by stratified random design. Data based on North Carolina Division of Marine Fisheries trawl surveys, 1987-1991. Adapted from Able and Kaiser (1994).

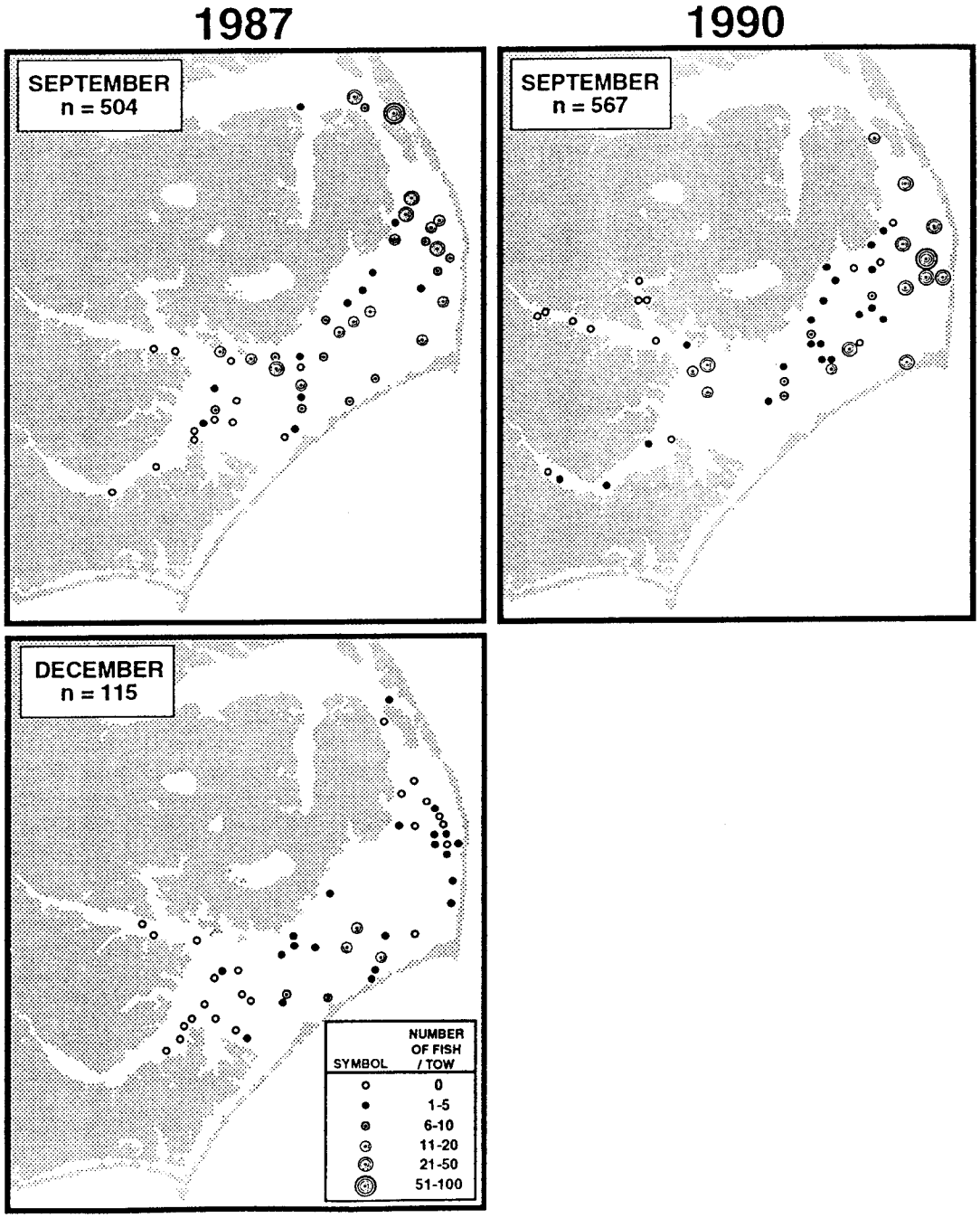


Figure 13. cont'd.

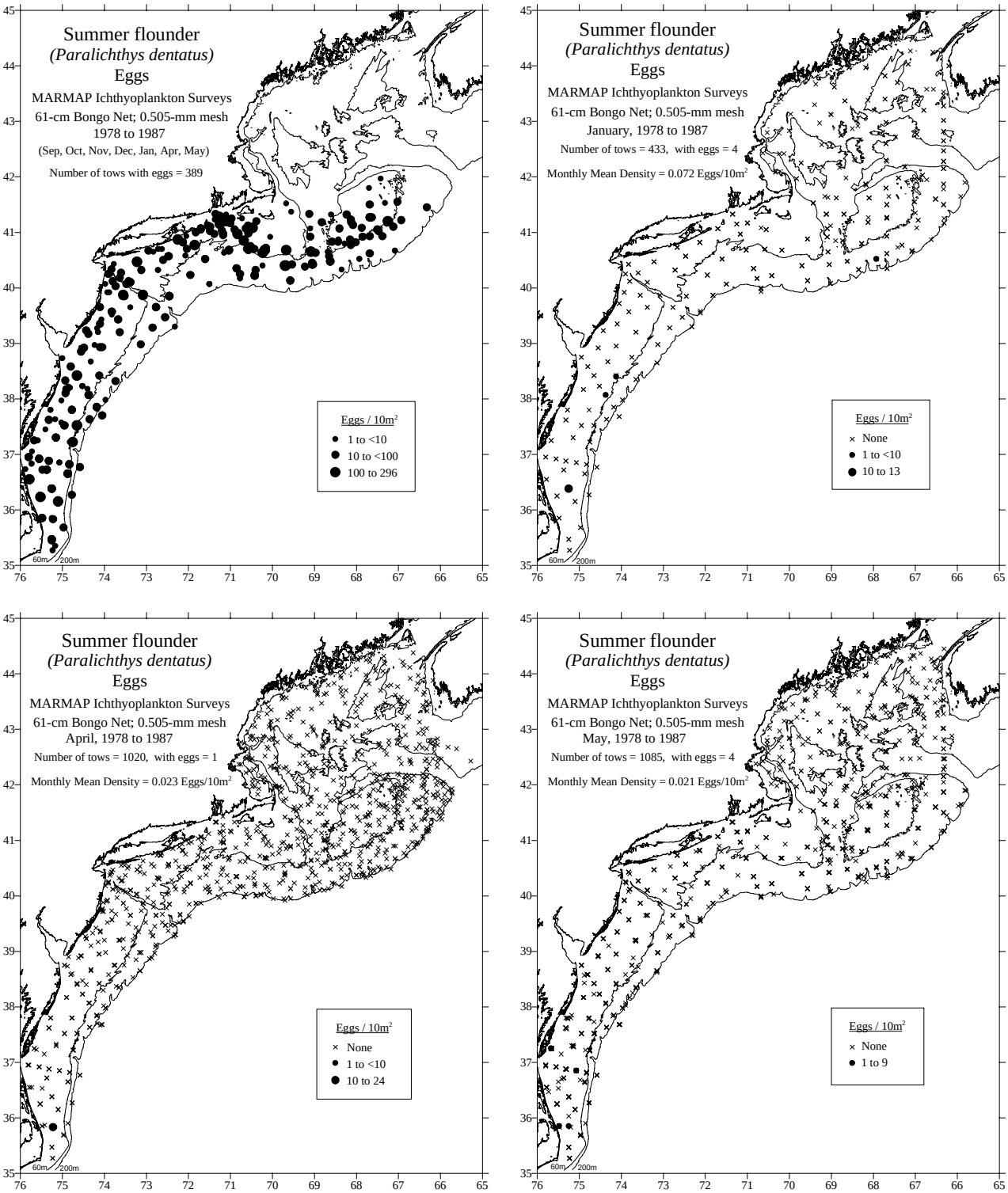


Figure 14. Distribution and abundance of summer flounder eggs collected during NEFSC MARMAP offshore ichthyoplankton surveys from Cape Sable to Cape Hatteras during 1978-1987 [see Reid *et al.* (1999) for details].

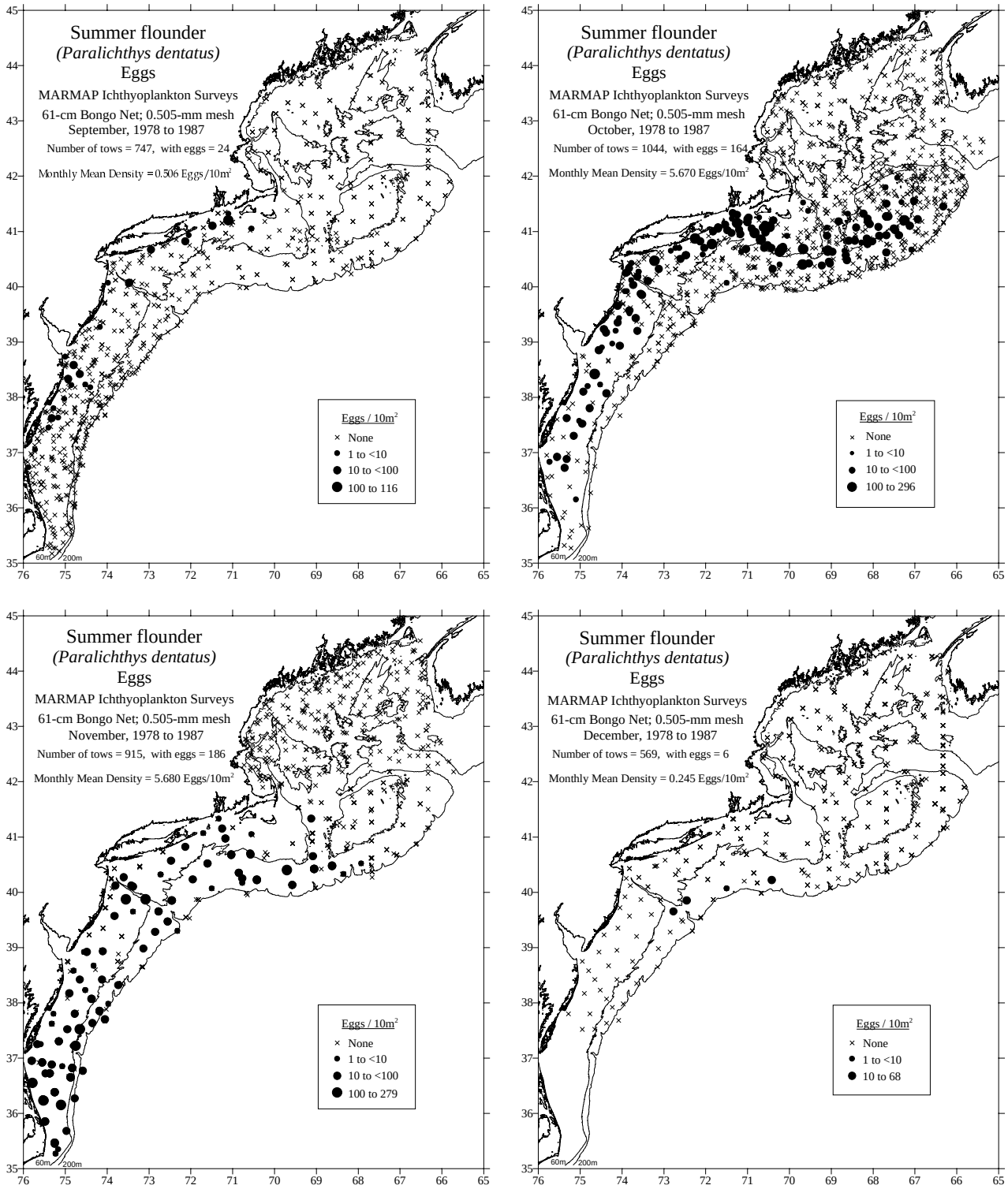


Figure 14. cont'd.

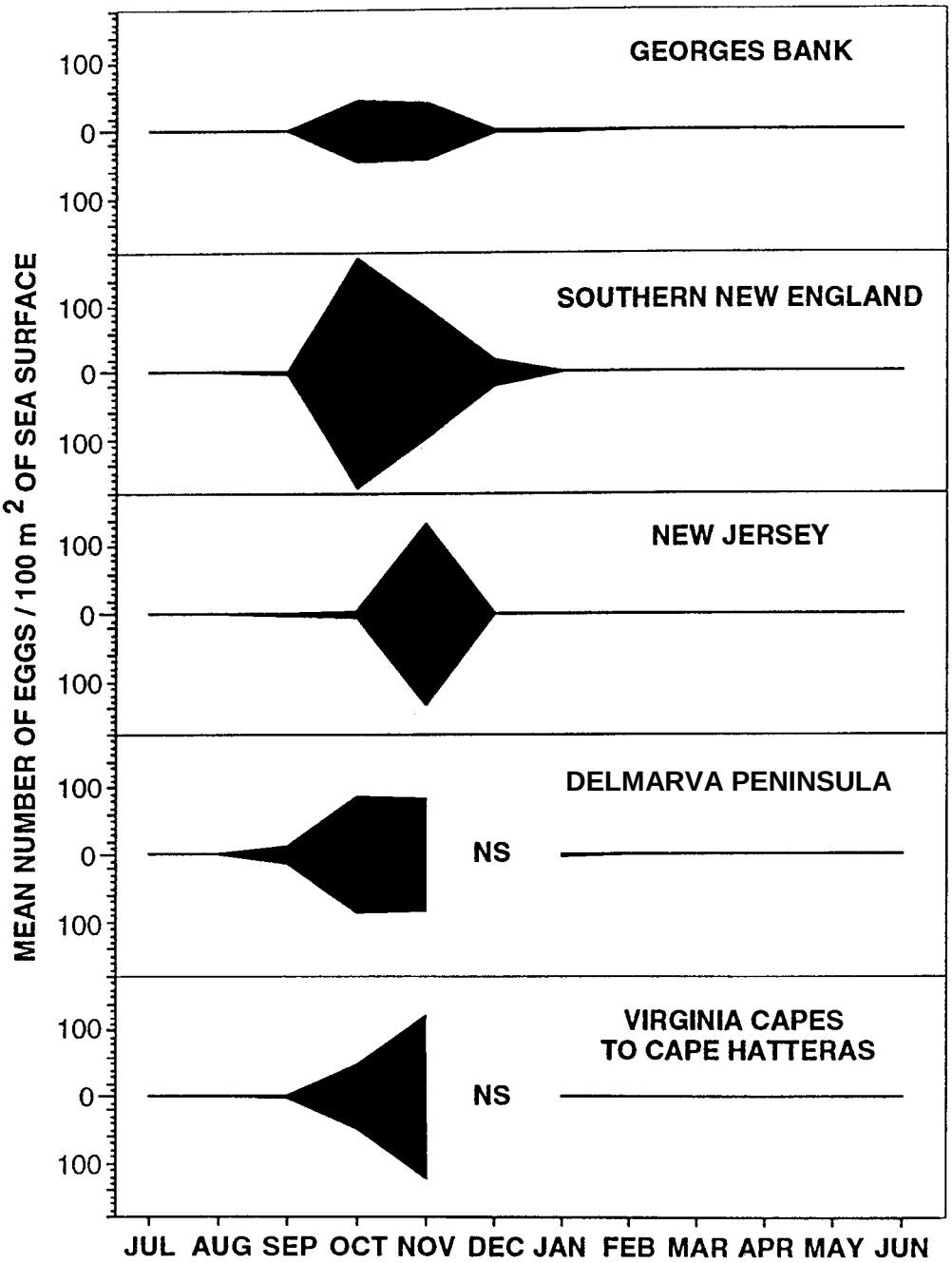


Figure 15. Monthly abundance of summer flounder eggs by region from NEFSC MARMAP offshore ichthyoplankton surveys from Cape Sable to Cape Hatteras during 1979-1981, 1984, and 1985 [see Reid *et al.* (1999) for details]. NS = no samples. Adapted from Able and Kaiser (1994).

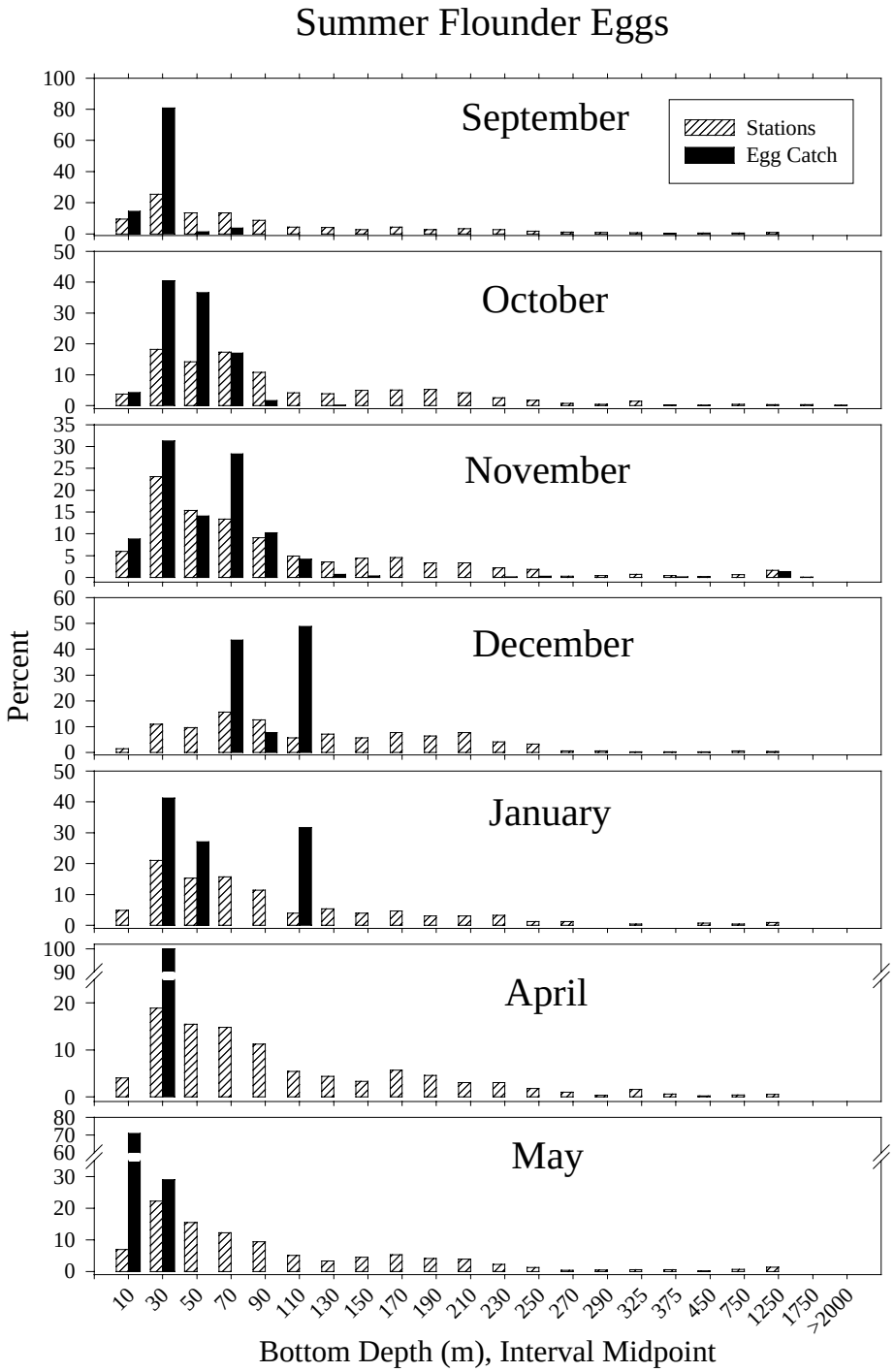


Figure 16. Abundance of summer flounder eggs relative to water depth based on NEFSC MARMAP offshore ichthyoplankton surveys [1978-1987, all years combined; see Reid *et al.* (1999) for details]. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

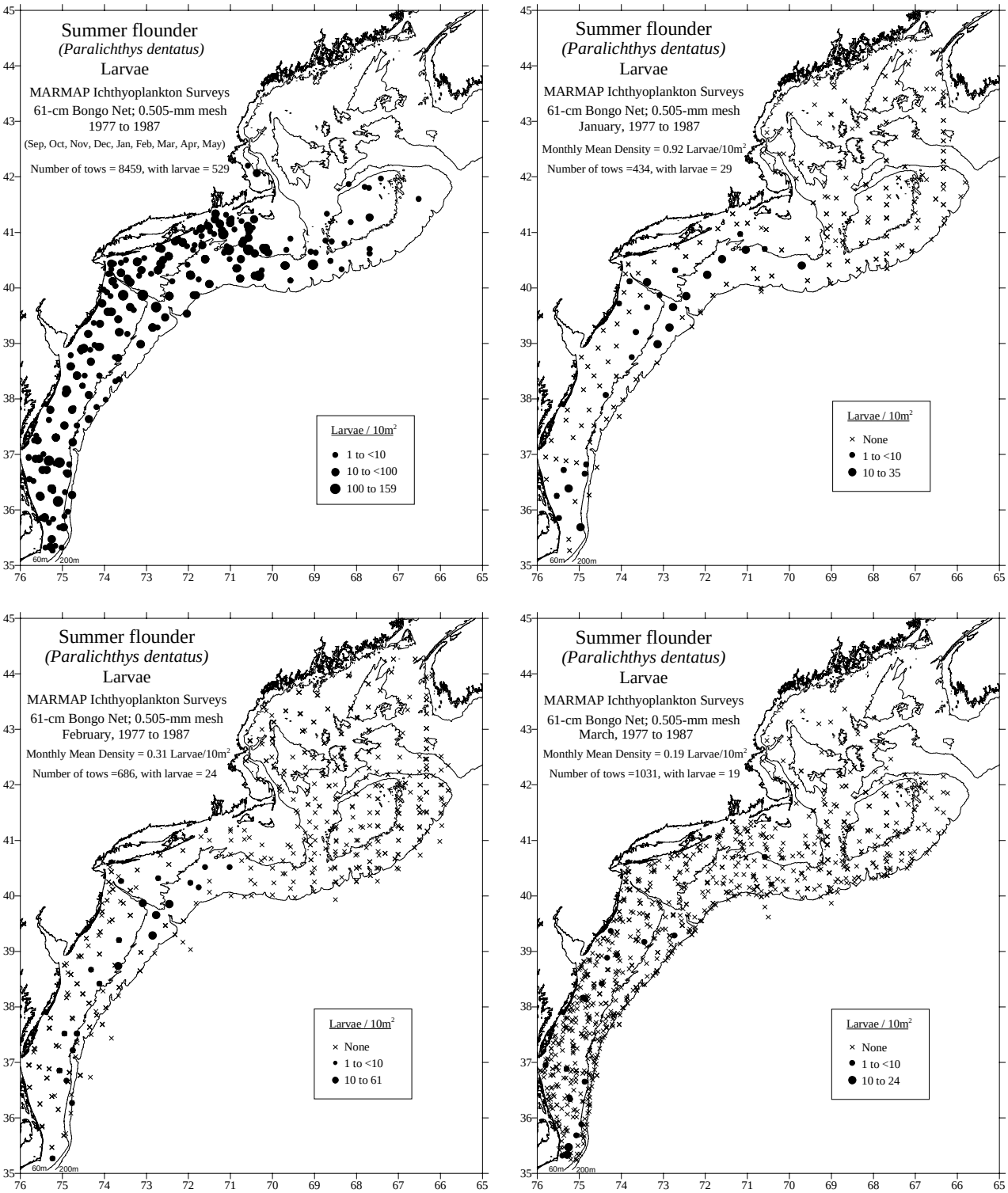


Figure 17. Distribution and abundance of summer flounder larvae collected during NEFSC MARMAP offshore ichthyoplankton surveys from Cape Sable to Cape Hatteras during 1977-1987 [see Reid *et al.* (1999) for details].

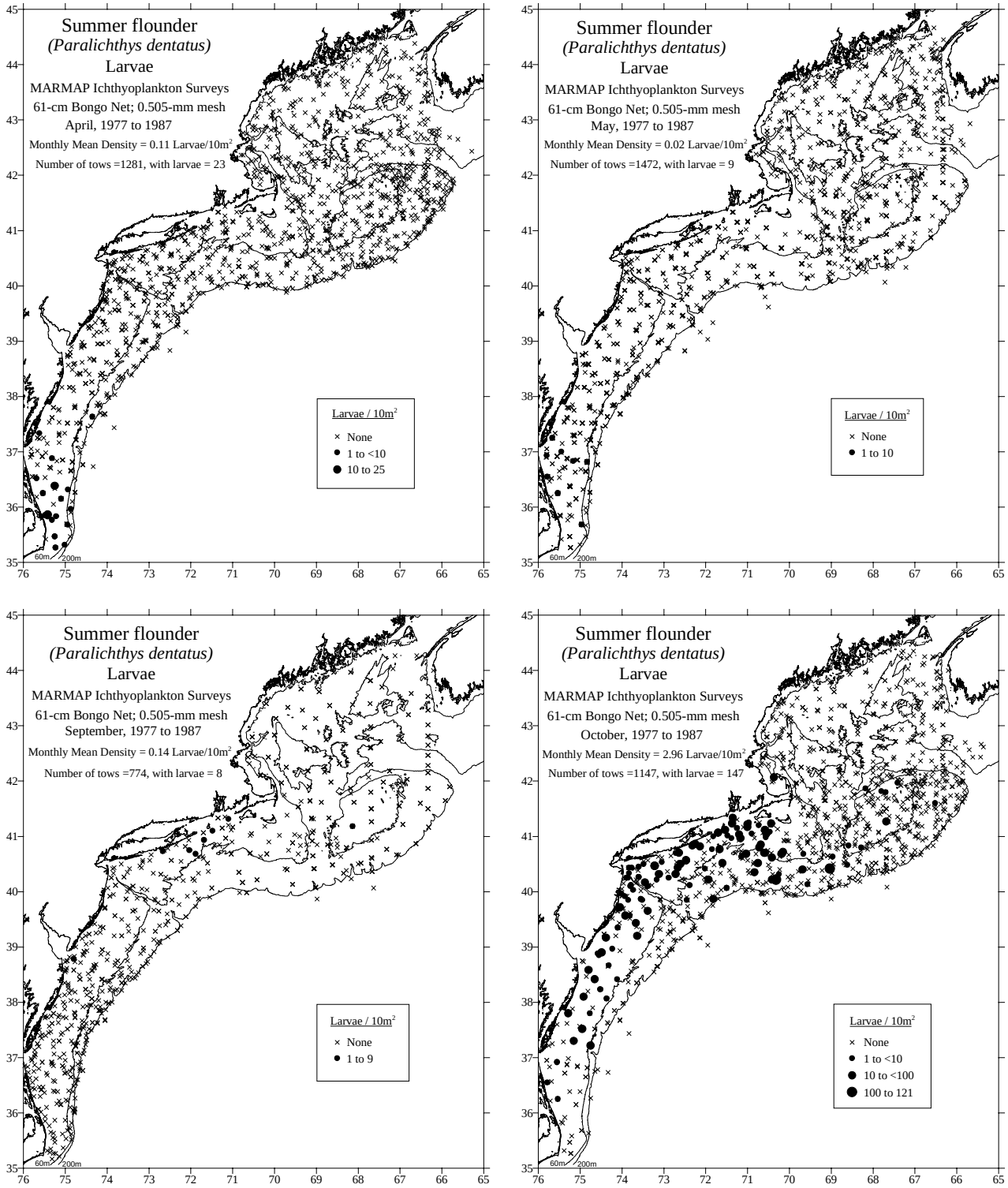
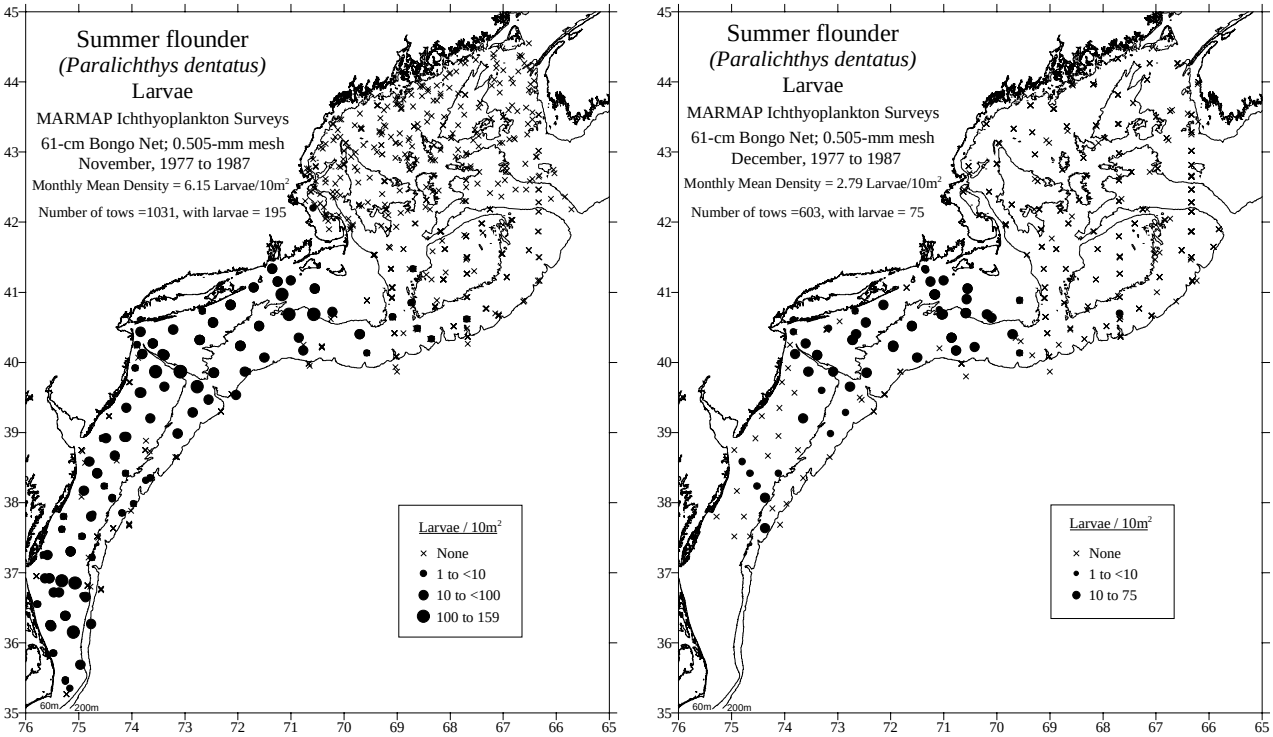


Figure 17. cont'd.



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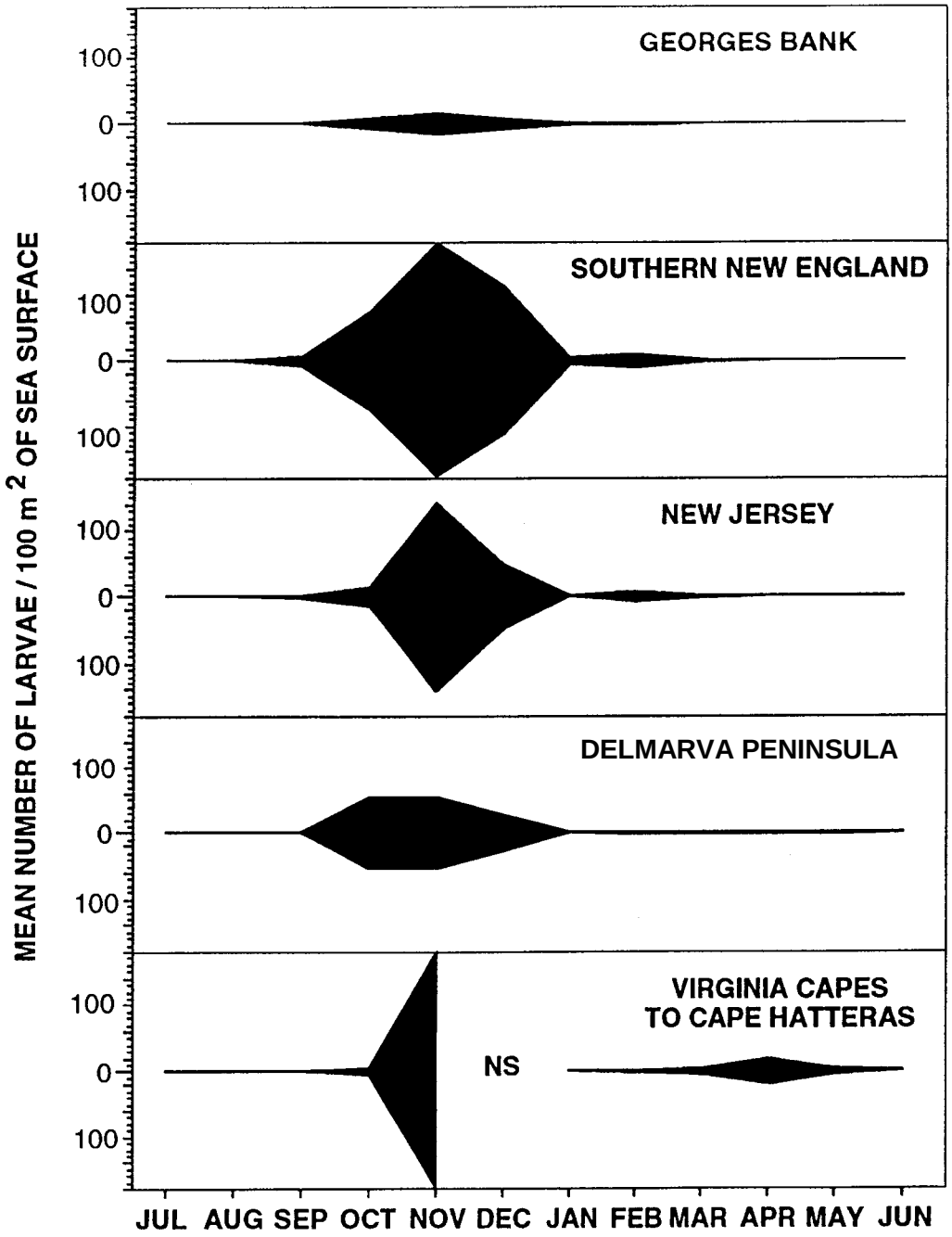


Figure 18. Monthly abundance of summer flounder larvae by region from NEFSC MARMAP offshore ichthyoplankton surveys from Cape Sable to Cape Hatteras during 1979-81, 1984, and 1985 [see Reid *et al.* (1999) for details]. NS = no samples. Adapted from Able and Kaiser (1994).

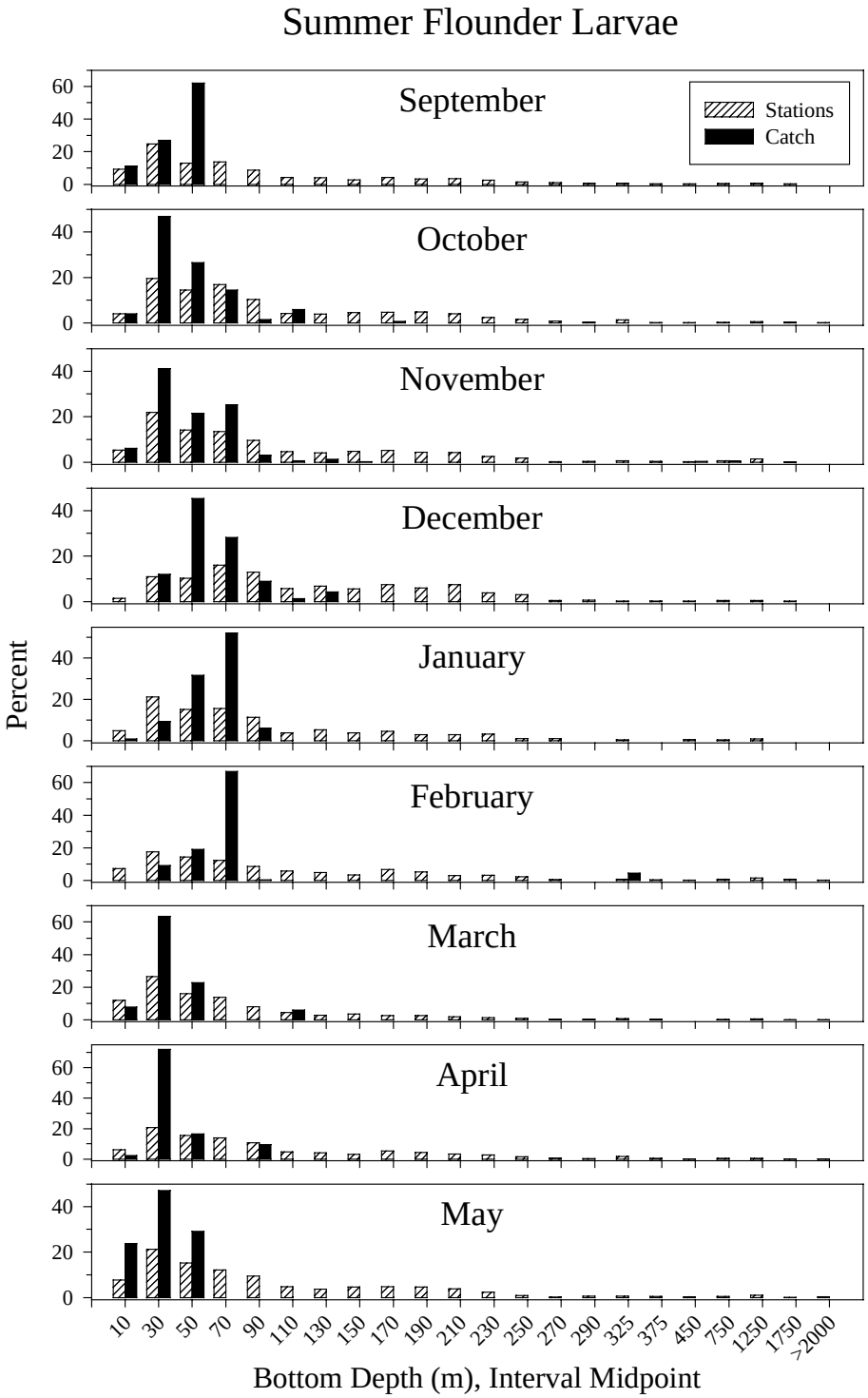


Figure 19. Abundance of summer flounder larvae relative to water depth based on NEFSC MARMAP offshore ichthyoplankton surveys [1977-1987, all years combined; see Reid *et al*. (1999) for details]. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

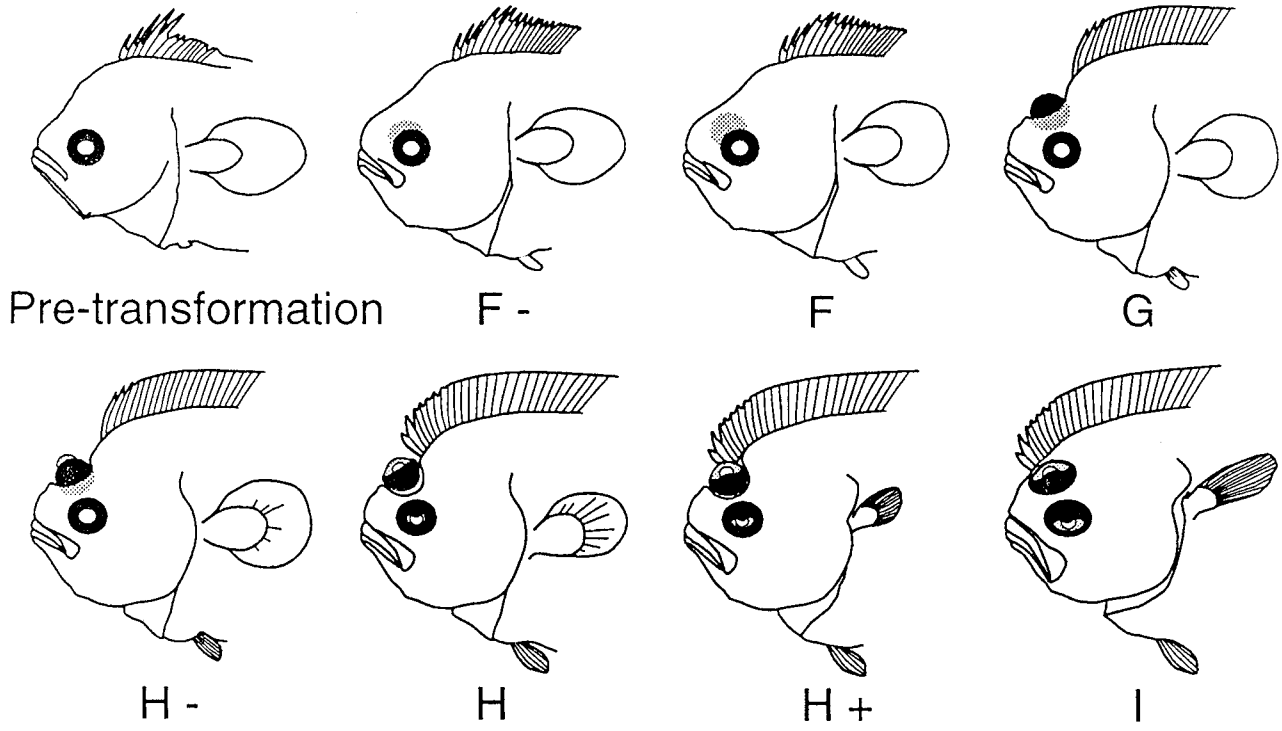


Figure 20. Classification of the transformation stages of summer flounder based on degree of eye migration [adapted from Keefe and Able (1993) and Able and Kaiser (1994)]. The right and left eyes are bilateral and symmetrical in pre-transformation individuals. At the first stage of transformation, F -, the eyes are bilateral but asymmetrical with the right eye just dorsal to the left eye. By stage G, the right eye is visible from the left side of the fish. Stage H - differs from G in that the cornea of the eye is visible from the left side of the fish. At Stage H, the right eye has reached the dorsal midline. By Stage H +, the right eye has reached the left side of the head but has not yet reached its final resting place. At Stage I, the eye is set in the socket and the dorsal canal is closed.

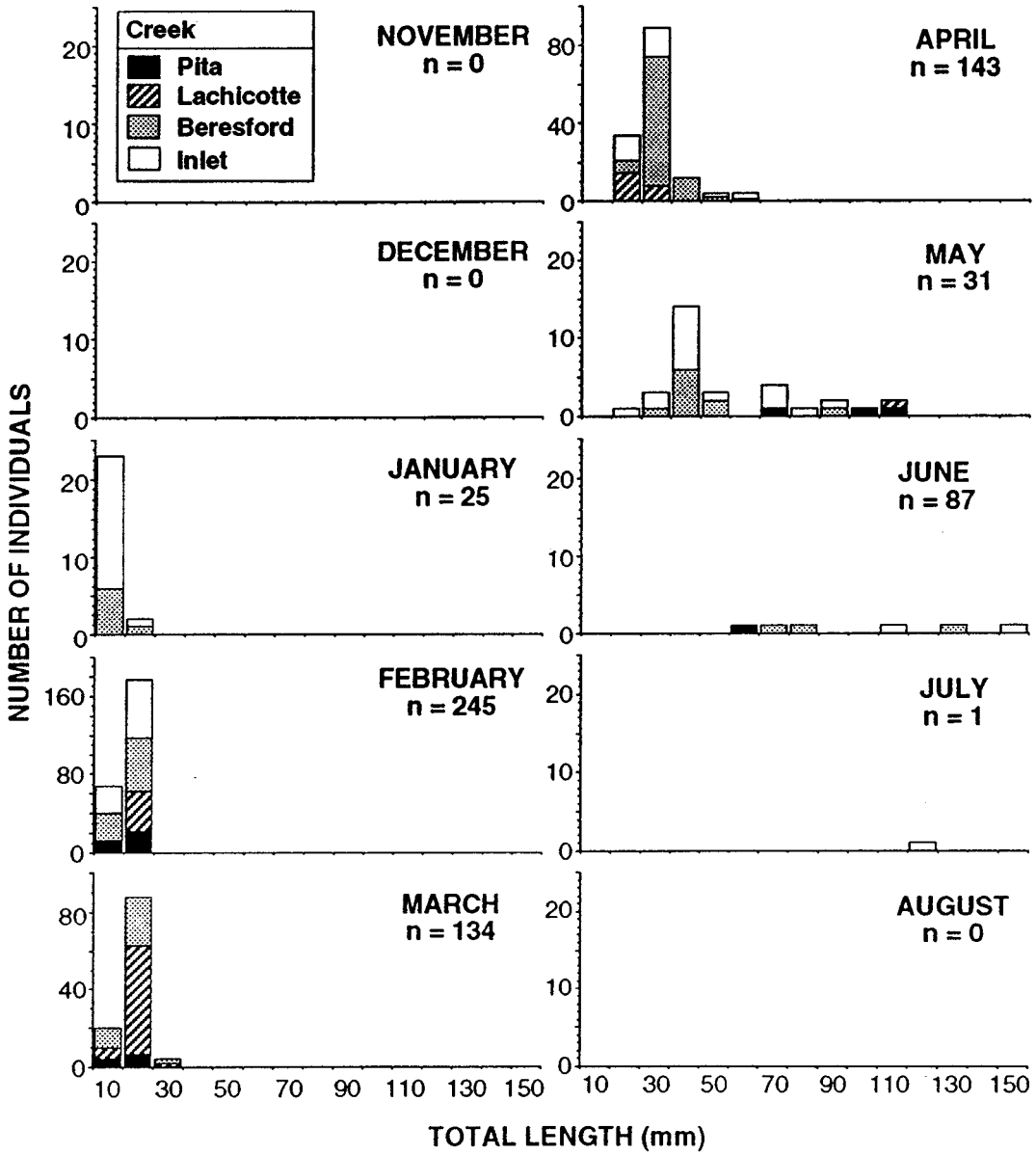


Figure 21. Length frequency distributions for transforming larval and juvenile summer flounder collected during 1986-1987 from estuarine marsh creeks in Charleston Harbor, South Carolina, using a rotenone/block net method (Wenner *et al.* 1990a). Adapted from Able and Kaiser (1994).

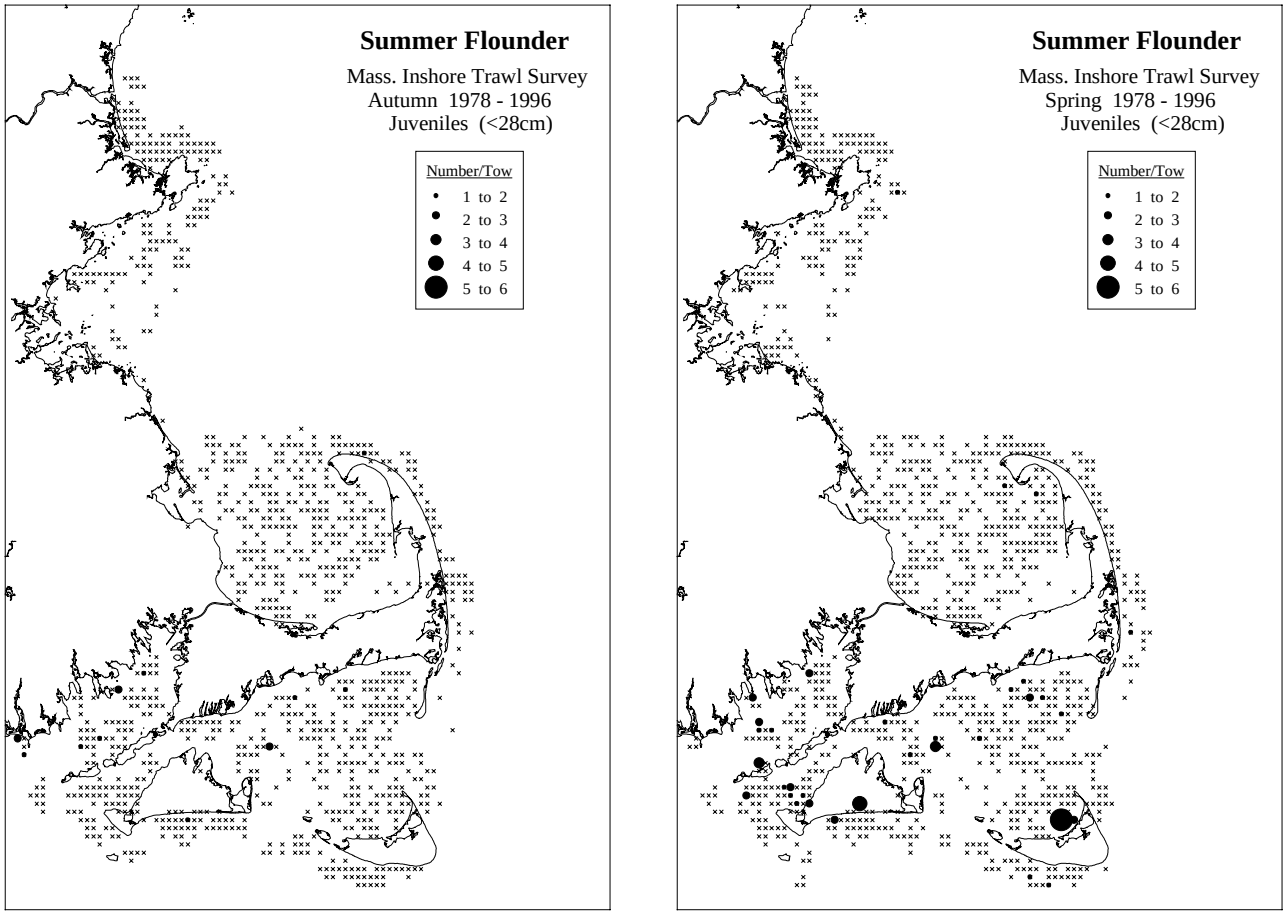


Figure 22. Distribution and abundance of juvenile summer flounder in Massachusetts coastal waters from shore out to 3 miles during fall (typically September) and spring (typically May), based on bottom trawl surveys by the Massachusetts Division of Marine Fisheries from 1978-1996 (Howe *et al.* 1997; Reid *et al.* 1999). Collections where no juveniles were caught are shown as small x's.

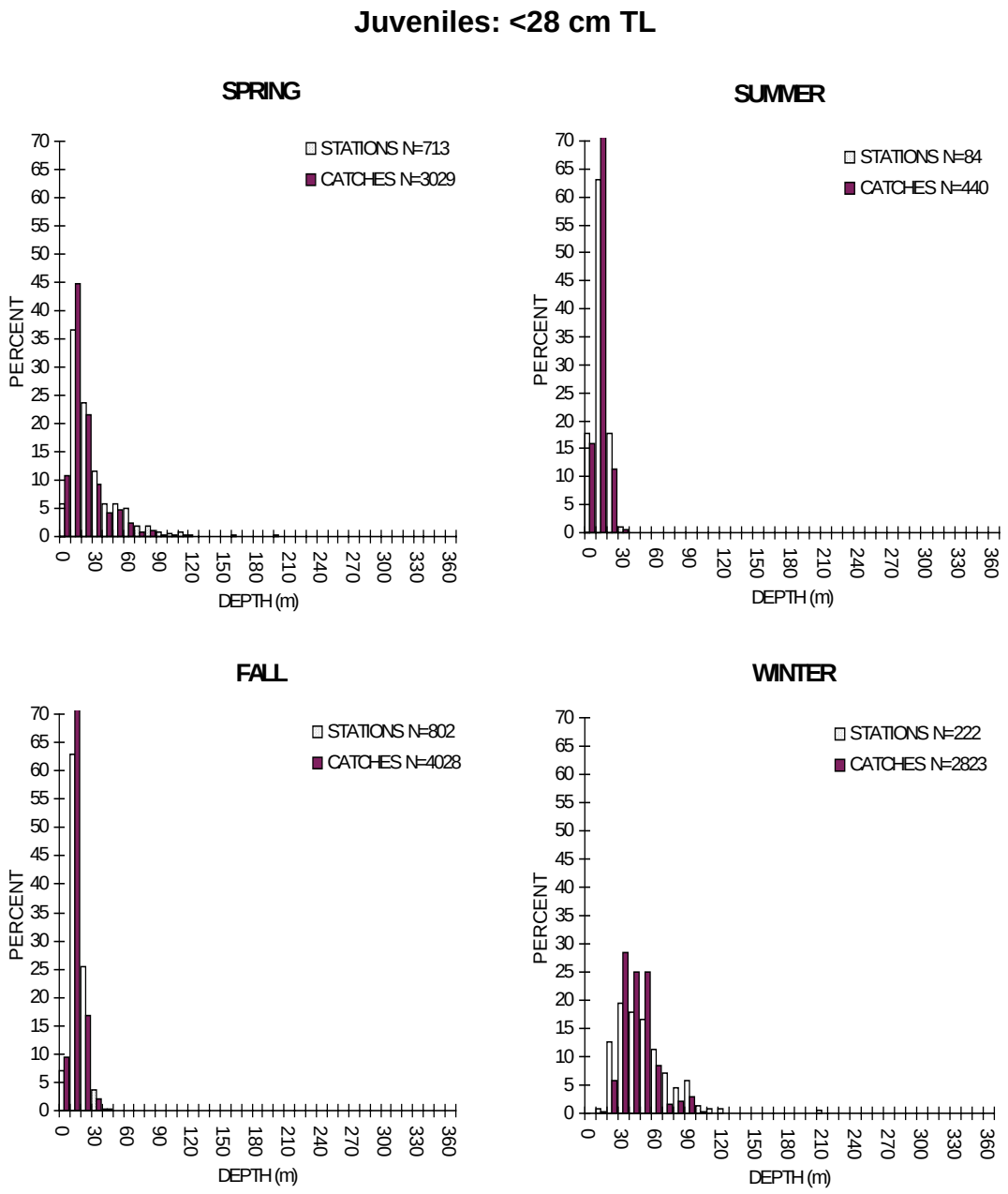


Figure 23. Seasonal abundance of juvenile summer flounder relative to water depth based on NEFSC bottom trawl surveys [1963-1997, all years combined; see Reid *et al.* (1999) for details]. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

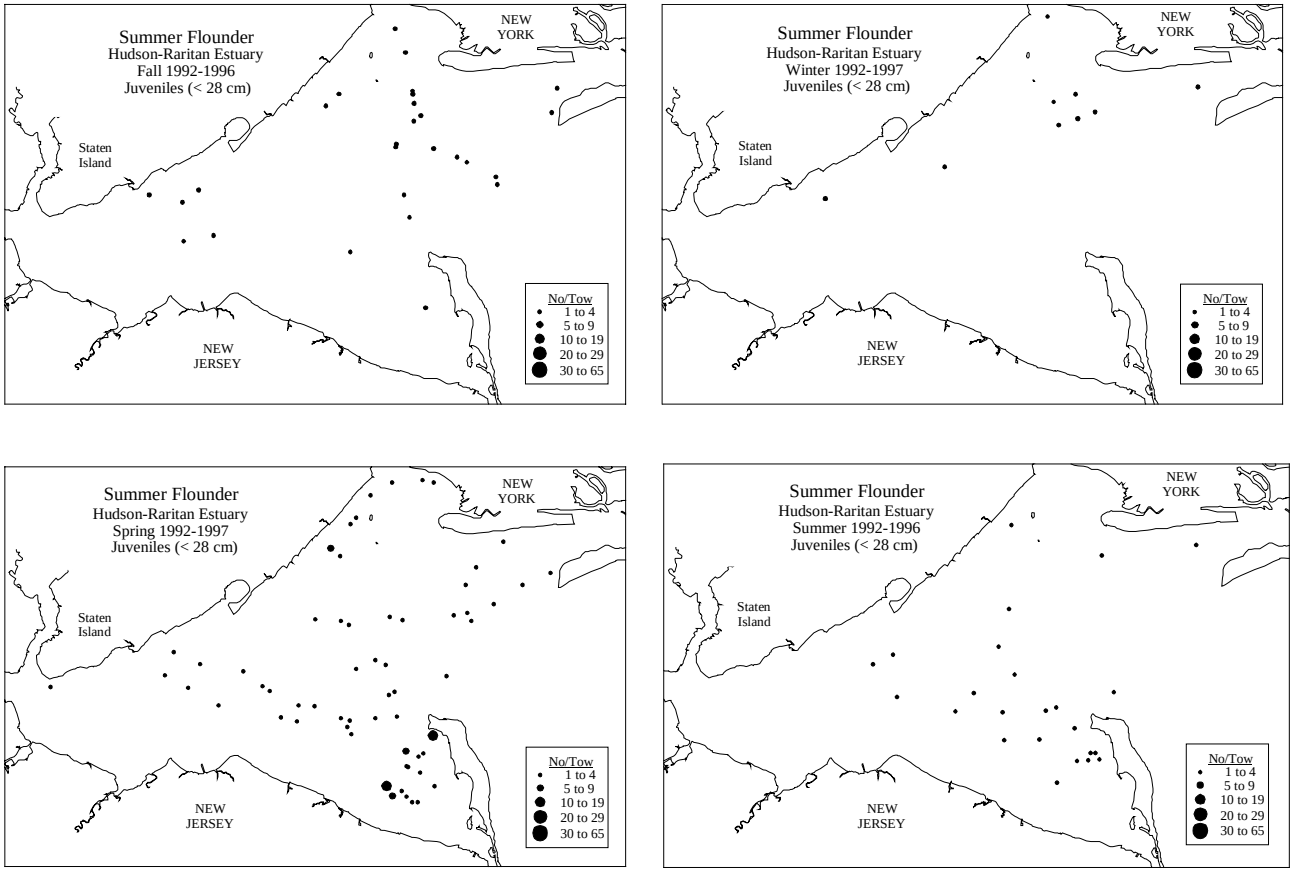


Figure 24. Distribution and relative abundance of juvenile summer flounder collected in the Hudson-Raritan estuary during Hudson-Raritan trawl surveys in fall (October-December, 1992-1996), winter (January-March, 1992-1997), spring (April and June, 1992-1996), and summer (July and August, 1992-1996) [see Reid *et al.* (1999) for details].

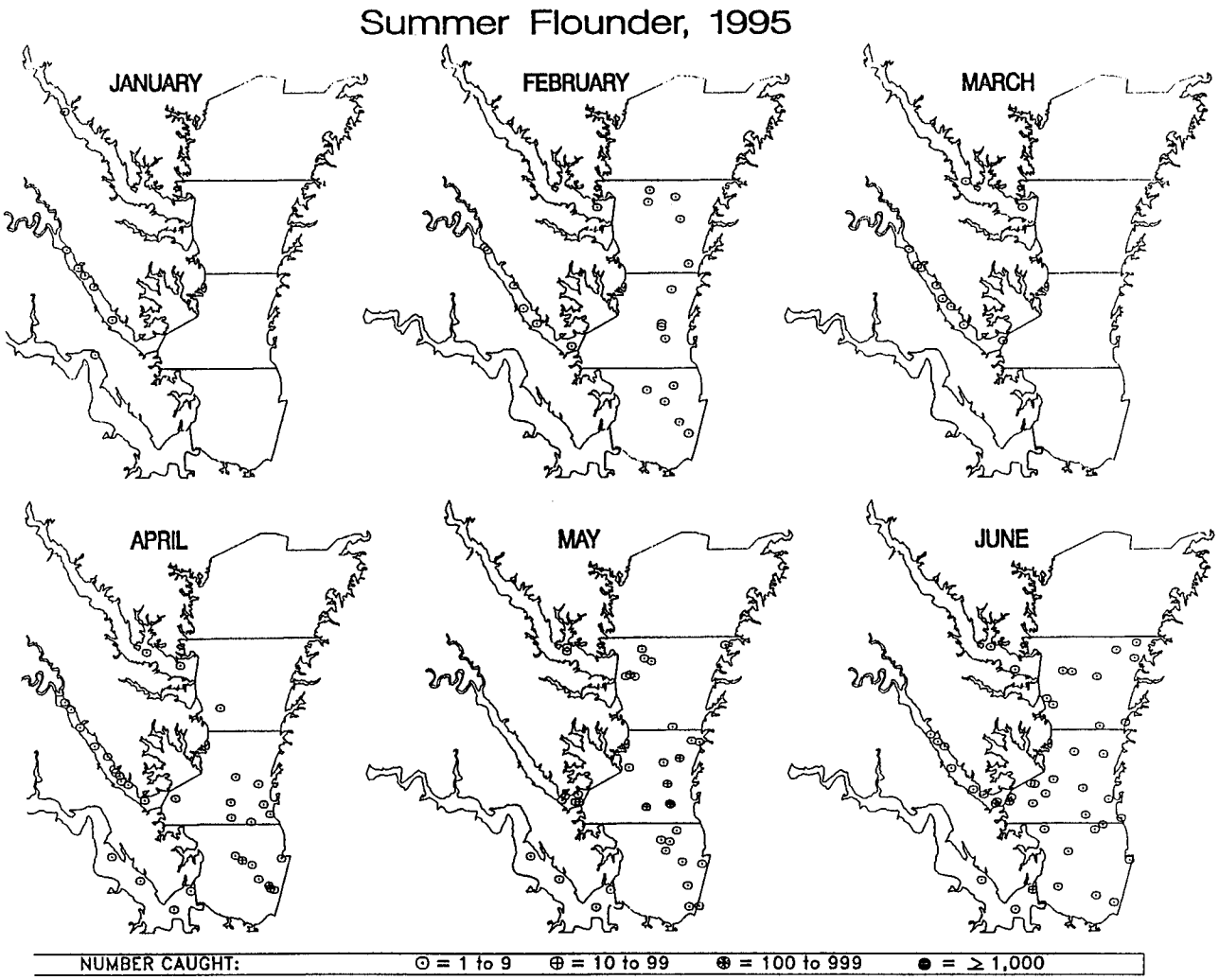


Figure 25. Monthly distribution of summer flounder in the main stem of Chesapeake Bay and in the major Virginia tributaries (from north to south: Rappahannock, York, James Rivers) from January-December 1995. Density values are the total number of individuals caught in a 9.1 m semi-balloon otter trawl with 38 mm mesh and 6.4 mm codend. Adapted from Geer and Austin (1996).

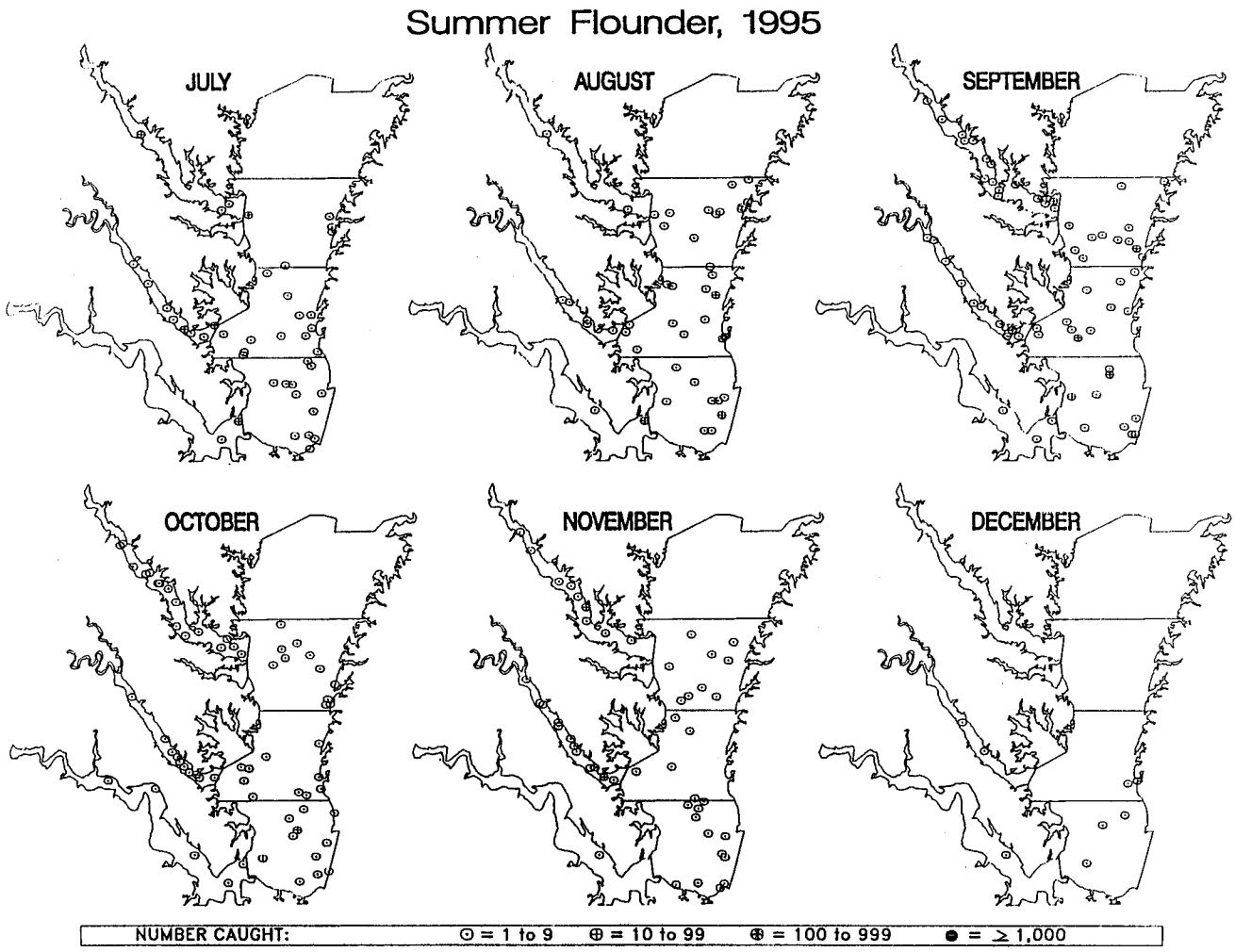
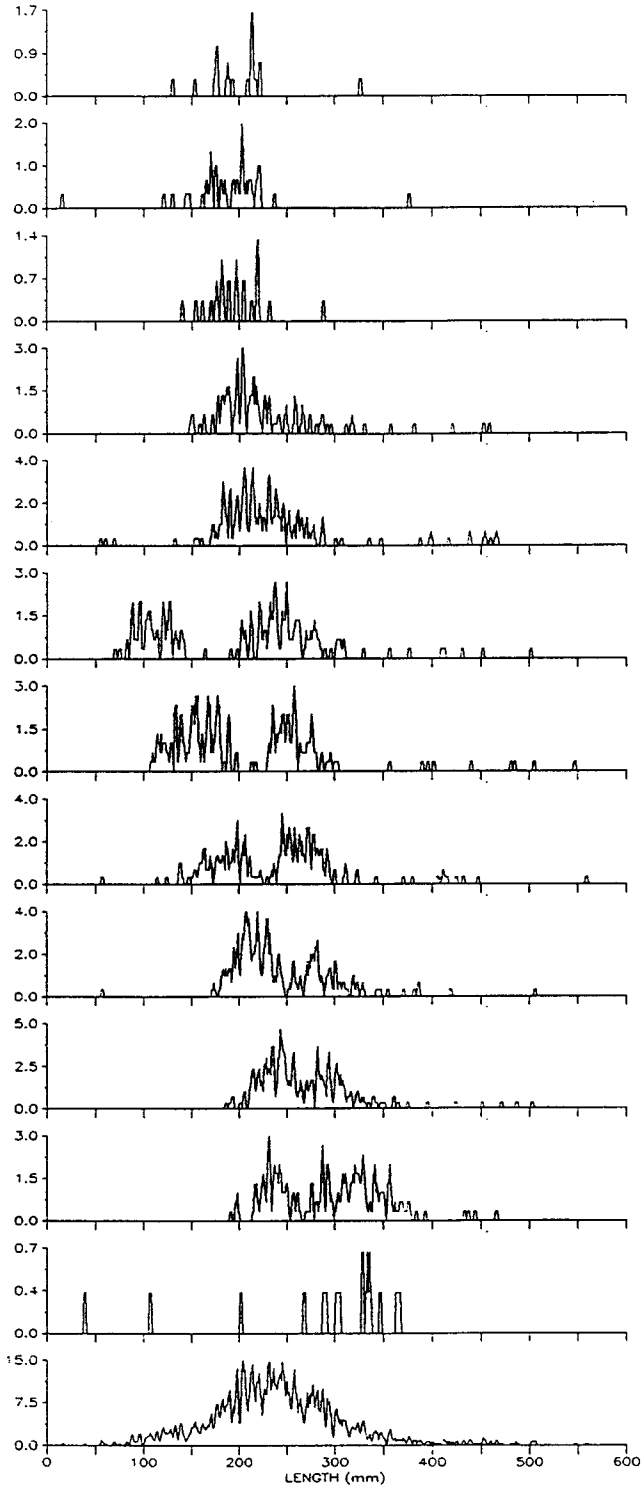


Figure 25. cont'd.



JANUARY	950109 – 950113				
NO. CGHT.	–	19	MEAN SIZE	–	199.1
NO. MEAS.	–	19	S.E. SIZE	–	9.1
NO. HAULS	–	40	MIN. SIZE	–	128
CAT./HAUL	–	0.5	MAX. SIZE	–	325
FEBRUARY	950201 – 950216				
NO. CGHT.	–	42	MEAN SIZE	–	187.4
NO. MEAS.	–	42	S.E. SIZE	–	7.3
NO. HAULS	–	73	MIN. SIZE	–	14
CAT./HAUL	–	0.6	MAX. SIZE	–	375
MARCH	950301 – 950313				
NO. CGHT.	–	23	MEAN SIZE	–	194.2
NO. MEAS.	–	23	S.E. SIZE	–	6.4
NO. HAULS	–	40	MIN. SIZE	–	138
CAT./HAUL	–	0.6	MAX. SIZE	–	286
APRIL	950406 – 950418				
NO. CGHT.	–	105	MEAN SIZE	–	225
NO. MEAS.	–	105	S.E. SIZE	–	5.6
NO. HAULS	–	73	MIN. SIZE	–	146
CAT./HAUL	–	1.4	MAX. SIZE	–	457
MAY	950503 – 950511				
NO. CGHT.	–	176	MEAN SIZE	–	231.1
NO. MEAS.	–	176	S.E. SIZE	–	5
NO. HAULS	–	79	MIN. SIZE	–	53
CAT./HAUL	–	2.2	MAX. SIZE	–	465
JUNE	950601 – 950614				
NO. CGHT.	–	165	MEAN SIZE	–	200.8
NO. MEAS.	–	165	S.E. SIZE	–	6.6
NO. HAULS	–	88	MIN. SIZE	–	68
CAT./HAUL	–	1.9	MAX. SIZE	–	500
JULY	950705 – 950724				
NO. CGHT.	–	181	MEAN SIZE	–	208
NO. MEAS.	–	181	S.E. SIZE	–	5.8
NO. HAULS	–	88	MIN. SIZE	–	106
CAT./HAUL	–	2.1	MAX. SIZE	–	545
AUGUST	950801 – 950810				
NO. CGHT.	–	195	MEAN SIZE	–	237.7
NO. MEAS.	–	195	S.E. SIZE	–	4.7
NO. HAULS	–	88	MIN. SIZE	–	55
CAT./HAUL	–	2.2	MAX. SIZE	–	557
SEPTEMBER	950905 – 950920				
NO. CGHT.	–	210	MEAN SIZE	–	241.4
NO. MEAS.	–	210	S.E. SIZE	–	3.5
NO. HAULS	–	105	MIN. SIZE	–	55
CAT./HAUL	–	2	MAX. SIZE	–	504
OCTOBER	951002 – 951018				
NO. CGHT.	–	224	MEAN SIZE	–	266.2
NO. MEAS.	–	224	S.E. SIZE	–	3.3
NO. HAULS	–	105	MIN. SIZE	–	184
CAT./HAUL	–	2.1	MAX. SIZE	–	501
NOVEMBER	951110 – 951133				
NO. CGHT.	–	170	MEAN SIZE	–	292.2
NO. MEAS.	–	170	S.E. SIZE	–	4.1
NO. HAULS	–	99	MIN. SIZE	–	189
CAT./HAUL	–	1.7	MAX. SIZE	–	464
DECEMBER	951201 – 951213				
NO. CGHT.	–	16	MEAN SIZE	–	281.9
NO. MEAS.	–	16	S.E. SIZE	–	23.1
NO. HAULS	–	102	MIN. SIZE	–	37
CAT./HAUL	–	0.2	MAX. SIZE	–	365
JAN – DEC	950109 – 951213				
NO. CGHT.	–	1526	MEAN SIZE	–	237.3
NO. MEAS.	–	1526	S.E. SIZE	–	1.8
NO. HAULS	–	980	MIN. SIZE	–	14
CAT./HAUL	–	1.6	MAX. SIZE	–	557

Figure 26. Monthly length frequency summary for summer flounder in the main stem of Chesapeake Bay and the major Virginia tributaries (Rappahannock, York, James Rivers) from January-December 1995. The y-axis represents the total number caught for each size class, in mm. The bottom plot is a summary of all fish for the entire year. Adapted from Geer and Austin (1996).

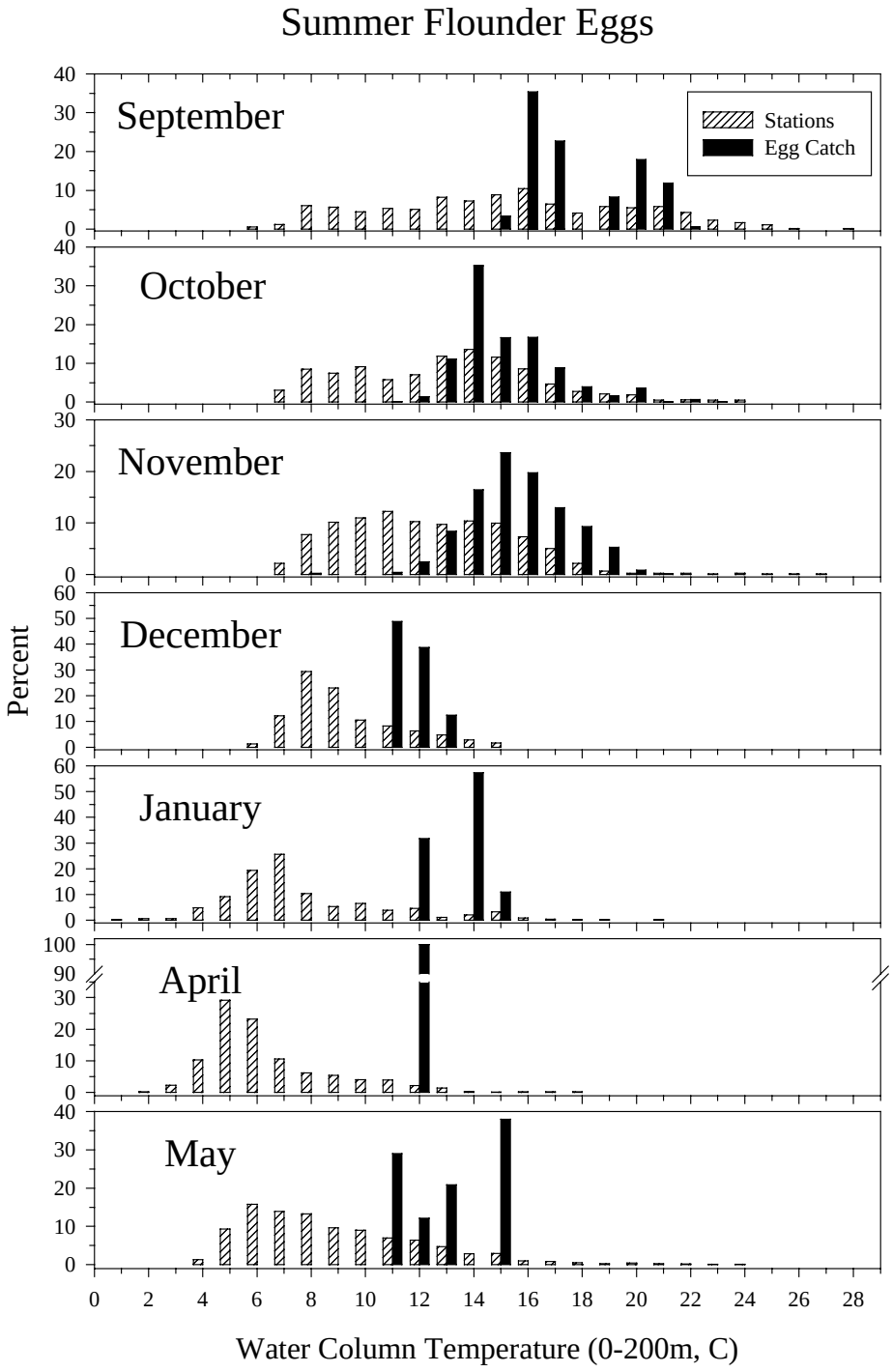


Figure 27. Abundance of summer flounder eggs relative to water column temperature (to a maximum of 200 m) based on NEFSC MARMAP offshore ichthyoplankton surveys [1978-1987, all years combined; see Reid *et al.* (1999) for details]. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

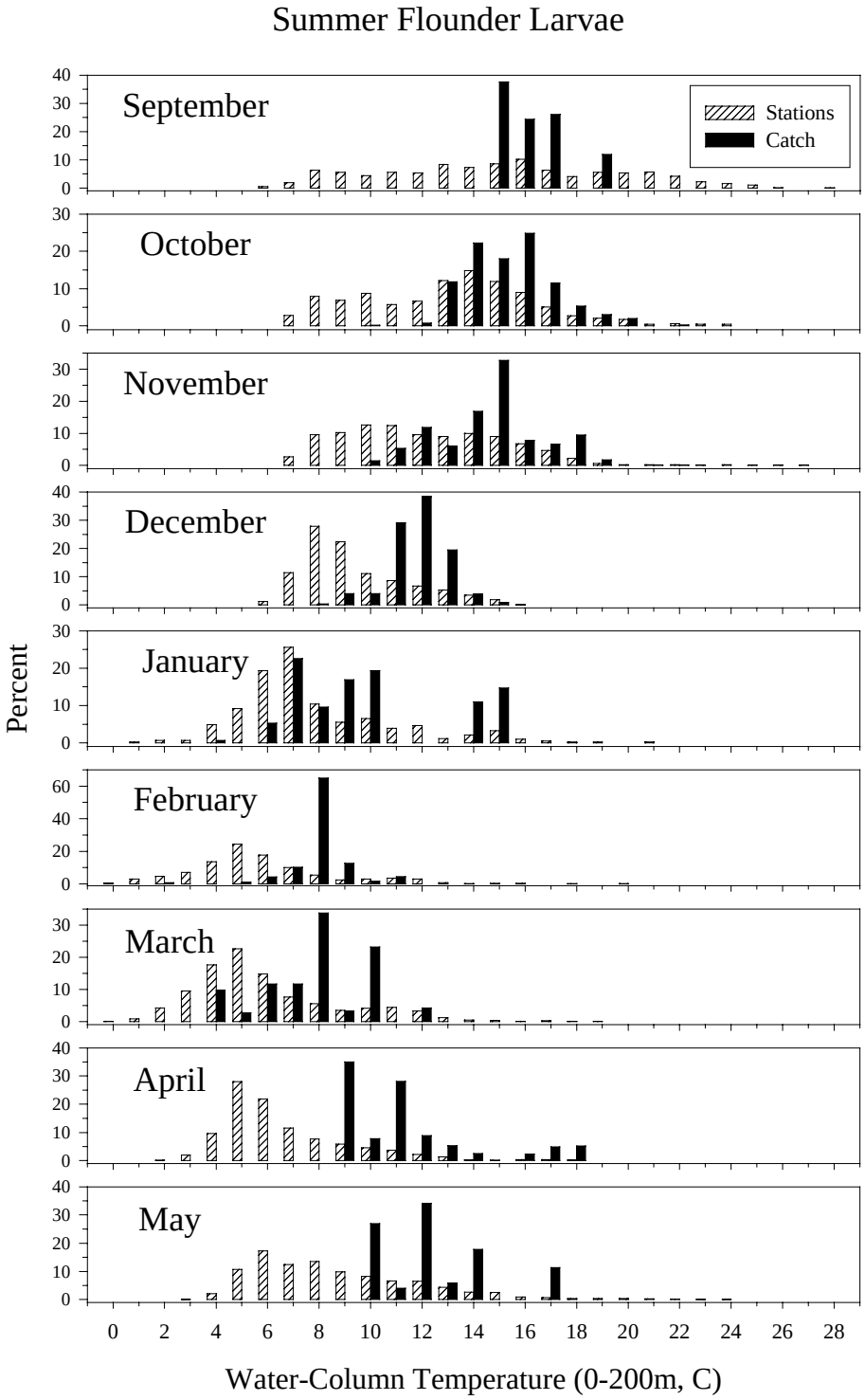


Figure 28. Abundance of summer flounder larvae relative to water column temperature (to a maximum of 200 m) based on NEFSC MARMAP offshore ichthyoplankton surveys [1977-1987, all years combined; see Reid *et al.* (1999) for details]. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

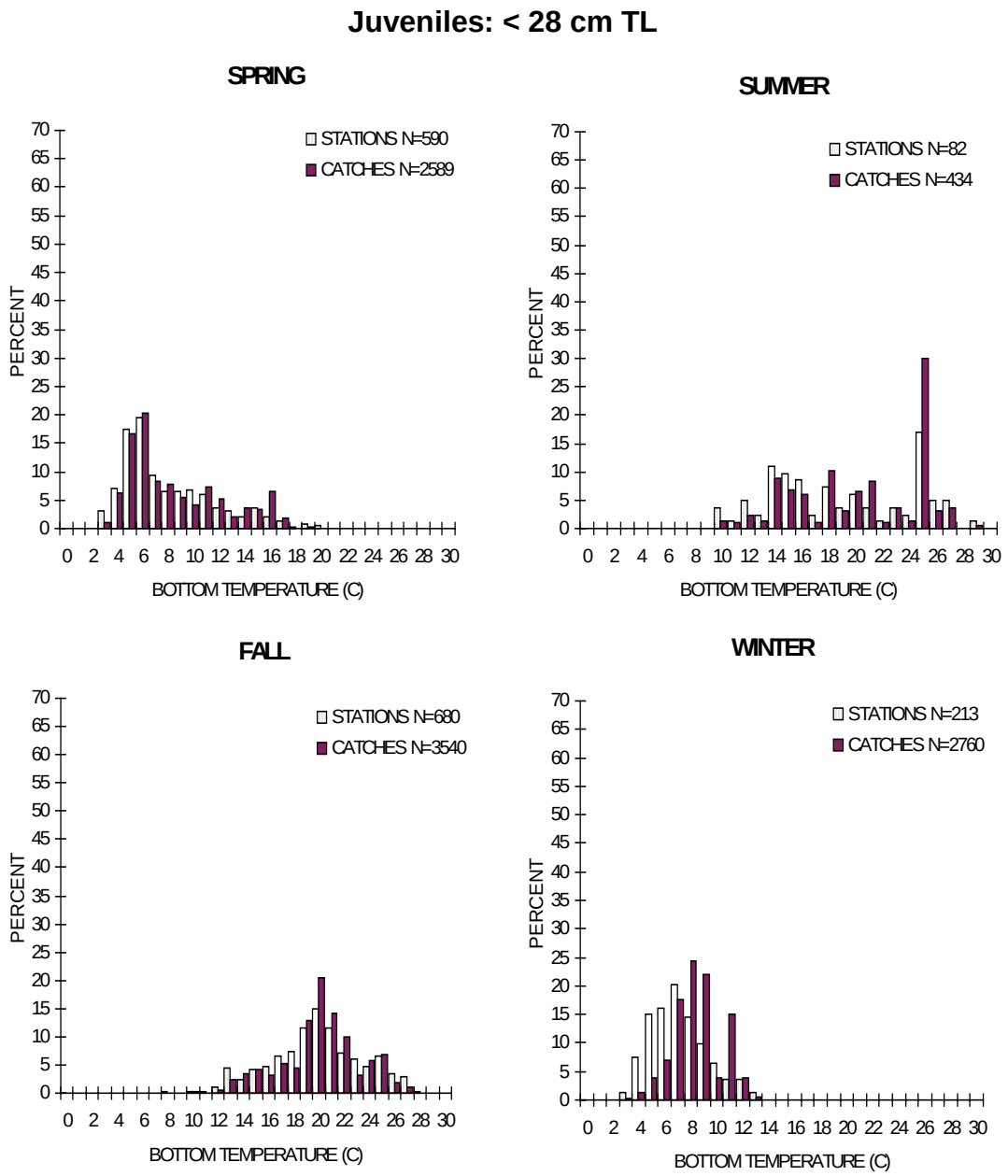


Figure 29. Seasonal abundance of juvenile summer flounder relative to bottom water temperature based on NEFSC bottom trawl surveys [1963-1997, all years combined; see Reid *et al.* (1999) for details]. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

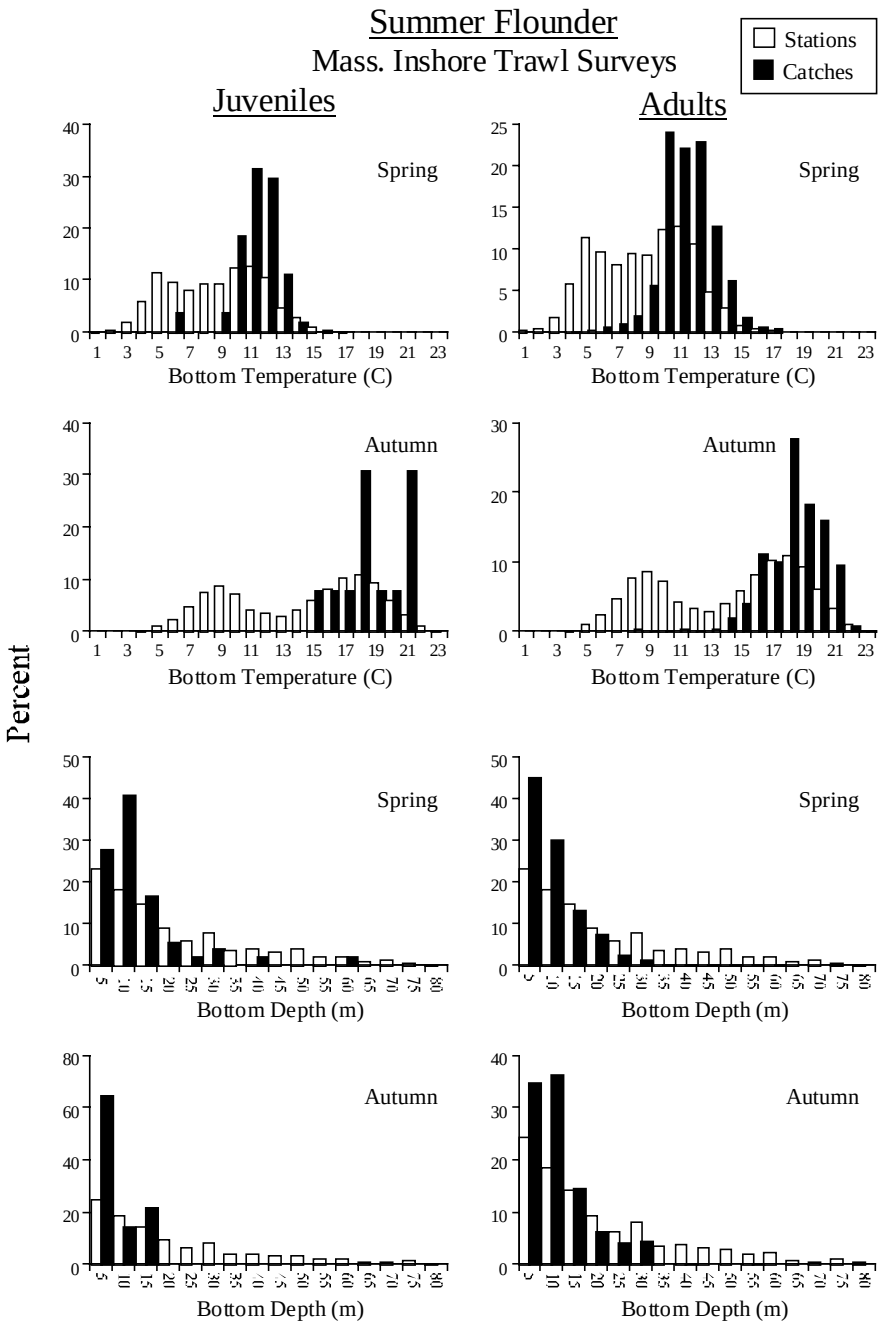


Figure 30. Abundance of juvenile and adult summer flounder relative to bottom water temperature and depth based on Massachusetts inshore trawl surveys (spring and autumn 1978-1996, all years combined). Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

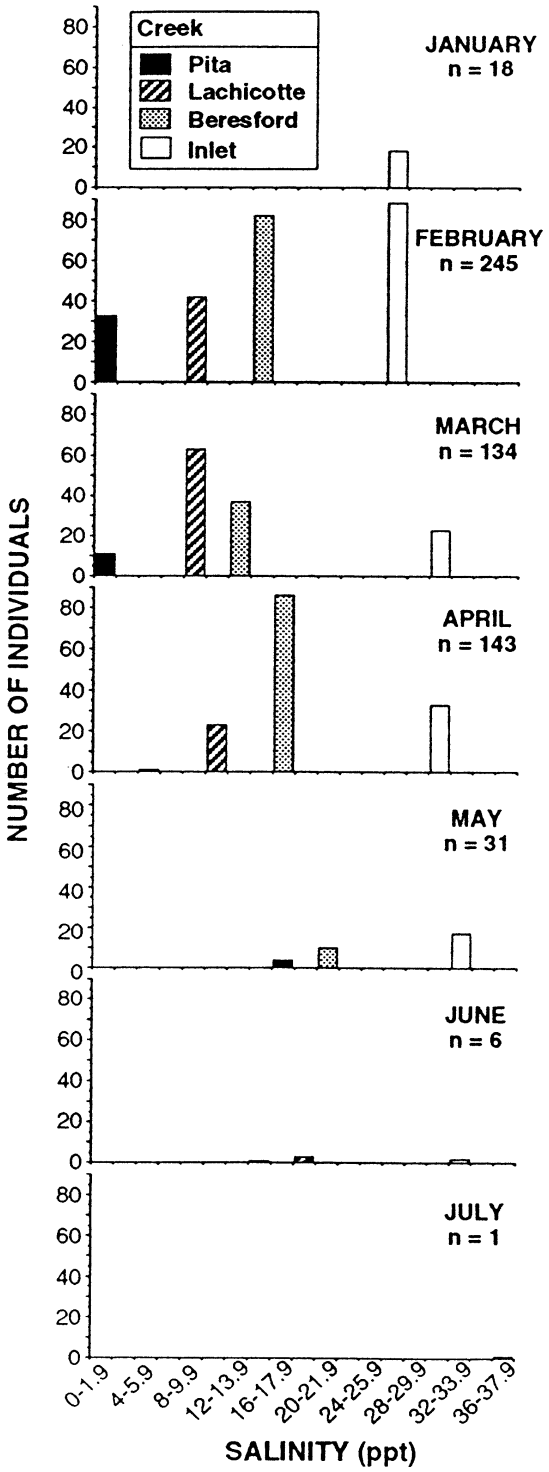


Figure 31. Abundance of juvenile summer flounder relative to salinity in four Charleston Harbor, South Carolina marsh creeks during 1987. Fish were collected using a rotenone/block net method [data based on Wenner *et al.* (1990a)]. Adapted from Able and Kaiser (1994).

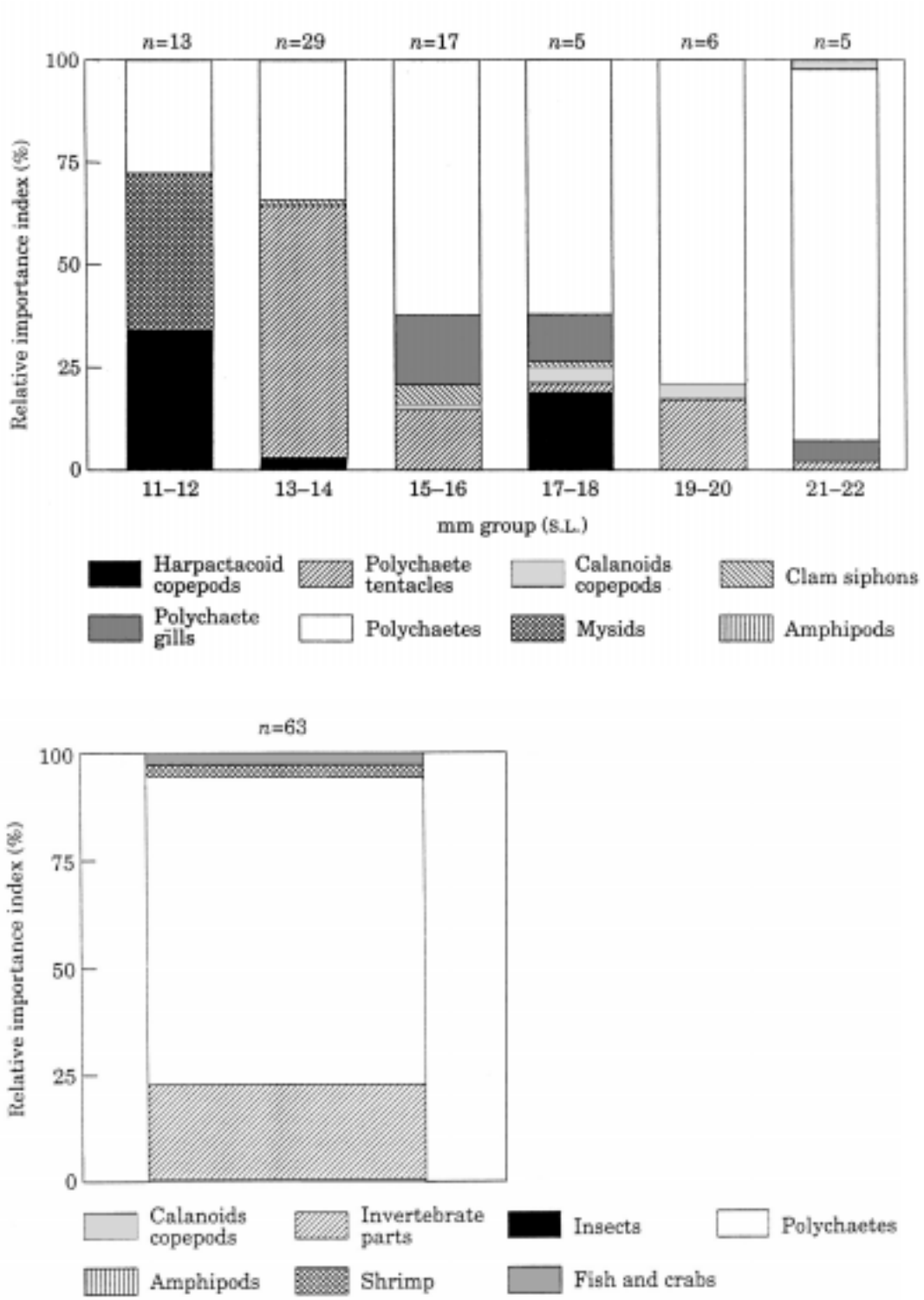


Figure 32. Relative importance of each diet item (percentage of total number multiplied by the frequency of occurrence) to: (top) different length groups of summer flounder during the immigration period, January-March 1988, in the Newport and North Rivers, North Carolina; and (bottom) to 20-60 mm SL summer flounder following segregation from southern flounder in April-June 1988 in the Newport and North Rivers, North Carolina. Relative importance values are presented as the percentage of the sum of all values for (top) each 2 mm length group and for (bottom) each species. Adapted from Burke (1995).

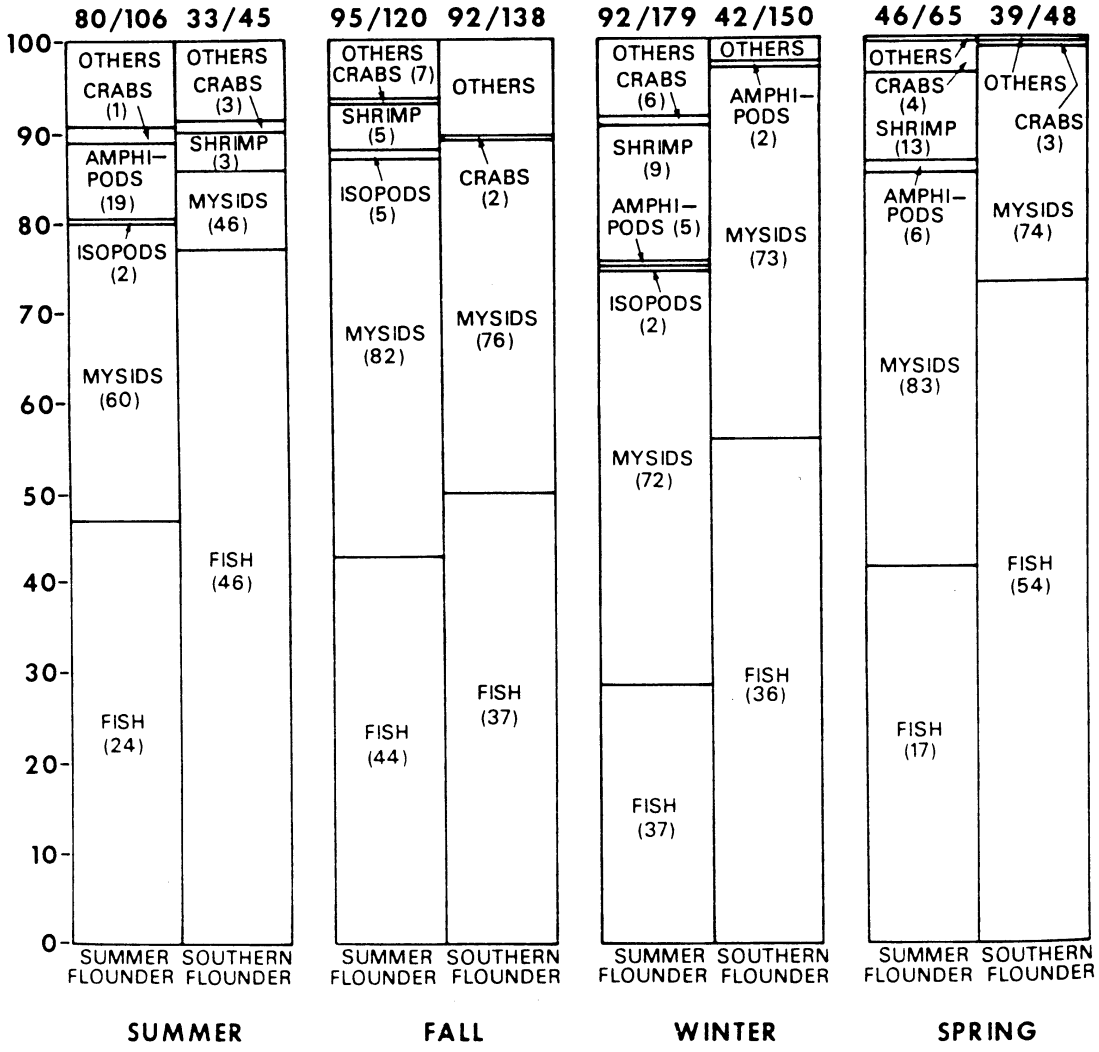


Figure 33. Percentage of volume and (in parentheses) percentage of occurrence of food items occurring in the seasonal diet of young (100-200 mm TL) summer and southern flounder from the Neuse River and Pamlico Sound, North Carolina. Numbers above each bar graph indicate the number of stomachs with food/the total number of stomachs examined. Adapted from Powell and Schwartz (1979).

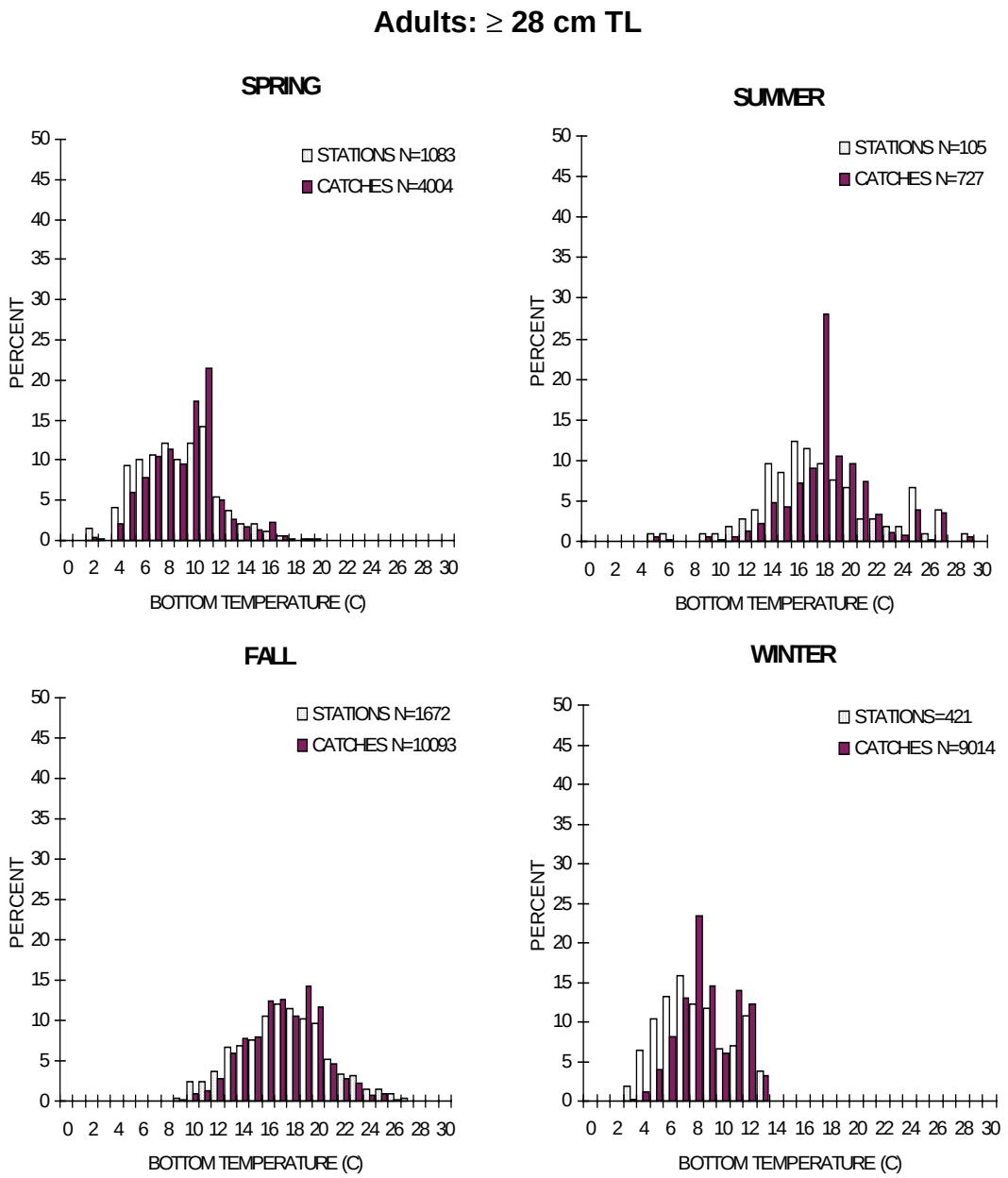


Figure 34. Seasonal abundance of adult summer flounder relative to bottom water temperature based on NEFSC bottom trawl surveys [1963-1997, all years combined; see Reid *et al.* (1999) for details]. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2).

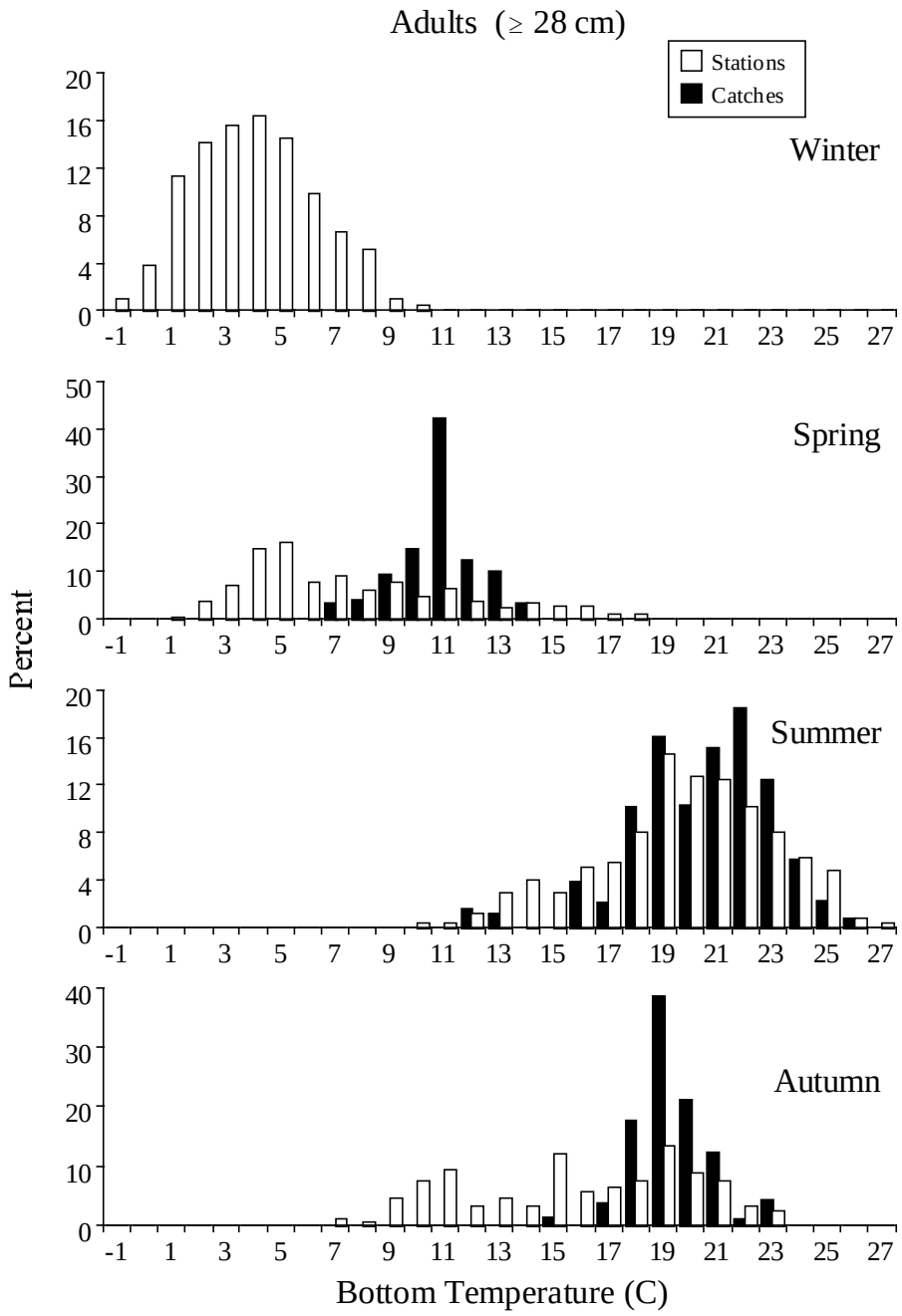


Figure 35. Seasonal abundance of adult summer flounder relative to mean bottom water temperature based on Rhode Island Division of Fish and Wildlife bottom trawl surveys of Narragansett Bay, 1990-1996 [see Reid *et al.* (1999) for details]. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

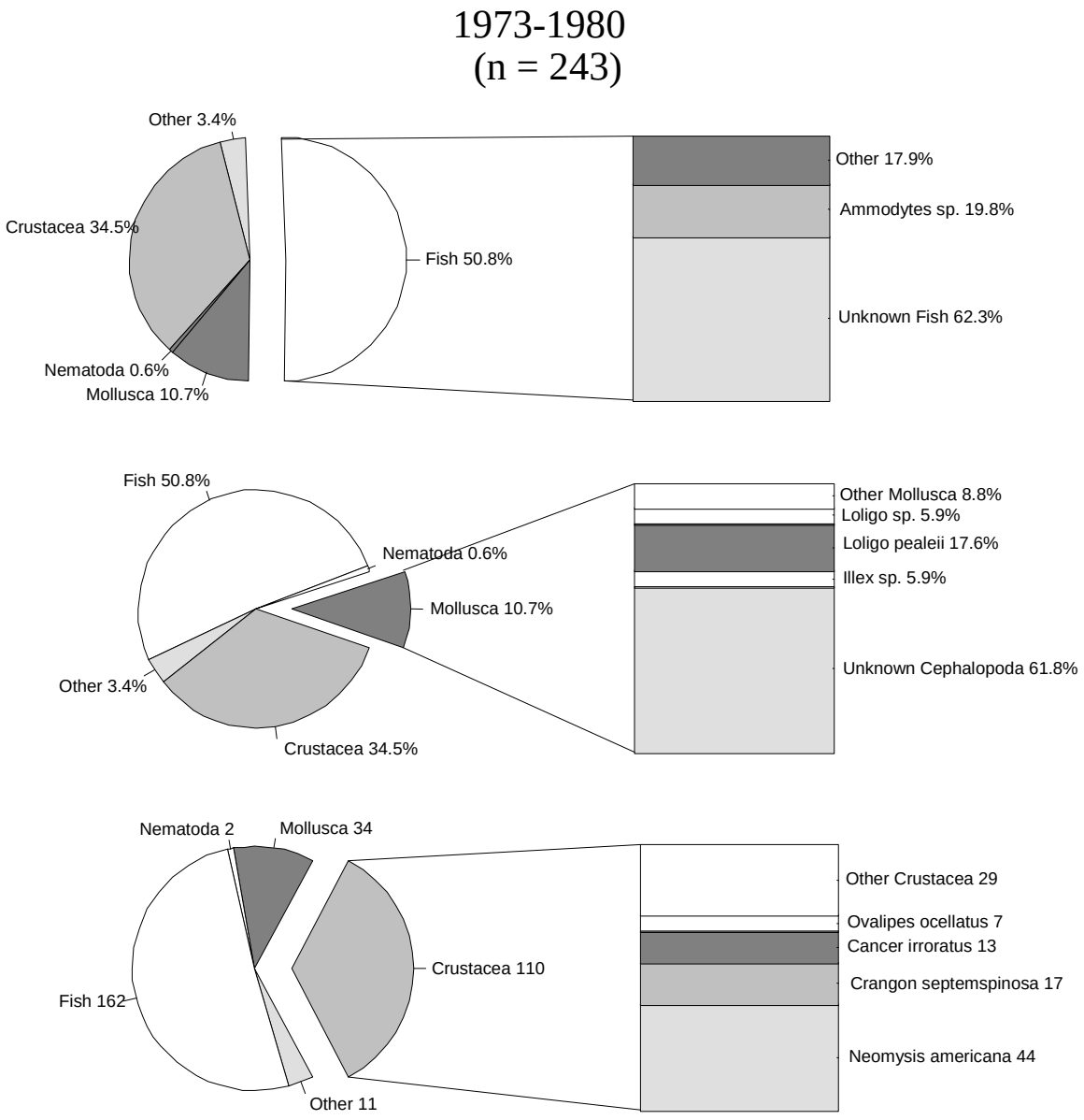


Figure 36. Abundance (percent occurrence) of the major prey items in the diet of summer flounder collected during NEFSC bottom trawl surveys from 1973-1980 and 1981-1990, focusing on fish, crustaceans, and mollusks. The category “animal remains” refers to unidentifiable animal matter. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details].

1981-1990
(n = 469)

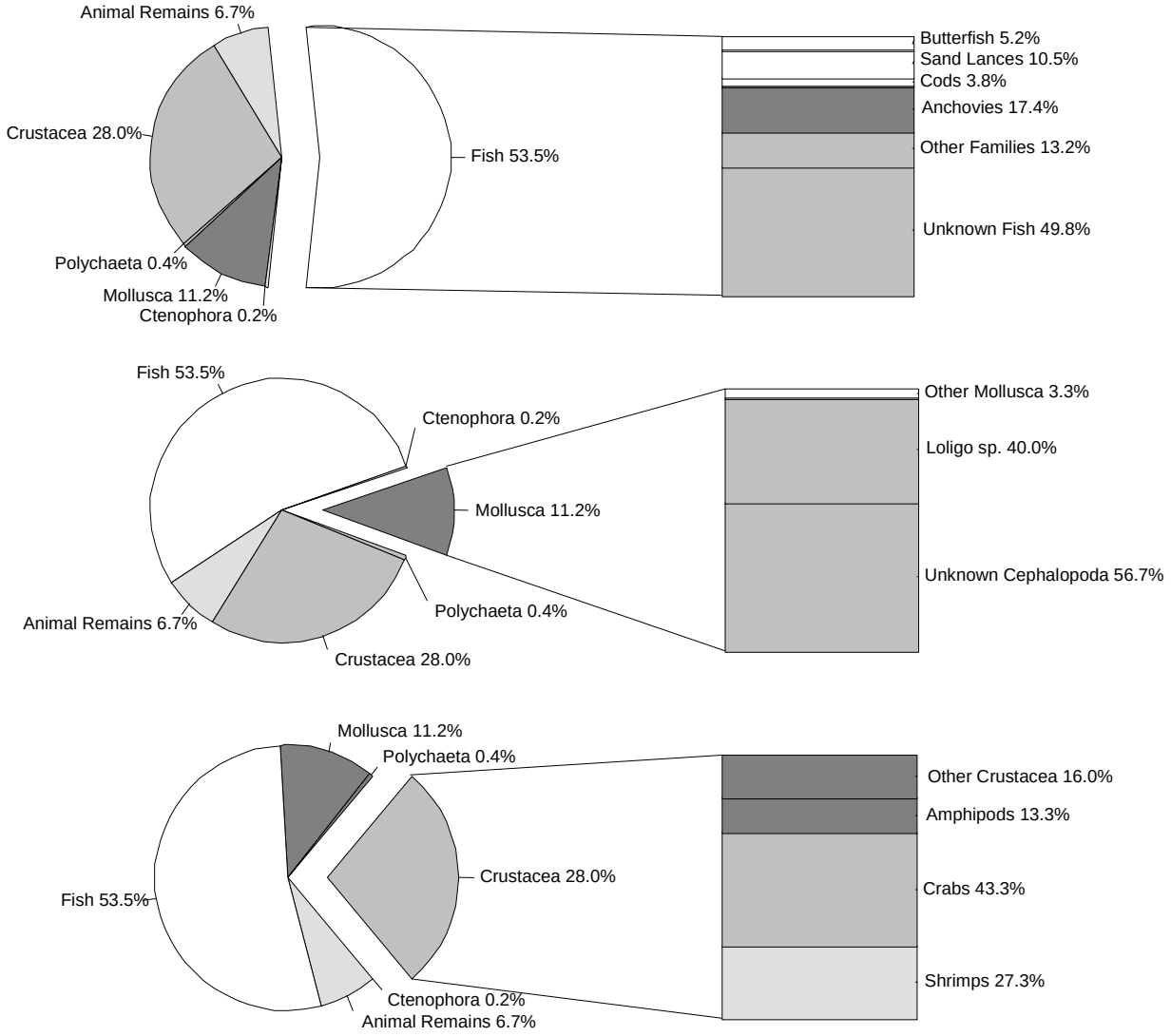


Figure 36. cont'd.

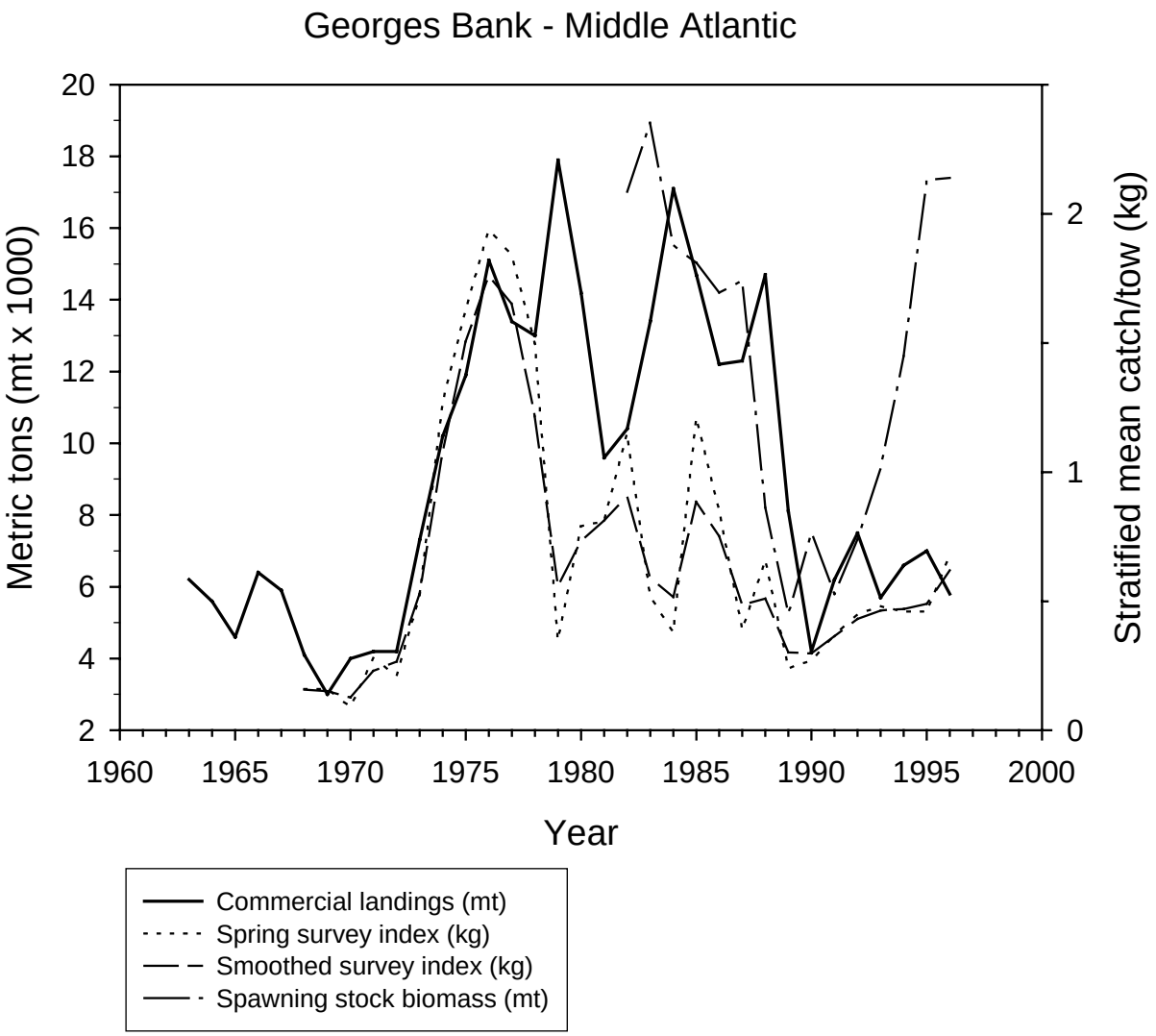


Figure 37. Commercial landings, NEFSC survey indices, and stock biomass for summer flounder on Georges Bank and in the Mid-Atlantic region.

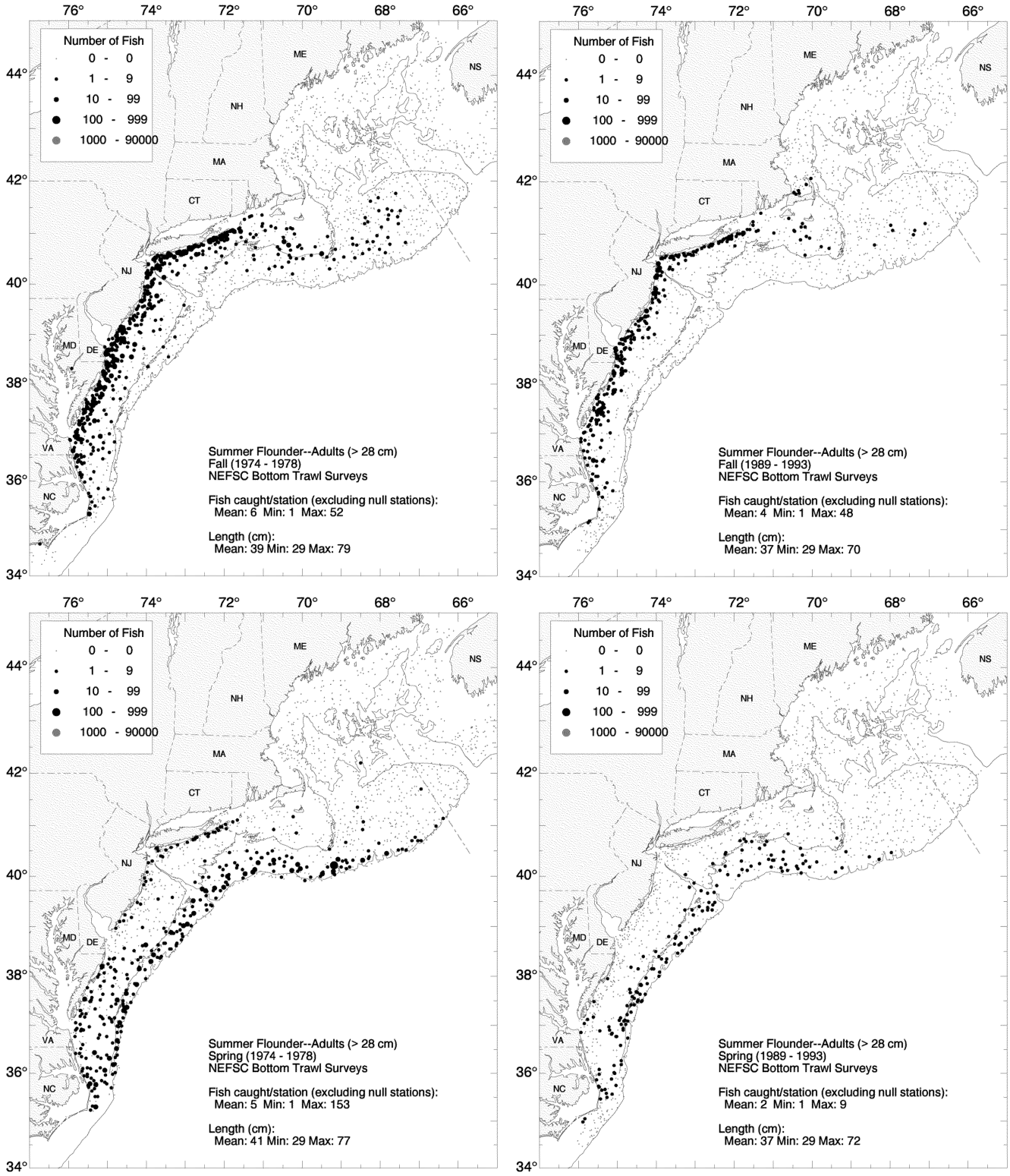


Figure 38. Distribution and abundance of adult and juvenile summer flounder during a period of high abundance (1974-1978) and a period of low abundance (1989-1993) based on spring and fall NEFSC bottom trawl surveys [see Reid *et al.* (1999) for details].

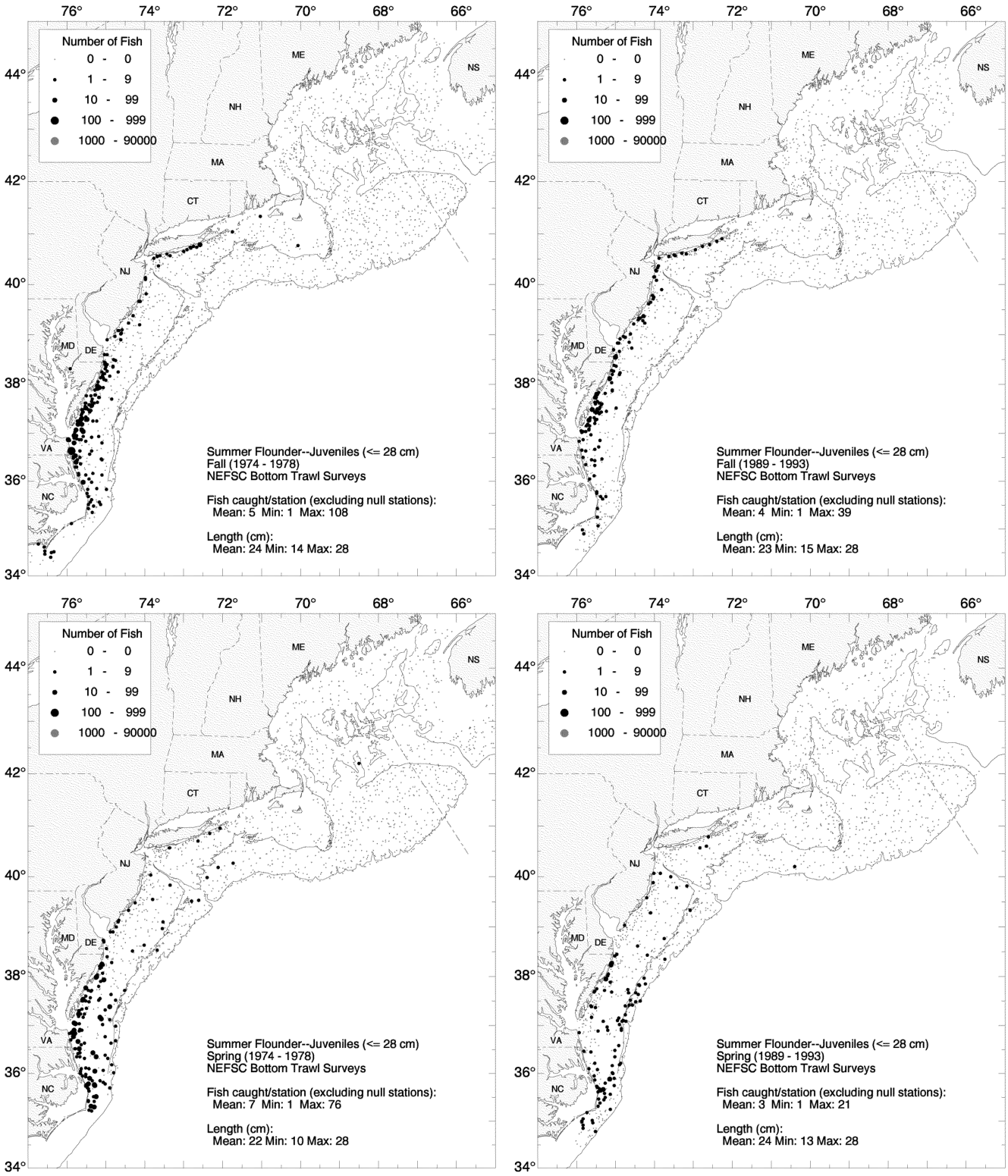


Figure 38. cont'd.

Publishing in *NOAA Technical Memorandum NMFS-NE*

Manuscript Qualification

This series represents a secondary level of scientific publishing in the National Marine Fisheries Service (NMFS). For all issues, the series employs thorough internal scientific review, but not necessarily external scientific review. For most issues, the series employs rigorous technical and copy editing. Manuscripts that may warrant a primary level of scientific publishing should be initially submitted to one of NMFS's primary series (*i.e., Fishery Bulletin, NOAA Technical Report NMFS,* or *Marine Fisheries Review*).

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The ethics of scientific research and scientific publishing are a serious matter. All manuscripts submitted to this series are expected to adhere -- at a minimum -- to the ethical guidelines contained in Chapter 1 ("Ethical Conduct in Authorship and Publication") of the *CBE Style Manual*, fifth edition (Chicago, IL: Council of Biology Editors). Copies of the manual are available at virtually all scientific libraries.

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For spelling of scientific and common names of fishes, mollusks, and decapod crustaceans from the United States and Canada, use *Special Publications* No. 20 (fishes), 26 (mollusks), and 17 (decapod crustaceans) of the American Fisheries Society (Bethesda, MD). For spelling of scientific and common names of marine mammals, use *Special Publication* No. 4 of the Society for Marine Mammalogy (Lawrence, KS). For spelling in general, use the most recent edition of *Webster's Third New International Dictionary of the English Language Unabridged* (Springfield, MA: G.&C. Merriam).

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STANDARD MAIL A

Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific ournals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in three categories:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series includes: data reports of long-term or large area studies; synthesis reports for major resources or habitats; annual reports of assessment or monitoring programs; documentary reports of oceanographic conditions or phenomena; manuals describing field and lab techniques; literature surveys of major resource or habitat topics; findings of task forces or working groups; summary reports of scientific or technical workshops; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing. Limited free copies are available from authors or the NEFSC. Issues are also available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series includes: data reports on field and lab observations or experiments; progress reports on continuing experiments, monitoring, and assessments; background papers for scientific or technical workshops; and simple bibliographies. Issues receive internal scientific review but no technical or copy editing. No subscriptions. Free distribution of single copies.

Fishermen's Report **and** ***The Shark Tagger*** -- The ***Fishermen's Report*** (FR) is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of the FR; copies are available through free subscription. ***The Shark Tagger*** (TST) is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of the TST; copies are available only to participants in the tagging program.

To obtain a copy of a technical memorandum or a reference document, or to subscribe to the fishermen's report, write: Research Communications Unit, Northeast Fisheries Science Center, 166 Water St., Woods Hole, MA 02543-1026. An annual list of NEFSC publications and reports is available upon request at the above address. Any use of trade names in any NEFSC publication or report does not imply endorsement.

NOAA Technical Memorandum NMFS-NE-190

Essential Fish Habitat Source Document:

Atlantic Cod, *Gadus morhua*, Life History and Habitat Characteristics

Second Edition

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

November 2004

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181. In press.

182. **U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments – 2003.** By Gordon T. Waring, Richard M. Pace, Janeen M. Quintal, Carol P. Fairfield, and Katherine Maze-Foley, eds., Nicole Cabana, Phillip J. Clapham, Timothy V.N. Cole, Gregory L. Fulling, Lance P. Garrison, Aleta A. Hohn, Blair G. Maise, Wayne E. McFee, Keith D. Mullin, Debra L. Palka, Patricia E. Rosel, Marjorie C. Rossman, Frederick W. Wenzel, and Amy L. Whitingham, contribs. May 2004. vii + 287 p., 47 figs., 58 tables, 4 app., index. NTIS Access. No. PB2004-106431.

NOAA Technical Memorandum NMFS-NE-190

This series represents a secondary level of scientific publishing. All issues employ thorough internal scientific review; some issues employ external scientific review. Reviews are -- by design -- transparent collegial reviews, not anonymous peer reviews. All issues may be cited in formal scientific communications.

Essential Fish Habitat Source Document:

Atlantic Cod, *Gadus morhua*, Life History and Habitat Characteristics

Second Edition

R. Gregory Lough

National Marine Fisheries Serv., 166 Water St., Woods Hole, MA 02543

U. S. DEPARTMENT OF COMMERCE
Donald L. Evans, Secretary
National Oceanic and Atmospheric Administration
Vice Admiral Conrad C. Lautenbacher, Jr., USN (ret.), Administrator
National Marine Fisheries Service
William T. Hogarth, Assistant Administrator for Fisheries
Northeast Fisheries Science Center
Woods Hole, Massachusetts

November 2004

Editorial Notes on "Essential Fish Habitat Source Documents" Issued in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For "Essential Fish Habitat Source Documents" issued in the *NOAA Technical Memorandum NMFS-NE* series, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division largely assume the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production is performed by, and all credit for such production rightfully belongs to, the staff of the Ecosystems Processes Division.

Internet Availability and Information Updating

Each original issue of an "Essential Fish Habitat Source Document" is published both as a paper copy and as a Web posting. The Web posting, which is in "PDF" format, is available at: *http://www.nefsc.noaa.gov/nefsc/habitat/efh*.

Each issue is updated at least every five years. The updated edition will be published as a Web posting only; the replaced edition(s) will be maintained in an online archive for reference purposes.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991a[a], b[b]), mollusks (*i.e.*, Turgeon *et al.* 1998[c]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[d]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[e]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[f]; McEachran and Dunn 1998[g]).

---

[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991a. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991b. World fishes important to North Americans. *Amer. Fish. Soc. Spec. Publ.* 21; 243 p.

[c]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[d]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[e]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[f]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (Washington, DC)* 96:686-726.

[g]McEachran, J.D.; Dunn, K.A. 1998. Phylogenetic analysis of skates, a morphologically conservative clade of elasmobranchs (Chondrichthyes: Rajidae). *Copeia* 1998(2):271-290.

PREFACE TO SECOND EDITION

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NOAA Fisheries to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NOAA Fisheries has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in a series of EFH species reports (plus one consolidated methods report). The EFH species reports are a survey of the important literature as well as original analyses of fishery-independent data sets from NOAA Fisheries and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and understandably are referred to as the "EFH source documents."

NOAA Fisheries provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

The initial series of EFH species source documents were published in 1999 in the *NOAA Technical Memorandum NMFS-NE* series. Updating and review of the EFH components of the councils' Fishery Management Plans is required at least every 5 years by the NOAA Fisheries Guidelines for meeting the Sustainable Fisheries Act/EFH Final Rule. The second editions of these species source documents were written to provide the updated information needed to meet these requirements. The second editions provide new information on life history, geographic distribution, and habitat requirements via recent literature, research, and fishery surveys, and incorporate updated and revised maps and graphs. This second edition of the Atlantic cod EFH source document is based on the original by Michael P. Fahay, Peter L. Berrien, Donna L. Johnson, and Wallace W. Morse, with a foreword by Jeffrey N. Cross (Fahay *et al*. 1999).

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NOAA Fisheries, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

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INTRODUCTION

The Atlantic cod (Figure 1) is a demersal gadoid distributed in the northwest Atlantic Ocean from Greenland to Cape Hatteras, North Carolina (Figure 2). Densities are highest off Newfoundland, in the Gulf of St. Lawrence and on the Scotian Shelf, while in U.S. waters, densities are highest on Georges Bank and the western Gulf of Maine. The Georges Bank cod stock is the most southerly cod stock in the world (Wise 1958). Atlantic cod are managed as two stocks in American waters: (1) Gulf of Maine and (2) Georges Bank and southward (Mayo 1995). Little interchange occurs between the two areas. Cod occurs from nearshore areas to depths exceeding 400 m (rarely). The greatest concentrations off the northeast coast of the U.S. are on rough bottoms in waters between 10 and 150 m and at temperatures between 0 and 10°C.

A regular pattern of migrations, associated with reproduction and seasonal temperature change, has been observed in the Newfoundland stock (Rose 1993). Here, huge schools of cod leave wintering areas in deep oceanic waters and follow tongues of deep, relatively warm, oceanic waters ("highways") across the shelf to summer feeding areas nearshore. They then move northward along the Newfoundland coast in late summer, and eventually return to wintering areas. Spawning occurs in dense concentrations (> 1 fish/m^3) as they begin this mass movement, with multiple pairs of spawning fish observed in "columns" above the mass. As this huge mass of fish migrates inshore, it periodically encounters important prey aggregations (e.g., capelin and shrimp) and disperses. The mass is led by the largest size class (or "scouts") and the smallest fish are found at the rear. Fahay (NOAA Fisheries, NEFSC, James J. Howard Marine Sciences Laboratory, Highlands, NJ, pers. comm.) postulates that the youngest learn the route from the oldest, and that loss of the largest fish (through fishery pressure directed at them) could result in changes in this migration pattern. Similar changes have been observed in Norwegian herring stocks, but observations of such migrations are lacking in the two U.S. stocks. Off New England, Atlantic cod typically move into coastal waters during the fall and then retreat into deeper waters during spring. Another seasonal movement occurs in the Great South Channel area where they move southwesterly during autumn, spend the winter in southern New England and the Mid-Atlantic coast, and then return in the spring.

Atlantic cod attain ages of 20 years. Most enter fisheries at ages 2-5. They can grow to lengths of 130 cm and weights of 25-35 kg and average 26 cm by the end of their first year. Median age at sexual maturity is 1.7-2.3 years at lengths between 32 and 41 cm (O'Brien *et al.* 1993). Fecundity is high and a large female may produce between 3 and 9 million eggs. Spawning occurs near bottom during winter and early spring, usually in water temperatures between 5 and 7°C. Eggs are pelagic and drift for 2-3 weeks before hatching. The larvae are also pelagic until they reach 4-6 cm in about 3 months, when they descend to the bottom. Further details of the life history of Atlantic cod are summarized in the Final EIS for Amendment 5 (NEFMC 1993) for the multispecies complex, and certain data are updated in Amendment 7, Vol. 1 of the Multispecies FMP (NEFMC 1996); see also Amendment 13, Vol. II of the Multispecies FMP (NEFMC 2003). Generalizations contained in those summaries suffice to describe most biological and life history traits of cod occurring off the northeastern coast of the U.S. This document examines dietary requirements and expands somewhat on spawning patterns, distributions and habitat characteristics of four life history stages (eggs, larvae, juveniles, adults).

This document is mostly concerned with the northwest Atlantic stocks. New research applications have involved the development of circulation models to simulate the potential transport pathways of eggs and larvae from spawning sites under realistic conditions, and the use of genetic markers to identify stocks and potential intermixing. Also, there is a considerable body of literature on hypotheses for the collapse of the northern Atlantic cod off Newfoundland by the early 1990's. While not immediately relevant to the Georges Bank/Gulf of Maine stocks, they explore the interplay of over-fishing and environmental change, the relative contributions of inshore and offshore stocks, and the causes and effects of the contraction of spawning stock. Since December 1994 there has been a year-round closure to commercial fishing of a large part of Georges Bank to rebuild the spawning stock. Fortunately, a major field program (U.S. GLOBEC) conducted monthly (January-July) ichthyoplankton surveys on Georges Bank from 1995 to 1999. The resulting cod egg and larval data are presented in the same format so that a comparison can be made with the prior Northeast Fisheries Science Center (NEFSC) Marine Resources Monitoring, Assessment and Prediction (MARMAP) ichthyoplankton survey data from 1977-1987.

LIFE HISTORY

EGGS

Atlantic cod eggs are pelagic, buoyant, spherical, and transparent. Their diameter ranges from 1.2-1.7 mm. The chorion is smooth (unsculptured) and the yolk is homogeneous. There are no oil globules and the perivitelline space is narrow (Fahay 1983; Markle and Frost 1985). Hatching occurs after 8 to 60 days in varying temperatures (Hardy 1978) and averages 2-3 weeks in typical spring conditions (Lough *et al.* 1989).

Temperature, more than season, also exerts the most influence on egg and hatchling sizes (Miller *et al.* 1995).

LARVAE

Larvae hatch at sizes between 3.3 and 5.7 mm, with pigmented eyes, but unformed mouth parts. The body is long and tapering and the vent opens laterally on the finfold, rather than at its margin. The preanus length is < 50% of the total length. Characteristic pigment includes pairs of bars on the dorsal and ventral edges of the body and individual melanophores under the notochord tip. Pollock (*Pollachius virens*) larvae are similar, but have five primary caudal rays on the superior hypural; Atlantic cod larvae have four (Fahay 1983). Some studies have found increased growth rates with warmer temperatures (e.g., Laurence 1978); others have correlated enhanced growth with concentrations of zooplankton prey (Suthers *et al.* 1989). Several studies have described developing larvae drifting in a clockwise pattern around Georges Bank with high concentrations over the southern flank at depths between 50 and 100 m (e.g., Lough *et al.* 1989; Lough and Manning 2001). Larvae occur from near-surface to depths of 75 m, and larvae move deeper with growth (Hardy 1978; Lough and Potter 1993).

JUVENILES

Transformation to the juvenile stage occurs at sizes greater than 20 mm, when all fin rays are formed (Fahay 1983). Descent from the water column to bottom habitats occurs at sizes of 2.5-6 cm (Fahay 1983; Lough *et al.* 1989) or < 7 cm (Bailey 1975). Most remain on the bottom after this descent, and there is no evidence of a subsequent, diel, vertical migration (Bailey 1975). Coloration during this initial descent mimics the substrate, reducing predation (Lough *et al.* 1989). By the end of their first year, juvenile cod reach a mean length of 26 cm (Penttila and Gifford 1976).

ADULTS

Adults are heavy-bodied and have a large head, blunt snout and a distinct barbel under the lower jaw tip. Color varies, but usually includes many small spots and a pale lateral line. Color can change depending on bottom habitats. There are three distinct dorsal fins and two distinct anal fins. Vertebrae number 50-59 and fin ray counts are: D_1: 13-16; D_2: 19-24; D_3: 18-21; A_1: 20-24; A_2: 17-22. Size averages 2.3-3.6 kg and the largest recorded was 95.9 kg (Scott and Scott 1988). They tend to move in schools, usually on the bottom, although they may also occur in the water column.

REPRODUCTION

Both size and age at maturity have declined in recent decades, likely in response to the fishery harvesting older and larger fish, or to a general decline in stock biomass due to intense exploitation. In a Scotian Shelf study (Beacham 1983), the median age at maturity declined about 50% between 1959 (when age at 50% maturity was 5.4 years in males and 6.3 years in females) and 1979 (when age at 50% maturity was 2.8 years in both sexes). Median lengths at maturity declined from 51 to 39 cm in males and 54 to 42 cm in females. This "smaller and younger at maturity" trend continued between 1972 and 1995 in all zones between Georges Bank and Labrador (Trippel *et al.* 1997). As of 1994, in U.S. waters, sexual maturity was reached at ages between 1.7 and 2.3 years (median) and lengths between 32 and 41 cm (average) (O'Brien *et al.* 1993). Presently (2000-2002), age and length at maturity have increased slightly for both Georges Bank and Gulf of Maine stocks (O'Brien 1999). Age and length at 50% maturity for Georges Bank and Gulf of Maine stocks are shown in Table 1. Gulf of Maine cod attain sexual maturity at a later age than Georges Bank cod which is related to differences in growth rates between the two stocks. The recently developed maturation reaction-norm analyses (Barot *et al*. 2004a, b) also indicated a shift towards lower ages and sizes of maturation for Georges Bank and Gulf of Maine cod stocks. The trend for Georges Bank cod to mature earlier than the Gulf of Maine cod was thought to be due mostly to environmental differences. Georges Bank is a highly productive and warmer shallow bank compared to the deeper Gulf of Maine. The reaction-norm approach supports the hypothesis that the Georges Bank and Gulf of Maine cod stocks have changed genetically in response to fishing.

On Georges Bank, an analysis of the MARMAP ichthyoplankton data set indicates that 60% of spawning occurs between February 23 and April 6, based on the abundance of Stage III eggs, back-calculated to spawning date. Ninety percent occurs between mid-November and mid-May, with a median date of mid-March (Colton *et al.* 1979; Page *et al.* 1998). Spawning begins along the southern flank of Georges Bank and progresses toward the north and west. It ends latest in the year on the eastern side of the bank. Historically, cod have spawned on both eastern and western Georges Bank. During the MARMAP period (1978-1987), spawning could either be split between eastern and western Georges Bank, or occur

predominantly on one side or the other (Lough *et al*. 2002). Composite egg distributions indicate that the most intense spawning activity occurs on the Northeast Peak of Georges Bank (Page *et al.* 1998). Data from the more recent U.S. GLOBEC Georges Bank surveys (1995-1999) also indicated peak spawning occurs during the February-March period and mostly on the Northeast Peak (Mountain *et al*. 2003). The results of the present compilation of egg distributions indicate that most spawning occurs not only on the Northeast Peak of Georges Bank, but also around the perimeter of the Gulf of Maine, and over the inner half of the continental shelf off southern New England. It occurs year-round, with a peak in winter and spring. Peak spawning is related to environmental conditions. It is delayed until spring when winters are severe and peaks in winter when they are mild (Smith *et al.* 1979; Smith *et al.* 1981). Spawning peaks in April on Browns Bank (Hurley and Campana 1989). Within the Gulf of Maine, cod generally spawn throughout the winter and early spring in most locations, but the period of peak spawning varies depending on location (Schroeder 1930). In general, spawning occurs later in the year in the more northerly regions. Within Massachusetts Bay, Fish (1928) reported peak spawning activity during January and February. Bigelow and Welsh (1924) noted that north of Cape Ann, Massachusetts, most spawning occurred between February and April and further north, between Cape Elizabeth and Mt. Desert Island, Maine, the peak spawning period was between March and May. It has also been noted that cod spawning occurs mostly at night and may be crepuscular (Klein-MacPhee 2002). Reproduction also occurs in nearshore areas, such as Beverly-Salem Harbor, MA, where eggs are found November through July (with a peak in April) at temperatures between -2 and 20°C (Elliott *et al.* 1979).

Hanke *et al*. (2000) recently summarized all the available ichthyoplankton survey data from the Scotian Shelf, eastern Gulf of Maine, and the Bay of Fundy region, from 1975-1997, and provided evidence for a spring and fall spawning, but with regional differences. In March-April spawning was observed off southwestern Nova Scotia including Browns Bank, Georges Bank, and the Emerald/Western/Sable Island Bank area. Spawning occurs again in November and December on Georges Bank and the entire Nova Scotia coast, west of Grand Manan and on Western/Sable Island/ Banquereau Bank.

Ames (2004) characterized the Gulf of Maine historical Atlantic cod fishing and spawning grounds during the 1920's when stocks were high, compared with our present day knowledge. Four subpopulations were identified: Bay of Fundy, Downeast, Midcoast, and Western, each with 3-6 spawning components. Inshore cod feeding grounds were generally rocky bottoms along the 100 m isobath. Spawning occurred in channels and basins bordering the rocky, shallow, historic fishing grounds. Compared with recent survey data of cod eggs (Berrien and Sibunka 1999), it appears that more than half of the historic spawning grounds are inactive and show no evidence of spawning. Ames cites three factors that contributed to the collapse of the spawning components: (1) directed fishing with otter trawls and gillnets on coastal spawning aggregations, (2) pollution of coastal nursery grounds, and (3) destruction of anadromous forage stock by the construction of dams.

FOOD HABITS

The Atlantic cod has a varied diet. Reported food items vary by life history stage and study area (Table 2). The most frequently observed food items from the 1973-2001 NEFSC food habits database [see Link and Almeida (2000) for details on methodology] for cod ≤ 50 cm were crustaceans; cod ≥ 51 cm ate mostly fishes (Table 3;Figure 3). A comprehensive analysis and summary of cod trophic patterns on the northeastern U.S. continental shelf has been made by Link and Garrison (2002) based on a 25-year time series from the NEFSC food habits database. Early juveniles consumed more pelagic than benthic invertebrates, medium cod consumed benthic invertebrates and fish, and larger cod consumed larger amounts of fish. Cannibalism increased with size. Diets shifted significantly over 3 decades concurrent with shifts in forage species. Cod are opportunistic feeders, preferring sand lance, *Cancer* crabs, and herring.

In another study, leading fish (also known as "scouts") at the head of migrating shoals were larger, were more successful in feeding on preferred prey (fishes and pelagic invertebrates), and had a more varied diet than those following, which tended to feed mostly on benthic invertebrates (Deblois and Rose 1996). Although cannibalism is not often reported to occur in this species, recent studies suggest the importance of habitat segregation of Age 1 cod from older year classes in order to avoid it (Gotceitas *et al.* 1997).

PREDATION AND MORTALITY

Yolk sac larvae are vulnerable to zooplankton predators including *Aurelia, Thysanoessa*, and *Euchaeta* (Bailey 1984). Planktivorous fish can be important predators of larval fish, especially Atlantic herring and Atlantic mackerel as they migrate northward in the spring and overlap with patches of larvae on the southern flank of Georges Bank (Garrison *et al*. 2000). Juvenile cod are preyed upon by many piscivorous fish, such as dogfish, silver hake, larger cod, and sculpin (Edwards and Bowman 1979).

Because of their large size, adults have few enemies other than large sharks. Young stages, however, are preyed upon by spiny dogfish, winter skate, silver hake, sea raven, squid (northern shortfin), Atlantic halibut, fourspot flounder, and adult cod.

MIGRATION

In the middle part of their range, cod are non-migratory in the strictest sense, only undertaking minor seasonal movements in reaction to changing temperatures. At the extremes of their range, however, cod migrate annually (see Introduction). In the extreme northern region (east coast of Labrador) cod are only present during summer and early fall. In the Middle Atlantic Bight as far south as Chesapeake Bay, cod only occur during winter and spring and retreat north and east to Nantucket Shoals as shallow waters in the southern part of the Bight exceed 20°C (Heyerdahl and Livingstone 1982).

STOCK STRUCTURE

Several stocks have been recognized in Canadian and U.S. waters. In U.S. waters three (or four) stocks occur: (1) in the Gulf of Maine, north of Provincetown; (2) on Georges Bank; (3) in southern New England, south and west of Nantucket Shoals; and (4) along the Middle Atlantic Bight, although the latter three intermingle. In U.S. waters, cod are managed as two stocks, the Gulf of Maine stock, and the Georges Bank and southward stock (Mayo 1995). The inshore Gulf of Maine stock appears to be relatively distinct from the offshore cod stocks on the banks of the Scotian Shelf and Georges Bank based on tagging studies (McKenzie 1956; Wise 1963; Hunt *et al*. 1999) and parasitic copepods (Sherman and Wise 1961). Although there is some mixing of the Gulf of Maine and Georges Bank stocks, their life history parameters, growth, and maturity, are basically different (Pentilla and Gifford 1976, Serchuck *et al*. 1994, O'Brien 1999). Part of the difference in growth between stocks may be attributed to genetic variations (Imsland and Jónsdóttir 2003). General conclusions by Imsland and Jónsdóttir (2003) from basin-scale genetic studies suggest that distinct subpopulations occur between most inshore and offshore areas, and among offshore areas themselves, and that the likelihood of inshore spawning stock contributing to offshore recovery is low (Beacham *et al*. 2002). Recent genetic studies by Lage *et al*. (2004) suggest that Nantucket Shoals cod are distinct from Georges Bank cod. Whereas Lage *et al*. (2004) did not find any significant genetic differences between Georges Bank and Browns Bank, Ruzzante *et al*. (1998) did. The degree of stock separation may be related to the isolation of spawning locations and times, and different circulation patterns. On Georges Bank, a clockwise gyre circulation pattern tends to retain and isolate the eggs and larvae spawned there (Lough and Bolz 1989; Werner *et al*. 1993; Lough and Manning 2001). Model simulations by Page *et al*. (1999) suggest that cod spawning occurs in areas and times of the year that have the longest residence times (> 35 days). However, advective losses can occur sporadically off the northeast peak and southern flank of Georges Bank (Lough *et al*. 1994). While significant numbers of larvae can be advected across the Great South Channel to Nantucket shoals, the southwest residual flow in the Nantucket Shoals area would tend to keep the early life stages from returning to Georges Bank. However, based on biophysical modeling of a related species, haddock, by Brickman (2003), there is a high probability of significant crossover events from Browns Bank to Georges Bank by two pathways, directly across the Northeast Channel, and from the Gulf of Maine. While crossover events are episodic in nature (Smith *et al*. 2003), the study indicates that Browns Bank can be a significant source of larvae for Georges Bank cod stocks, and similarly, Western Bank can be an upstream source for larvae found on Browns Bank.

GEOGRAPHICAL DISTRIBUTION

Atlantic cod in the northwest Atlantic are distributed from Cape Chidley, Labrador to Cape Henry, VA (Figure 4). The areas of highest abundance are in Canadian waters and include the eastern coast of Labrador south of Cape Harrison, off eastern Newfoundland, the Flemish Cap, the Grand Bank, the Gulf of St. Lawrence, and the Scotian Shelf.

The estuarine occurrences of early life history stages between Maine and the Chesapeake Bay are shown in Table 4. These are expressed as relative abundance characterizations, based on the observations of biologists working in each of the systems listed, but they are not quantitative measurements and should be considered as presence or absence indicators only. Despite these limitations, it is apparent that no early life history stages are commonly collected south of Buzzards Bay, and north of there they are uncommon in systems comprised mostly of low salinity zones.

EGGS

During MARMAP sampling between the Gulf of Maine and Cape Hatteras, 1978-1987, eggs were distributed throughout the study area, with centers of abundance in western Gulf of Maine, Georges Bank,

and southern New England waters (Berrien and Sibunka 1999). Although they occurred year-round, densities were much lower during August and September. Maximum average densities of eggs occurred during March on Georges Bank. A downward trend in abundance was observed between 1979 and 1987 in this study area (Berrien and Sibunka 1999). Monthly distribution maps presented here (Figure 5) pertain to the same MARMAP collections. In general, eggs were most dense on the Northeast Peak of Georges Bank and around the perimeter of the Gulf of Maine, as well as lower densities in southern New England waters (Figure 5). Monthly densities peaked in March-April, declined through the summer, and began to increase again in the fall. Note the relative lack of sampling in the Gulf of Maine during March, when densities might be expected to be high.

Model simulations for the MARMAP years (Lough *et al*. 2002) show how variable spawning within a bank gyre system can have different consequences for transport and survival of eggs and larvae. Particles released from the Northeast Peak usually had higher retention than releases from western Georges Bank; however, the western Georges Bank releases could contribute significantly to retention, especially during the winter period when there is wind loss of particles from the Northeast Peak.

O'Brien *et al*. (2003) found a significant correlation between egg abundance and spawning stock biomass for Georges Bank cod. While there was considerable variability in egg survival that was unrelated to recruitment, there was a strong positive correlation between the abundance of small and large larvae and 0-group juveniles and that of recruits at age 1 (Lough *et al.* 2002). Variability in egg survival could be explained partially by the age diversity of repeat spawners, bottom temperature, and the spatial distribution of the eggs (O'Brien *et al*. 2003). The proportion of egg mortality that can be attributed to egg quality, advective loss, or predation has not been quantified.

During the GLOBEC years, 1995-1999, when sampling was only conducted from January through July on Georges Bank, the composite egg plots (Figure 6) show eggs to be broadly distributed across Georges Bank with higher concentrations on the eastern part, peaking in February and March. However, the station abundance estimates were about an order of magnitude lower than during the MARMAP period.

LARVAE AND PELAGIC JUVENILES

Larvae also occurred in MARMAP samples year-round. They were most abundant in March-May over Georges Bank and southern New England (Figure 7), although sampling was light during March in the Gulf of Maine. Few larvae were collected between August and October.

During the GLOBEC years, 1995-1999, when sampling was only conducted from January through July on Georges Bank, the composite larval plots (Figure 8) show larvae to be wide spread across the Bank from January through May. Highest station abundance occurred along the deeper flank waters during March and April, but at about an order of magnitude lower than observed during the MARMAP period.

Prior to settling to the bottom in early summer, pelagic juveniles (20-50 mm) are broadly distributed over the entire Georges Bank (Lough *et al*. 1989).

JUVENILES

By July, juvenile pelagic fish on Georges Bank have reached a length of 4-6 cm and become more associated with the bottom and begin the changeover to a demersal feeding life style. Submersible studies on eastern Georges Bank (Lough *et al*. 1989) have observed from data collected during five years (1984-1987, 1989) that the recently-settled juveniles are widely dispersed over the Bank and are present on a range of sediment types from sand to gravelly sand to gravel pavement (Figure 9). However, by late July and August, the juveniles are present predominantly on the gravel pavement habitat on the northeastern part of the Bank and are absent from the sandy bottoms (Figure 10). The gravel pavement extends along the northern edge and Northeast Peak for 150 km and covers an area of more than 3000 km^2. The gravel habitat appears to favor the survival of recently-settled juveniles through predator avoidance and/or increased food availability associated with the frontal system. Several studies have stressed the importance of cobble substrates over finer grained bottoms after settlement (e.g., Bigelow and Schroeder 1953; Colton 1978; Klein-MacPhee 2002). By day, the young cod remain on the bottom, but at night they rise several meters into the water column and drift in the tidal current while feeding. During late summer, as the juveniles continue to grow, they are carried to the east and southeast in the residual bottom current, and by fall they are more widely dispersed and are no longer confined to the gravel pavement habitat. When predators are present, juvenile cod take refuge in a wide variety of complex substrates and vegetation and their diel activity patterns reported in the literature vary considerably (Keats *et al*. 1987; Keats 1990; Keats and Steele 1992; Gotceitas and Brown 1993; Gotceitas *et al*. 1994, 1995, 1997; Gregory and Anderson 1997a, b; Grant and Brown 1998a, b; Lindholm *et al*. 1999; Laurel *et al*. 2003, 2004). Nearshore nurseries (including grass beds) may be significantly more important to survival of juveniles than offshore habitats

(for examples, see studies cited in Appendix 1: Juveniles).

The distribution of older juveniles (≤ 34 cm TL) from the NEFSC bottom trawl surveys closely matches that of spawning activity, with centers of abundance on Georges Bank and the western part of the Gulf of Maine [Figure 11; note that winter and summer distributions are presented as presence data only, precluding a discussion of abundances, for details see Reid *et al*. (1999). Also see the distribution of immature Atlantic cod, < 37 cm, resulting from NEFSC bottom trawl survey cruises, 1968-1986 in Wigley and Gabriel (1991)]. In winter they are concentrated near Massachusetts Bay, on the Northeast Peak of Georges Bank, and in southern New England near the 50 m isobath. During spring trawl surveys, densities are highest in the area north and south of Cape Ann, Massachusetts. During summer, juveniles are mostly found along the western shore of the Gulf of Maine, but also occur on the Northeast Peak of Georges Bank, on Browns Bank, and along the 50 m isobath south of Cape Cod. Large numbers of juveniles are concentrated around Cape Ann/Massachusetts Bay and south/southeast of Cape Cod in the fall.

The distributions and abundances of Atlantic cod along the coasts of Maine and New Hampshire, based on spring and fall 2000-2004 Maine-New Hampshire inshore groundfish surveys (Sherman *et al*. 2005), are shown in Figure 12. Cod were patchy in occurrence, and the majority were juveniles (Figure 13). Cod abundance was low compared to some of the other species in the survey, with a slight increase in numbers in the spring of 2004 (Figure 14), although Sherman *et al*. (2005) state that no real trends can be seen in overall abundance.

The spring and fall 1978-2003 Massachusetts inshore trawl surveys [Figure 15; see Reid *et al*. (1999) for details] show that in the spring, very high numbers are found in Massachusetts Bay, with large numbers of juveniles also found north of Cape Ann, on the outside of Cape Cod, and near Martha's Vineyard. High concentrations are also found in Massachusetts Bay and Nantucket Sound. In the fall, large numbers occur around Cape Ann and throughout Cape Cod Bay, but they are absent in Nantucket Sound.

Very few juvenile cod were collected during 1990-1996 trawl surveys of Narragansett Bay undertaken by the Rhode Island Division of Fish and Wildlife. See below for cod occurrences in Long Island Sound and Hudson-Raritan Estuary/Sandy Hook Bay.

ADULTS

NEFSC bottom trawl surveys (Figure 16; again, winter and summer distributions are presented as presence data only, precluding a discussion of abundances) show that during winter adults are scattered over Georges Bank, southern New England, and the central/northern Mid-Atlantic Bight, as well as in the western part of the Gulf of Maine. In spring, densities are highest in the western part of the Gulf of Maine (Massachusetts Bay and Cape Ann), south of Cape Cod, and especially on the Northeast Peak of Georges Bank, with additional collections made throughout southern New England and the central/northern part of the nearshore Middle Atlantic Bight. During summer, adult cod are concentrated along the coastal Gulf of Maine and south/southeast of Cape Cod and the Northeast Peak of Georges Bank, as well as being scattered throughout the Gulf and on Browns Banks; they are mostly absent from southern New England and south. In the fall, the highest densities are again found in the western part of the Gulf of Maine (Massachusetts Bay and Cape Ann), south of Cape Cod near the Great South Channel, and on the Northeast Peak/northern edge of Georges Bank; adults are generally absent south of southern New England.

The distributions of the adults in both the spring and fall 1978-2003 Massachusetts inshore trawl surveys are shown in Figure 17. More adults are caught in the spring, where they occur abundantly around Cape Ann, in Massachusetts Bay, and around the tip and eastern side of Cape Cod. Most of the adults caught during the fall are restricted to south of Cape Ann and the tip of Cape Cod.

Only one adult cod was collected in a survey of Narragansett Bay by the Rhode Island Division of Fish and Wildlife, 1990-1996. Cod do not regularly occur in Long Island Sound. In a survey of that body of water by the State of Connecticut, 1992-1997, only three (unmeasured) cod were collected, all near the eastern end of the sound, during the spring, at temperatures of 9-10°C. A NEFSC trawl survey of the Hudson-Raritan Estuary/Sandy Hook Bay during 1992-1997 collected only two cod, both during winter.

HABITAT CHARACTERISTICS

The results of a literature review directed at habitat requirements of four life history stages of Atlantic cod are presented in Appendix 1 and a synthesis of some of those data are presented in Table 5. These tables include data from U.S. (and certain non-U.S.) western Atlantic stocks, but exclude data from the eastern Atlantic. Data from Canadian waters were included only if the results could reasonably be applied to U.S. stocks. Specifics of some Canadian studies (e.g., distribution relative to temperatures within a distinct region) were not included since they have little applicability to U.S. waters.

In general, distributions of young stages of Atlantic cod tend to be restricted to the vicinity of major

spawning centers. With increasing age, they tend to be more widely distributed and occur in deeper, colder and more saline water (Tremblay and Sinclair 1985).

Regime shifts, or rapid, large-scale changes in fish populations and other communities in marine ecosystems, are driven by both environmental forcing and fishing (Rothschild and Shannon 2004). Latitudinal shifts for groundfish in the Gulf of Maine have been observed in response to temperature changes (Mountain and Murawski 1992). Growth of cod depends on temperature, and mean bottom temperature accounts for most of the observed differences in growth rates in Atlantic cod stocks (Brander 1995). Physiologically, growth performance of cod is optimal near 10°C (Pörtner *et al*. 2001), so that global warming would lead to a northward shift in populations. Temperature also affects maturation and spawning times (Hutchings and Myers 1994). Changes in spawning times and locations have different consequences for recruitment. Temperature and salinity records for the Gulf of Maine/Scotian Shelf region show alternating cold and warm periods which can be broadly related to the NAO index (Werner *et al*. 1999). The cooling of the shelf waters in the 1960s was largely due to the increased flow of the Labrador Slope water penetrating into the shelf. From the 1970s to the mid-1990s, there has been a general, but more variable, warming on the shelf. Scotian Shelf cold and warm anomalies generally precede those in Georges Bank by 2-3 years. More recently in 1997-1998, cold and fresh Labrador Slope water has been observed to again be penetrating the Scotian Shelf and Gulf of Maine. All cod stocks in this region declined by the late 1960s with the intensive fishery effort, and in the 1970s all stocks showed some improved recruitment, but declined to very low levels in the early 1990s. Failure of these cod stocks to recover despite restricted fishing since the mid-1990s has been termed "the cod recruitment dilemma" and Swain and Sinclair (2000) have implicated the increased abundance of herring and mackerel in the southern Gulf of St. Lawrence to have had a negative effect on cod recruitment by preying on and competing with the young stages. Choi *et al*. (2004) continues on the theme of the alternation of the pelagic and demersal species but shows how interacting factors may have led to the restructuring of the Scotian Shelf ecosystem over the past four decades. While ground fish have historically dominated the Scotian Shelf, their continual removal has allowed the pelagic biomass to increase since the mid-1980s at the same time that environmental conditions began to favor the pelagics (increased water-column stratification) and limit the demersals (cold bottom water). The present "pelagic regime" appears to have decoupled the benthic-pelagic systems where less energy is passing from primary production to benthic prey for the demersals.

EGGS

An analysis of nearly 50 years of trawl data in Canadian waters concluded that spawning rarely occurs beyond the continental shelf, but rather occurs near where eggs and larvae are likely to be retained (Hutchings *et al.* 1993). These authors concluded that inshore spawning populations contribute more to recruitment than those farther offshore. In MARMAP sampling between 1979 and 1987, eggs were collected from virtually all depths sampled, but primarily from depths < 100 m (Berrien and Sibunka 1999; see also Figure 18). Many reports describe eggs occurring in the upper 10 m of the water column, although spring rainfalls can lower the salinity and they will then sink to lower depths. Although eggs are collected in a wide range of temperatures and salinities, several studies have found optimum conditions for incubation, hatching and development, depending on study site (Table 5).

Data from the NEFSC MARMAP ichthyoplankton surveys and the GLOBEC Georges Bank survey were used to determine the relationships between cod egg abundances and bottom depth or water column temperature. During the MARMAP surveys from January to July, eggs were mostly collected at temperatures of 4-8°C (Figure 18). From August thru November, they were found at higher temperatures of approximately 9-14°C, while in December they were caught at temperature range of 6-12°C. Most eggs were found over a depth range of 30-110 m, occurring in the shallower end of the range from October thru January (Figure 18). During the GLOBEC Georges Bank survey from January to July, the majority of eggs were found in a narrow temperature range of about 4-8°C (Figure 19). Their depth range on Georges Bank during that same period was centered around 70-90 m (Figure 20).

A lab study by Laurence and Rogers (1976) found that egg mortality was independent of temperature, but that mortality increased at lower salinities within the range of 26-36 ppt.

LARVAE AND PELAGIC JUVENILES

Several studies have found increased recruitment success when dispersion of larvae from spawning areas by currents is reduced (Cong *et al.* 1996). Although larvae have been collected from a wide range of temperatures, most are found in temperatures < 8°C, although growth rates may be enhanced in warmer temperatures (e.g., Lawrence 1978) and one study found no increased mortality when larvae were exposed to higher temperatures (Iversend and Danielssen 1984). Larvae can survive undercooling to -1.8°C but if in direct contact with ice they froze at -1.36°C (Valerio *et*

al. 1992). When larvae are 3-8 days old, they are positively phototactic and are reported to occur from the surface to 75 m depths, moving deeper in the water column as they grow older (Hardy 1978, Lough and Potter 1993).

During the MARMAP surveys (Figure 21), larvae were mostly found in a temperature range of about 4-5°C from February to March, at temperatures of 5-6°C in April, 6-8°C in May, and 7-9°C in June, and 8-9°C in July. Thereafter they were found in increasingly warmer temperatures of about 9-11°C thru November; in December they were caught mostly at temperatures of 8-11°C and in January they were found in lower temperatures of about 4-8°C. The majority of larvae were found over a depth range of 30-70 m throughout the MARMAP survey period (Figure 21). During the GLOBEC Georges Bank survey most larvae were caught at temperatures of 4-6°C from February to April and 6-7°C from May to June (Figure 22). Most were found at depths of 50-70 m in February, 70-90 m in March and April, 70 m in May, and 210 m in June (Figure 23).

JUVENILES

The substrate preferences of juvenile cod have already been discussed under Geographic Distribution.

The spring and fall distributions of juvenile Atlantic cod relative to bottom water temperature, depth, and salinity based on NEFSC bottom trawl surveys from the Gulf of Maine to Cape Hatteras are shown in Figure 24. In spring, they were found in waters between 2-10ºC, with the majority at 4-5ºC. During that season they were found over a depth range of 11-300 m, with most spread between about 21-120 m. Juveniles were found at salinities between 31-35 ppt, with almost all of them found between 32-33 ppt. During autumn, juveniles were found over a temperature range of 3-17°C, with most spread between about 8-10°C. During this time, they were found over depths ranging from 11-400 m; the majority were spread over depths roughly from 31-120 m. They were found at salinities ranging from about 31-35 ppt, with the majority between 32-33 ppt.

The spring and autumn distributions of juvenile Atlantic cod in Massachusetts coastal waters relative to bottom water temperature and depth based on Massachusetts inshore trawl surveys are shown in Figure 25. During the spring, juveniles were found in waters ranging from 2-16°C with the majority spread between about 5-12ºC. Their depth range was from 6-85 m, with the majority between about 6-25 m. In the autumn they were found in temperatures ranging from 5-18ºC, with most spread between 6-10ºC. Juveniles were found over a depth range of 6-85 m, with the majority found between about 16-65 m.

ADULTS

Adult cod are typically found on or near the bottom along rocky slopes and ledges. They prefer depths between 40 and 130 m, but are sometimes found in midwater. Cod rarely occur deeper than 200 m. Larger individuals remain closer to the bottom in deeper water, and many move to offshore banks during summer (Hardy 1978; Cohen *et al.* 1990). Several studies have ascertained a preference by adult cod for coarse sediments over finer mud and silt (Scott 1982b). They engage in diel vertical migrations, where they make forays off the bottom and into the water column at night (several studies; e.g., Beamish 1966). Cod can occur in temperatures from near freezing to 20°C, and are usually found in temperatures < 10°C, except during fall when they can occur in warmer temperatures. Larger fish are generally found in colder waters (Cohen *et al.* 1990).

The spring and fall distributions of adult Atlantic cod relative to bottom water temperature, depth, and salinity based on NEFSC bottom trawl surveys from the Gulf of Maine to Cape Hatteras are shown in Figure 26. In spring, they were found in waters between 2-12ºC, with the majority at 4-6ºC. They were found over a depth range of 1-300 m. Adults were found at salinities between 30-35 ppt, with > 50% at 33 ppt. During autumn, adults were found over a temperature range of 3-17°C, with the majority spread between 6-11°C. During this season they were found over depths ranging from 11-400 m. They were found at salinities ranging from about 31-35 ppt, with the majority between 32-34 ppt.

The spring and autumn distributions of adult Atlantic cod in Massachusetts coastal waters relative to bottom water temperature and depth based on Massachusetts inshore trawl surveys are shown in Figure 27. During the spring, adults were found in waters ranging from 1-14°C, with the majority spread between 4-8ºC. Their depth range was from 6-85 m, with the majority < 56 m. In the autumn they were found in temperatures ranging from 4-13ºC, with most spread between 7-10ºC and at 12ºC. Adults were found over a depth range of 26-85 m, with peaks between 51-65 m.

RESEARCH NEEDS

Essential fish habitat is defined as those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity. Our knowledge of habitat requirements of Atlantic cod is scant beyond the distribution and relative abundance levels (EFH tiers 1 and 2). Scientists have only recently begun to investigate the early settlement stage and its associated

substrate preferences (Lough *et al.* 1989) and the importance of certain bottom habitat types to the survival of young-of-the-year (e.g., Tupper and Boutilier 1995). Associated with these studies are those equating bottom habitats with the avoidance of predation, including cannibalism (e.g., Gotceitas *et al.* 1997) or the importance of habitat segregation between year classes (e.g., Fraser *et al.* 1996). These kinds of studies are essential to improving our understanding of the importance of habitat at tiers 3 and 4 (effects of habitat variables on growth and/or survival). However, recent studies have documented regime shifts on decadal time scales over large areas of the continental shelf as a result of complex interaction of environmental factors and biological processes. Ecosystem based studies such as Choi *et al*. (2004), with continued monitoring of the environment, are needed to better understand the long-term changes in stocks.

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Table 1. Age and length at 50% maturity for two stocks of Atlantic cod, *Gadus morhua*..
Data for 1994 are from Mayo (1995). Similar results were obtained in a Canadian study for zones near U.S. waters (Trippel *et al.* 1997). Recent data are from L. O'Brien, (NOAA Fisheries, NEFSC, Woods Hole Laboratory, Woods Hole, MA, pers.comm.), pooled for the period 2000-2002.

1994	**Georges Bank**	**Georges Bank**	**Gulf of Maine**	**Gulf of Maine**
	Males	Females	Males	Females
Age at 50% Maturity	1.9 years	1.7 years	2.3 years	2.1 years
Length at 50% Maturity	41 cm	39 cm	36 cm	32 cm

2000-2002	**Georges Bank**	**Georges Bank**	**Gulf of Maine**	**Gulf of Maine**
	Males	Females	Males	Females
Age at 50% Maturity	2.1 years	2.1years	2.9 years	2.6 years
Length at 50% Maturity	42.2 cm	43.3cm	44.0 cm	43.3 cm

Table 2. Food habits of Atlantic cod.

Source	Study Area and Food Habits
	LARVAE
Bainbridge and McKay (1968)	Greenland: Larvae (3-10 mm) mostly eat nauplii and copepodites of the copepods *Calanus* and *Temora*. Also euphausiids.
Kane (1984)	Georges Bank: Larvae eat nauplii and copepodites of *Pseudocalanus* mostly; some *Calanus* eggs and nauplii.; some *Oithona* copepodites.
Marak (1960)	Georges Bank, Gulf of Maine: Larvae eat most abundant prey. 4-18 mm eat mostly larval copepods; 18+ mm eat mostly adult copepods.
McLaren and Avendano (1995)	Scotian Shelf (Western Bank): Larvae predominant prey: 2 species of the copepod *Pseudocalanus*.
McLaren *et al*. (1997)	Scotian Shelf (Western Bank): Early larvae feed predominantly on nauplii and copepodites of *Pseudocalanus* (mostly *P. newmani*); fewer *Centropages*, *Oithona,* and *Paracalanus*.
Lough and Mountain (1996)	Georges Bank: Primarily nauplii and copepodites of *Pseudocalanus* and *Oithona*; some *Calanus* nauplii.
Lough *et al*. (1996)	Georges Bank: Early larvae prey on nauplii and copepodites of *Pseudocalanus*.
Sherman *et al*. (1981)	Georges Bank: Larvae eat nauplii and copepodites of *Pseudocalanus* mostly; some *Calanus* nauplii.
	JUVENILES AND ADULTS
Bowman (1975)	Gulf of Maine: Primary item: herring. Also redfish, mackerel, cod, and red and rock crabs.
Bigelow and Schroeder (1953); Klein-MacPhee 2002	Gulf of Maine: Mollusks most important. Also other invertebrates.
Casas and Paz (1994)	Flemish Cap: Invertebrates (crustaceans and polychaetes) dominant in juvenile diets; adults consume mostly fish, mainly redfish (*Sebastes* sp.).
Casas *et al*. (1991)	Flemish Cap: Hyperiid amphipods main item in juvenile cod; as size increases, shift to fish as food item. Most important fish prey are juvenile redfish (*Sebastes* sp.). Rate of cannibalism very low.
Hacunda (1981)	Central Maine coast: Crustaceans most important, especially amphipods, *Unciola, Leptocheirus*, and decapods *Crangon, Cancer*.
Keats *et al.* (1987)	Conception Bay, Newfoundland: < 12.5 cm ate mostly small zooplankton; > 12.5 cm ate mostly benthic organisms, in areas with thick macroalgal cover. Latter not used as food source, however.
Keats and Steele (1992)	Newfoundland (eastern): Juveniles (Age 0 and 1) feed mostly during daylight and most prey was planktonic.
Kohler and Fitzgerald (1969)	Gulf of St. Lawrence, offshore Nova Scotian Banks: Small cod ate mostly crustaceans, switch to fish diet as they grow. Species taken depends on relative abundance of prey. Herring most important in GOSL, sand lance on Nova Scotian Banks. Some seasonal variation within areas and by depth.
Langton (1982)	Northwest Atlantic: Initially crustaceans, switch to fishes with growth. Overlaps with white hake (*Urophycis tenuis*) and, at smaller sizes, with haddock (*Melanogrammus aeglefinus*).
Langton and Bowman (1980)	Gulf of Maine: Diet by weight (%) - Pisces 69.5, Clupeidae 23.3, Crustacea 26.1, other decapods 14.1, Mollusca 0.7, Echinodermata 0.4.

Table 2 Cont'd.

Source	Study Area and Food Habits
	JUVENILES AND ADULTS (cont'd.)
Lilly and Parsons (1991)	Northeast Newfoundland: Northern shrimp (*Pandalus borealis*) identified as important food item of cod throughout shrimp's range.
Link and Garrison (2002)	Northeast U.S. Continental Shelf: Summary of 25 year time series of food habits data. Cod have omnivorous diet, prefer sand lance, *Cancer* crabs, and herring.
Methven and Piatt (1989)	Newfoundland: Capelin very important diet item. When abundance is high, occurrences in cod stomachs high; when abundance low, occurrences in cod stomachs low.
Minet and Perodou (1978)	SW Newfoundland and NE Gulf of St. Lawrence: Capelin and crustaceans most important components. In some areas, larger cod ate more herring, redfish, and American plaice.
Perry and Neilson (1988)	Georges Bank: Late pelagic juveniles. Calanoid copepods numerically most abundant, mysiid *Neomysis americana* biomass most important; harpacticoid *Tisb*e, some *Pagurus* larvae.
Robichaud *et al.* (1991)	Cape Breton I., Nova Scotia: Cod fed on snow crabs (*Chionecetes* sp.) and toad crabs (*Hyas* spp.), with the latter selected somewhat more often.
Sameoto *et al*. (1994)	Scotian Shelf: Late pelagic juveniles. *C. finmarchicus* copepodite IV-V, *Pseudocalanus* female, and *Temora* male preferred prey. (Emerald and Lahave Basin). Small euphausiids (*Meganytiphanes norvegica*) significant part of diet at night, 20 m.
Tyler (1972)	Passamaquoddy Bay: Winter - *Meganyctiphones, Mysis, Pandalus*; summer - *Meganyctiphones, Clupea, Pandalus.*
Whitehead *et al.* (1986)	Northeastern Atlantic: Diet variable: fishes - herring, capelin, haddock, codling; invertebrates - euphausiids, hyperiids, amphipods, polychaetes.
Witman and Sebens (1992)	Gulf of Maine: Cod fed heavily on tethered brittle stars in this experiment.

Table 3. Minor diet items of Atlantic cod.
Based on the NEFSC Food Habits database from 1973-1990. Listed below are items occurring at 1-5 percent frequency. See Figure 3 for items occurring more frequently. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details].

1973-1980: Diet Item	**Percent Frequency**	**1981-1990: Diet Item**	**Percent Frequency**
Polychaeta	4.70	Euphausiidae	4.68
Unciola irrorata	4.70	Decapoda (shrimp)	3.92
Eualus pusiolus	4.50	Paguridae	3.77
Trematoda	4.35	Ophiuroidea	3.64
Pagurus acadianus	3.49	*Cancer* sp.	3.24
Gastropoda	3.24	Bivalvia	2.81
Decapoda (crab)	3.03	*Cancer irroratus*	2.54
Ophiopholis aculeata	2.98	Gastropoda	2.26
Pandalidae	2.88	*Merluccius bilinearis*	2.26
Pandalus montagui	2.53	Gammaridea	2.11
Ammodytes sp.	2.53	Crustacea	1.63
Caprellidae	2.43	Mollusca	1.63
Cancridae	2.43	*Cancer borealis*	1.61
Decapoda	2.38	Isopoda	1.61
Paguridae	2.33	*Crangon septemspinosa*	1.56
Cephalapoda	2.22	Rock	1.45
Lysianassidae	2.18	Aphroditidae	1.44
Cancer borealis	2.18	Pectinidae	1.15
Ophiuroidea	2.12		
Aphroditidae	2.07		
Pagurus sp.	2.07		
Sand	2.07		
Aeginna longicornis	1.97		
Holothuroidea	1.87		
Pontogeneia inermis	1.82		
Cirolanidae	1.82		

Table 3 Cont'd.

1973-1980: Diet Item	Percent Frequency	1981-1990: Diet Item	Percent Frequency
Hyas sp.	1.72		
Axius serratus	1.52		
Bivalvia	1.52		
Politolana polita	1.47		
Pectinidae	1.47		
Pandalus borealis	1.32		
Neomysis americana	1.32		
Calanoida	1.32		
Gastropoda operculum	1.32		
Copepoda	1.26		
Anonyx sarsi	1.16		
Crangonidae	1.11		
Mollusca	1.11		
Clupeidae	1.11		
Syrrhoe crenulata	1.01		
Euphausiidae	1.01		

Table 4. Distribution of life history stages of Atlantic cod in representative estuaries between Maine and Chesapeake Bay.
Occurrences are not quantitative and may be based on a single, or very few, specimens. Estimates of relative abundance from Jury *et al.* (1994) and Stone *et al.* (1994).

Estuary	Eggs	Larvae	Juveniles	Adults
Passamaquoddy Bay	None	Common	Common	Common
Englishman, Machias Bays	Common	Common	Abundant	Common
Narraguagus Bay	Common	Common	Abundant	Common
Blue Hill Bay	Common	Common	Abundant	Common
Penobscot Bay	None	Common	Common	Common
Muscongus Bay	Rare	Rare	Common	Common
Damariscotta Bay	Rare	Rare	Common	Common
Sheepscot River	Abundant	Abundant	Common	Abundant
Kennebec/Androscoggin Rivers	None	None	Common	Common
Casco Bay	Common	Common	Common	Common
Saco Bay	Common	Common	Common	Common
Wells Harbor	Rare	Rare	Rare	None
Great Bay	Common	Common	Rare	Rare
Merrimack River	Rare	Rare	Rare	Rare
Massachusetts Bay	Common	Common	Common	Common
Boston Harbor	Common	Common	Common	Common
Cape Cod Bay	Common	Common	Common	Common
Waquoit Bay	Rare	Rare	Rare	None
Buzzards Bay	Common	Common	Common	Common
Narragansett Bay	Rare	Rare	Rare	Rare
Long Island Sound	Rare	Rare	Rare	Rare
Connecticut River	None	None	None	None
Gardiners Bay	Rare	Rare	Rare	Rare
Great South Bay	None	None	None	None
Hudson River/Raritan Bay	None	Rare	None	None
Barnegat Bay to Chesapeake Bay	None	None	None	None

Table 5. Summary of life history and habitat parameters for Atlantic cod.
Based partially on data contained in Appendix 1, Table of Habitat Parameters. This table is the same as that in the first Atlantic cod EFH source document (Fahay *et al*. 1999); more recent studies were reviewed (see Appendix 1), but no new information of relevance to this table was found.

Life History Stage	Spatial and Temporal Distribution	Temperature	Salinity	Depth/ Substrate/ Vegetation	Diel/ Light/ Vertical	Predator/ Prey
Eggs [1]	Pelagic. Bays, harbors, offshore banks. Spawning begins in fall, peaks winter and spring.	Most 2.0-8.5°C for incubation. 12.0°C upper limit. Mortality independent of temperature.	Most 32-33 ppt. Eggs sink in spring freshets. Inverse relationship with mortality, 26-36 ppt.	Usually < 70 m.	Near surface unless salinities low. Eggs in poor condition may sink.	--
Larvae [2]	Pelagic. Most over Georges Bank, perimeter of Gulf of Maine, southern New England, continental shelf. Densest in spring.	Most 4-8°C in winter-spring, 7-12°C in summer-fall.	Most 32-33 ppt.	--	Youngest from surface to 75 m. Move deeper with age. Migrate vertically in reaction to light.	Growth strongly correlated with zooplankton volume. Yolk sac larvae vulnerable to zooplankton predators.
Juveniles [3]	Mostly in shoal waters, coastal or offshore banks, during summer. Deeper water in winter.	6-20°C. More tolerant of extremes than adults. Temperature preferences differ winter-summer.	30-35 ppt.	'Cobble' preferred over finer grains. Uses vegetation for predator avoidance. Survival may be enhanced in structurally complex habitats.	Some changes in vertical distribution, day/night (see Appendix 1).	Avoid predation by seeking refuge in structured habitats.
Adults [4]	Seasonal migrations except in Gulf of Maine. Most dense Massachusetts Bay, northeast Georges Bank, Nantucket Shoals.	Generally < 10°C, varies seasonally.	Wide range of oceanic salinities. Mortality < 2.3 ppt.	Rocky, pebbly, gravelly. Avoid finer sediments.	Usually on bottom during day, may move up into water column at night.	Varied diet. Predation by large sharks, spiny dogfish, and, as juveniles, older cod.

[1] Bonnet (1939); Bigelow and Schroeder (1953); Laurence and Rogers (1976); Hardy (1978).
[2] Rau (1974); Hardy (1978); Bailey (1984); Suthers *et al.* (1989).
[3] Bigelow and Schroeder (1953); Hardy (1978); MacDonald *et al.* (1984); Clark and Green (1990); Gotceitas and Brown (1993).
[4] Bigelow and Schroeder (1953); Beamish (1966); Odense *et al.* (1966); Hardy (1978); Scott (1982b); Cohen *et al.* (1990).

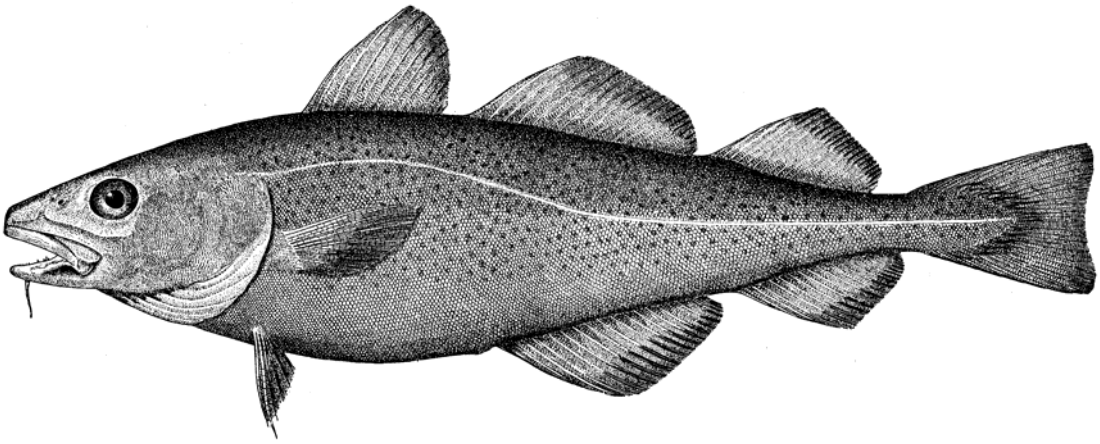
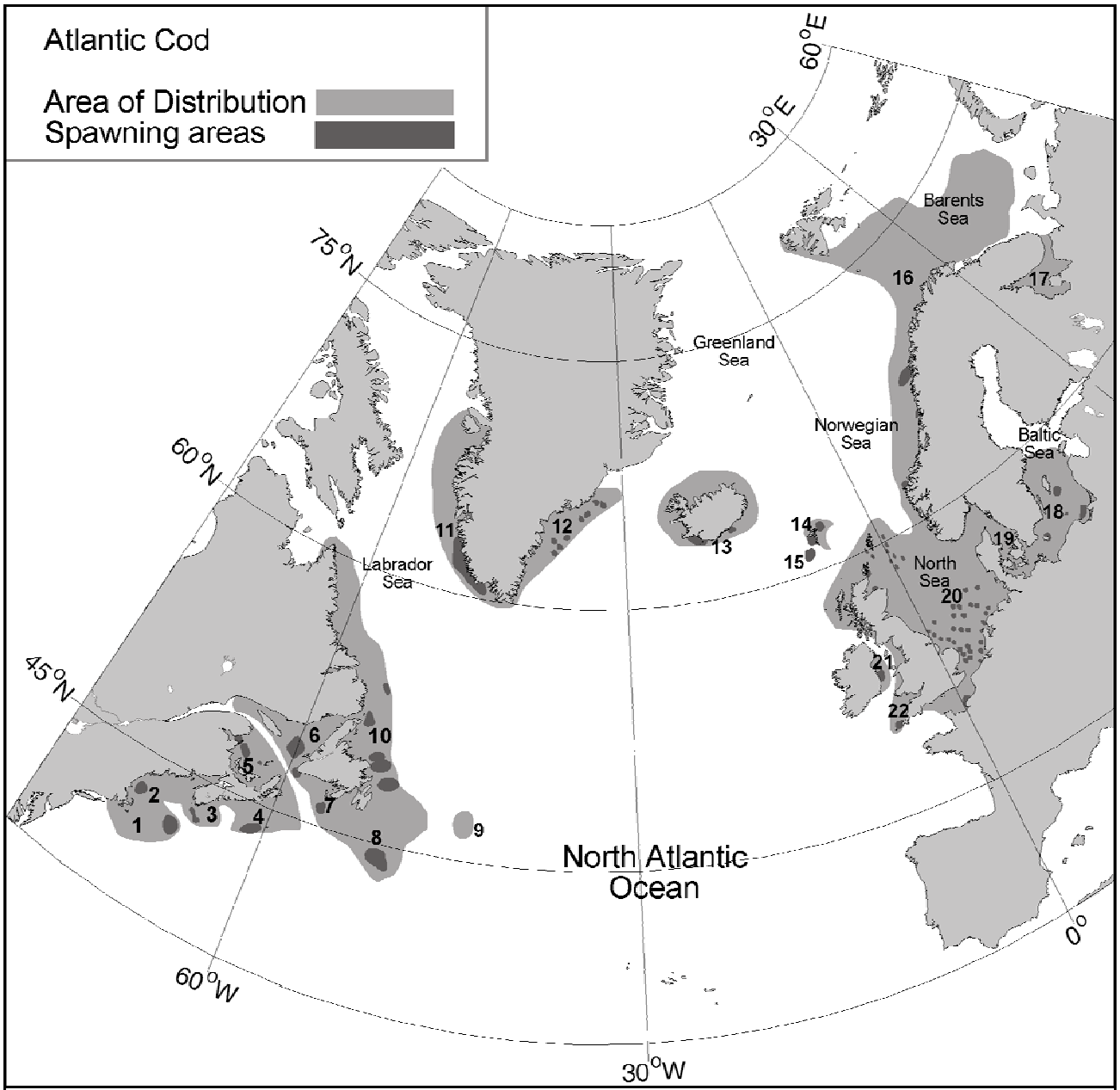


Figure 1. The Atlantic cod, *Gadus morhua* (from Goode 1884).



1 Georges Bank	9 Flemish Cap	16 North East Arctic
2 Gulf of Maine	10 Northern Newfoundland / Southern Labrador	17 White Sea
3 Western Scotian Shelf	11 West Greenland	18 Baltic Sea
4 Eastern Scotian Shelf	12 East Greenland	19 Kattegat
5 Southern Gulf of St. Lawrence	13 Iceland	20 North Sea-West Scotland -English Channel
6 Northern Gulf of St. Lawrence	14 Faroe Plateau	21 Irish Sea
7 Southern Newfoundland	15 Faroe Bank	22 Celtic Sea
8 Grand Bank		

Figure 2. Distribution of Atlantic cod stocks in the North Atlantic showing principle spawning sites. Source: Brander (1994).

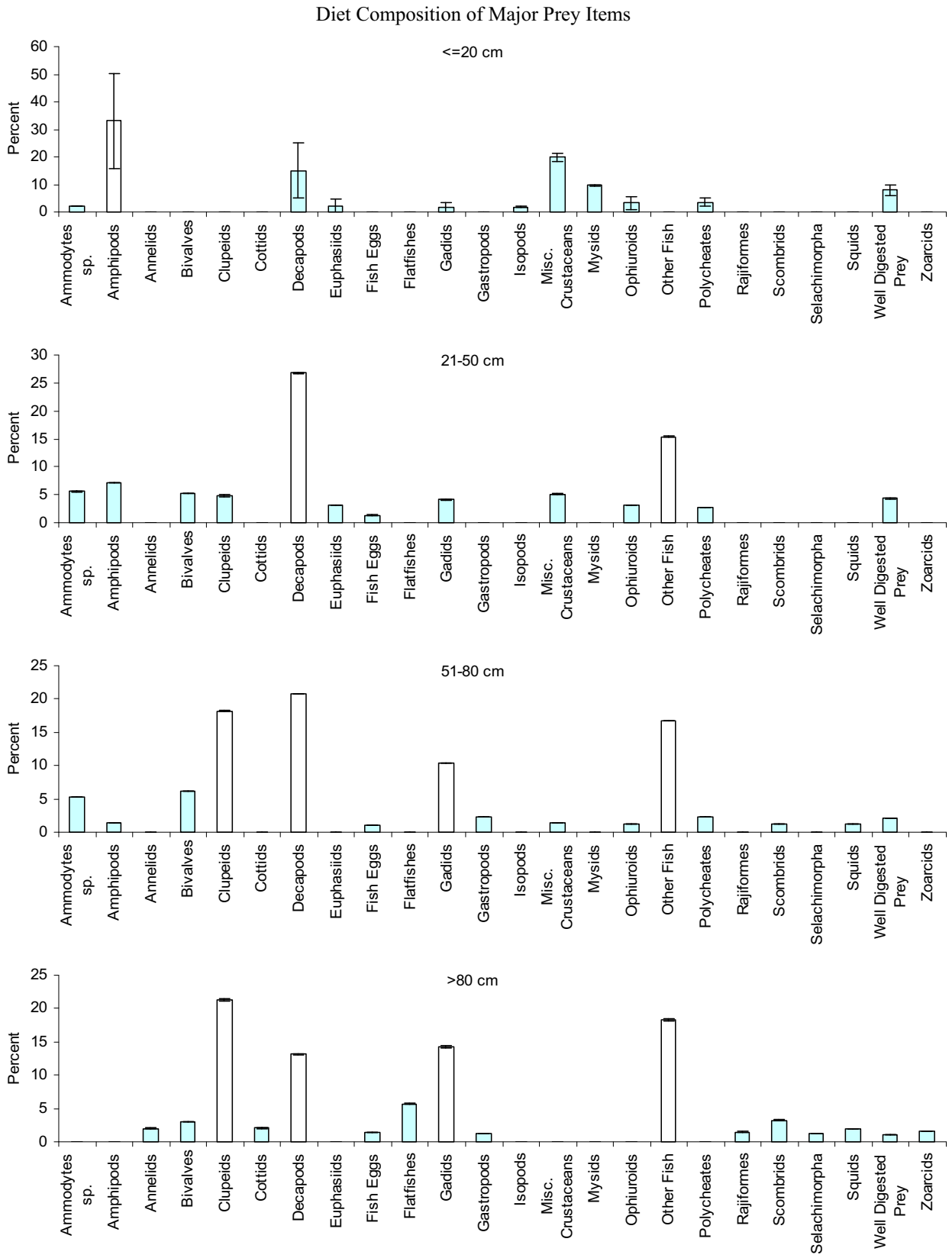
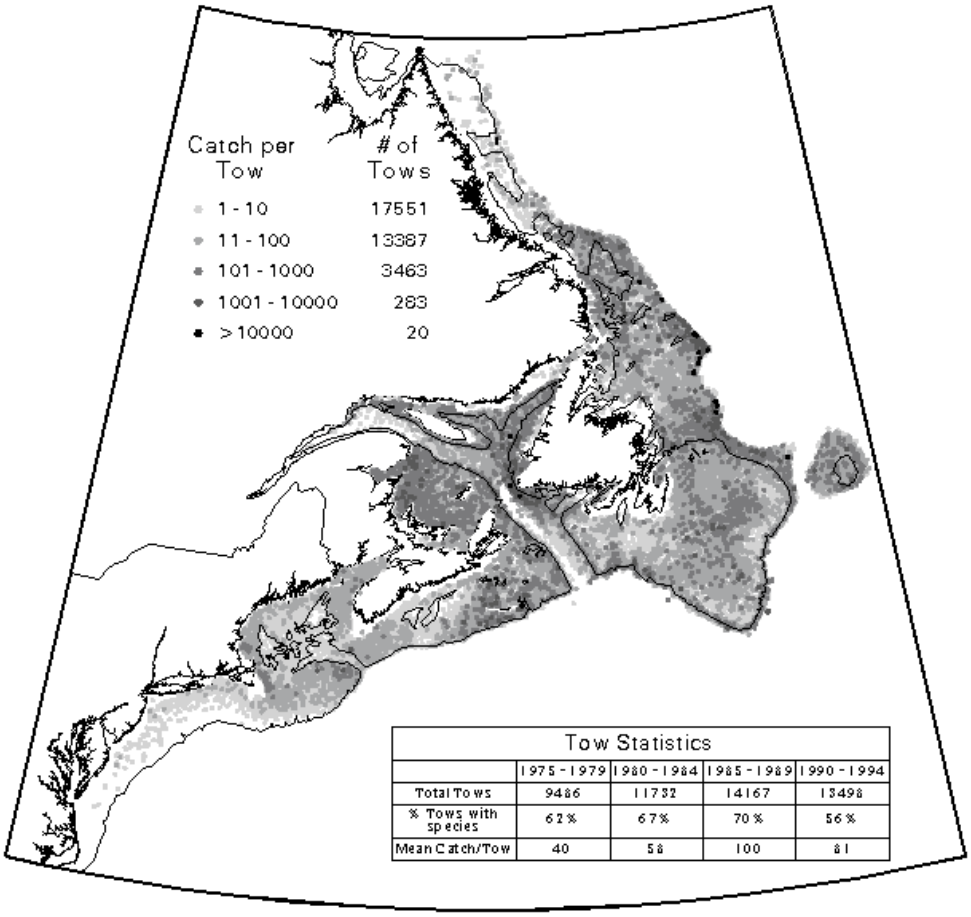


Figure 3. Percent by weight of the major prey items in the diet of three size categories of Atlantic cod. From specimens collected during NEFSC bottom trawl surveys from 1973-2001 (all seasons). For details on NEFSC diet analysis, see Link and Almeida (2000).



Tow Statistics

	1975 - 1979	1980 - 1984	1985 - 1989	1990 - 1994
Total Tows	9486	11732	14167	13498
% Tows with species	62%	67%	70%	56%
Mean Catch/Tow	40	58	100	81

Figure 4. Overall distribution and abundance of Atlantic cod in the northwest Atlantic Ocean. Based on research trawl surveys conducted by Canada (DFO) and the United States (NMFS) from 1975-1994 (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

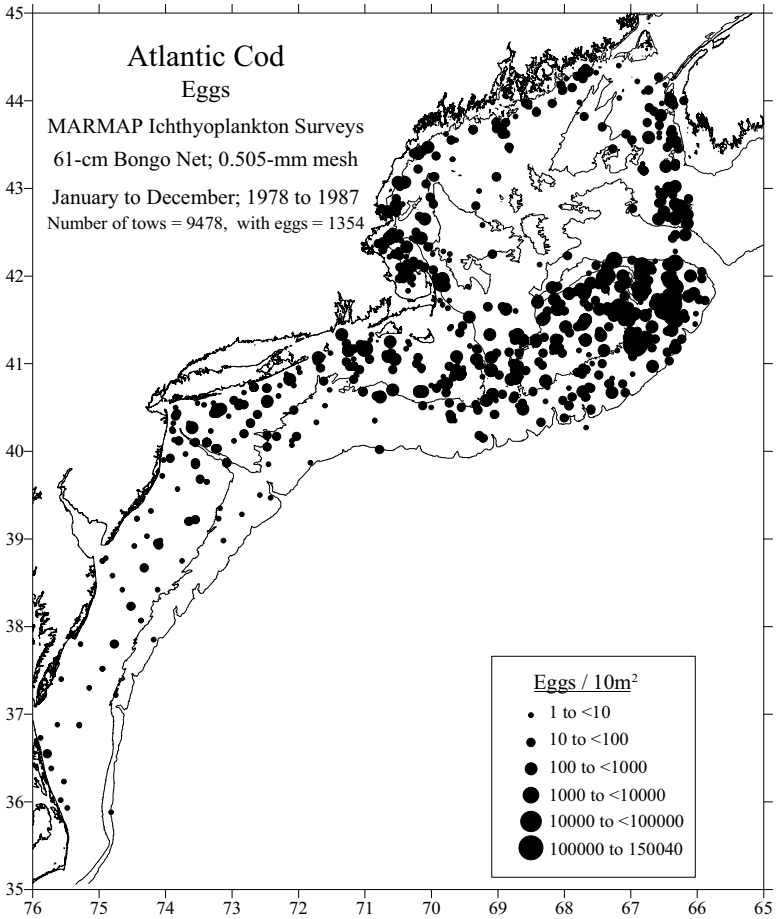


Figure 5. Distributions and abundances of Atlantic cod eggs collected during NEFSC MARMAP ichthyoplankton surveys.
For all available months and years from 1978 to 1987 combined.

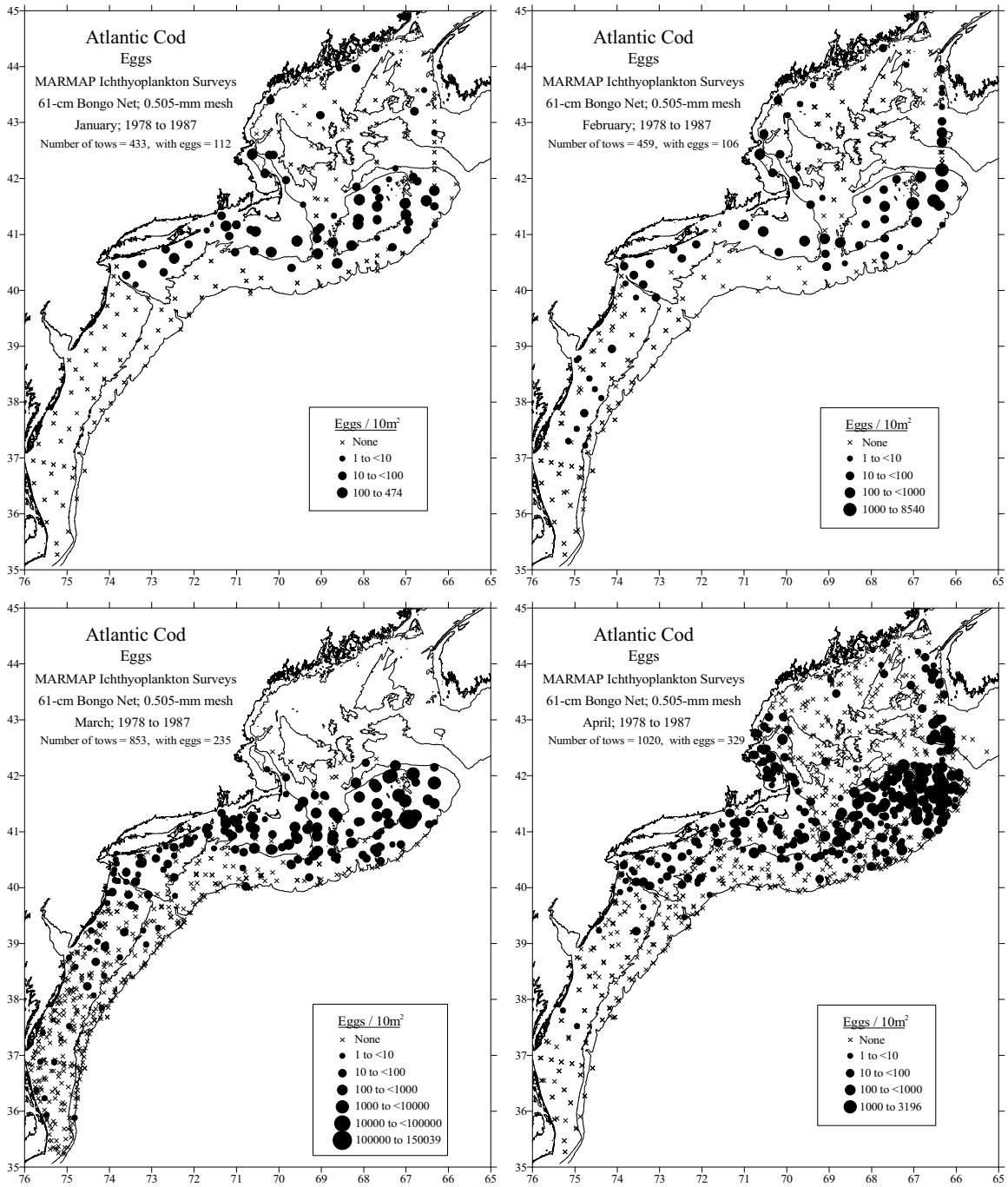


Figure 5. Cont'd.
From MARMAP ichthyoplankton surveys, January through April, 1978-1987.

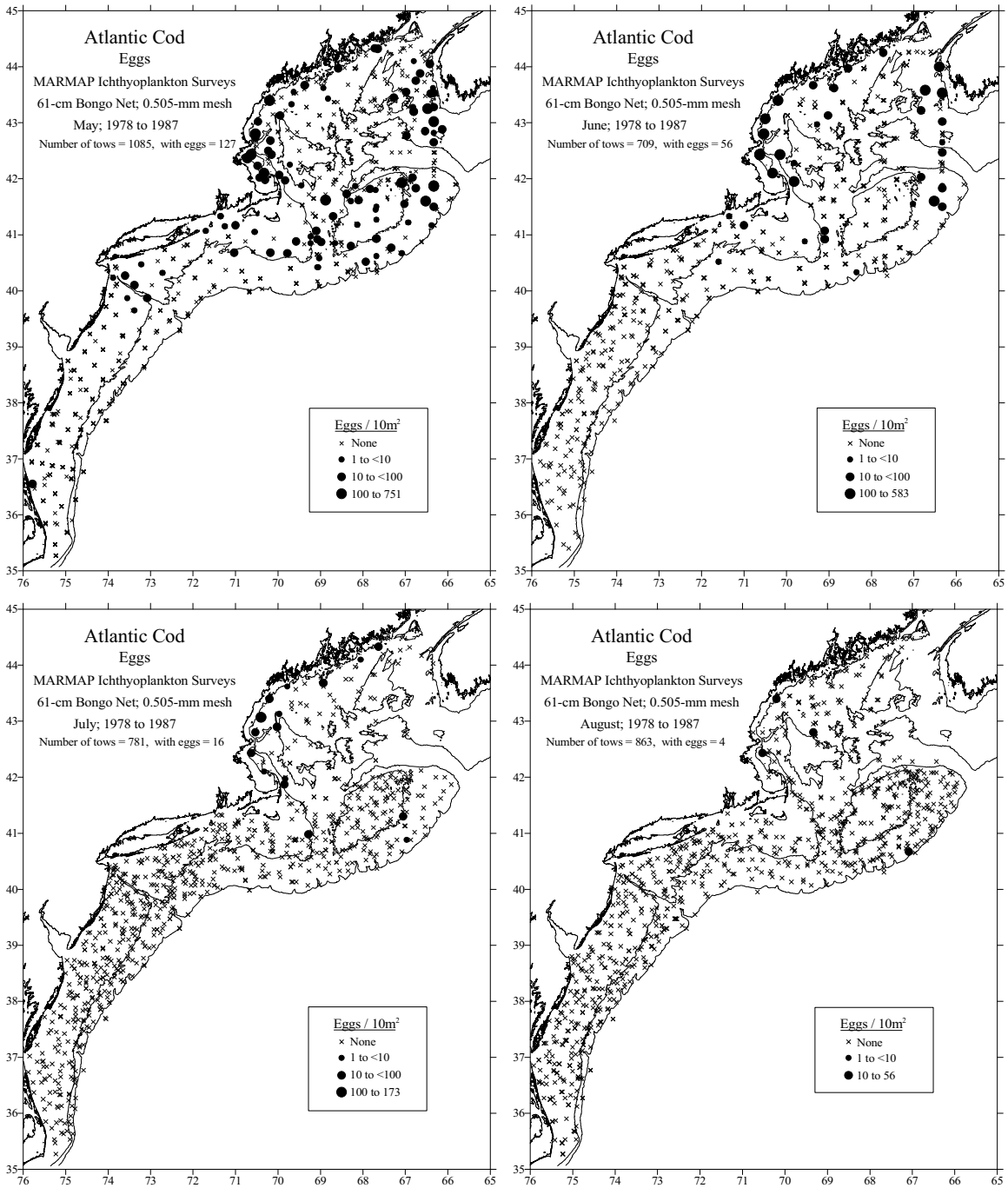


Figure 5. Cont'd.
From MARMAP ichthyoplankton surveys, May through August, 1978-1987.

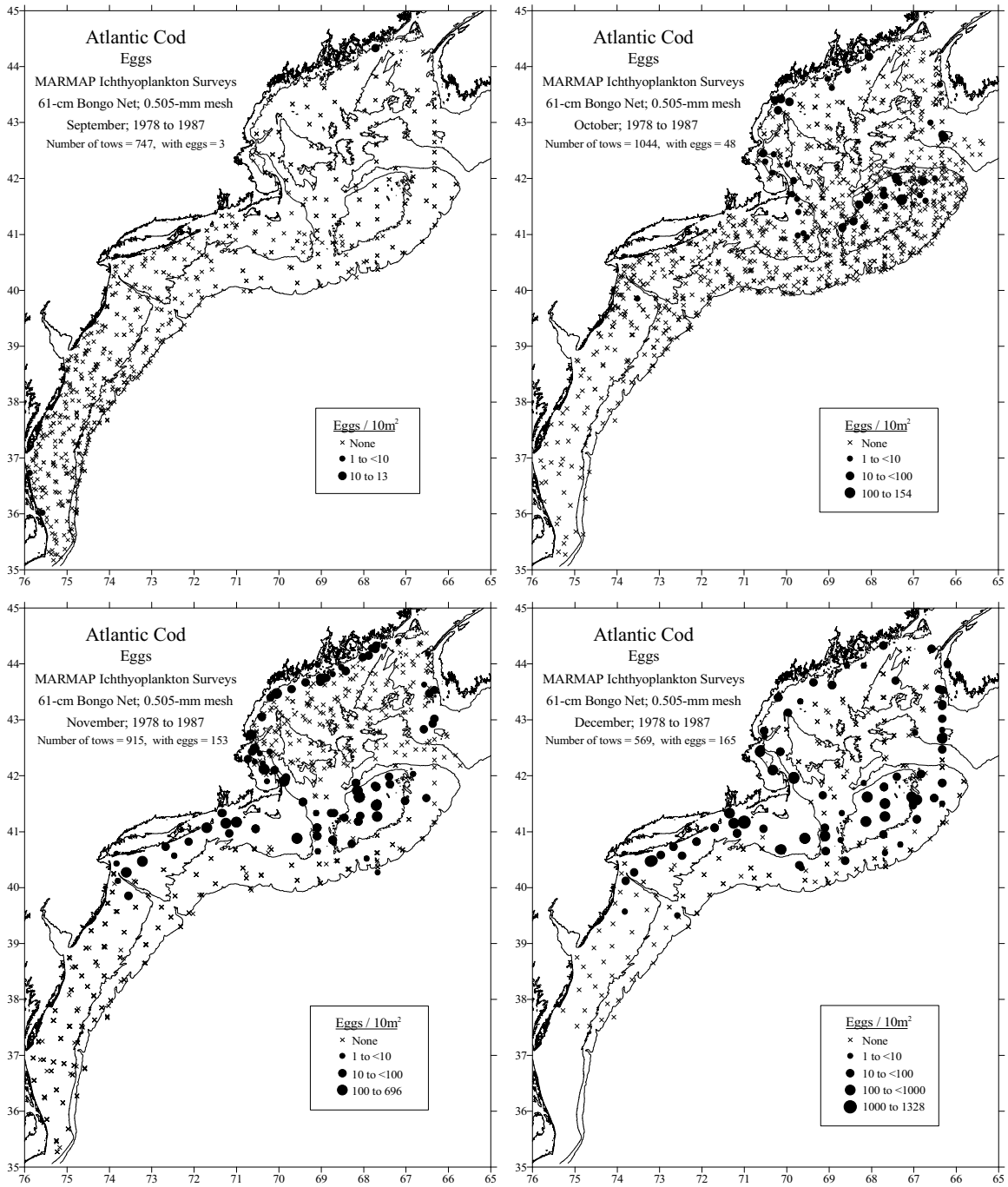


Figure 5. Cont'd.
From MARMAP ichthyoplankton surveys, September through December, 1978-1987

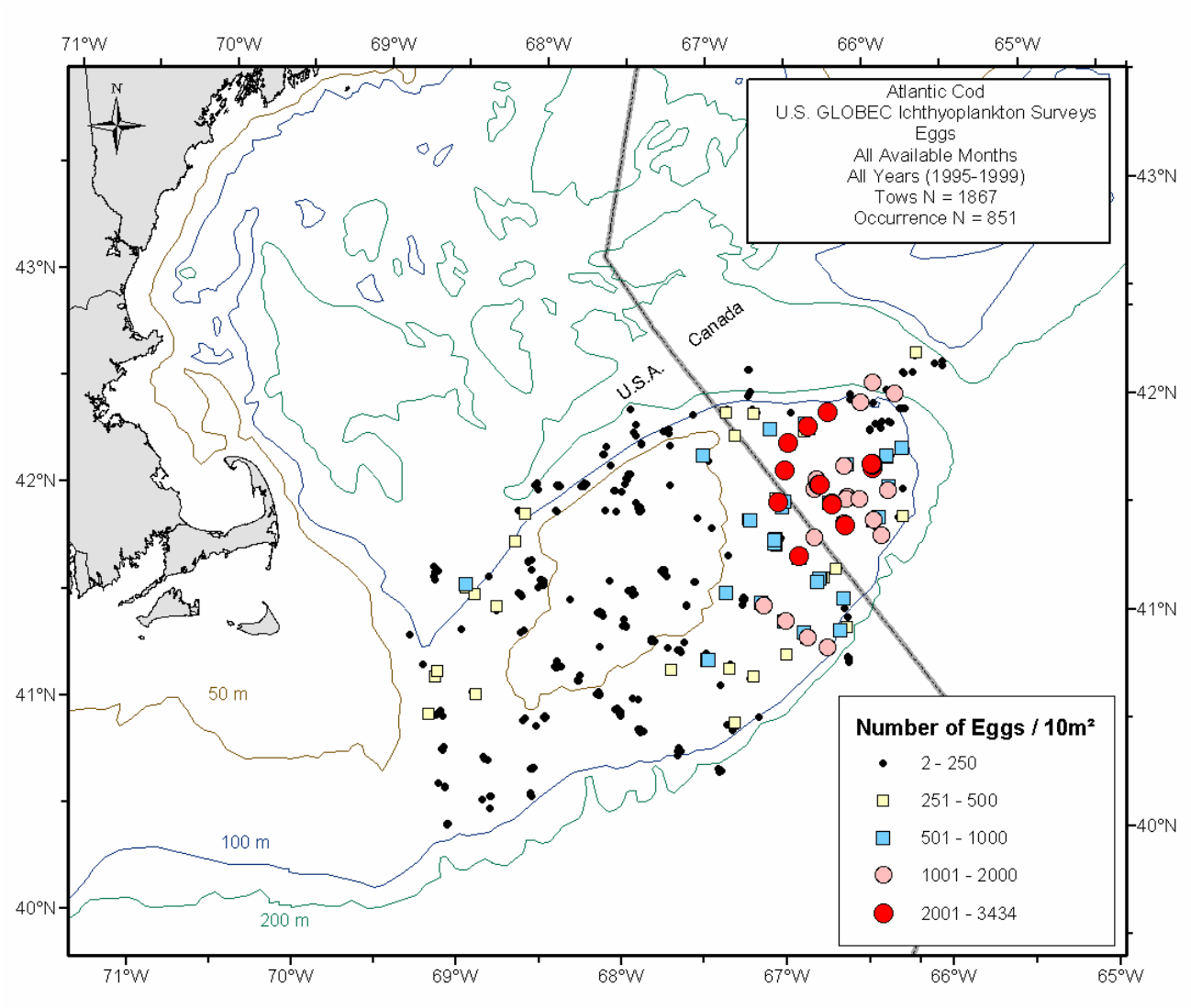


Figure 6. Distributions and abundances of Atlantic cod eggs collected during GLOBEC Georges Bank ichthyoplankton surveys.
For all available years (February-July, 1995; January-June, 1996-1999) combined.

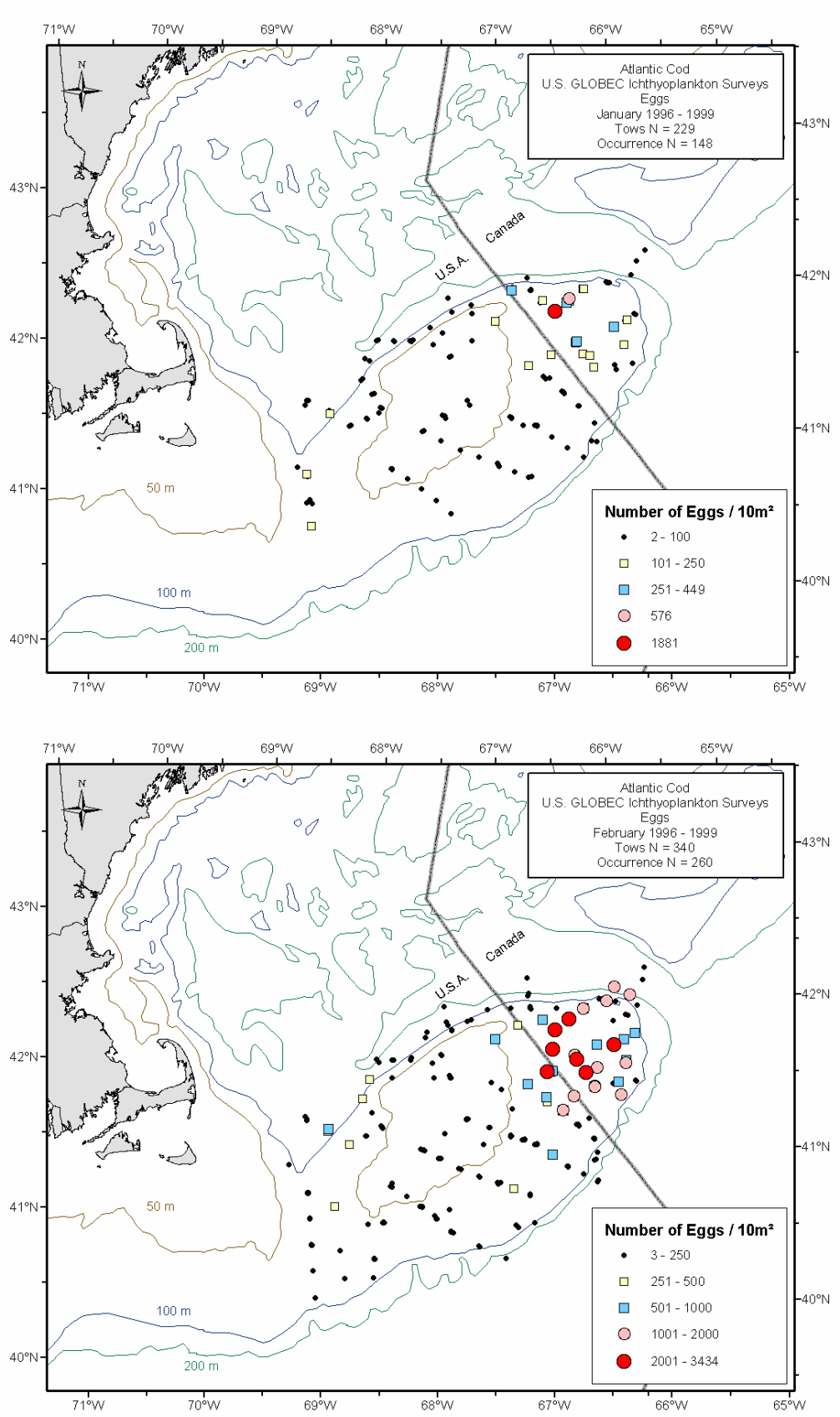
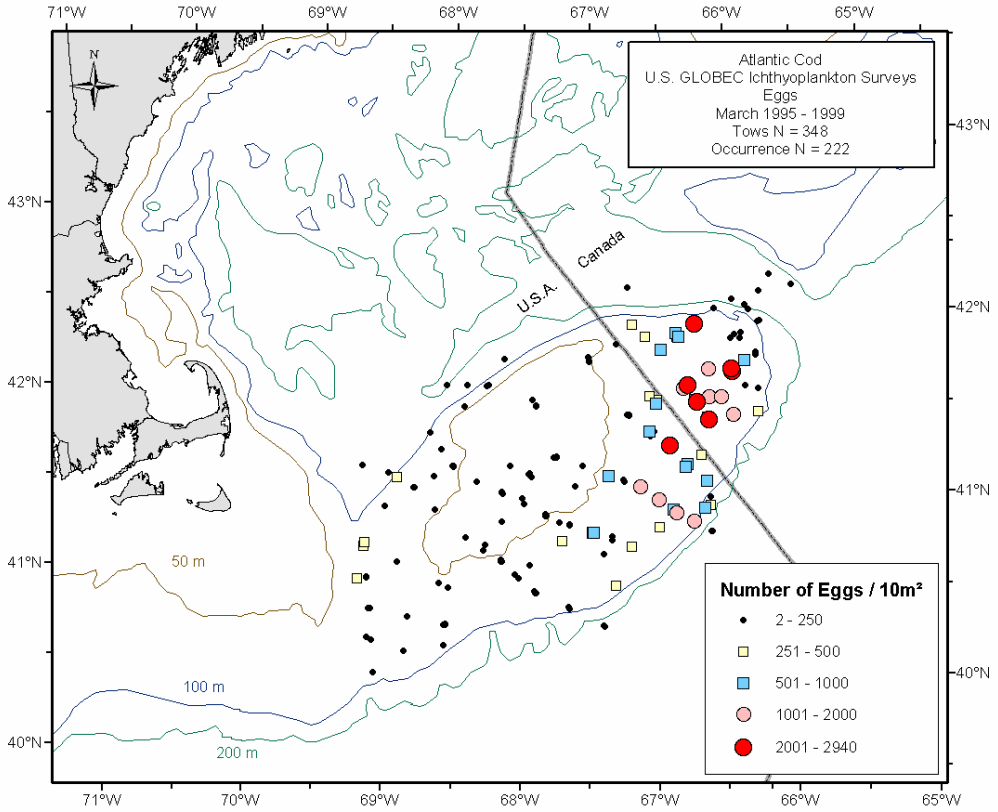


Figure 6. Cont'd.
From GLOBEC ichthyoplankton surveys, January and February, for all available years combined.



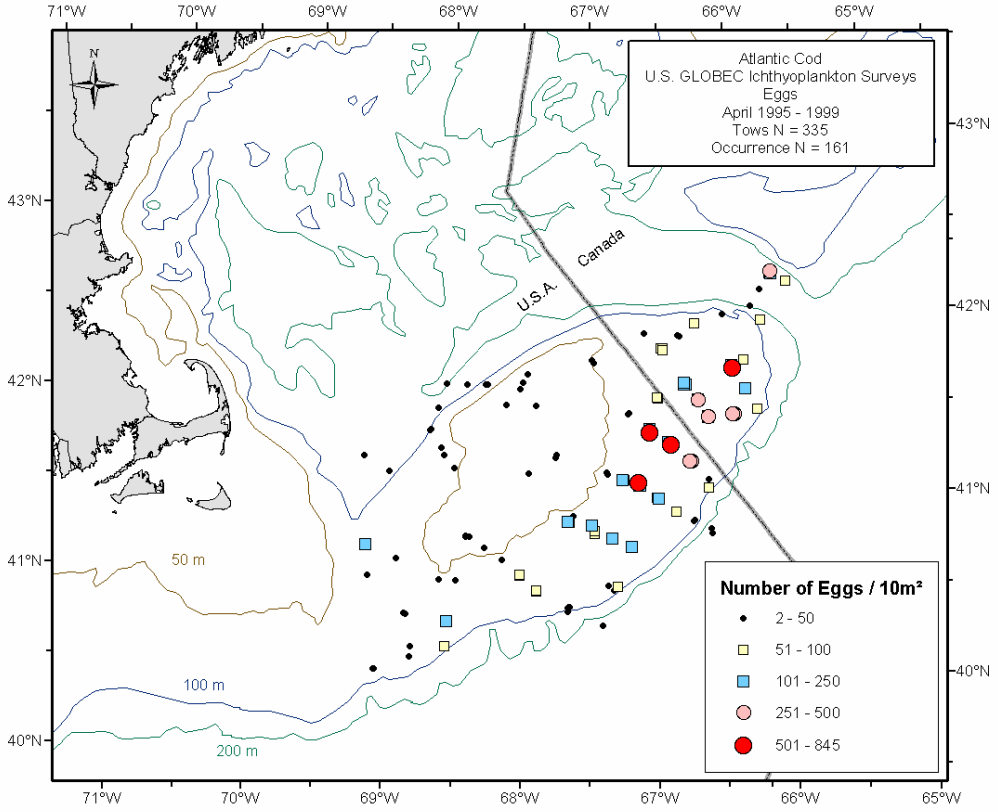


Figure 6. Cont'd.
From GLOBEC ichthyoplankton surveys, March and April, for all available years combined.

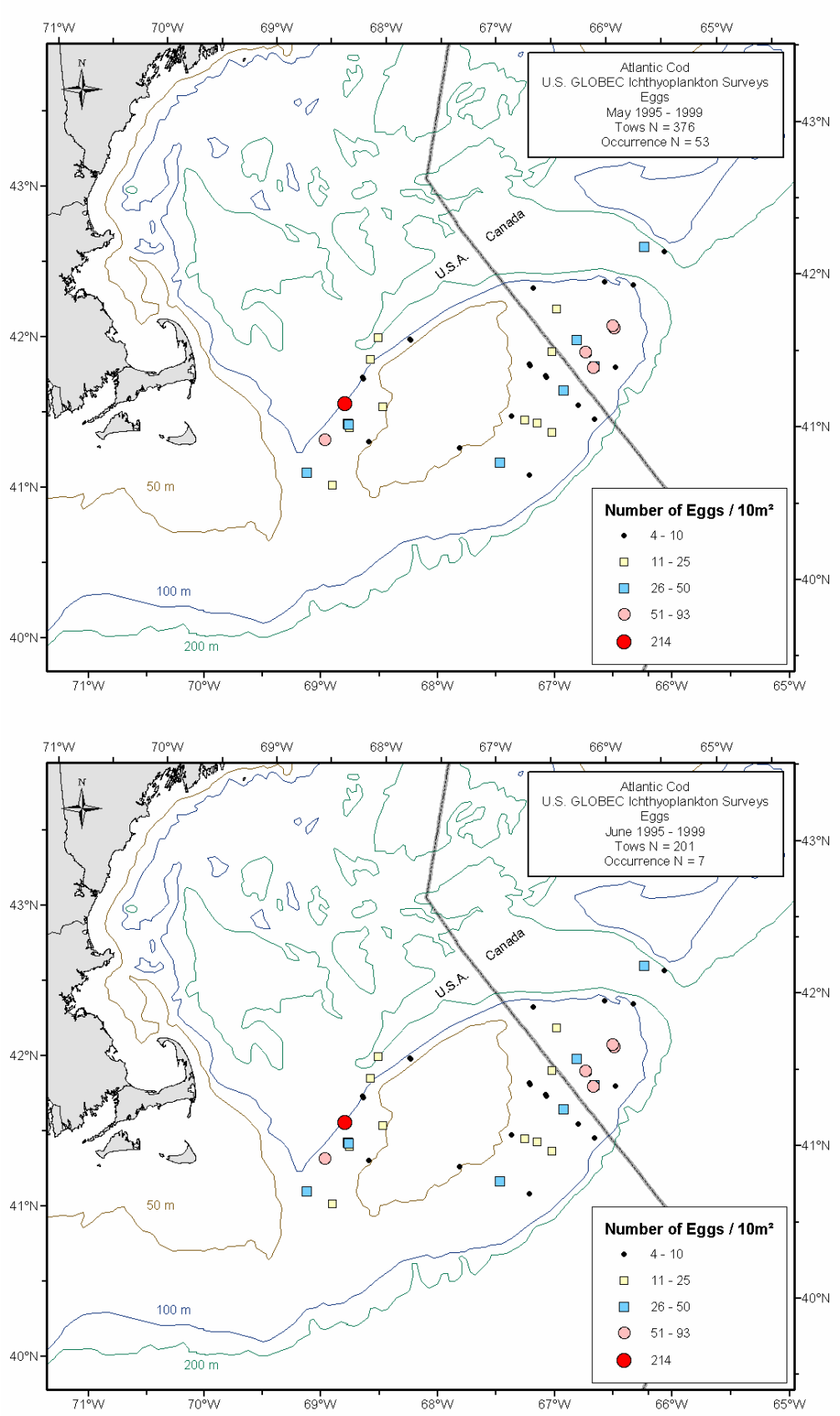


Figure 6. Cont'd.
From GLOBEC ichthyoplankton surveys, May and June, for all available years combined.

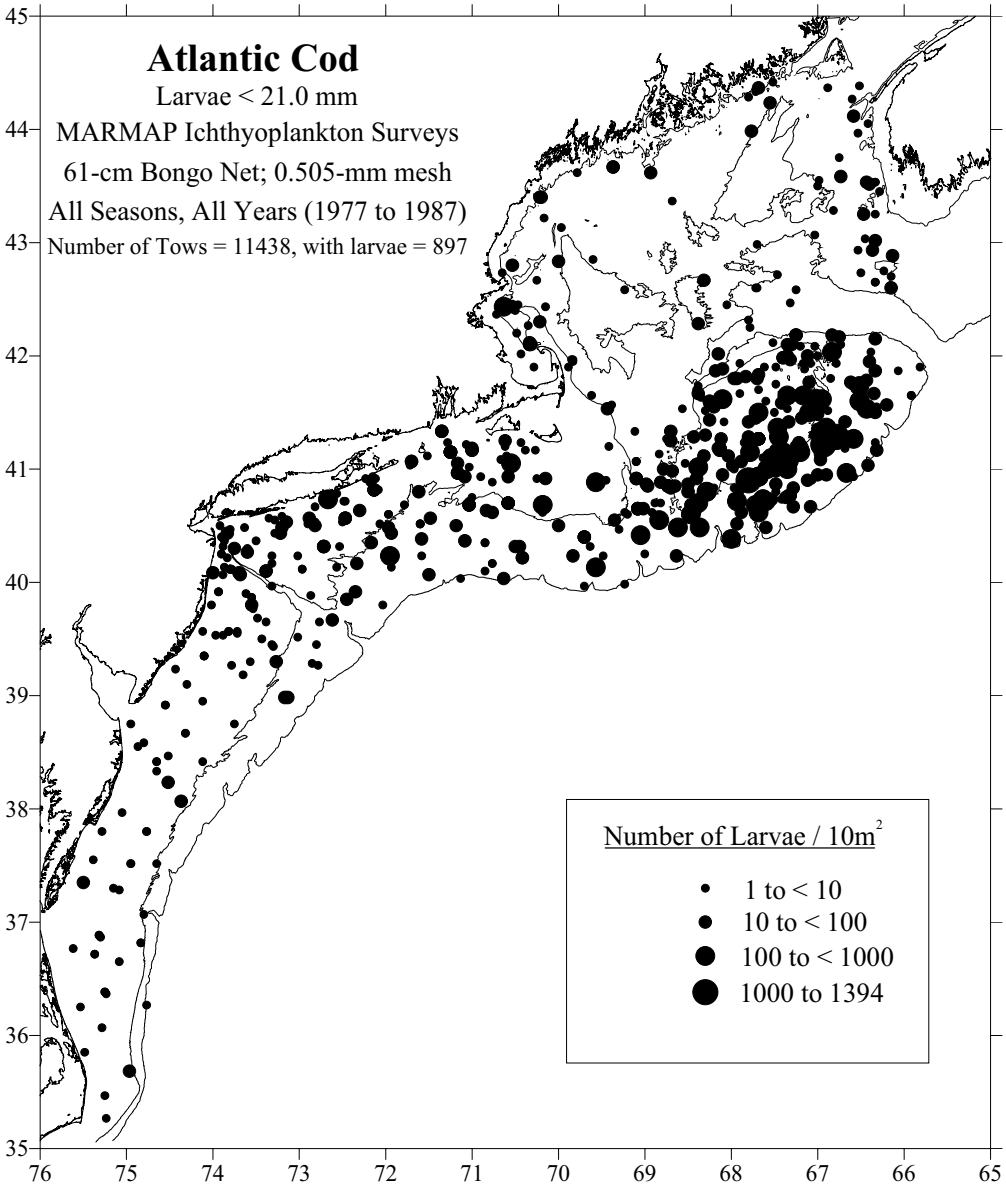


Figure 7. Distributions and abundances of Atlantic cod larvae collected during NEFSC MARMAP ichthyoplankton surveys.
For all available months and years from 1977 to 1987 combined.

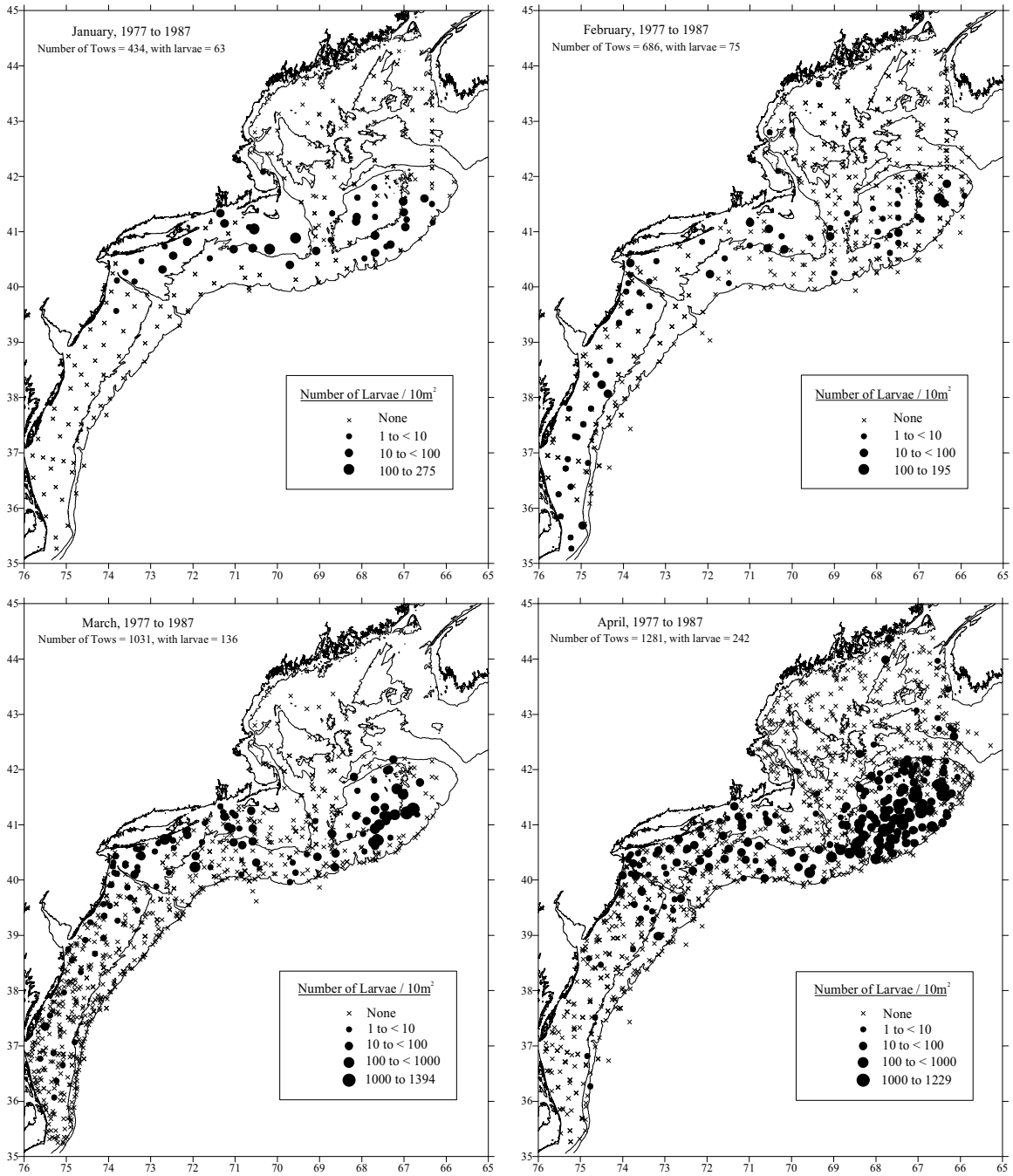


Figure 7. Cont'd.
From MARMAP ichthyoplankton surveys, January through April, 1977-1987.

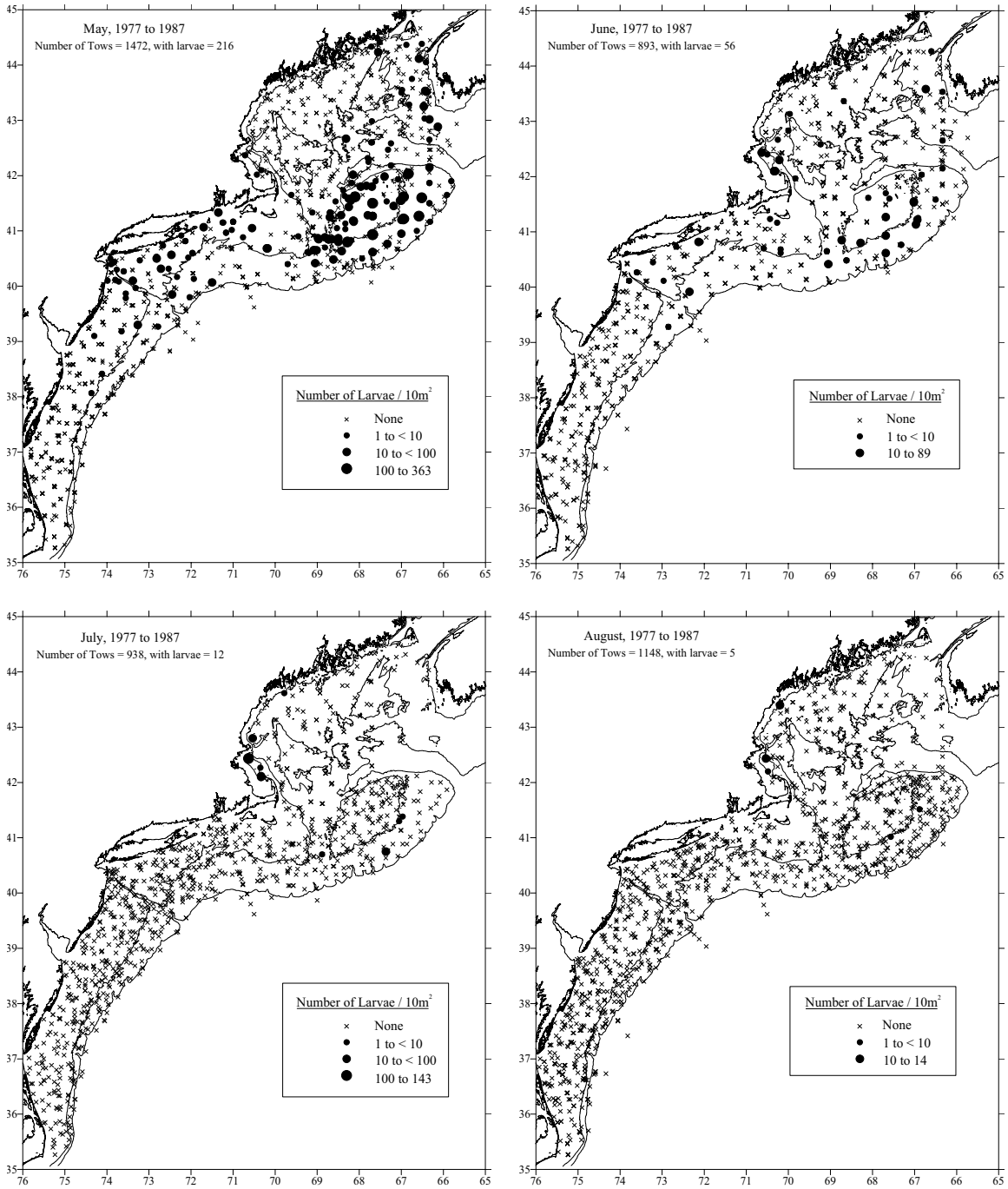


Figure 7. Cont'd.
From MARMAP ichthyoplankton surveys, May through August, 1977-1987.

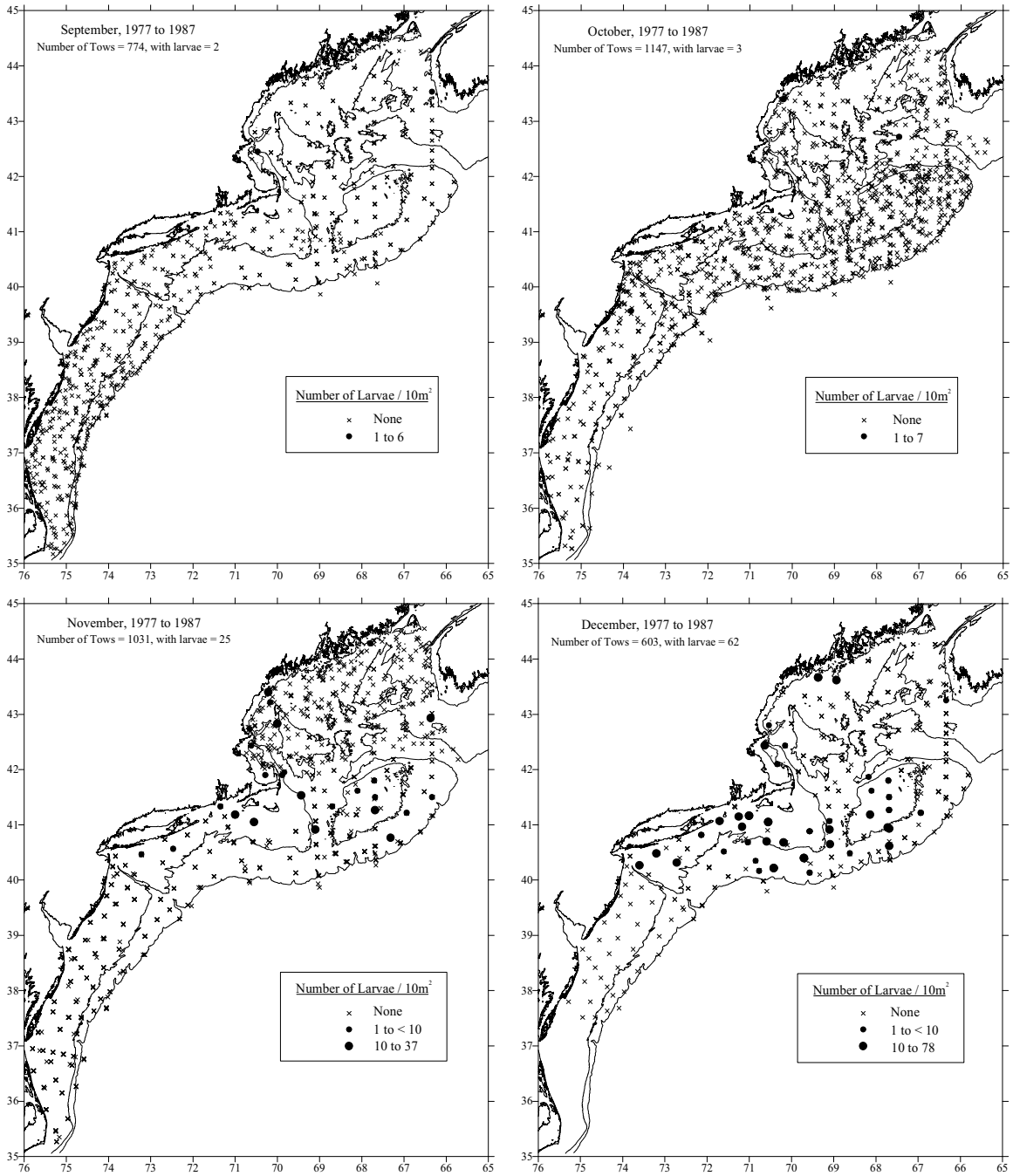


Figure 7. Cont'd.
From MARMAP ichthyoplankton surveys, September through December, 1977-1987.

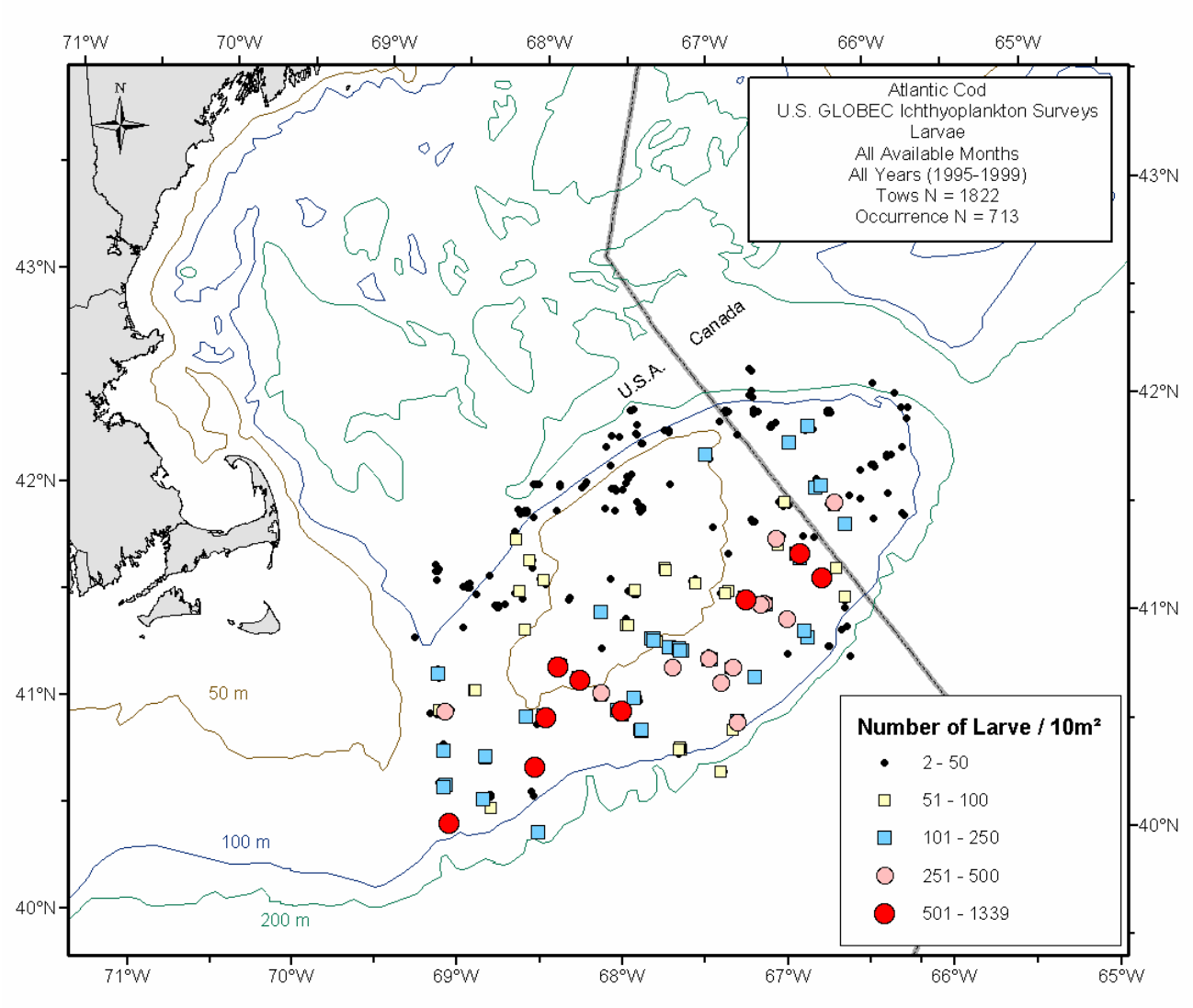
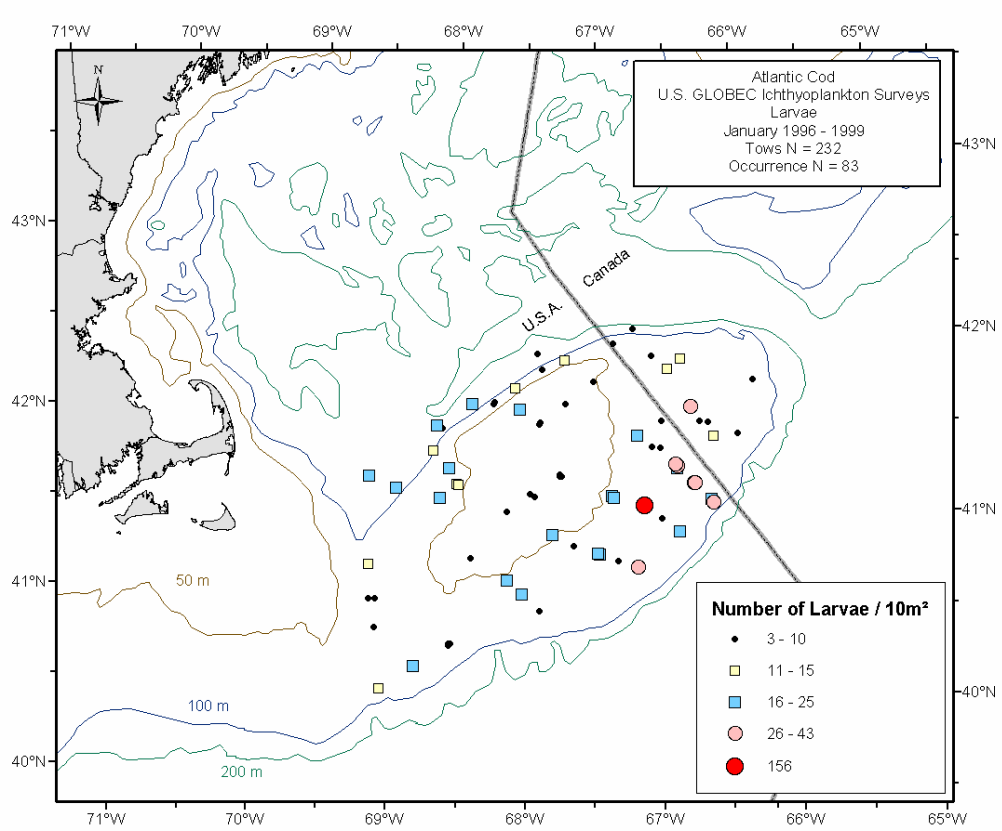


Figure 8. Distributions and abundances of Atlantic cod larvae collected during GLOBEC Georges Bank ichthyoplankton surveys.
For all available years (February-July, 1995; January-June, 1996-1999) combined.



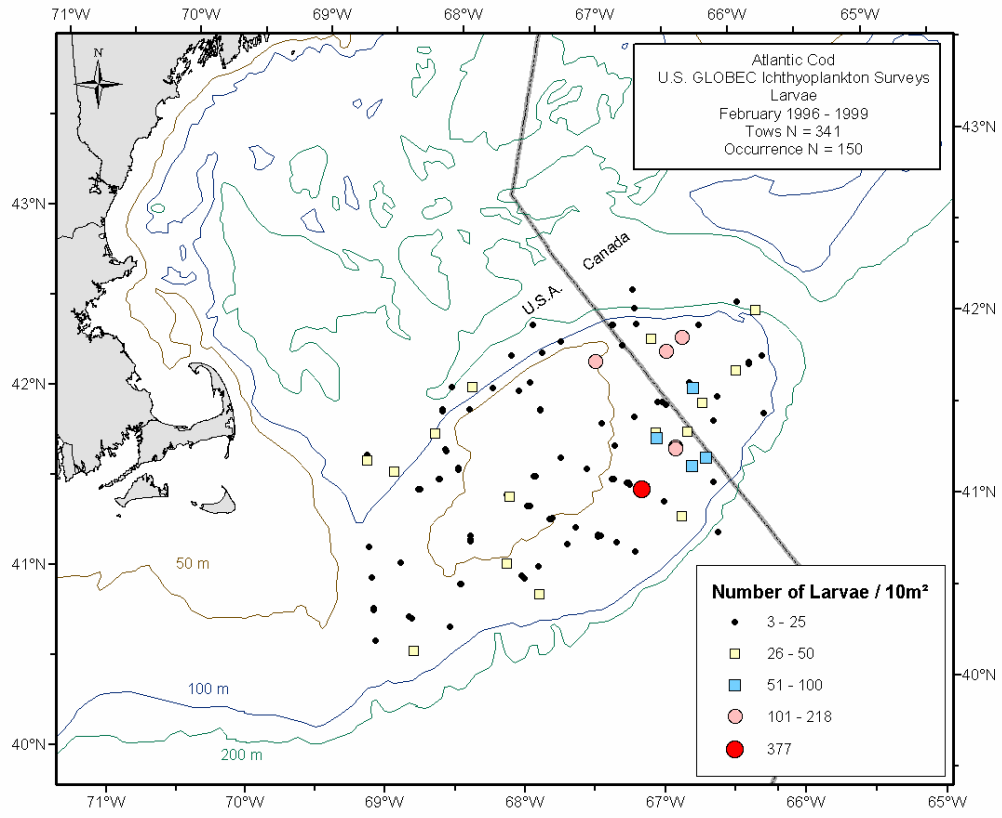
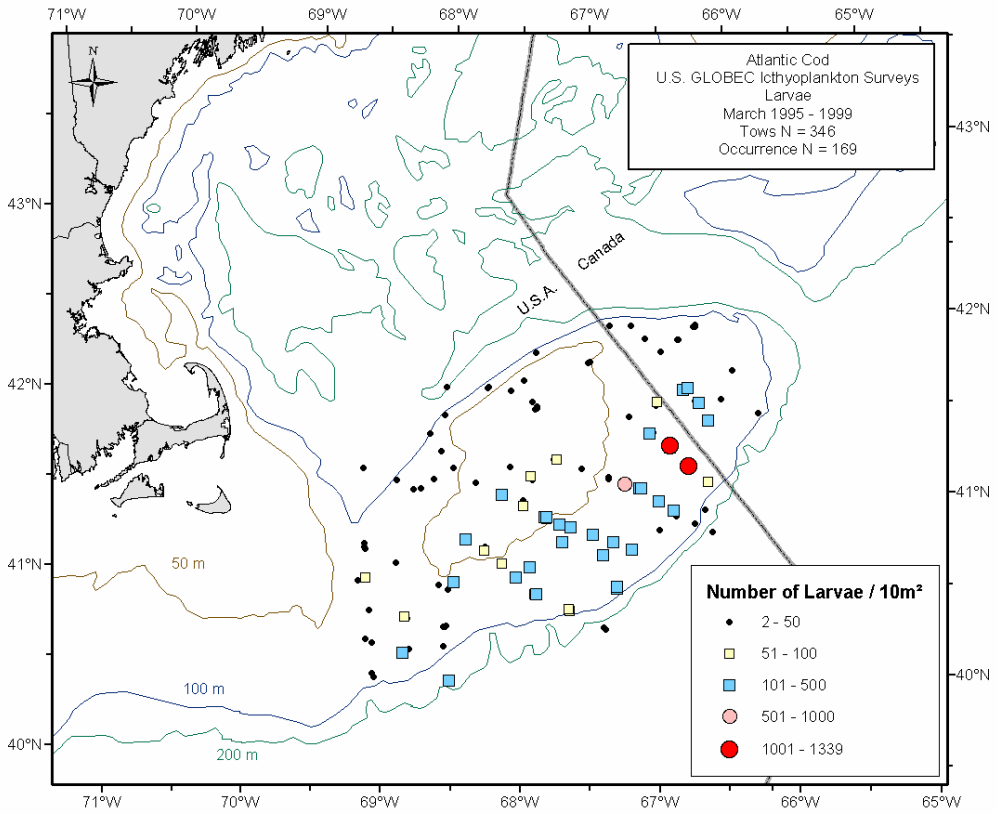


Figure 8. Cont'd.
From GLOBEC ichthyoplankton surveys, January and February, for all available years combined.



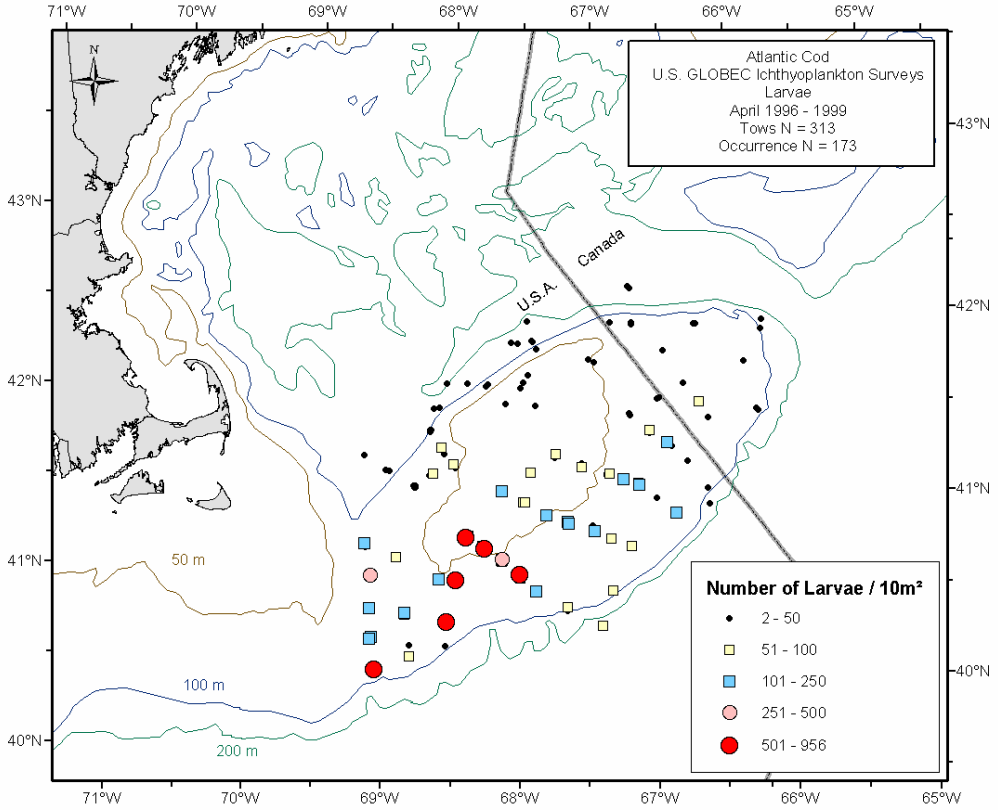


Figure 8. Cont'd.
From GLOBEC ichthyoplankton surveys, March and April, for all available years combined.

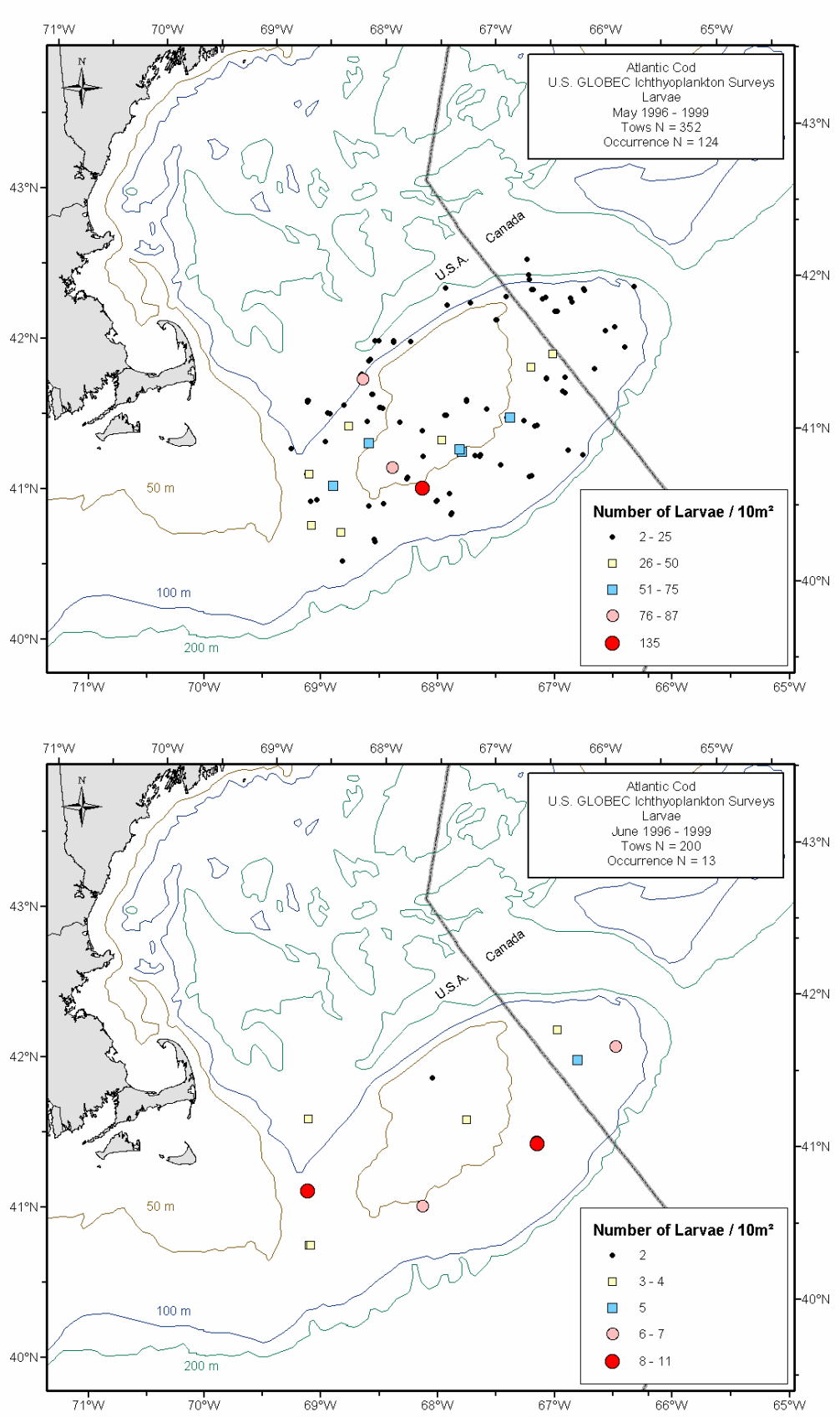


Figure 8. Cont'd.
From GLOBEC ichthyoplankton surveys, May and June, for all available years combined.

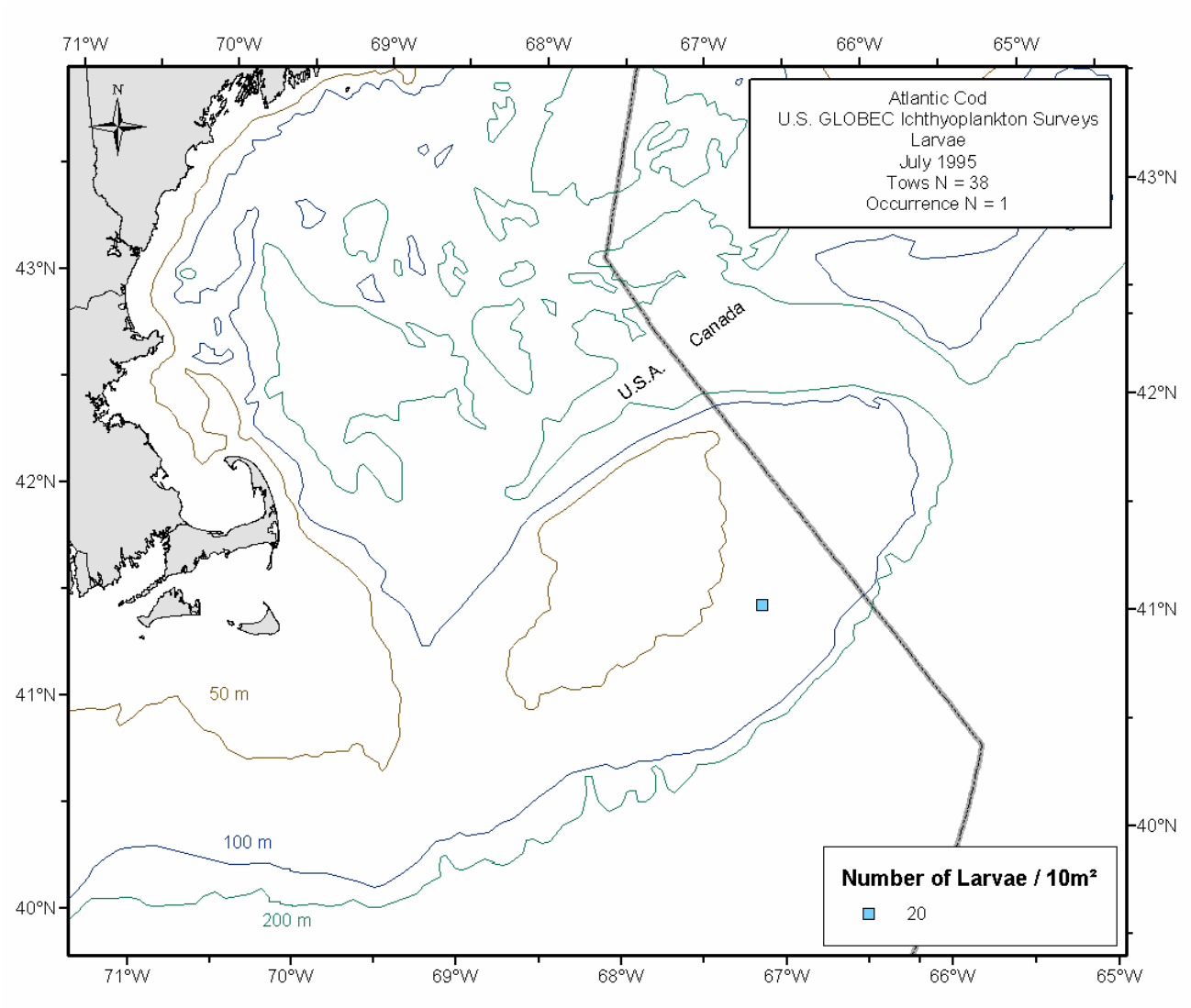


Figure 8. Cont'd.
From GLOBEC ichthyoplankton surveys, July 1995.

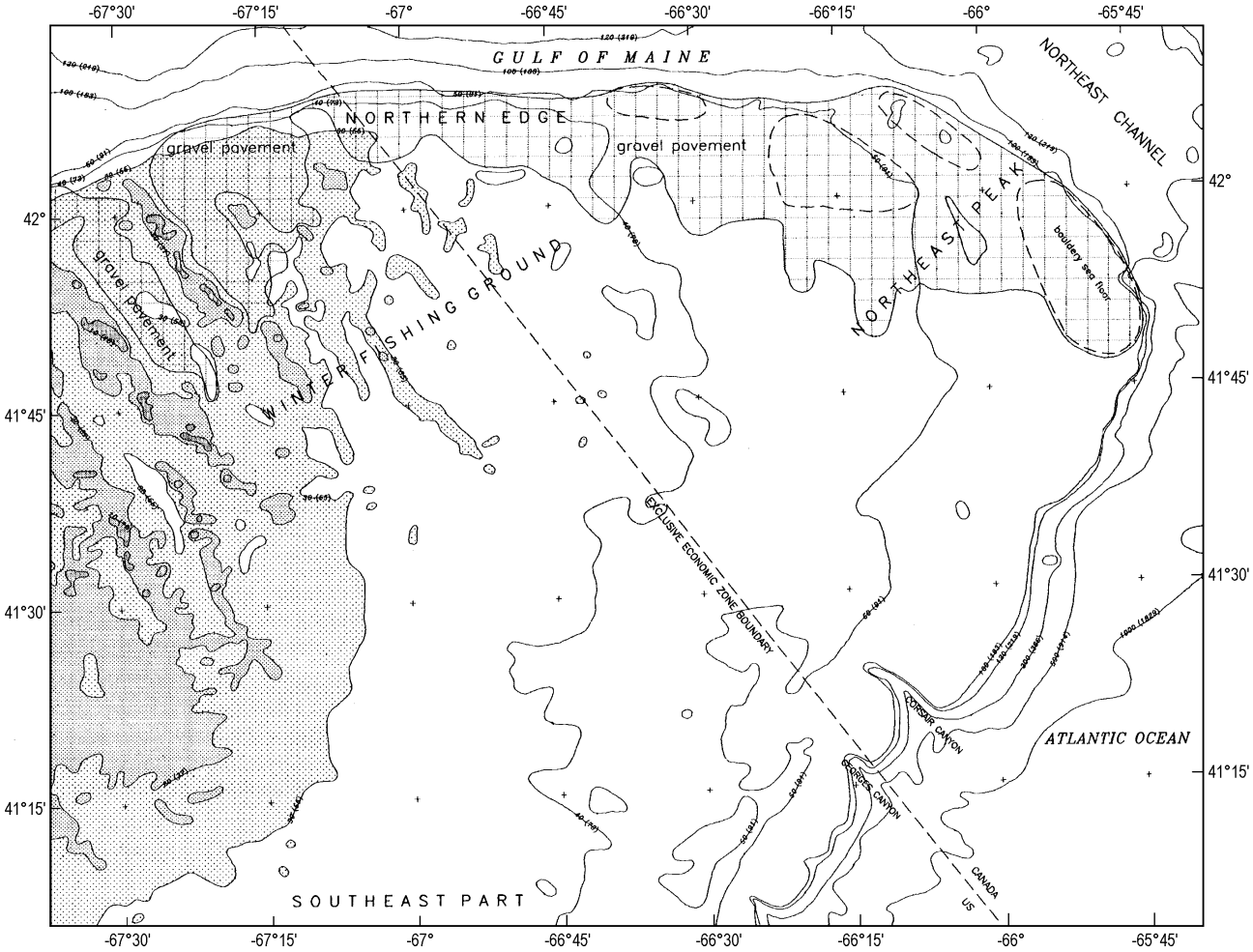


Figure 9. Topographic map of Georges Bank showing gravel distribution, from Valentine and Lough (1991).

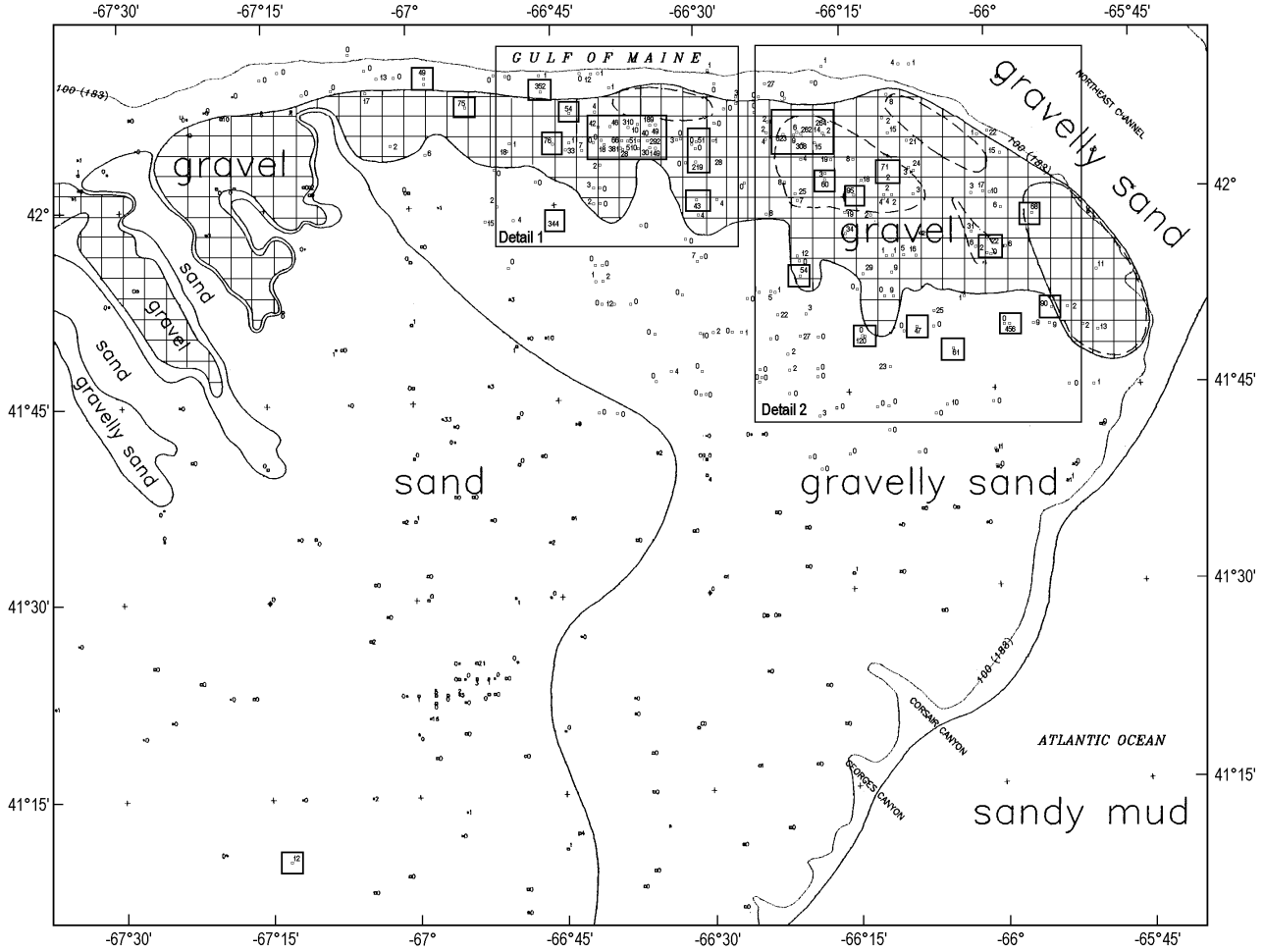


Figure 10. Distribution and abundance of recently-settled juvenile cod on eastern Georges Bank in relation to sediments. Source: Valentine and Lough (1991).

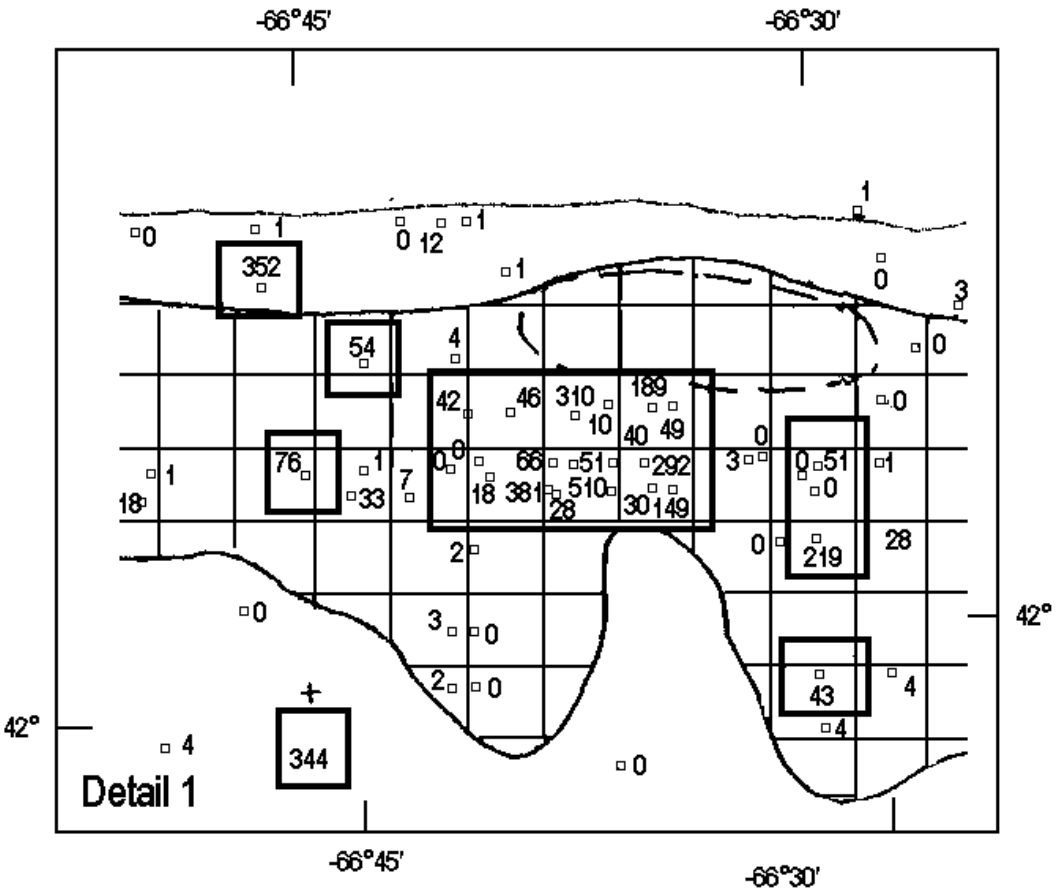


Figure 10. Cont'd.

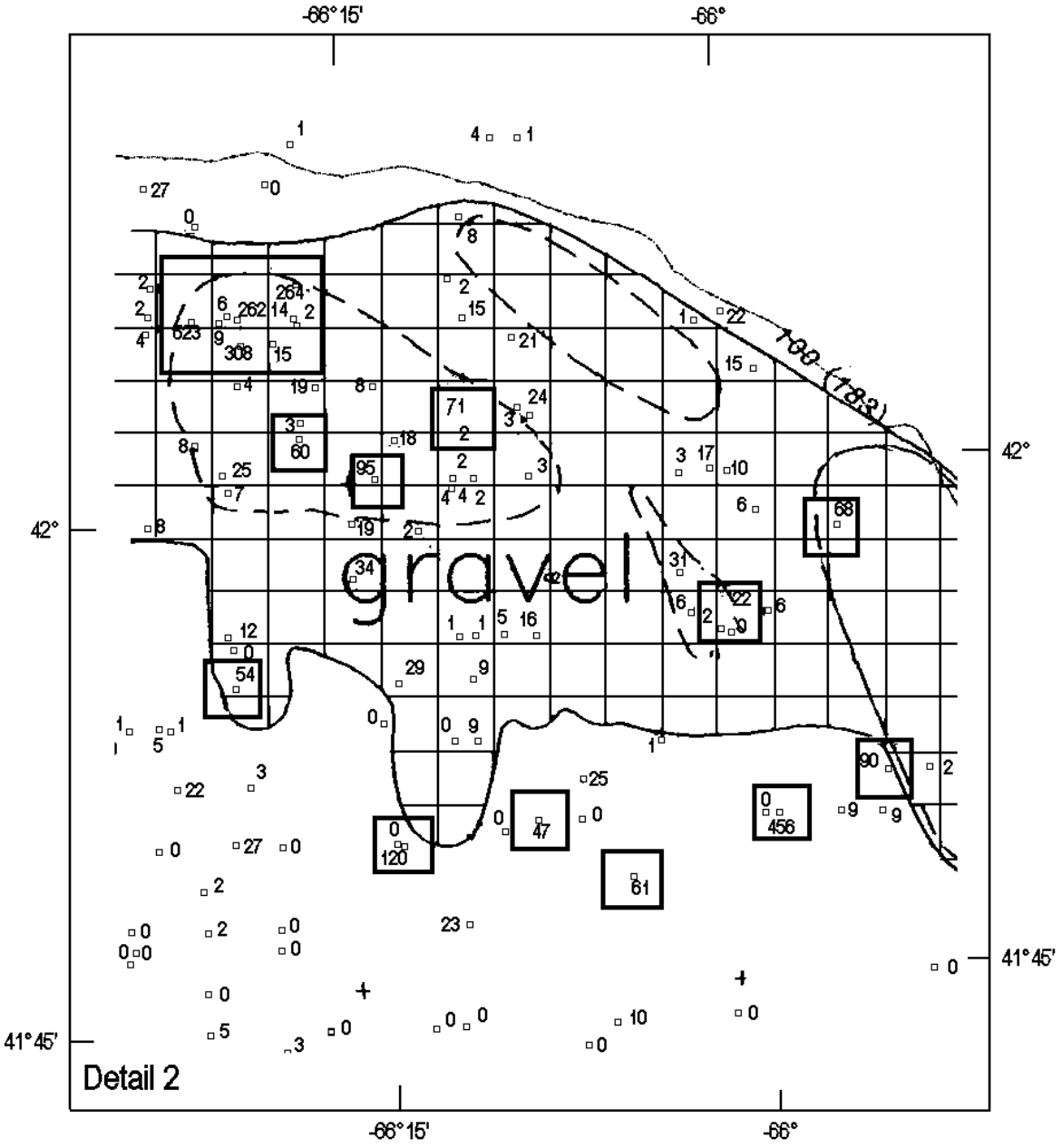


Figure 10. Cont'd.

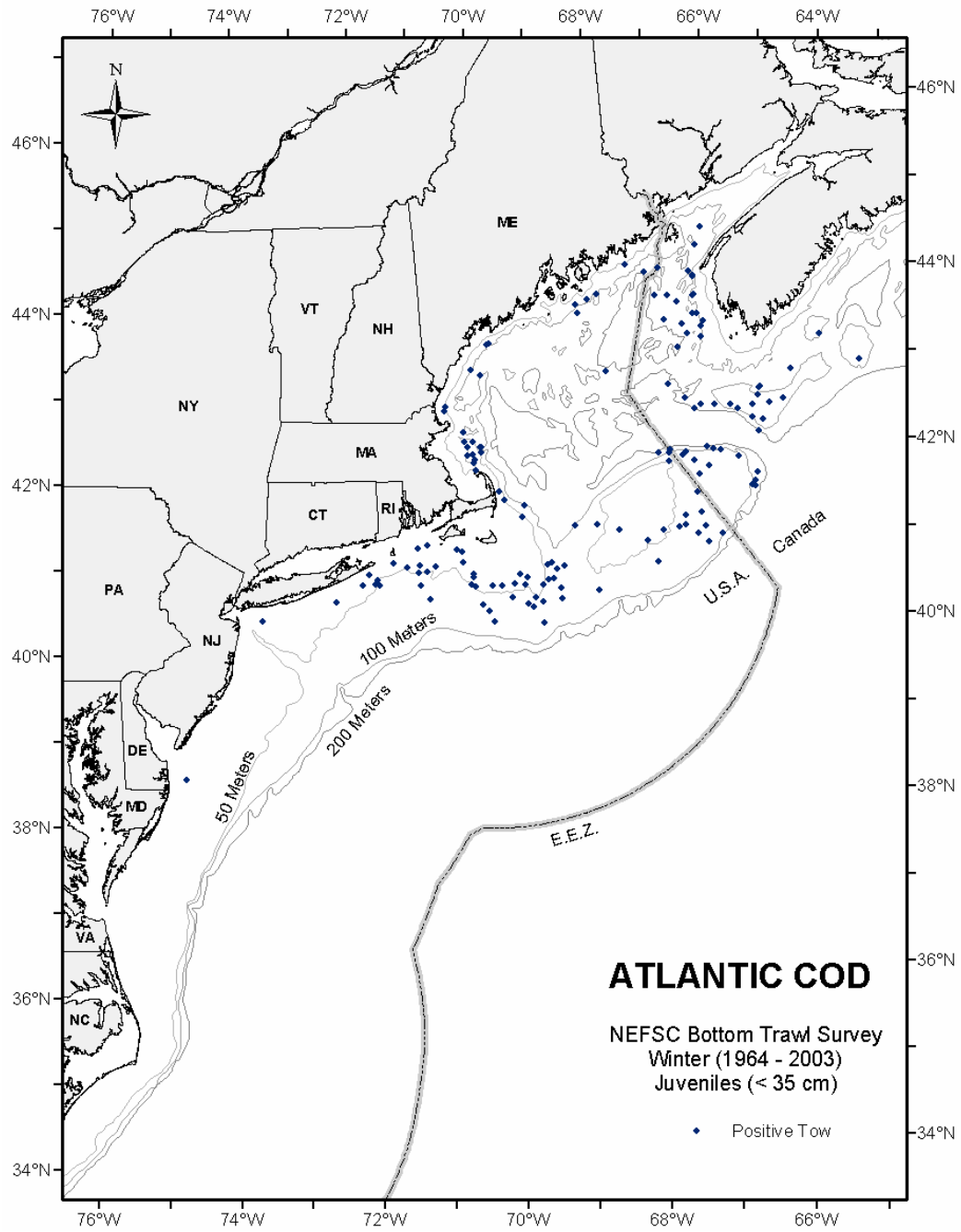


Figure 11. Seasonal distributions and abundances of juvenile Atlantic cod collected during NEFSC bottom trawl surveys.
From NEFSC winter bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence only.

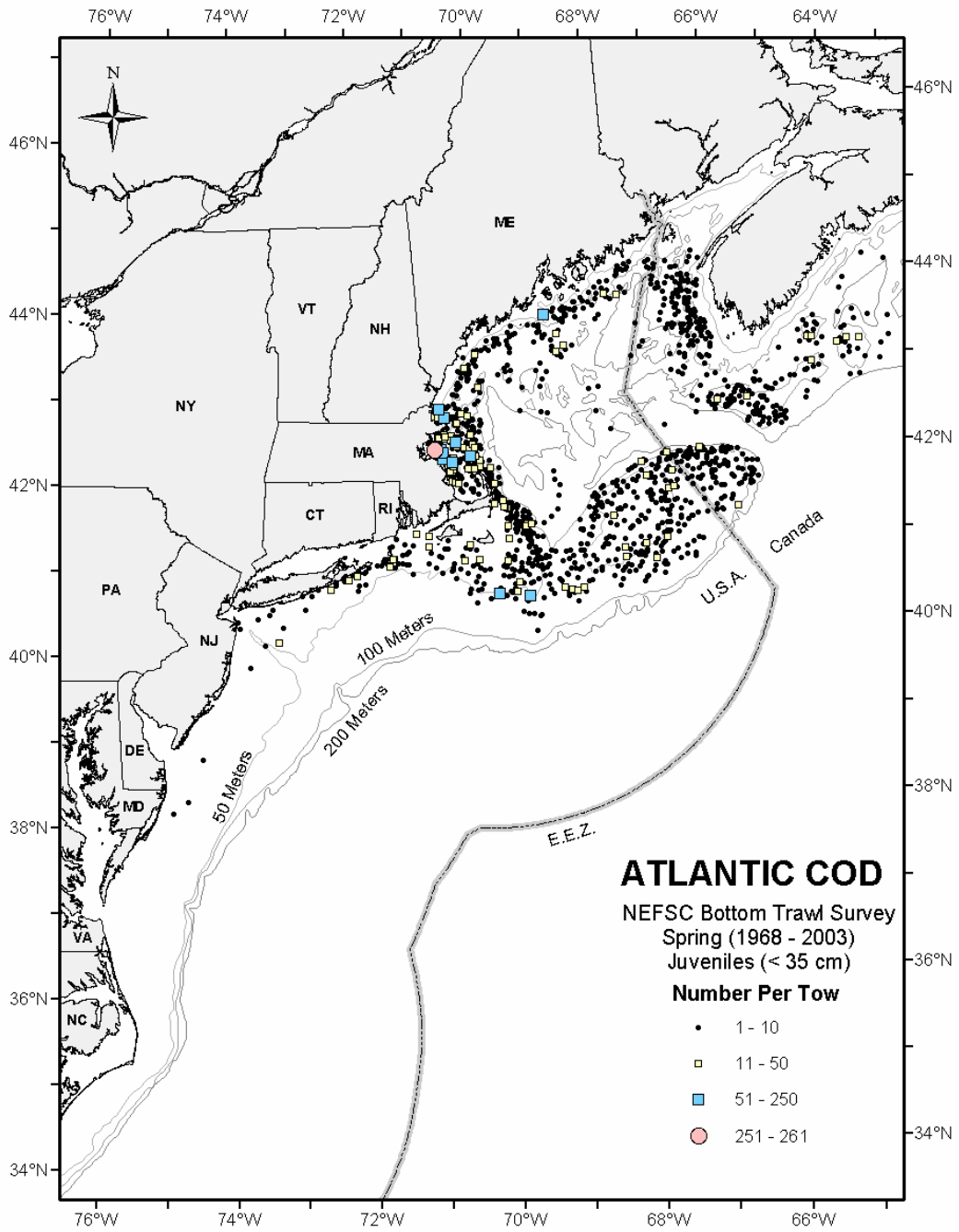


Figure 11. Cont'd.
From NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where juveniles were not found are not shown.

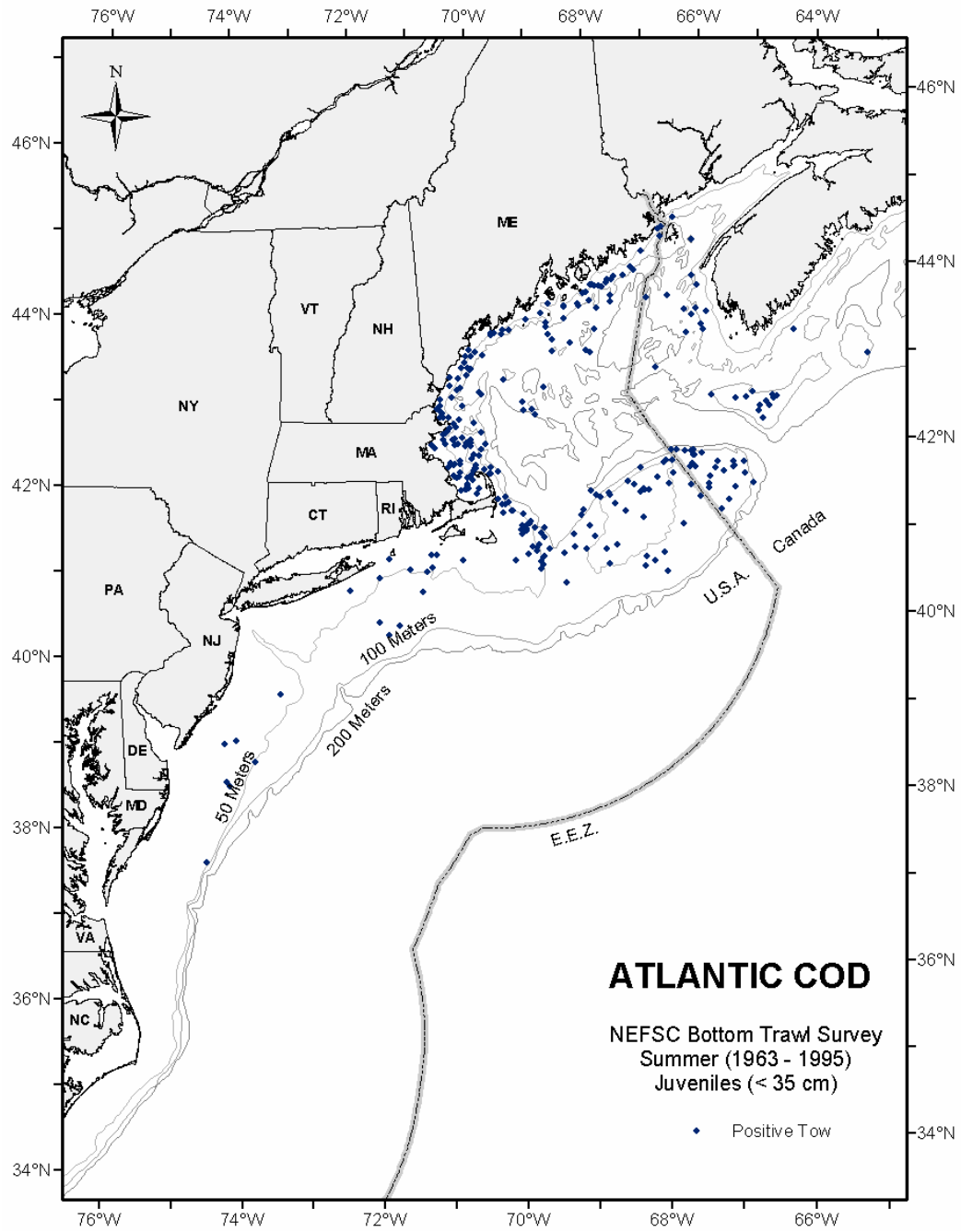


Figure 11. Cont'd.
From NEFSC summer bottom trawl surveys (1963-1995, all years combined). Distributions are displayed as presence only.

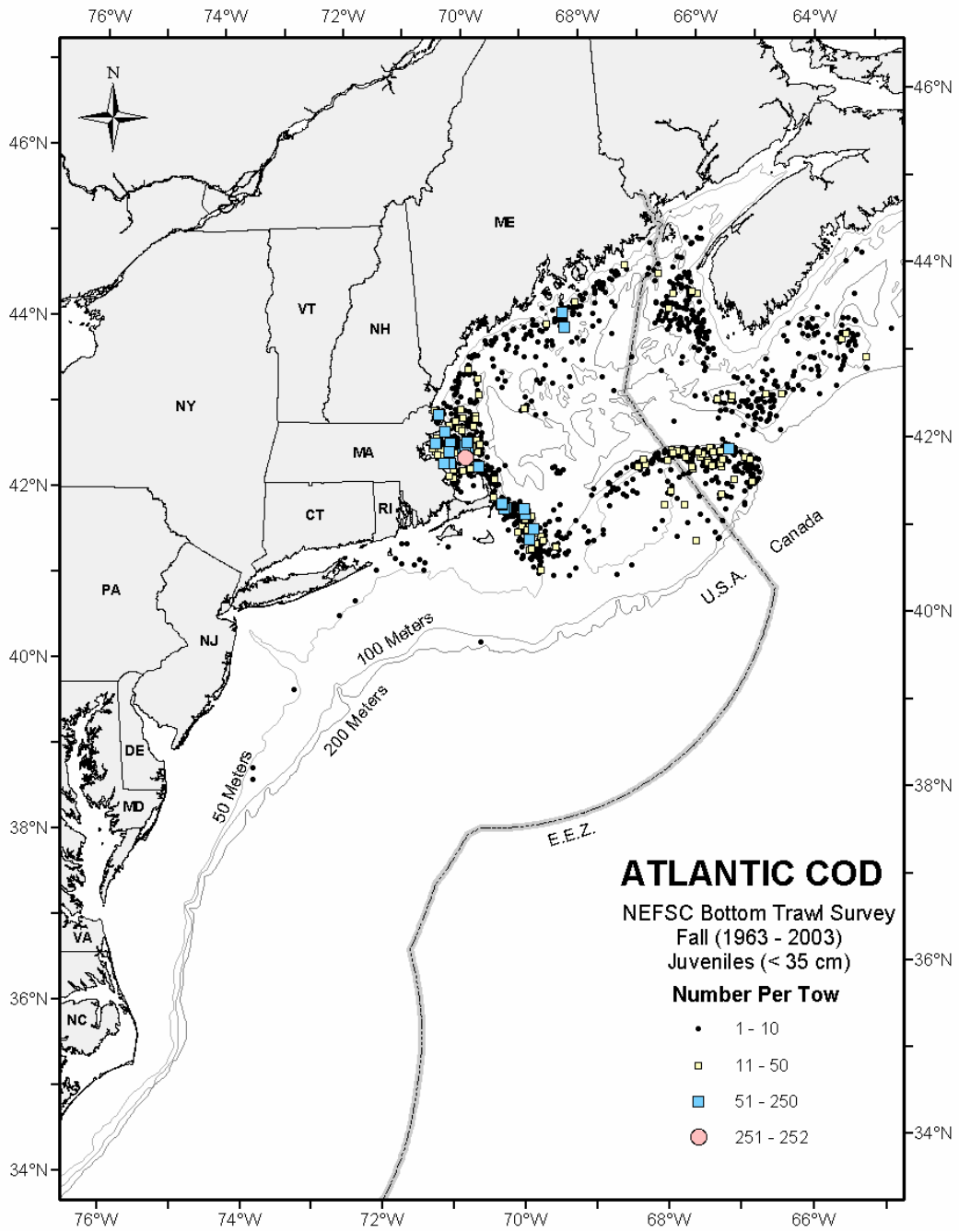


Figure 11. Cont'd.
From NEFSC fall bottom trawl surveys (1963-2003, all years combined). Survey stations where juveniles were not found are not shown.

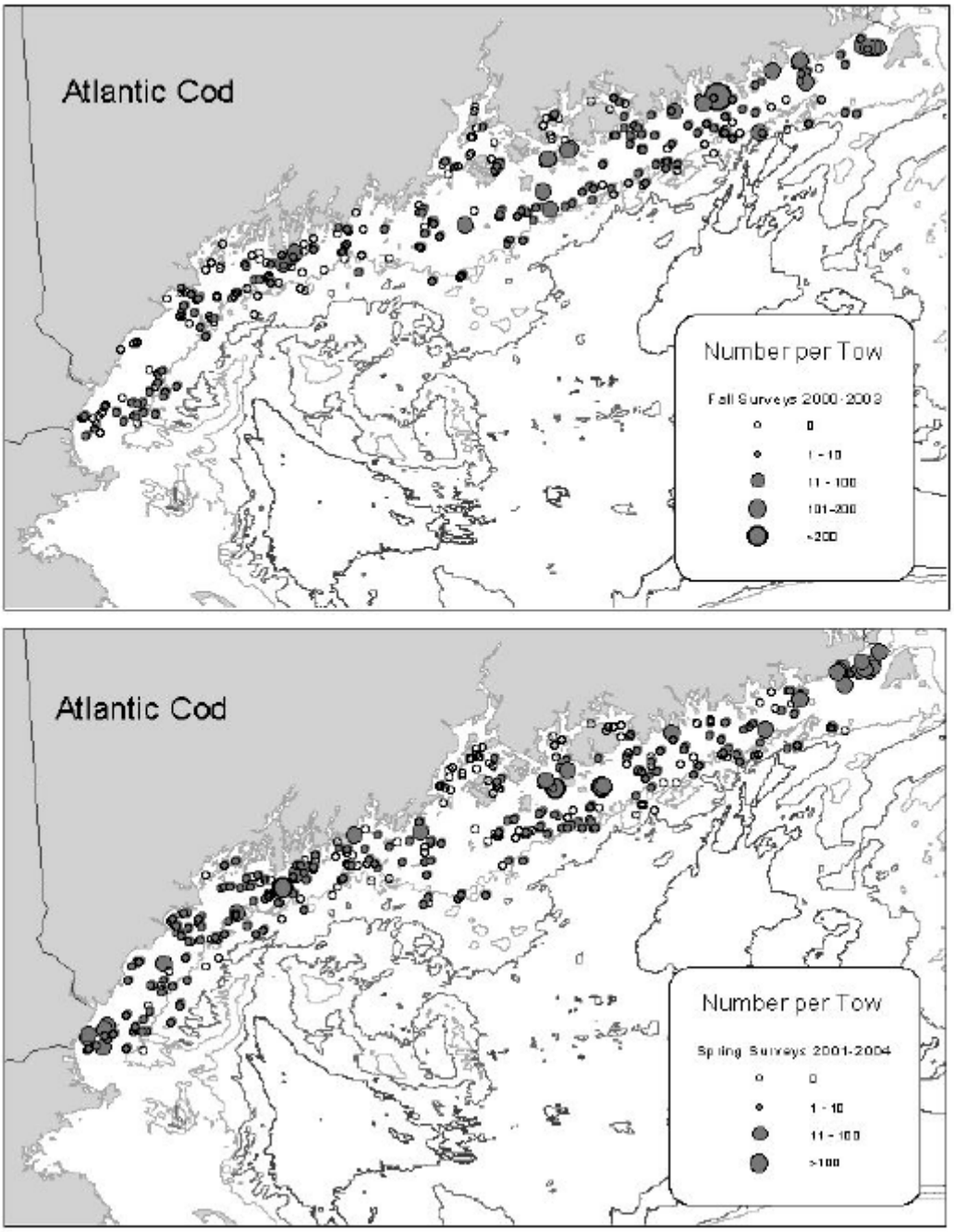
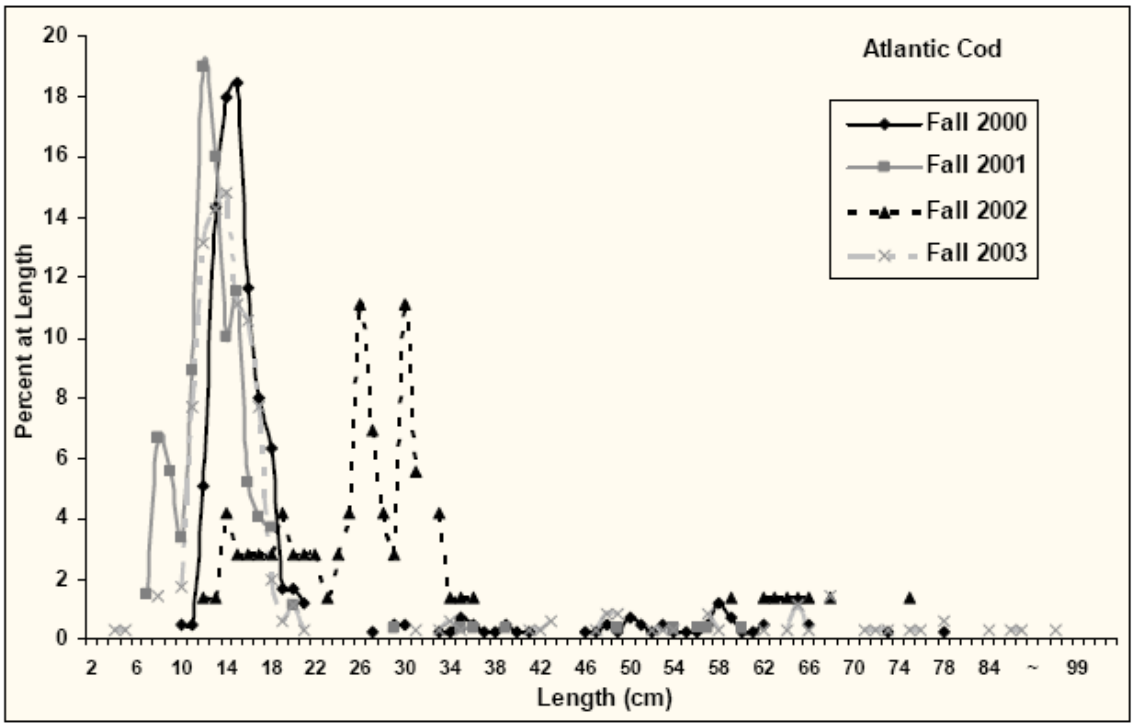


Figure 12. Distribution and abundance of Atlantic cod along the coasts of Maine and New Hampshire. From the Maine – New Hampshire spring 2001-2004 and fall 2000-2003 inshore groundfish trawl surveys. For details on the survey, see Sherman *et al*. (2005).



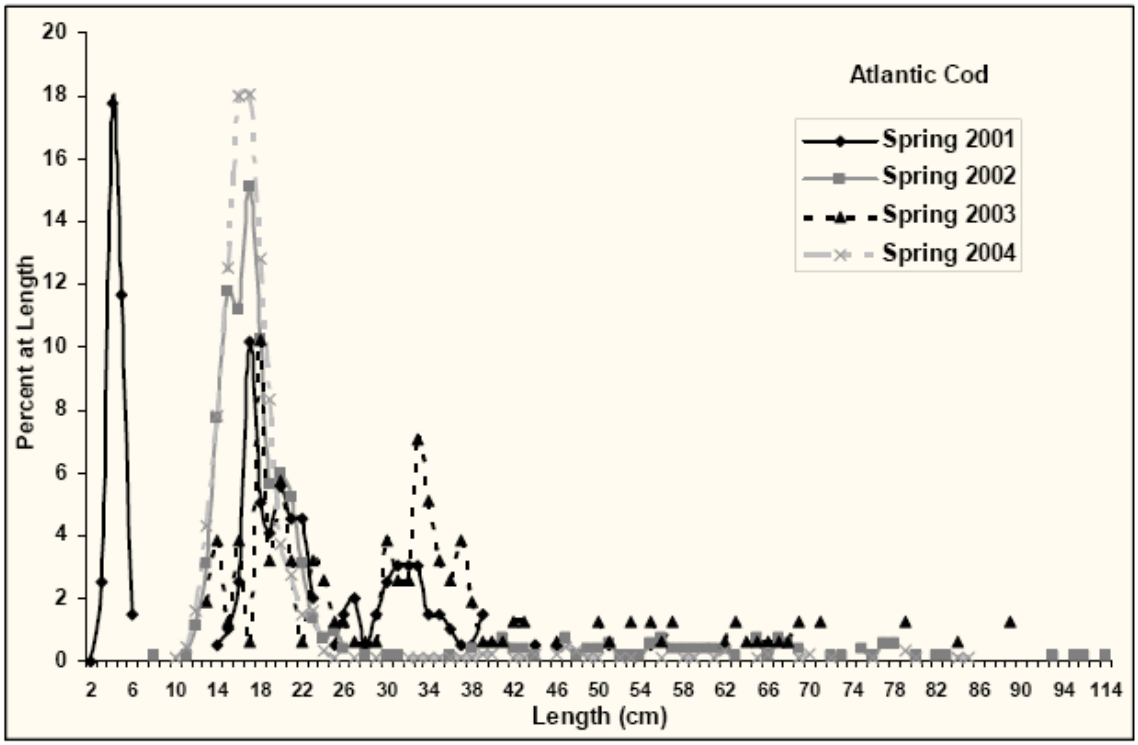


Figure 13. Length frequency plots for Atlantic cod caught along the Maine and New Hampshire coasts, by season/year. Based on the Maine – New Hampshire inshore groundfish trawl survey for spring 2001-2004 and fall 2000-2003. Source: Sherman *et al*. (2005).

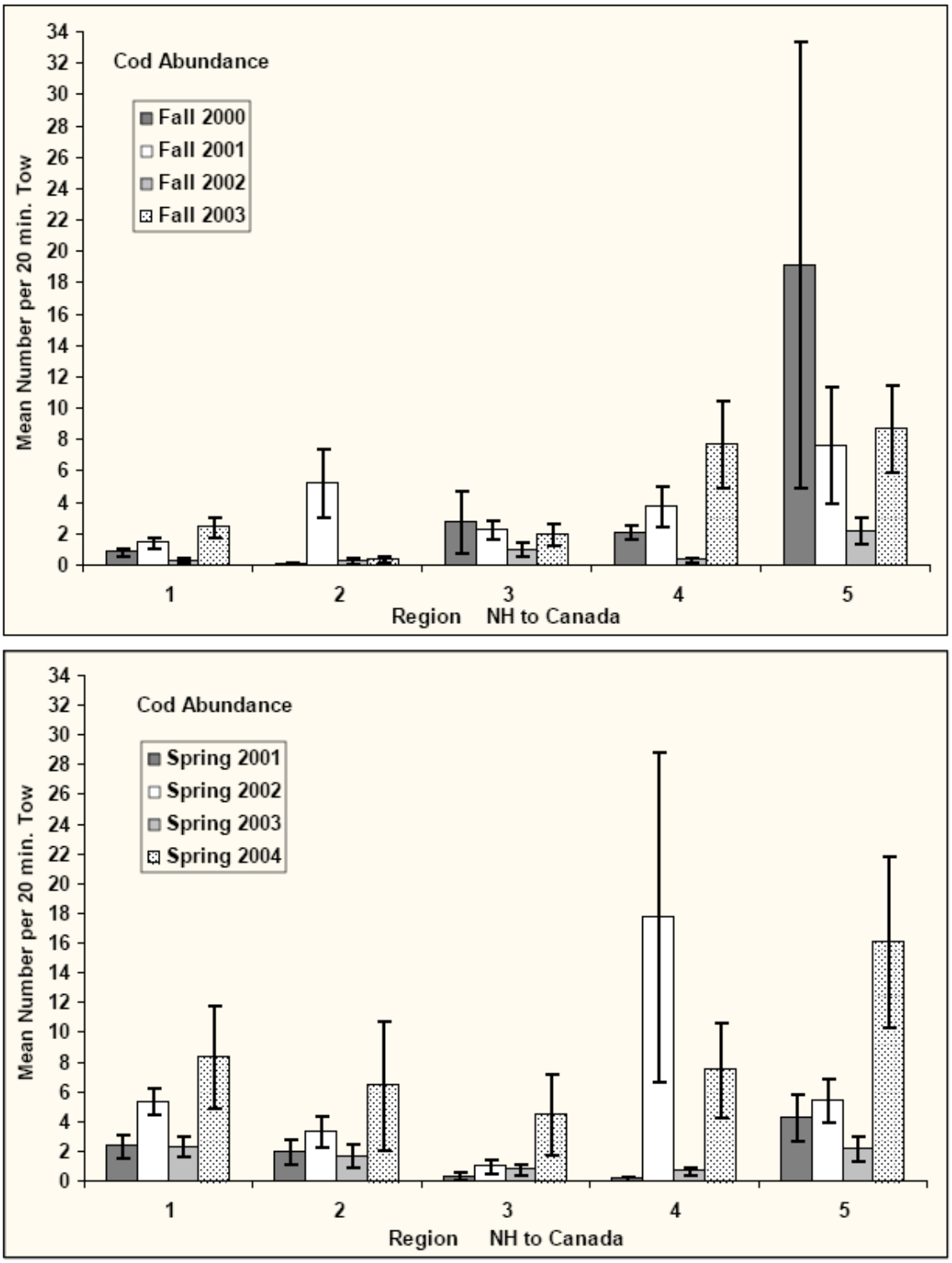


Figure 14. Regional catch-per-unit-effort of Atlantic cod caught along the Maine and New Hampshire coasts, by season/year.
Based on the Maine – New Hampshire inshore groundfish trawl survey for spring 2001-2004 and fall 2000-2003. Region 1 = NH–Southern ME; Region 2 = Casco Bay–Midcoast ME; Region 3 = Penobscot Bay, ME; Region 4 = Jerico–Frenchmens Bay, ME; Region 5 = Downeast ME. Source: Sherman *et al*. (2005).

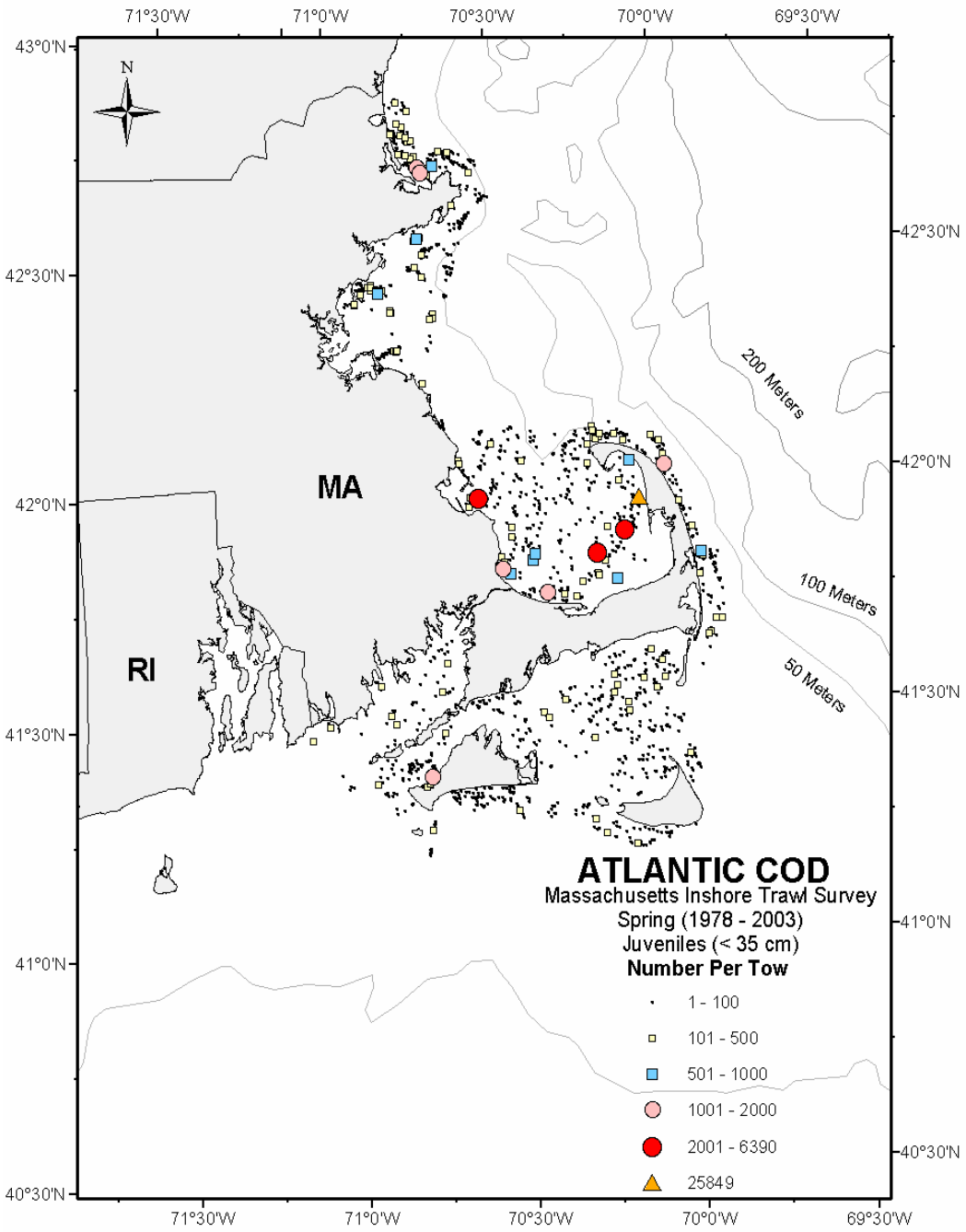


Figure 15. Seasonal distributions and abundances of juvenile Atlantic cod in Massachusetts coastal waters. From spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

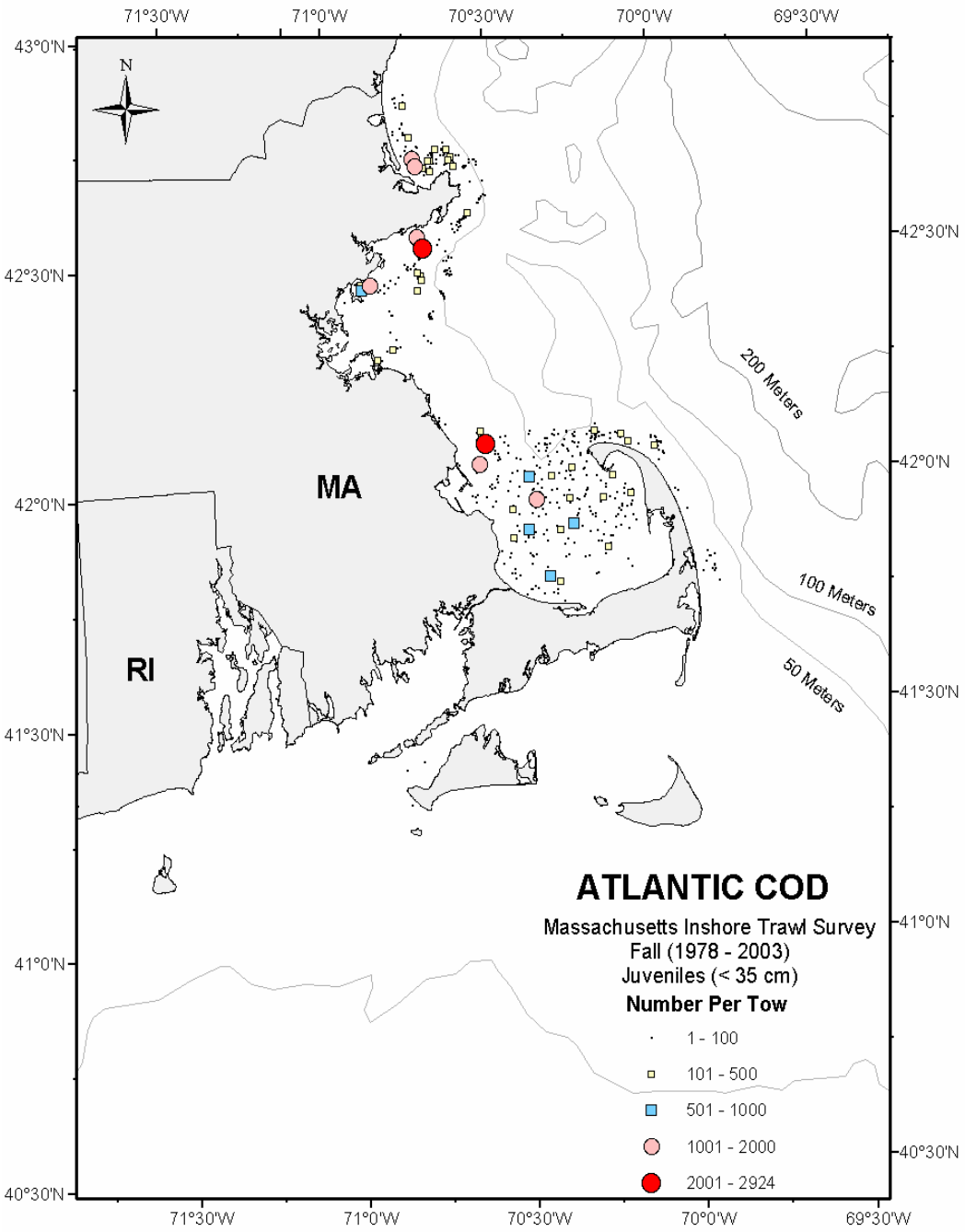


Figure 15. Cont'd.
From fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

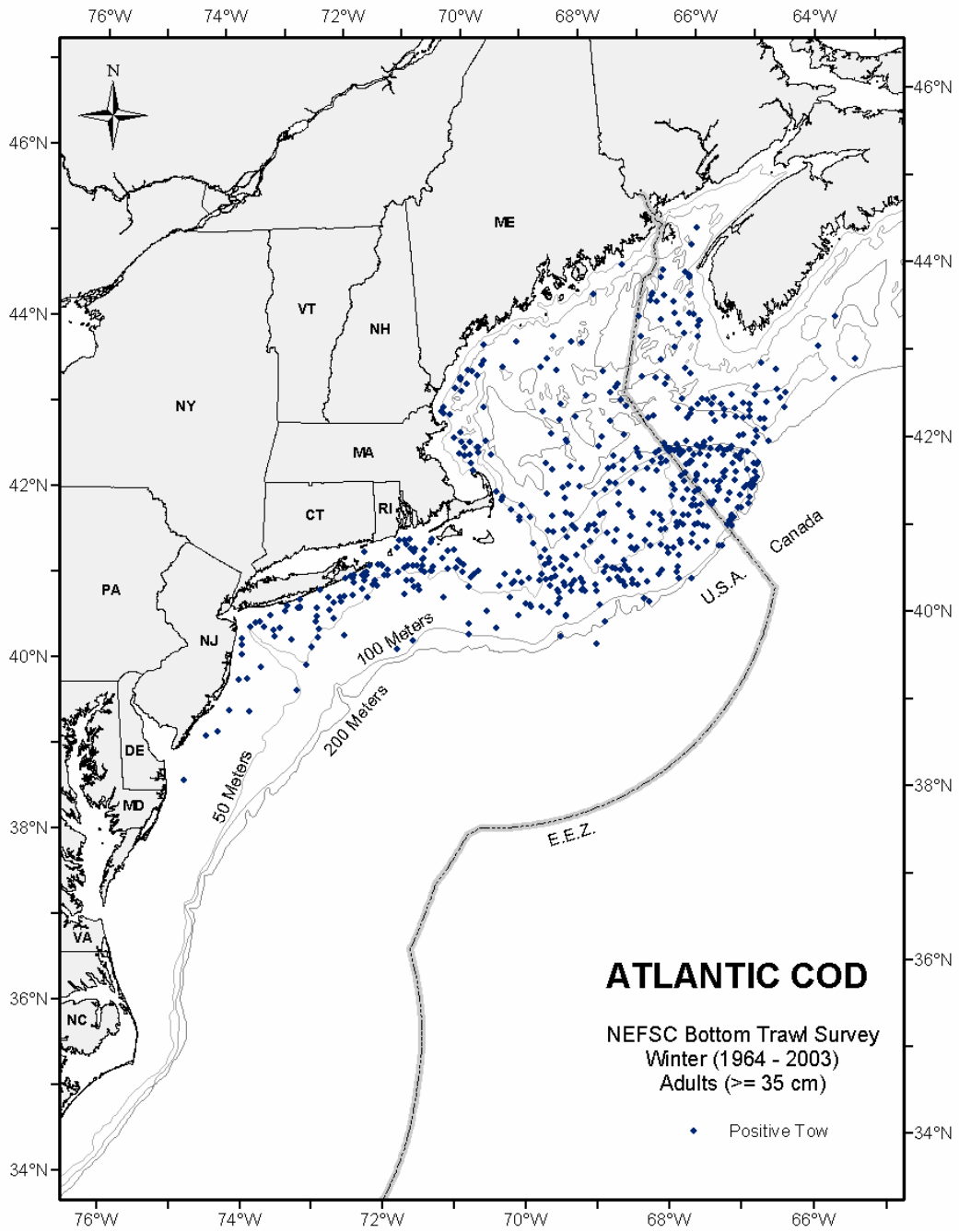


Figure 16. Seasonal distributions and abundances of adult Atlantic cod collected during NEFSC bottom trawl surveys. From NEFSC winter bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence only.

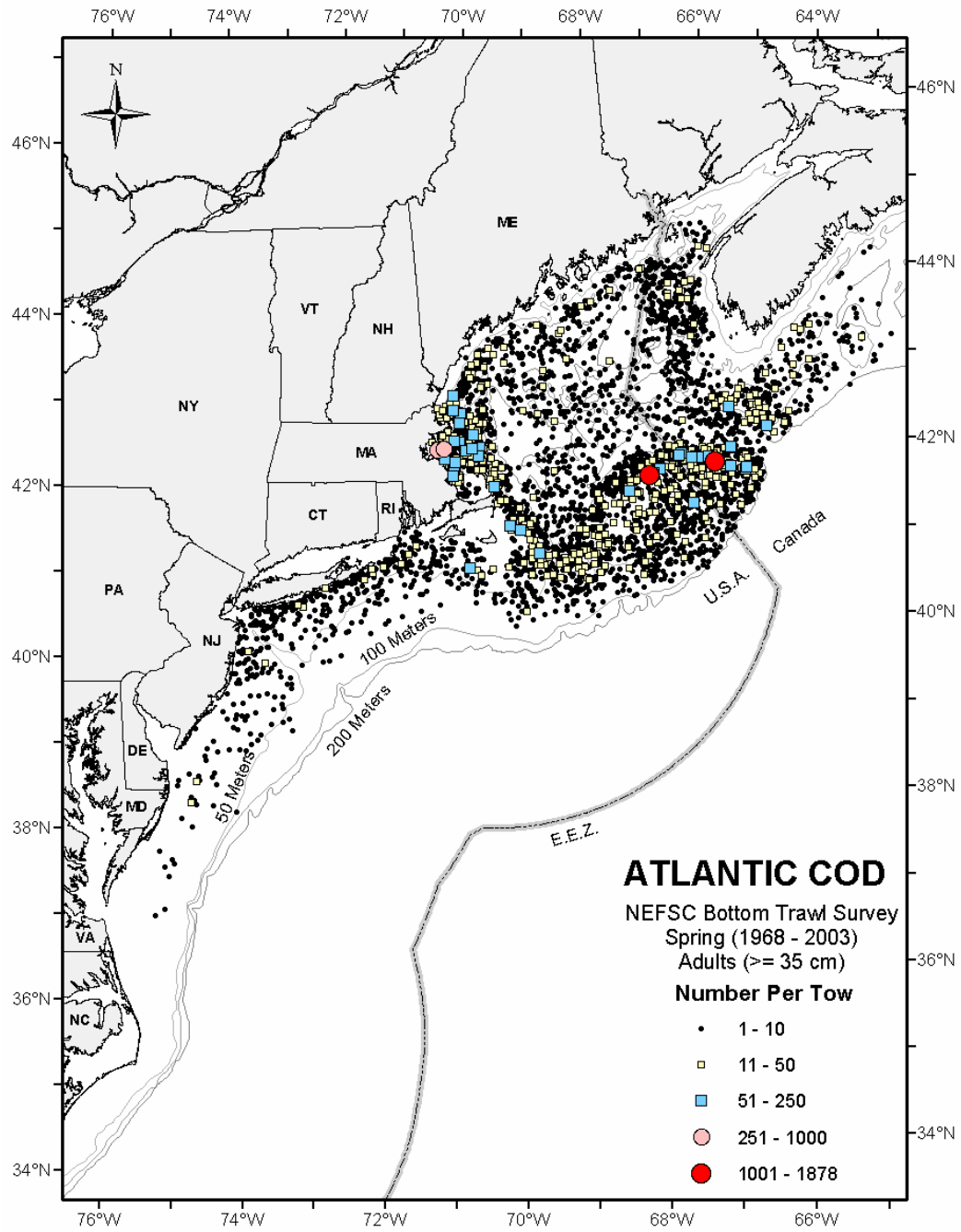


Figure 16. Cont'd.
From NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where adults were not found are not shown.

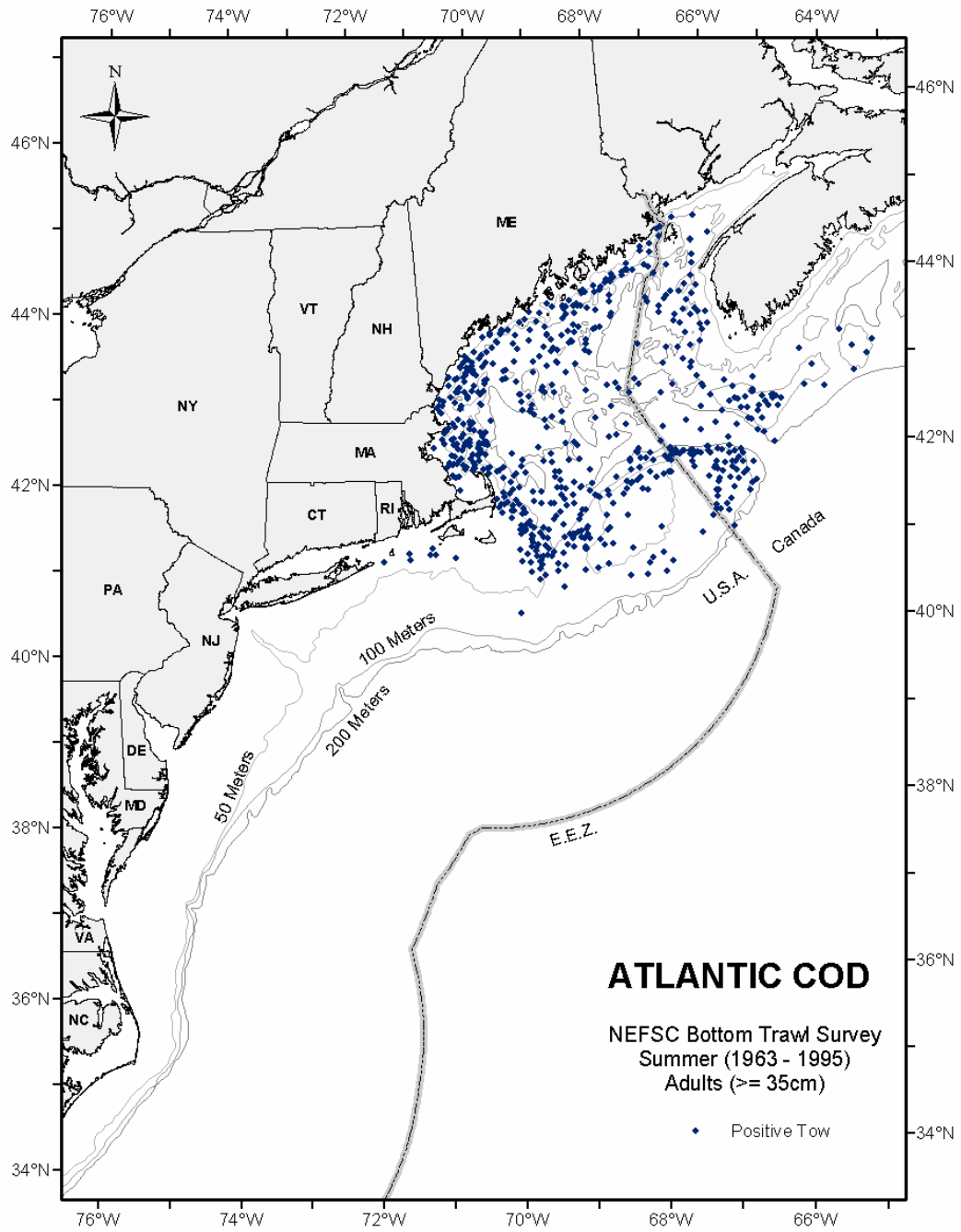


Figure 16. Cont'd.
From NEFSC summer bottom trawl surveys (1963-1995, all years combined). Distributions are displayed as presence only.

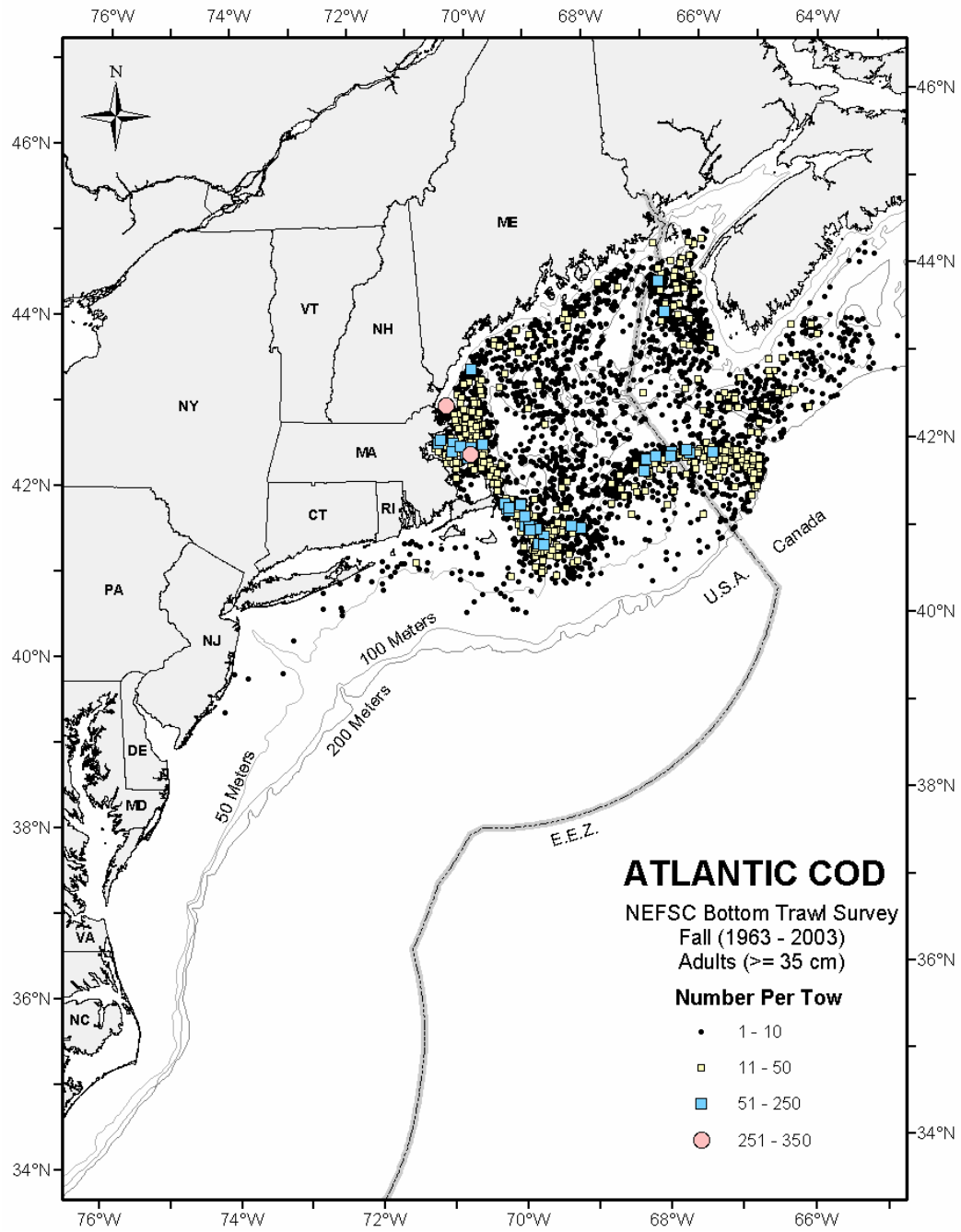


Figure 16. Cont'd.
From NEFSC fall bottom trawl surveys (1963-2003, all years combined). Survey stations where adults were not found are not shown.

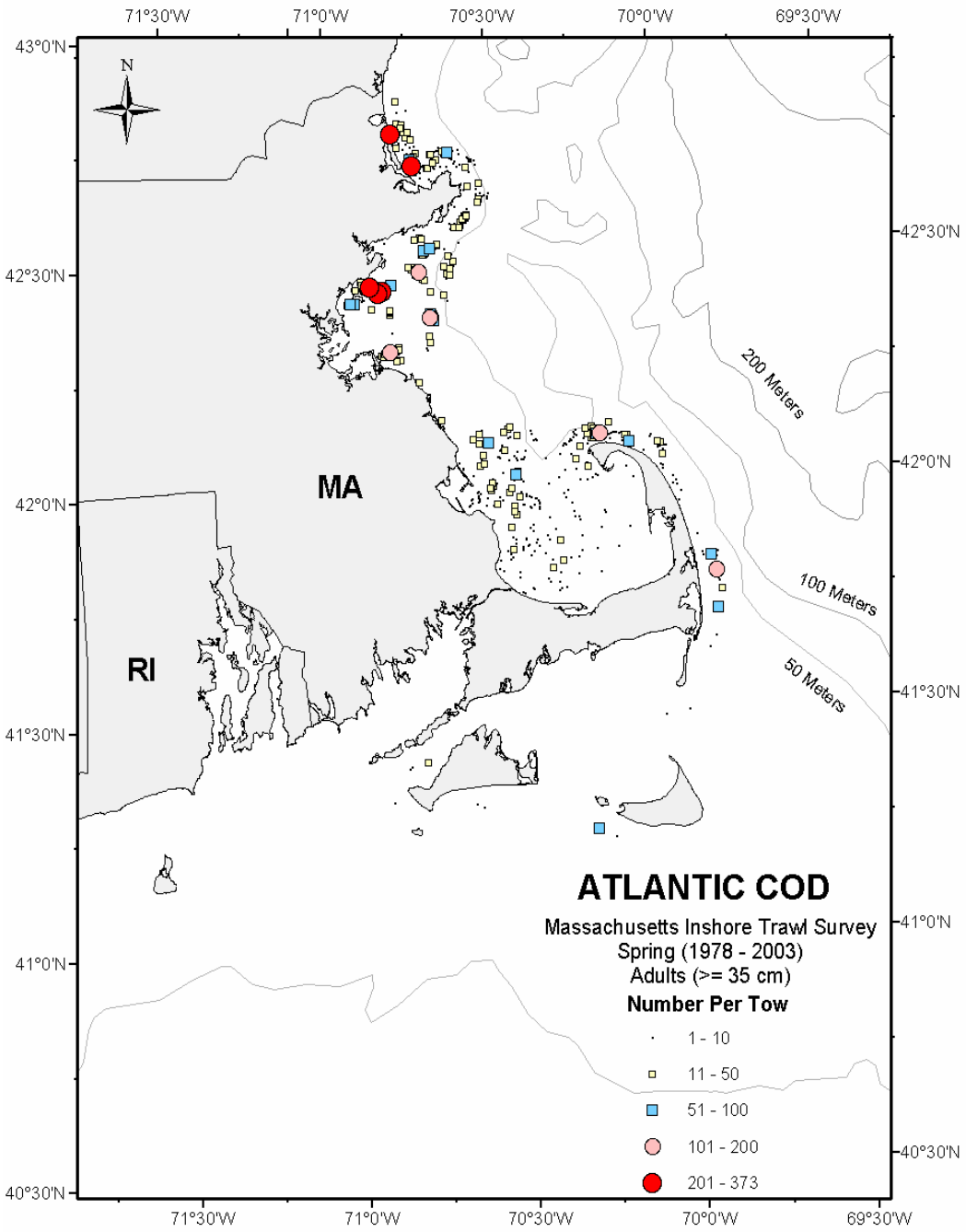


Figure 17. Seasonal distributions and abundances of adult Atlantic cod in Massachusetts coastal waters. From spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.

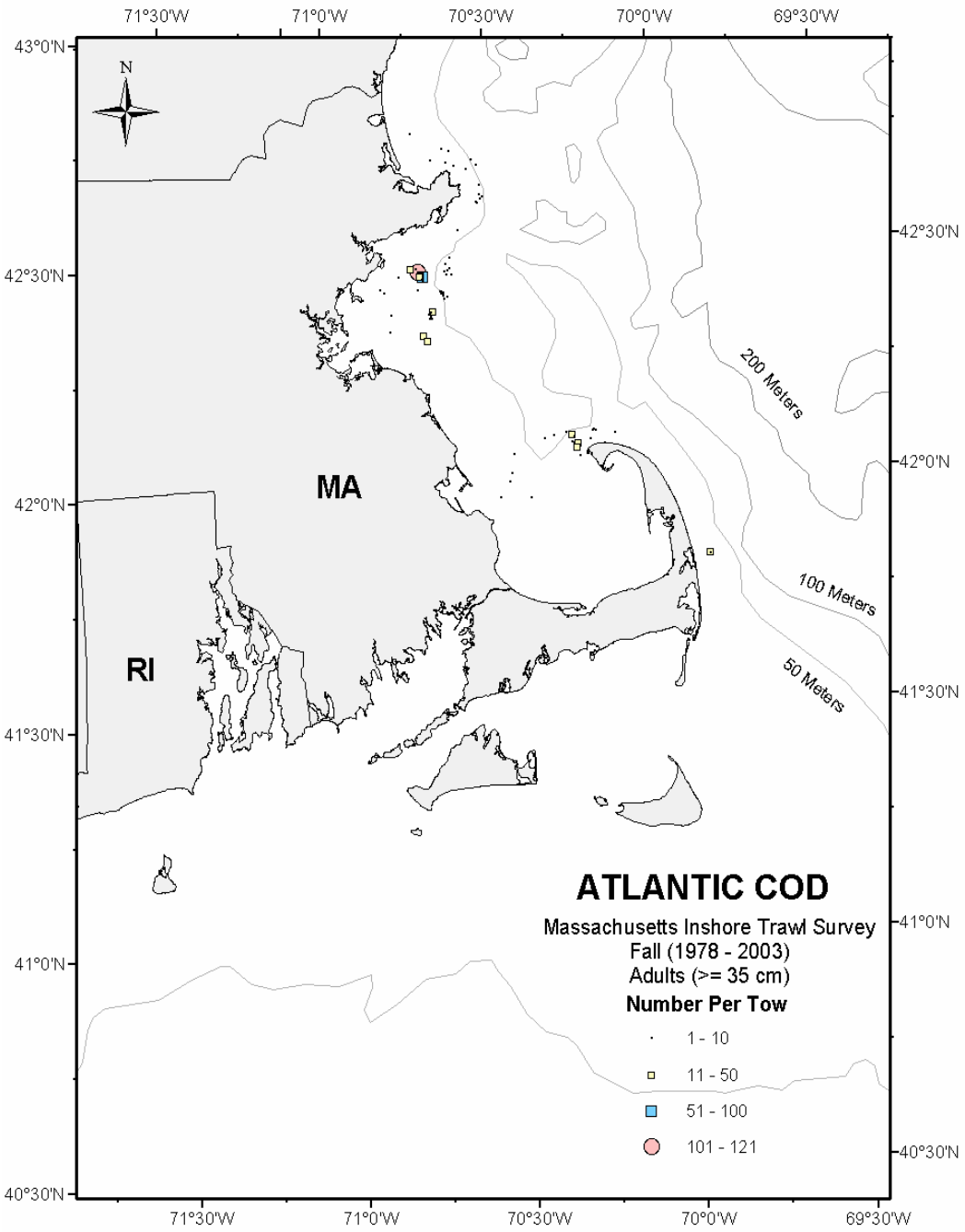


Figure 17. Cont'd.
From fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.

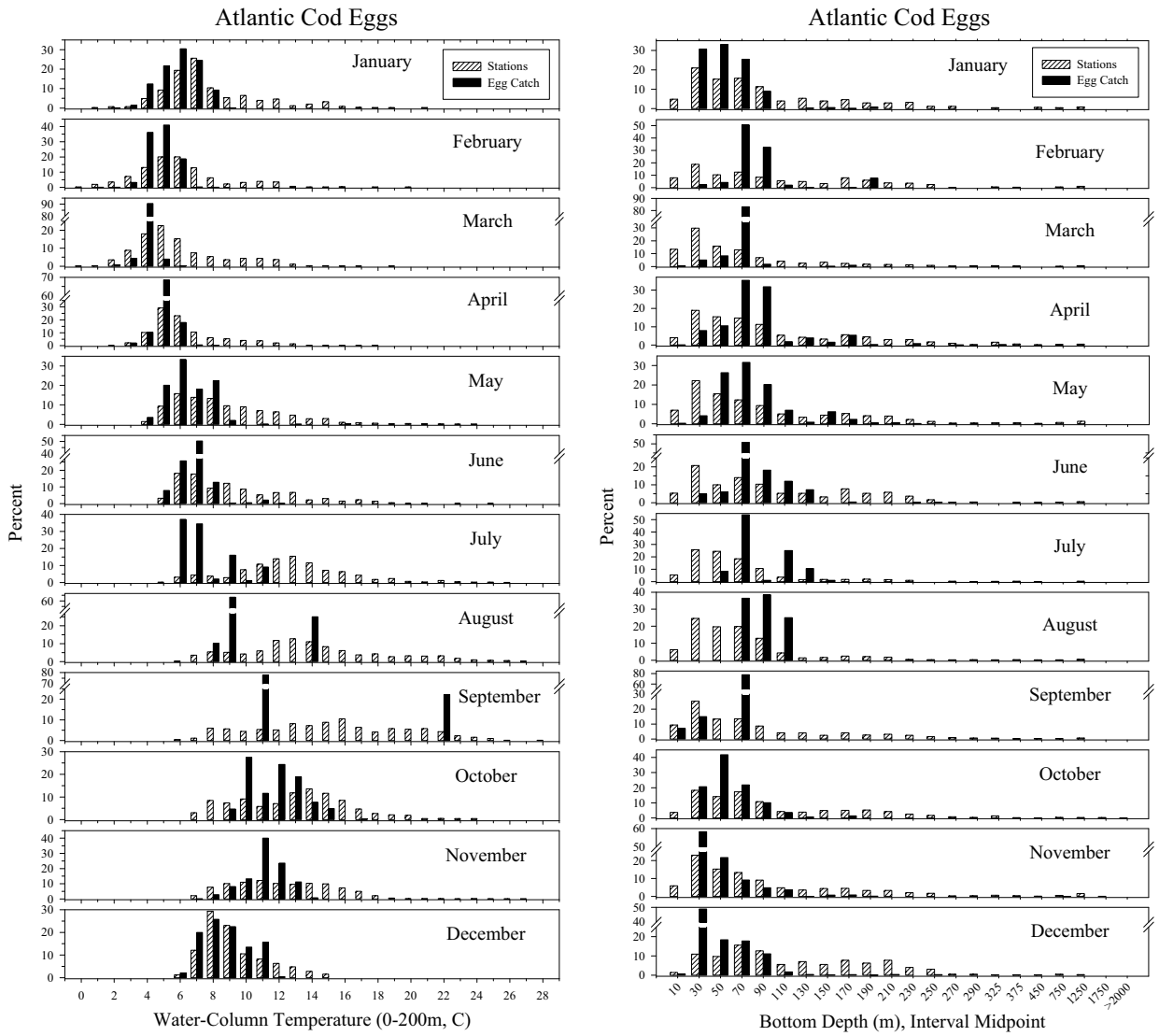


Figure 18. Monthly distributions of Atlantic cod eggs collected during NEFSC MARMAP ichthyoplankton surveys relative to water column temperature and bottom depth.
For all available months and years from 1978-1987combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth interval changes with increasing depth.

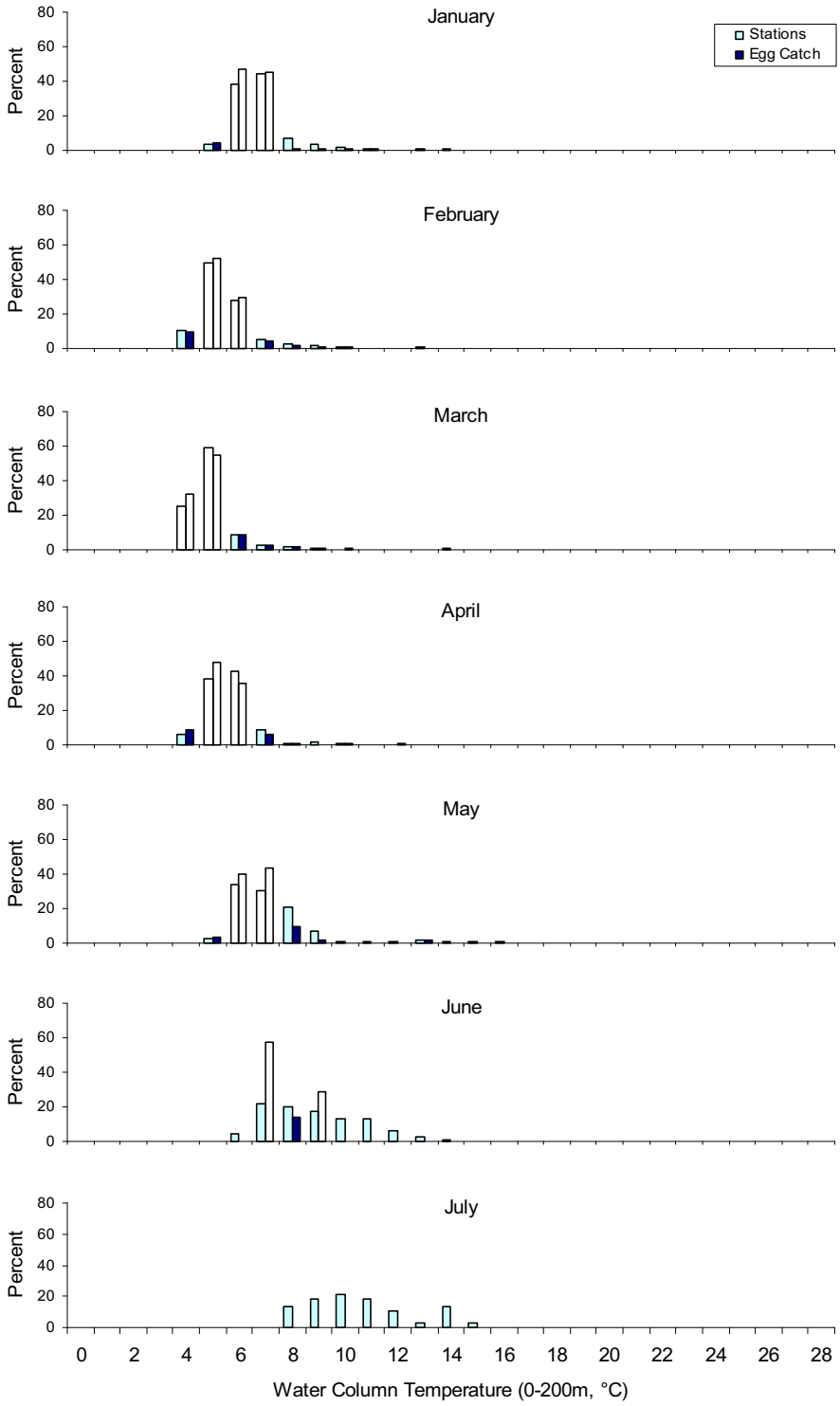


Figure 19. Distributions of Atlantic cod eggs collected during GLOBEC ichthyoplankton surveys relative to water column temperature.
From GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10m^2).

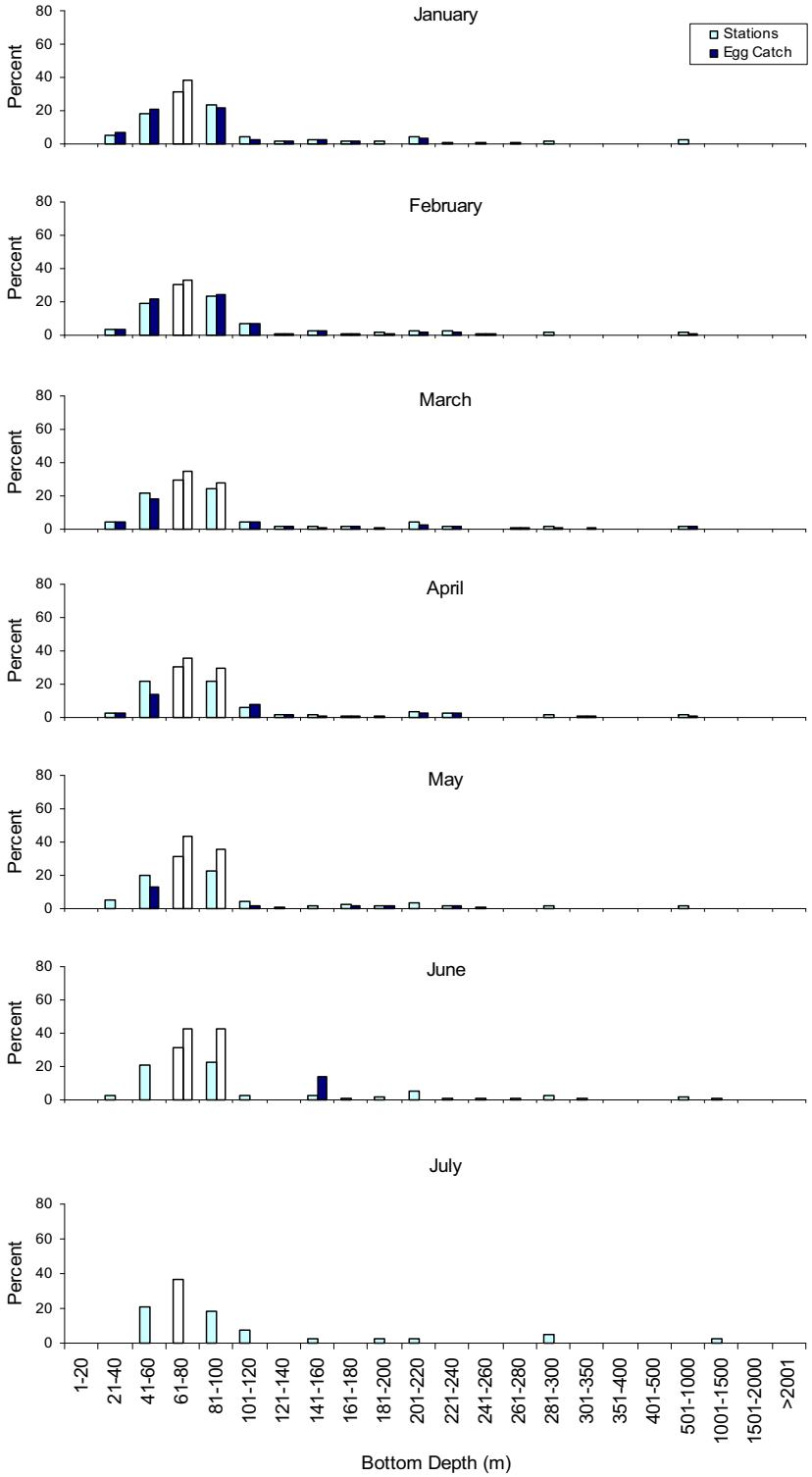


Figure 20. Distributions of Atlantic cod eggs collected during GLOBEC ichthyoplankton surveys relative to bottom depth.
From GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10m^2). Note that the bottom depth intervals change with depth.

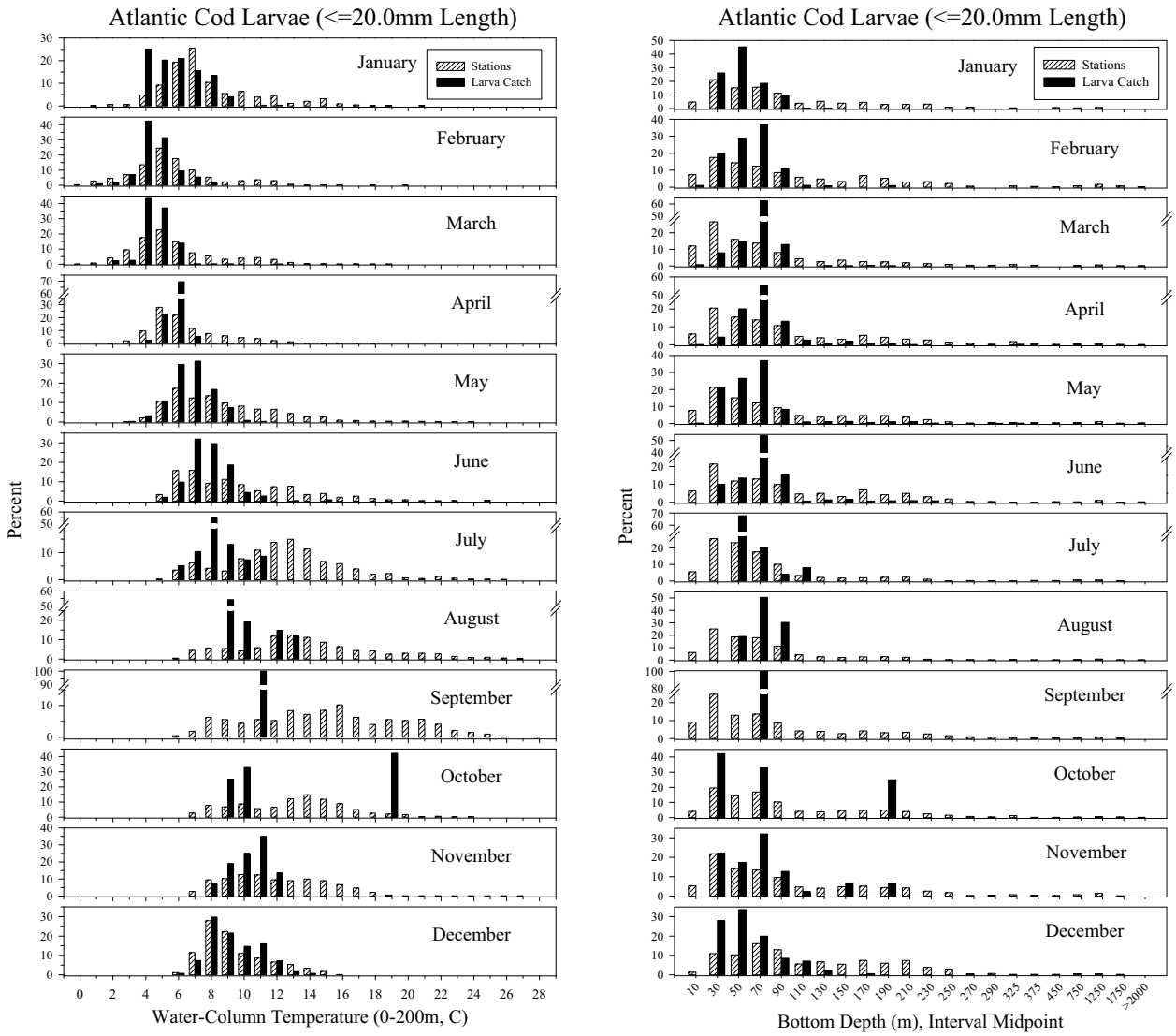


Figure 21. Monthly distributions of Atlantic cod larvae collected during NEFSC MARMAP ichthyoplankton surveys relative to water column temperature and bottom depth.
For all available months and years from 1977-1987combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth interval changes with increasing depth.

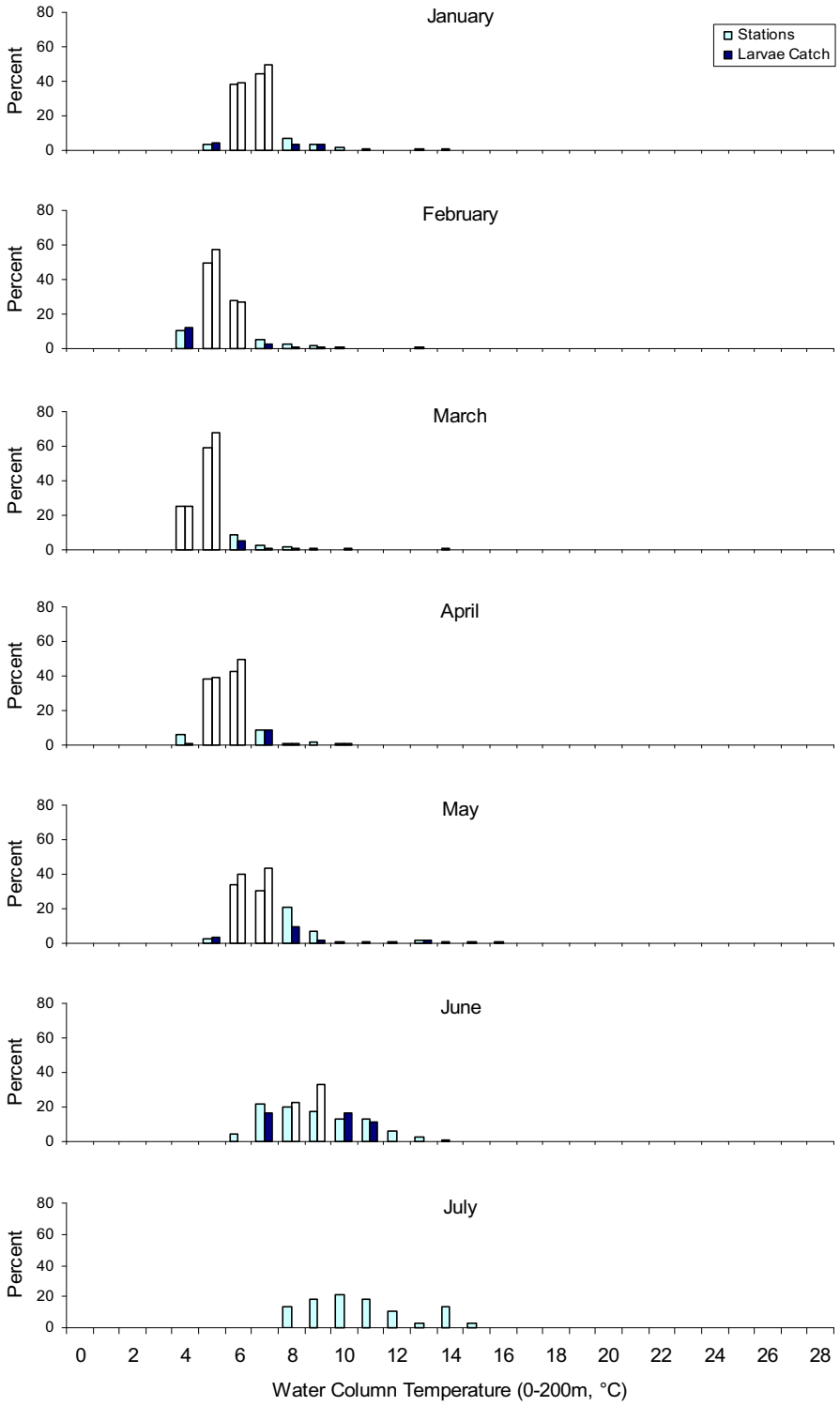


Figure 22. Distributions of Atlantic cod larvae collected during GLOBEC ichthyoplankton surveys relative to water column temperature.
From GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10m^2).

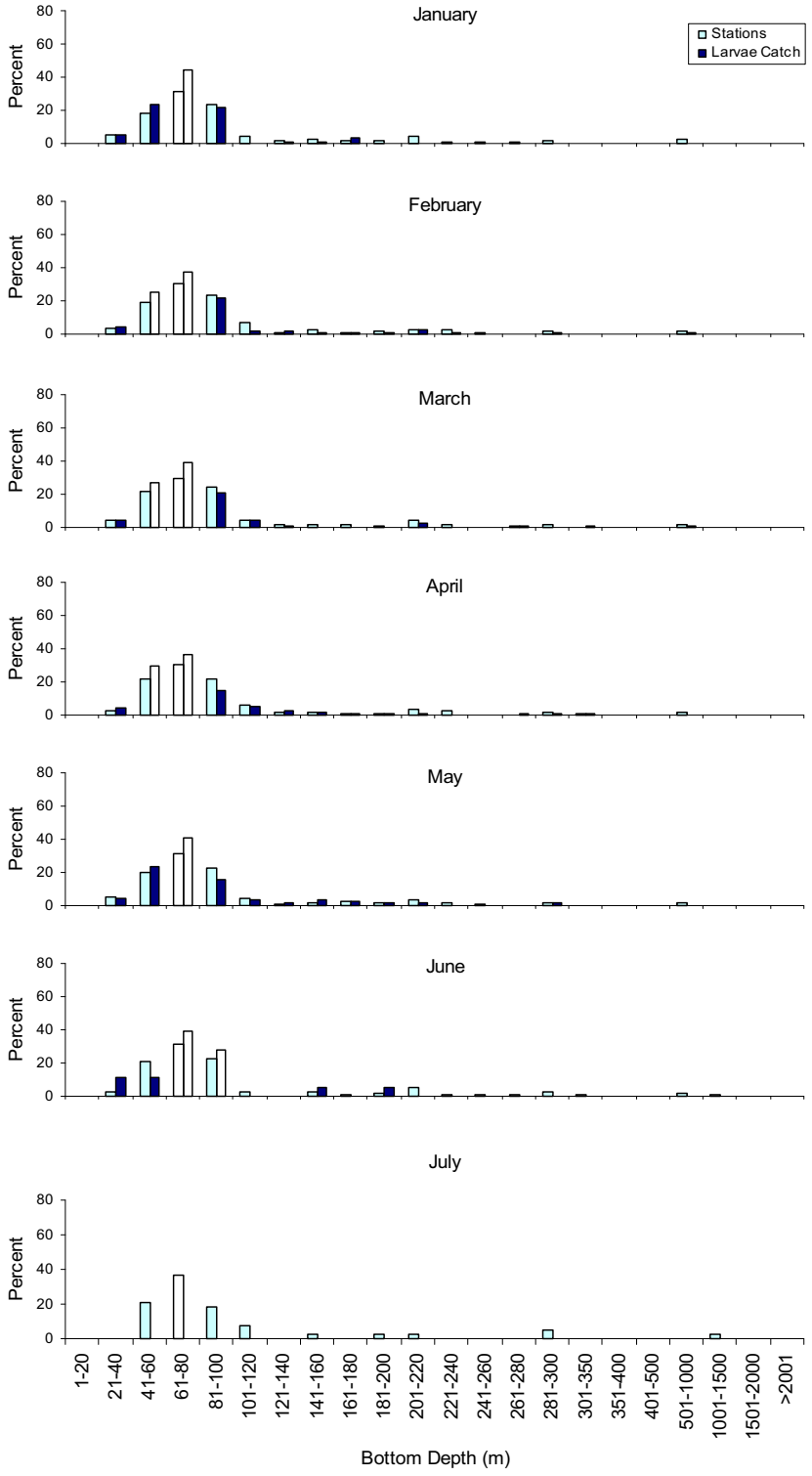


Figure 23. Distributions of Atlantic cod larvae collected during GLOBEC ichthyoplankton surveys relative to bottom depth.
From GLOBEC Georges Bank surveys (February-July, 1995; January-June 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10m^2). Note that the bottom depth intervals change with depth.

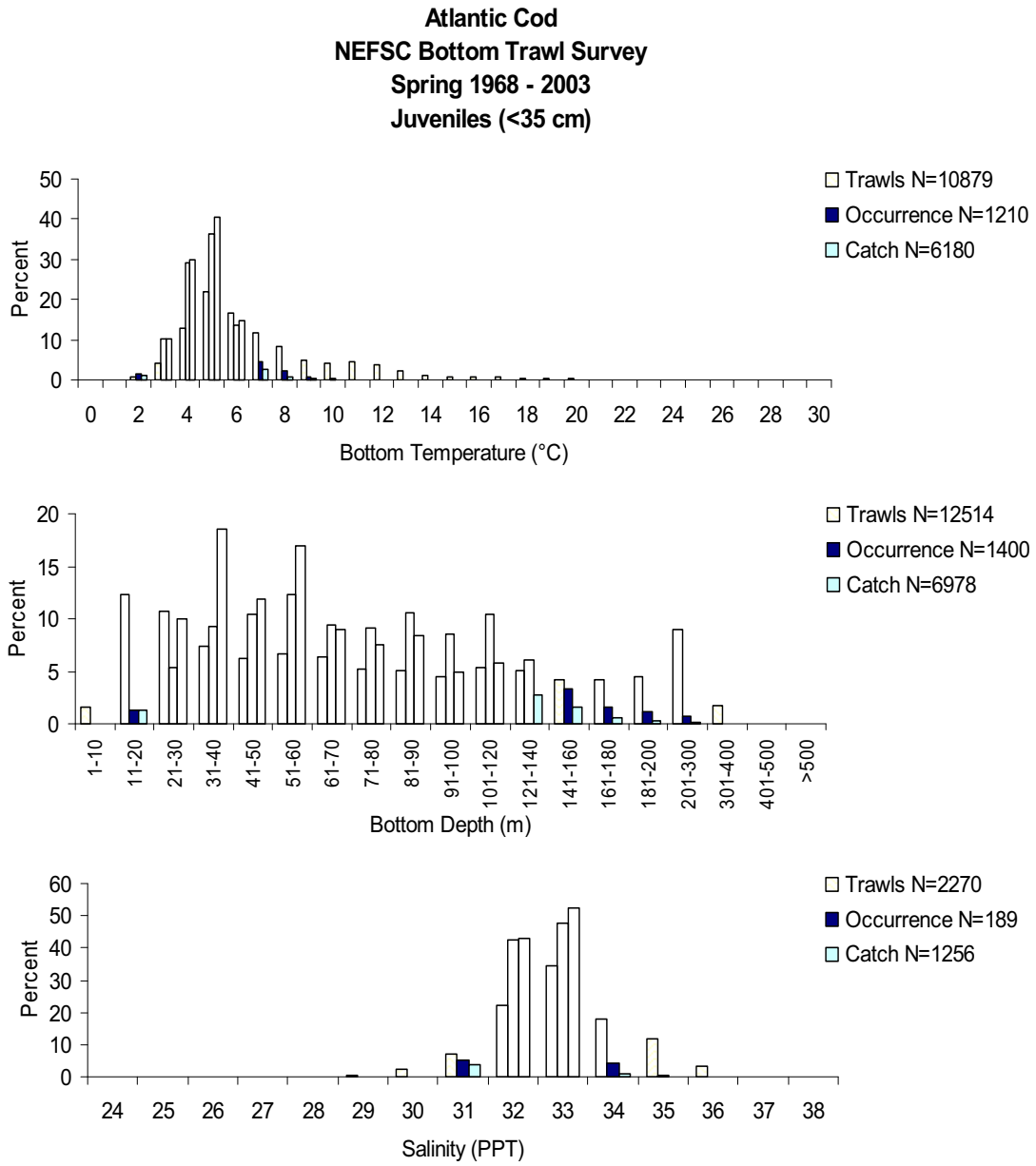


Figure 24. Distributions of juvenile Atlantic cod and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic cod occurred and medium bars show, within each interval, the percentage of the total number of Atlantic cod caught. Note that the bottom depth interval changes with increasing depth.

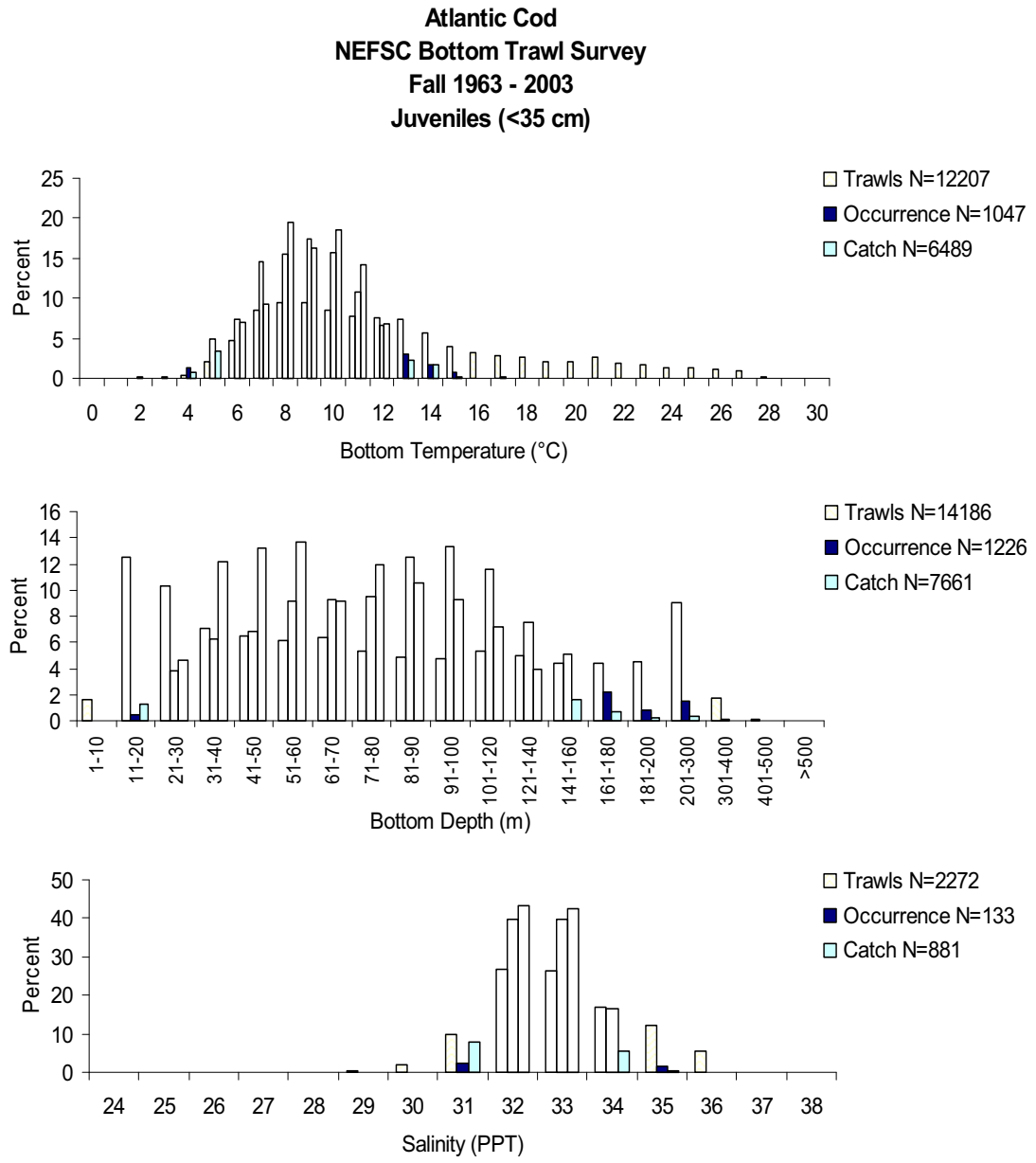


Figure 24. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic cod occurred and medium bars show, within each interval, the percentage of the total number of Atlantic cod caught. Note that the bottom depth interval changes with increasing depth.

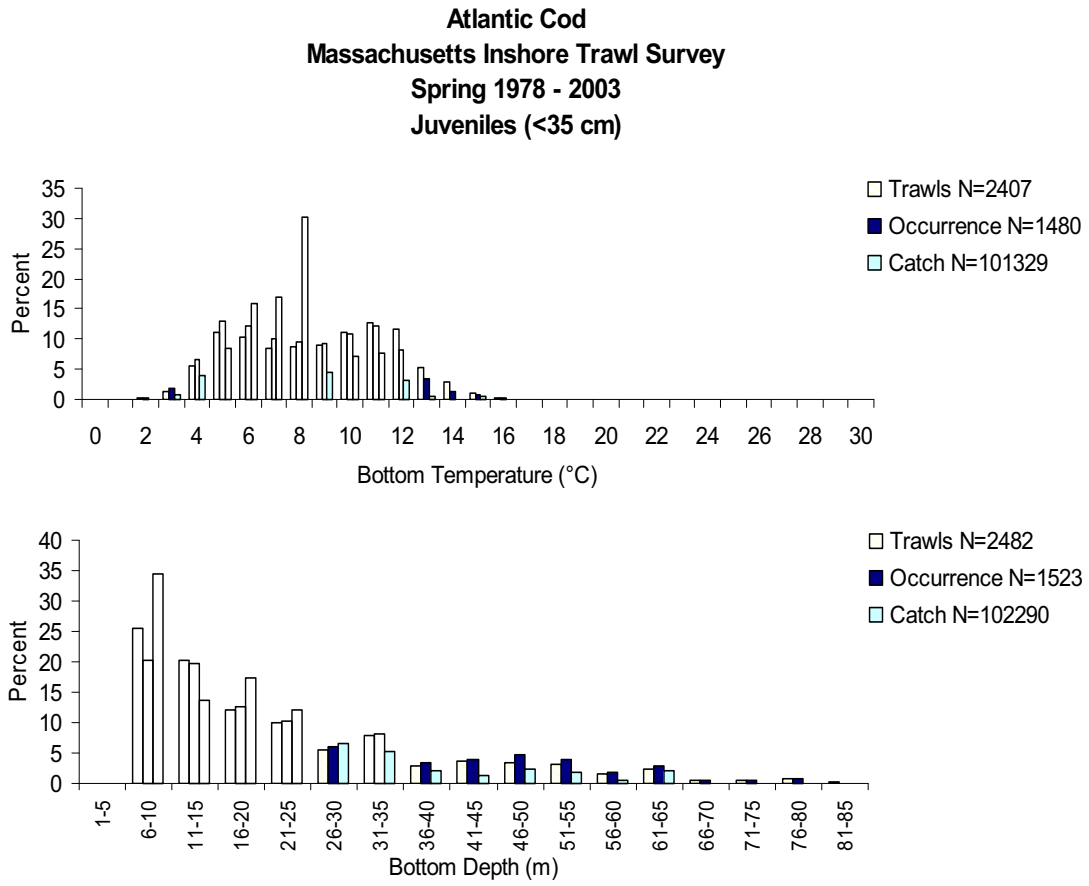


Figure 25. Distributions of juvenile Atlantic cod and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic cod occurred and medium bars show, within each interval, the percentage of the total number of Atlantic cod caught.

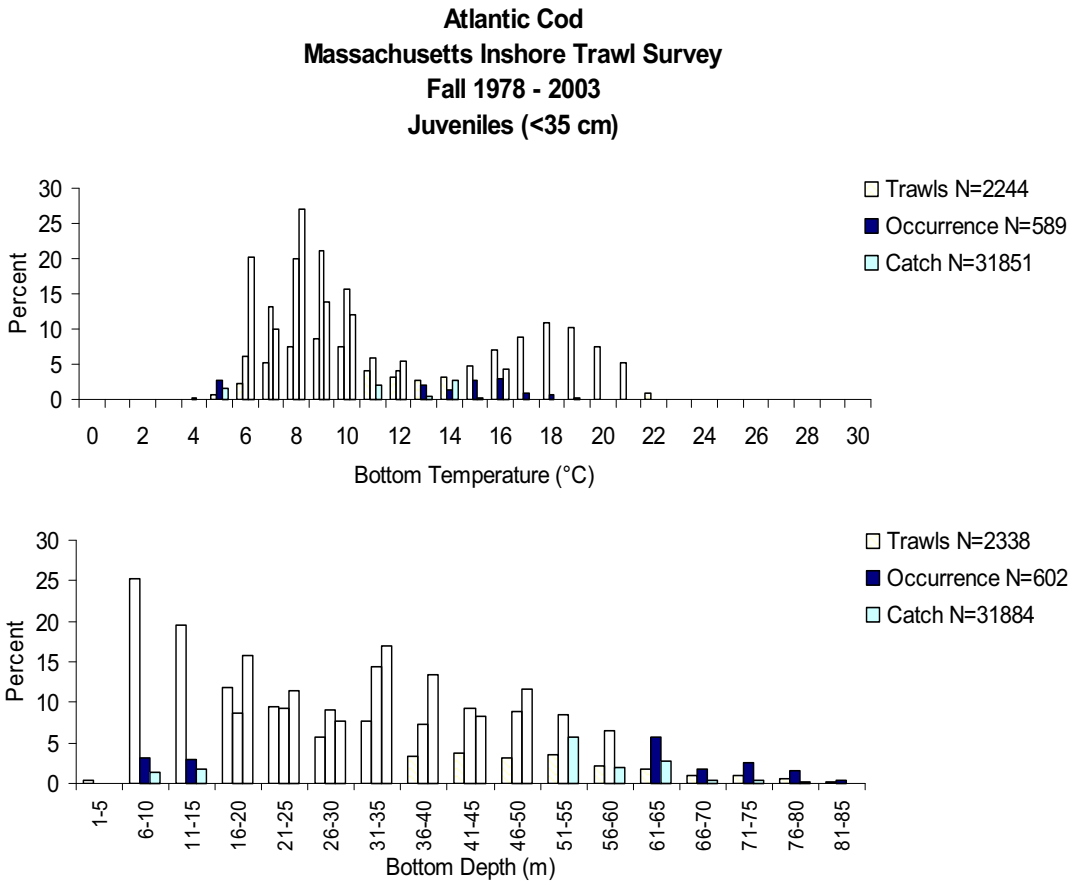


Figure 25. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic cod occurred and medium bars show, within each interval, the percentage of the total number of Atlantic cod caught.

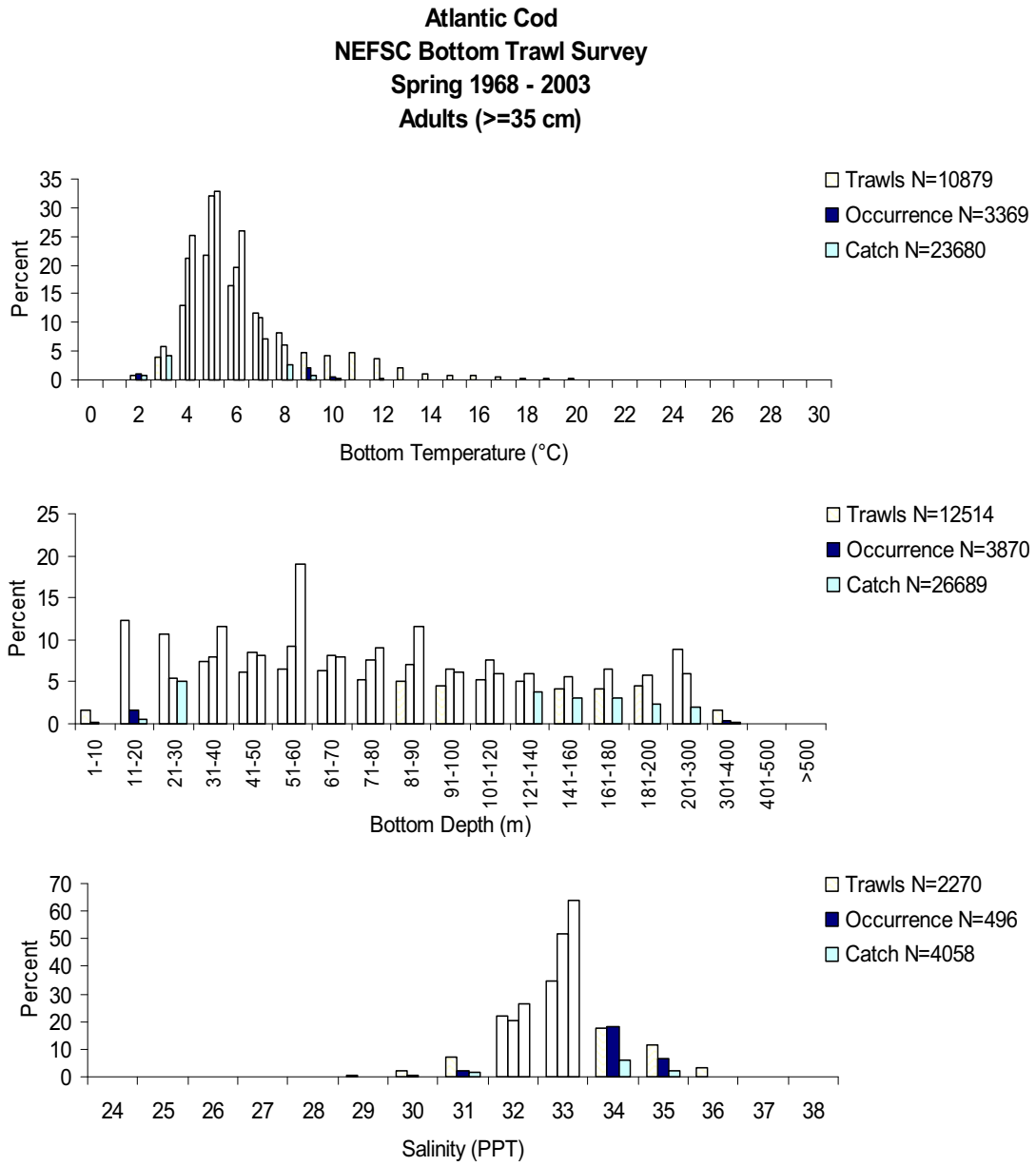


Figure 26. Distributions of adult Atlantic cod and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic cod occurred and medium bars show, within each interval, the percentage of the total number of Atlantic cod caught. Note that the bottom depth interval changes with increasing depth.

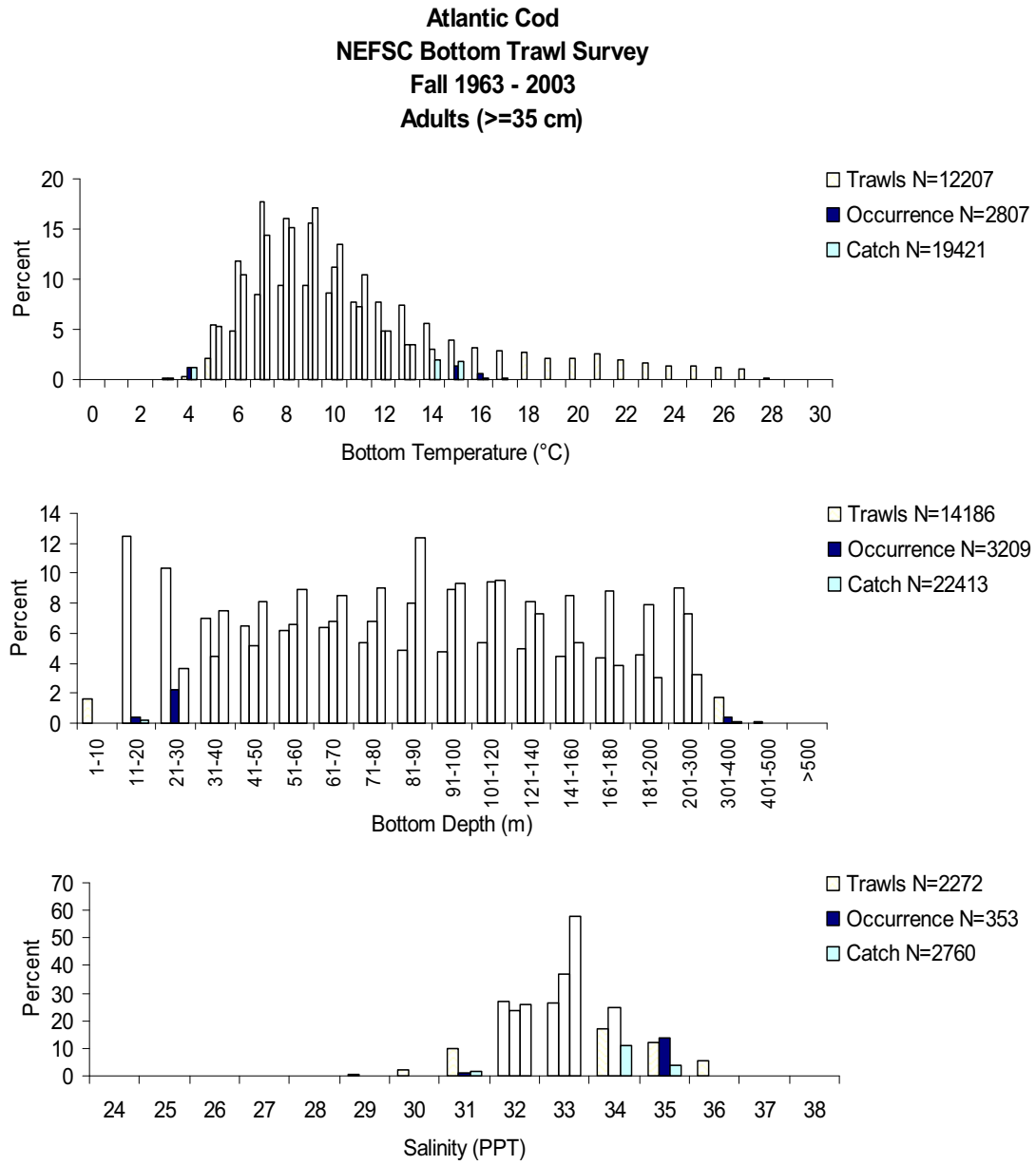


Figure 26. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic cod occurred and medium bars show, within each interval, the percentage of the total number of Atlantic cod caught. Note that the bottom depth interval changes with increasing depth.

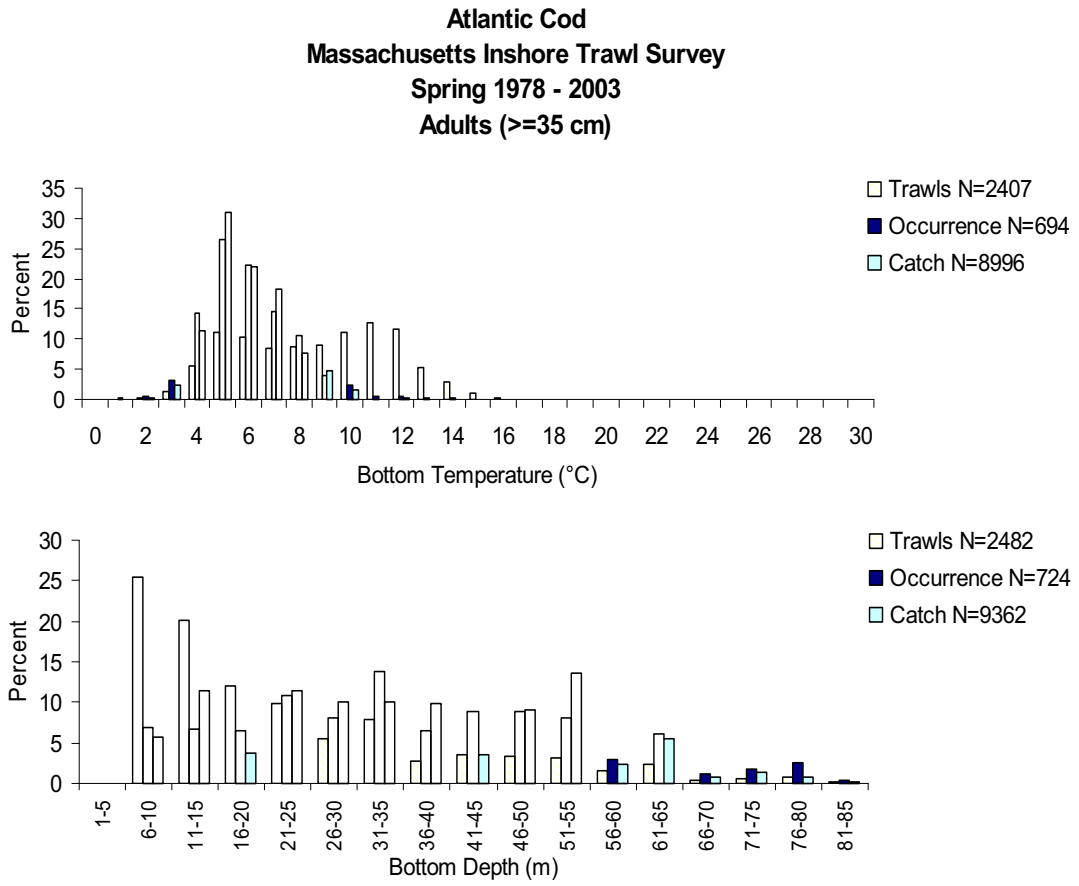


Figure 27. Distributions of adult Atlantic cod and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic cod occurred and medium bars show, within each interval, the percentage of the total number of Atlantic cod caught.

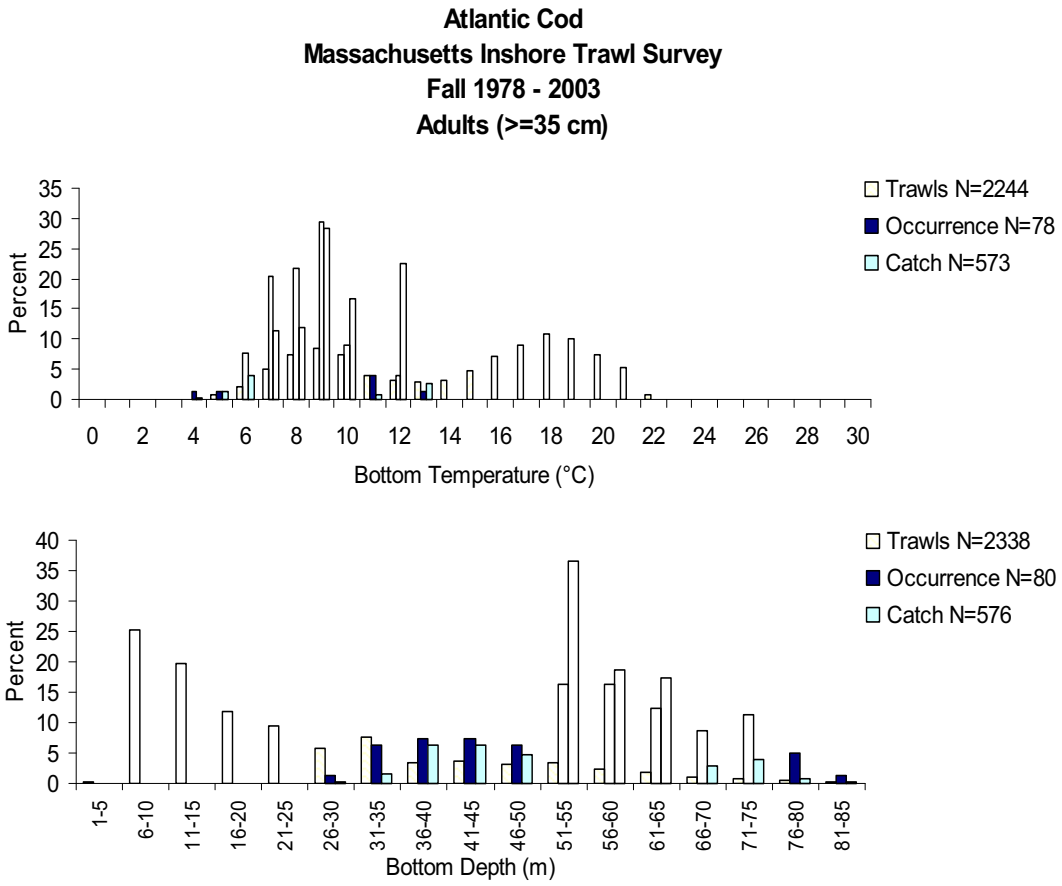


Figure 27. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic cod occurred and medium bars show, within each interval, the percentage of the total number of Atlantic cod caught.

Appendix 1. Table of habitat parameters for Atlantic cod, *Gadus morhua*.

This table is separated into four parts based on life history stage. Abbreviations: SS = Scotian Shelf; Nfld = Newfoundland; GOSL = Gulf of St. Lawrence; PB = Passamaquoddy Bay; GOM = Gulf of Maine; GB = Georges Bank; Mass Bay = Massachusetts Bay; SNE = southern New England (Nantucket Shoals to Hudson Canyon); MAB = Mid-Atlantic Bight.

SPAWNING/EGGS

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Currents/ Circulation	Light/Vertical
Anderson and de Young (1995)	Northeastern Nfld shelf	Studied vertical distribution and relative condition of eggs.	Temperature has effect on vertical distribution	Salinity (water density) has effect on vertical distribution	---	Eggs in poor condition found deeper in water column.
Bigelow and Schroeder (1953)	GOM	Pelagic. Spawn Mass Bay 3-10 miles from shore Nov.-Apr.; Ipswich Bay Feb-May; west coast Maine Mar.-May (into mid-summer). Also Isles of Shoals, Casco Bay, Sheepscot River. Always < 50 fm.	Bottom temperatures 0.6-8.9°C for spawning (2.2-5.6°C in Mass Bay). 5.0-8.3°C optimum for hatching. High mortalities at 0°C.	Sink in spring freshets	Drift southwest following coastline, 10-30 days	Near surface if salinities high
Bonnet (1939)	Lab study	Ipswich Bay. Spawns at yearly minimum temperature (March)	0.5-3.0°C. 12°C upper limit for development.	---	Eggs spawned in Ipswich bay would drift 120 miles before larvae settled to bottom.	---
Brander and Hurley (1992)	SS	Spring spawning proceeds from southwest to northeast along shelf.	---	---	Spawning matches production of copepods.	---
Cohen *et al.* (1990)	North Atlantic	Most productive area in western North Atlantic is eastern half of GB and Grand Banks, followed by southwest GOM.	0-12°C with most 0-6°C. GOM stock spawns in colder water than others.	---	---	Spawn near bottom, unless temperatures unsuitable, then migrate into water column.
Colton (1978)	GOM	Spawn in Nantucket Shoals and Mass Bay, Jan.-Apr. (peak Jan.). Also Georges and Browns Banks, Ipswich Bay, southwest GOM.	---	---	---	---
Fish (1928)	Mass Bay, southwest GOM	Peak spawning in Mass Bay in January	10.1°C (Nov.) to 0°C (Jan.).	---	Advected out of Mass Bay by currents.	---
Hanke *et al*. (2000)	SS, eastern GOM, Bay of Fundy; 1975-1997	Evidence for a spring and fall spawning, but with regional differences. In March-April spawning observed off southwestern Nova Scotia including Browns Bank, GB, and the Emerald/Western/Sable Island Bank area. Spawning occurs again in November/December on GB and entire Nova Scotia coast, west of Grand Manan and on Western/Sable Island/ Banquereau Bank.	---	---	---	---

Appendix 1. cont'd.

SPAWNING/EGGS

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Currents/ Circulation	Light/Vertical
Hardy (1978)	GB, GOM	Pelagic. Spawn in inlets, bays, harbors, coastal and offshore banks. Usually < 73 m.	0-6°C for spawning. 2.0-8.5°C optimum for incubation	Spawning salinity thru range 10.0-35.5 ppt. Eggs sink in spring freshets. High mortality at low salinites (9.9-12.5 ppt).	---	Upper 10 m. Sink with age.
Lough *et al*. (1994)	GB, January-June 1982 vs. 1985	Particles tracked from Northeast Peak spawning in monthly mean flow fields and the 1982 and 1985 wind stresses from Feb through May.	---	---	Greater losses of particles in surface layers < 25 m along southern flank and Northeast Peak when wind stress along-shelf to the northeast. Results consistent with greater losses in 1982 associated with strong northeast wind in April.	Particles released in six horizontal layers.
Lough *et al.* (1996)	GB, May 1992	Vertical distribution of eggs at mixed and stratified sites on southern flank.	Mixed site: 4-7°C. Stratified site: 4-10°C.	---	Inferred southwest transport along southern flank.	At shoal site, eggs distributed through water column. At stratified site, eggs most abundant in surface 20 m with maximum density just above base of thermocline at 20-10 m.
Lough *et al*. (2002)	GB, January-May 1977-1987	Modeling specific year, weekly transport and retention of eggs from Northeast Peak and Western GB spawning areas.	---	---	Specific year flow fields estimated from January to July.	Considerable wind loss of particles at surface; retention consistent at depth (30 m). High recruitment occurred during years of high retention.
Miller *et al.* (1995)	SS, Oct.-May, 1991-1993	Peak spawning during fall.	Temperature (more than season) exerts most influence on egg size (and hatchling size).	---	---	---
Mountain *et al*. (2003)	GB, monthly surveys January-July 1995, 1996	Peak egg abundance in Februrary-March on Northeast Peak of GB	---	---	Advection of egg cohorts consistent with mean climatological pattern. Seasonal egg mortality rates 12-14% d^{-1}.	---

Appendix 1. cont'd.

SPAWNING/EGGS

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Currents/ Circulation	Light/Vertical
O'Brien *et al*. (2003)	GB, 1978-2000	Egg survivorship was significantly related to age diversity of repeat spawners, spatial distribution of eggs, and bottom temperature.	---	---	---	---
Page *et al*. (1999)	GB, bi-monthly	Inferred mean spawning locations compared with patterns in particle residence times and locations.	---	---	Spawning occurs at times and locations characterized by model residence times >35 days: Northeast Peak during March-April.	Particles released at 1, 10, 20, 30, 40, 50 m depth in mean climatological bi-monthly flow fields.
Rau (1974)	Browns Bank, GB, Nantucket Shoals, February-March 1973	Most eggs found over central and northeast GB.	Most collected at 3-5°C.	Most collected at 32-33 ppt.	---	---
Valerio *et al.* (1992)	Nfld	Studied freezing resistance of eggs and larvae. No antifreeze proteins detected.	If chorion intact, capable of undercooling to -4.0°C. Froze at -4.1 to -17.0°C.	---	---	---
Werner *et al*. (1993)	GB, March-April	Modeling mean March-April transport of eggs from Northeast Peak.	---	---	Eggs in surface advected off bank, but below surface transported to southwest and retained on-bank if shoalward of 70-m isobath.	Vertical position of eggs specified in simulations based on day and night field observations.

Appendix 1. cont'd.

LARVAE

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Currents/ Circulation	Light/ Vertical	Predators/ Prey (See Food Habits tables also)
Garrison *et al*. (2000)	GB, April-May 1990, 1994, 1995.	Spatial overlap of cod larvae and herring and mackerel predators on southern flank determined.	Larvae occurred mostly in well-mixed water where mean temperature < 7°C.	Mean range: 32.2-32.7 psu	Intrusions of Scotian Shelf water and Slope water increased spatial overlap of predators.	---	Atlantic herring and Atlantic mackerel as they migrate northward in the spring and overlap with patches of larvae on the southern flank of GB.
Hanke *et al*. (2000)	SS, 1975-1982.	Composite data from several programs. Fall and spring spawning populations observed, progressively older larvae found on western SS.	---	---	---	---	---
Laurence (1978)	Laboratory study	Growth rates increase with increasing temperatures.	4°C: 4.15%/d. 7°C: 6.67%/d. 10°C: 8.75%/d.	---	---	---	---
Lough and Bolz (1989)	GB, April, May 1981, May 1983	Consistent cross-shelf age gradient with older larvae found nearer the shoals.	---	---	Average shoalward age gradient consistent with near-bottom cross-isobath current of ca. 1 cm s^{-1}.	Retention of larvae on the shoals enhanced by residing nearer to bottom in waters < 70 m.	---
Lough and Potter (1993)	GB, spring and summer 1981-1986	Vertical distribution patterns of eggs, larvae, and juveniles described from spawning to settlement.	Range: 4-14°C.	Range: 32.5-33.2 ppt	---	Larvae distributed throughout mixed water column, but concentrated within or above thermocline when strongly stratified. Older larvae deeper by day and shoaler by night indicating diel vertical migration.	---

Appendix 1. cont'd.

LARVAE

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Currents/ Circulation	Light/ Vertical	Predators/ Prey (See Food Habits tables also)
Lough and Manning (2001)	GB, May 1997	Model simulation of larvae near the developing tidal front on southern flank.	Surface signature of tidal front 7°C.	Sigma-t values given.	Complex frontal circulation of converging and diverging cells.	Vertical positioning important. Larvae caught in near surface jet transported southwest along flank, while larvae near bottom advected shoalward across the front.	---
Lough and Mountain (1996)	GB, April-May 1981; May 1983.	Effects of small-scale turbulence on larval feeding in well-mixed and stratified water on southern flank.	Turbulence minimal at or below pycnocline (ca. 25 m).	---	Higher turbulence near surface due to wind mixing and at depth due to shear in the tidal current near bottom.	Maximum feeding occurs at low to intermediate turbulence levels where prey is >10-20 prey l^{-1}; i.e., near pycnocline.	See Food Habits table.
Lough *et al*. (1994)	GB, January-June 1982 vs. 1985	Particles tracked from Northeast Peak spawning in monthly mean flow fields and the 1982 and 1985 wind stresses from Feb through May.	---	---	Greater losses of particles in surface layers < 25 m along southern flank and Northeast Peak when wind stress along-shelf to the northeast. Results consistent with greater losses in 1982 associated with strong northeast wind in April.	Particles released in six horizontal layers.	---
Lough *et al*. (1996)	GB, May 1992	Vertical distribution of larvae at mixed and stratified sites on southern flank.	Mixed site: 4-7°C. Stratified site: 4-10°C.	---	Inferred southwest transport along southern flank.	At shoal site, larvae distributed through water column. At stratified site, larvae most abundant in surface 20 m with maximum density just above base of thermocline at 20-10 m.	---

Appendix 1. cont'd.

LARVAE

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Currents/ Circulation	Light/ Vertical	Predators/ Prey (See Food Habits tables also)
Lough *et al*. (2005)	GB, May 1993, 1994	Biophysical 1-D growth model used to compare field derived growth rates (RNA-DNA based) at stratified sites on southern flank. Model includes effect of light on larval feeding response.	Thermocline near 20 m. Temperatures above 20 m, 7-9°C; below 20 m, 6-7°C.	---	Higher turbulence near surface due to wind mixing and at depth due to shear in the tidal current near bottom.	Vertical growth profiles resulted from depth-dependent food limitation and prey selectivity coupled with greater metabolic costs induced by higher temperatures in May 1994. Minimum light level for feeding typically near 60 m depth, so that most of water column had non-limiting feeding. Possible feeding inhibition in surface 10 m due to high light levels.	---
Mountain *et al*. (2003)	GB, monthly surveys January-July 1995, 1996.	Peak abundance in March-April on southern flank GB.	---	---	Movement of larval cohorts between surveys consistent with mid-depth climatological flow fields around GB.	Larvae concentrated in middle and upper part of water column.	---
Myers and Drinkwater (1989)	MAB, GB, Grand Banks	Examined effect of warm core ring activity on recruitment success in 17 groundfish stocks, 1973-1986.	---	---	Increased ring activity reduced recruitment in all stocks except GB cod.	Rings presumably entrained larvae of most stocks offshore.	---

Appendix 1. cont'd.

LARVAE

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Currents/ Circulation	Light/ Vertical	Predators/ Prey (See Food Habits tables also)
Perry and Neilson (1988)	GB	Studied diel vertical distributions of cod and haddock late larvae in isothermal and stratified sites.	Thermocline may limit nightly upward migration.	---	---	Near bottom during day, in midwater at night. Migrations in reaction to light levels. Late larval haddock did not change depth as much as cod larvae.	---
Rau (1974)	Browns Bank, GB, Nantucket Shoals, February-March 1973	Most larvae (2-7 mm) between northeast GB and Nantucket Shoals.	Most collected 3-5°C.	Most collected 32-33 ppt.	---	---	---
Suthers *et al.* (1989)	SS	Recent growth in presumed inshore nursery area was less than in offshore waters, based on examination of birthdate distributions.	Temperature only rarely correlated with growth.	---	---	---	Growth rate strongly correlated with zooplankton biomass.
Werner *et al.* (1993)	GB	Examined tidal currents, wind stress, Scotian Shelf inflow, advection and vertical distribution of larvae on Northeast Peak. Spawning shoalward of 70 m isobath enhances eventual retention of larvae on Georges Bank.	---	---	Larvae in surface layers subject to off-shelf advection via Ekman transport. Downwelling near shelf break allows larvae to avoid advection.	---	---

Appendix 1. cont'd.

JUVENILES

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Substrate/ Vegetation	Currents/ Circulation	Light/Diel	Predators/ Prey (See Food Habits tables also)
Clark and Green (1990)	Conception Bay, Nfld	Studied diel, depth, seasonal movements in Broad Cove. Seasonal change in diel behavior due to disappearance of shallow (< 30 m) summer thermocline.	Summer: day: 4.1-4.6°C; night: 10-12°C. Fall: stayed in warmer water.	---	Summer: wide-ranging (> 3 km/day), between deep, cold and shallow, warmer water. Fall: small home ranges over sand in shallows; resting areas over rocks in shallows.	---	Summer: day, inactive; night, active. Fall: day, active; night, inactive.	Active periods coincide with feeding.
Fraser *et al.* (1996)	Laboratory Study	Studied interactions of 0+, 1+, and 3+ (predator) cod and their reactions to two different substrate types: sand/cobble and sand/gravel.	---	---	Some habitat segregation between Age 0+ and Age 1+, except when Age 3+ present, then both hid in cobble.	---	---	When predator present, 0+ and 1+ cod used same refuge (cobble).
Gotceitas and Brown (1993)	Laboratory study	Studied substrate preference with and without a predator (e.g., a larger cod) present.	---	---	Cobble preferred over finer grained substrates when predator present. After predator leaves, larger juveniles return to fine grains, smaller remain in cobble.	---	---	Fewer juveniles succumb to predation in cobble than in finer grained substrates.
Gotceitas *et al.* (1994)	Trinity Bay, Nfld and laboratory studies, 1993	Nearshore bay, various substrates. July-mid-December.	---	---	Predator absent: preferred finer grains and avoided vegetation. Predator present: preferred cobble and hide in vegetation.	---	---	See Substrate/ Vegetation column
Gotceitas *et al.* (1995)	Nfld	Studied reactions of 0+ cod to predator in combinations of substrates and artificial 'kelp'.	---	---	With no predator, 0+ prefer fine grain substrates, avoid 'kelp'. When predator present, 'kelp' provides protection from predation.	---	---	Juveniles select refuge type (cobble or 'kelp') when predator present.
Gotceitas *et al.* (1997)	Nfld	Studied vegetated and non-vegetated habitats, plus several bottom substrates with and without predator using SCUBA and seines.	---	---	Eelgrass used as nearshore nursery by 0+ cod. For refuge from predation and when combined with cobble, stem density was important.	---	---	Predator absent: 0+ used sand and gravel. Predator present: 0+ hid in cobble or eelgrass.
Grant and Brown (1998a)	Nfld	Studied diel distribution in eelgrass habitat and diet differences between 0+ and 1+ cod.	---	---	After settlement in grass beds, Age 0+ change habits on diel basis.	---	Age 0+ in water column during day, disperse to bottom at night. Older year classes do opposite.	Age 0+ feed mostly on zooplankton during day; Age 1+ mostly on benthos and fish at night.

Appendix 1. cont'd.

JUVENILES

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Substrate/ Vegetation	Currents/ Circulation	Light/Diel	Predators/ Prey (See Food Habits tables also)
Grant and Brown (1998b)	Nfld	Studied encounters between just-settled juveniles and older cod (predators) in eelgrass and no-eelgrass habitats in Trinity Bay.	---	---	After settlement, juveniles display preference for eelgrass beds, but remain localized over grass and no-grass habitats for several weeks, perhaps through first winter.	---	Juveniles aggregate in grass beds during day, disperse at night. Different pattern by older cod results in reduced encounters.	Risk of cannibalism high in coastal habitats. Localized movements and preference for grass beds are mechanisms to avoid predation.
Gregory and Anderson (1997a)	Placentia Bay, Nfld. April, October / November 1995	Submersible and QTC View acoustical seabed classification system for habitat use by age 1-4 juveniles. Occurred most abundantly at 60-120 m.	5.5°C at surface, declining to minus 1.0°C at 75 m.	---	Substrate selection was age specific. Age 1 cod found primarily in areas with gravel substrate and low relief. Age 2-4 cod found mostly associated with coarse substrate and high relief. Macroalgae cover substrate not selected by either group.	Slight tidal current (max 0.1 to 0.2 m s^{-1}).	Suggest diel movements do not occur among juveniles at spring water temperatures (~-1.0°C).	Predator avoidance behavior indicates young mottled individuals rely on crypsis, whereas older uniform-colored individuals associated with a specific physical feature.
Hardy (1978)	Northwest Atlantic	Coastal waters, rock pools, shallow inlets, river mouths, harbors. Leave coastal areas by mid-June (Massachusetts). 0+ average 35 m (range 8-42 m); 1+ range 73-274 m.	Range 6-20°C	From < 31.3 to 35.0 ppt.	---	---	---	---
Keats (1990)	Bonavista Bay, Nfld	Examined diel depth distributions of juveniles.	---	---	---	---	Arrive in shallow water at dusk, remain until pre-dawn, then migrate into deeper water.	
Keats and Steele (1992)	Bonavista Bay, Nfld. May-August 1986	Described in Keats (1990).	---	---	---	---	Juveniles move into shallow water at night and mostly rest near bottom.	Diet consists mostly of planktonic prey taken during daytime.
Keats *et al.* (1987)	Conception Bay, Eastern Nfld	Observations of juveniles in macroalgal habitat and adjacent sea-urchin dominated 'barrens'.	---	---	More abundant in macroalgal areas, used as cover, than in 'barrens'.	---	Diel not tested	Epiphytic food source not utilized.

Appendix 1. cont'd.

JUVENILES

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Substrate/ Vegetation	Currents/ Circulation	Light/Diel	Predators/ Prey (See Food Habits tables also)
Laurel *et al*. (2003)	Bonavista Bay, Nfld. Summer/autumn 1999 and 2000	Various sizes of artificial eelgrass mats deployed with tethered age 0-yr cod to monitor local predation rates.	---	---	Artificial eelgrass mats of 5 sizes.	---	---	Predation rates negatively correlated with patch size, suggesting that larger patches reduced predator foraging ability. However, high predator densities in largest eelgrass mat resulted in higher rates of predation than expected.
Laural *et al*. (2004)	Bonavista Bay, Nfld 1996, 1998-2001.	Shallow coastal areas < 6 m depth with substrate varying from mud to bedrock, often associated with vegetative cover, eelgrass being the most common. Bi-weekly seine surveys, mark-recapture and lab experiments conducted.	---	---	Cod initially settle in August/September, and again in October, mostly associated with eelgrass but periodically over sand as density in eelgrass increased. Cod formed tighter aggregations over sand than eelgrass. Mark-recapture experiments indicated movement between sites. Habitat suitability dynamic rather than fixed variable.	---	---	Eelgrass supports higher densities of prey such as pelagic and epiphytic zooplankton.
Lindholm *et al*. (1999)	Aquarium experiments on predation of 0-year juveniles by 3+ cod over 5 seafloor habitats.	Habitats vary in complexity to mimic the range of impacts of mobile fishing gear given a gradient in fishing effort.	Aquarium maintained at 8-10°C.	---	Experimental habitats: sand, cobble, minimum density short sponge, maximum density short sponge, and tall sponge. Significant decrease in 0-yr mortality with epifaunal density compared to flat sand. Epifaunal density found to be more significant than epifaunal height in reducing 0-yr mortality.	---	12 h light/dark regime.	---
Lough *et al.* (1989)	GB	Descend to bottom at 4-6 cm. 0+ (newly settled) fish dense on northeastern GB, 70-100 m depth during summer.	---	---	Pebble-gravel deposits.	Fall, transported southeast-ward by gyre.	Migrate into lower water column at night to feed on inverte-brates.	Coloration mimics substrate, reduces vulnerability to predation.

Appendix 1. cont'd.

JUVENILES

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Substrate/ Vegetation	Currents/ Circulation	Light/Diel	Predators/ Prey (See Food Habits tables also)
MacDonald *et al.* (1984)	Bay of Fundy and PB	Juveniles in PB in winter, close to beach in summer. (See "Adults")	0-6°C in winter; 8-13°C in summer.	30-31 ppt winter; 31-32 ppt summer.	Mud, gravel, rock in winter; sand, mud, rock in summer.	---	---	---
Murawski and Finn (1988)	GB	Evaluated species co-occurrences relative to temperature and depth preferences and spatial distribution by species and age. Overlap with silver hake, mostly in fall. See also "Adults"	YOY means: winter: 2.9°C, spring: 5.3°C, summer: 9.9°C, fall: 9.3°C.	---	YOY means: winter: 56 m, spring: 60 m, summer: 71 m, fall: 71 m.	---		---
Tatyankin (1972)	Barents Sea, 1967-1969 (laboratory study)	Determined preferred temperatures in gradient tank. In general, lower temperatures selected in winter, higher in summer. Older age classes preferred colder temperatures than younger.	Age 0+, summer: 7-11 °C. Age 1, winter: 3-6°C. Age 1+, fall: 5-8°C. Age 2, winter: 2-7°C.	---	---	---	---	---
Tupper and Boutilier (1995)	St. Margaret's Bay, Nova Scotia	Studied survival and 0+ densities in four different bottom habitats (sand, seagrass, cobble, rock-reef).	---	---	Settlement equal among habitats, but subsequent densities highest in structurally complex habitat types.	---	---	Higher survival and densities appear to be related to shelter opportunities and reduced predation.

Appendix 1. cont'd.

JUVENILES

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Substrate/ Vegetation	Currents/ Circulation	Light/Diel	Predators/ Prey (See Food Habits tables also)
Wigley and Serchuk (1992)	GB, SNE. 1982-1986. Commercial landings data and spring and fall research-vessel data.	Ages 1-4 distributed at different depths in spring (57, 58, 68, 86 m, respectively). During autumn age 3 fish co-occurred with age 1-2 fish at 86 m. 0-group fish mean depth at 69 m. Seasonal shift in age 2 fish. Both the Nantucket Shoals and GB populations move to deeper water in the summer/fall along the 100 m contour, the western side of the Great South Channel, and the Northern Edge and Northeast Peak areas. Distribution patterns delineated more by depth than temperature. 0-group in autumn distinct from all other age-groups with respect to temperature and depth.	Mean temperatures for all age groups 5.3ºC in spring and 9.2ºC in autumn. Mean temperature for 0-group 10.0ºC. Seasonal shifts most likely associated with temperature.	---	---	---	---	Fall occurrence of some age-3 fish with ages 1-2 may be related to diet.

Appendix 1. cont'd.

ADULTS

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Depth/ Substrate/ Vegetation	Currents/ Circulation	Light/ Diel/ Vertical	Predators/ Prey (See Food Habits tables also)
Bigelow and Schroeder (1953)	GOM	Non-migratory in GOM. Surface to 250 fm, but few > 100 fm. Most 5-75 fm. Usually within 1 fm of bottom. As shallow as 7 fm in summer, 3 fm in winter.	0-12.8°C. Prefer < 10.0 °C.	---	Mostly rocky, pebbly, sandy, or gravelly bottoms.	---	---	Large sharks and spiny dogfish.
Colvo-coresses and Musick (1984)	MAB, continental shelf	Analyzed faunal associations, and zones occupied seasonally. Occurs with *Pseudo-pleuronectes americanus* and *Hemitripterus americanus*.	Boreal species, spring, < 10°C. "Relatively absent" during fall.	---	< 100 m.	---	---	---
Helser and Brodziak (1996)	GOM, GB, SNE, MAB	Demonstrated seasonal differences in depth and bottom temperature preferences.	Spring: < 4.9 °C; Fall: weaker association with temperatures.	---	Spring: < 72 m; Fall: weaker association with depth	---	---	---
Jean (1965)	GOSL; SS	GOSL: 35-145 m in summer; 130-180 m in winter. SS: 65-110 m in summer; 90-135 m in winter.	GOSL: 0-6°C in summer; 1-3 °C in winter. SS: 1-8°C in summer; 2-4 °C in winter.	---	---	---	---	---
Link and Garrison (2002)	SS, GOM, GB, SNE, MAB. Spring and fall research survey cruises 1973-1998. 25-yr time series of food habits data.	Omnivorous diet shifted significantly over 3 decades concurrent with forage species abundance and distribution.	---	---	---	---	---	Cod are opportunistic feeders, prefer sand lance, Cancer spp., crabs and herring, regardless of abundance or overlap. Early juveniles consumed more pelagic than benthic invertebrates, medium cod consumed benthic invertebrates and fish, and larger cod consumed larger amounts of fish. Cannibalism increased with size.

Appendix 1. cont'd.

ADULTS

Authors	Study Area and Period	Habitat (Spatial and Temporal)	Temperature	Salinity	Depth/ Substrate/ Vegetation	Currents/ Circulation	Light/ Diel/ Vertical	Predators/ Prey (See Food Habits tables also)
MacDonald *et al.* (1984)	Bay of Fundy and PB	Adults in PB summer; GOM, SS winter. (See "Juveniles").	8-13°C summer; 4-8°C winter.	31-32 ppt in summer; 31-32 ppt in winter.	Mud, rock in summer.	---	---	---
Mountain and Murawski (1992)	SS, GOM, GB, SNE, MAB. Spring NEFSC research survey cruises 1963-1990.	Significant correlation between GB weighted mean catch and areal average temperature, but unable to determine if distributional change either a north-south shift or change in water depth.	Significant decadal changes in spring temperatures from cold 1960's to warmer 1970's and intermediate 1980's. Interannual variations of ±2-4°C observed in all shelf regions.	---	---	---	---	---
Murawski and Finn (1988)	GB	Evaluated species co-occurrences relative to temperature and depth preferences and spatial distribution by species and age. Overlap with silver hake, mostly in fall. Also see "Juveniles"	Age 1+ means in winter: 4.2°C; spring: 5.4°C; summer: 8.0 °C; fall: 9.3°C.	---	Age 1+ means in winter: 88 m; spring: 67 m; summer: 72 m; fall: 84 m.	---	---	---
Odense *et al.* (1966)	Bay of Chaleur (laboratory study)	Studied tolerance to low salinity.	5-6°C (not manipulated).	First mortalities when salinities reached 2.7 ppt; complete mortality at 2.3 ppt.	---	---	---	---
Rose and Leggett (1988)	GOSL	Onshore movements and inshore abundance of cod were affected by winds, upwellings, and downwellings.	Cod usually located where temps -0.5 to 8.5°C.	---	---	When alongshore winds create temperature changes, cod numbers decrease.	---	---
Rose and Leggett (1989)	GOSL	Cod were aggregated within narrow temperature range, unless prey present, then found in wider range.	Without prey, usually between 0 and 5°C.	---	---	---	---	When capelin present, range -0.5 to 8.5°C.
Scott (1982a)	SS, Bay of Fundy	Determined preferred depths, temperatures, and salinities for several groundfish species. Compared to other gadoids, cod prefers shallower, colder, less saline waters.	0-13°C (mean 4.9°C). Preferred temperature showed increase northeast to southwest, means 3.2 to 7.8°C.	31-34 ppt (mean 32.8 ppt).	27-366 + m, (mean 95 m). Preferred range 37-90 m.	---	---	---
Tyler (1971)	PB compared to bays south. Analyzed regular and periodic components in fish community.	Cod was member of 'regular' community (present throughout year), but most abundant March-April.	As annual temperature fluctuations increase (in southern bays), fewer 'regular' species.	29.5-29.6 ppt in Mar-Apr.; 32.3 ppt in Sept.	Sampled brown mud bottom, sloping from 38-55 m.	---	---	---

Publishing in *NOAA Technical Memorandum NMFS-NE*

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This series represents a secondary level of scientific publishing in the National Marine Fisheries Service (NMFS). For all issues, the series employs thorough internal scientific review, but not necessarily external scientific review. For most issues, the series employs rigorous technical and copy editing. Manuscripts that may warrant a primary level of scientific publishing should be initially submitted to one of NMFS's primary series (*i.e., Fishery Bulletin, NOAA Technical Report NMFS,* or *Marine Fisheries Review*).

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Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Currently, there are three such media:

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NOAA Technical Memorandum NMFS-NE-192

Essential Fish Habitat Source Document:

Atlantic Herring, *Clupea harengus*, Life History and Habitat Characteristics

Second Edition

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

July 2005

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188. In preparation by authors.

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Essential Fish Habitat Source Document:

Atlantic Herring, *Clupea harengus*, Life History and Habitat Characteristics

Second Edition

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July 2005

Editorial Notes on "Essential Fish Habitat Source Documents" Issued in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For "Essential Fish Habitat Source Documents" issued in the *NOAA Technical Memorandum NMFS-NE* series, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division largely assume the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production is performed by, and all credit for such production rightfully belongs to, the staff of the Ecosystems Processes Division.

Internet Availability and Information Updating

Each original issue of an "Essential Fish Habitat Source Document" is published both as a paper copy and as a Web posting. The Web posting, which is in "PDF" format, is available at: *http://www.nefsc.noaa.gov/nefsc/habitat/efh*.

Each issue is updated at least every five years. The updated edition will be published as a Web posting only; the replaced edition(s) will be maintained in an online archive for reference purposes.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Nelson *et al*. 2004[a]; Robins *et al.* 1991[b]), mollusks (*i.e.*, Turgeon *et al.* 1998[c]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[d]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[e]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species.

---

[a]Nelson, J.S.; Crossman, E.J.; Espinosa-Pérez, H.; Findley, L.T.; Gilbert, C.R.; Lea, R.N.; Williams, J.D. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. 6th ed. *Amer. Fish. Soc. Spec. Publ.* 29; 386 p.

[b]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. World fishes important to North Americans. *Amer. Fish. Soc. Spec. Publ.* 21; 243 p.

[c]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[d]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[e]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

PREFACE TO SECOND EDITION

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NOAA Fisheries to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NOAA Fisheries has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in a series EFH species reports (plus one consolidated methods report). The EFH species reports are a survey of the important literature as well as original analyses of fishery-independent data sets from NOAA Fisheries and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and understandably are referred to as the "EFH source documents."

NOAA Fisheries provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

The initial series of EFH species source documents were published in 1999 in the *NOAA Technical Memorandum NMFS-NE* series. Updating and review of the EFH components of the councils' Fishery Management Plans is required at least every 5 years by the NOAA Fisheries Guidelines for meeting the Sustainable Fisheries Act/EFH Final Rule. The second editions of these species source documents were written to provide the updated information needed to meet these requirements. The second editions provide new information on life history, geographic distribution, and habitat requirements via recent literature, research, and fishery surveys, and incorporate updated and revised maps and graphs. This second edition of the Atlantic herring EFH source document is based on the original by Robert N. Reid, Luca M. Cargnelli, Sara J. Griesbach, David B. Packer, Donna L. Johnson, Christine A. Zetlin, Wallace W. Morse, and Peter L. Berrien, with a foreword by Jeffrey N. Cross (Reid *et al*. 1999a).

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NOAA Fisheries, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

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INTRODUCTION

The Atlantic herring, *Clupea harengus* (Figure 1), is a pelagic, schooling, plankton-feeding species that inhabits both sides of the North Atlantic Ocean. In the western North Atlantic this species ranges from Labrador to Cape Hatteras and supports major commercial fisheries. Adult herring undergo complex north-south migrations for feeding, spawning, and overwintering. Herring produce demersal eggs and spawn during the summer and fall in the Gulf of Maine – Georges Bank region. Larvae overwinter offshore and in coastal waters and metamorphose into juveniles in the spring. Juveniles and adults are heavily preyed upon by a variety of marine fish, marine mammals, and seabirds.

Herring are assessed and managed in U.S. waters as a single stock complex with two major spawning components, one in the Gulf of Maine and another on Georges Bank and Nantucket Shoals. Herring that spawn in the Bay of Fundy and off southwest Nova Scotia are assessed and managed by Canada. The U.S. stock complex has fully recovered from the effects of over-exploitation during the 1960s and 1970s and is currently under-utilized, although there is concern that exploitation rates in the Gulf of Maine may be too high.

This report provides information on the life history, stock status, geographical distribution, and habitat characteristics of different life stages of Atlantic herring in U.S. and Canadian waters of the northwest Atlantic from Cape Hatteras to the Gulf of Maine (Figure 2).

LIFE HISTORY

This section provides a brief review of the biology and life history of Atlantic herring in U.S. and Canadian waters of the northwest Atlantic. More detailed reviews are provided by Bigelow and Schroeder (1953), Sindermann (1979), Kelly and Moring (1986), Tupper *et al*. (1998), and Munroe (2002).

EGGS

Atlantic herring deposit demersal eggs in 5-90 m of water in areas with strong tidal currents on a variety of substrates ranging from boulders, rocks, and gravel, to sand, shell fragments, and macrophytes. The eggs are 1.0-1.4 mm in diameter (Fahay 1983) and are adhesive, adhering to the bottom and forming extensive egg beds that are often many layers deep. They remain attached to the bottom throughout the incubation period, which varies from 10-15 days in the Gulf of Maine region during the fall spawning season.

LARVAE

The larvae are 4-10 mm long at hatching (Able and Fahay 1998) and retain a yolk-sac for the first few days after hatching. The duration of the yolk-sac stage varies with temperature, from 2.5 days at 14.5°C to 6 days at 8°C (Mansueti and Hardy 1967; Lough *et al*. 1982). The yolk sac is absorbed by the time the larvae reach 8-12 mm SL (Blaxter and Holliday 1963). While they have a yolk sac, they are negatively buoyant and remain in deep water on or near the bottom. Divers observed yolk-sac larvae among the branches of a benthic red alga (*Ptiloda serrata*) at a spawning site on Jeffreys Ledge for several days after hatching (Cooper *et al*. 1975) and observations made from a submersible on Georges Bank revealed a dense aggregation of yolk-sac larvae being carried by the current 15 cm above the bottom (Caddy and Iles 1973).

The larval stage of fall-spawned herring in the Gulf of Maine lasts 4-8 months, depending on the timing of spawning. The larval stage is shortest for early-spawned (August) larvae, and longest for late-spawned (December) herring. Currents affect the pelagic larvae; however, they may or may not disperse randomly from the spawning grounds. Some larvae are retained for several months after hatching on or near the spawning site, while others are dispersed soon after hatching and drift with residual currents (Iles and Sinclair 1982; Sinclair and Iles 1985; Townsend *et al*. 1986; Chenoweth *et al*. 1989; Smith and Morse 1993).

Larvae produced off southwestern Nova Scotia are retained initially near the spawning ground and then drift into the Bay of Fundy (Iles 1971; Stephenson and Power 1988). Larvae produced in coastal Gulf of Maine waters generally remain inshore (Graham 1982) and disperse in a westerly direction, entering bays and estuaries where they over-winter (Graham *et al*. 1972a; Graham and Townsend 1985). Some larvae are transported offshore, away from the coast (Townsend 1992). Larvae that hatch on Jeffreys Ledge are dispersed shoreward (Boyar *et al*. 1973). Some larvae from the southwestern Gulf of Maine are transported eastward into estuaries in the mid-coast region of Maine (Lazzari and Stevenson 1992), despite the fact that the surface currents flow in the opposite direction. During the winter, herring larvae in inshore waters are exposed to extremely low temperatures and food levels (Townsend and Graham 1981; Graham *et al*. 1990). It is not clear if larval survival is enhanced as a result of over-wintering in nearshore and estuarine waters or in coastal waters. Larvae from Nantucket Shoals and Georges Bank tend to drift to the southwest (Lough *et al*. 1980; Grimm 1983) and are transported as far south

as southern New Jersey, where they have been collected in the Great Bay – Little Egg Harbor estuary during the winter and spring (Able and Fahay 1998) and in Delaware Bay and its tributaries (NEFMC 1999). The NOAA Estuarine Living Marine Resources Program (ELMR) compiled information on the distribution and abundance of all life stages of Atlantic herring in estuaries in New England (Jury *et al*. 1994) and the Middle Atlantic (Stone *et al*. 1994). Larvae were 'highly abundant' from Englishman-Machias Bays (eastern Maine) to the Sheepscot River (central Maine). Larvae were rare or absent in estuaries south of Raritan Bay (Table 1).

The Atlantic herring is one of the few species that perform extensive vertical migrations as larvae. They make diel or semi-diel vertical migrations throughout the water column that may be linked to time of day or turbidity (related to light level), tidal currents, or shifts in prey abundance (Lough and Cohen 1982). Vertical movements may be a larval retention mechanism enabling them to control their displacement by tidal currents and move into estuaries (Graham 1972; Fortier and Leggett 1983; Stephenson and Power 1988; Lazzari *et al*. 1993).

Larvae in coastal Maine waters grow at a rate of about 2 mm a week between October and early January and from late February to March, but grow very little, if at all, in mid-winter (Townsend and Graham 1981). Lough *et al*. (1982) reported larval growth rates in the Gulf of Maine – Georges Bank area of 1.75 and 2.1 mm per week in the fall and less than 1 mm per week in the winter.

JUVENILES

Larvae metamorphose into juveniles at 40-55 mm standard length (SL) in the spring (April-May) (Sindermann 1979; Lough *et al*. 1982). Growth is rapid, with juveniles in coastal Maine waters reaching lengths of 90-125 mm by the end of their first year of life (Anthony 1972). Schooling behavior begins during metamorphosis and is well established by the time the larvae have made the transition to the juvenile life stage (Gallego and Heath 1994). In the Gulf of Maine, one-year-old juveniles move out of nearshore waters in the summer and fall to overwinter in deep bays or near the bottom in offshore areas (Boyar 1968). Two-year old juveniles return inshore the following spring when they are fully recruited to the coastal fishery. Juvenile herring do not make seasonal north-south migrations. Herring tagged as overwintering one-year-old juveniles in eastern and western Maine remained in close proximity to the area where they were tagged throughout the following summer (Creaser and Libby 1986). Some summer-feeding two-year-old juveniles tagged in southwestern Maine overwintered in Massachusetts Bay, but juveniles in eastern Maine had a greater tendency to remain there (Creaser and Libby 1988).

One and two-year-old juveniles form large schools in coastal waters throughout the Gulf of Maine in the spring and summer (Bigelow and Schroeder 1953). They are abundant or common in estuaries and embayments from Buzzards Bay to Delaware Bay, primarily in the spring, and have been reported in Narragansett Bay and Long Island Sound during all months of the year (Table 2). They are abundant or highly abundant in most estuaries and embayments north of Cape Cod and are particularly numerous between Penobscot Bay and Passamaquoddy Bay in the summer.

Juvenile herring perform diurnal vertical migrations that are linked to changing light intensity, most likely in response to movements of their prey (Blaxter 1985). They move up in the water column at twilight and remain near the surface when light intensity is low; activity is highest just after sunrise and just before sunset (Brawn 1960a; Tibbo 1964; Stickney 1972). Juvenile and adult herring feed on a variety of planktonic organisms (see "Feeding").

ADULTS

Like juveniles, adult herring are pelagic and form large schools, feeding on planktonic organisms. Adults in the Gulf of Maine region occupy inshore and offshore waters to depths of 200 m and make extensive seasonal migrations between summer and fall spawning grounds on Georges Bank and in the Gulf of Maine and overwintering areas in southern New England and the Mid-Atlantic region (see "Migrations"). Thermal oceanic fronts between colder and less saline continental shelf water and warmer, more saline continental slope water provide an abundance of plankton and other food sources and greatly influence the migratory behavior and spatial distribution patterns of this species (see "Habitat Characteristics").

Adults occur in estuaries and embayments from Passamaquoddy Bay (Bay of Fundy) to Long Island Sound (Table 3). They are abundant or highly abundant from April to November in estuaries and embayments north of Muscongus Bay, in mid-coast Maine. Adults generally are common or rare south of Long Island Sound. Adult herring behavior is affected by temperature changes. Herring probably have characteristic temperature ranges and tolerances during particular times of year (Blaxter and Holliday 1963) and can perceive temperature changes which are smaller than 0.1°C (Laevastu 1993). Vertical migrations linked to changing light intensity are pronounced. Observations during the summer in the North Sea have shown that adult herring remain below

the thermocline in the daytime, migrate upwards during sunset to form loose aggregations above the thermocline, disperse between the surface and the thermocline during the night, and aggregate close to the bottom during sunrise (Laevastu and Hayes 1981; Blaxter and Holliday 1963).

Median sizes and ages at maturity for male and female Atlantic herring during 1987-1989 autumn trawl surveys were 25.3 cm TL and age 2.9 years for males and 25.4 cm TL and 3.0 years for females (O'Brien *et al*. 1993). Boyar (1968) concluded that herring from the Gulf of Maine, Georges Bank, and southern Nova Scotia during the 1960s matured at age 4 and an average total length of 27.5 cm. Fewer herring matured at age 3 and at sizes around 26 cm. Growth and maturation rates appear to be density-dependant. Sinclair *et al*. (1982) correlated increased sizes at maturity in Nova Scotia with faster juvenile growth rates and Winters (1976) correlated decreased age at maturity with decreased adult biomass in the Gulf of St. Lawrence. Mean size at age of adult herring in U.S. waters of the northwest Atlantic has decreased steadily since 1983 as stock size has increased (Overholtz *et al*. 2004). Growth rates have been shown to increase progressively from Nova Scotia to Georges Bank, with intermediate growth rates in the western Gulf of Maine (Sindermann 1979). Mean lengths of herring on Georges Bank ranged from 23.7-25.6 cm at age 3 to 33.0-33.3 cm at age 7 during the 1960s (Boyar 1968). Atlantic herring can reach a maximum size of about 39 cm TL and 0.68 kg, and a maximum age of 15-18 years (Anthony 1972). However, herring caught in the U.S. commercial fishery seldom exceed 35 cm in length and 12 years of age (Overholtz *et al*. 2004).

REPRODUCTION

Most Atlantic herring in the Gulf of Maine region mature at 3 years of age and a total length of about 25 cm (O'Brien *et al*. 1993). In this report herring ≥ 25 cm were considered to be adults. Predicted fecundities range from 44,000 eggs for small (25 cm) females to about 250,000 for large (36 cm) females (Morse and Morris 1981; Kelly and Stevenson 1985).

In the northwest Atlantic, herring spawn from Labrador to Nantucket Shoals. Spawning occurs in the spring, summer, and fall in more northern latitudes, but summer and fall spawning predominates in the Gulf of Maine-Georges Bank region (Haegele and Schweigert 1985). Small spring spawning stocks used to exist in the Bay of Fundy (Bigelow and Schroeder 1953). Herring spawning grounds are located in high-energy environments with strong tidal currents (Iles and Sinclair 1982) and, based on information from egg and larval surveys and the distribution of sexually mature adults, are depicted - in very general terms - in Figure 3.

Historically, three primary herring spawning stocks have been recognized in the Gulf of Maine region: southwestern Nova Scotia, coastal Gulf of Maine, and Georges Bank/Nantucket Shoals. These larger stocks may be composed of a number of smaller stocks that occupy discrete, localized spawning locations within the larger spawning grounds. This has been confirmed off southwestern Nova Scotia, where spawning occurs on or near a series of offshore banks and ledges (Stephenson *et al*. 2001).

In U.S. waters of the Gulf of Maine, herring eggs have been observed along the eastern Maine coast, at several other locations along the Maine coast (e.g., outer Penobscot Bay and near Boothbay), on Jeffreys Ledge and Stellwagen Bank, and on eastern Georges Bank (see Geographic Distribution: Eggs, and Figure 6). Nantucket Shoals is known to be an important spawning ground based on the concentrations of recently-hatched larvae that were repeatedly collected there during the 1970s and 1980s (Grimm 1983; Smith and Morse 1993). High concentrations of recently-hatched larvae have also been collected in the vicinity of Cultivator Shoals on western Georges Bank, in the vicinity of Stellwagen Bank and Jeffreys Ledge, and on the outer continental shelf in southern New England (Grimm 1983; Smith and Morse 1993). High densities of recently-hatched larvae have also been observed in Saco Bay and Casco Bay on the southern Maine coast (Graham *et al*. 1972b, *et al*. 1973).

The spawning season in the Gulf of Maine-Georges Bank region begins in July and lasts until December. Spawning begins earlier in the northern areas of the Gulf. Off southwestern Nova Scotia, spawning occurs from July to November and peaks in September-October (Boyar 1968; Das 1968, 1972) Spawning in eastern Maine coastal waters during 1983-1988 extended from late July through early October, with peak spawning in late August (Stevenson 1989), but more recent egg bed surveys (1997-2002) in the same area indicated that spawning did not start until late August and lasted until October 21 (Neal and Brehme 2001; Neal 2003). Based on larval surveys, Graham *et al*. (1972b) concluded that spawning peaks in mid-September to mid-October in eastern Maine and in October in western Maine. Boyar *et al*. (1973) reported that spawning on Jeffreys Ledge in 1972 started in early September and peaked during the first three weeks of October. On Georges Bank, spawning occurs from late August to December (Boyar 1968; Berenbeim and Sigajev 1978; Lough *et al*. 1980) with a peak in September-October (Boyar 1968; Pankratov and Sigajev 1973; Grimm 1983). On Nantucket Shoals, spawning peaks from October to early November, 1-2 weeks later than on Georges Bank (Lough *et al*. 1980; Grimm 1983). Larval surveys conducted during 1971-1975 indicated that spawning on Georges Bank started on the northeast peak of the bank in September and

extended southwest to Nantucket Shoals in October, declined in November and was absent in December (Grimm 1983).

During spawning, it has been reported that the females first deposit ribbons of eggs on the substrate and then the males swim above them and release milt into the water (Blaxter and Holliday 1963). However, Messieh (1988) observed that females spawning in shallow water in the Gulf of St. Lawrence did not release their eggs until there was milt in the water and swam 30 cm above the bottom for four hours before spawning at night. A single school of spring-spawning herring in a bay in southwestern Norway was observed to separate into a pelagic component (a tight "ball") of fully-mature non-spawning fish and a demersal component of spawners that spread out in a flat layer at the bottom (Axelsen *et al*. 2000). Post-spawners seemed to return to the pelagic school. After spawning the two components rejoined each other in a loose, uneven layer at the surface. The majority of the herring in the school completed spawning within three days. A school of herring in eastern Maine was observed to remain near the site where they spawned for about a week; eggs were deposited on the bottom overnight and the next day the spent fish had dispersed from the spawning site (Stevenson and Knowles 1988).

In some cases egg masses are composed entirely of eggs that were all spawned at the same time (Caddy and Iles 1973; Stevenson and Knowles 1988), while in other cases several layers of eggs in different stages of development indicate that successive spawnings have occurred at the same site within a few days of each other (Pankratov and Sigajev 1973). Spawning often occurs repeatedly at the same site. Stevenson (1989) reported 49 spawning events at 24 different locations along the eastern Maine coast during 1983-1988. In a few cases, eggs were deposited at the same site twice in the same year.

Egg developmental rates are inversely related to temperature, varying from 40 days at 4-5°C to 6-8 days at 14.4-16°C, with an average incubation period of 10-15 days at temperatures (8-13°C) which prevail during the summer-fall spawning season in the Gulf of Maine (Bigelow and Schroeder 1953; Messieh 1988). In the Gulf of Maine, Atlantic herring spawn in fully saline seawater (32-33 ppt) (Munroe 2002).

FOOD HABITS

Atlantic herring prey upon a variety of planktivorous organisms. They are visual particulate feeders with diverse feeding behaviors, often switching between filtering and biting in response to light intensity and the size of available food (Bigelow and Schroeder 1953; Battle 1934; Blaxter 1966; Batty *et al*. 1990). All life stages of herring are opportunistic feeders, and will take advantage of whatever prey of the appropriate size is available. As they grow and the size of their jaws increases, they consume larger organisms. Their diet therefore varies with season, their age and size, and location.

Larvae begin exogenous feeding before the yolk sac is completely absorbed (Munroe 2002). Newly-hatched larvae (7-20 mm) in coastal waters of central Maine feed primarily on the small, early developmental stages of copepods; during the winter, larger larvae (21-30 mm) feed on the adult stages of small copepods as well (Sherman and Honey 1971). During the spring, when a wider variety of planktonic organisms are available and the larvae are larger, their diet includes organisms such as barnacle larvae, crustacean eggs, copepods, and free-swimming ciliate protozoans (tintinnids) (Sherman and Honey 1971). Three copepod species preyed upon by larval herring on Georges Bank are *Pseudocalanus* sp., *Paracalanus parvus*, and *Centropages typicus* (Cohen and Lough 1983).

Juveniles feed on up to 15 different groups of zooplankton; the most common are copepods, decapod larvae, barnacle larvae, cladocerans, and molluscan larvae (Sherman and Perkins 1971). Adults have a diet dominated by euphausiids, chaetognaths, and copepods (Bigelow and Schroeder 1953; Maurer and Bowman 1975). Maurer (1976) reported that the most important prey items of adult herring collected on Georges Bank were chaetognaths (*Sagitta elegans*, 43% by weight), euphausiids (*Meganyctiphanes norvegica*, 23%; *Thysanoessa inermis*, 6.1%), pteropods (*Limacina retroversa*, 6.2%), and copepods (3%). The copepod *Calanus finmarchicus* is a common prey item. In addition, adults also consume fish eggs and larvae, including larval herring, sand lance, and silversides (Munroe 2002).

Spring and summer are the most intense feeding times for both juvenile and adult herring (Munroe 2002). Although it has been observed that adult herring on Georges Bank stop feeding prior to spawning (Pankratov and Sigajev 1973), there are also studies showing that they continue feeding before spawning (Bradford and Iles 1992; Axelsen *et al*. 2000). Feeding occurs primarily at dawn and dusk in the upper water layers due to the diurnal vertical migrations of herring in response to changes in light intensity; they rise to the surface to feed at dusk and then sink toward the seabed at dawn (Brawn 1960a; Tibbo 1964; Stickney 1972; Blaxter 1985).

Food habits data collected during Northeast Fisheries Science Center (NEFSC) bottom trawl surveys [see Reid *et al.* (1999b) and Link and Almeida (2000)] reveal that the most abundant identifiable prey items (percent by weight) for Atlantic herring include amphipods, copepods, and euphasiids (Figure 4).

PREDATION AND MORTALITY

Herring is an important species in the food web of the northwest Atlantic. Demersal fish species that have been observed feeding on herring eggs include cod, haddock, cunner, and red hake; invertebrates that probably consume herring eggs include moon snails, hermit crabs, and starfish (McKenzie 1964; Caddy and Iles 1973; Cooper *et al*. 1975). Herring eggs and larvae are consumed by sand lance (Rankine and Morrison 1989). Herring larvae are also eaten by jellyfish (*Aurelia aurita*), Atlantic mackerel, and adult Atlantic herring (Bailey 1984; Bailey and Batty 1984; Moller 1984; Lett and Kohler (1976). Juvenile herring, especially "brit" (age-1 juveniles) are heavily preyed upon due to their abundance, small size, and schooling behavior (Munroe 2002).

Atlantic herring is an important prey species for a large number of piscivorous fish, elasmobranchs (sharks and skates), marine mammals, and seabirds in the northwest Atlantic. Unlike other pelagic fishes such as Atlantic mackerel, herring are smaller and vulnerable to predation over most, if not all, of their life (Overholtz *et al*. 2000). According to the diet composition data in Table 4, the principal finfish and elasmobranch species that feed on Atlantic herring (or on clupeid species as a group) are Atlantic cod, silver hake, thorny skate, bluefish, goosefish, weakfish, summer flounder, white hake, and – in certain locations and times of year – Atlantic bluefin tuna. Other species that feed on herring are spiny dogfish, Atlantic halibut, red hake, striped bass, dusky shark, and black sea bass. Short-finned squid (*Illex illecebrosus*) have also been observed feeding on juvenile herring (Bigelow and Schroeder 1953). The spiny dogfish is a much more important predator on Atlantic herring than is indicated by diet composition data. Link *et al*. (2002a) estimated that spiny dogfish consumed an average of 67,660 metric tons (mt) of Atlantic herring a year during 1977-1998, with a range of 15,526 to 148,197 mt. Thus, in some years, spiny dogfish may consume a greater quantity of herring biomass than is taken in the commercial fishery.

For many of the predator species listed in Table 4, herring made up a larger percentage of the diets of the larger size classes. This was the case for silver hake, summer flounder, white hake, bluefish, and goosefish. Link and Garrison (2002) reported that the percentages of herring in the stomachs of Atlantic cod increased from about 13% in 51-60 cm cod to 28% in 81-90 cm cod and then declined again to 6% in 111-120 cm cod. They also showed that herring made up a larger percentage of the diet of Atlantic cod in the Gulf of Maine than on Georges Bank or in southern New England. Garrison and Link (2000) reported higher percentages of Atlantic herring in the diet of silver hake on Georges Bank than in the Gulf of Maine or in southern New England. Bowman *et al*. (2000) reported similar results for silver hake and Atlantic cod. Chase (2002) reported very high percentages of Atlantic herring in bluefin tuna diets on Jeffreys Ledge and in the Great South Channel, but very low percentages in three other locations. Less dramatic spatial variations were reported for striped bass by Nelson *et al*. (2003).

Overholtz *et al*. (2000) estimated the consumption of Atlantic herring by 10 species of predatory fish in northeastern U.S. waters from 1977-1997, and found that the amount of herring consumed varied in response to changes in the abundance of herring and the abundance of predator populations in the late 1980s and throughout the 1990s. Consumption of Atlantic herring by these predatory fish peaked at over 200,000 metric tons (mt) during 1992 and 1993, declining to less than 100,000 mt in 1997 (Table 5). By far the most important predator on herring was spiny dogfish, followed by silver hake, cod, white hake, and bluefish. The declines in consumption of herring in the late 1990s were coincident with the declines in the abundance of these five species.

Read and Brownstein (2003) used survey-based estimates of abundance for eight species of marine mammals between 1991 and 1997 to estimate the total annual consumption of Atlantic herring by these species. Their estimates of marine mammal consumption ranged from about 94,000-190,000 mt of herring per year. Their results show that minke whales, harbor porpoises, and white-sided dolphins are major predators on Atlantic herring because of high proportions of herring (34-51%) in their diets, whereas fin and humpback whales consume large quantities of herring to sustain their large body mass. Despite a three-fold increase in the harbor seal population in the Gulf of Maine between 1981 and 1997, herring only make up 13% of their diet. Consequently, the mean consumption estimate for harbor seals is below 5,000 mt a year.

Read and Brownstein's (2003) mean (or "best") estimate of Atlantic herring consumed annually by marine mammals during 1991-1997 was about 140,000 mt, with a range of 93,000-200,000 mt. Adding these estimates to the most current (1997) estimate of 100,000 mt of Atlantic herring consumed by fish and elasmobranch predators reported by Overholtz *et al*. (2000) produces a total mean estimate of 240,000 mt, with a range of 193,000-300,000 mt. During the 1990s, the total amount of herring consumed by all predators could have been as high as 400-450,000 mt.

MIGRATION

Adult herring make extensive seasonal migrations between summer spawning grounds on Georges Bank and in the Gulf of Maine and overwintering areas in southern New England and the Mid-Atlantic region.

They seldom migrate seaward beyond a depth of about 100 m and usually inhabit waters closer to the surface than the bottom, except in midwinter (Hildebrand 1963). Adults from different spawning groups intermingle during the non-spawning phase of their seasonal cycle (Sinclair and Iles 1985). Juvenile herring make seasonal inshore-offshore movements, but do not make extensive north-south migrations (see Life History: Juveniles).

Three general migratory patterns are recognized off the northeast coast of the U.S., one for each of the three primary spawning stocks, based on the results of tagging studies (e.g., Stobo 1983 and Creaser *et al*. 1984) and observations from the commercial fishery (Sindermann 1979; Figure 5). Herring that spawn off southwest Nova Scotia move north along the eastern Scotian shelf after spawning, but some also move south to overwinter in the Gulf of Maine. Adults belonging to the Georges Bank/Nantucket Shoals stock overwinter south of Cape Cod and along the Mid-Atlantic coast. They move north onto Georges Bank and into the Gulf of Maine in the spring before congregating on spawning grounds southeast of Nantucket and on Georges Bank in the fall. Adults that spawn in the Gulf of Maine migrate southwest along the coast after spawning. Some of them overwinter south of Cape Cod and some remain in the southwestern region of the gulf. Thermal oceanic fronts between colder, and less saline continental shelf water and, warmer, more saline continental slope water provide an abundance of plankton and other food sources and greatly influence the migratory behavior of this species (see Habitat Characteristics: Adults).

STATUS OF THE STOCKS

Adult herring segregate into discrete spawning stocks in the summer and fall – on Georges Bank and Nantucket Shoals, in coastal waters of the Gulf of Maine, and off southwest Nova Scotia and in the Bay of Fundy. Each of the major spawning areas in the Gulf of Maine region consists of a number of smaller, discrete, spawning sites. Some degree of stock differentiation was achieved with early enzyme electrophoresis research (Ridgway *et al*. 1970, 1971), but more recent attempts to differentiate geographically isolated fall spawning stocks in eastern Canada and the northeast U.S. on the basis of more specific genetic characteristics have been unsuccessful (Kornfield *et al*. 1982; Kornfield and Bogdanowicz 1987; Safford and Booke 1992). Evidence for separate stocks is based on discrete larval distribution patterns (Iles and Sinclair 1982), differences in spawning times and locations (Boyar *et al*. 1973; Haegele and Schweigert 1985), distinct biological characteristics - such as growth rates (Anthony and Waring 1980) and meristic and morphometric characteristics (Anthony 1981; Safford 1985) - and the incidence of parasites (McGladdery and Burt 1985). McQuinn (1997) reviewed arguments for a discrete versus dynamic balance population concept for Atlantic herring and proposed that the population structure and dynamics of herring fit well within a metapopulation model. This model allows for significant mixing and gene flow among units that still retain considerable persistence and discreteness due to behaviorally-induced homing to spawning grounds.

The most compelling evidence supporting the existence of separate Gulf of Maine and Georges Bank-Nantucket Shoals stocks was the collapse of the large Georges Bank-Nantucket Shoals stock in the early 1970s after several years of heavy exploitation by foreign fishing fleets (Overholtz and Friedland 2002). This stock remained in a depleted state for 10-15 years, during which time the smaller Gulf of Maine stock continued to support a strong coastal fishery.

Trawl and larval survey data show that the Georges Bank stock has fully recovered and support the view that herring recolonized the bank in stages from the Gulf of Maine and Nantucket Shoals during the late 1980s (Smith and Morse 1993; Overholtz and Friedland 2002). Analysis of trawl survey shows that the geographic range of herring in U.S. waters of the northwest Atlantic was greatly reduced during the period of stock depletion and was more widely dispersed by the mid 1990s (Overholtz 2002; Overholtz and Friedland 2002). During 1968-1970 the spring-time center of distribution was south and west of Cape Cod and then gradually shifted northwards and eastwards as stock size declined. As abundance increased in the late 1980s, the center of the spring distribution moved southwards and westwards as adults that spawn on Georges Bank and on Nantucket Shoals migrated south and re-occupied the mid-Atlantic shelf.

The Bay of Fundy-southwest Nova Scotia stock is assessed by Canada as a component of a larger management unit that also includes coastal and outer shelf waters east of Nova Scotia. Biomass estimates derived from acoustic survey data indicate that the overall abundance of spawning herring declined from about 570,000 mt in 1997 to about 460,000 mt in 2000 and 2001, but increased in 2002 and 2003 (Melvin *et al*. 2004). Despite recent increases in spawning stock biomass (SSB), there are concerns that the stock is deteriorating: the total catch increased in 2003, but there are fewer adults in the population and SSB for two spawning components remains well below historical levels (Power *et al*. 2004). The abundance of herring that spawn at individual sites off southwest Nova Scotia varies from site to site in response to the amount of fishing that occurs at each site (Stephenson *et al*. 1999; Melvin *et al*. 2001). These observations support the view that each of these spawning aggregations constitutes a separate sub-stock of herring (Stephenson *et al* 2001). Some of these discrete

spawning sites are located within 10-15 miles of each other.

Herring that spawn on Georges Bank, Nantucket Shoals, and in coastal waters of the Gulf of Maine are currently assessed in the U.S. as a single coastal stock complex. According to a recent U.S. assessment, spawning stock biomass for the stock complex was about 1.4 million metric tons (mt) in 2001 while a Canadian assessment shows it to be about 600,000 mt (Overholtz *et al*. 2004). They both show the same downward trend in spawning stock size from about one million metric tons in the late 1960s to 100,000 mt between 1975 and 1985, but the U.S. assessment indicates a much more dramatic recovery during the last 20 years. Maximum sustainable yield (MSY) estimates from the U.S. assessment were 222,000 mt or 243,000 mt, based on two different model formulations (Overholtz *et al*. 2004). According to the U.S. assessment, current fishing mortality rates in the fishery are below 10%, indicating that the resource is significantly under-utilized. There is concern, however, that the inshore (Gulf of Maine) component of the stock, which is heavily exploited, is being over-harvested.

GEOGRAPHICAL DISTRIBUTION

EGGS

Atlantic herring eggs are demersal and adhere to the substrate and were not usually collected during the NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) ichthyoplankton surveys. A few i*n situ* surveys of herring spawning locations have been conducted in the Gulf of Maine – Georges Bank region during the past 40 years using divers, remotely-operated underwater vehicles equipped with video cameras, submersibles, dredges and grab samplers. Information obtained from these surveys is summarized in Table 6. Geo-referenced spawning site locations are shown in Figure 6, Figure 7, and Figure 8. Spawning location information in this document is based on the presence of herring eggs on the bottom. More general information on herring spawning grounds based on catches of fully mature adults or the abundance and distribution of recently-hatched larvae is summarized in Life History: Reproduction.

LARVAE

Herring larvae were collected during the 1977-1987 NEFSC MARMAP surveys from New Jersey to the Bay of Fundy and from nearshore waters to the seaward limit of the survey area (Figure 9). Larvae were collected in all months, but were most abundant in the fall (September – December). The highest mean monthly density (351 larvae/10 m^2) occurred in September when larvae were restricted to the northeastern Gulf of Maine. Larvae were relatively abundant in October (39 larvae/10 m^2) and November (49 larvae/10 m^2). The appearance of larvae off Nova Scotia and eastern Maine in September, followed by more widespread larval production throughout the Gulf of Maine and on Nantucket Shoals and Georges Bank in October and November, indicates that spawning begins earlier in the northeast (see also Bigelow and Schroeder 1953; Tupper *et al*. 1998). Mean densities were much lower (less than 6 larvae/10m^2) from December through August. The MARMAP surveys were conducted during the time when the abundance of the Georges Bank – Nantucket Shoals spawning stock of herring was very low.

The abundance and distribution of herring larvae on Georges Bank and Nantucket Shoals changed considerably between 1971 and 1990, as the number of herring spawning in these two areas declined in response to heavy fishing pressure and then increased beginning in the mid-1980s. By the end of the 1980s, larval abundance had increased to 1973-1974 levels on Georges Bank and exceeded the previous abundance levels on Nantucket Shoals (Figure 10). According to U.S. larval survey data compiled by Smith and Morse (1993), herring spawned on the northeast peak of Georges Bank and on Nantucket Shoals during 1971-75 (Figure 11). During 1976-1987, spawning was limited to a small area on Nantucket Shoals and in Massachusetts Bay. During 1988-1990, spawning spread over a larger area that included the western portion of Georges Bank (Cultivator Shoals), but not the northeast peak. More recent Canadian surveys have documented larval production in U.S. and Canadian waters on eastern Georges Bank, including – in 1994 – the northeast peak (Figure 12; Melvin *et al*. 1996).

JUVENILES AND ADULTS

NEFSC bottom trawl surveys show that the distributions of juvenile (Figure 13) and adult (Figure 14) herring overlap during the summer, fall, and winter and are very similar in the spring. (Note that winter and summer distributions are presented as presence/absence data, precluding a discussion of abundances.) In the summer and fall, herring are distributed throughout the Gulf of Maine and in the deeper waters of Georges Bank and the Great South Channel, with a few in offshore waters of southern New England. In the winter, their distribution shifts southward, extending from Georges Bank to Cape Hatteras, primarily in offshore waters. A few remain in the Gulf of Maine,

which is not sampled very heavily in the winter (Reid *et al*. 1999b). In the spring, juvenile herring occupy the entire region. The spring adult distribution extends from Cape Hatteras to Georges Bank and the southwestern and central Gulf of Maine and the Scotian shelf, but there are only a few along the Maine coast. Herring are more concentrated in nearshore waters of the Mid-Atlantic, southern New England, and Massachusetts Bay in the spring than they are in the winter.

The distributions and abundances of Atlantic herring along the coasts of Maine and New Hampshire, based on spring and fall 2000-2003 Maine-New Hampshire inshore groundfish surveys (Sherman *et al*. 2004), are shown in Figure 15. Most of these were juveniles (Figure 16).

The distributions and abundances of juveniles and adults in Massachusetts coastal waters, based upon the spring and fall 1978-2003 Massachusetts inshore trawl surveys, are shown in Figure 17 (juveniles) and Figure 18 (adults). In the spring, the largest catches of juvenile herring occurred along the northern shore of Nantucket Island and southern shore of Martha's Vineyard, as well as in Buzzards Bay north of Cape Ann. In the fall, large catches were found in Cape Cod Bay (Figure 17). The few adults found in the spring and fall were most abundant in near Cape Ann (Figure 18).

The seasonal distributions and abundances of juveniles and adults in Narragansett Bay, based upon the 1990-1996 Rhode Island bottom trawl surveys, are shown in Figure 19 (juveniles) and Figure 20 (adults). Catches of juveniles were patchy in Narragansett Bay (Figure 19). Catches were highest in summer when the largest mean catch (254 fish/tow) occurred at the station farthest offshore and five of the 12 stations in the bay had > 100 per tow. Abundance was lower during the remaining seasons. Adults (Figure 20) were scarce in winter when the highest mean catch was 12 per tow. Catches were smaller in other months and no adults were caught in summer.

The distributions and abundances of both juvenile and adult Atlantic herring in Long Island Sound from April to November 1984-1994, based on the Connecticut Fisheries Division bottom trawl surveys, are shown in Figure 21, Figure 22, and Figure 23. The following description of their distributions relative to depth and bottom type is taken verbatim from Gottschall *et al*. (2000).

Atlantic herring taken in the survey ranged from 3-33 cm (Figure 23). The percentage of adults was 81% and 94% in April and May respectively, but declined to 0% by October. Although herring were not measured in November, recorded observations indicated that most were adults (Gottschall *et al*. 2000).

Atlantic herring abundance in the Connecticut survey was highest during April and May (Figure 22) when adults were most abundant in Long Island Sound. In the spring sampling period they were widely distributed, but were especially abundant in the Western and Central Basins over mud bottom (Figure 21 and Figure 22B). Adult abundance declined through the spring months to very low abundance in the summer and fall periods, when most of the herring taken in the survey were juveniles. Although the survey did not effectively retain young-of-the-year, they were very abundant in the Sound during the summer months – in a separate sampling program, up to 80,000 per 15 minute tow were caught with an otter trawl equipped with a 6 mm codend liner [see reference in Gottschall *et al*. (2000)]. During the fall period, most herring were taken along the Connecticut side of the Sound in depths < 18 m, especially south of Milford (Figure 21 and Figure 22F). Abundance increased in November when adult fish were again taken. During November, abundance increased slightly with decreasing depth, and the largest catches occurred in the Central Basin (Gottschall *et al*. 2000).

Surveys of the Hudson-Raritan estuary show that juveniles were most abundant in winter and spring throughout the (Figure 24). Some were caught at the mouth of the estuary in summer, but they were rare in the fall. Adults (Figure 25) were common in winter, but not at any other time of year.

The Virginia Institute of Marine Science (VIMS) trawl surveys (1988-1999) and beach seine surveys (1994-1999) of Chesapeake Bay show that, although Atlantic herring were not often caught, nearly 90% of the catches were juveniles, with only three adults found from the seine surveys (Geer 2002). Juveniles were caught in the trawl survey during late winter and early spring, with peaks in April and May (Figure 26). During the winter juveniles were caught mostly in the tributaries but were distributed throughout the lower Chesapeake Bay in the spring (Figure 27). In the summer a few juveniles were found at the mouth of the Bay, and in the fall they were found in the mainstem of the Bay. Adults were only caught in the trawl survey during the winter (Figure 26 and Figure 28). Of the 9,321 herring captured during the beach seine surveys, over 86% came from a single sample in May 1996 (Geer 2002). They were found at the Bay mouth or along the Atlantic coast beaches (Figure 29).

HABITAT CHARACTERISTICS

Information on the habitat characteristics of Atlantic herring are presented here and summarized in Table 6 and Table 7.

EGGS

Atlantic herring eggs are spawned on the bottom in discrete beds in coastal and offshore waters of the Gulf of Maine, Georges Bank, and Nantucket Shoals. Depths reported during *in situ* egg bed surveys ranged from 5 m at Grand Manan Island to 73 m at a spawning site in eastern Maine (Table 6). Eggs have been reported on Jeffreys Ledge between depths of 53 and 59 m. Pre-spawning aggregations of adult herring have been observed on the northern edge of Georges Bank in depths of 50-100 m (Pankratov and Sigajev 1973). Munroe (2002) reported the maximum spawning depth in the Gulf of Maine region to be about 90 m.

Eggs have been observed on a variety of substrates that include rocks (ranging from pebbles to boulders), gravel, shell fragments, sand, and benthic macroalgae and epifauna attached to hard substrates (Table 6). Spawning sites have also been located by interviewing lobster fishermen who have seen eggs attached to their traps (Stevenson 1989). Gravel and shell fragments have been identified as the preferred substrate for herring eggs in nearshore spawning areas in eastern Maine, gravel and rocks with an attached red alga on Jeffreys Ledge, and gravel on Georges Bank. Fine sand and mud are not good substrates for herring eggs and often define the edges of egg beds. Fine sediments do not provide a stable substrate for attached eggs (Drapeau 1973) and are not characteristic of relatively shallow, tidally-energetic benthic habitats where herring spawn (Iles and Sinclair 1982). Egg beds on the northern edge of eastern Georges Bank surveyed by U.S. and Soviet scientists between 1964 and 1970 were all located in elongated ridges of gravel at depths of 40-50 m between gravelly sand and large sand ridges 10-20 m in height (Valentine and Lough 1991).

In the Gulf of Maine region, herring eggs have been observed as individual eggs, clumps, or patches and in cohesive mats up to 5 cm thick (Table 6). In some cases egg beds are quite uniform in thickness and in others they vary considerably, from several centimeters deep to individual eggs at the edges of the egg bed (Table 6). Egg mortality is directly related to current speed and the amount of oxygen that is available to eggs in the lower layers. Stevenson and Knowles (1988) observed that eggs throughout an egg mass 3 cm thick developed at the same rate and that in most samples collected from the egg mat, less than 1% of the eggs were dead (egg mortality was less than 5% in all samples). In contrast, Cooper *et al*. (1975) observed 50-70% egg mortality in the lower portion of an egg mat 4-5 cm thick.

The sizes of egg beds that have been surveyed in the Gulf of Maine and on Georges Bank have varied from 0.07-1.39 km^2 (Table 6). Egg beds on the eastern Maine coast are typically longer than they are wide, following depth contours that parallel the shoreline (Figure 7). Egg beds that were surveyed on offshore banks (Georges Bank and Trinity Ledge) were more irregular in shape (McKenzie 1964; Pankratov and Sigajev 1973). Eggs on Georges Bank, Trinity Ledge, and eastern Maine were all deposited in fairly flat or gradually sloping bottom areas. Eggs at one site on Jeffreys Ledge were found on top of an underwater "hill" and down a 20-40 degree rocky slope to talus material at the base of the hill and beyond (Cooper *et al*. 1975).

Herring spawning sites are characterized by strong bottom currents. Tidal currents up to two knots in velocity have been measured during egg bed surveys in the Gulf of Maine and on Georges Bank (Table 6). Strong currents prevent siltation (which would impede egg adherence to the substrate and smother eggs), supply oxygen to the developing eggs, and remove metabolites (Drapeau 1973).

Bottom temperatures measured during herring egg bed surveys in the Gulf of Maine region have ranged from a low of 7°C to a high of 15°C (Table 6). The temperature range for normal egg development and survival is not known with certainty. Bigelow and Schroeder (1953) reported that temperatures above 20°C and below 5°C were lethal, but experiments in Europe have shown that egg development was normal between 1°C and 22°C, with mortality at –0.8°C (Blaxter and Holliday 1963). Slightly lower minimum temperatures have ranged from –1.2 to 0°C for herring stocks off northern Europe (Kelly and Moring 1986).

Atlantic herring in the Gulf of Maine spawn in fully saline seawater (32-33 ppt) (Munroe 2002). However, laboratory experiments show that fertilization, egg development, and hatching can succeed in salinities of 5.9-52.5 ppt, with maximum fertilization at 25 ppt or more and maximum hatching success at 20-35 ppt (Holliday and Blaxter 1960). Hatching success is low at dissolved oxygen concentrations below 20% saturation (Bishai 1960). Eggs covered with 1 cm of sediment do not survive (100% mortality) while a thin film of sediment causes 85% mortality, but there was no effect of suspended sediments at any concentration up to 7,000 mg/l on hatching success (Messieh *et al*. 1981). Eggs incubated in 30 micrograms/l copper during incubation had relatively high mortality rates and premature hatching, with 70% of the larvae being deformed (Blaxter 1977).

LARVAE

Once the yolk-sac is absorbed (within a few days after hatching), herring larvae are pelagic and begin to feed on planktonic organisms. They are transported away from spawning areas and overwinter in inshore bays and estuaries, or in offshore coastal waters, for 4-8 months before metamorphosing to juveniles in the spring. Herring larvae are tolerant of wide ranges of

temperature and salinity, and low oxygen concentrations. In laboratory experiments, upper and lower temperature tolerances of newly hatched herring larvae were 22-24°C and –0.75 to –1.8°C (Blaxter and Holliday 1963). Larvae tolerated salinities of 1.4-60 ppt for 24 hours and 2.5-52.5 ppt for 7 days (Blaxter and Holliday 1963; Blaxter and Hunter 1982). De Silva and Tytler (1973) reported 50% mortality of larvae exposed to oxygen concentrations of 1.9-3.6 mg/l at 10°C after 96 hours. Eggs and larvae held under films of crude oil in concentrations of 1 ml or 20 ml/l or in emulsions experienced toxicities that varied with the origin of the oil (Kühnhold 1969, as cited in Blaxter and Hunter 1982). Fractions with lower boiling points seemed more harmful. Larvae swim into oil dispersants and are narcotized (Wilson 1974). High mortality of newly hatched larvae has been observed at copper concentrations of 1,000 micrograms/l; larvae were more resistant than eggs (Blaxter 1977).

In the NEFSC MARMAP survey, most larvae were collected at 8-14°C from September to November; maximum abundance was at 9-12°C (Figure 30). In December, larvae occurred at 6-11°C with the majority collected at 8-9°C. Temperatures at the time of collection decreased each month from January to March and increased from April to August. Larvae were collected at stations with bottom depths ranging from 10-250 m, although most were collected at stations with depths of 50-90 m.

JUVENILES

Laboratory experiments have shown that juvenile herring tolerate higher and lower temperatures than adults. The preferred temperature range for juveniles is 8-12°C and physiological stress has been observed at temperatures below 4°C and above 16°C (Stickney 1969). Brawn (1960b) reported that 50% of juvenile herring exposed to temperatures between 19.5 and 21.2°C died within 48 hours and that they survived at temperatures as low as -1.1°C. The blood of Atlantic herring contains antifreeze proteins (AFP) which allows them to survive in icy seawater. Plasma-freezing points are significantly lower and AFP activity significantly higher in juveniles than in adults (Chadwick *et al.* 1990).

Salinity is probably not as important a factor as temperature in affecting the distribution and movements of Atlantic herring (Munroe 2002). There is a tendency for herring to prefer higher salinities and to avoid brackish conditions with increasing age. Laboratory studies indicate that juveniles prefer salinities of 28-32 ppt (Stickney 1969), and can tolerate salinities as low as 5 ppt for brief periods of time (Brawn 1960c). Their salinity preference is temperature dependent. Stickney (1969) reported that juveniles preferred salinities above 29 ppt at temperatures below 10°C, but there was no salinity preference at temperatures above 10°C. Juveniles occupy inshore coves and estuaries with low salinities in the spring and summer of their first year of growth (Townsend 1992), whereas older juveniles avoid brackish estuarine conditions (Recksieck and McCleave 1973).

The spring and fall distributions of juvenile Atlantic herring relative to bottom water temperature, depth, and salinity based on NEFSC bottom trawl surveys from the Gulf of Maine to Cape Hatteras are shown in Figure 31. In the spring, juveniles were found between 2-12°C, with most between 3-7°C. During autumn, they were found between 5-17°C, with the majority between 6-10°C. They occurred on the outer continental shelf to a maximum depth of 300 m in the spring and fall. In the spring, the majority were found in depths < 100 m. They were caught in a salinity range of 30-35 ppt in the spring and 32-35 ppt in the autumn, with the majority found at 32-33 ppt during spring and 33-34 ppt in the autumn.

The spring and autumn distributions of juvenile Atlantic herring in Massachusetts coastal waters relative to bottom water temperature and depth based on 1978-2003 Massachusetts inshore trawl surveys are shown in Figure 32. Juveniles were collected at temperatures ranging from 1-16°C during the spring and 4-21°C during the autumn. Catch rates were high at 11°C in the spring and at 8°C in the fall. In the spring, they were found over depths ranging from 6-85 m, with higher catches between 11-20 m. During autumn they were found from 1-85 m, with a very high catch at 21-25 m.

In the Narragansett Bay bottom trawl survey, most juveniles were caught at 17-21°C in the summer, and 10-11°C and 18-20°C in the fall, 2-6°C in the winter, and 10 and 12°C in the spring (Figure 33). Most were caught between depths of 11-40 ft (3-12 m) in the spring, summer, and fall surveys. Catch rates were high at bottom depths of 91-100 ft (27-30 m) in all seasons and also at 51-60 ft (15-18 m) in spring.

The distributions and abundances of both juvenile and adult Atlantic herring in Long Island Sound relative to depth and bottom type were discussed previously under Geographic Distribution: Juveniles and Adults (Figure 22; Gottschall *et al.* [2000]).

In the Hudson-Raritan estuary, most juvenile herring were caught during winter, spring, and summer bottom trawl surveys at 3-5°C and 14-21°C, but they were most abundant at 15-18°C (Figure 34). Most were caught between 15 ft and 55 ft (4-16 m), dissolved oxygen (DO) concentrations of 6-12 mg/l, and salinities of 21-31 ppt. Catch rates were highest in depths of 30-55 ft (9-16 m), DO levels of 10 and 11 mg/l, and salinities of 21, 26, 27 and 31 ppt. Most juveniles were caught in the winter and spring surveys, with some in the summer and very few in the fall (Figure 34).

The hydrographic preferences of juvenile Atlantic herring in Chesapeake Bay from the 1988-1999 VIMS

trawl surveys are shown in Figure 35 (all years and months combined). Geer (2002) states that the juveniles are found primarily at temperatures between 10-16°C and at salinities > 14 ppt. It appears they prefer dissolved oxygen levels of 9 mg/l and depths of < 10 m (Figure 35).

ADULTS

Like juvenile herring, adults utilize pelagic habitats, only using the bottom for spawning. Observations of seasonal distribution on Georges Bank suggested a preferred temperature range of 5-9°C (Zinkevich 1967). Adults regularly enter bays and estuaries, but are rarely found in low salinities (Hildebrand 1963; Munroe 2002). Bigelow and Schroeder (1953) reported that the lower limit of salinity for adult Atlantic herring in the Gulf of Maine was probably 28 ppt.

Factors which may affect herring distribution include currents and frontal zones (Sutcliffe *et al*. 1977; Sinclair and Iles 1985). Jakobsson (1980) reported that the densest concentrations of herring in Icelandic waters were in waters just at or just inside the edge of the continental shelf in boundary areas of warm and cold water masses. Depth, substrate type, and zooplankton abundance were significant factors affecting the presence and relative abundance of adult herring in the northern North Sea in 1992, 1994, and 1995 (Maravelias 1999). Herring were more abundant in depths < 150 m, on plankton "patches" or on their edges, and on gravel-sand seabeds where they spawned 1-2 months later. These relationships were stable over time, despite a substantial reduction in stock size (Maravelias *et al*. 2000b). Further analysis showed that there were more herring in areas where sea surface temperatures were between 11°C and 14°C, the thermocline was 25-45 m deep, and the difference between surface and bottom waters was only 3°C (Maravelias *et al*. 2000a). In more stratified waters (with colder bottom water), herring abundance decreased. This research supports the hypothesis that well-mixed waters and transition zones between well-mixed and stratified waters are preferred habitats for adult herring. Furthermore, as stock size decreased, herring aggregated in fewer, more distinct regions with these habitat characteristics. Schools were also found preferentially over areas of hard substrate and there was a strong relationship with particular topographic features within the survey area; i.e., a low ridge and two escarpments (Reid and Maravelias 2001).

Fronts created by currents and eddies act as distribution boundaries for herring through their direct effects on the fish themselves, and also indirectly by aggregating planktonic food organisms and increasing the production of zooplankton. Mixing, such as occurs in the frontal zones at the edge of the continental shelf or as a result of increased current flow and turbulence on the edges of offshore banks causes elevated nutrient levels, increased primary production, and increased zooplankton abundance.

The spring and fall distributions of adult Atlantic herring relative to bottom water temperature, depth, and salinity based on NEFSC bottom trawl surveys from the Gulf of Maine to Cape Hatteras are shown in Figure 36. In the spring, adults were found between 2-13°C, with most between 4-7°C. During autumn, they were found between 4-16°C, with the majority between 6-10°C. They occurred on the outer continental shelf to a maximum depth of 300 m in the spring and the fall. In the fall, most were found > 80 m, while in the spring, the majority were found at shallower depths. They were caught in a salinity range of 27-35 ppt in the spring and 32-35 ppt in the autumn, with the majority found at 33 ppt during spring and 33-34 in the autumn.

The spring and autumn distributions of adult Atlantic herring in Massachusetts coastal waters relative to bottom water temperature and depth based on Massachusetts inshore trawl surveys are shown in Figure 37. Adults were collected at temperatures ranging from 2-13°C during the spring and 4-14°C during the autumn. Most were found at 4-5°C in the spring and at 6-10°C in the fall; the catch was high at 7°C in the fall. In the spring, they were found over depths ranging from 6-85 m, with higher catches between 46-50 m and 76-80 m. During autumn they were found from 21-85 m, with most at depths > 50 m.

In Narragansett Bay during the winter, most adults were caught in bottom temperatures of 3-7°C and depths of 20, 40-60, and 100 ft (6-30 m), while in the spring, most were caught at 3-5°C and 7-11°C and depths of 20-40, 70 and 100 ft in the spring (Figure 38). High catch rates occurred at 6°C in winter and 4-5°C in spring and at 100 ft at both times of year. In the fall, high catches occurred at 12°C and at 30 ft. Most adults were caught in the winter and spring surveys: none were caught in the summer.

In the Hudson-Raritan estuary, most adults were caught at bottom temperatures of 2-6°C, depths of 15-45 ft (4-14 m), dissolved oxygen (DO) concentrations of 9-12 mg/l, and salinities of 24-33 ppt. Catches were highest at 3-6°C, depths of 15-25 ft (10-14 m), DO levels of 11 mg/l, and salinities of 24-25 and 28-31 ppt. Most adults were caught in the winter (Figure 39).

The hydrographic preferences of the few adult Atlantic herring caught in Chesapeake Bay during the 1988-1999 VIMS trawl surveys are shown in Figure 40 (all years and months combined). Adults were found in only during the winter at greater depths and colder waters than the juveniles (Geer 2002). They preferred dissolved oxygen levels of 11 mg/l and salinities > 14 ppt.

RESEARCH NEEDS

The following research needs are based in part on a summary provided by Tupper *et al*. 1998.

Discrete populations/metapopulations within the Atlantic coastal stock complex need to be identified. This would involve identifying the major and minor spawning components within the Gulf of Maine – Georges Bank region and the degree to which they intermix at different times of year. Research methods that should be considered include the examination of environmentally-induced traits (scales, otoliths, and possibly morphometrics), and tagging studies. Tagging studies could be conducted in conjunction with other surveys (*e.g.*, acoustic surveys during the summer and fall spawning seasons). Modern genetic techniques (*e.g.*, cDNA fingerprinting) and physiological performance indices might be useful for stock differentiation purposes and should be evaluated. Pertinent questions that should be addressed include:

- During the winter, what is the degree of mixing among adults that spawn on Georges Bank, Nantucket Shoals, and in the Gulf of Maine and migrate to southern New England and the mid-Atlantic region?

- During the summer and fall, what is the degree of mixing between adults that spawn in different locations?

Given the concerns that have been expressed regarding the status of the Gulf of Maine spawning stock (see Status of The Stocks), stock assessment surveys or analyses that would indicate trends in population size in the Gulf of Maine are badly needed. Procedures used to estimate population size or resource status for the different components of the coastal stock complex are complicated by the fact that adults from each spawning group mix to an unknown degree in different geographical areas and at different times of year. A large-scale larval herring survey, conducted repeatedly (*e.g.*, at two-week intervals) throughout the spawning season on all known spawning grounds, would provide useful information for comparing the relative intensity of spawning by the different components of the resource and for evaluating to what extent larval production (and spawning stock size) on Georges Bank, Nantucket Shoals, and the southwest Gulf of Maine has changed since the last large-scale larval herring survey was done in these areas in 1990.

Existing surveys of pre-spawning aggregations of adult herring should be continued: currently, acoustic surveys are conducted in the Gulf of Maine and on the northern edge of Georges Bank (See Overholtz *et al.* 2004). New technologies, such as multi-beam acoustic equipment, towed-array video, and laser illumination, could provide surveying tools. The applicability of alternative assessment models that have been used with other pelagic resource species (*e.g.*, surplus production, multi-species virtual population analyses, ecosystem-level models such as ECOSIM and ECOPATH) should be evaluated. The natural mortality rate that is routinely applied in stock assessment models (18% a year) needs to be validated and the degree to which it varies for different age groups of herring, and in response to annual changes in the population abundance of herring, herring predators, and other prey species, should be determined. Also, stock assessment information could possibly be improved by developing a direct method for estimating annual changes in the abundance of juvenile herring that recruit to exploited stocks.

More information is needed concerning the physical characteristics of benthic herring egg habitats and their vulnerability to disturbance by mobile, bottom-tending fishing gear, by natural disturbance, and, especially in nearshore spawning areas, to other habitat impacts related to human activities that are not associated with fishing.

In the pelagic realm, more information is needed regarding oceanographic features that affect the abundance and distribution of larval, juvenile, and adult herring. Research in the northern North Sea (see Habitat Characteristics: Adults) has demonstrated that the abundance of pre-spawning adults is higher in oceanographic fronts between well-mixed and stratified water masses (such as exist along the edges of offshore banks) where the abundance of their zooplanktonic food supply is high. Given the relatively large amount of information that is available for this species, its importance as a prey species, and the fact that the juveniles and adults are amenable to acoustic survey procedures, the Atlantic herring is an excellent subject for pelagic habitat research. Most pelagic fisheries-related research in the Gulf of Maine region has been directed at factors affecting the distribution, growth, and survival of larvae, but not juvenile and adult fish.

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Table 1. Relative abundance of Atlantic herring life stages in New England and Mid-Atlantic estuaries and embayments by salinity zone.

	Eggs			Larvae			Juveniles		
	T	**M**	**S**	**T**	**M**	**S**	**T**	**M**	**S**
Passamaquoddy Bay					C	A		A	H
Englishman/Machias Bays			C		A	H		C	H
Narraguagus Bay					A	H		C	H
Blue Hill Bay					A	H		C	H
Penobscot Bay					H	H		C	H
Muscongus Bay					A	H		A	A
Damariscotta River				A	H		C	A	
Sheepscot River				A	H		C	A	
Kennebec/Androscoggin Rivers				C	C		C	C	
Casco Bay			R		A	A		C	A
Saco Bay					C	A		C	A
Wells Harbor	•			•	C	A	•	A	H
Great Bay					C	C		C	C
Merrimack River		•		C	•		C	•	
Massachusetts Bay	•	•		•	•	A	•	•	A
Boston Harbor	•			•	R	A	•	C	A
Cape Cod Bay	•		R	•		C	•	C	A
Waquoit Bay						R		R	R
Buzzards Bay						R		C	C
Narragansett Bay						C		C	C
Long Island Sound					R	R		C	C
Connecticut River			•			•		R	•
Gardiners Bay	•			•			•	R	C
Great South Bay, NY	•			•			•		C
Hudson River/Raritan Bay					C	C		C	C
Barnegat Bay, NJ					R	R		C	C
New Jersey Inland Bays					R	R		C	C
Delaware Bay					R	R		C	C
Delaware Inland Bays	•			•			•		R
Chincoteague Bay	•	•		•	•		•	•	R
Chesapeake Bay Mainstem									R
Chester River			•			•			•
Choptank River			•			•			•
Patuxent River			•			•			•
Potomac River			•			•			•
Tangier/Pocomoke Sound	•		•	•		•	•		•
Rappahannock River			•			•			•
York River, VA			•			•			•
James River, VA			•			•			•

Based on Estuarine Living Marine Resources (ELMR) data in Jury *et al.* (1994) and Stone *et al.* (1994).
Salinity zone: T = tidal fresh, M = mixing zone, S = seawater, • = salinity zone not present.
Relative abundance: H = highly abundant, A = abundant, C = common, R = rare, blank = not present.

Table 1. Cont'd.

	Spawning Adults			Adults		
	T	**M**	**S**	**T**	**M**	**S**
Passamaquoddy Bay					A	H
Englishman/Machias Bays			C		C	H
Narraguagus Bay					C	H
Blue Hill Bay					C	H
Penobscot Bay					C	H
Muscongus Bay					C	A
Damariscotta River					C	A
Sheepscot River					C	A
Kennebec/Androscoggin Rivers					C	C
Casco Bay				R		R
Saco Bay						R
Wells Harbor	•			•	R	C
Great Bay					R	C
Merrimack River			•		R	•
Massachusetts Bay	•	•		•	•	A
Boston Harbor	•			•	C	A
Cape Cod Bay	•		R	•	C	A
Waquoit Bay	•			•		R
Buzzards Bay	•			•	C	C
Narragansett Bay					C	A
Long Island Sound					C	A
Connecticut River			•		R	•
Gardiners Bay	•			•	R	C
Great South Bay, NY	•			•		A
Hudson River/Raritan Bay					C	C
Barnegat Bay, NJ					C	C
New Jersey Inland Bays					C	C
Delaware Bay					R	C
Delaware Inland Bays	•			•		R
Chincoteague Bay	•	•		•	•	
Chesapeake Bay Mainstem					R	C
Chester River			•			•
Choptank River			•			•
Patuxent River			•			•
Potomac River			•			•
Tangier/Pocomoke Sound	•		•	•		•
Rappahannock River			•		R	•
York River, VA			•		R	•
James River, VA			•		R	•

Salinity zone: T = tidal fresh, M = mixing zone, S = seawater, • = salinity zone not present. Relative abundance: H = highly abundant, A = abundant, C = common, R = rare, blank = not present.

Table 2. Distribution and abundance of juvenile Atlantic herring in New England and Mid-Atlantic estuaries and embayments.

Month: / **Bay/River/Estuary:**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Passamaquoddy Bay	A	A	A	A	H	H	H	H	H	H	A	A
Englishman/Machias Bays	A	A	A	A	H	H	H	H	H	A	A	A
Narraguagus Bay	A	A	A	A	H	H	H	H	H	A	A	A
Blue Hill Bay	A	A	A	A	H	H	H	H	H	A	A	A
Penobscot Bay	C	C	C	A	H	H	H	H	H	H	A	C
Muscongus Bay				R	A	A	A	A	A	A	C	R
Damariscotta River				R	A	A	A	A	C	C	C	R
Sheepscot River				R	A	A	A	A	C	C	C	R
Kennebec/Androscoggin Rivers				R	C	C	C	C	C	C	C	R
Casco Bay				R	A	A	A	A	A	C	C	R
Saco Bay				R	A	A	A	A	A	C	C	R
Wells Harbor				C	H	H	H	H	H	A	A	R
Great Bay				C	C	C	C	C	C	C	C	R
Merrimack River				R	C	C	C	C	C	C	C	
Massachusetts Bay	A	A	A	A	A	C	C	C	A	A	A	A
Boston Harbor	A	A	A	A	A	C	C	C	A	A	A	A
Cape Cod Bay	A	A	A	A	A	C	C	C	C	A	A	A
Buzzards Bay	C	C	C	C	C	R	R	R	R	C	C	C
Narragansett Bay	C	C	C	C	C	C	C	C	C	C	C	C
Long Island Sound	C	C	C	C	C	C	C	C	C	C	C	C
Gardiners Bay	R	R	R	R	C	C	C	C	R	R	R	R
Great South Bay	R	R	C	C	C	C	R	R	R	R	C	C
Hudson River/ Raritan Bay	C	C	C	C	C	R	R	R	R	R	R	R
Barnegat Bay	R	R	R	C	C	C	R	R	R	R	R	R
New Jersey Inland Bays	R	R	R	C	C	C	R	R	R	R	R	R
Delaware Bay				C	C	R	R	R	R	R		
Chincoteague Bay			R	R	R							
Chesapeake Bay			R	R	R							

Based on Estuarine Living Marine Resources (ELMR) data in Jury *et al.* (1994) and Stone *et al.* (1994). Relative abundance: H = highly abundant, A = abundant, C = common, R = rare, blank = not present.

Table 3. Distribution and abundance of adult Atlantic herring in New England and Mid-Atlantic estuaries and embayments.

Month:	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Bay/River/Estuary:												
Passamaquoddy Bay	A	A	A	A	H	H	H	H	H	H	A	A
Englishman/Machias Bays	C	C	C	A	H	H	H	H	H	A	A	C
Narraguagus Bay	C	C	C	A	H	H	H	H	H	A	A	C
Blue Hill Bay	C	C	C	A	H	H	H	H	H	A	A	C
Penobscot Bay	C	C	C	A	H	H	H	H	H	H	A	C
Muscongus Bay				R	C	C	C	C	A	A	C	R
Damariscotta River				R	C	C	C	C	A	A	C	R
Sheepscot River				R	C	C	C	C	A	A	C	R
Kennebec/Androscoggin Rivers				R	C	C	C	C	C	C	C	R
Casco Bay				R	C	C	C	C	C	C	C	R
Saco Bay				R	C	C	C	C	C	C	C	R
Wells Harbor				R	C	C	C	C	C	C	C	R
Great Bay				R	R	R	R	R	C	C	C	R
Merrimack River					R	R	R	R	R	R	R	
Massachusetts Bay	A	A	A	A	C	R	R	R	C	C	A	A
Boston Harbor	A	A	A	A	A	R	R	R	C	C	C	A
Cape Cod Bay	A	A	A	A	C	R	R	R	C	C	A	A
Buzzards Bay	C	C	C	C	C	R	R	R	R	C	C	C
Narragansett Bay	A	A	A	A	C	C	C	C	C	C	C	C
Long Island Sound	A	A	A	A	A	C	C	C	C	C	A	A
Gardiners Bay	R	R	R	R	C	C	C	C	R	R	R	R
Great South Bay	A	A	C	R	R	R	R	R	R	R	A	A
Hudson River/ Raritan Bay	C	C	C	C	C	R	R	R	R	R	R	R
Barnegat Bay	C	R									C	C
New Jersey Inland Bays	C	R	R	R	R	R	R	R	R	R	C	C
Delaware Bay	C	R	R	R	R	R	R	R	R	R	C	C

Based on Estuarine Living Marine Resources (ELMR) data in Jury et al. (1994) and Stone et al. (1994). Relative abundance: H = highly abundant, A = abundant, C = common, R = rare, blank = not present.

Table 4. Percentage of Atlantic herring in the diets of 15 predators in the northeast U.S. Atlantic coast ecosystem.

Predator species	Size (cm)	Percent herring in diet		Years	Location	Number stomachs examined	Taxon			Source
		By wt	By vol				*C. harengus*	Herrings	Clupeidae	
Atlantic cod	51-120+	15		1973-1975	NE shelf	8,176 over entire time period		✓		Link and Garrison (2002)
		17		1976-1980				✓		
		2		1981-1985				✓		
		11		1986-1990				✓		
		25		1991-1998				✓		
	61-70	4.4		1977-1980		86			✓	Bowman *et al*. (2000)
	71-80	9.7				52			✓	
	81-90	6.5				91			✓	
Silver hake	< 20		4	1973-1997	NE shelf	8,722	✓		✓	Garrison and Link (2000)
	20-50		9			26,070	✓		✓	
	> 50		25			1,037	✓		✓	
	26-30	4.0		1977-1980		323	✓		✓	Bowman *et al*. (2000)
	31-35	11.1				373	✓			
	41-45	20.5				72	✓		✓	
	> 45	23.3				75	✓		✓	
Summer flounder	41-45	5.5		1977-1980	NE shelf	80			✓	Bowman *et al*. (2000)
	56-60	13.4				44			✓	
	Mean = 36	8		1990-2000		na		✓		Link *et al*. (2002b)
Atlantic halibut	41-50	11.1		1977-1980	NE shelf	26			✓	Bowman *et al*. (2000)
	Mean = 58	4		1973-1998		155		✓		Link *et al*. (2002b)
Spiny dogfish	51-60	2.5		1977-1980	NE shelf	235			✓	Bowman *et al*. (2000)
	61-70	1.6				207			✓	
	71-80	8.3				697	✓		✓	
	81-90	0.3				368			✓	
	91-100	1.3				423	✓			
White hake	20-50+		20	1991-1997	NE shelf	na	✓		✓	Garrison and Link (2000)
	20-50		2	1973-1997		5,341	✓		✓	
	> 50		13			6,049	✓		✓	
Red hake	> 50		2	1973-1997		1,713			✓	
Bluefin tuna	Mean = 221	87.2		1988-1992	Jeffreys Ledge	147	✓			Chase (2002)
	Mean = 221	48.4			Great South Channel	210	✓			
	Mean = 240	6			Stellwagen Bank	111	✓			
	Mean = 251	3.1			Cape Cod Bay	273	✓			
	Mean = 124	2.5			South of Martha's Vineyard	57	✓			
Bluefish	"Adults"	11.3		1994	Georges Bank	50	✓			Buckel *et al*. (1999)
		17.6		1995		44	✓			
	21-30	2.7		1977-1980	NE shelf	239			✓	Bowman *et al*. (2000)
	31-40	2.3				71	✓			
Striped bass	30-120	3.4		1997-2000	North shore MA	1,536	✓			Nelson *et al*. (2003)
	25-120	0.2			Cape Cod Bay	1,019	✓			
	30-120	0			Nantucket Sound	451	✓			
Dusky shark	91-100	1.5		1977-1980	NE shelf	18			✓	Bowman *et al*. (2000)
Thorny skate	61-70	36.5		1977-1980	NE shelf	36	✓			
	71-80	25.5				42	✓			
	> 90	20.8				18	✓			
Goosefish	51-60	1.9		1977-1980	NE shelf	104			✓	Bowman *et al*. (2000)
	81-90	1.2				86			✓	
	> 90	15.0				103	✓		✓	
Black sea bass	21-25	2.3		1977-1980	NE shelf	188	✓			Bowman *et al*. (2000)
Weakfish	21-30	11.2		1977-1980	NE shelf	196			✓	Bowman *et al*. (2000)

Table 5. Annual consumption (metric tons) of Atlantic herring by various predators.

Fish and Elasmobranch Predators		Marine Mammal Predators	
Species	Estimated Annual Consumption, 1977-1997	Species	Estimated Annual Consumption, 1991-1997
Spiny Dogfish	36,000-214,000	Fin Whale	16,081-62,362
Silver Hake	11,500-36,000	Minke Whale	11,648-22,108
Georges Bank Cod	1,900-13,000	Humpback Whale	31,046-35,507
White Hake	500-20,000	Pilot Whale	149-512
Bluefish	500-13,600	Harbor Porpoise	20,863-27,655
Fluke	200-3,100	White-sided Dolphin	7,852-35,591
Pollock	200-3,100	Harbor Seal	4,853
Red Hake	200-3,100	Gray Seal	1,310
Goosefish	200-3,100		
Winter Skate	200-3,100		
Gulf of Maine Cod	200-3,100		
	Estimated Annual Consumption, 1977-1998		
Spiny Dogfish	15,526-148,197 (mean = 67,660)		
Winter Skate	20-2,329 (mean = 928)		

Sources: Overholtz *et al*. (2000) (finfish and elasmobranchs, 1977-1997); Link *et al*. (2002a) (finfish and elasmobranchs, 1977-1998); Read and Brownstein (2003) (marine mammals).

Table 6. Atlantic herring spawning site survey data and habitat parameters.

Authors	**Observation or sampling method**	**Location**	**Date of survey**	**Size of egg beds (km^2)**	**Depth (m)**
McKenzie (1964)	Biological dredge	Trinity Ledge, southwest Nova Scotia	Sept 1961	.067	11-13
Caddy and Iles (1973)	Submersible	Northern edge of eastern Georges Bank	Sept/Oct 1970	1.1 [a] 0.53 [a] 0.3 [a]	50
Boyar *et al*. (1973)	Dredge	Jeffreys Ledge	Oct 1972		53-59
Cooper *et al*. (1975)	SCUBA divers, grab samples	Jeffreys Ledge	Oct 1974	0.78 1.39	35-55
Stevenson and Knowles (1988)	ROV, grab samples, and SCUBA	Eastern Maine	Sept 1985, 1986	0.8	20-50
Neal and Brehme (2001); Neal (2003)	Small benthic sampler	Eastern Maine	1997-2002		28-73
Neal and Brehme (2001)	Small benthic sampler	Grand Manan	Sept 2000		5-12
P. Valentine, U.S. Geological Survey, Woods Hole Field Center, 384 Woods Hole Road, Quissett Campus, Woods Hole, MA 02543, pers. comm.	Underwater video, grab sample	Stellwagen Bank	Oct 1996		34

[a] Egg bed sizes reported by Pankratov and Sigajev (1973).
[b] Temperatures reported by Graham and Chenoweth (1973).

Table 6. Cont'd.

Authors	**Substrate**	**Bottom temp. (°C)**	**Bottom current (knots)**	**Other**
McKenzie (1964)	Flat, sandy bottom with few small stones, no vegetation; eggs also attached to an alga (*Desmarestia aculeata*) in a nearby site that was not surveyed.	11.3-12	1.5-2	Egg mat 3.25 cm thick at deepest point, tapering to individual eggs spaced 2-6 mm apart; herring eggs in haddock stomachs.
Caddy and Iles (1973)[a]	Pebbles 2-10 mm in diameter, boulders embedded in gravel, and on epifaunal growth; eggs thin or absent on sand.	13-15[b]	1-2	Eggs 1-2 cm thick in discrete bed. Predators (red hake, sculpin, dogfish, skate, hermit crabs, starfish, moon snails) left steep sided craters in egg layer – 8% eggs removed by predators.
Boyar *et al*. (1973)	Boulders, rocks, and gravel	7-8.5		Eggs collected in clumps, layers up to 5 mm thick.
Cooper *et al*. (1975)	80-90% eggs in *Ptiloda serrata* attached to rocks, few on non-algal covered rock surfaces at one site. At another, bedrock, boulder, rock, gravel, shell, 10% *Ptiloda* on bedrock. 90% eggs on rock-gravel. Deeper than 55 m, fine sand, no eggs.	9.5	0-1	Cunner most abundant predator observed feeding on eggs; red alga (*Ptiloda*) and eggs in cod stomachs. Hatching success > 99% at one site where egg cover was sparse. 50-70% egg mortality at bottom of 4-5 cm thick egg mass.
Stevenson and Knowles (1988)	Egg cover thickest on gravel and shell fragments, very few or no eggs on rocks or fine sand/shells at edges of egg beds.			Eggs at two sites in continuous "carpet" 1-3 cm thick, in clumps and patches at two other sites. Egg mortality negligible, no signs of predation, egg development uniform throughout egg mass.
Neal and Brehme (2001); Neal (2003)	Egg mats predominantly on gravel, eggs also observed on shell fragments and rocks			
P. Valentine, pers. comm.	Coarse sand			

Table 7. Summary of habitat characteristics and requirements for Atlantic herring in the northwest Atlantic continental shelf ecosystem.

Eggs

Habitat	Discrete, demersal, egg "beds" in coastal waters and on offshore banks and ledges in the Gulf of Maine and on Georges Bank with strong bottom currents and coarse substrate.
Depth	5-90 m.
Substrate	Boulders, rocks, gravel, coarse sand, shell fragments, macrophytes, and on a variety of benthic organisms and man-made structures (e.g., lobster traps); not on mud or fine sand.
Temperature	Bottom temperatures over egg beds ranged from 7-15ºC; egg development normal 1-22ºC; development rates/incubation times inversely related to temperature (10-15 days at 8-13ºC).
Salinity	32-33 ppt in situ, maximum hatching success 20-35 ppt (lab studies).
Other	Low hatching success at dissolved oxygen concentrations < 20% saturation; 100% mortality of eggs under 1 cm of sediment, 85% mortality under thin film of sediment.
Predators	Cod, haddock, cunner, red hake, sand lance, probably moon snails, hermit crabs and starfish.
Prey	Not applicable.

Larvae

Habitat	Pelagic, in estuaries, coastal, and offshore waters between Bay of Fundy and New Jersey; remain on or near bottom for first few days after hatching, until yolk-sac is absorbed, then rise to surface and are dispersed by currents.
Depth	Collected from very shallow water to 200 m, most 50-90 m.
Substrate	Not applicable.
Temperature	Lab study shows larvae tolerate wide temperature range (-1.8 to 24ºC).
Salinity	Lab study shows larvae tolerate wide salinity range (2.5-52.5 ppt for 7 days).
Other	50% mortality in dissolved oxygen concentrations of 1.9-3.6 mg/l at 10ºC after 96 hours; crude oil in concentrations of 1-20 ml/l is toxic; narcotized by oil dispersants (lab studies).
Predators	Sand lance, jellyfish, Atlantic mackerel, Atlantic herring.
Prey	Developmental stages of copepods (7-20 mm larvae, in fall); small adult copepods (21-30 mm, in winter); wide variety of planktonic organisms (> 30 mm, in spring).

Juveniles

Habitat	Pelagic; one-year-olds in nearshore waters during summer and fall, overwinter in deeper, coastal waters; two-year-olds in inshore/offshore continental shelf waters of Gulf of Maine, deeper waters of Georges Bank in summer and fall, Cape Hatteras to deeper parts of Georges Bank in winter, widespread from Cape Hatteras to Bay of Fundy in spring.
Depth	Collected in bottom trawl surveys to edge of continental shelf (300 m), mostly < 100 m in spring; migrate up in water column at dusk and down at dawn.
Substrate	Not applicable.
Temperature	Lab studies show that juveniles prefer 8-12ºC, physiological stress < 4ºC and > 16º C, can survive -1.1ºC, 50% juveniles exposed to 19.5-21.2ºC died within 48 hrs; most caught 3-7ºC in spring and 6-10ºC in fall NEFSC bottom trawl surveys.
Salinity	Lab studies show that juveniles prefer 28-32 ppt, can tolerate as low as 5 ppt for a short time, salinity preference is temperature-dependant (> 29 ppt below 10ºC, no preference > 10ºC); one-year-olds in coves/estuaries with low salinities, two-year-olds avoid brackish water.
Other	Spatial distribution affected by currents, frontal zones, and availability of zooplanktonic food organisms (see adults).
Predators	Heavily preyed upon by a variety of marine fish, marine mammals, and seabirds (see adults).
Prey	Feed on up to 15 types of zooplankton; most common are copepods, decapod larvae, barnacle larvae, cladocerans, and molluscan larvae.

Table 7. Cont'd.

Adults

Habitat	Pelagic, but spawn on bottom; inshore/offshore continental shelf waters of the Gulf of Maine and deeper parts of Georges Bank in summer and fall, Cape Hatteras to deeper parts of Georges Bank in winter, distributed across shelf in mid-Atlantic, southern New England, deeper waters of Georges Bank, and the southwest portion of the Gulf of Maine in spring.
Depth	Collected in bottom trawl surveys to edge of continental shelf (300 m), mostly < 80 m in fall and at shallower depths in spring; diel vertical migrations similar to juveniles; more abundant < 150 m in northern North Sea in summer.
Substrate	Pre-spawning aggregations more abundant over gravel/sand in northern North Sea.
Temperature	Field observations suggest adults prefer 5-9ºC on Georges Bank in summer/fall; most caught 4-7ºC in spring and 6-10ºC in fall NEFSC trawl surveys; adults more abundant in areas of northern North Sea where summer sea surface temperatures are 11-14ºC, thermocline 25-45 m deep, and difference between surface and bottom water temperatures was only 3ºC.
Salinity	Adults most abundant 27-35 ppt in spring NEFSC trawl surveys, 32-34 ppt at other times of year.
Other	Well-mixed (unstratified) waters and transition zones (fronts) between well-mixed and stratified waters are preferred habitats for adults; also more abundant in or on edges of plankton "patches."
Predators	Important forage species in NW Atlantic ecosystem; principal finfish and elasmobranch predators are cod, silver hake, thorny skate, bluefish, monkfish, weakfish, summer flounder, white hake, and spiny dogfish – also, at certain locations and times of year – Atlantic bluefin tuna; principal marine mammal predators are minke whales, harbor porpoise, white-sided dolphins, fin and humpback whales.
Prey	Principal zooplankton prey organisms are euphausiids, amphipods, copepods, chateognaths, pteropods, mysids, and pandalid shrimp; adults also consume fish eggs and larvae (including their own).

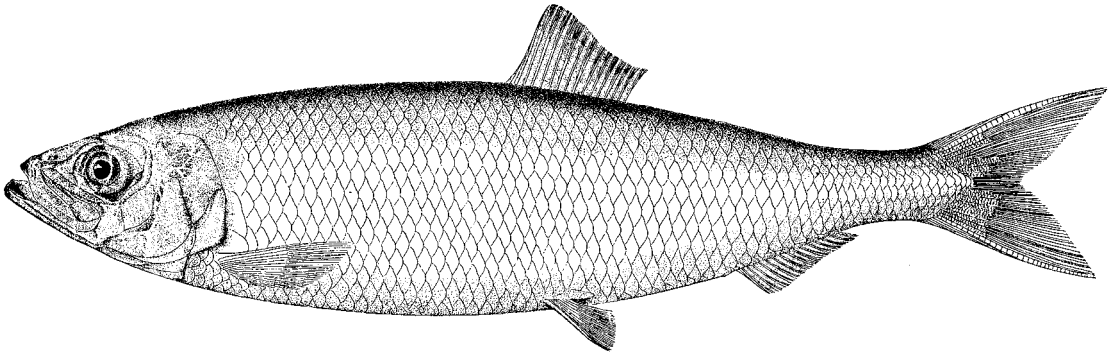

Figure 1. The Atlantic herring, *Clupea harengus* L. (from Goode 1884).

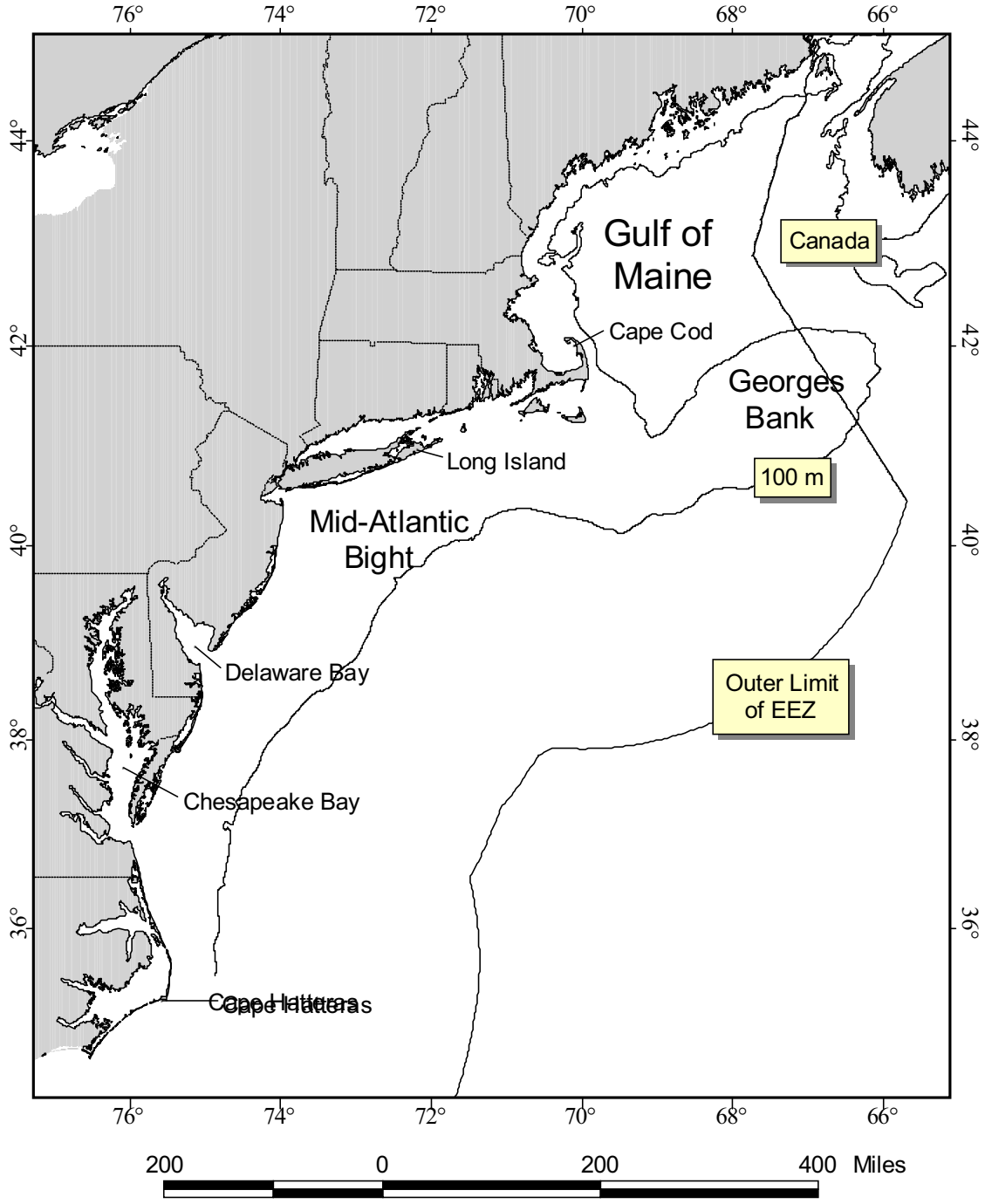

Figure 2. Northeast U.S. Atlantic coast ecosystem.

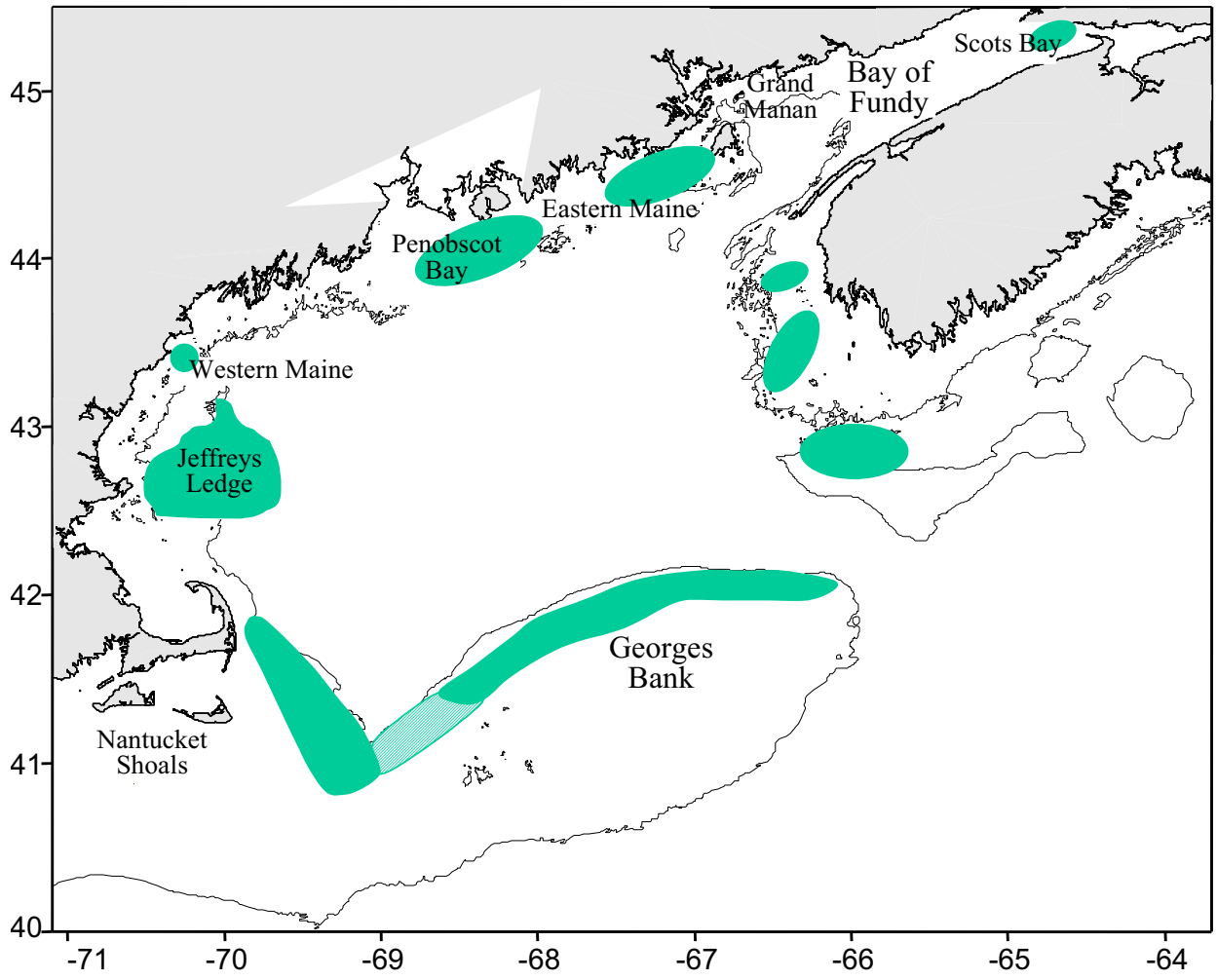

Figure 3. Generalized view of principal Atlantic herring spawning areas in the Gulf of Maine and on Georges Bank. Source: Overholtz *et al.* 2004.

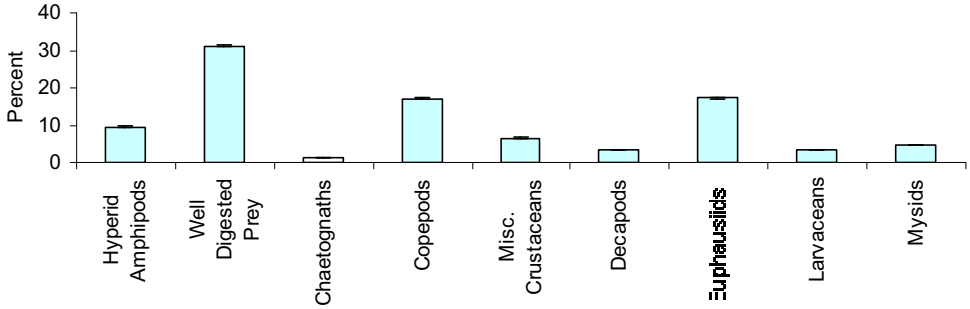

Figure 4. Percent by weight of the major prey items in the diet of Atlantic herring. Specimens were collected during NEFSC bottom trawl surveys from 1973-2001 (all seasons). For details on NEFSC diet analysis, see Link and Almeida (2000).

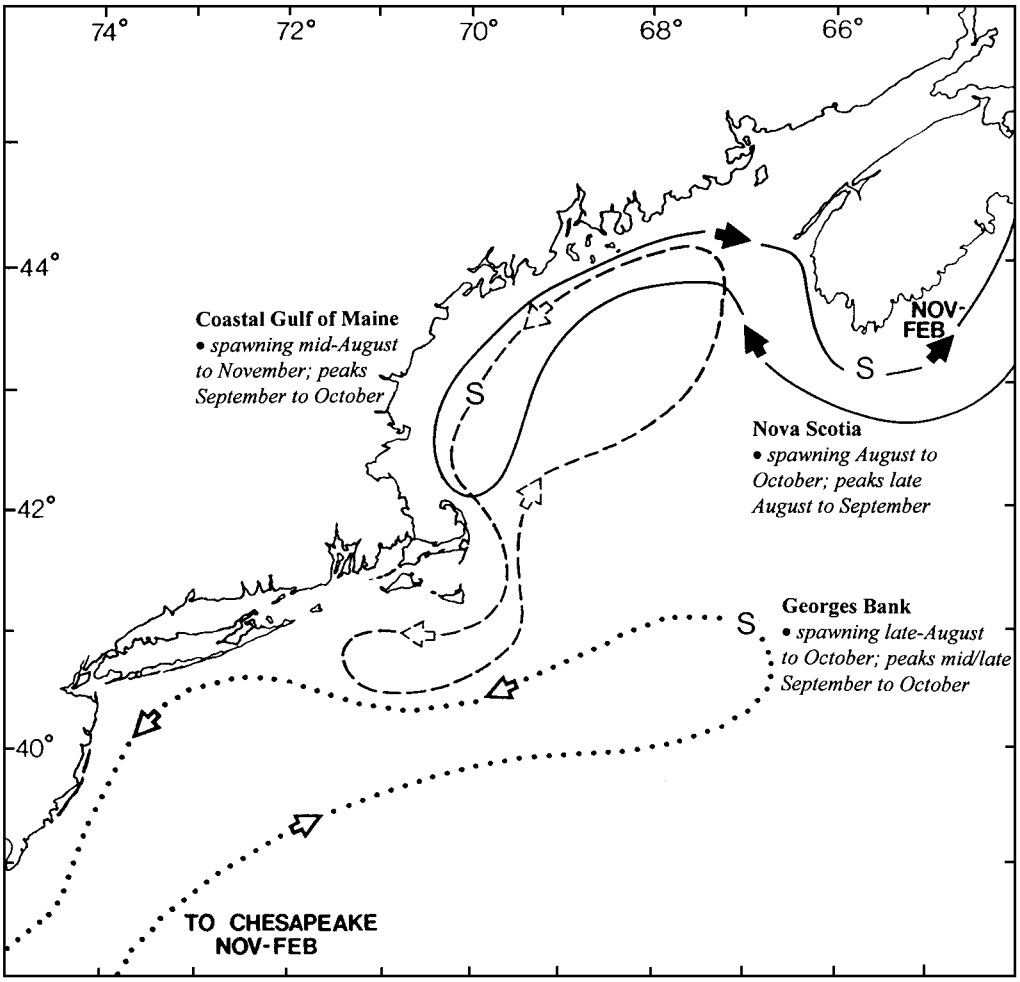

Figure 5. Hypothesized seasonal movements of three Atlantic herring spawning stocks inhabiting U.S. waters, based on Sindermann (1979).

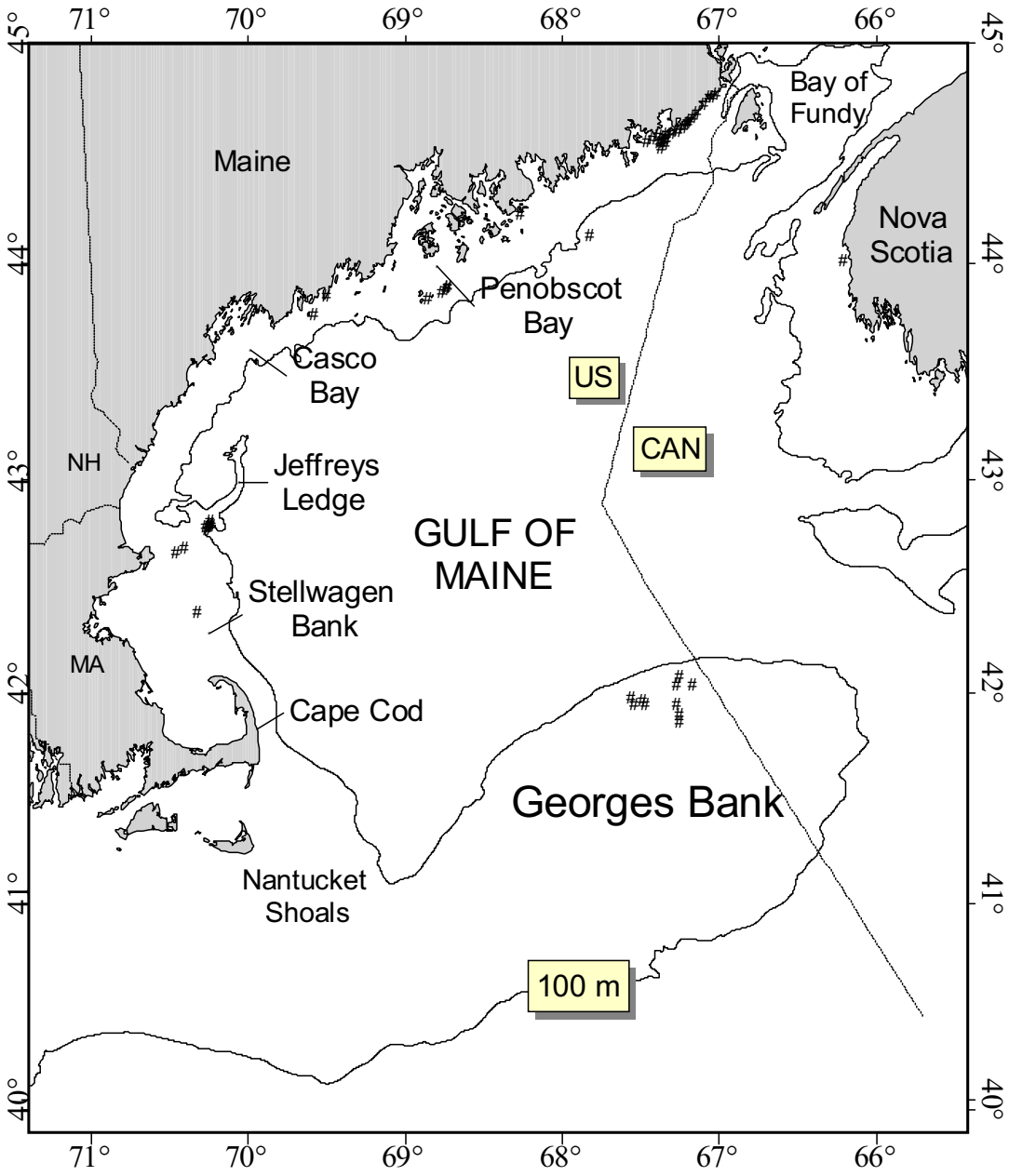

Figure 6. Geo-referenced *in situ* observations of Atlantic herring eggs (see Table 6).

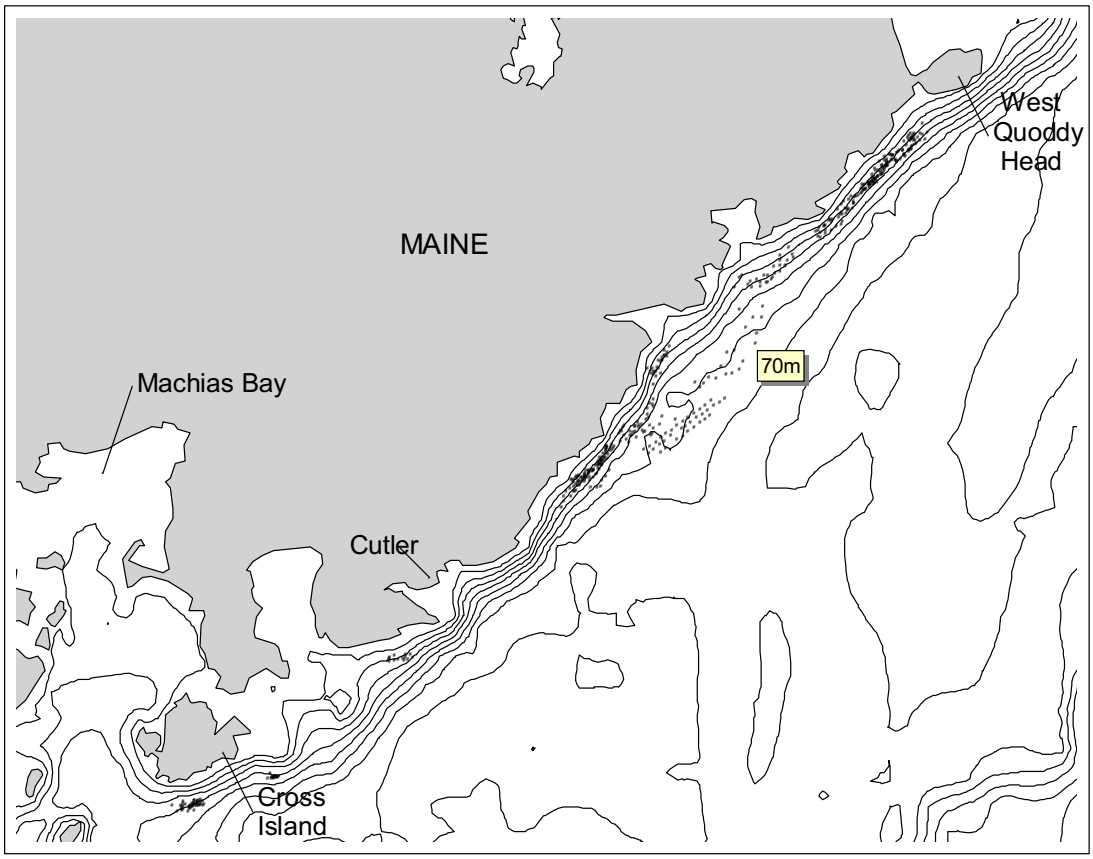

Figure 7. Atlantic herring spawning sites in eastern Maine, 1997-2002. Depth contours in 10 m intervals. Source: Island Institute, Rockland, ME [see Neal and Brehme (2001) and Neal (2003)].

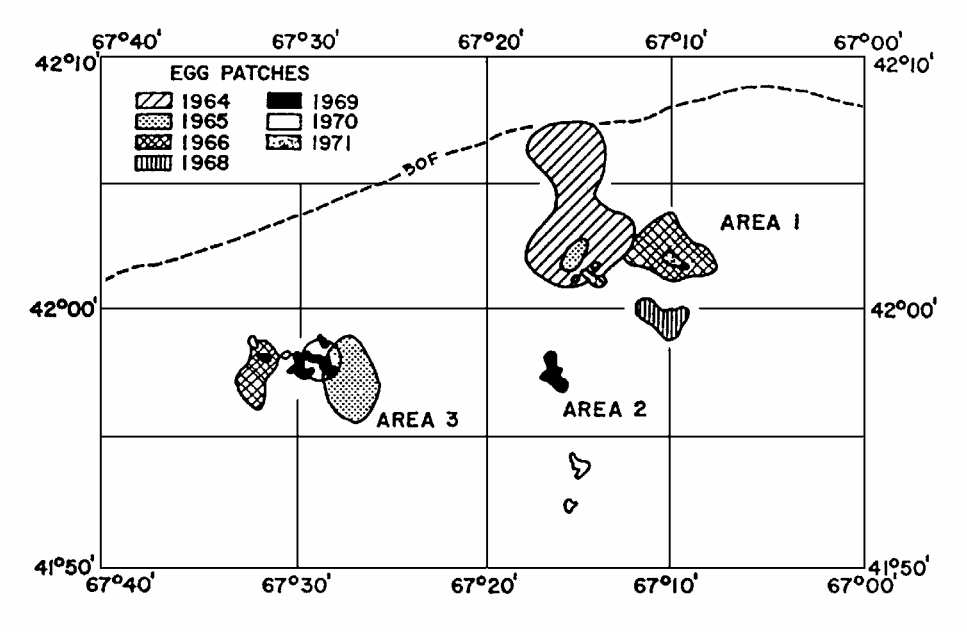

Figure 8. Principal spawning grounds of Atlantic herring on Georges Bank, 1964-1971 (excluding 1967), with a comparison of egg patch sizes among years. Source: Anthony and Waring (1980).

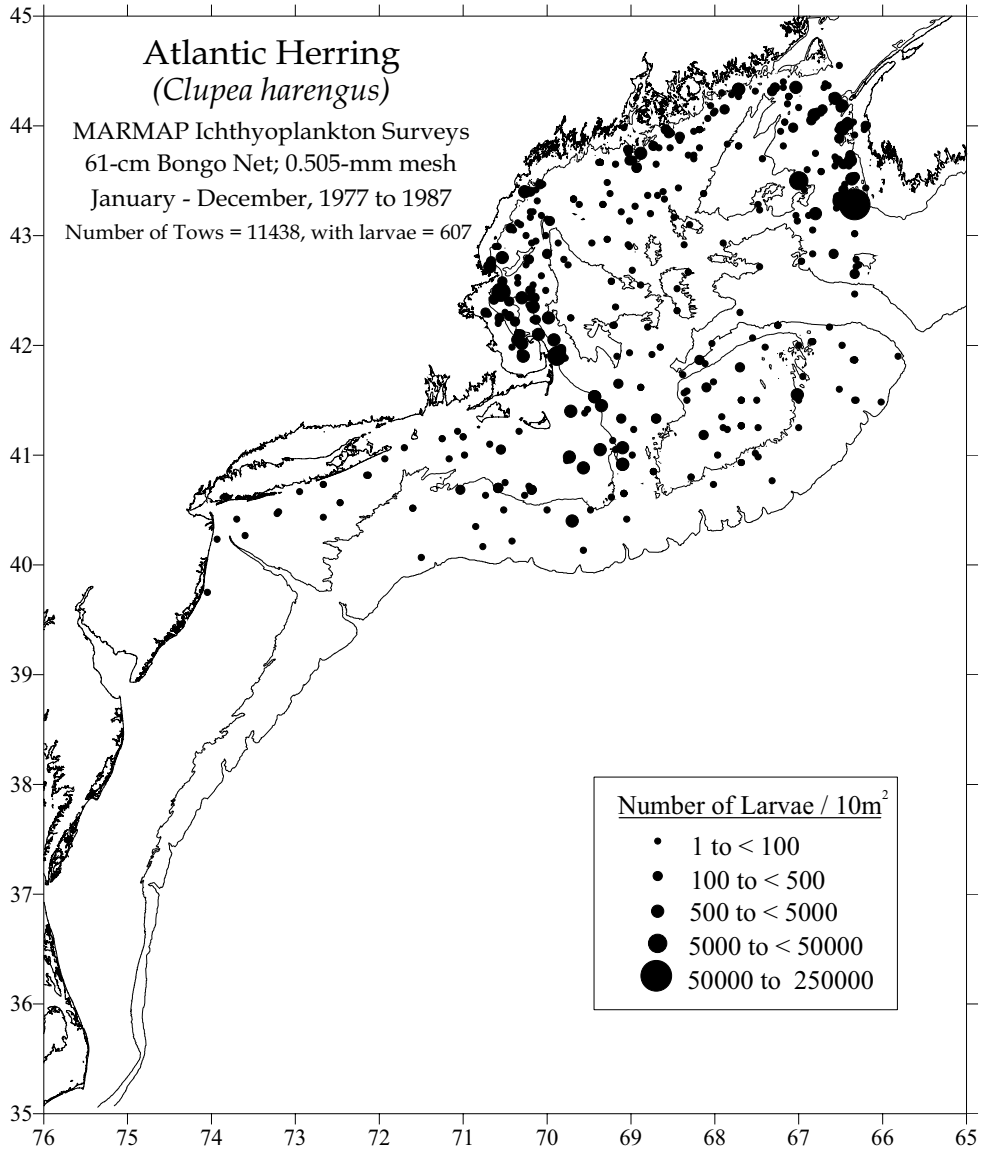

Figure 9. Distributions and abundances of Atlantic herring larvae collected during NEFSC MARMAP ichthyoplankton surveys.
For all available months and years from 1977 to 1987 combined.

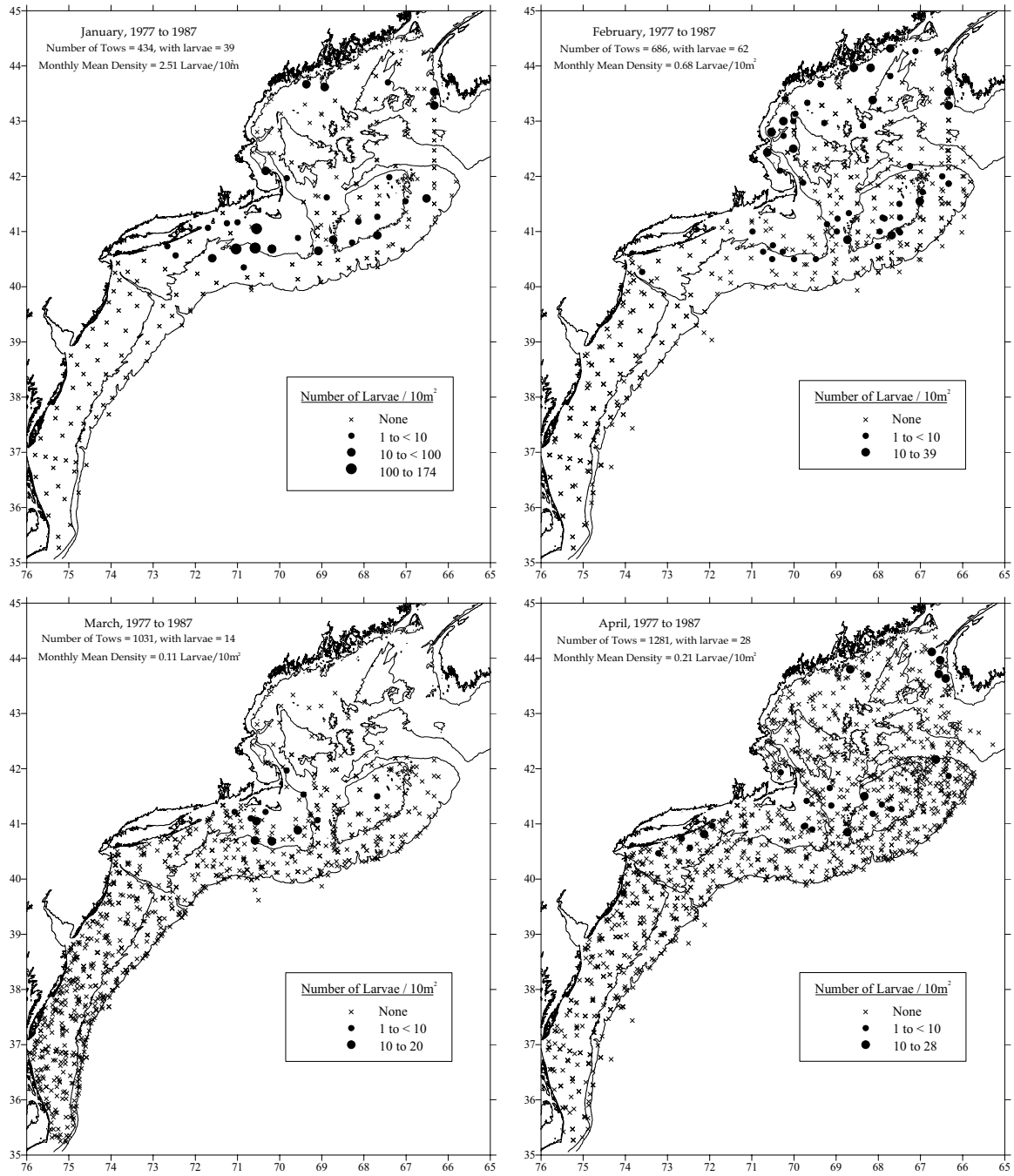

Figure 9. Cont'd.
From MARMAP ichthyoplankton surveys, January through April, 1977-1987.

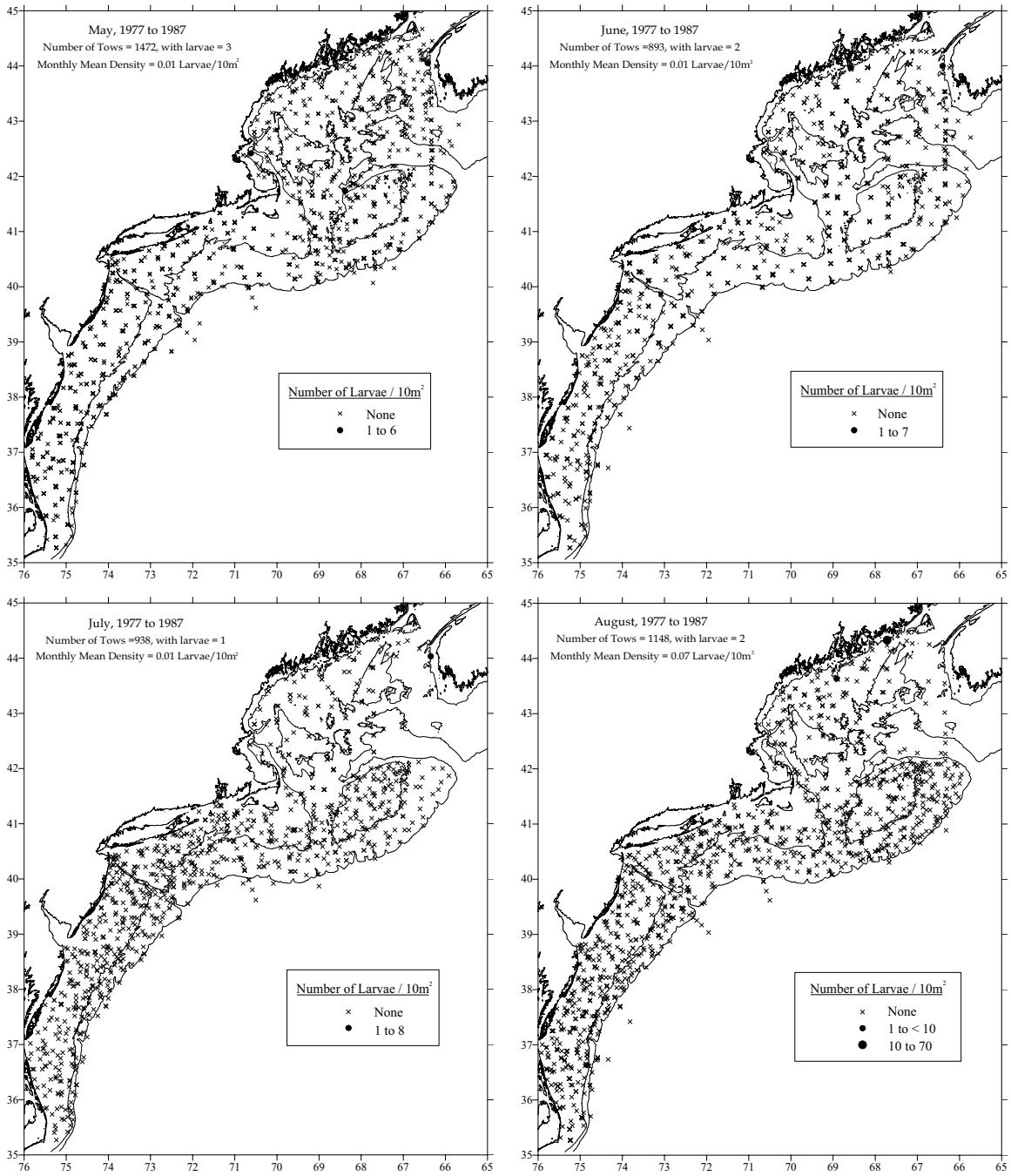

Figure 9. Cont'd.
From MARMAP ichthyoplankton surveys, May through August, 1977-1987.

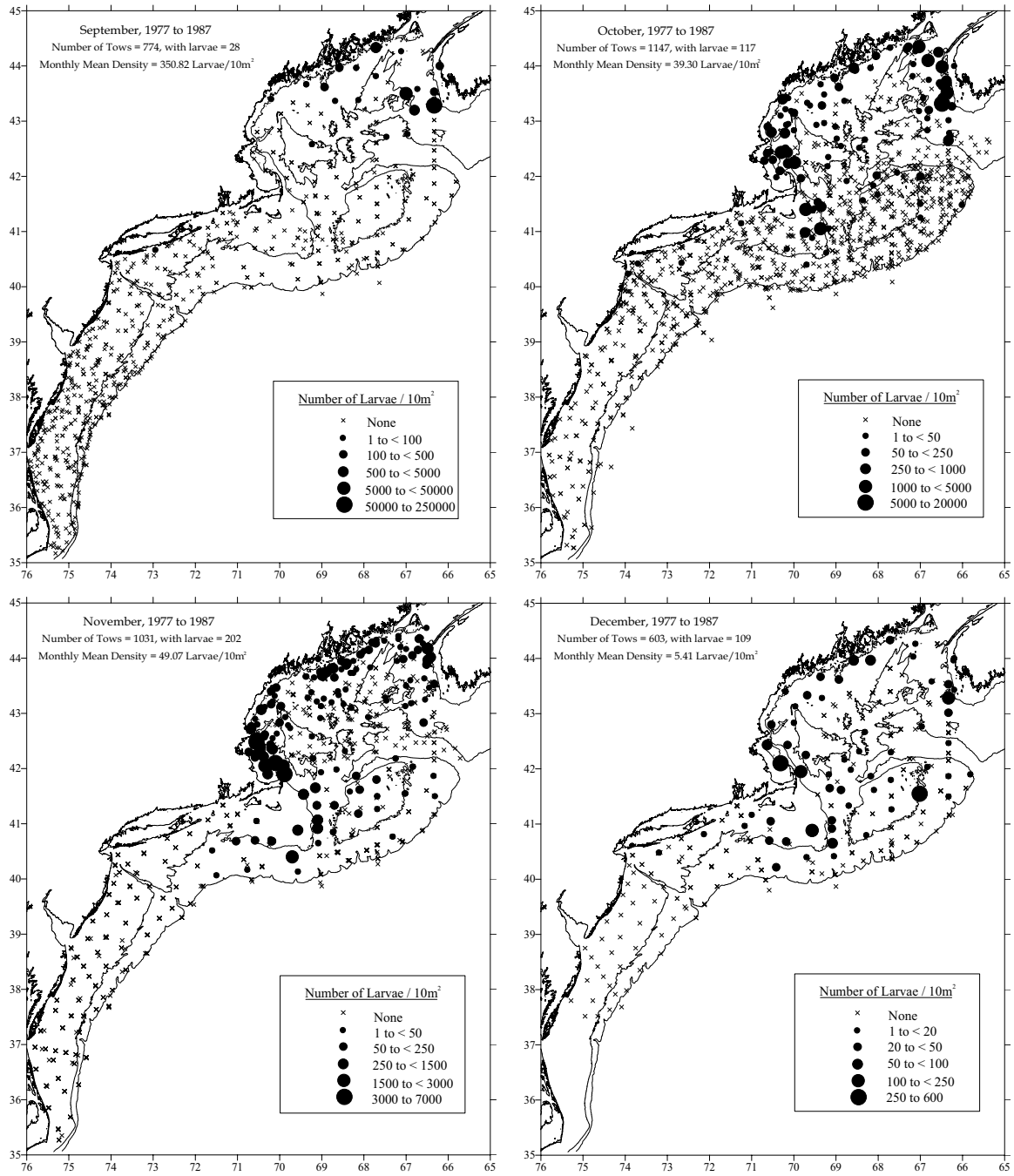

Figure 9. Cont'd.
From MARMAP ichthyoplankton surveys, September through December, 1977-1987.

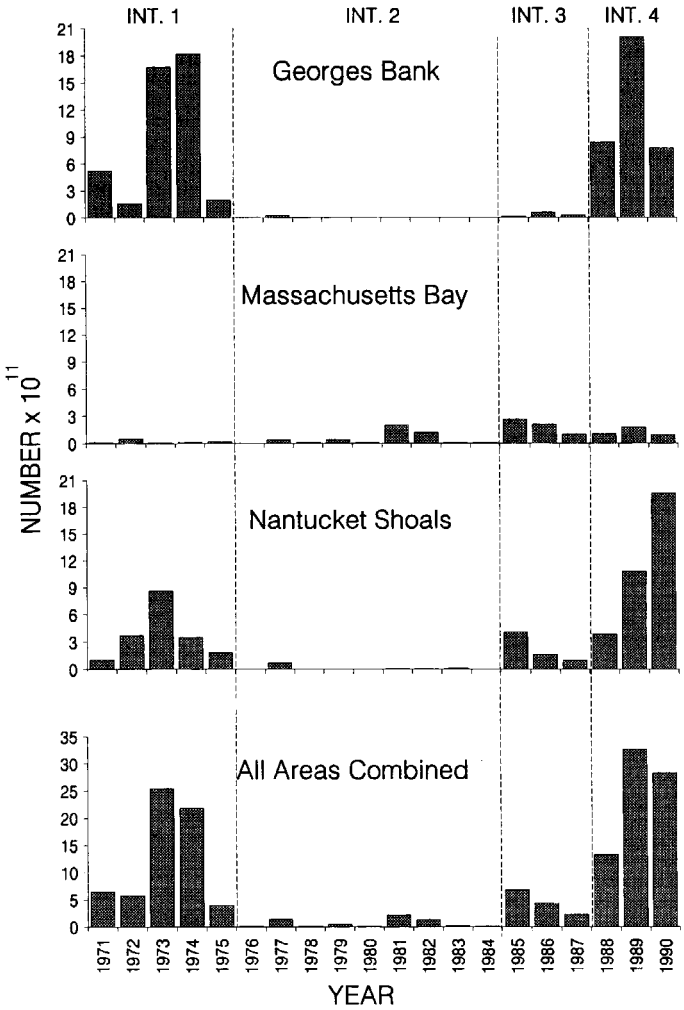

Figure 10. Changes in abundance of Atlantic herring larvae on Georges Bank, Nantucket Shoals, and in Massachusetts Bay from 1971-1990.
Source: Smith and Morse (1993). Intervals (Int.) denote periods of changing spawning patterns.

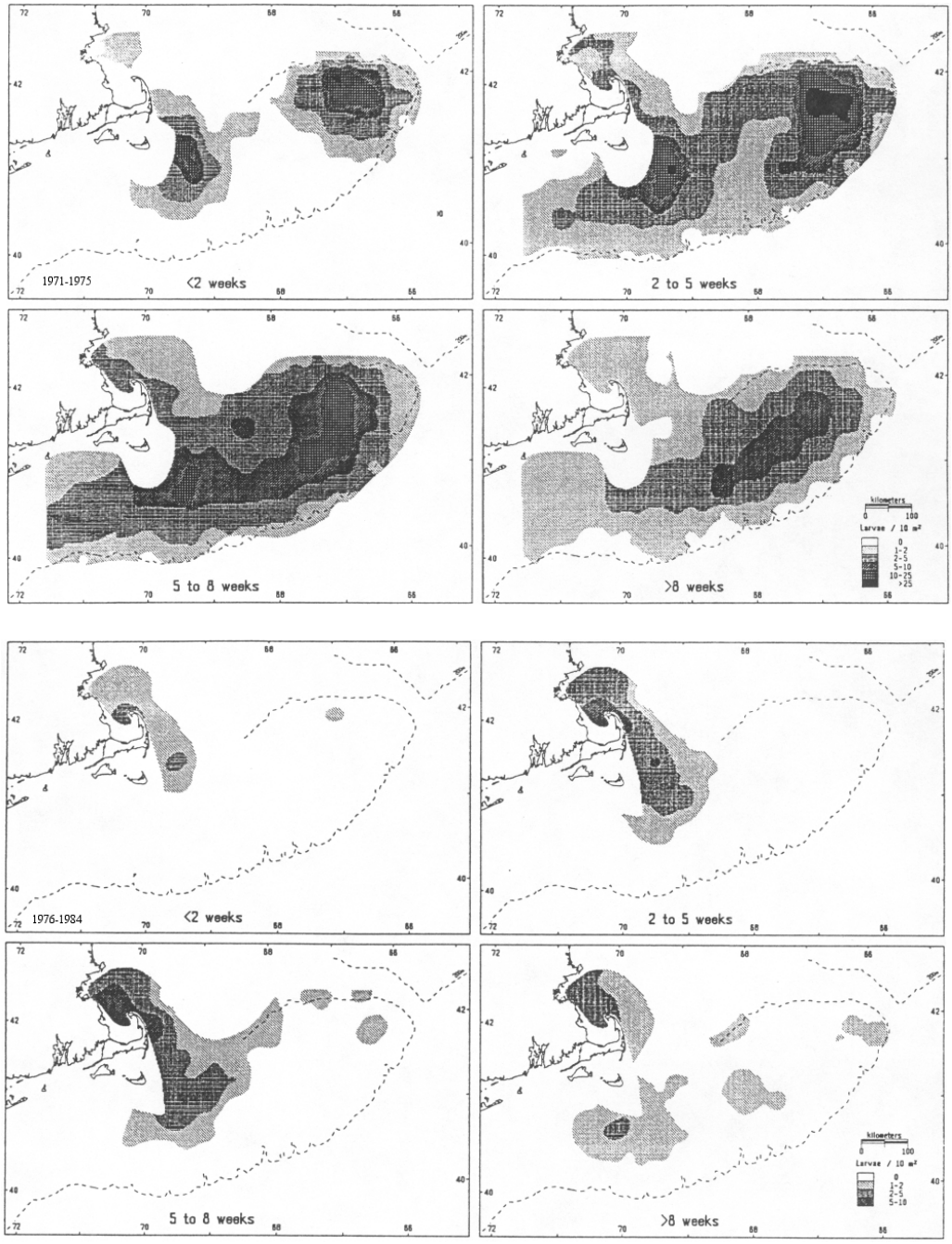

Figure 11. Distribution of Atlantic herring larvae by age in the Georges Bank area, 1971-1990.
Source: Smith and Morse (1993).

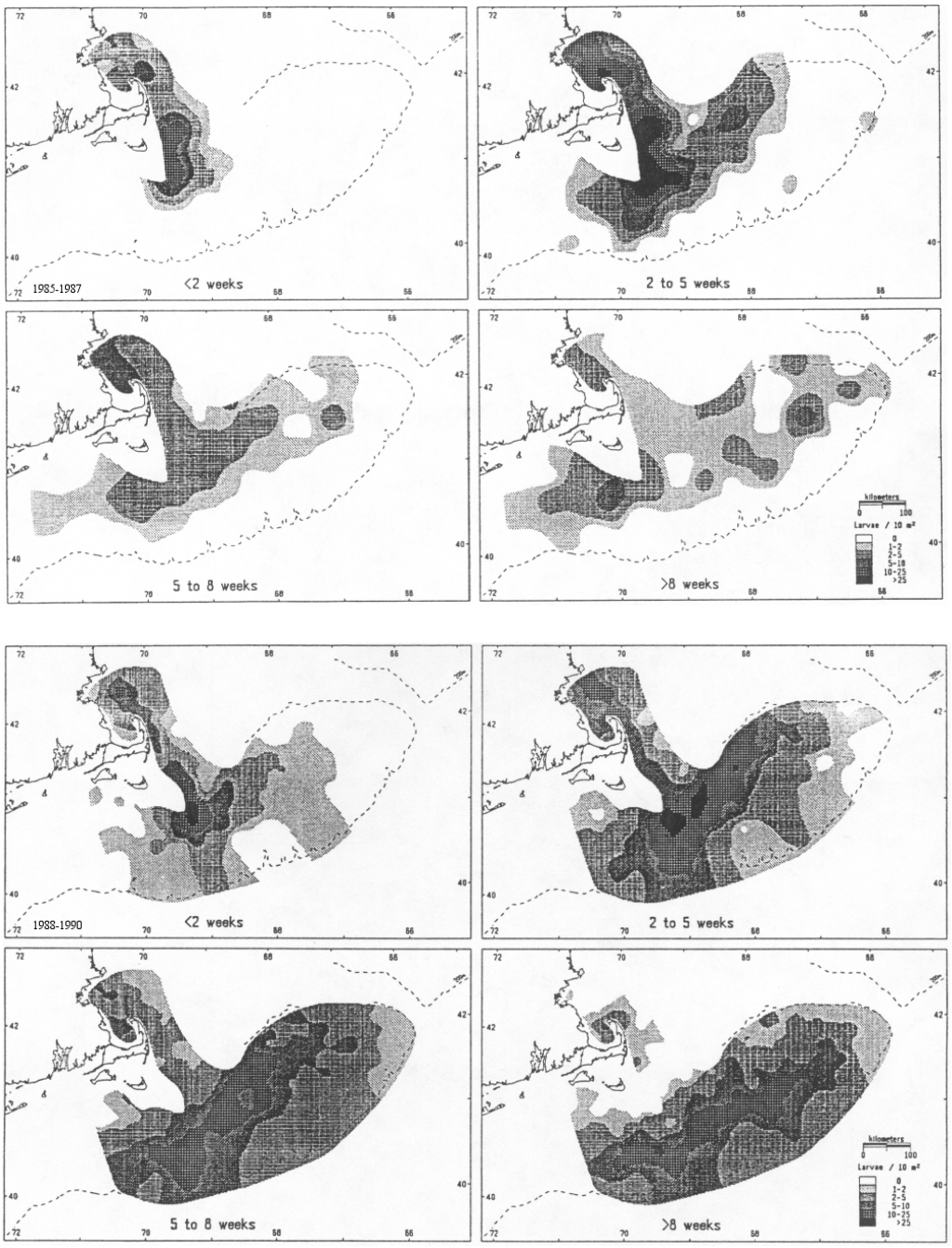

Figure 11. Cont'd.

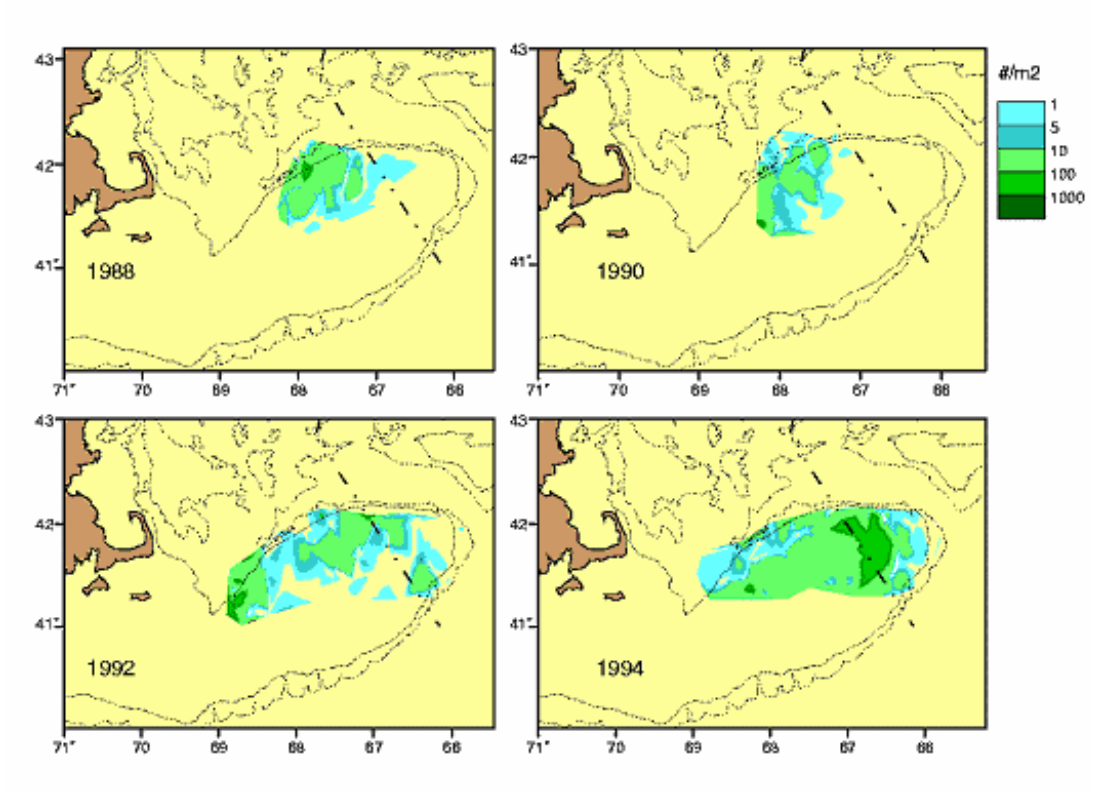

Figure 12. Distribution of recently-hatched Atlantic herring larvae on Georges Bank, 1988-1994. Source: Melvin *et al*. (1996).

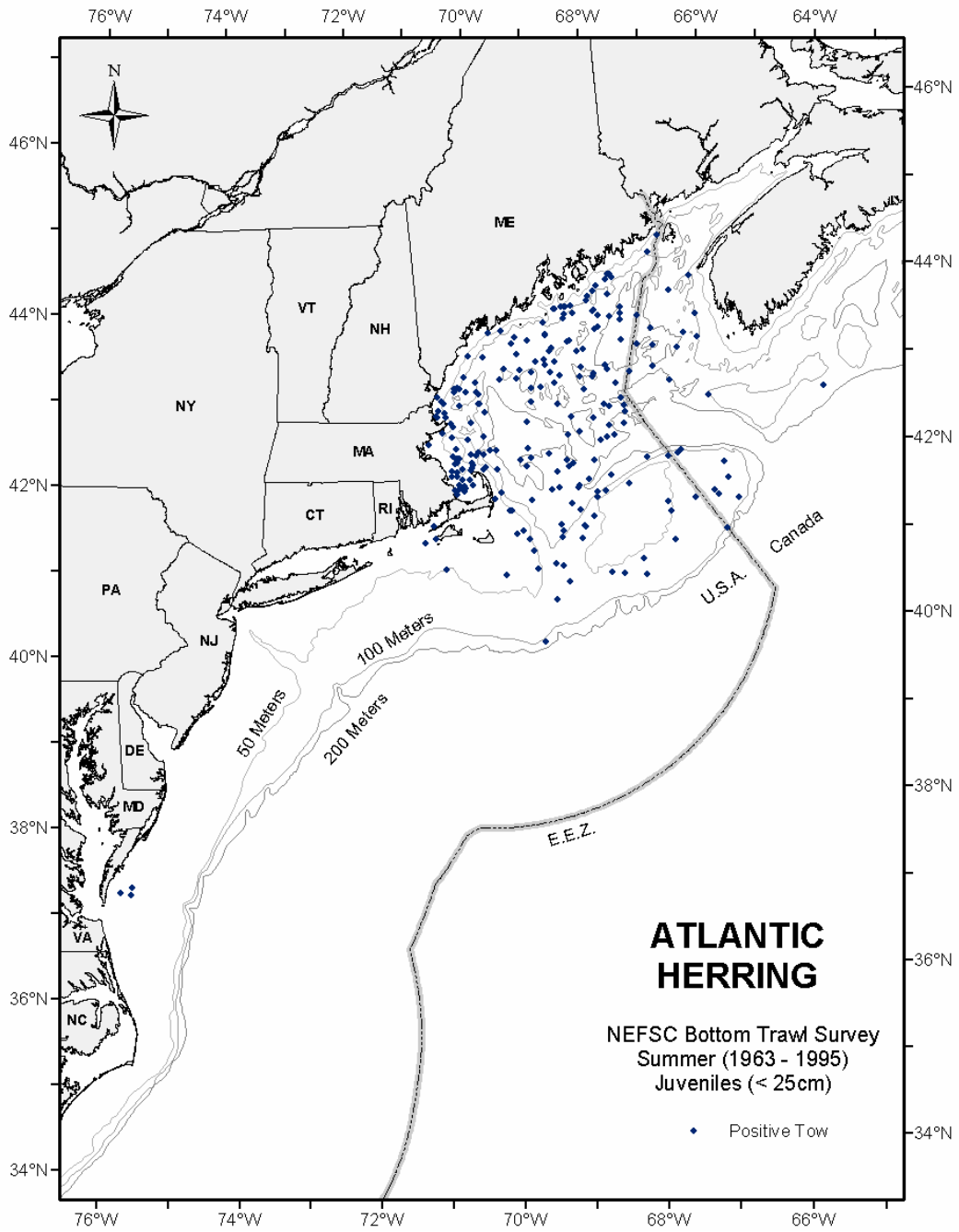

Figure 13. Seasonal distributions and abundances of juvenile Atlantic herring collected during NEFSC bottom trawl surveys.
From NEFSC summer bottom trawl surveys (1963-1995, all years combined). Distributions are displayed as presence/absence only.

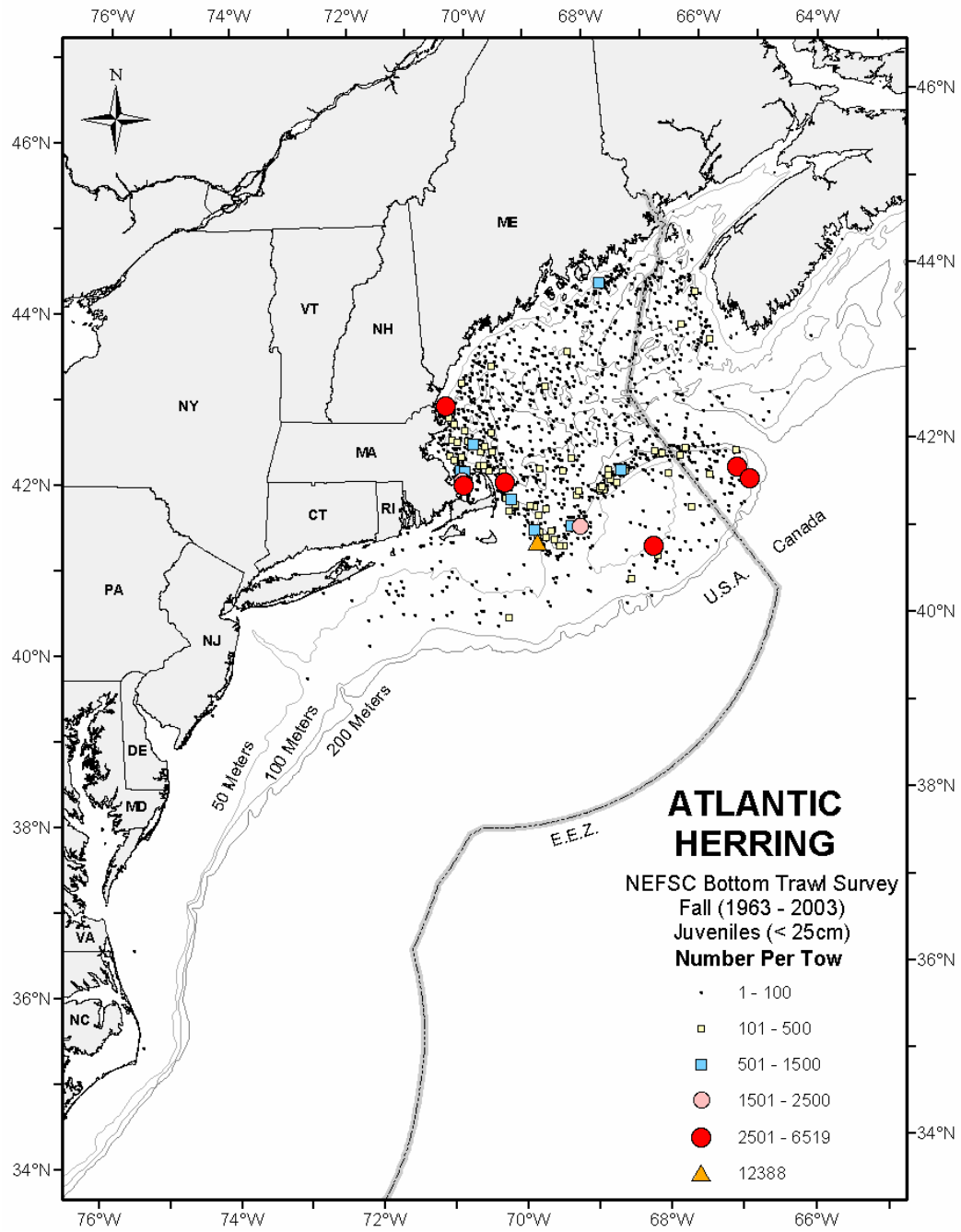

Figure 13. Cont'd.
From NEFSC fall bottom trawl surveys (1963-2003, all years combined). Survey stations where juveniles were not found are not shown.

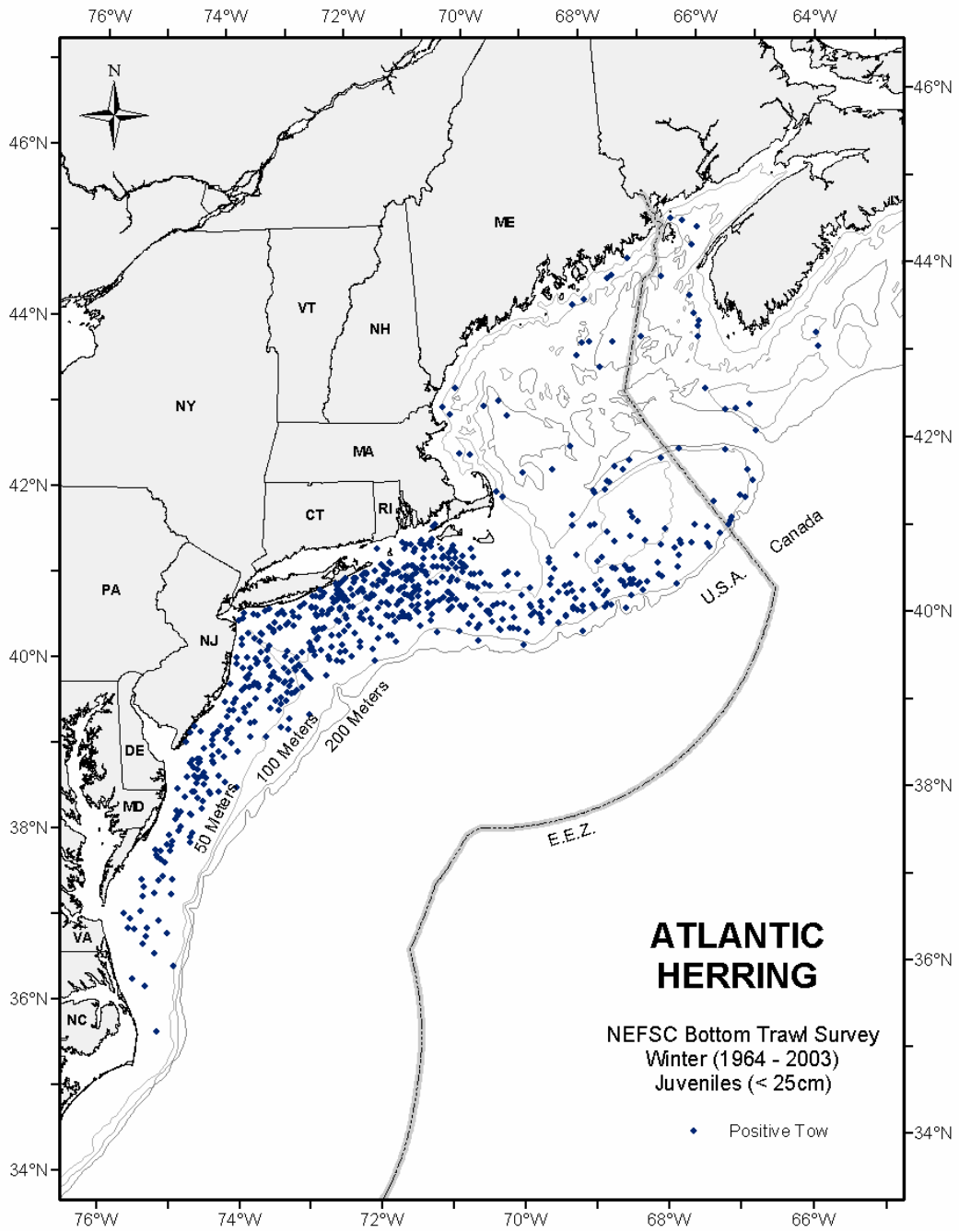

Figure 13. Cont'd.
From NEFSC winter bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence/absence only.

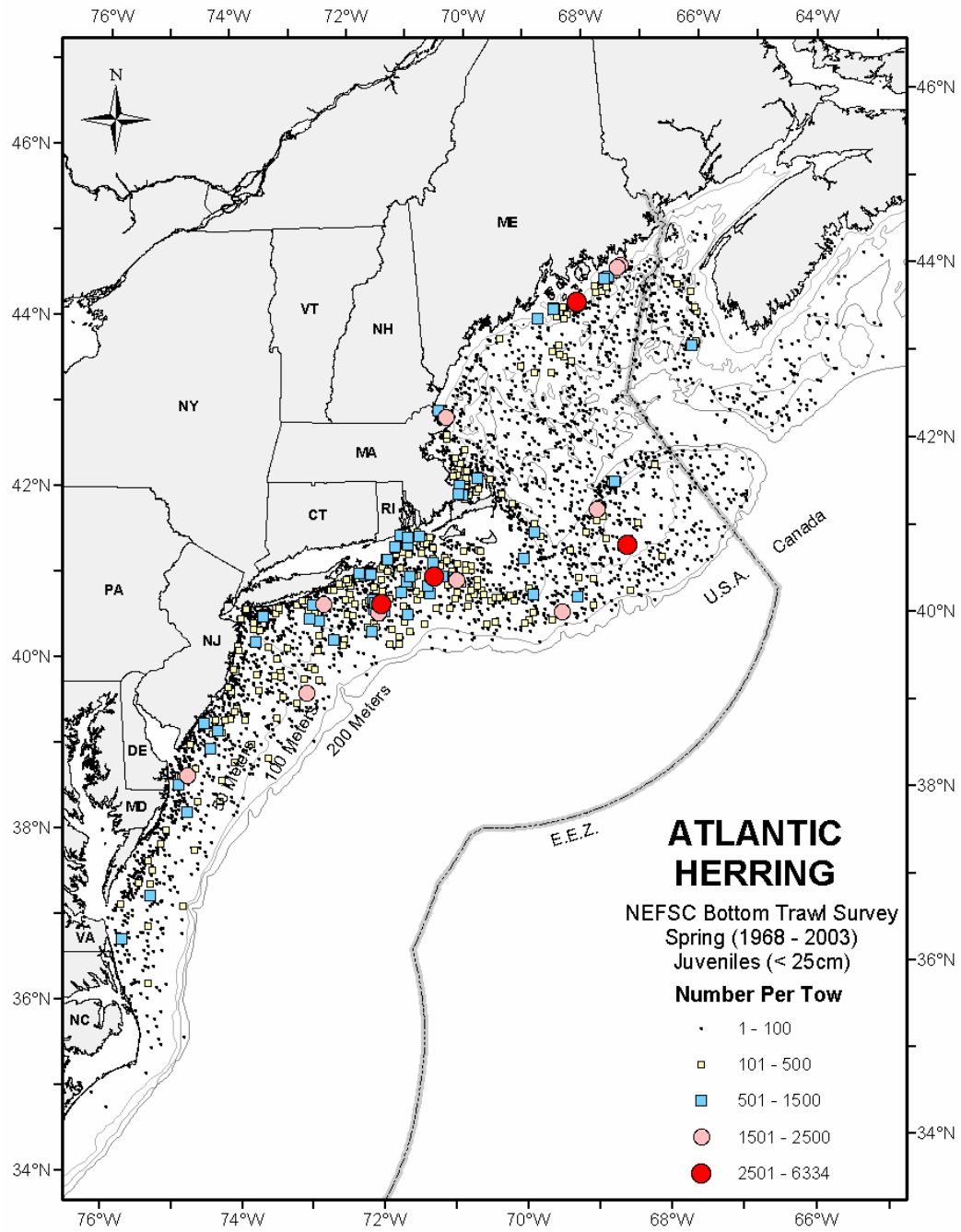

Figure 13. Cont'd.
From NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where juveniles were not found are not shown.

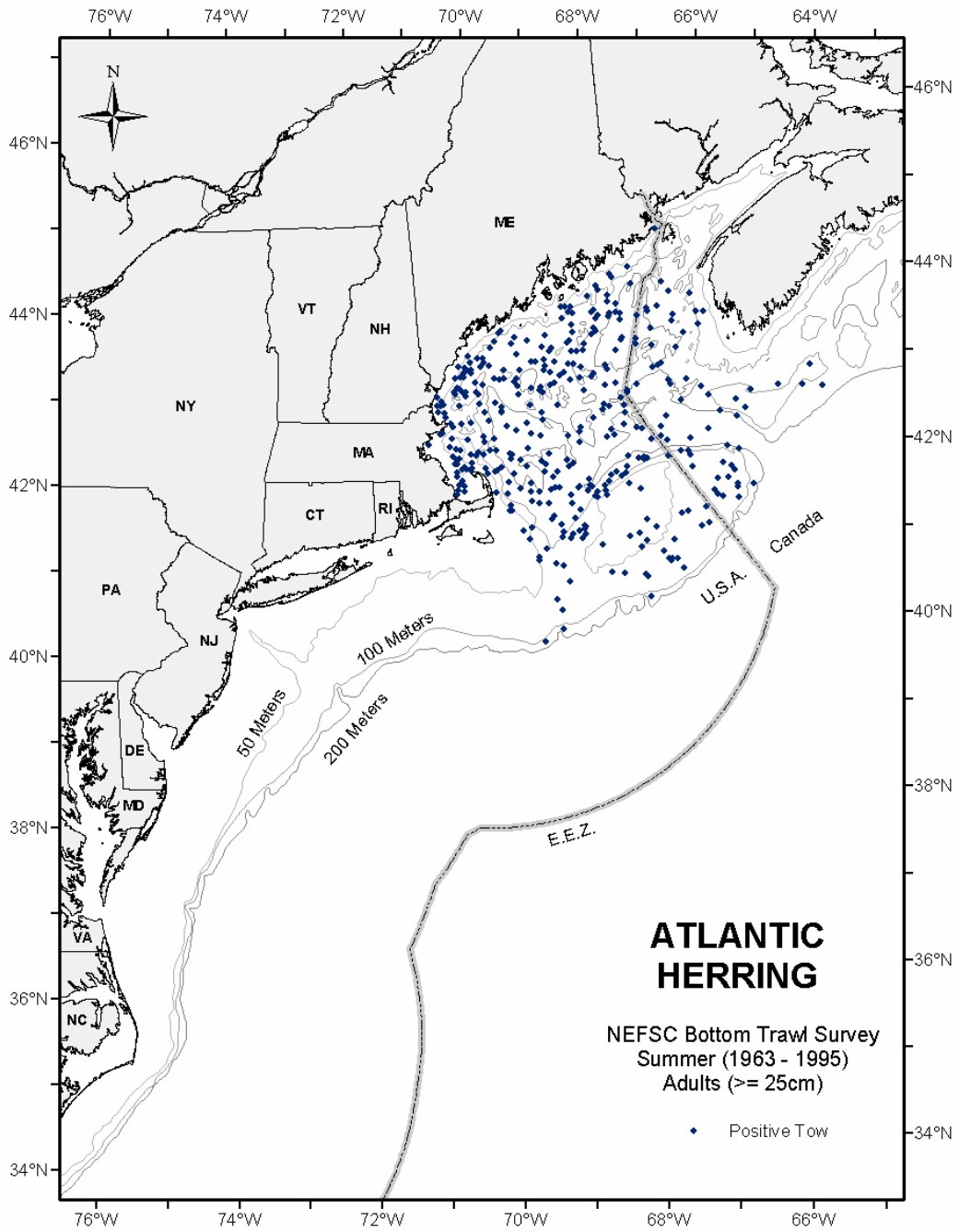

Figure 14. Seasonal distributions and abundances of adult Atlantic herring collected during NEFSC bottom trawl surveys.
From NEFSC summer bottom trawl surveys (1963-1995, all years combined). Distributions are displayed as presence/absence only.

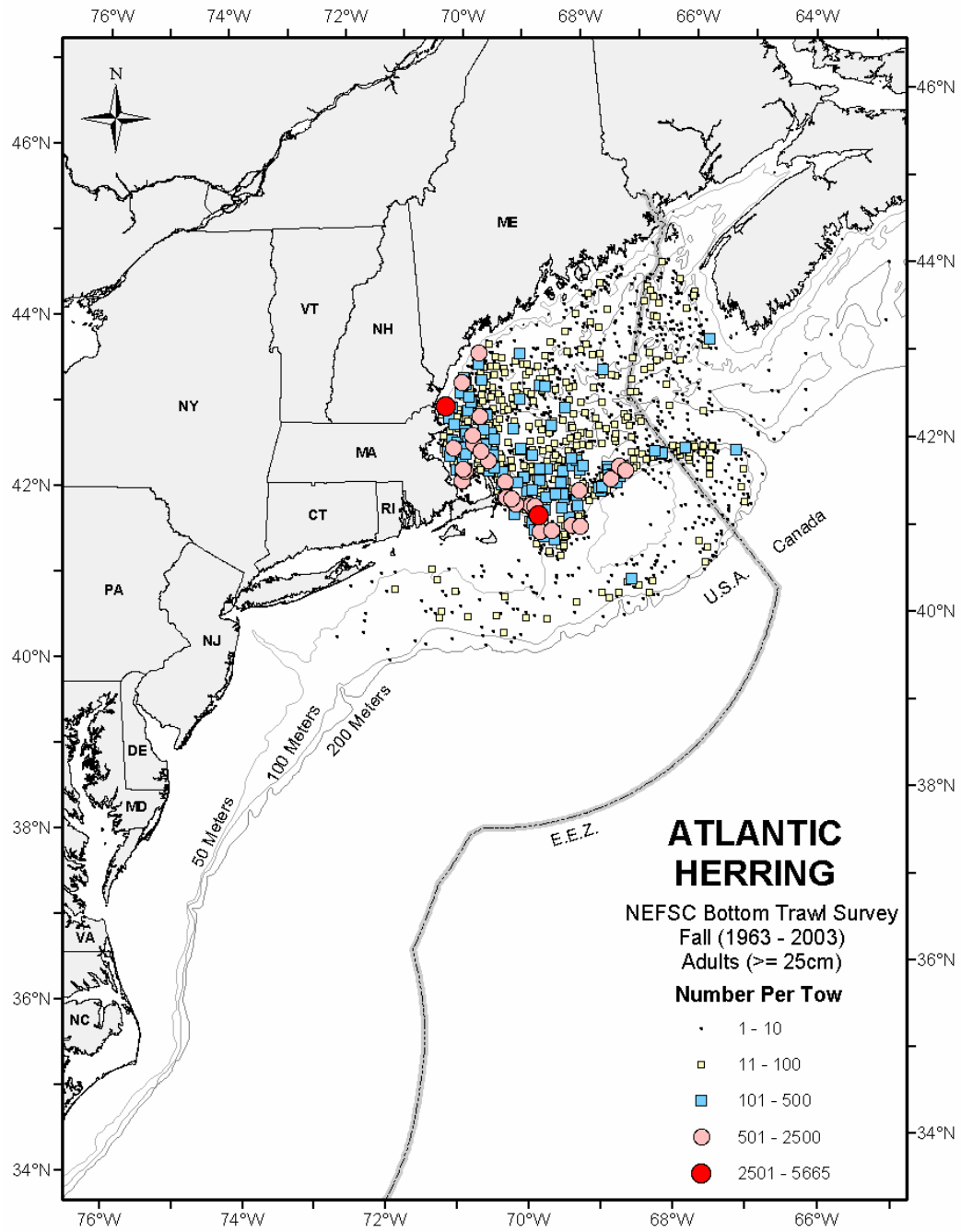

Figure 14. Cont'd.
From NEFSC fall bottom trawl surveys (1963-2003, all years combined). Survey stations where adults were not found are not shown.

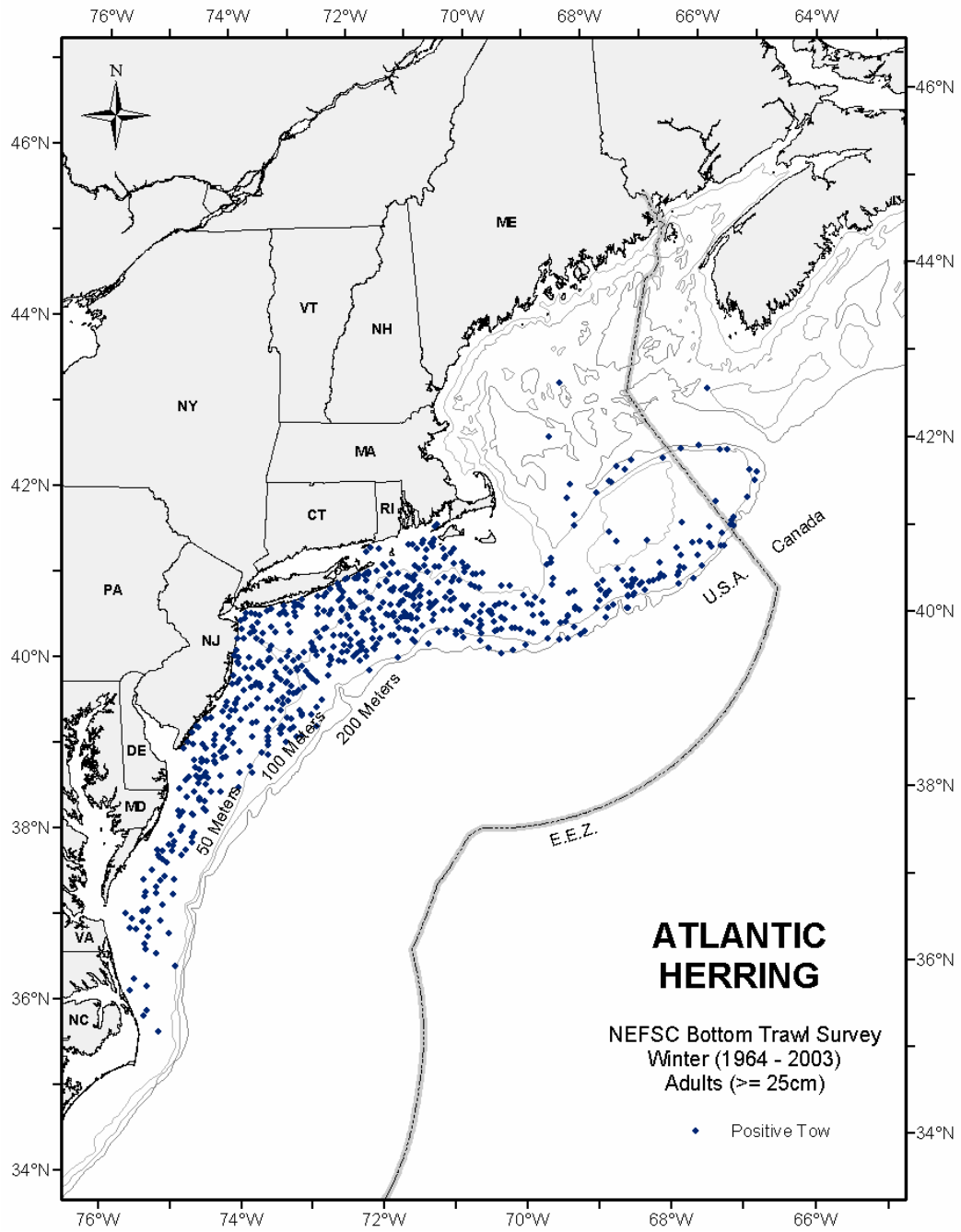

Figure 14. Cont'd.
From NEFSC winter bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence/absence only.

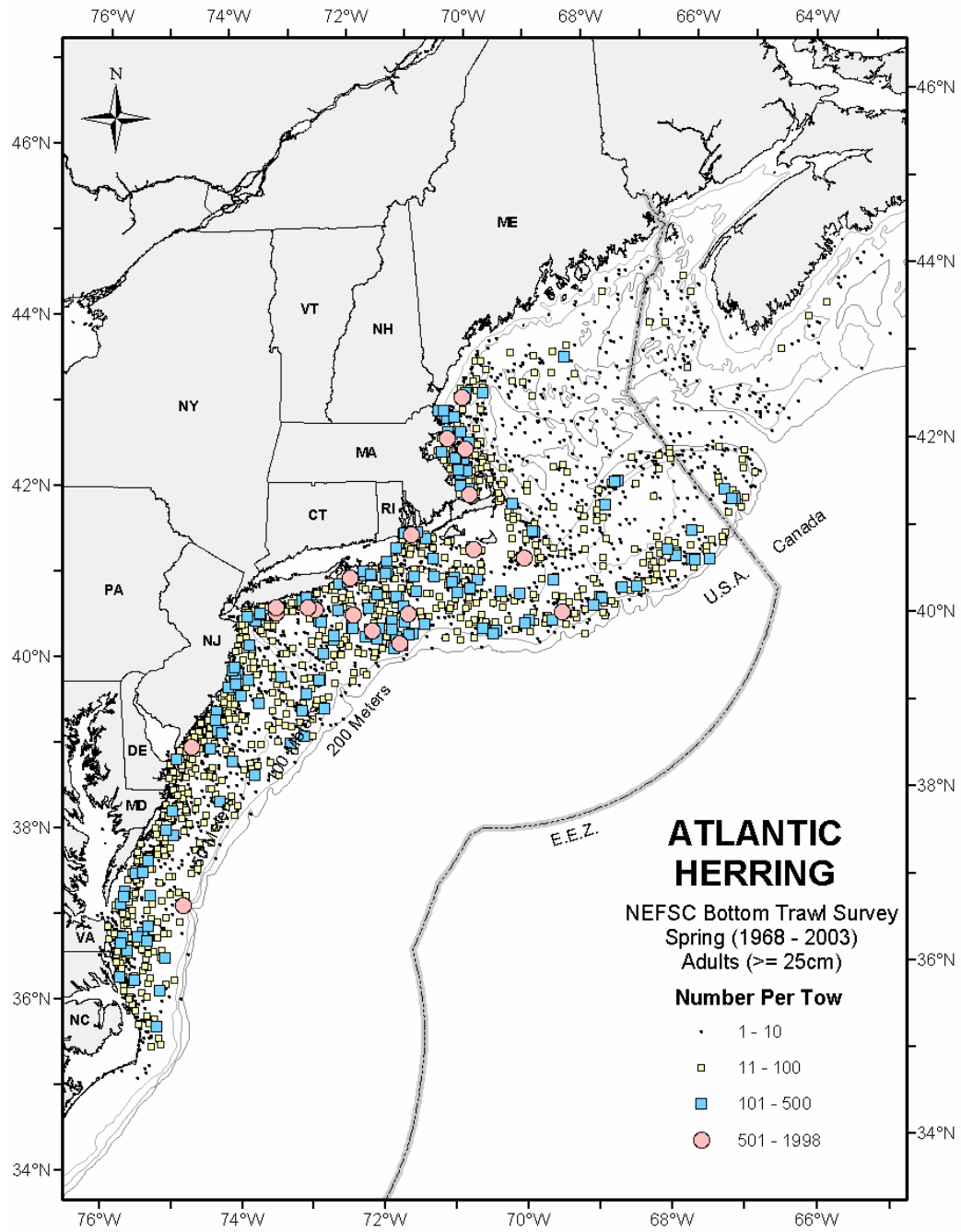

Figure 14. Cont'd.
From NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where adults were not found are not shown.

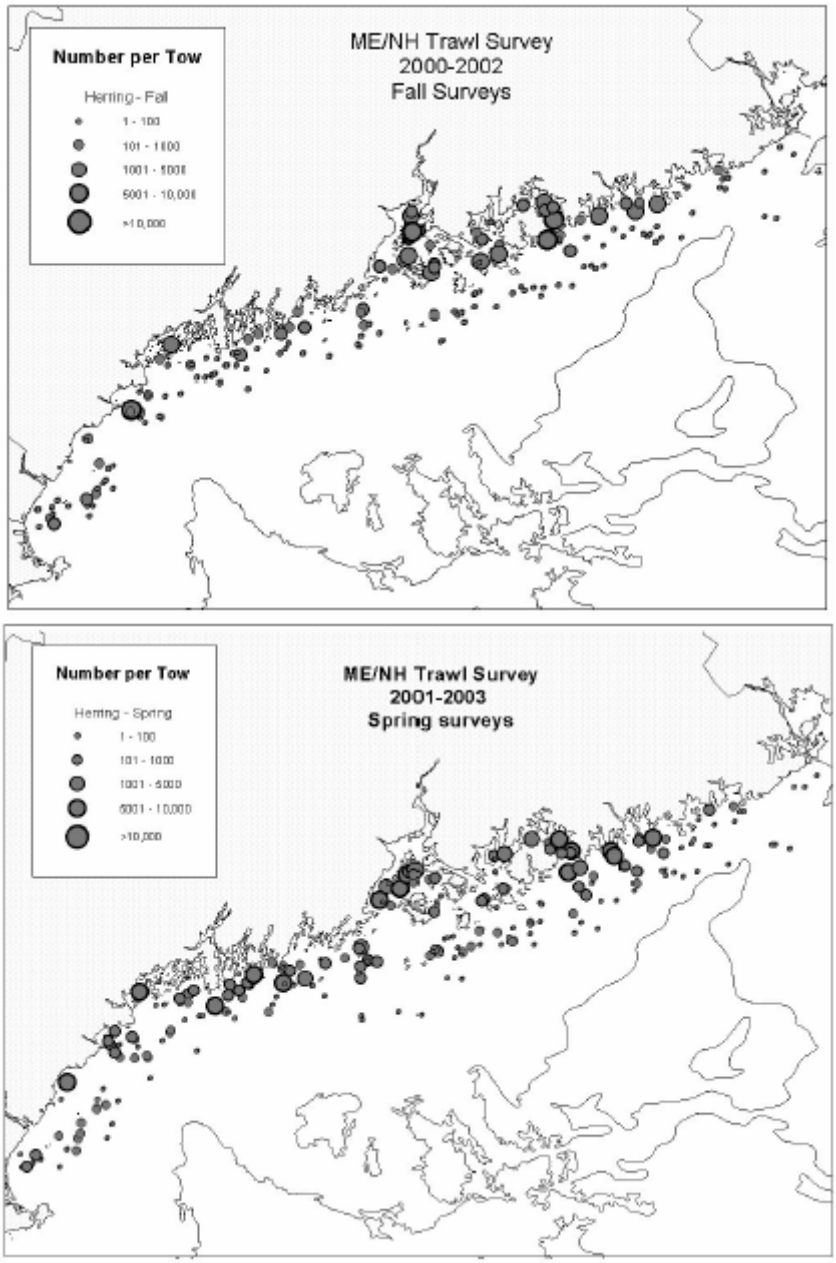

Figure 15. Distribution and abundance of Atlantic herring along the coasts of Maine and New Hampshire during spring of 2001-2003 and fall 2000-2002, from the Maine – New Hampshire inshore groundfish trawl survey. For details on the survey, see Sherman *et al*. (2004).

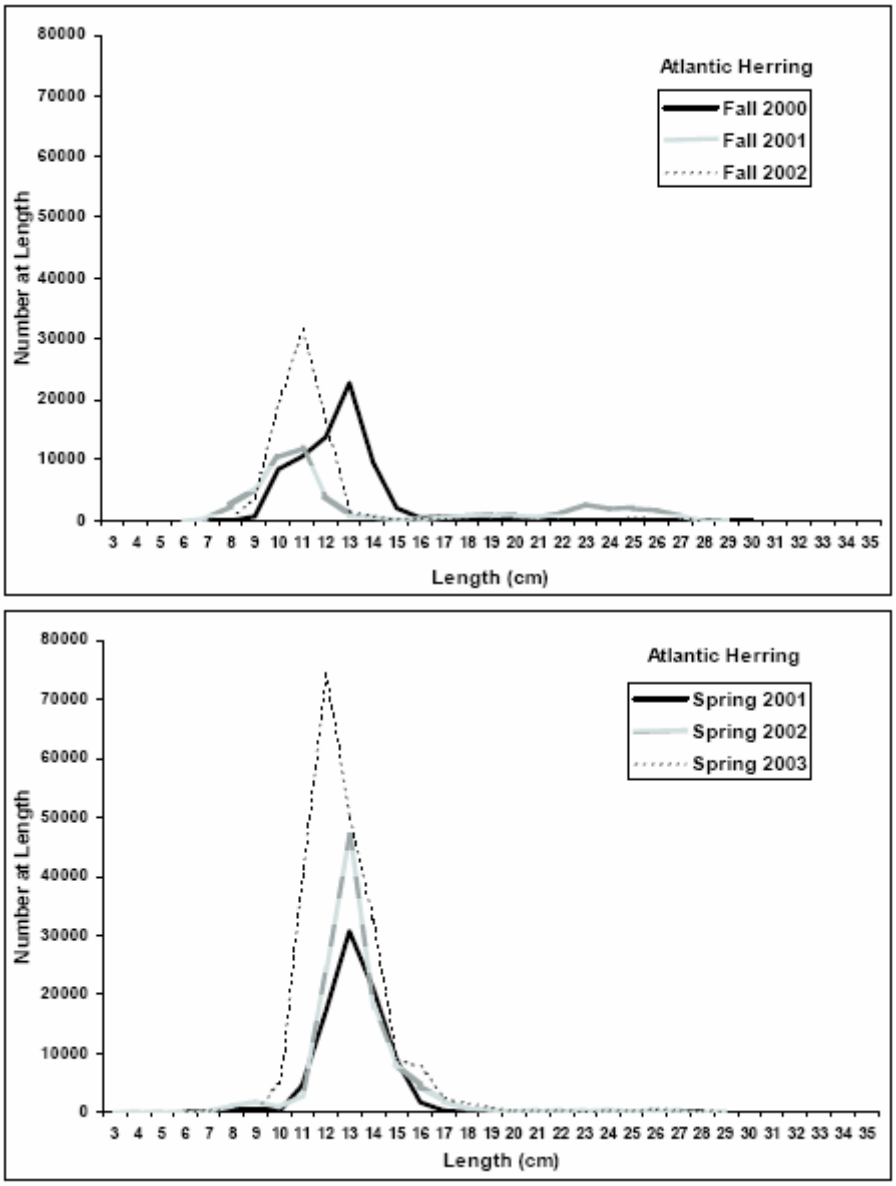

Figure 16. Length frequency plots for Atlantic herring caught along the Maine and New Hampshire coasts, by season/year. Based on the Maine – New Hampshire inshore groundfish trawl survey for spring 2001-2003 and fall 2000-2002. Source: Sherman *et al*. (2004).

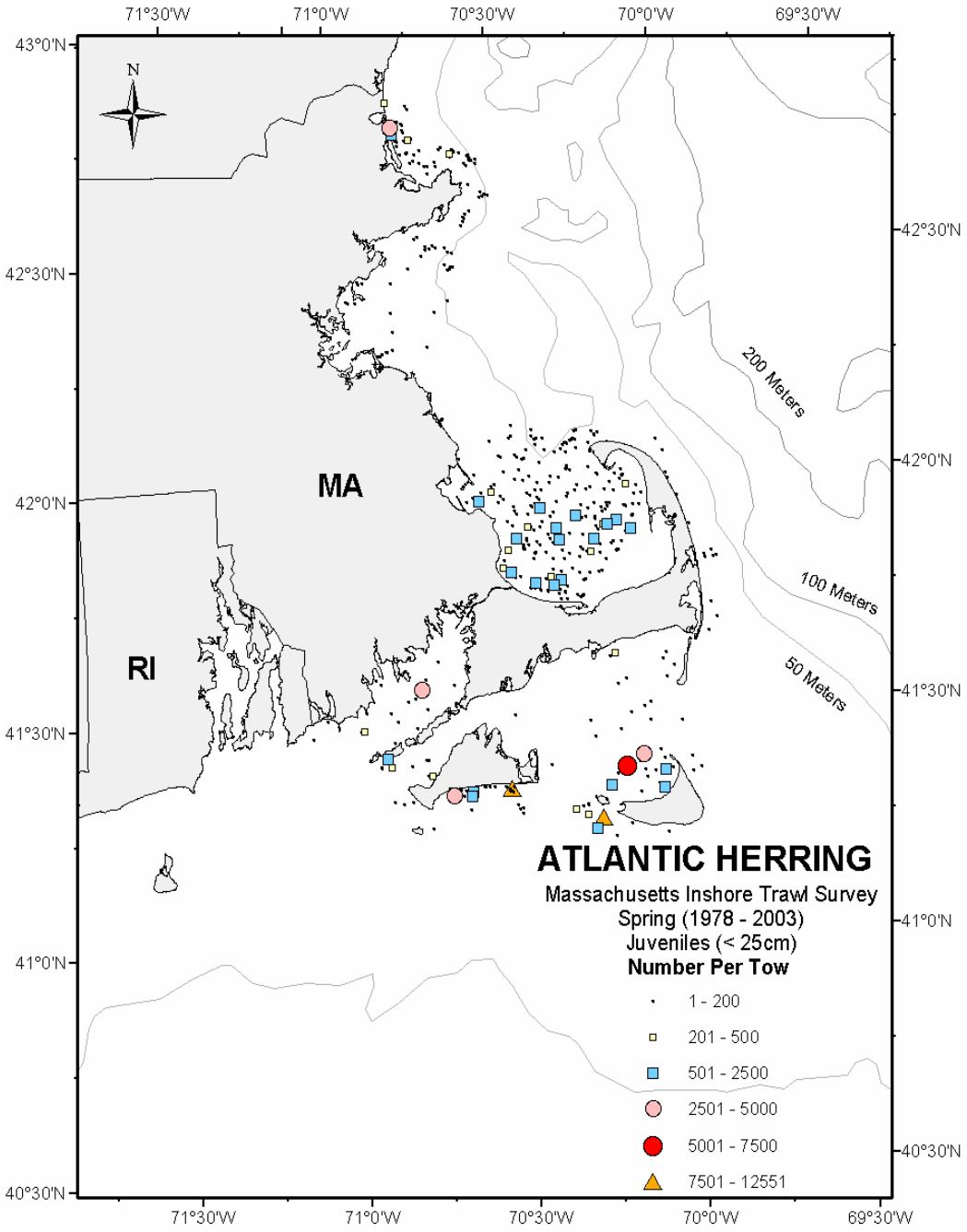

Figure 17. Seasonal distributions and abundances of juvenile Atlantic herring in Massachusetts coastal waters. From spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

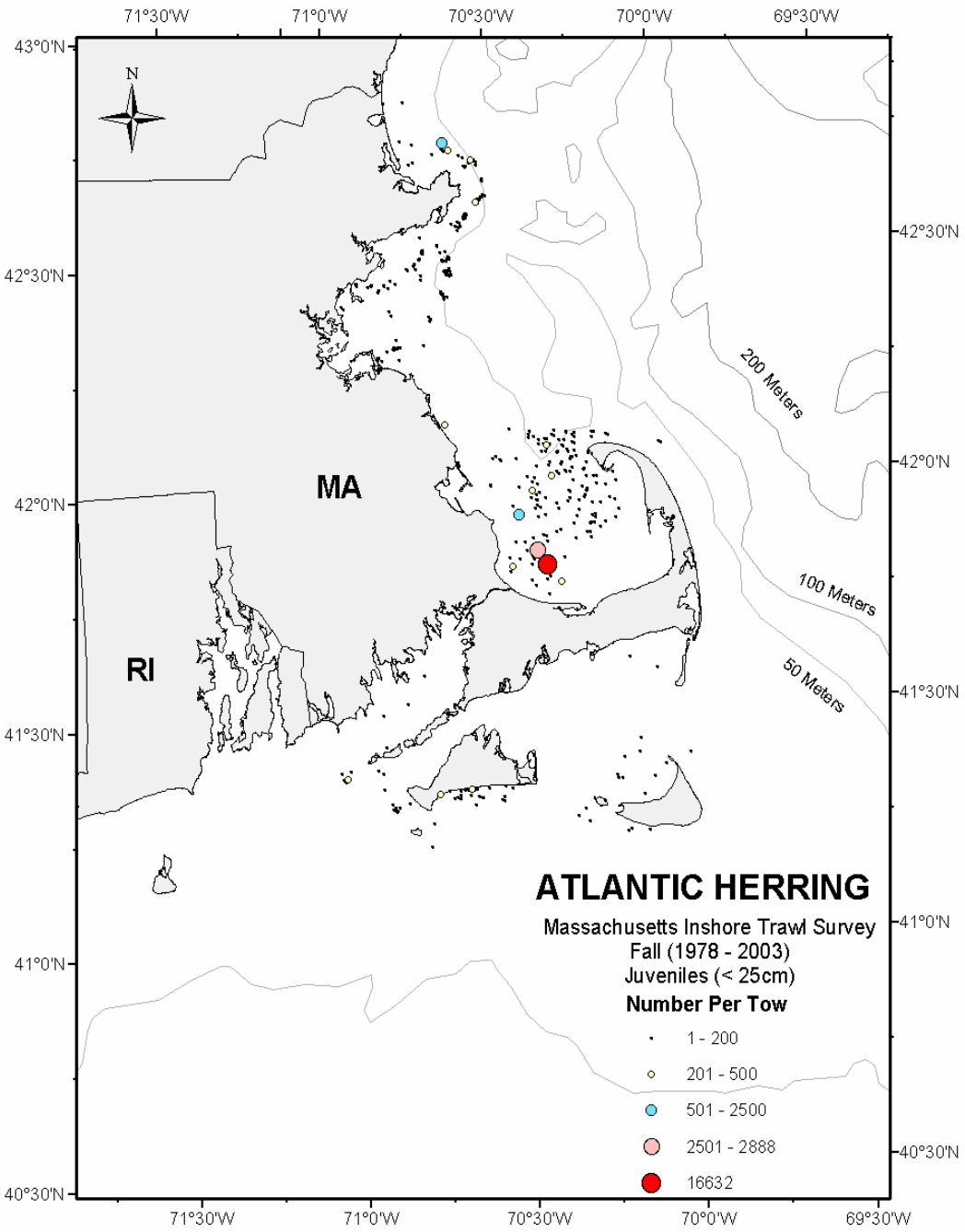

Figure 17. Cont'd.
From fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

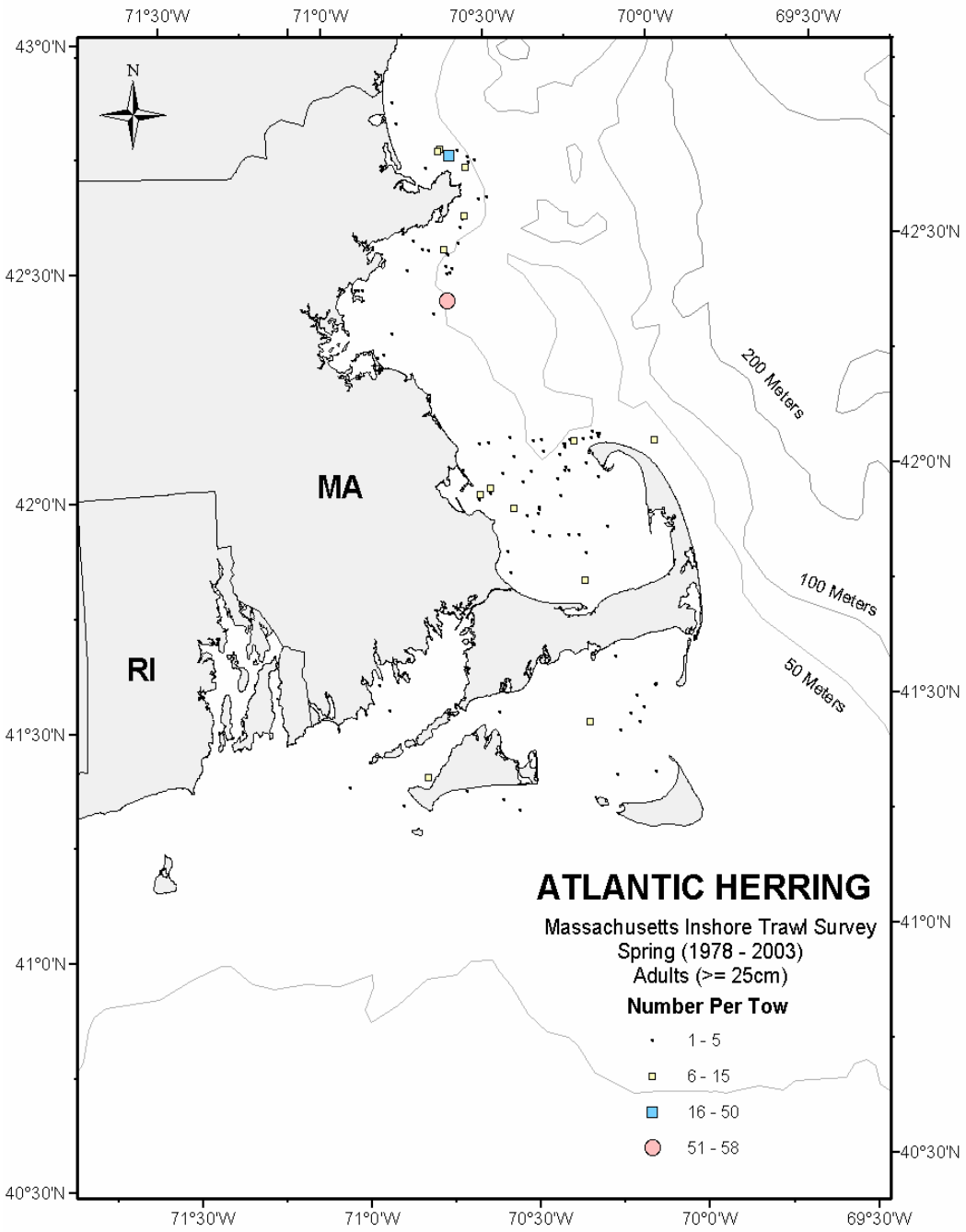

Figure 18. Seasonal distributions and abundances of adult Atlantic herring in Massachusetts coastal waters. From spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.

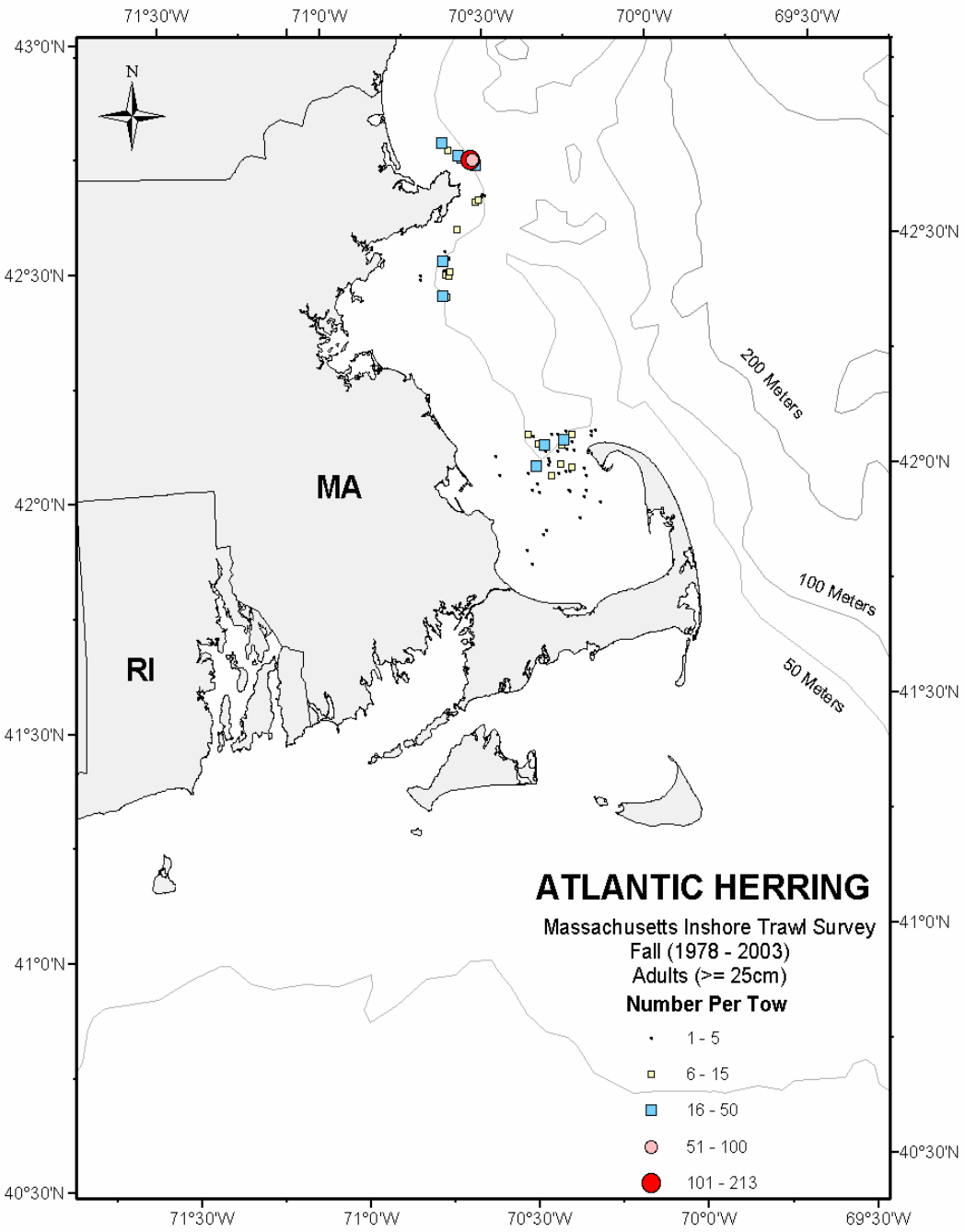

Figure 18. Cont'd.
From fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.

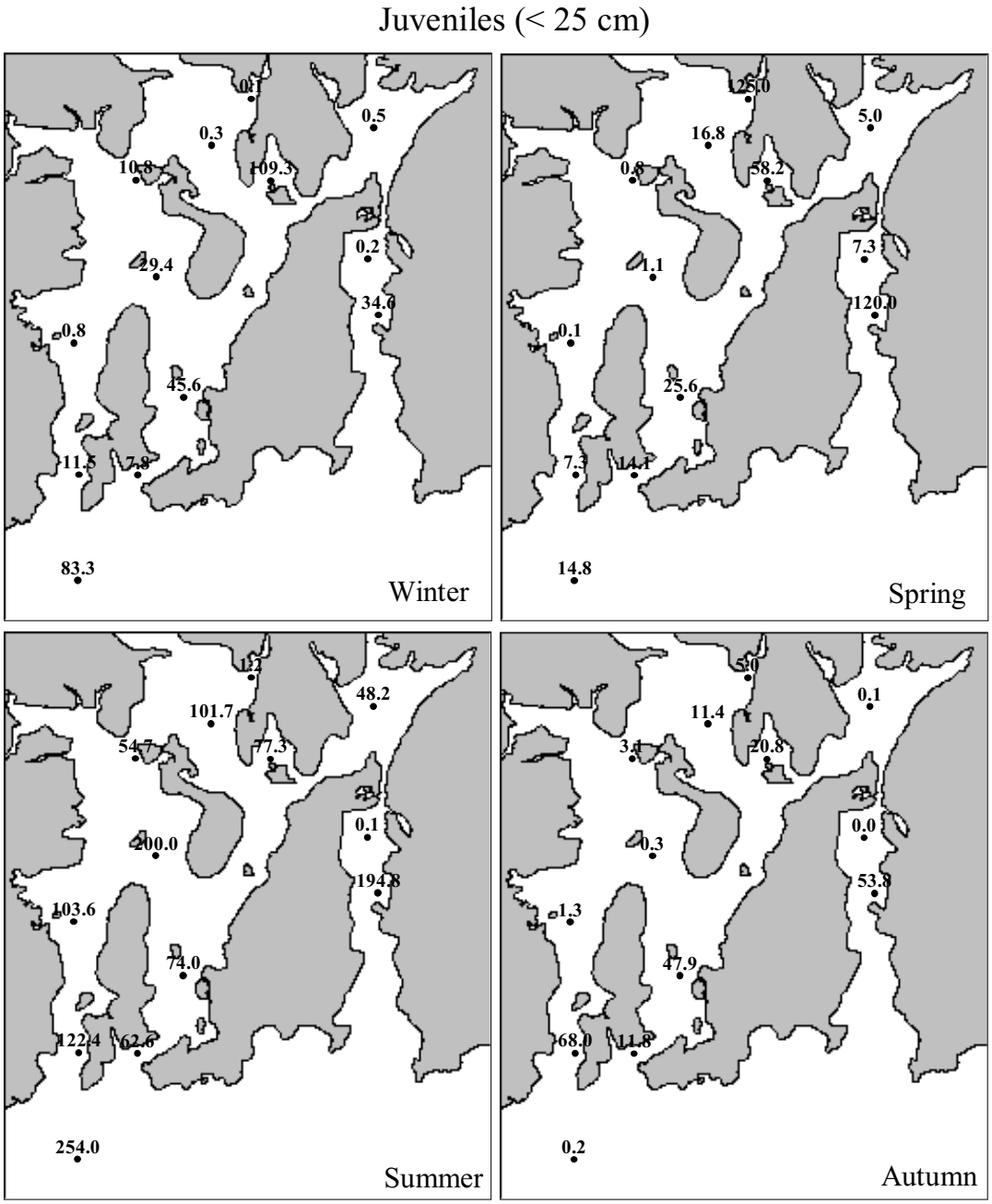

Figure 19. Seasonal distribution and abundance of juvenile Atlantic herring in Narragansett Bay. Based upon the Rhode Island bottom trawl surveys, 1990-1996. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999b) for details].

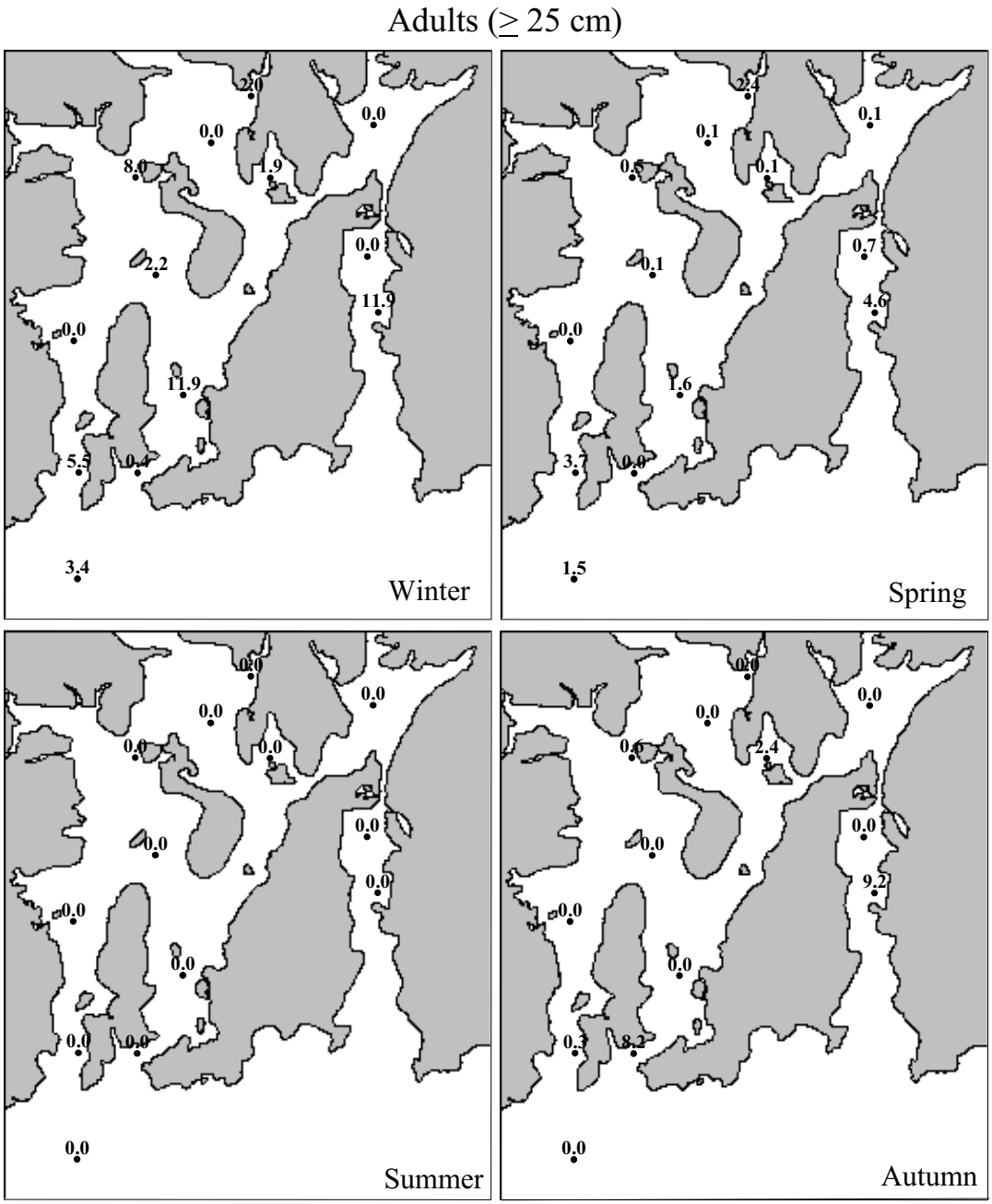

Figure 20. Seasonal distribution and abundance of adult Atlantic herring in Narragansett Bay.
Based upon the Rhode Island bottom trawl surveys, 1990-1996. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999b) for details].

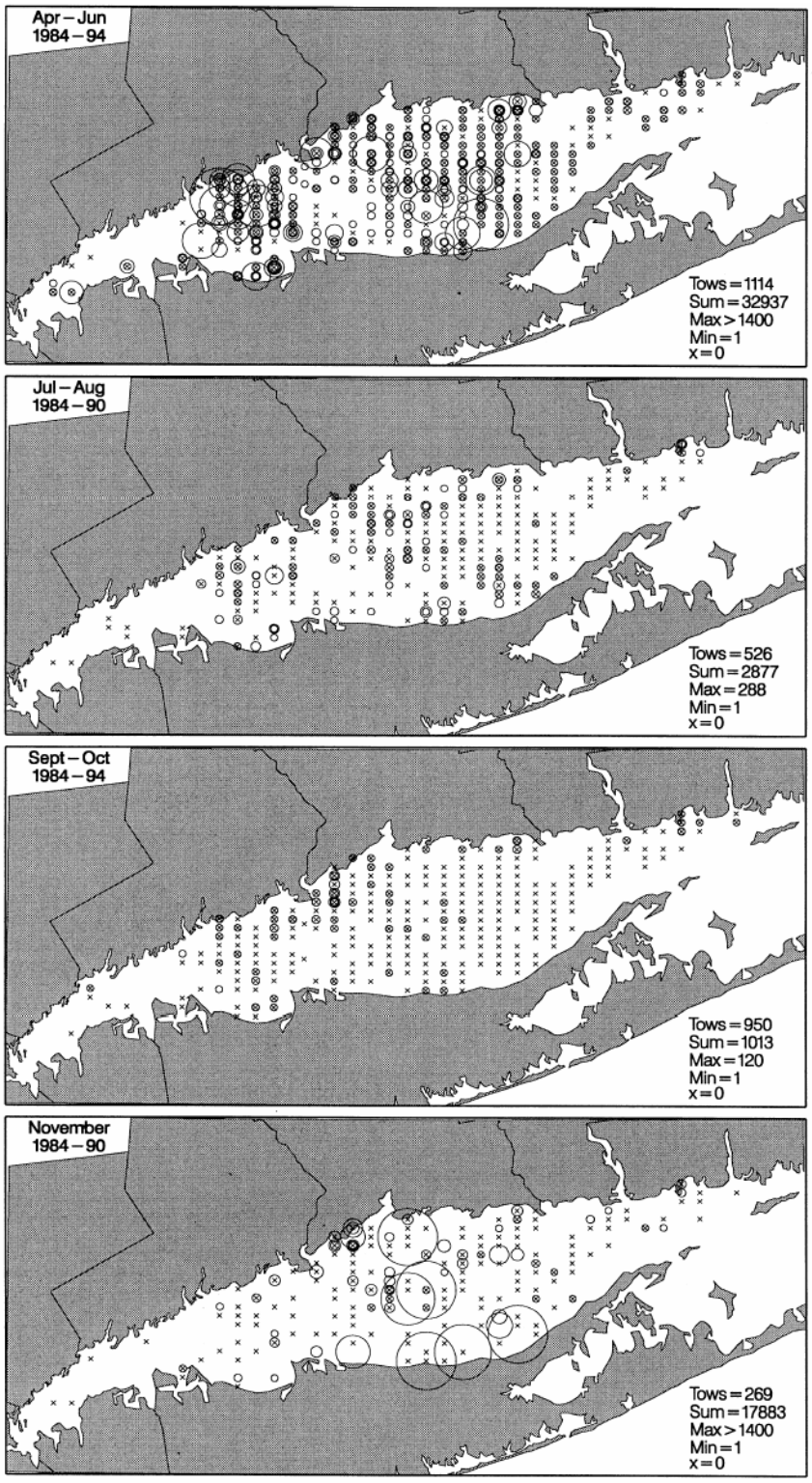

Figure 21. Distribution and abundances of juvenile and adult Atlantic herring in Long Island Sound. Based on the finfish surveys of the Connecticut Fisheries Division, 1984-1994 [from Gottschall *et al.* (2000)]. Circle diameter is proportional to the number of fish caught, and is scaled to the maximum catch (indicated by "max=" or "max>"). Collections were made with a 14 m otter trawl at about 40 stations chosen by stratified random design.

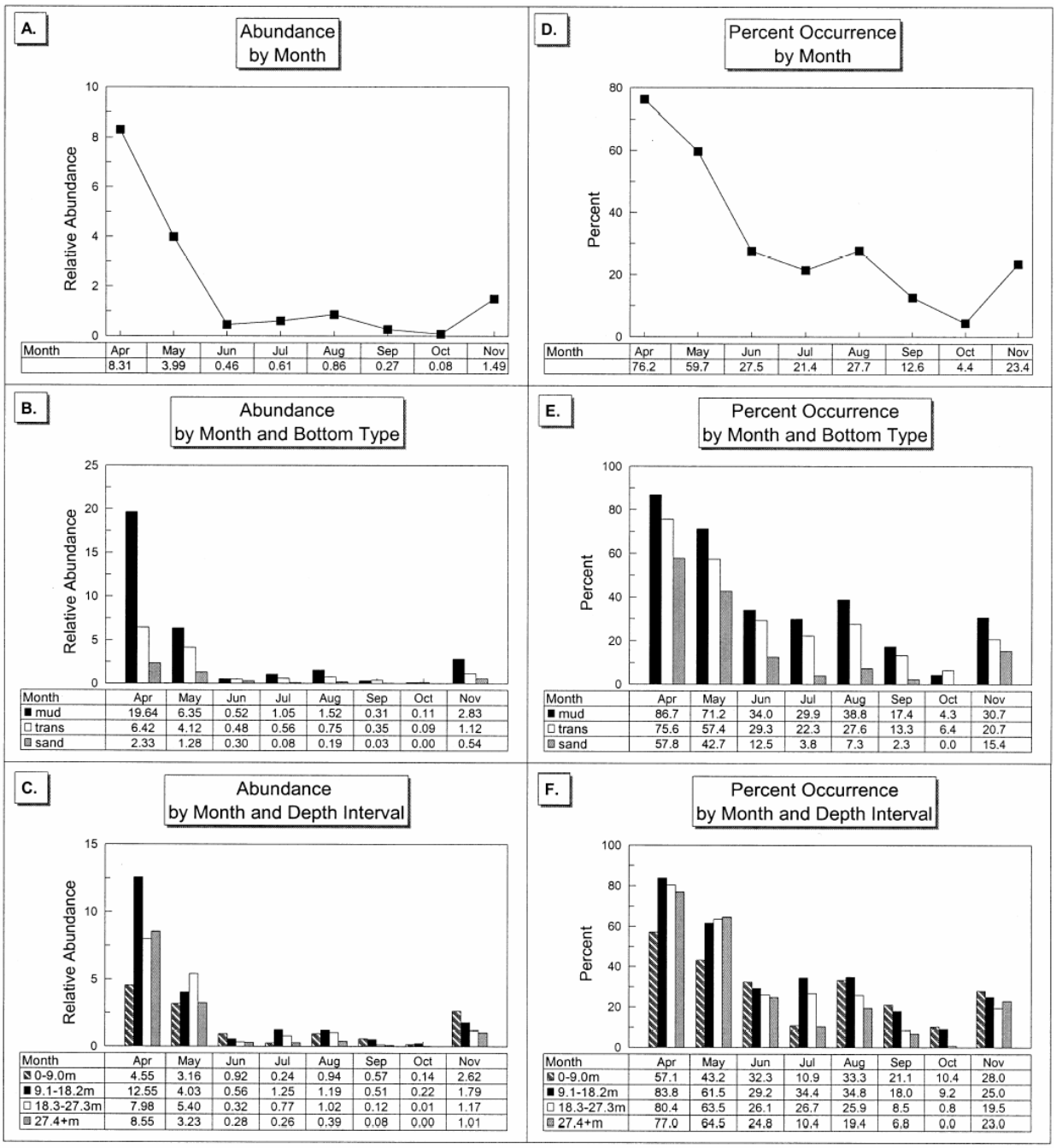

Figure 22. Relative abundance (geometric mean catch/tow) catch/tow and percent occurrence (proportion of samples in which at least one individual was observed) for juvenile and adult Atlantic herring in Long Island Sound. By month, month and bottom type, and month and depth interval. From Gottschall *et al.* (2000).

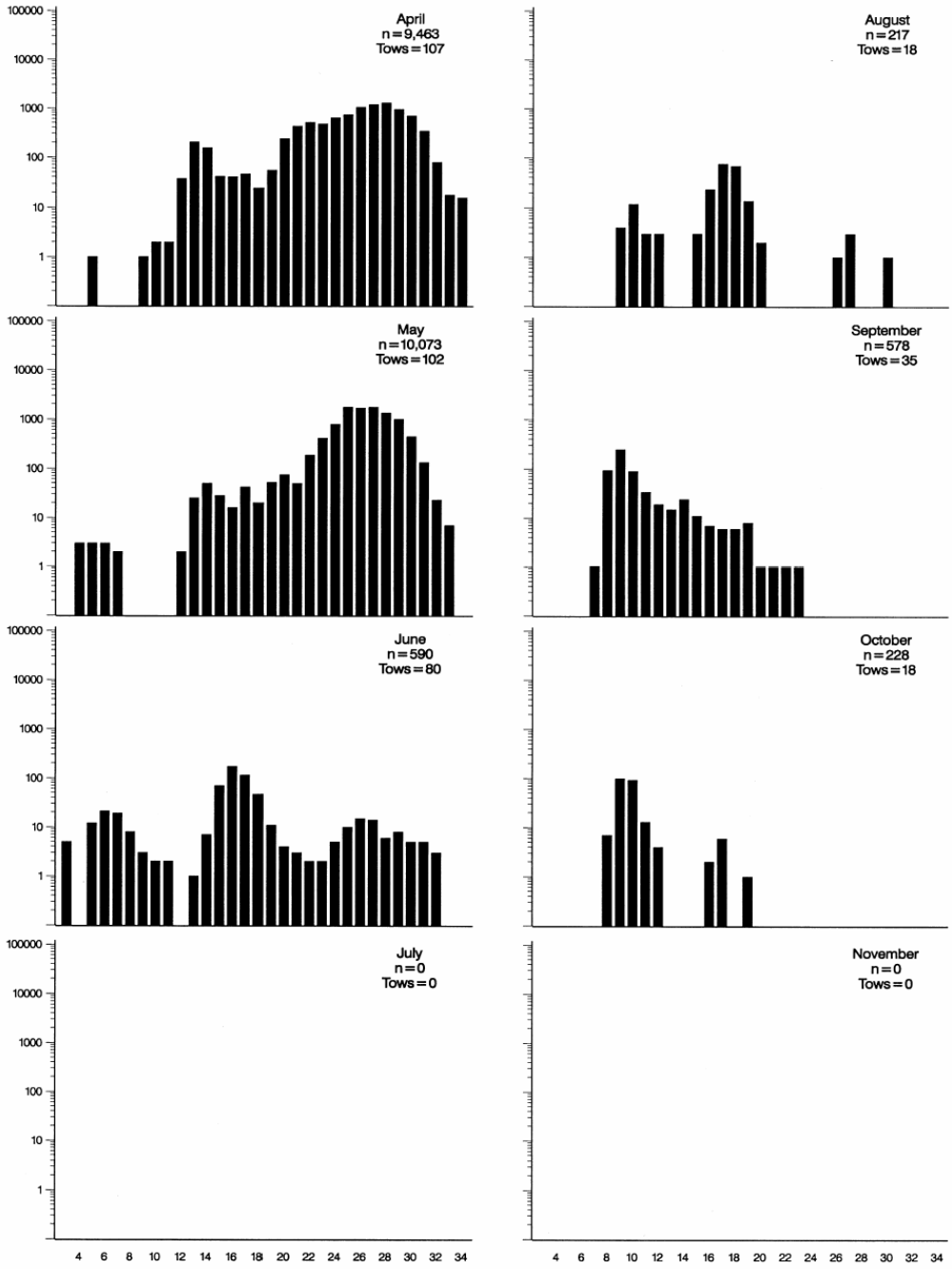

Figure 23. Monthly $\log_{10}$ length frequencies (cm) of juvenile and adult Atlantic herring collected in Long Island Sound. Based on 21,149 fish taken in 360 tows between 1989 and 1994. From Gottschall *et al.* (2000).

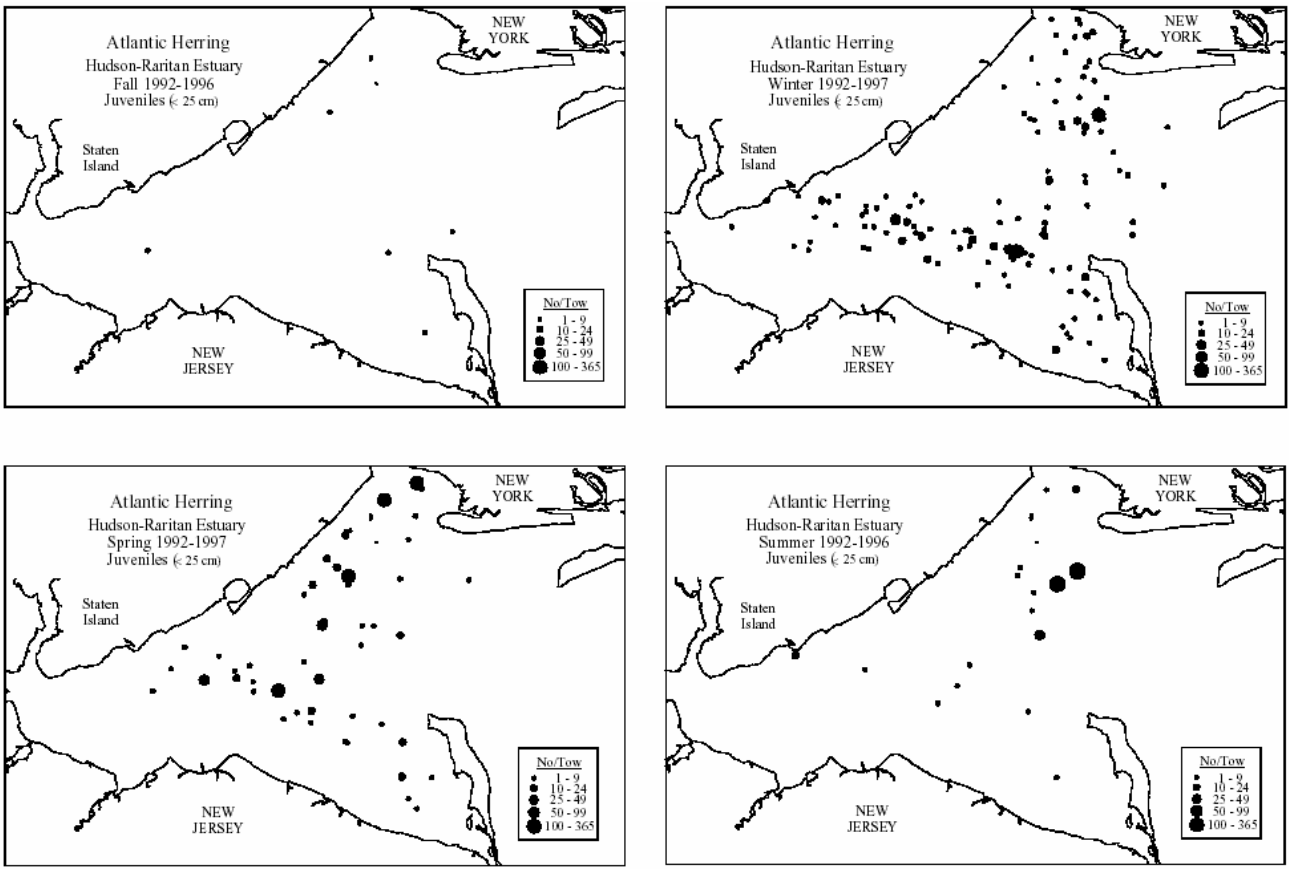

Figure 24. Seasonal distribution and abundance of juvenile Atlantic herring in the Hudson-Raritan Estuary. Based on Hudson-Raritan trawl surveys, January 1992 – June 1997 [see Reid *et al.* (1999b) for details].

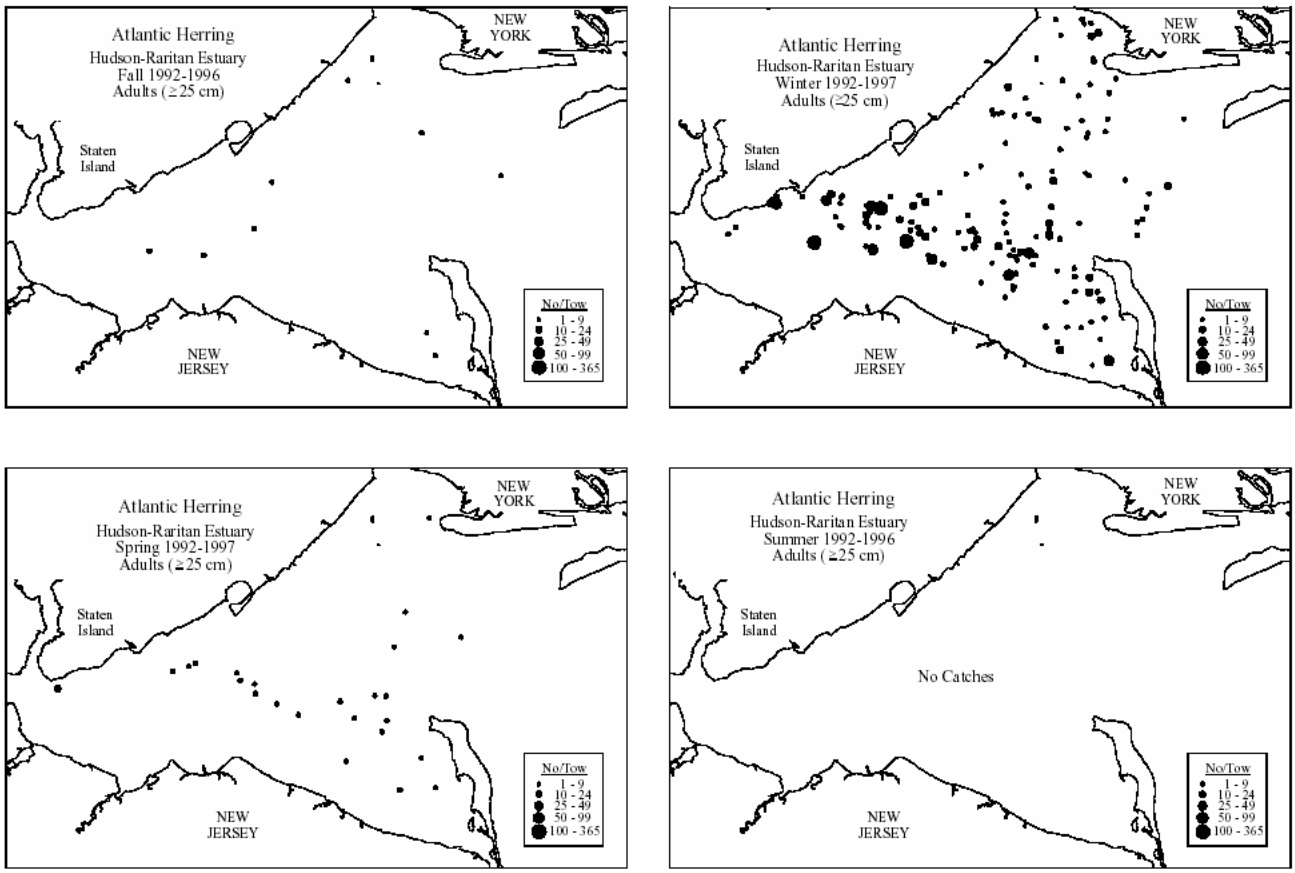

Figure 25. Seasonal distribution and abundance of adult Atlantic herring in the Hudson-Raritan Estuary. Based on Hudson-Raritan trawl surveys, January 1992 – June 1997 [see Reid *et al.* (1999b) for details].

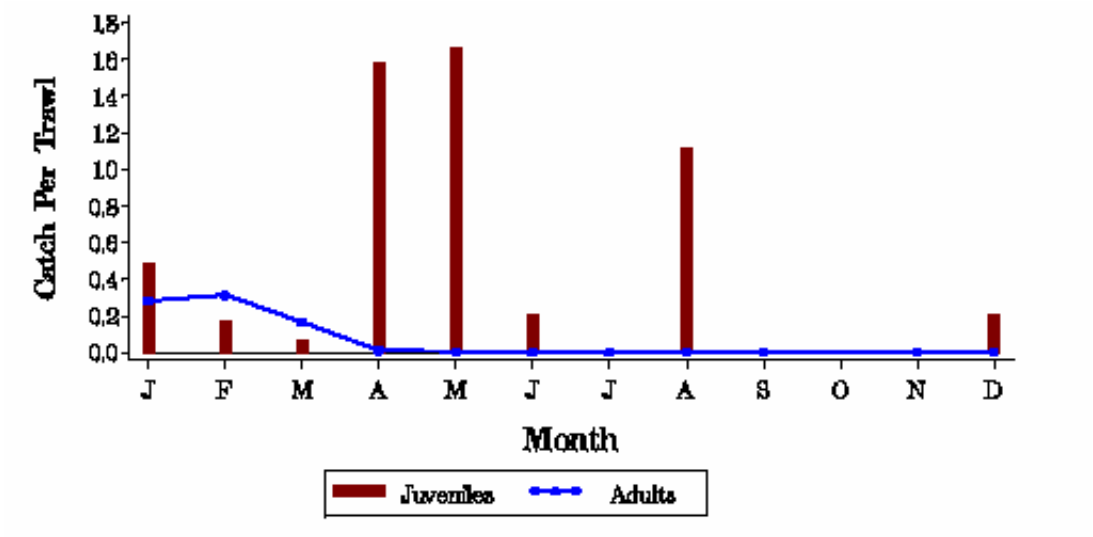

Figure 26. Catch per unit effort for total catch of juvenile and adult Atlantic herring in Chesapeake Bay, from the Virginia Institute of Marine Science's (VIMS) trawl surveys, 1988-1999 (all years combined). Monthly surveys were conducted using a random stratified design of the main stem of the Bay using a 9.1 m semi-balloon otter trawl with 38 mm mesh and 6.4 mm cod end with a tow duration of five minutes. Source: Geer (2002).

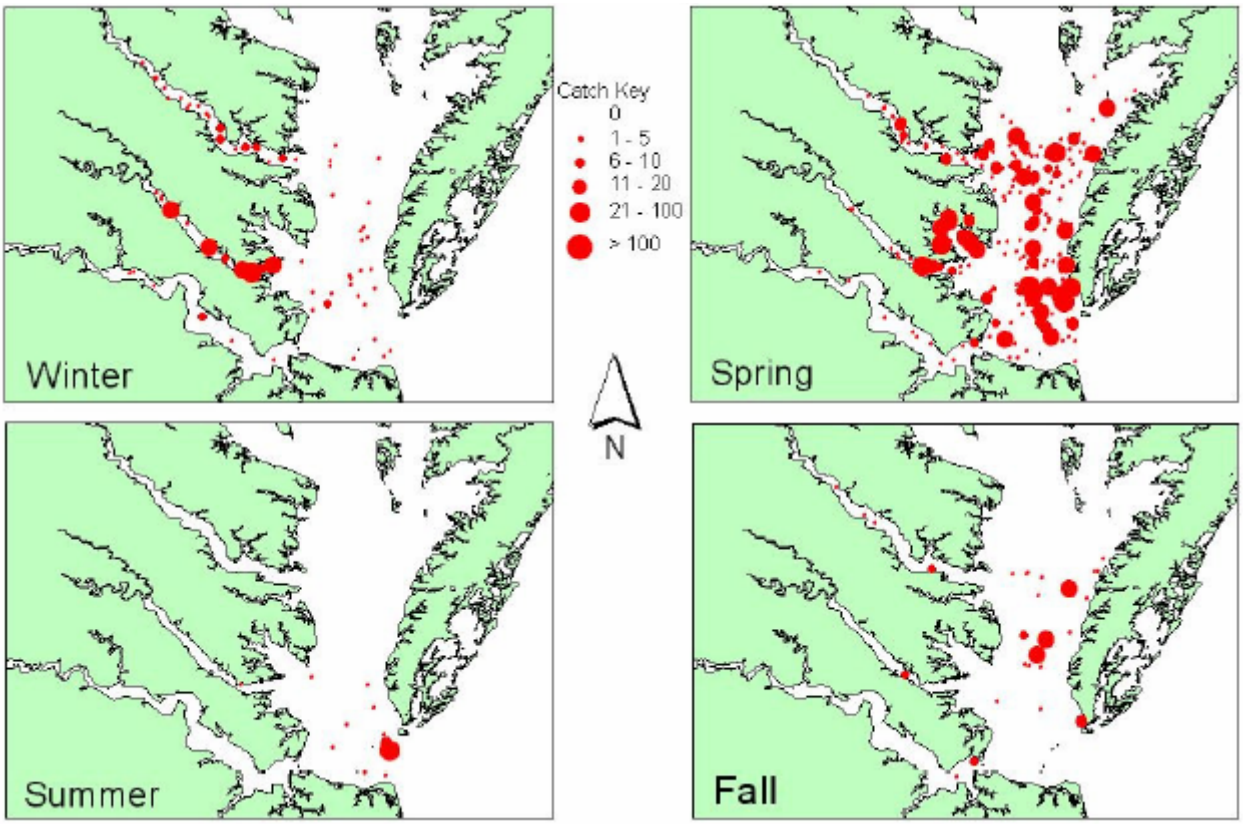

Figure 27. Seasonal distribution and abundance of juvenile Atlantic herring in Chesapeake Bay, from the VIMS trawl surveys, 1988-1999 (all years combined). Source: Geer (2002).

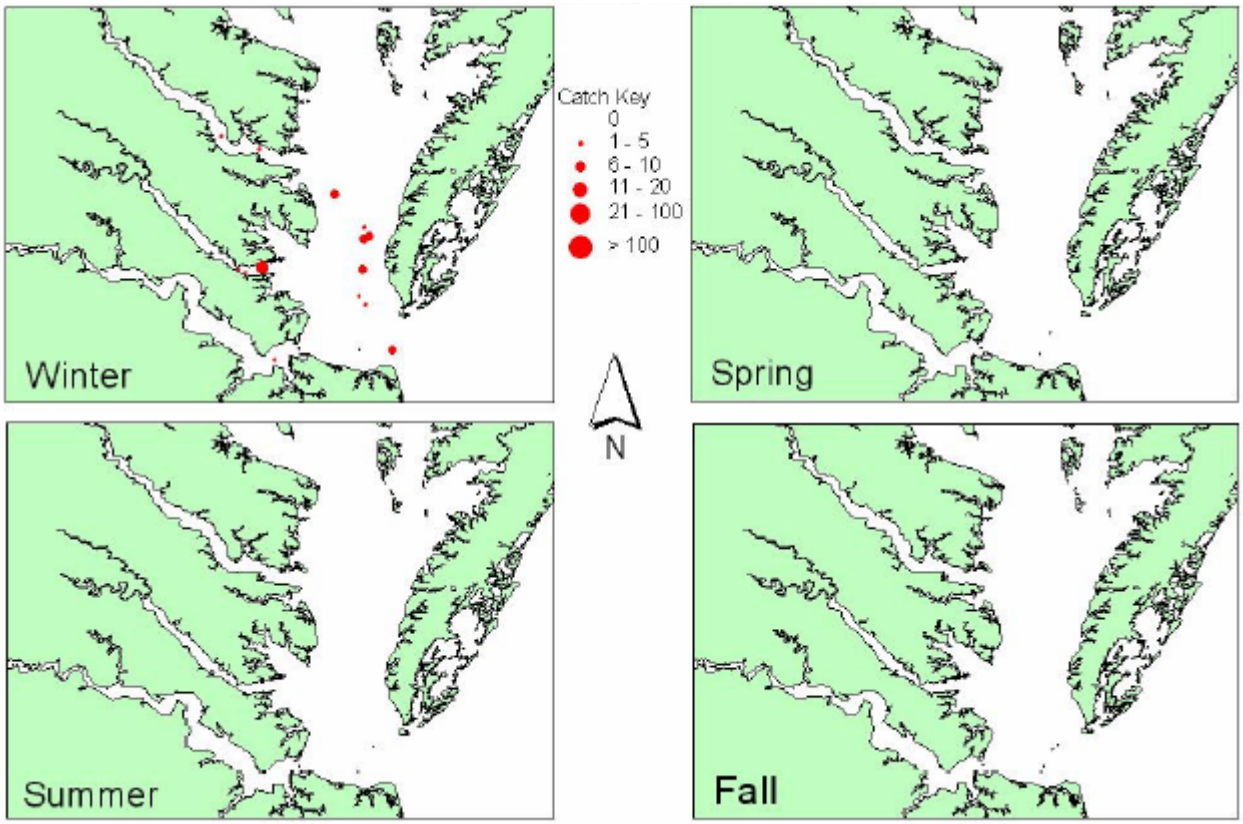

Figure 28. Seasonal distribution and abundance of adult Atlantic herring in Chesapeake Bay, from the VIMS trawl surveys, 1988-1999 (all years combined). Source: Geer (2002).

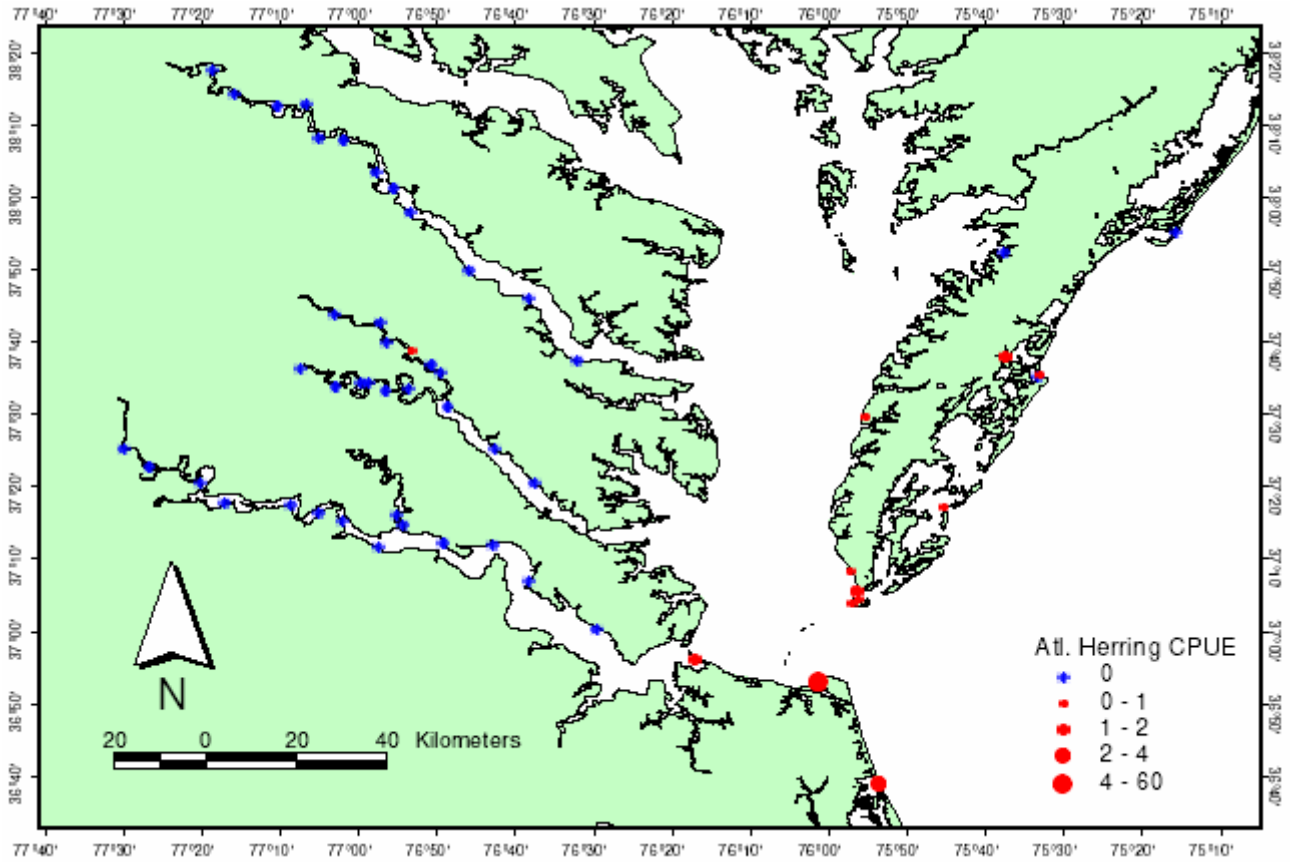

Figure 29. Atlantic herring catch per unit effort by site from the VIMS beach seine surveys, 1994-1999 (all years combined). Source: Geer (2002).

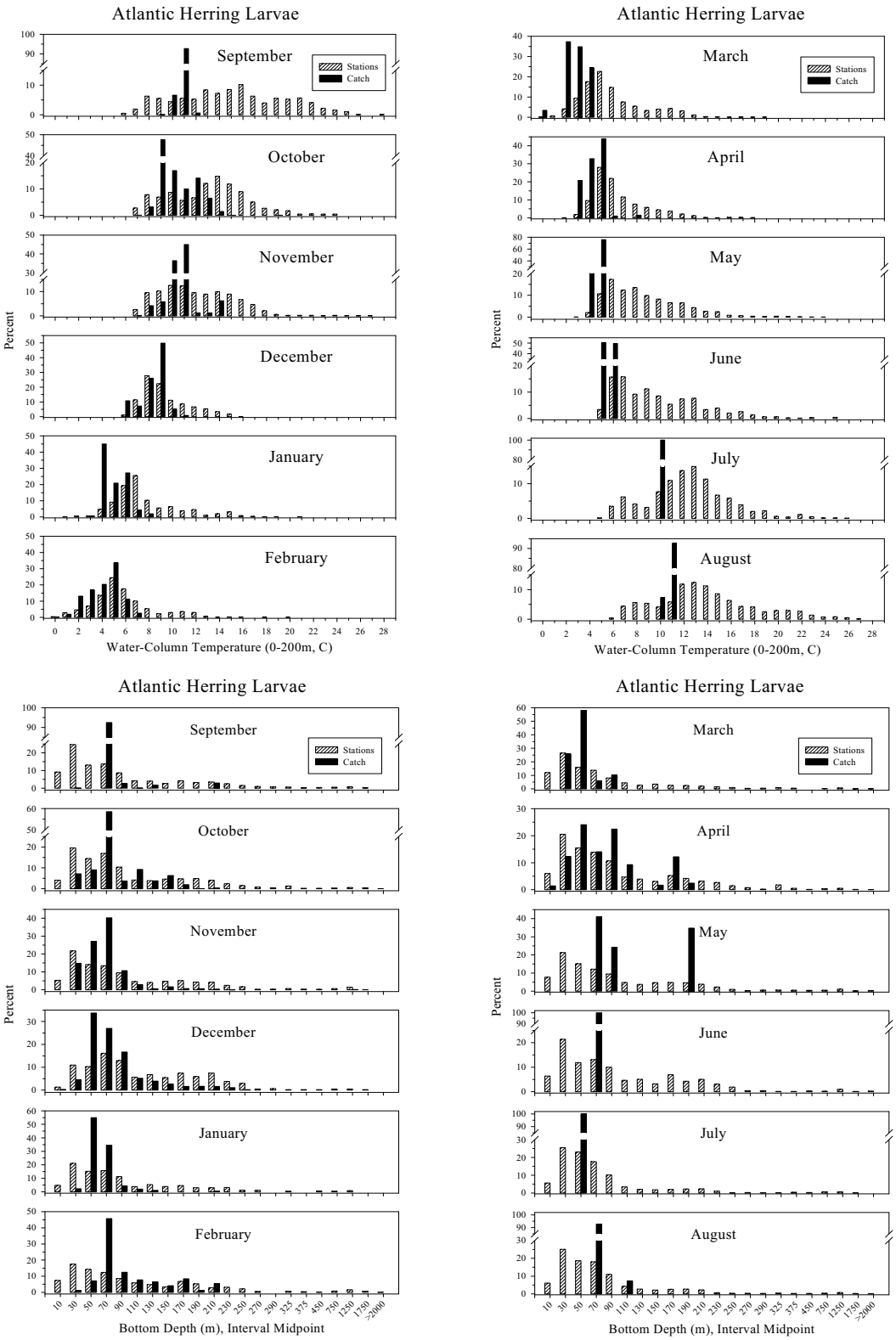

Figure 30. Distributions of Atlantic herring larvae collected during NEFSC MARMAP icthyoplankton surveys relative to water column temperature and bottom depth.
For the years 1977-1987, by month for all years combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth interval changes with increasing depth.

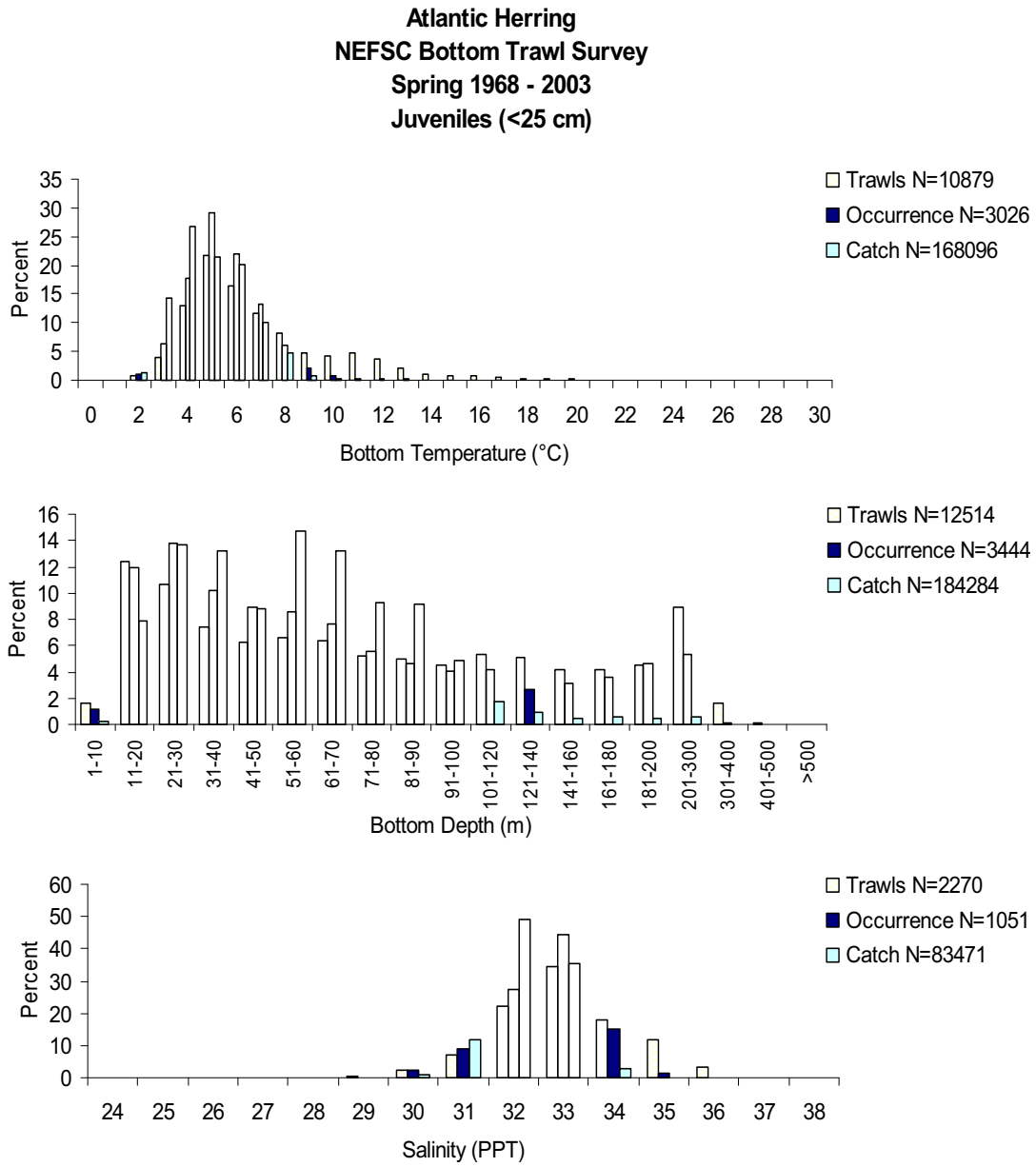

Figure 31. Distributions of juvenile Atlantic herring and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic herring occurred and medium bars show, within each interval, the percentage of the total number of Atlantic herring caught. Note that the bottom depth interval changes with increasing depth.

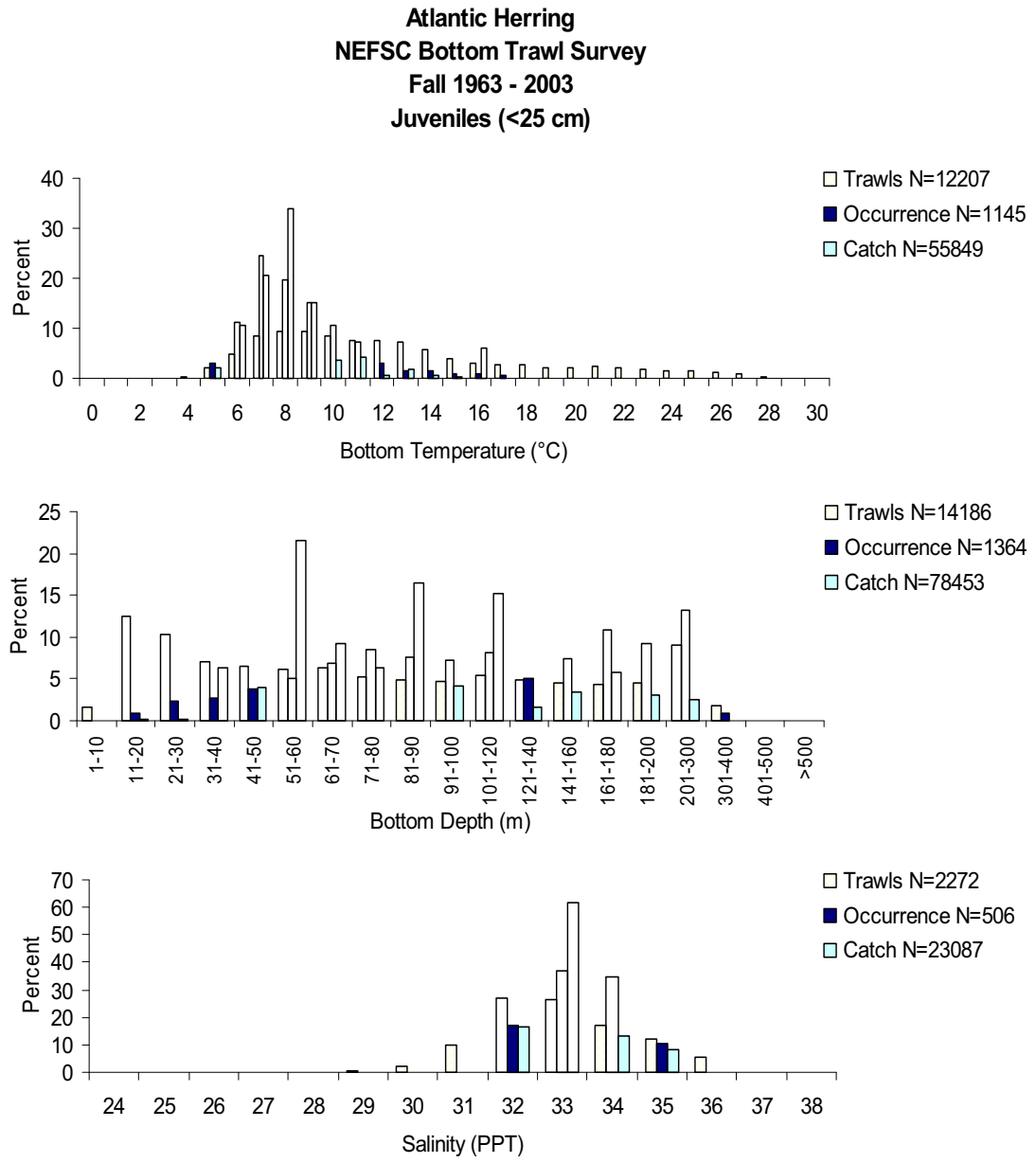

Figure 31. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic herring occurred and medium bars show, within each interval, the percentage of the total number of Atlantic herring caught. Note that the bottom depth interval changes with increasing depth.

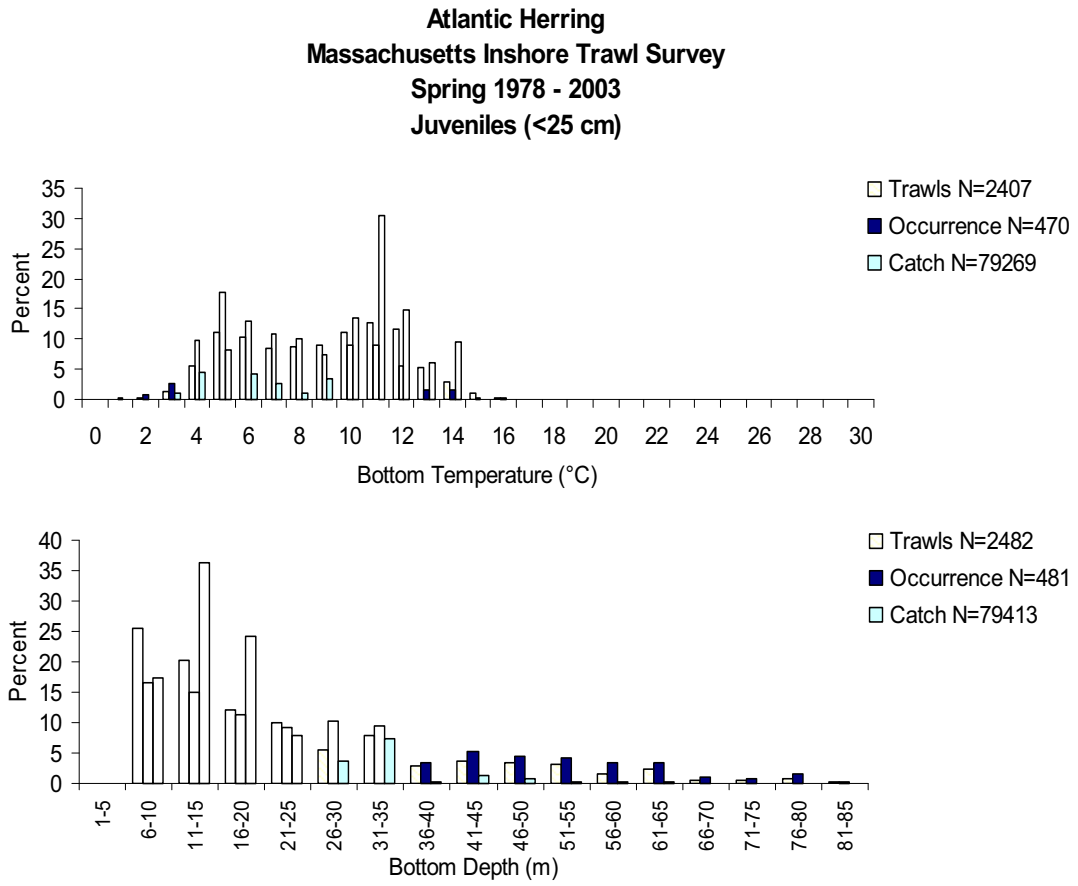

Figure 32. Distributions of juvenile Atlantic herring and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic herring occurred and medium bars show, within each interval, the percentage of the total number of Atlantic herring caught.

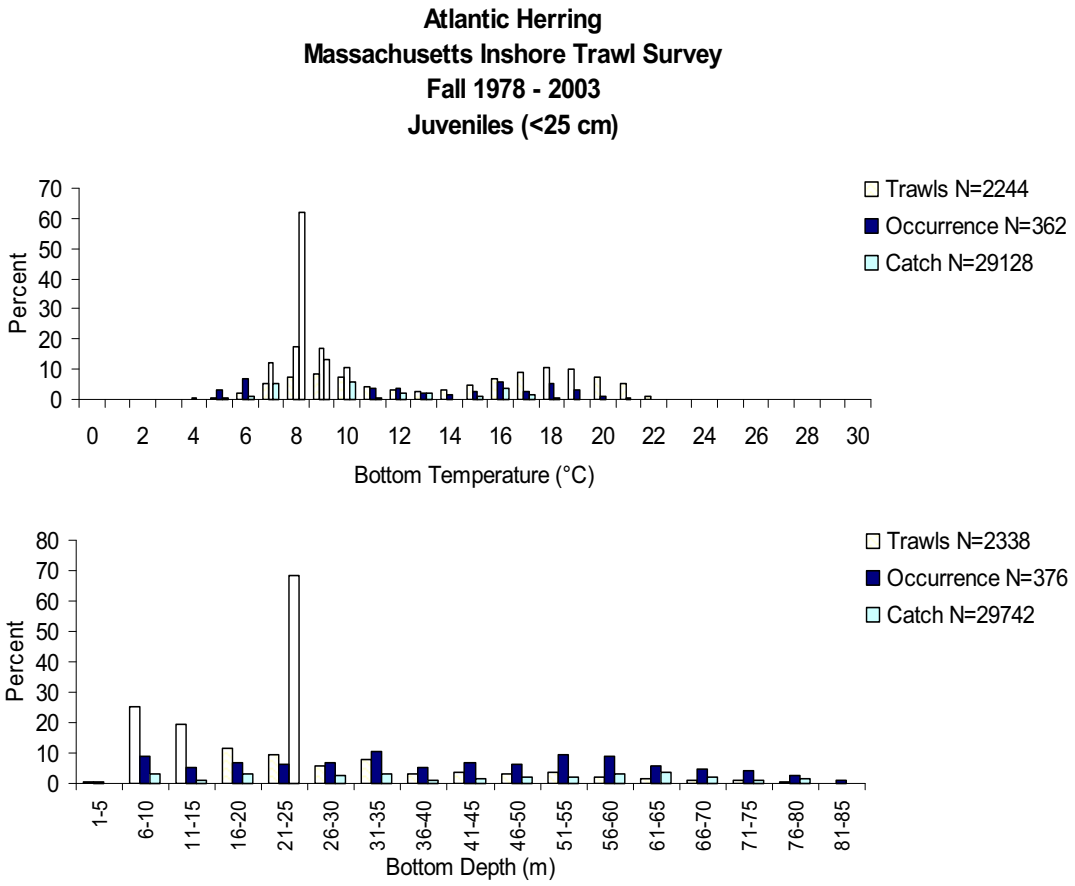

Figure 32. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic herring occurred and medium bars show, within each interval, the percentage of the total number of Atlantic herring caught.

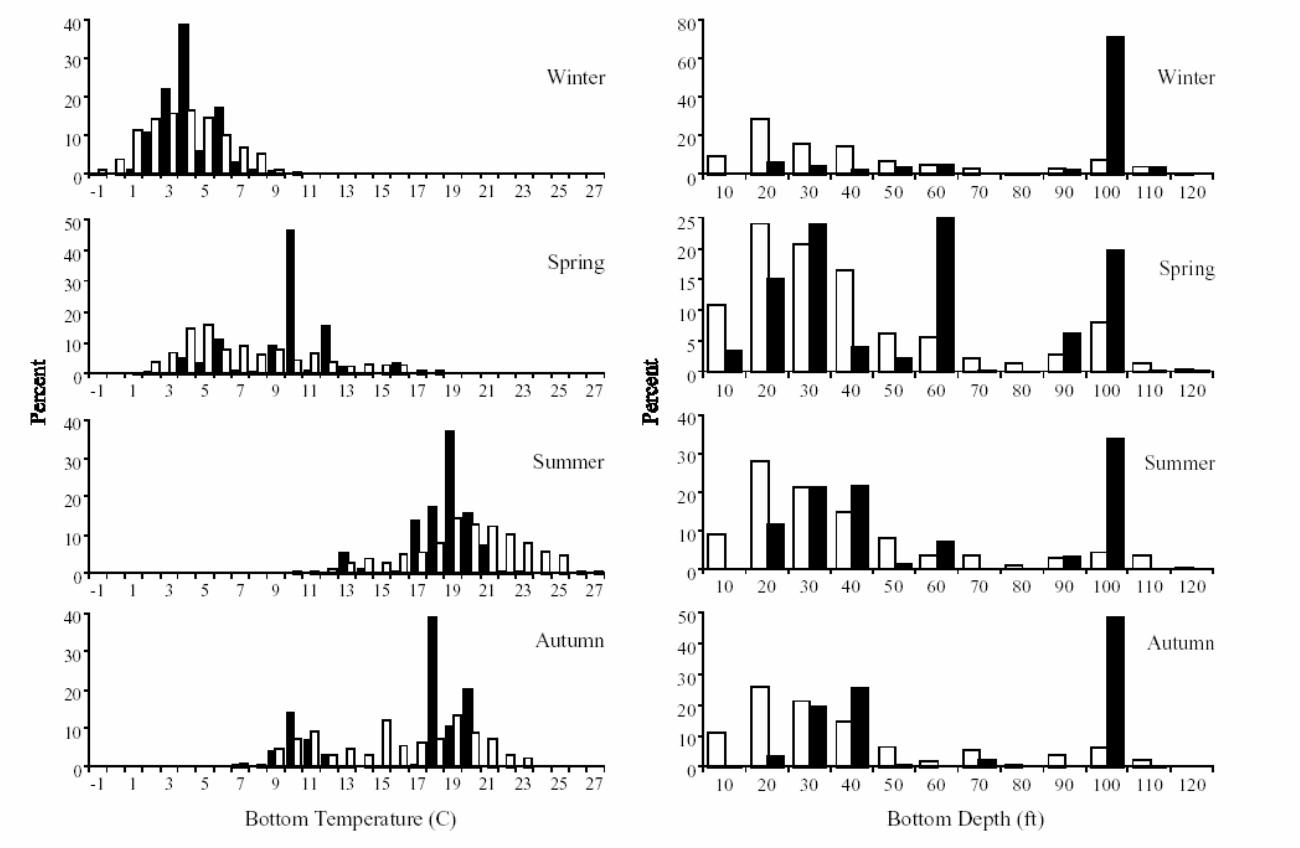

Figure 33. Distributions of juvenile Atlantic herring in Narragansett Bay relative to mean bottom temperature and bottom depth.
Based on the Rhode Island bottom trawl survey, 1990-1996. Open bars represent stations surveyed and closed bars represent fish collected.

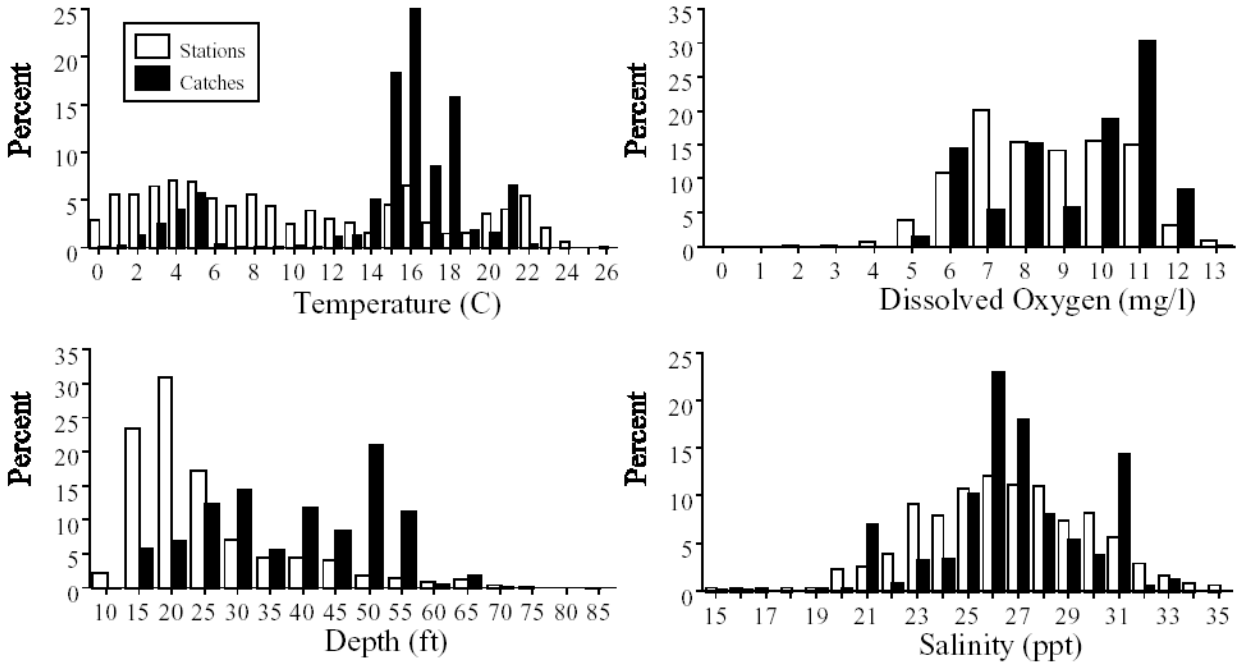

Figure 34. Distributions of juvenile Atlantic herring in the Hudson-Raritan Estuary relative to mean water temperature, depth, dissolved oxygen, and salinity.
Based on the Hudson-Raritan trawl surveys, 1992-1997. Open bars represent stations surveyed and closed bars represent fish collected.

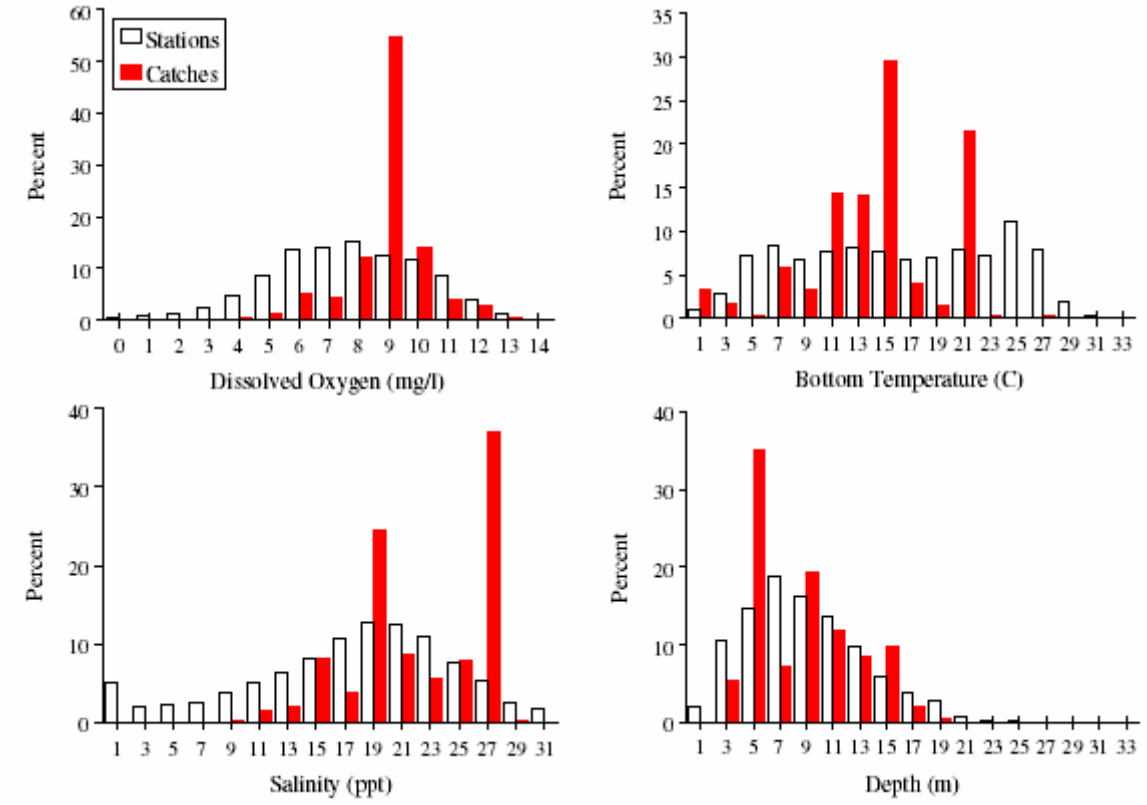

Figure 35. Hydrographic preferences for juvenile Atlantic herring in Chesapeake Bay, from the VIMS trawl surveys, 1988-1999 (all years combined). Source: Geer (2002).

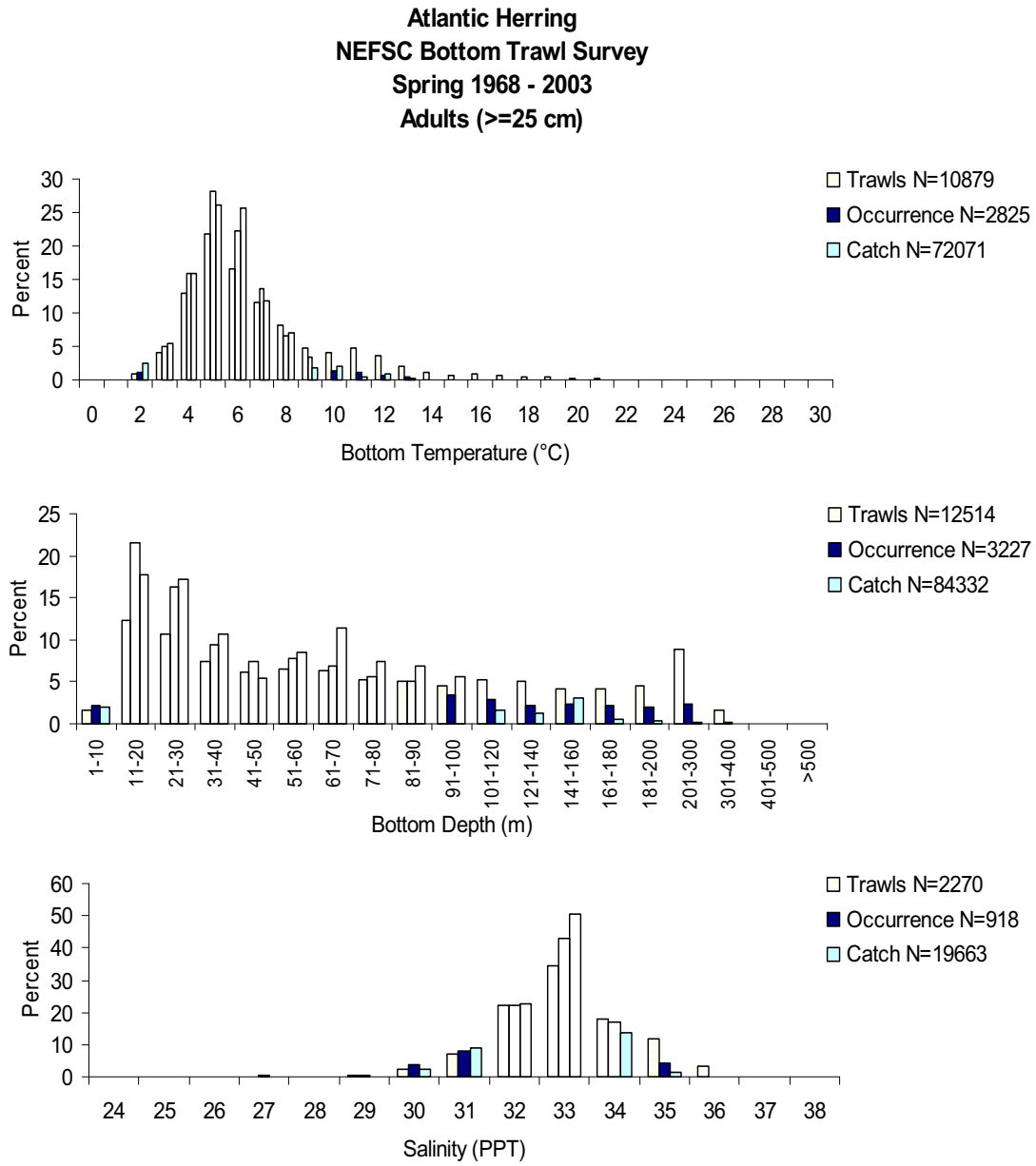

Figure 36. Distributions of adult Atlantic herring and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic herring occurred and medium bars show, within each interval, the percentage of the total number of Atlantic herring caught. Note that the bottom depth interval changes with increasing depth.

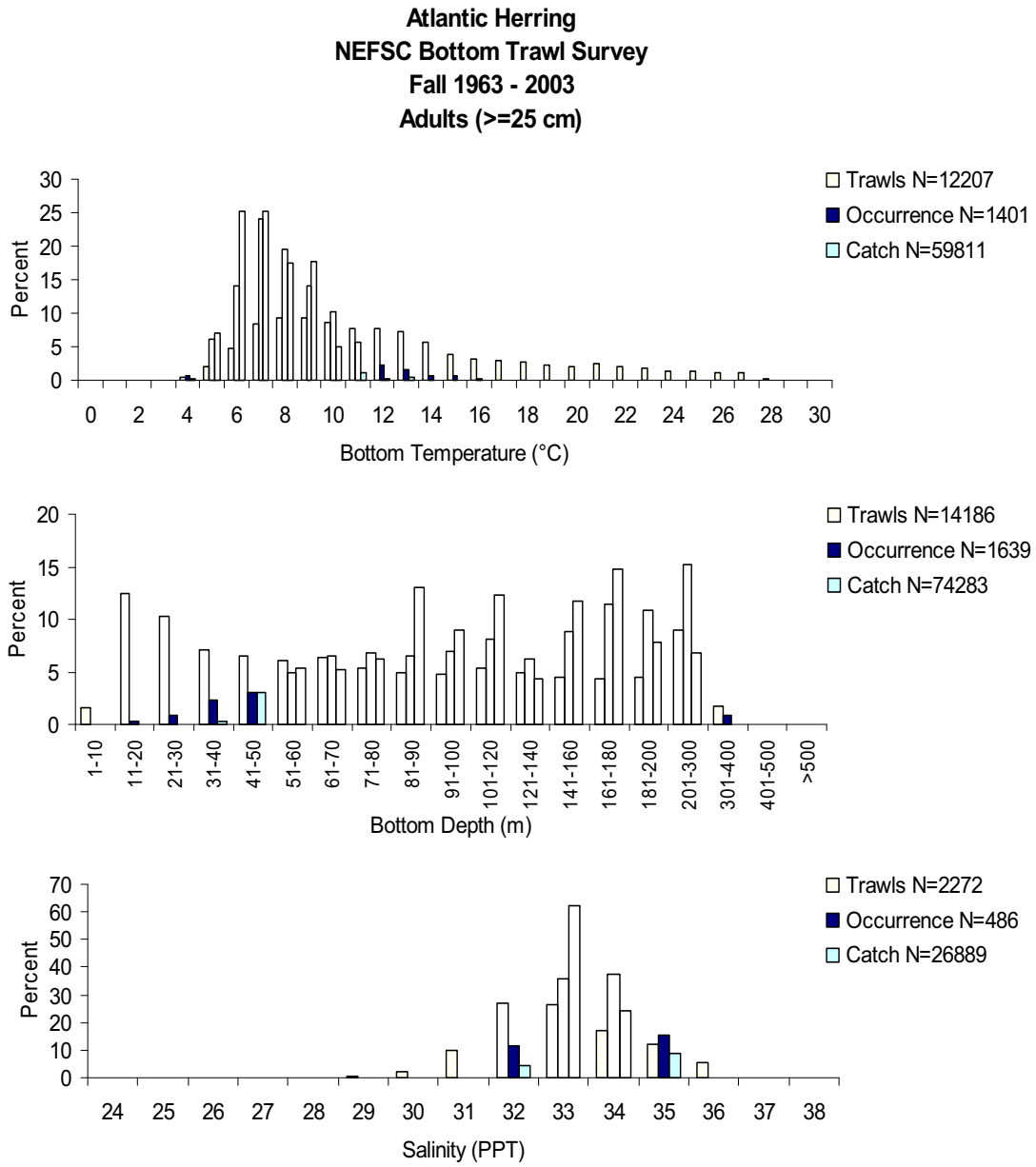

Figure 36. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic herring occurred and medium bars show, within each interval, the percentage of the total number of Atlantic herring caught. Note that the bottom depth interval changes with increasing depth.

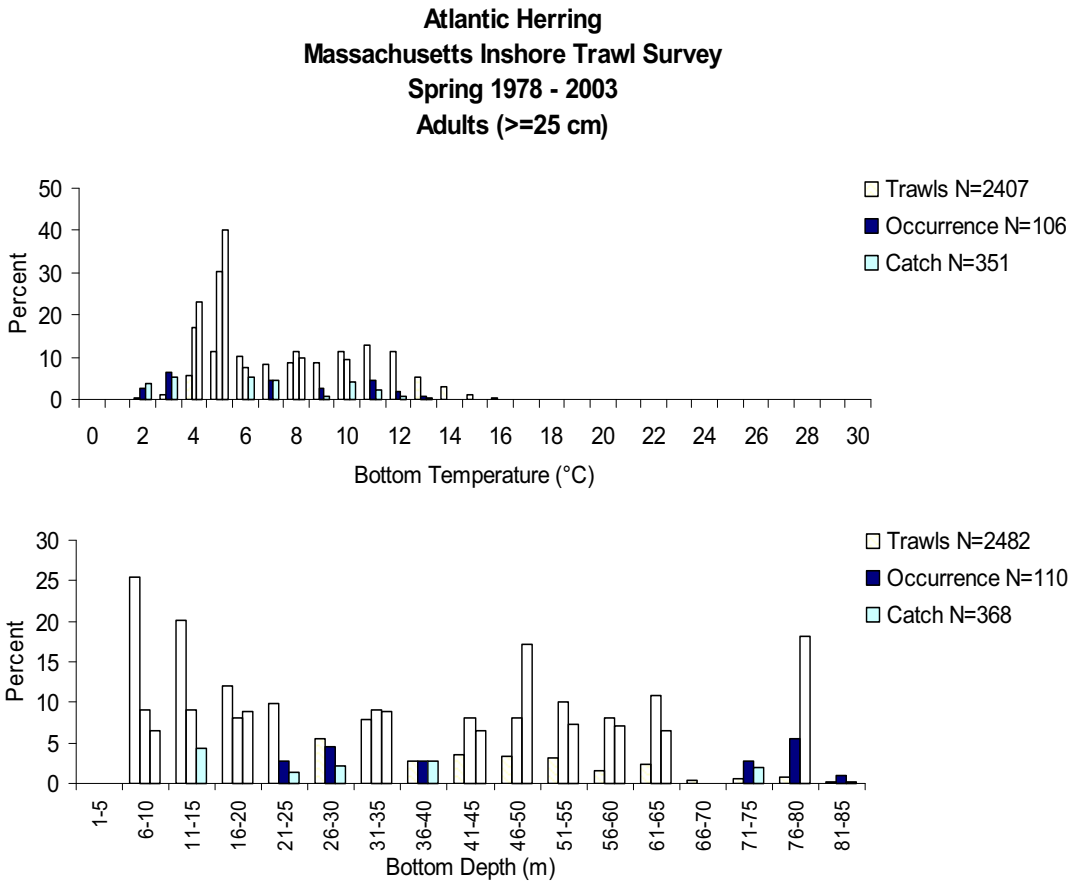

Figure 37. Distributions of adult Atlantic herring and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic herring occurred and medium bars show, within each interval, the percentage of the total number of Atlantic herring caught.

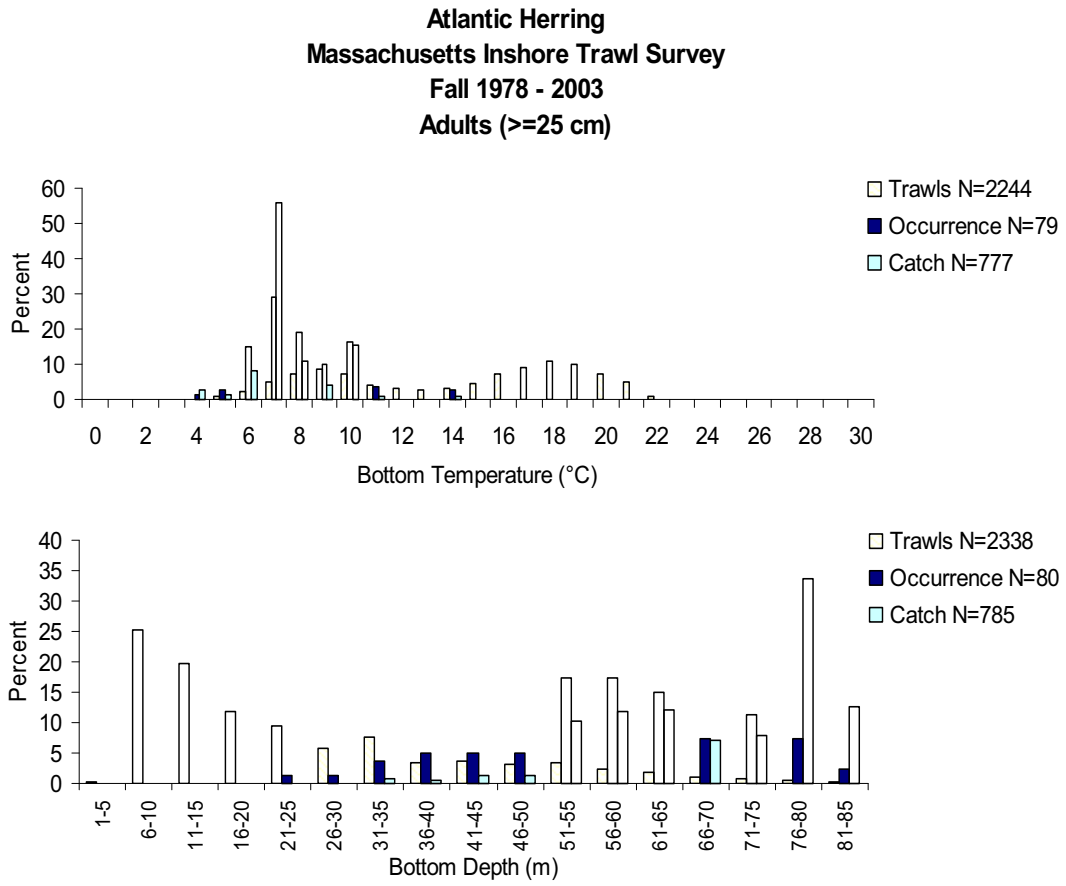

Figure 37. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which Atlantic herring occurred and medium bars show, within each interval, the percentage of the total number of Atlantic herring caught.

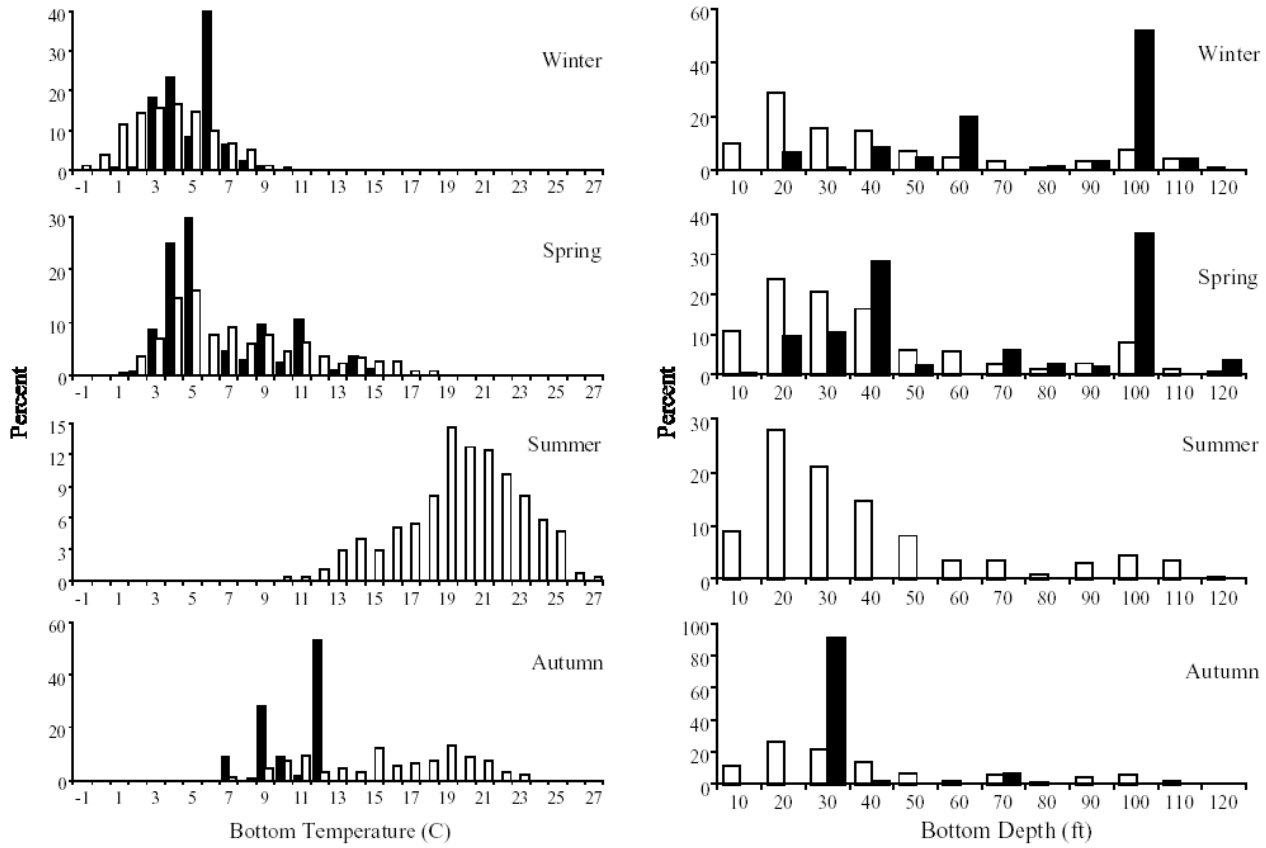

Figure 38. Distributions of adult Atlantic herring in Narragansett Bay relative to mean bottom temperature and bottom depth.
Based on the Rhode Island bottom trawl survey, 1990-1996. Open bars represent stations surveyed and closed bars represent fish collected.

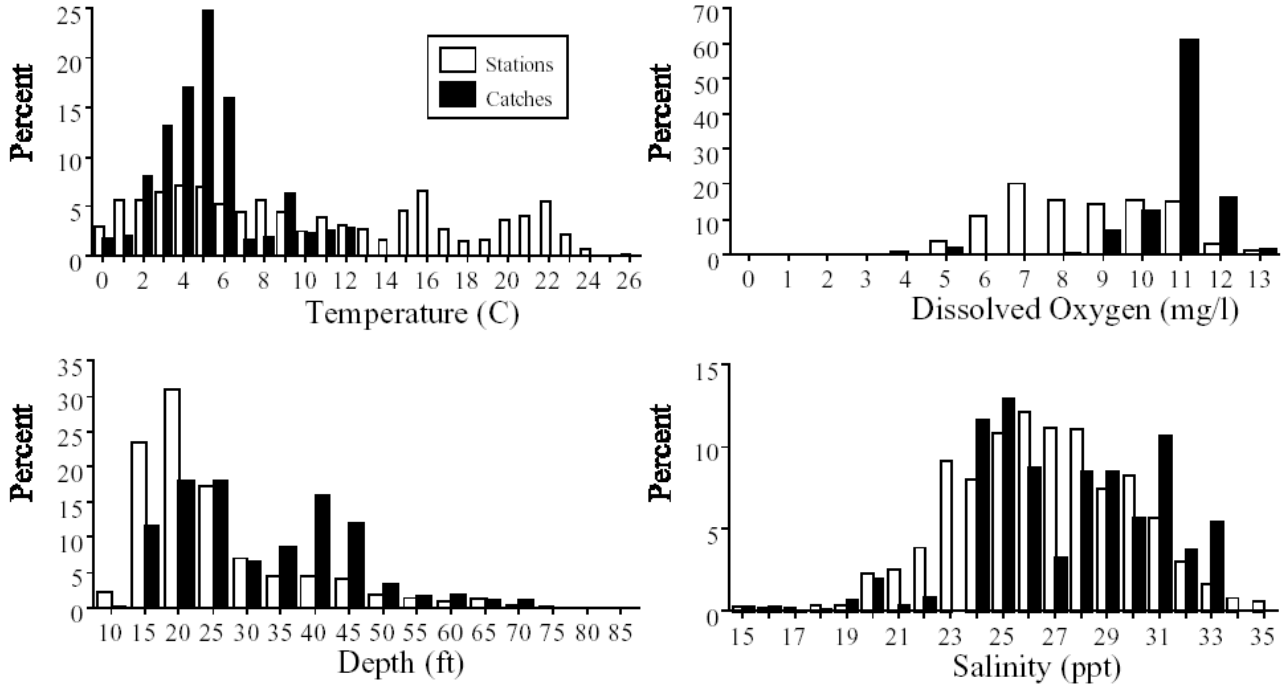

Figure 39. Distributions of adult Atlantic herring in the Hudson-Raritan Estuary relative to mean water temperature, depth, dissolved oxygen, and salinity.
Based on the Hudson-Raritan trawl surveys, 1992-1997. Open bars represent stations surveyed and closed bars represent fish collected.

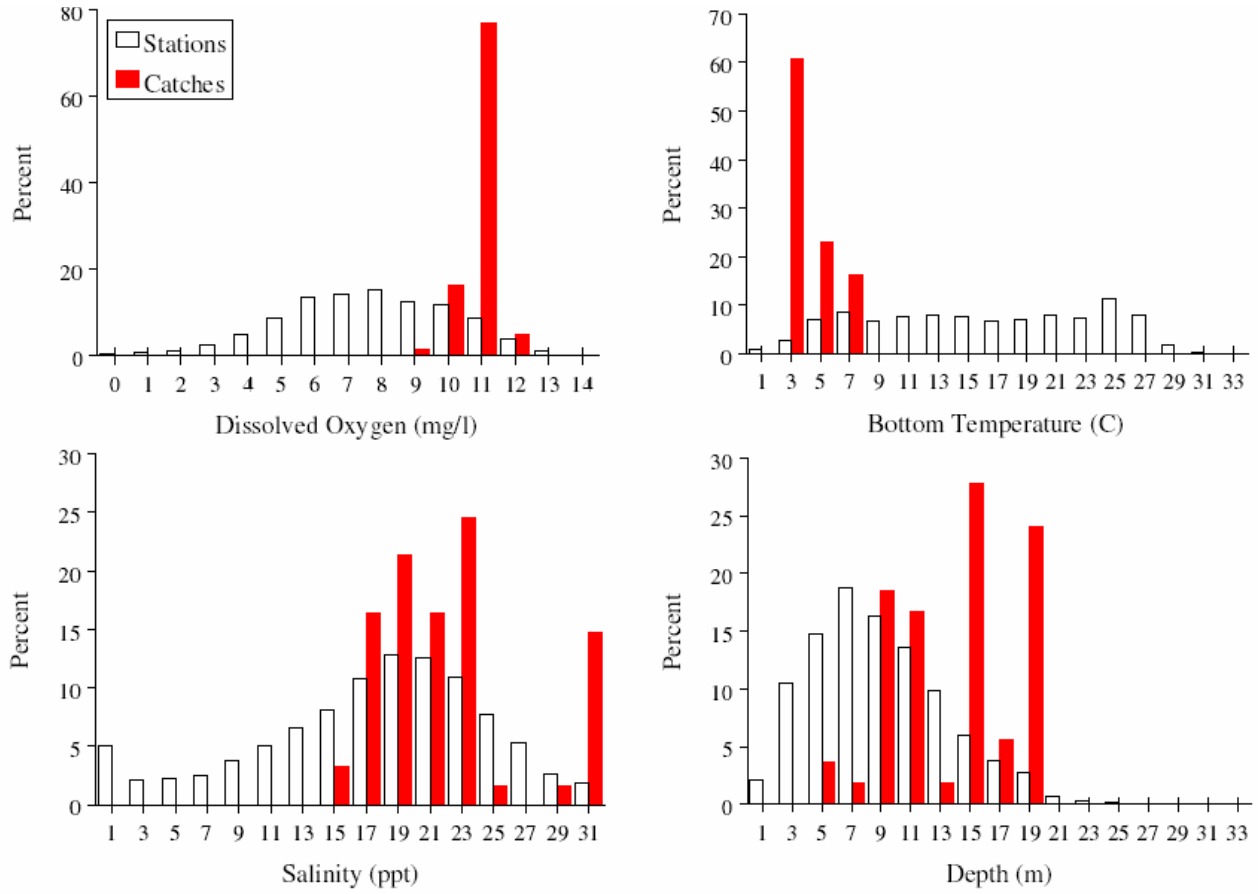

Figure 40. Hydrographic preferences for adult Atlantic herring in Chesapeake Bay, from the VIMS trawl surveys, 1988-1999 (all years combined). Source: Geer (2002).

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Authors must submit one paper copy of the double-spaced manuscript, one disk copy, and original figures (if applicable). NEFSC authors must include a completely signed-off "NEFSC Manuscript/Abstract/Webpage Review Form." Non-NEFSC authors who are not federal employees will be required to sign a "Release of Copyright" form.

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Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Currently, there are three such media:

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NOAA Technical Memorandum NMFS-NE-193

Essential Fish Habitat Source Document:

Longfin Inshore Squid, *Loligo pealeii*, Life History and Habitat Characteristics

Second Edition

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

August 2005

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Essential Fish Habitat Source Document:

Longfin Inshore Squid, *Loligo pealeii*, Life History and Habitat Characteristics

Second Edition

Larry D. Jacobson

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Northeast Fisheries Science Center
Woods Hole, Massachusetts

August 2005

Editorial Notes on "Essential Fish Habitat Source Documents" Issued in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For "Essential Fish Habitat Source Documents" issued in the *NOAA Technical Memorandum NMFS-NE* series, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division largely assume the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production is performed by, and all credit for such production rightfully belongs to, the staff of the Ecosystems Processes Division.

Internet Availability and Information Updating

Each original issue of an "Essential Fish Habitat Source Document" is published both as a paper copy and as a Web posting. The Web posting, which is in "PDF" format, is available at: *http://www.nefsc.noaa.gov/nefsc/habitat/efh*.

Each issue is updated at least every five years. The updated edition will be published as a Web posting only; the replaced edition(s) will be maintained in an online archive for reference purposes.

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The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Nelson *et al*. 2004[a]; Robins *et al.* 1991[b]), mollusks (*i.e.*, Turgeon *et al.* 1998[c]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[d]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[e]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species.

---

[a]Nelson, J.S.; Crossman, E.J.; Espinosa-Pérez, H.; Findley, L.T.; Gilbert, C.R.; Lea, R.N.; Williams, J.D. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. 6th ed. *Amer. Fish. Soc. Spec. Publ.* 29; 386 p.

[b]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. World fishes important to North Americans. *Amer. Fish. Soc. Spec. Publ.* 21; 243 p.

[c]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

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PREFACE TO SECOND EDITION

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NOAA Fisheries to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NOAA Fisheries has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in a series of EFH species reports (plus one consolidated methods report). The EFH species reports are a survey of the important literature as well as original analyses of fishery-independent data sets from NOAA Fisheries and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and understandably are referred to as the "EFH source documents."

NOAA Fisheries provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

The initial series of EFH species source documents were published in 1999 in the *NOAA Technical Memorandum NMFS-NE* series. Updating and review of the EFH components of the councils' Fishery Management Plans is required at least every 5 years by the NOAA Fisheries Guidelines for meeting the Sustainable Fisheries Act/EFH Final Rule. The second editions of these species source documents were written to provide the updated information needed to meet these requirements. The second editions provide new information on life history, geographic distribution, and habitat requirements via recent literature, research, and fishery surveys, and incorporate updated and revised maps and graphs. This second edition of the longfin inshore squid EFH source document is based on the original by Luca M. Cargnelli, Sara J. Griesbach, Cathy McBride, Christine A. Zetlin, and Wallace W. Morse, with a foreword by Jeffrey N. Cross (Cargnelli *et al*. 1999).

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NOAA Fisheries, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

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INTRODUCTION

The longfin inshore squid, *Loligo pealeii*, is a schooling species of the molluscan family Loliginidae (Figure 1). It is distributed in continental shelf and slope waters from Newfoundland to the Gulf of Venezuela, and occurs in commercial abundance from southern Georges Bank to Cape Hatteras. The fishery for longfin inshore squid is managed by the Mid-Atlantic Fishery Management Council under the Atlantic Mackerel, Squid and Butterfish Fishery Management Plan, Amendment 8 (MAFMC 1998). Within the range of commercial exploitation, the population is considered to be a single stock unit. This Essential Fish Habitat Source Document provides information on the life history and habitat characteristics of longfin inshore squid inhabiting the Gulf of Maine, Georges Bank, and the Middle Atlantic Bight.

LIFE HISTORY

See Brodziak (1995) for a brief synopsis of life history. More detailed information is provided here.

EGGS AND LARVAE

The 1 mm x 1.6 mm eggs are encased in a gelatinous capsule as they pass through the female oviduct during mating. Each capsule contains 150-200 eggs (Arnold *et al.* 1974; Gosner 1978; MAFMC 1998) and is about 50-80 mm long and 1 cm in diameter (Gosner 1978; Lange 1982; MAFMC 1998). During spawning, the male cements bundles of spermatophores into the mantle cavity of the female. The jelly is penetrated by sperm as the egg capsules pass through the oviduct (Black *et al.* 1987). The egg capsules are laid on the bottom in clusters 50-60 cm wide composed of hundreds of capsules (Gosner 1978; Griswold and Prezioso 1981). Each female lays 20-30 capsules (Lange 1982). The number of eggs spawned per female has been reported as 950-8,500 (Haefner 1959), 3,500-6,000 (Summers 1971), 2,500-15,900 (Vovk 1972b), and 3,000-6,000 (MAFMC 1998). Development time varies from 257 to 642 hrs depending on water temperature; 26.7 days to hatching at 12-18°C, 18.5 days at 15.5-21.3^{o}C, and 10.7 days at 15.5-23.0^{o}C (Summers 1971).

Larvae of the longfin inshore squid are referred to as paralarvae (Young and Harman 1988). Little is known about them because they are planktonic, being found in the water column near the surface (McMahon and Summers 1971), and require special sampling techniques. Larvae 2-4 mm in length have been caught in the Gulf of Maine (Bigelow 1924).

JUVENILES AND SUBADULTS

There are two juvenile stages. 'Juvenile' is the stage after the paralarval stage and before the 'subadult' stage. The subadult stage is before maturity, when morphological characteristics of adults are attained (Young and Harman 1988). The shift from inhabiting surface waters to a demersal lifestyle occurs at 45 mm (Vecchione 1981). Off Martha's Vineyard, the juvenile life stage lasts about 1 month. Subadults migrate by November to the outer shelf areas where they remain until March (Summers 1968a, b). Subadults are thought to overwinter in deeper waters along the edge of the continental shelf (Black *et al.* 1987). Young-of-the-year (subadults) are found with adults in mid-summer bottom trawl catches (Summers 1968a, b). Juveniles and subadults grow quickly, with growth rates dependent on temperature (Hatfield *et al*. 2001).

Sexual maturity is first reached at about 8-12 cm (Macy 1980; Brodziak and Hendrickson 1999). The length at which 50% of individuals are sexually mature (L_{50}) is 16-20 cm, depending on season and location (Brodziak 1995; Macy and Brodziak 2001; Hatfield and Cadrin 2002).

ADULTS

Historically, the lifespan of longfin inshore squid was believed to be 1-2 years (Summers 1971; Lange 1982). However, Brodziak and Macy (1996), using statolith aging, demonstrated exponential growth and a lifespan of less than 1 year.

Longfin inshore squid reach sizes greater than 40-50 cm mantle length (ML), although most are less than 30 cm (Vecchione *et al.* 1989; Brodziak 1995). They are sexually dimorphic – males grow more rapidly and reach larger size at age than females (Brodziak 1995). Growth depends on temperature (Hatfield *et al*. 2001) and is highest for individuals hatched during winter (Macy and Brodziak 2001). Longfin inshore squid migrate offshore during late autumn and overwinter in warmer waters along the edge of the continental shelf; they return inshore during the spring and early summer (MAFMC 1998). Mature individuals enter inshore waters before immature ones (Macy 1982). Off Massachusetts, larger individuals migrate inshore in April-May while smaller individuals move inshore in the summer (Lange 1982). Longfin inshore squid form large schools based on size prior to feeding (Macy 1980) and make diurnal vertical migrations up into the water column at night (MAFMC 1998). This

movement may be associated with the pursuit of food organisms such as euphausiids.

REPRODUCTION

Brodziak and Macy (1996), Macy and Brodziak (2001), and Hatfield and Cadrin (2002) show that longfin inshore squid spawn year round with seasonal and geographic peaks that vary among years and geographic areas (Lange and Sissenwine 1980). Most eggs are spawned in May and hatching occurs in July (Summers 1971). Spawning has been reported from August to September in the Bay of Fundy (Stevenson 1934), from May to August in New England waters (Summers 1971; Macy 1980), and from late spring to early summer in the Middle Atlantic (Lange and Sissenwine 1983; Black *et al.* 1987). Mesnil (1977) reported that spawning on the Scotian Shelf and Georges Bank occurs during early spring and late summer. Spawning south of Cape Hatteras may also be important (Hatfield and Cadrin 2002).

Spawning has been reported in the Gulf of Maine in Cobequid Bay and Massachusetts Bay (Bigelow 1924), the Bay of Fundy (Stevenson 1934), Minas Basin (Cohen 1976), along the eastern coast of Nova Scotia in St. Margaret's and Terrence bays (Dawe *et al.* 1990), on Georges Bank (Mesnil 1977), and in the Middle Atlantic in Narragansett and Delaware bays (Haefner 1959; Griswold and Prezioso 1981).

Based on recent research, reproductive biology and behavior is complicated for longfin inshore squid. Visual and chemical cues regulate competition among males for females on spawning grounds (Buresch *et al*. 2003). Females may lay multiple clutches over periods of up to several weeks (Maxwell and Hanlon 2000; King *et al*. 2003). Eggs in the same capsule from a single female may have multiple fathers from multiple spawning events and females appear to store sperm from spawning events for later use (Buresch *et al*. 2001).

FOOD HABITS

The diet of the longfin inshore squid changes with size; small immature individuals feed on planktonic organisms (Vovk 1972b; Tibbetts 1977) while larger individuals feed on crustaceans and small fish (Vinogradov and Noskov 1979). Cannibalism is observed in individuals larger than 5 cm (Whitacker 1978). Studies by Vovk and Khvichiya (1980) and Vovk (1985) showed that juveniles 4.1-6 cm long fed on euphausiids and arrow worms, while those 6.1-10 cm fed mostly on small crabs, but also on polychaetes and shrimp. Adults 12.1-16 cm long fed on fish (clupeids, myctophids) and squid larvae/juveniles, and those > 16 cm fed on fish and squid (Vovk and Khvichiya 1980; Vovk 1985). Fish species preyed on by longfin inshore squid include silver hake, mackerel, herring, menhaden (Langton and Bowman 1977), sand lance, bay anchovy, menhaden, weakfish, and silversides (Kier 1982). Maurer and Bowman (1985) demonstrated the following seasonal and inshore/offshore differences in diet: in offshore waters in the spring, the diet is composed of crustaceans (mainly euphausiids) and fish; in inshore waters in the fall, the diet is composed almost exclusively of fish; and in offshore waters in the fall, the diet is composed of fish and squid.

PREDATION

Many pelagic and demersal fish species, as well as marine mammals and diving birds, prey upon juvenile and adult longfin inshore squid (Lange and Sissenwine 1980; Vovk and Khvichiya 1980; Summers 1983). Marine mammal predators include longfin pilot whale, *Globicephala melas*, and common dolphin, *Delphinus delphis* (Waring *et al.* 1990; Overholtz and Waring 1991; Gannon *et al.* 1997). Fish predators include bluefish, sea bass, mackerel, cod, haddock, pollock, silver hake, red hake, sea raven, spiny dogfish, angel shark, goosefish, dogfish, and flounder (Maurer 1975; Langton and Bowman 1977; Gosner 1978; Lange 1980).

GEOGRAPHICAL DISTRIBUTION

Longfin inshore squid occur from Newfoundland to the Gulf of Venezuela, however, the principal concentrations exploited in the United States occur from Georges Bank to Cape Hatteras (Brodziak 1995). Longfin inshore squid are generally found at water temperatures of at least 9°C (Lange and Sissenwine 1980). The population makes seasonal migrations that appear to be related to bottom water temperatures; they move offshore during late autumn to overwinter along the edge of the continental shelf and return inshore during the spring and early summer (MAFMC 1998). When inshore waters are coldest during winter and early spring, the population concentrates along the outer edge of the continental shelf. The inshore movement to the shelf areas takes place when water temperatures are rising (Black *et al.* 1987) and begins in the south and proceeds north along the coast (MAFMC 1998). A northerly extension of the range has been noted in summer (Black *et al.* 1987).

The terms 'pre-recruit' (unexploited sizes) and 'recruit' (exploited sizes) are often used in reference to

longfin inshore squid. Exploitation begins at a minimum mantle length of about 9 cm. Thus, pre-recruits are ≤ 8 cm and recruits are ≥ 9 cm.

EGGS AND LARVAE

The egg and larval stages of longfin inshore squid were not sampled by the Northeast Fisheries Science Center (NEFSC) Marine Resources Monitoring, Assessment and Prediction program (MARMAP) offshore ichthyoplankton surveys.

PRE-RECRUITS

The NEFSC bottom trawl surveys [see Reid *et al*. (1999) for details] captured longfin inshore squid pre-recruits during all seasons (Figure 2; note that winter and summer distributions are presented as presence only data, precluding a discussion of abundances.). In winter, pre-recruits were captured from Cape Hatteras to Nantucket Shoals, although most were found south of Long Island. They were generally found offshore and concentrated toward the 200 m isobath. They were distributed a little farther inshore in the southern part of the range, presumably due to warmer water temperatures. In the spring, the distribution extended farther to the south, with high concentrations south of Cape Hatteras, and farther to the north, with high numbers in southern New England and some catches on Georges Bank and the Scotian Shelf. Higher concentrations were found near the 200 m isobath. In summer, they were concentrated nearshore, with a few found on central Georges Bank. In autumn, longfin inshore squid were distributed along the coast of Maine, in Massachusetts Bay, and from Georges Bank to south of Cape Hatteras from nearshore to the 200 m isobath, with some of the highest concentrations found nearshore. This presumably indicates the beginning of the offshore migration.

The spring and fall distributions and abundances of pre-recruits around coastal Massachusetts, based on Massachusetts inshore bottom trawl surveys [see Reid et al. (1999) for details], are shown in Figure 3. In the spring, high concentrations occurred south of Cape Cod and around Martha's Vineyard and Nantucket Island. Low numbers were found in and around Cape Cod Bay, and none were captured north of Cape Cod. Much higher numbers of pre-recruits were found in the fall. High concentrations were found in Buzzards Bay, around Martha's Vineyard and Nantucket Island, throughout Cape Cod Bay, in Massachusetts Bay, and north and south of Cape Ann. The lower numbers of pre-recruits in inshore waters in the spring was most likely due to the survey occurring prior to the main part of the inshore migration.

The seasonal distributions and abundances of prerecruits in Narragansett Bay, based upon the 1990-1996 Rhode Island bottom trawl surveys, are shown in Figure 4. In winter, very few were caught, and they were only found at one station near the entrance to the Bay. Catches increased slightly in spring, and were highest during summer and autumn. This pattern corresponds to inshore migrations beginning in early spring.

The distributions and abundances of both pre-recruit and recruit longfin inshore squid in Long Island Sound from April to November 1986-1994, based on the Connecticut Fisheries Division bottom trawl surveys, are shown in Figure 5, Figure 6, and Figure 7. The following description of their distributions relative to depth and bottom type is taken almost verbatim from Gottschall *et al*. (2000).

Longfin inshore squid taken in the survey ranged from 2-40 cm mantle length (Figure 5), with the largest squid present in May and June. Squid were rarely observed in April (4% occurrence), but from May through November they were commonly taken throughout the Sound. The percent occurrence varied little during these months, ranging from 63% in July to 81% in September (Figure 6D). Abundance remained stable through late spring and summer (Figure 6A), and then increased dramatically in fall when squid ranging in size from 2-12 cm recruited to the trawl.

Although squid were commonly encountered throughout Long Island Sound in late spring, they were most abundant east of Stratford Shoal, particularly in depths > 18 m on the transitional and sand bottom (Figure 6B and C) of the Mattituck Sill and the adjacent portion of the Central Basin (Figure 7). In addition, they were concentrated in Niantic Bay. In contrast, longfin inshore squid appeared to be more dispersed in summer. In fall, when small squid were abundant, they were distributed throughout the Sound, but were more abundant in the Central and Western Basins. During the fall generally, abundance tended to increase with depth and was highest over mud bottom, with abundance over transitional and sand bottoms ranking second and third respectively. Although the abundance of squid was very low in November, they were still commonly encountered throughout the Sound (65% occurrence). Abundance was similar over all bottom types but, as in the fall period, abundance tended to increase with depth (Gottschall *et al*. 2000).

Longfin inshore squid pre-recruits were captured in the Hudson-Raritan estuary during spring, summer, and fall (Figure 8). They were found almost exclusively in the eastern portion of the bay and were collected in the highest numbers in the summer and autumn.

RECRUITS

NEFSC bottom trawl surveys captured longfin inshore squid recruits during all seasons (Figure 9; again note that winter and summer distributions are presented as presence data, precluding a discussion of abundances.). Their seasonal distributions are nearly identical to that of pre-recruits and illustrate the spring and summer inshore and the autumn offshore migrations.

The distribution of longfin inshore squid recruits in waters off Massachusetts was almost identical to that of pre-recruits, although the overall number of recruits was much lower (Figure 10).

Recruits were caught during all seasons in Narragansett Bay (Figure 11). Catches were low in winter, increased somewhat in spring, and were highest during summer and autumn. This pattern corresponds to inshore migrations beginning in spring.

The distributions and abundances of both pre-recruits and recruits in Long Island Sound were discussed previously.

Longfin inshore squid recruits were captured in the Hudson-Raritan estuary during spring, summer, and fall (Figure 12). They were found mostly in the eastern portion of the bay; the highest catches occurred in summer and autumn.

The 1988-1999 Virginia Institute of Marine Science (VIMS) trawl surveys of Chesapeake Bay suggests that recruit longfin inshore squid (> 12 cm) appeared in their catches primarily in April, with a few in May, and most likely were limited to sites around the Bay mouth and eastward (Geer 2002).

HABITAT CHARACTERISTICS

Information on the habitat characteristics and preferences of the longfin inshore squid are summarized in Table 1.

EGGS AND LARVAE

Egg masses are commonly found attached to rocks and small boulders on sandy/muddy bottom and on aquatic vegetation, such as *Fucus* sp., *Ulva lactuca*, *Laminaria* sp. and *Porphyra* sp. (Arnold *et al.* 1974; Griswold and Prezioso, 1981; Summers 1983). The eggs are demersal, are generally laid in waters < 50 m deep (Bigelow 1924; Griswold and Prezioso 1981; Lange 1982), and are found at temperatures of 10-23°C (McMahon and Summers 1971) and salinities of 30-32 ppt (McMahon and Summers 1971).

The larvae are pelagic near the surface (McMahon and Summers 1971; McConathy *et al.* 1980) and occur at temperatures of 10-26°C and salinities of 31.5-34.0 ppt (Vecchione 1981). Surface waters are important to hatchlings and larvae and individuals move deeper as they grow older (Vecchione 1981). Longfin inshore squid larvae were common in ichthyoplankton samples across a wide range of depths and areas (Vecchione *et al*. 2001).

PRE-RECRUITS

Juveniles inhabit the upper 10 m of the water column over water 50-150 m deep (Mercer 1969; Vovk and Khvichiya 1980; Brodziak and Hendrickson 1999). They are found at surface water temperatures of 10-26°C (Vecchione 1981; Brodziak and Hendrickson 1999) and salinities of 31.5-34.0 ppt (Vecchione 1981). Longfin inshore squid move up (nighttime) and down (daytime) in the water column on a daily (diel) basis (Hatfield and Cadrin 2002) but the importance of off-bottom habitat is unknown because sampling has been primarily with bottom trawls. Diel migration patterns depend on squid size and season (Hatfield and Cadrin 2002).

Distributions of pre-recruits relative to bottom water temperature, depth, and salinity based on spring and fall NEFSC bottom trawl surveys are shown in Figure 13. During the spring surveys, pre-recruits were found in a temperature range of 4-21ºC, with the majority at about 8-14ºC. They were found over a depth range of 1-400 m, and a salinity range of 31-36, with most found at 34-36 ppt. During the fall the pre-recruits were found over a wider temperature range of 6-28ºC, with peaks in abundance between roughly 10-19ºC. Their depth range during that season was between 1-400 m, with the majority found above about 60 m. Their salinity range was between 29-36 ppt, with the majority at 32-33 ppt.

The spring and autumn distributions of pre-recruits in Massachusetts coastal waters relative to bottom water temperature and depth based on Massachusetts inshore bottom trawl surveys are shown in Figure 14. In the spring, the pre-recruits were found at a temperature range of 5-17ºC, with most at 10-14ºC. Their depth range was from 6 m to a depth of approximately 65 m; the majority were found between 6-25 m. In the fall they were found over a wider temperature range of 5-22ºC, with bimodal peaks at about 8-10ºC and a larger one 16-20ºC. Their depth range during fall was between 1-85 m, with the majority found between about 6-35 m.

In the Narragansett Bay bottom trawl survey, pre-recruits were found at depths ranging from 10-110 feet (3-367 m) (Figure 15). In winter the few pre-recruits caught were taken at 90 feet (27 m), in summer and spring most were caught at 20-40 feet (6-12 m) and

100-110 feet (30-34 m), and in autumn most were caught at 100 feet (30 m). Pre-recruits were collected at temperatures ranging from 9-25°C. They were collected at temperatures of 10°C in winter, from 9-16°C in spring, from 11-25°C with most at 19°C in summer, and from 13-23°C with most at 20°C in autumn.

In the Hudson-Raritan estuary, pre-recruits were collected at temperatures ranging from 11-24°C, but most were taken at 16-21°C. They were also collected at depths of 15-75 ft (~5-23 m), with most at 30 ft (9 m) and 45-50 ft (14-15 m), and salinities of 20-33 ppt, with the highest catch at 30 ppt. They were found at dissolved oxygen levels of 5-10 mg/L, with most at 7-8 mg/L (Figure 16). Longfin inshore squid require oxygen concentrations greater than 4 mg/L (Howell and Simpson 1994).

The distributions and abundances of both pre-recruit and recruit squid in Long Island Sound relative to depth and bottom type, based on surveys by Gottschall *et al*. (2000), were discussed previously in Geographic Distribution: Pre-recruits.

RECRUITS

Adult longfin inshore squid inhabit the continental shelf and upper continental slope to depths of 400 m (Vecchione *et al.* 1989), but depth varies seasonally. In spring they occur at depths of 110-200 m (Serchuk and Rathjen 1974; Lange and Sissenwine 1980), in summer and autumn they inhabit inshore waters as shallow as 6-28 m (Summers 1968a, b; Serchuk and Rathjen 1974; Gosner 1978; Howell and Simpson 1994), and in winter they inhabit offshore waters to depths of 365 m (Lange 1982). They are found on mud or sand/mud substrate (Howell and Simpson 1994), at surface temperatures ranging from 9-21°C, and bottom temperatures ranging from 8-16°C (Summers 1969; Lux *et al.* 1974; Serchuck and Rathjen 1974; Lange and Sissenwine 1980; Macy 1980; Brodziak and Hendrickson 1999). Adults, like juveniles, migrate up and down in the water column in response to light conditions and the importance of off-bottom habitat is unknown.

Distributions of recruits relative to bottom water temperature, depth, and salinity based on spring and fall NEFSC bottom trawl surveys are shown in Figure 17. During the spring, recruits were found in a temperature range of 4-21ºC, with the majority at about 7-13ºC. They were found over a depth range of 1-400 m, and a salinity range of about 30-36, with most found at 34-35 ppt. During the fall the pre-recruits were found over a wider temperature range of 6-28ºC, with a peak between about 10-15ºC. Their depth range during that season was between 1-400 m, with the majority found above about 70 m. Their salinity range was between 30-37 ppt, with most at 32-33 ppt.

Around Massachusetts in the spring, the recruits were found at a temperature range of 6-17ºC, with most at 10-13ºC (Figure 18). Their depth range was from about 1 m to approximately 50 m, with the majority found between 6-20 m. As with the pre-recruits, the recruits in the fall were found over a wider temperature range of 5-22ºC, with bimodal peaks at about 8-10ºC and a larger one 16-20ºC. Their depth distribution during fall was similar to that of the pre-recruits (range of 1-85 m, with the majority found between about 6-35 m).

In Narragansett Bay, recruits were found at depths ranging from 10 to 120 ft (3-37 m) (Figure 19). In winter the few recruits caught were taken at 90-100 ft (27-30 m). In summer and spring they were taken at depths ranging from 10-120 ft (3-37 m). In spring, about 40% were caught at 100-110 feet (30-34 m), with another 20% found at 70 ft (21 m), while in summer, the majority were caught at 100-110 ft. In autumn, most were caught at 90-100 feet (27-30 m). Recruits were taken at temperatures ranging from 7-25°C (Figure 19). Seasonally they were collected at 7-10°C in winter, with almost all caught at 10°C; at 9-16°C in spring, with most at 9-13°C; at 9-25°C in summer, with most at 18-21°C; and at 11-23°C in autumn, with a peak at 15°C.

In the Hudson-Raritan estuary, recruits were collected at temperatures ranging from 9-24°C, but most were at 16-17°C (Figure 20). They were also collected at depths of 10-75 ft (~5-23 m), with most at 50 and 60 ft (~15-18 m), and salinities of 20-33 ppt, with the highest catch at 30 ppt. They were found at dissolved oxygen levels of 5-11 mg/L, with most at 7-8 mg/L. Longfin inshore squid require oxygen concentrations greater than 4 mg/L (Howell and Simpson 1994).

RESEARCH NEEDS

- Human impacts may be significant on sandy bottom habitats used by inshore longfin squid for their eggs. However, little information is available on egg habitat locations, seasonal occurrence, sediment characteristics, and depth or water chemistry. This type of information might be useful for designating marine reserves, seasonal closed areas, and other measures.
- Additional information about use of off-bottom habitat and vertical distribution of inshore longfin squid in the water column is needed for stock assessment and management. This is because a substantial portion of the inshore longfin squid stock may be unavailable to bottom trawl surveys that are used to track abundance.
- Information about distribution of inshore longfin squid in deepwater off the continental shelf and south of Cape Hatteras would be useful because

bottom trawl surveys do not reach these areas and an unknown portion of the stock is resident there (NEFSC 2002).

- More information on growth rates and maturity are needed from geographically and temporally diverse studies.
- The commercially exploited population from Cape Hatteras to Georges Bank, inshore and offshore and in all seasons, is considered a single stock unit. More information is needed on stock structure, including gene flow and levels of genetic differentiation among geographic areas.

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Table 1. Summary of life history and habitat characteristics for longfin inshore squid, based on the pertinent literature. This table is essentially the same as that used in the first longfin inshore squid EFH source document (Cargnelli *et al*. 1999); more recent studies have not been added.

Life Stage	Size and Growth	Habitat	Substrate	Temperature	Salinity
Eggs [1]	Incubation time varies with temperature: 26.7 d at 12-18°C, 18.5 d at 15.5-21.3°C, and 10.7 d at 15.5-23.0°C.	Eggs generally in shallow waters, < 50 m and near shore.	Egg masses are commonly found on sandy/mud bottom; usually attached to rocks/boulders, pilings, or algae such as *Fucus*, *Ulva lactuca*, *Laminaria* and *Porphyra* sp.	Eggs found in waters 10-23°C; usually > 8°C. Optimal development at 12°C.	Found at 30-32 ppt.
Larvae [2]	Paralarvae range in size from 1.4-15 mm ML (mantle length). Growth rates slower for winter-hatched animals than spring-hatched.	Found in coastal, surface waters in spring, summer, and fall. Hatchlings found in surface waters day and night. Move deeper in water column as they grow larger.		Found at 10-26°C (at lower temperatures found at higher salinities).	Found at 31.5-34.0 ppt.
Juveniles [3]	Size ranges from approximately 15 mm - 8 cm. At 6-8 cm sexual size dimorphism is evident, before offshore migrations occur. Growth rates of young-of-the-year are 12-38 mm/month.	Inhabit upper 10 m at depths of 50-100 m on continental shelf. Found in coastal inshore waters in spring/fall, offshore in winter. Migrate to surface at night. Ontogenetic descent: at 45 mm, chromatophores are concentrated on dorsal rather than ventral surface, indicating a change from inhabiting surface waters to demersal lifestyle.		Found at 10-26°C (at lower temperatures found at higher salinities). Juveniles prefer warmer bottom temperatures and shallower depths in fall than adults.	Found at 31.5-34.0 ppt.
Adults [4]	Smallest size at maturity 8 cm ML; most are > 10 cm ML. Males grow faster than females and attain larger sizes; larger sizes at higher latitudes. Growth is rapid, faster in warm months (1.5-2.0 cm/month) than in cold months (0.4-0.6 cm/month). Life span is < 1 year. Maximum size and age are ~50 cm ML, 3 yrs.	Range from Newfoundland south to Cape Hatteras, on continental shelf and upper slope. Most abundant from Gulf of Maine to Hatteras. March-October: inshore, shallow waters up to 180 m. Winter: offshore deeper waters, up to 400 m on shelf edge. Most abundant at bottom during the day; move upwards at night. Generally found at greater depths and cooler bottom temperatures in the fall than juveniles. Importance of off-bottom habitat poorly understood.	Mud or sandy mud.	Found at surface temperatures ranging from 9-21°C and bottom temperatures ranging from 8-16°C.	

[1] Bigelow (1924); McMahon and Summers (1971); Arnold *et al.* (1974); Griswold and Prezioso (1981); Lange (1982); Summers (1983); Dawe *et al.* (1990).
[2] McMahon and Summers (1971); McConathy *et al.* (1980); Vecchione (1981); Nesis (1982); Vovk (1983); Young and Harman (1988).
[3] Summers (1968a, b); Mercer (1969); Macy (1980); Vovk and Khvichiya (1980); Vecchione (1981); Young and Harman (1988); Brodziak and Henderson (1999).
[4] Haefner (1964); Summers (1968a, b, 1969, 1971, 1983); Rathjen (1973); Lux *et al.* (1974); Serchuk and Rathjen (1974); Cohen (1976); Mesnil (1977); Gosner (1978); Sissenwine and Bowman (1978); Lange (1980, 1982); Lange and Sissenwine (1980); Macy (1980); Nesis (1982); Vecchione *et al.* (1989); Dawe *et al*. (1990); Howell and Simpson (1994); Brodziak and Macy (1996); Brodziak and Henderson (1999).

Table 1. Cont'd.

Life Stage	Prey	Predators	Spawning	Notes
Eggs [1]	N/A		Most eggs are spawned in May, hatching occurs in July. Fecundity ranges from 950-15,900 eggs per female.	Eggs are demersal. Enclosed in a gelatinous capsule containing up to 200 eggs. Each female lays 20-30 capsules. Laid in masses made up of hundreds of egg capsules from different females.
Larvae [2]	Primary prey are copepods.			"Paralarvae" defined as stage after hatching when cephalopods are pelagic. Tentacles are non-functional at ≤ 15 mm.
Juveniles [3]	Primary prey varies with size: < 4.0 cm: plankton, copepods; 4.1-6.0 cm: euphausiids, arrow worms; 6.1-10.0 cm: crabs, polychaetes, shrimp. Cannibalism observed in specimens larger than 5 cm ML (small *Illex illecebrosus* were found in 49 of 322 *Loligo* stomachs).	Many pelagic and demersal fish species as well as marine mammals and birds.		Changes in habitat as the squid grows are indicated by changes in the diet.
Adults [4]	Fish prey includes silver hake, mackerel, herring, menhaden, sand lance, bay anchovy, menhaden, weakfish, and silversides. Invertebrate prey includes crustaceans (*Crangon, Palaeomonetes* sp.) and squid. 15 cm adults can eat fish up to half their mantle length. At 16-25 cm, consume more fish and less crustaceans as growth increases; > 25 cm, more squid than fish eaten; and > 30 cm, almost exclusively squid.	Predators include many fishes (bluefish, sea bass, mackerel, cod, haddock, pollock, hakes, sea raven, goosefish, flounder, dogfish, angel sharks, skates), pilot whale (*Globicephala melas*) and common dolphin (*Delphinus delphis*), and diving birds.	Spawning occurs on Scotian Shelf, Georges Bank, Gulf of Maine, and from Nantucket Shoals to Cape Hatteras in shallow waters, 10-90 m, from April-November (New England: May-August; Bay of Fundy: Aug-September). Georges Bank: two broods - early spring and late summer. Spring spawn: hatch in June, mature over winter. Summer spawn: hatch in fall, mature in 2nd winter. Mating occurs during inshore migration in spring. Mortality occurs after first spawning.	*Loligo* form schools according to size class prior to feeding. Oxygen requirement > 4 ml/l. Larger individuals migrate earlier (April-May) than smaller ones.

[1] Haefner (1959); Summers (1971); Vovk (1972b), Arnold *et al.* (1974); Gosner (1978); Griswold and Prezioso (1981); Lange (1982); Nesis (1982); Lange and Sissenwine (1983).
[2] Vecchione (1981); Vovk (1983); Young and Harman (1988).
[3] Vovk (1972b, 1985); Tibbetts (1977); Whitaker (1978); Vinogradov and Noskov (1979); Vovk and Khvichiya (1980); Vecchione (1981).
[4] Stevenson (1934); Summers (1969, 1971); Vovk (1972a, 1985); Rathjen (1973); Maurer (1975); Cohen (1976); Langton and Bowman (1977); Mesnil (1977); Tibbetts (1977); Gosner (1978); Vinogradov and Noskov (1979); Lange (1980, 1982); Lange and Sissenwine (1980, 1983); Macy (1980); Griswold and Prezioso (1981); Kier (1982); Summers (1983); Maurer and Bowman (1985); Dawe *et al.* (1990); Waring *et al.* (1990); Overholtz and Waring (1991); Howell and Simpson (1994); Brodziak and Macy (1996); Gannon *et al.* (1997).

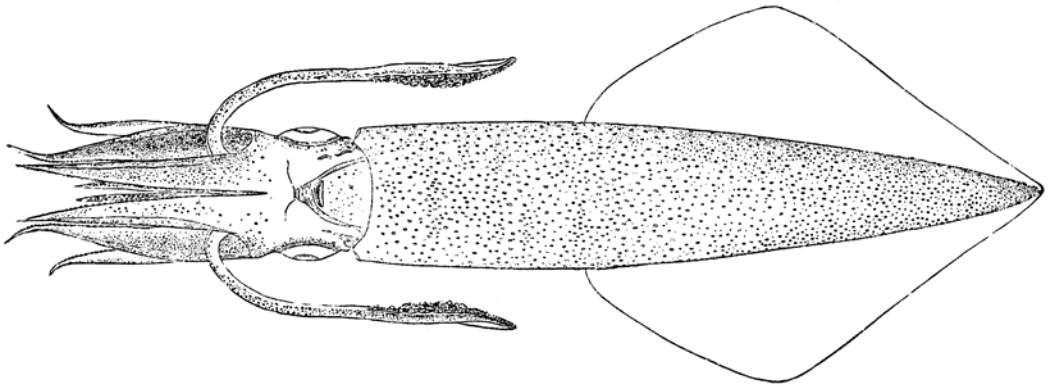


Figure 1. The longfin inshore squid, *Loligo pealeii* (from Goode 1884).

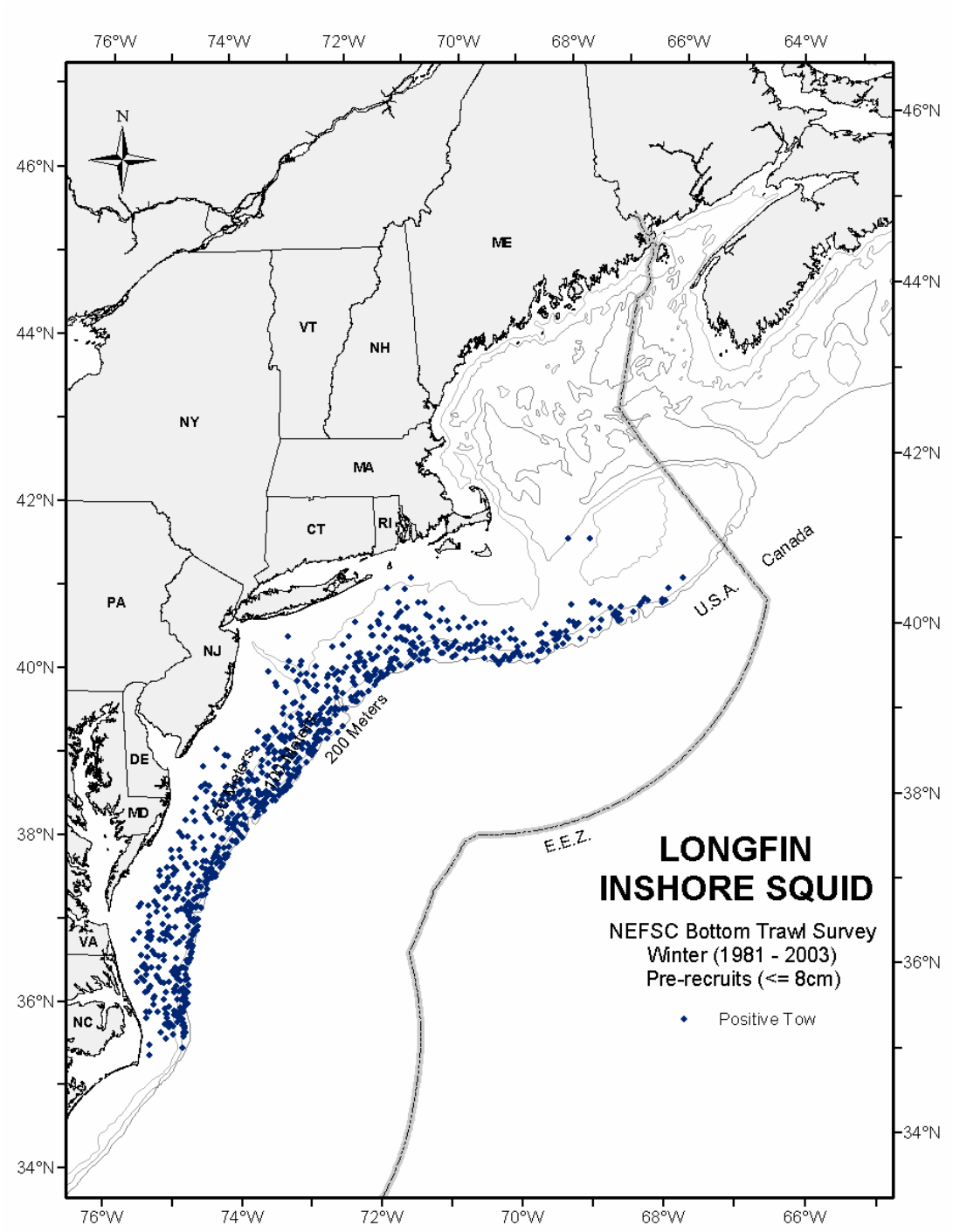


Figure 2. Seasonal distributions and abundances of pre-recruit longfin inshore squid collected during NEFSC bottom trawl surveys.
Based on NEFSC winter bottom trawl surveys (1981-2003, all years combined). Distributions are displayed as presence only.

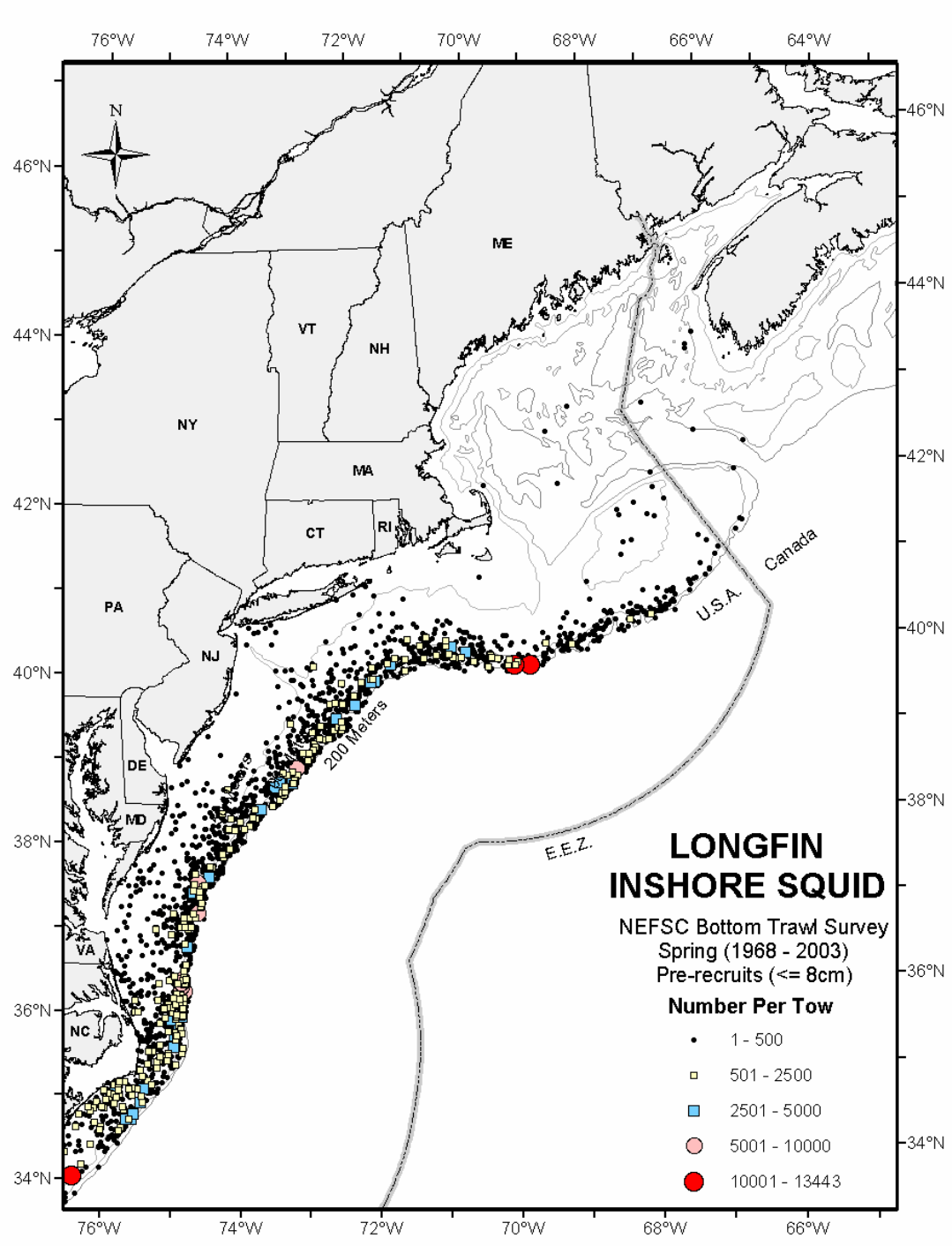


Figure 2. Cont'd.
Based on NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where pre-recruits were not found are not shown.

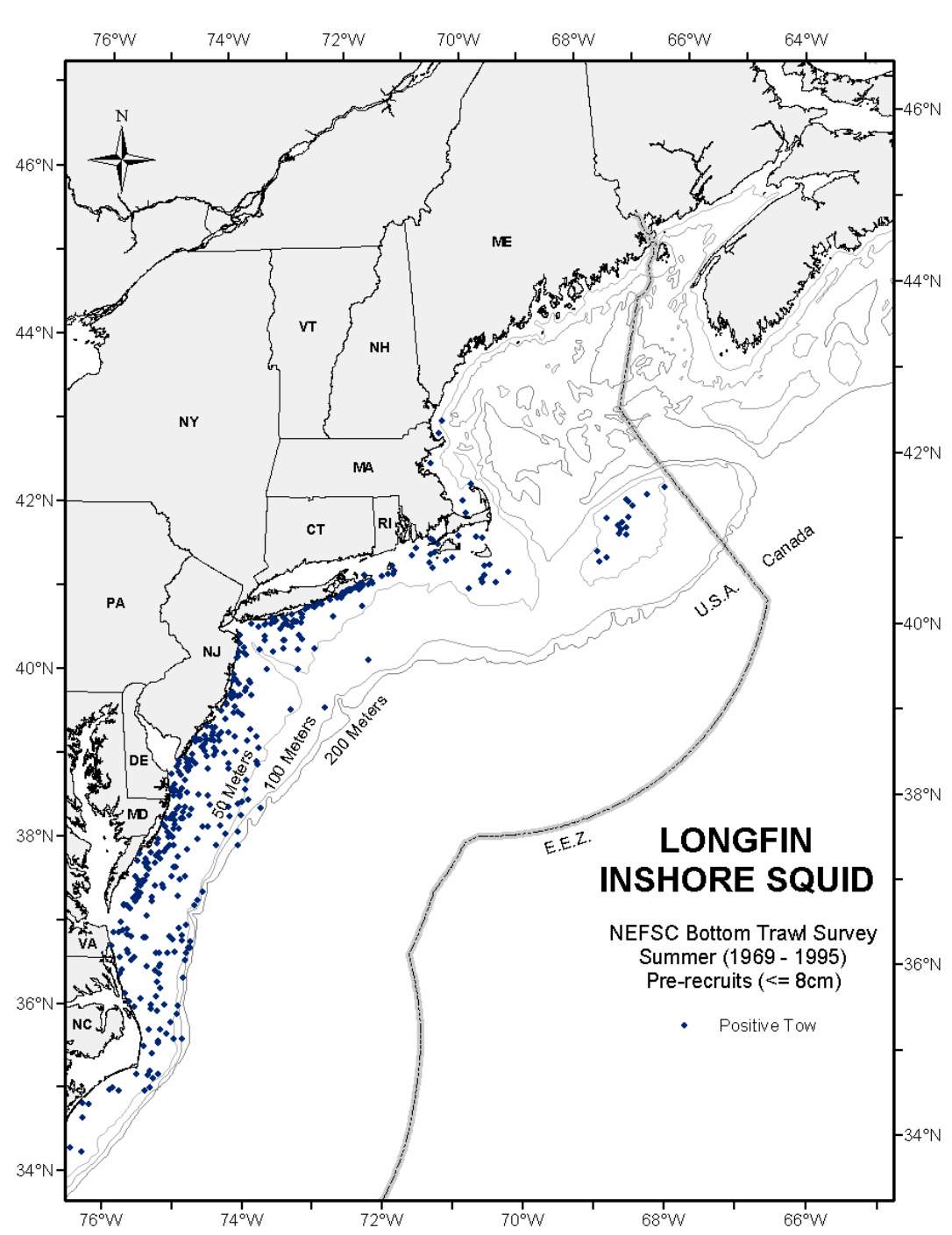


Figure 2. Cont'd.
Based on NEFSC summer bottom trawl surveys (1969-1995, all years combined). Distributions are displayed as presence only.

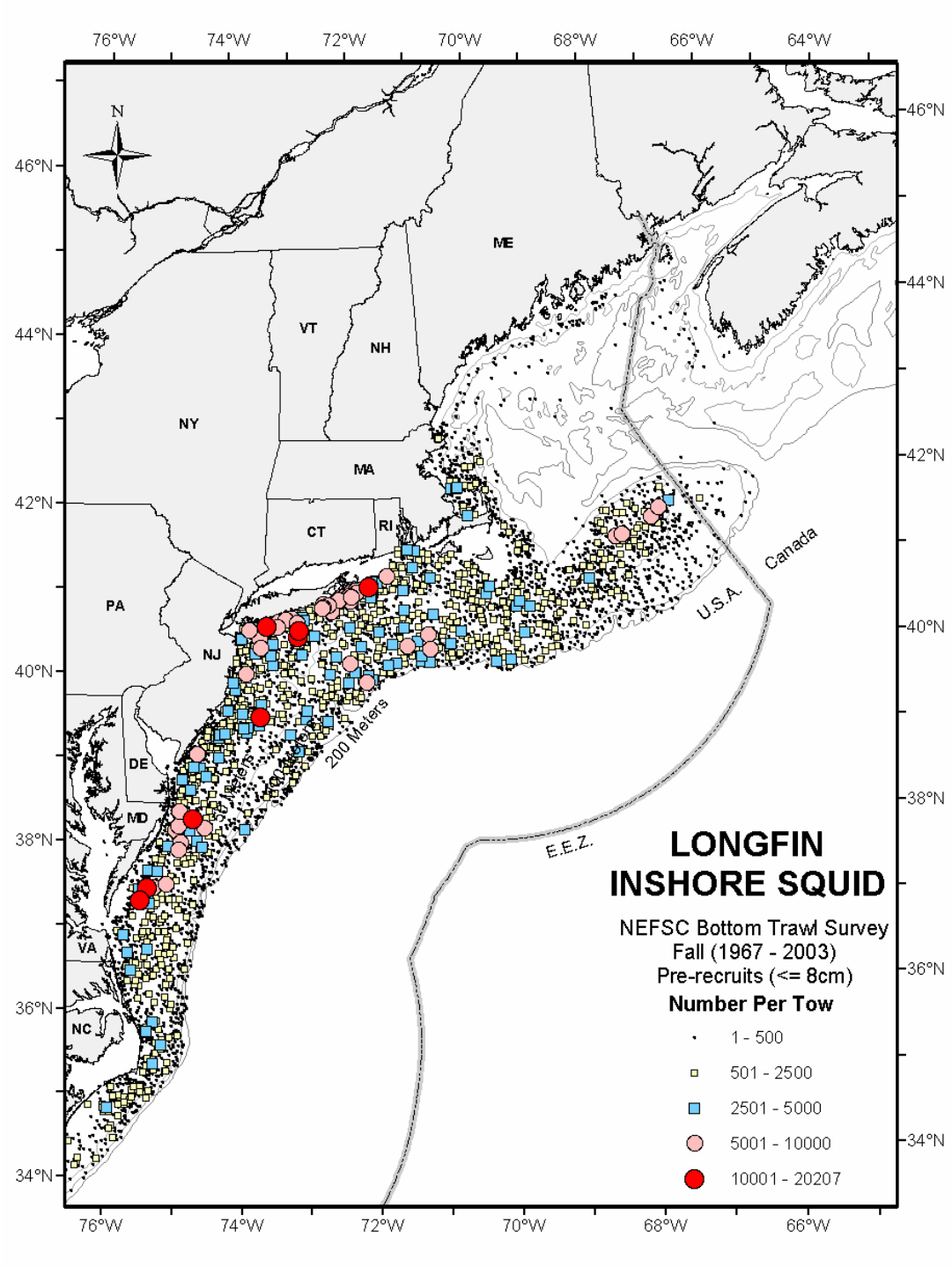


Figure 2. Cont'd.
Based on NEFSC fall bottom trawl surveys (1967-2003, all years combined). Survey stations where pre-recruits were not found are not shown.

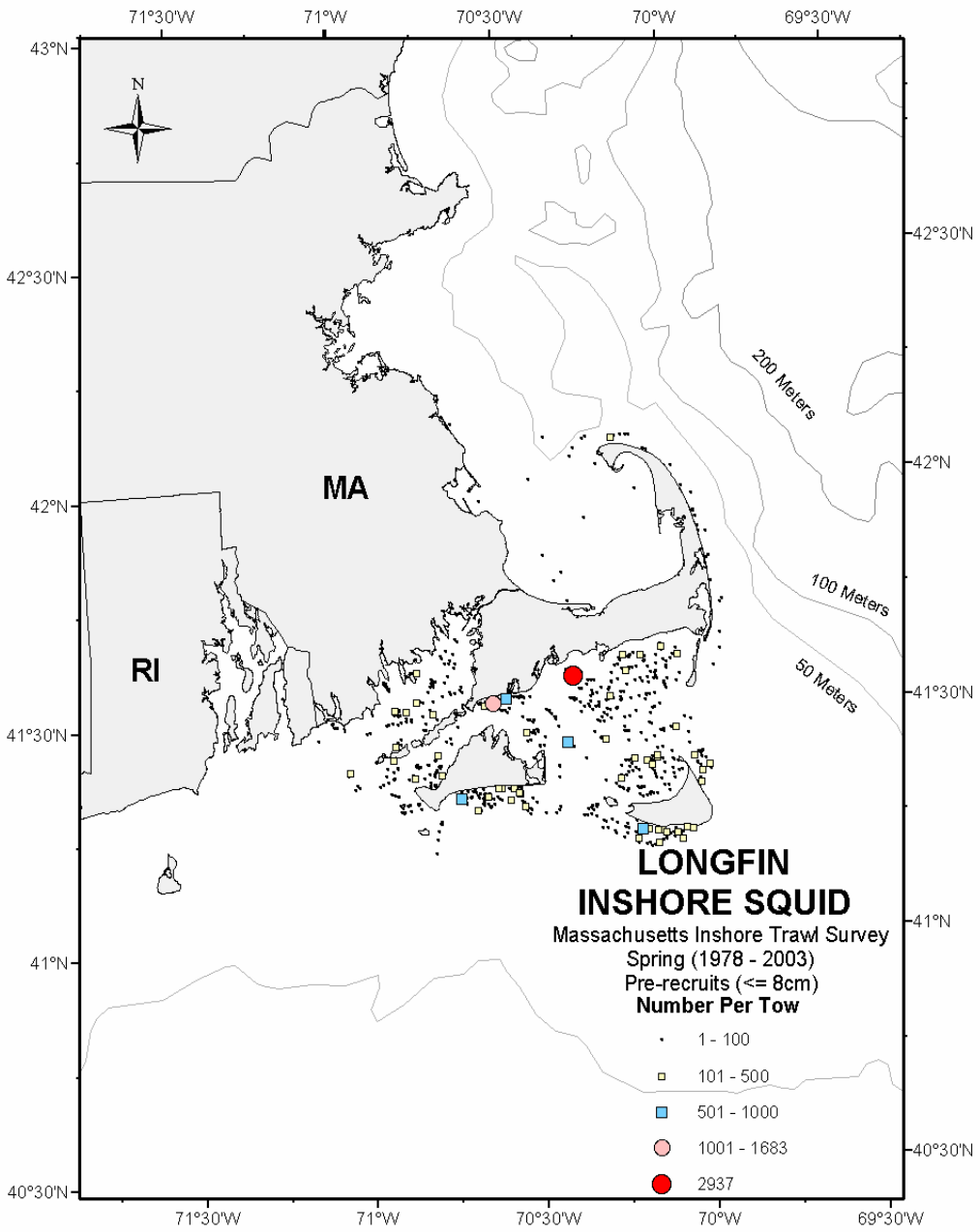


Figure 3. Distribution and abundance of pre-recruit longfin inshore squid in Massachusetts coastal waters. Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where pre-recruits were not found are not shown.

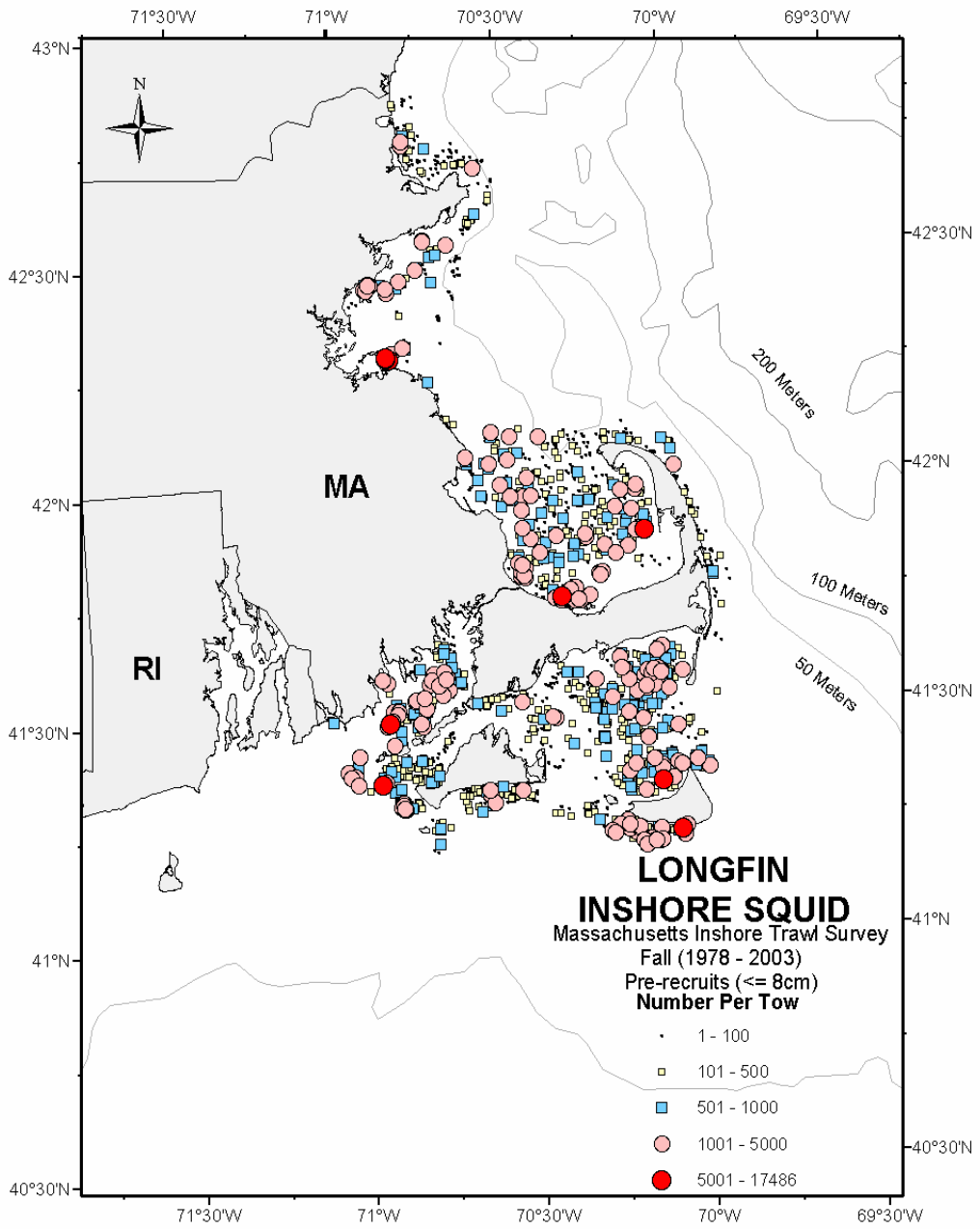


Figure 3. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where pre-recruits were not found are not shown.

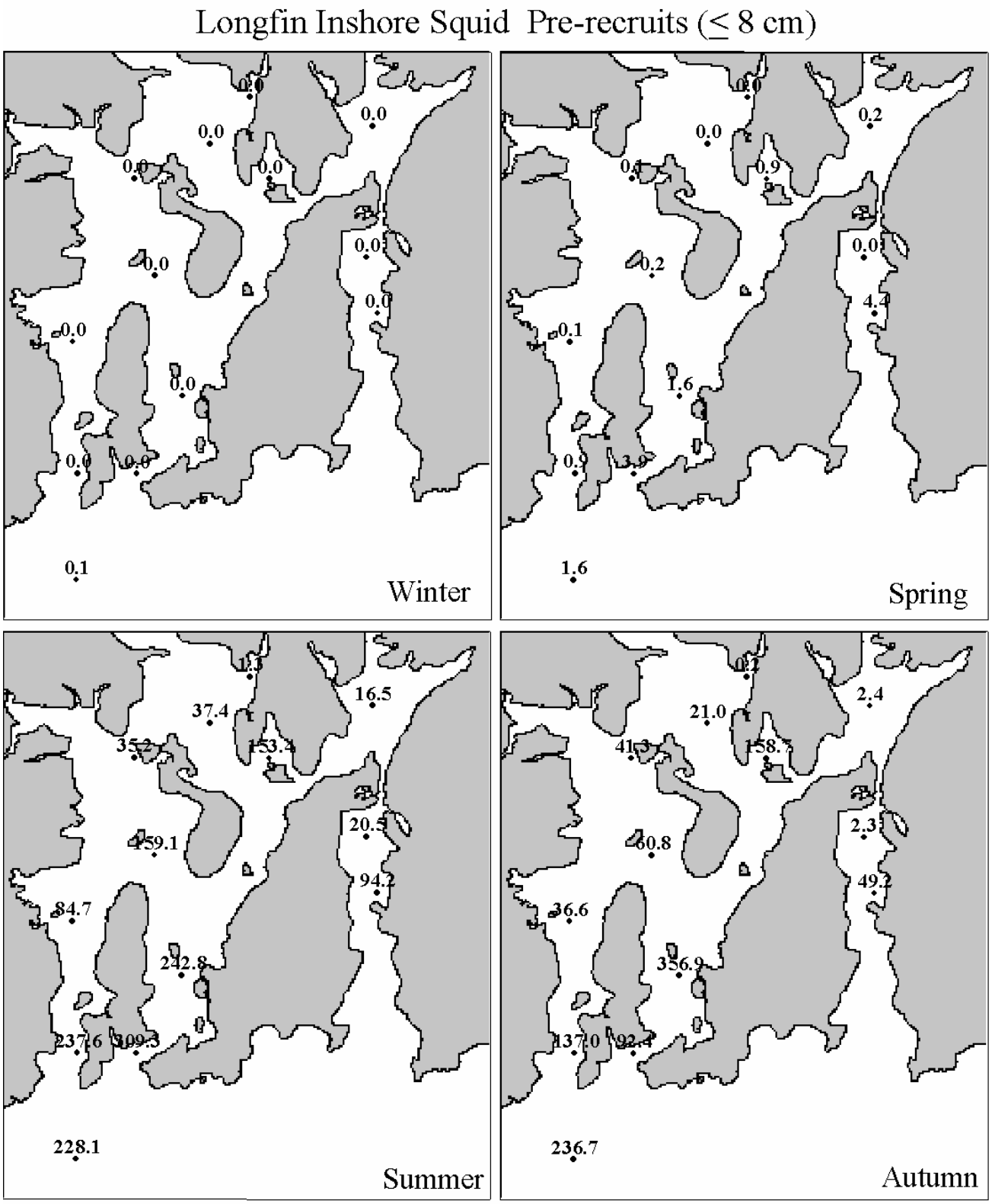


Figure 4. Seasonal distribution and abundance of longfin inshore squid pre-recruits in Narragansett Bay. Based upon the 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].

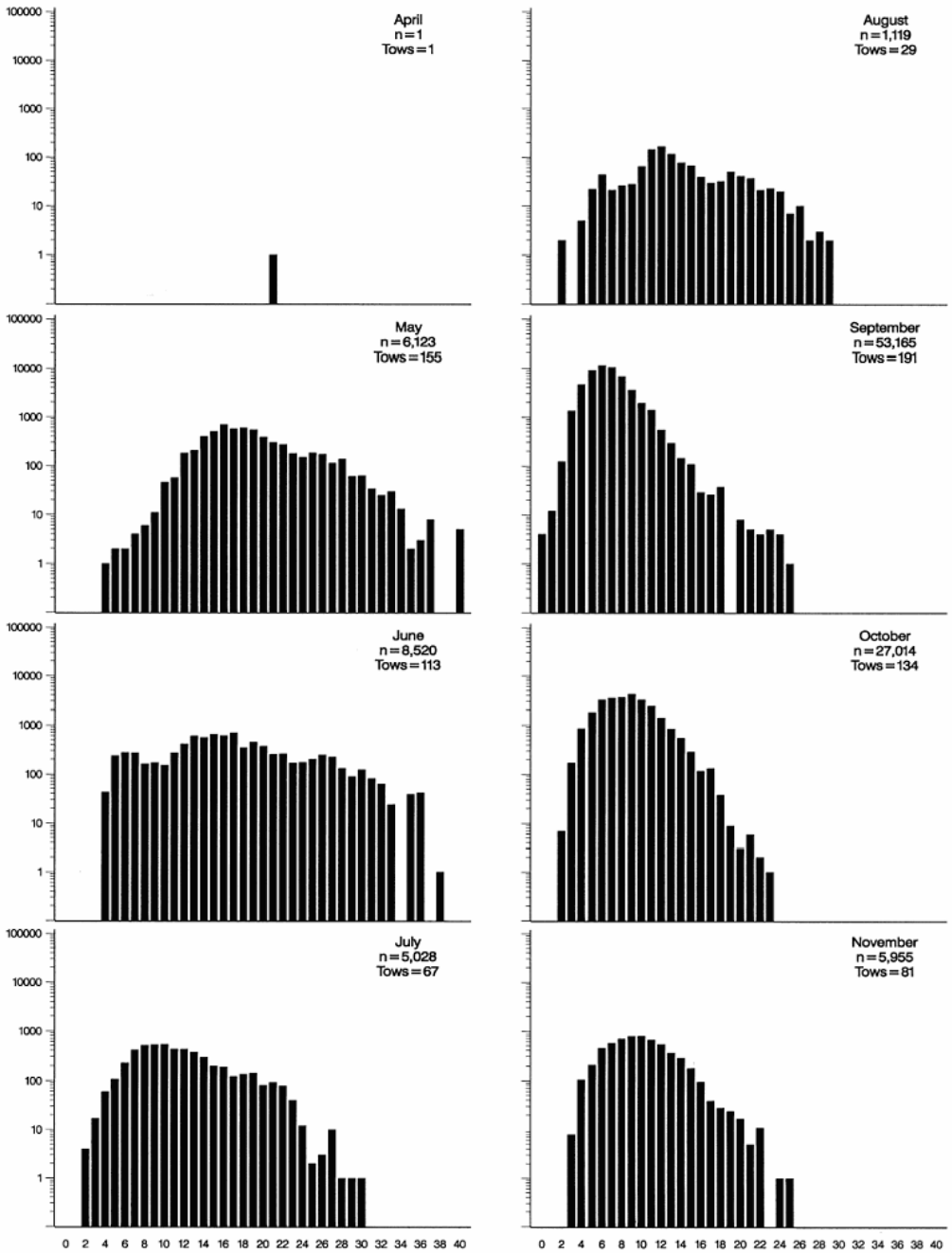


Figure 5. Monthly $\log_{10}$ length frequencies (cm) of longfin inshore squid collected in Long Island Sound, based on 106,925 squid taken in 771 tows between 1987 and 1994. Source: Gottschall *et al.* (2000).

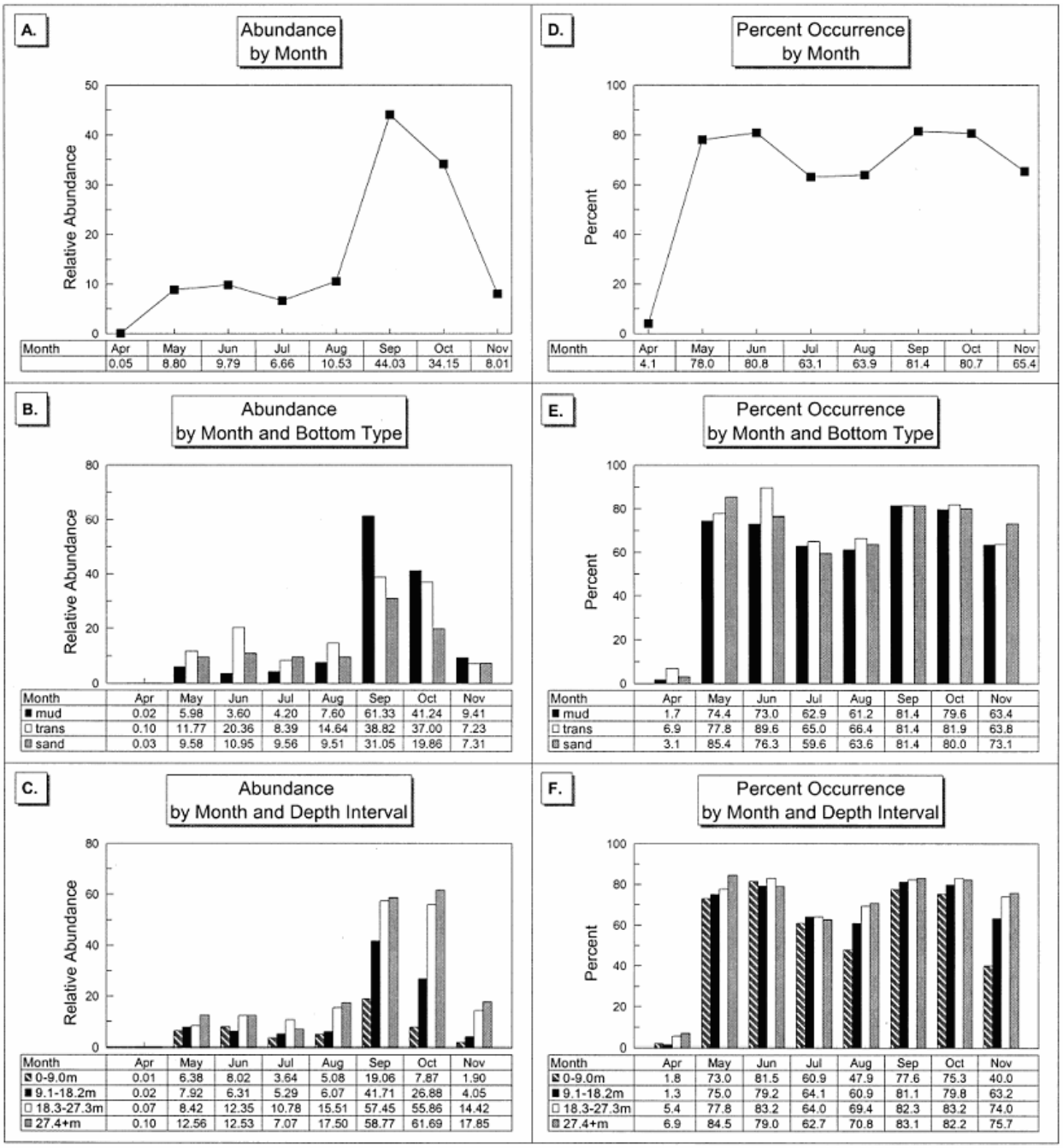


Figure 6. Relative abundance (geometric mean catch/tow) catch/tow and percent occurrence (proportion of samples in which at least one individual was observed) for longfin inshore squid in Long Island Sound, by month, month and bottom type, and month and depth interval. Source: Gottschall *et al.* (2000).

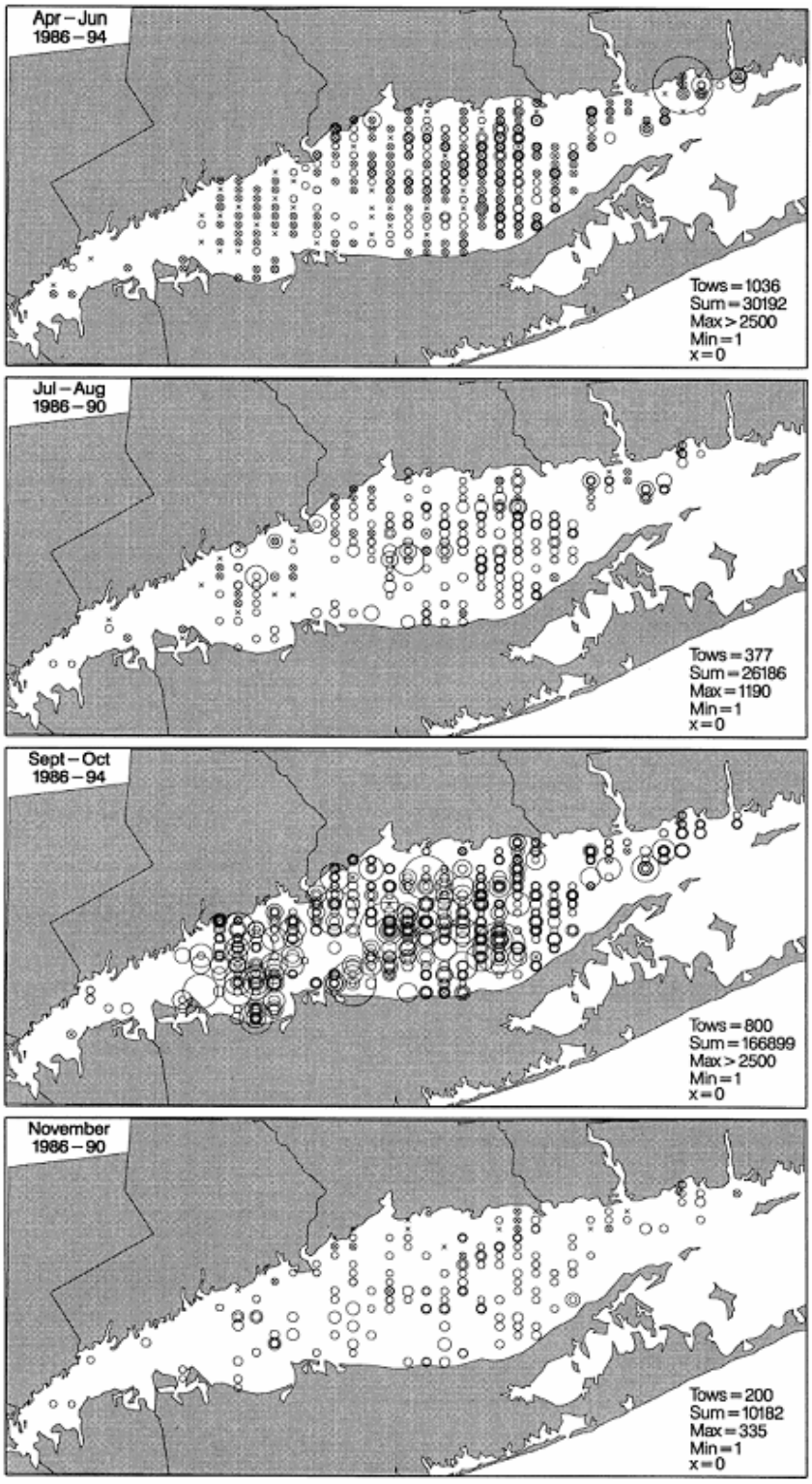


Figure 7. Distribution and abundances of longfin inshore squid in Long Island Sound, based on the finfish surveys of the Connecticut Fisheries Division, 1986-1994. Source: Gottschall *et al.* (2000). Circle diameter is proportional to the number of squid caught, and is scaled to the maximum catch (indicated by "max=" or "max>"); the largest circle represents a tow with a catch of > 2,500 squid. Collections were made with a 14 m otter trawl at about 40 stations chosen by stratified random design.

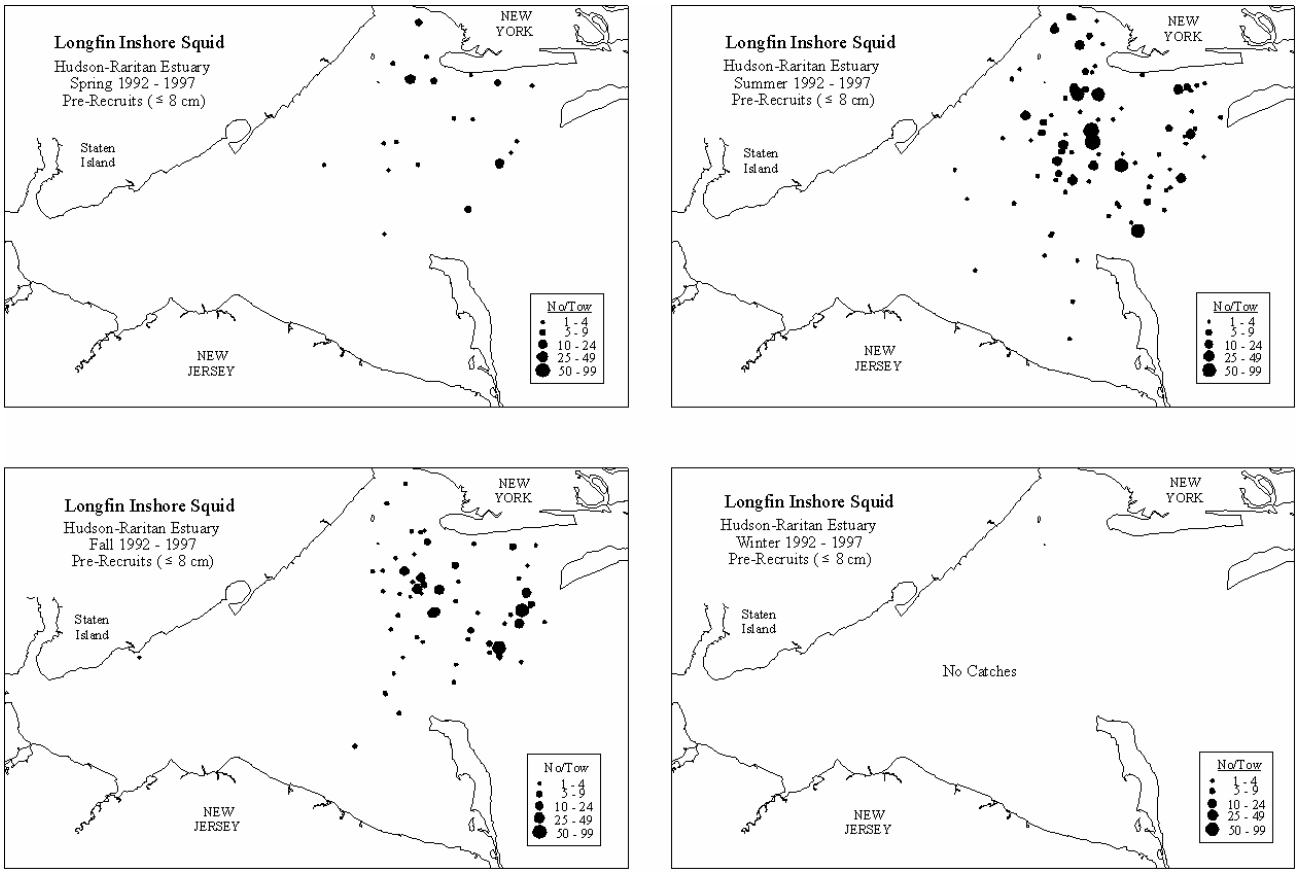


Figure 8. Seasonal distribution and abundance of longfin inshore squid pre-recruits collected in the Hudson-Raritan estuary.
Based on NEFSC Hudson-Raritan trawl surveys, January 1992 – June 1997 [see Reid *et al.* (1999) for details].

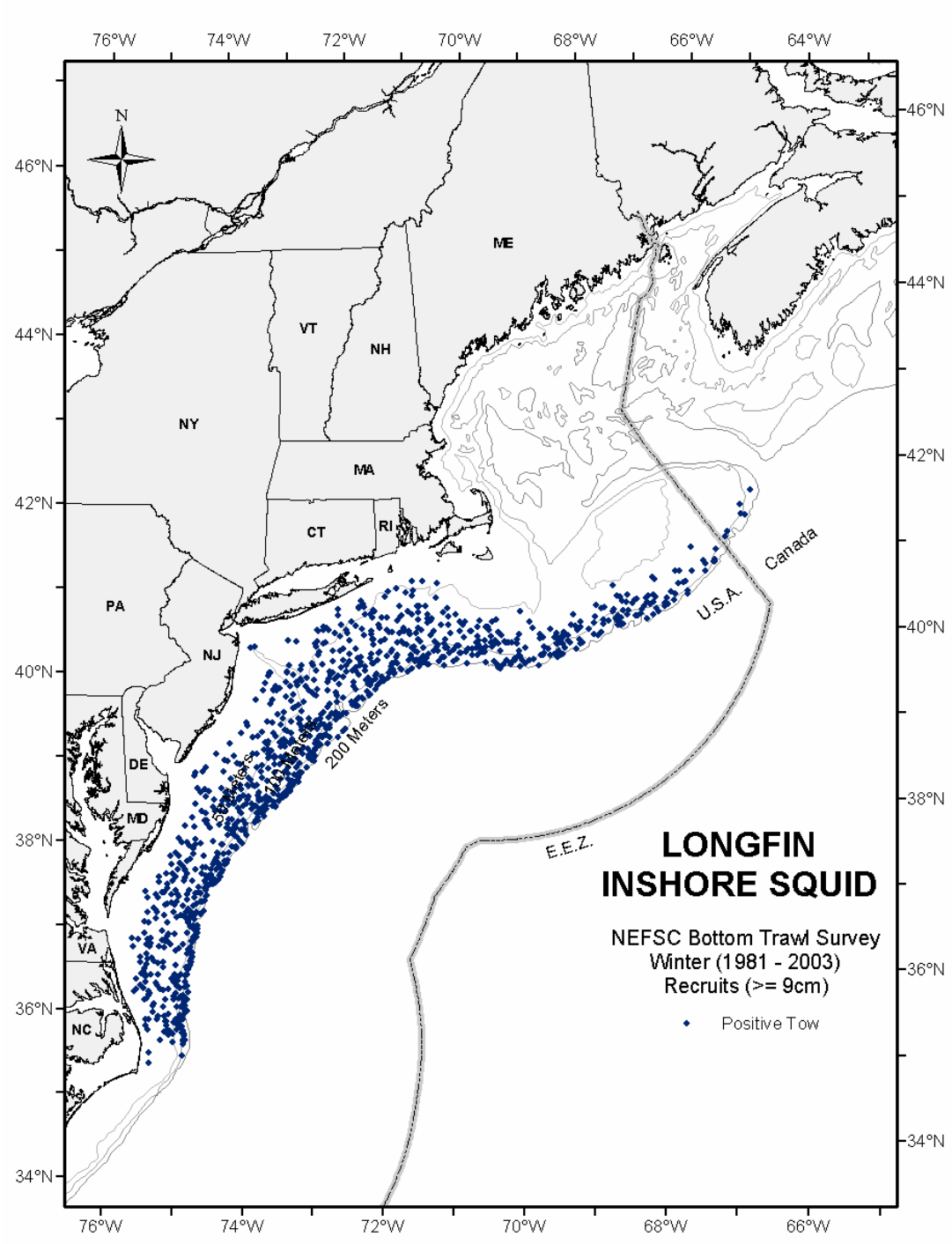


Figure 9. Seasonal distributions and abundances of recruit longfin inshore squid collected during NEFSC bottom trawl surveys.
Based on NEFSC winter bottom trawl surveys (1981-2003, all years combined). Distributions are displayed as presence only.

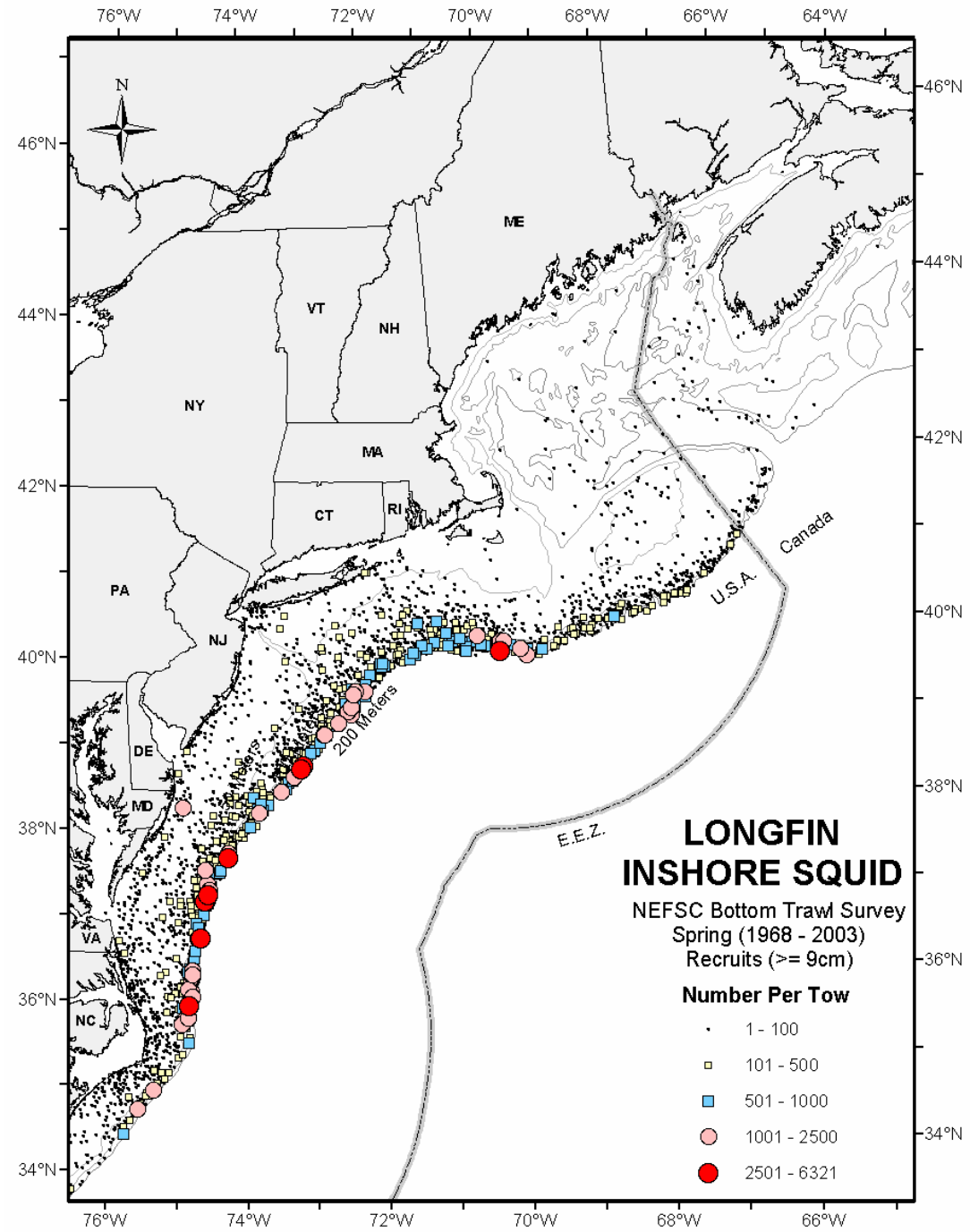
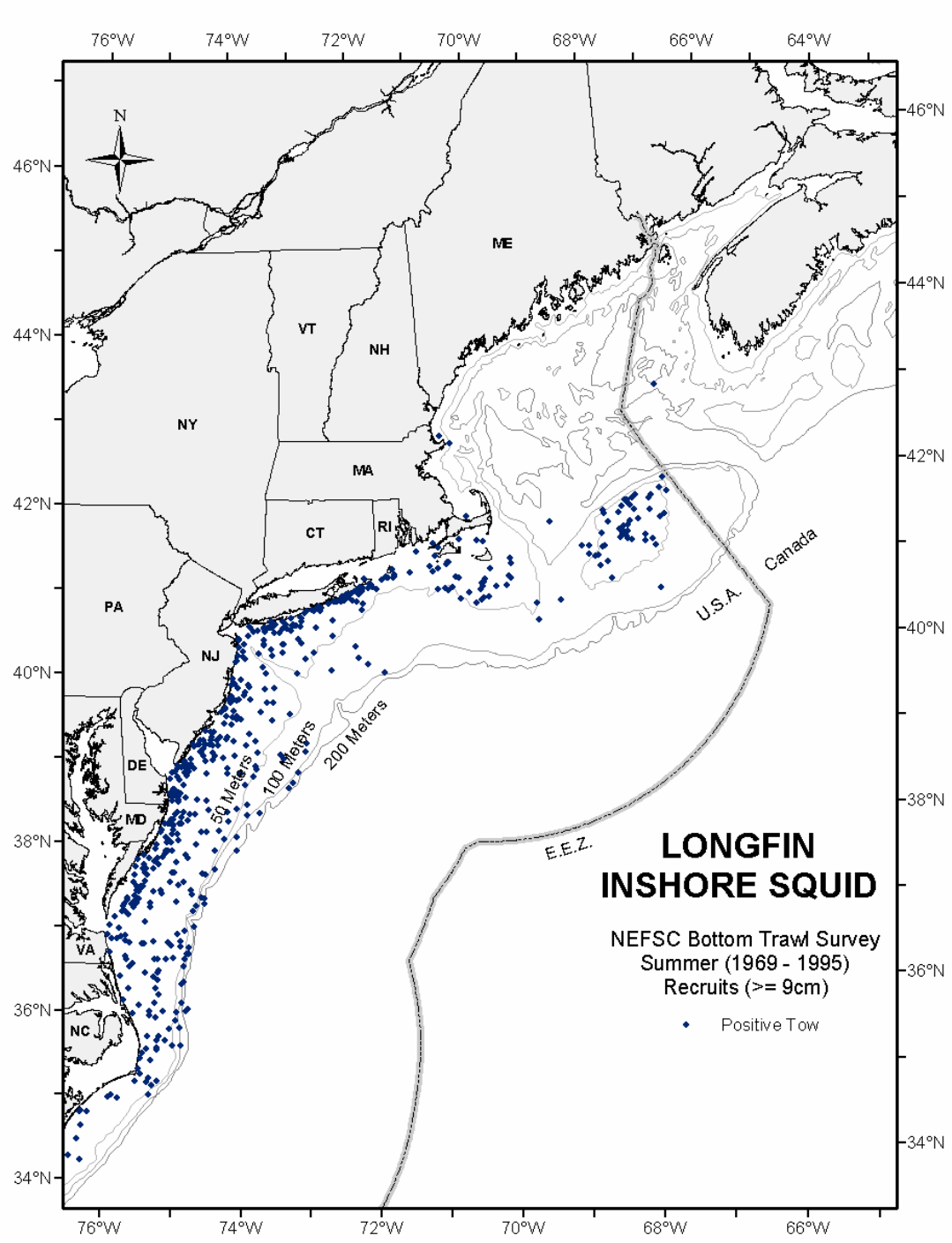


Figure . Cont'd.
Based on NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where recruits were not found are not shown.



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Based on NEFSC summer bottom trawl surveys (1969-1995, all years combined). Distributions are displayed as presence only.

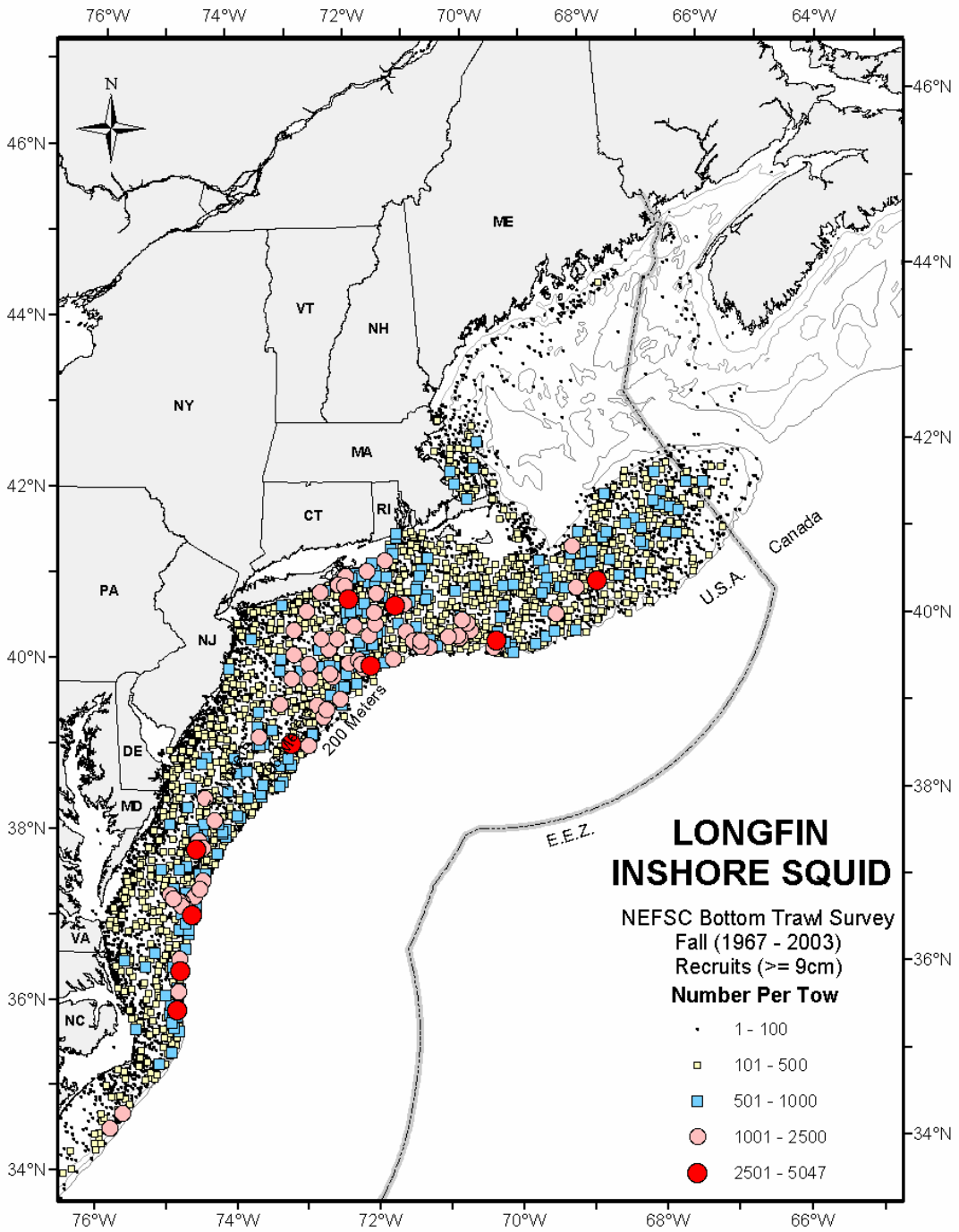

Figure 9. Cont'd.
Based on NEFSC fall bottom trawl surveys (1967-2003, all years combined). Survey stations where recruits were not found are not shown.

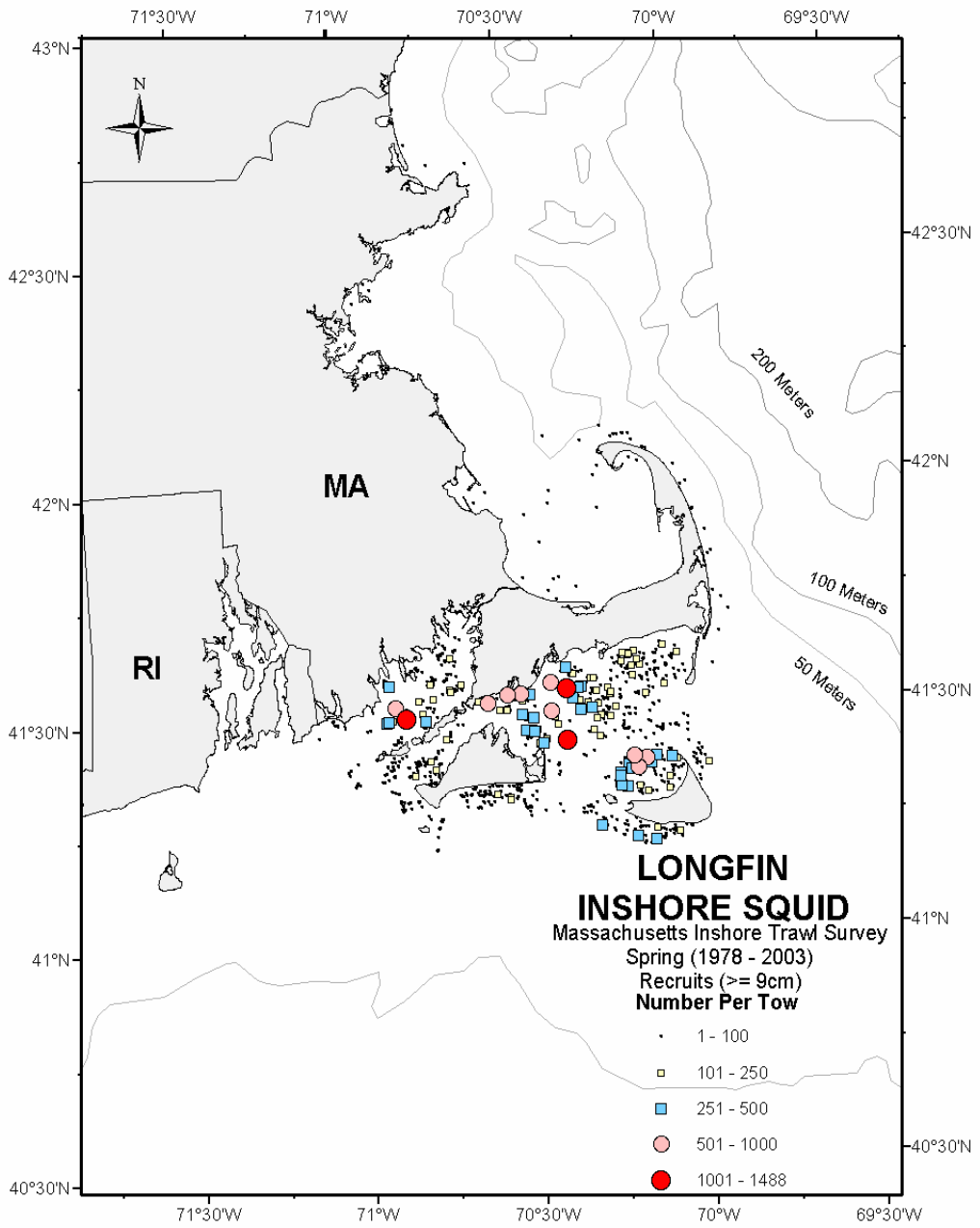

Figure 10. Seasonal distributions and abundances of recruit longfin inshore squid in Massachusetts coastal waters. Based spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where recruits were not found are not shown.

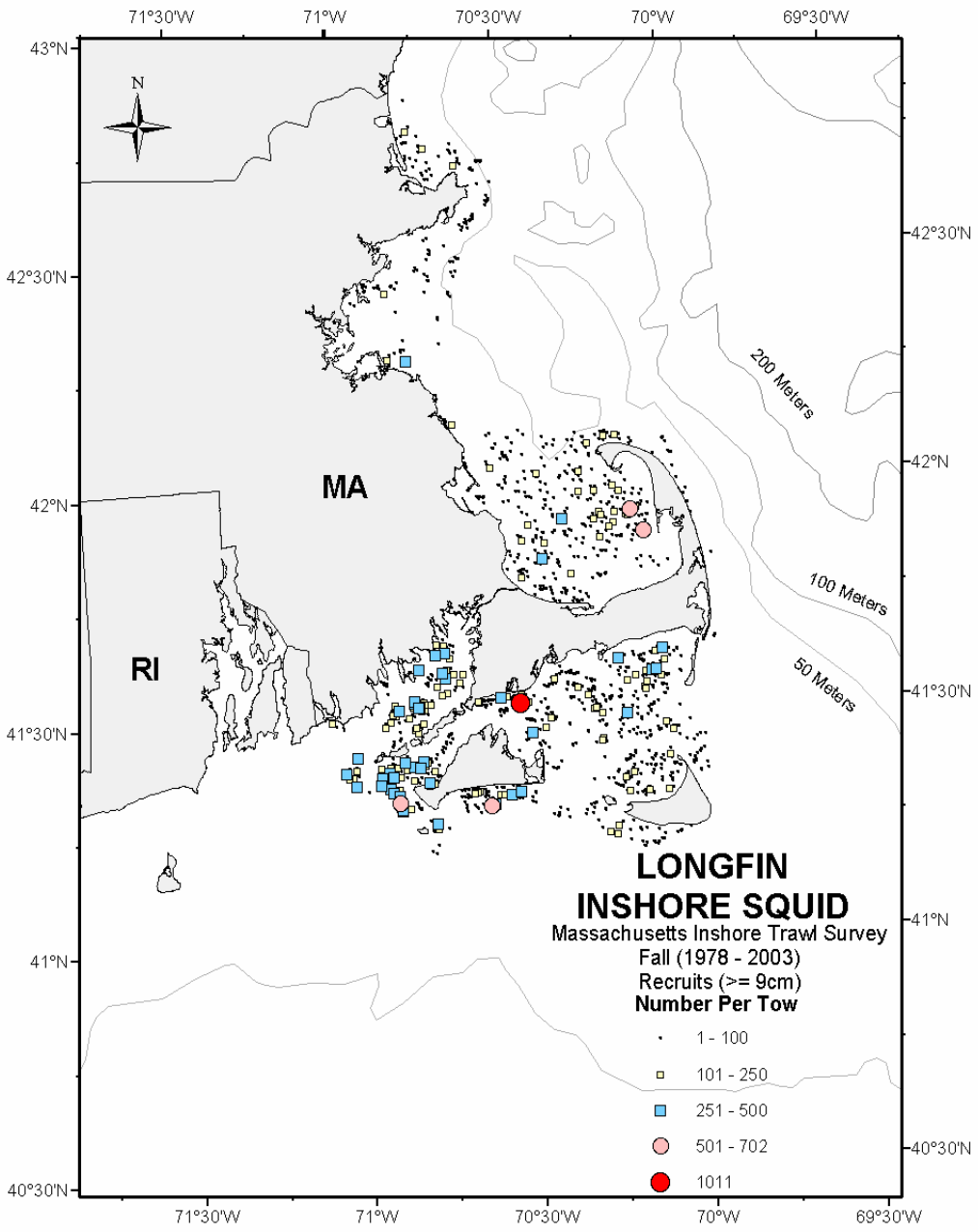

Figure 10. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where recruits were not found are not shown.

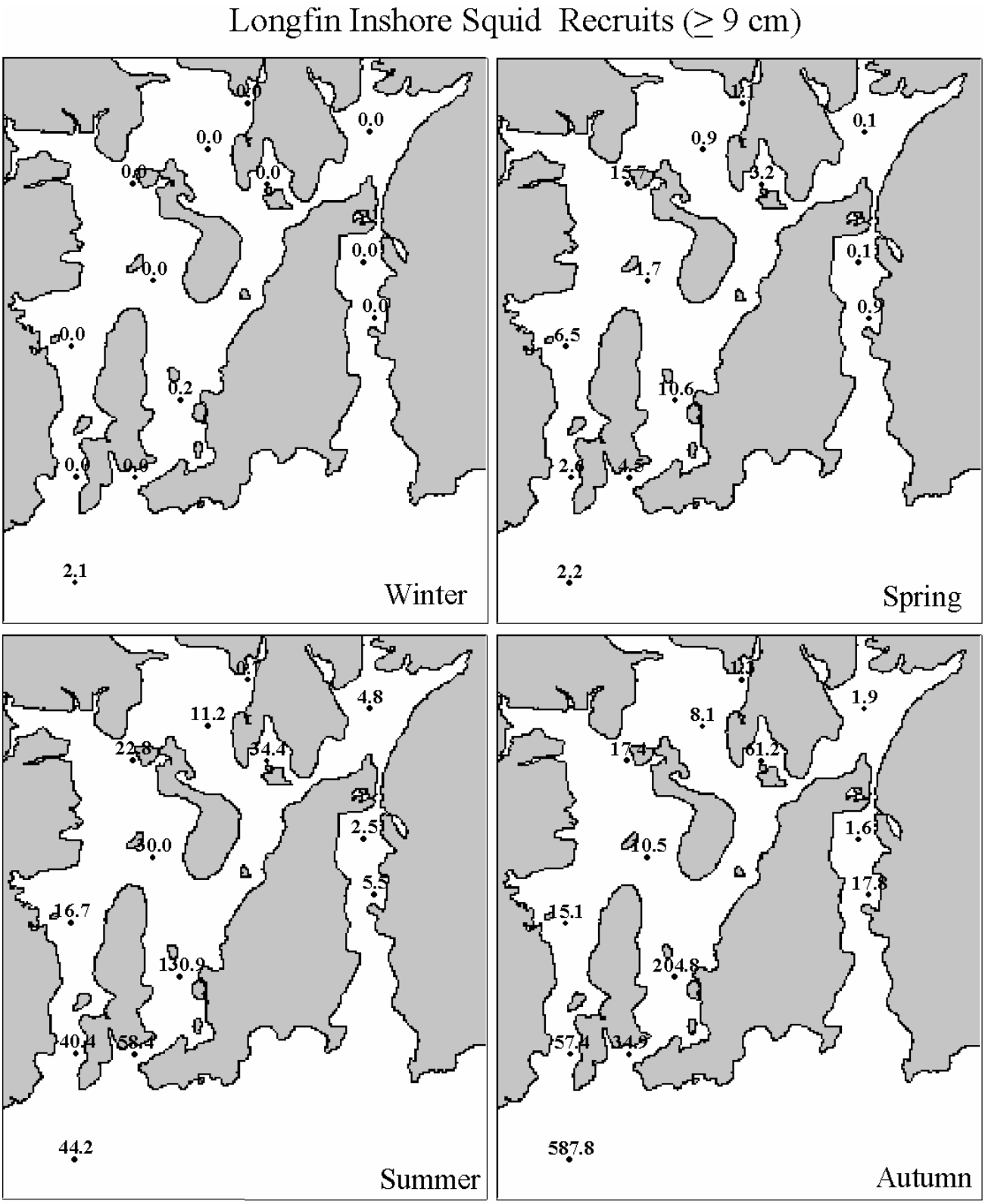

Figure 11. Seasonal distribution and abundance of longfin inshore squid recruits in Narragansett Bay.
Based upon the 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place.

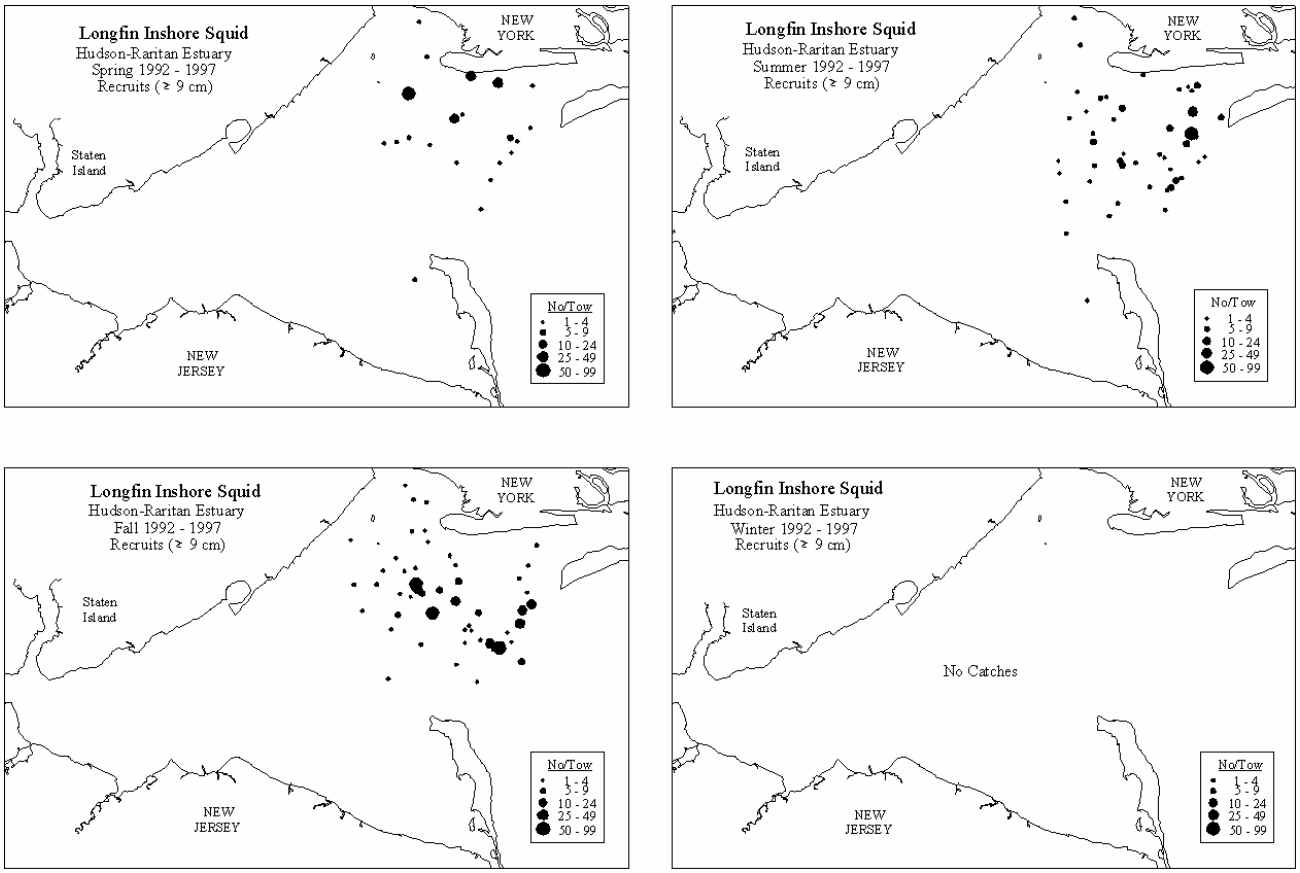

Figure 12. Seasonal distribution and abundance of longfin inshore squid recruits collected in the Hudson-Raritan estuary.
Based on NEFSC Hudson-Raritan trawl surveys, January 1992 – June 1997.

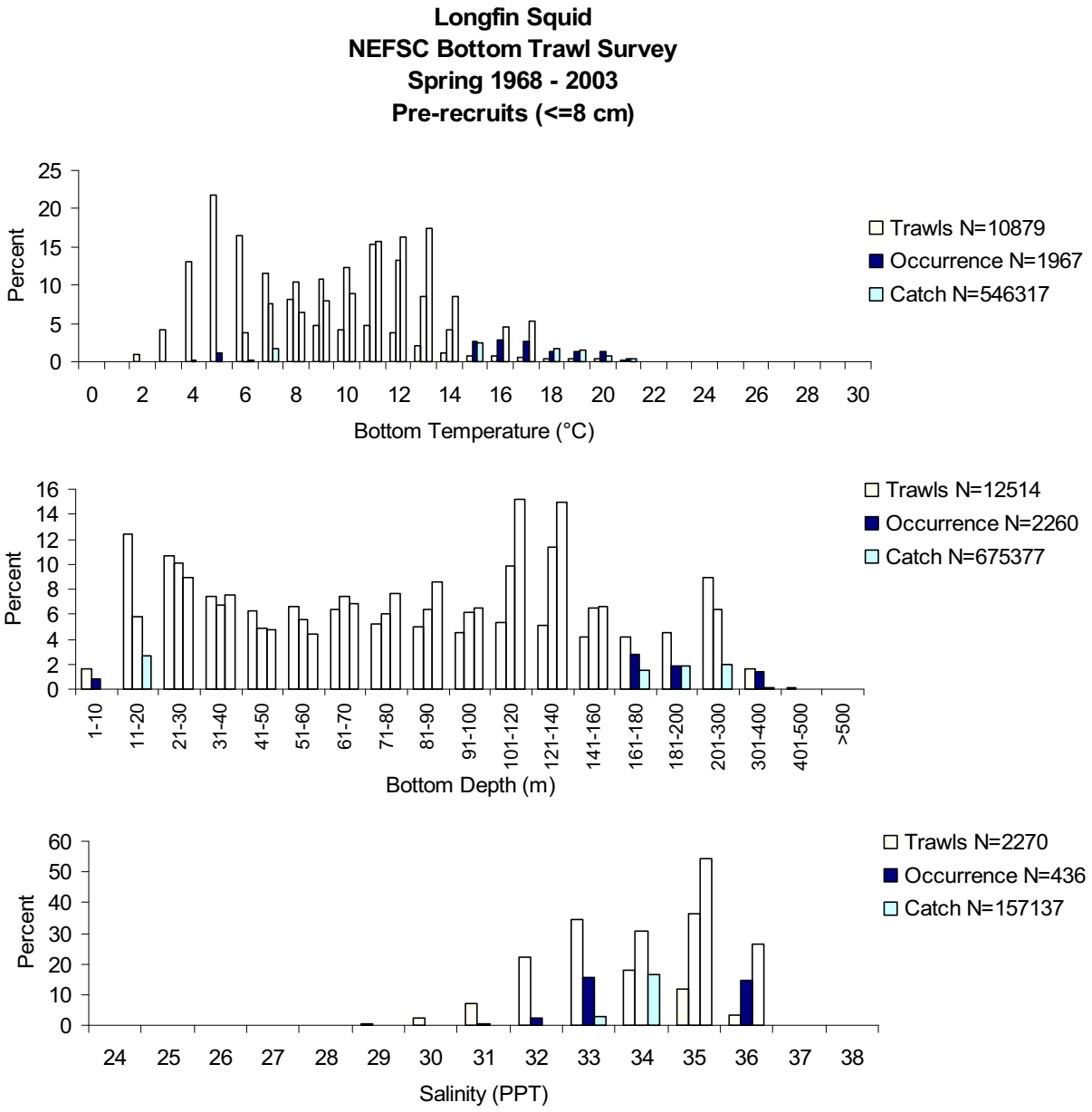

Figure 13. Distributions of pre-recruit longfin inshore squid and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught. Note that the bottom depth interval changes with increasing depth.

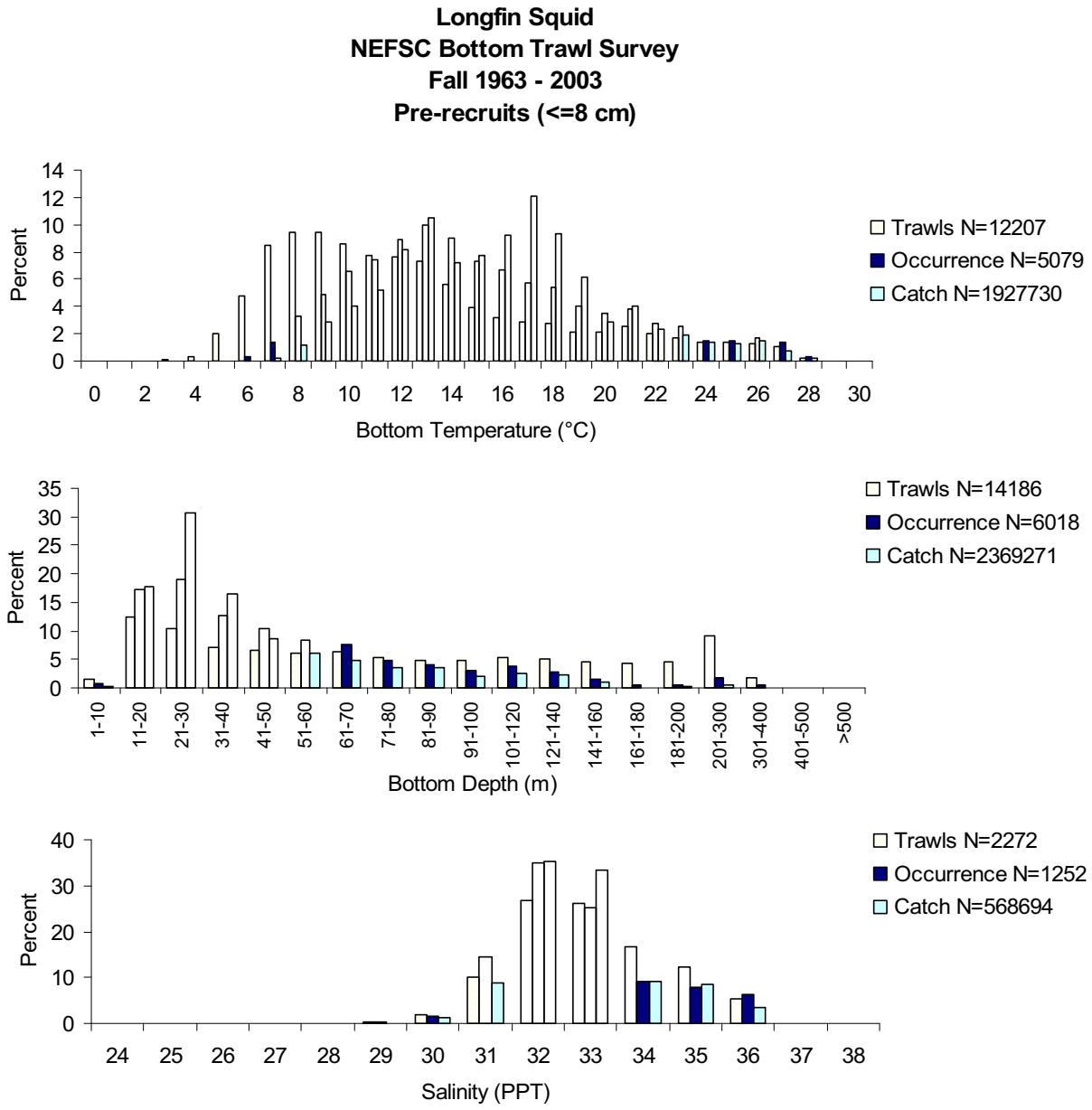

Figure 13. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1967-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught. Note that the bottom depth interval changes with increasing depth.

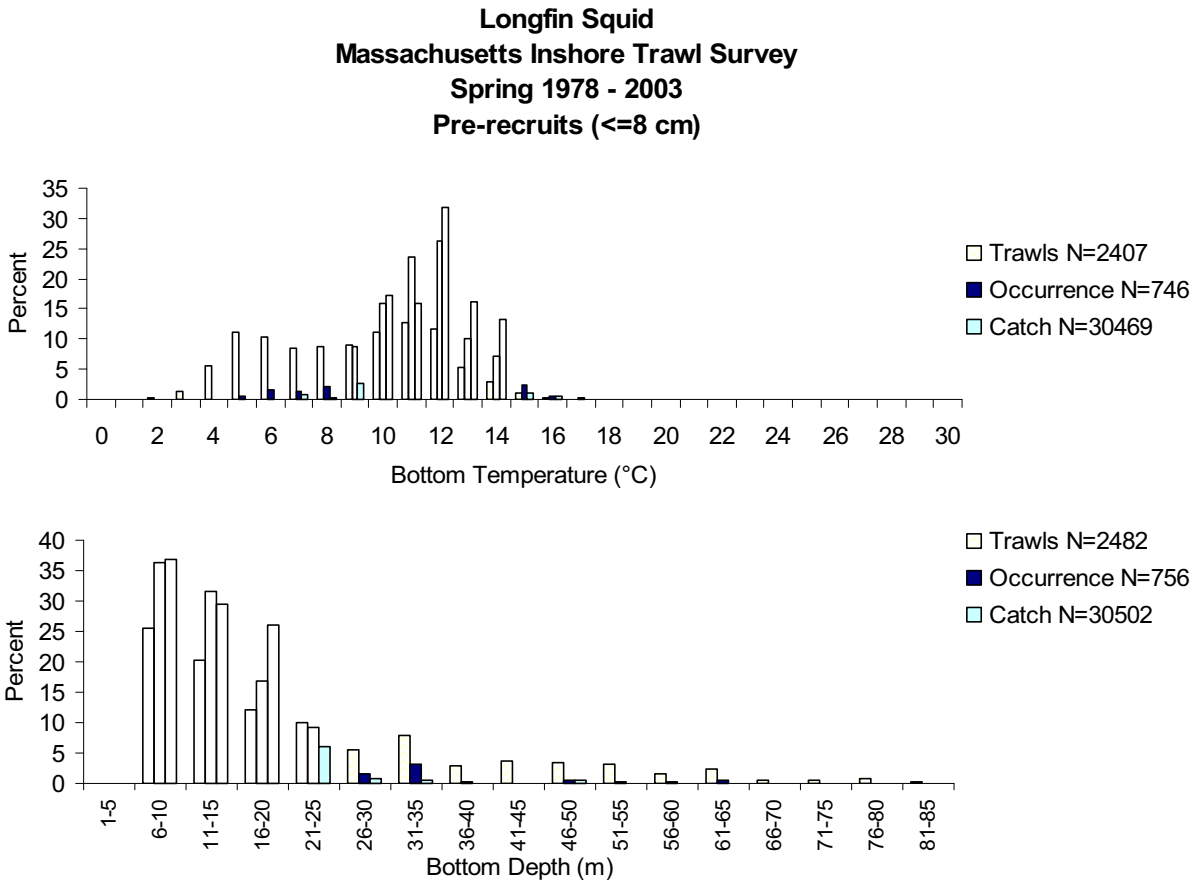

Figure 14. Distributions of pre-recruit longfin inshore squid and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught.

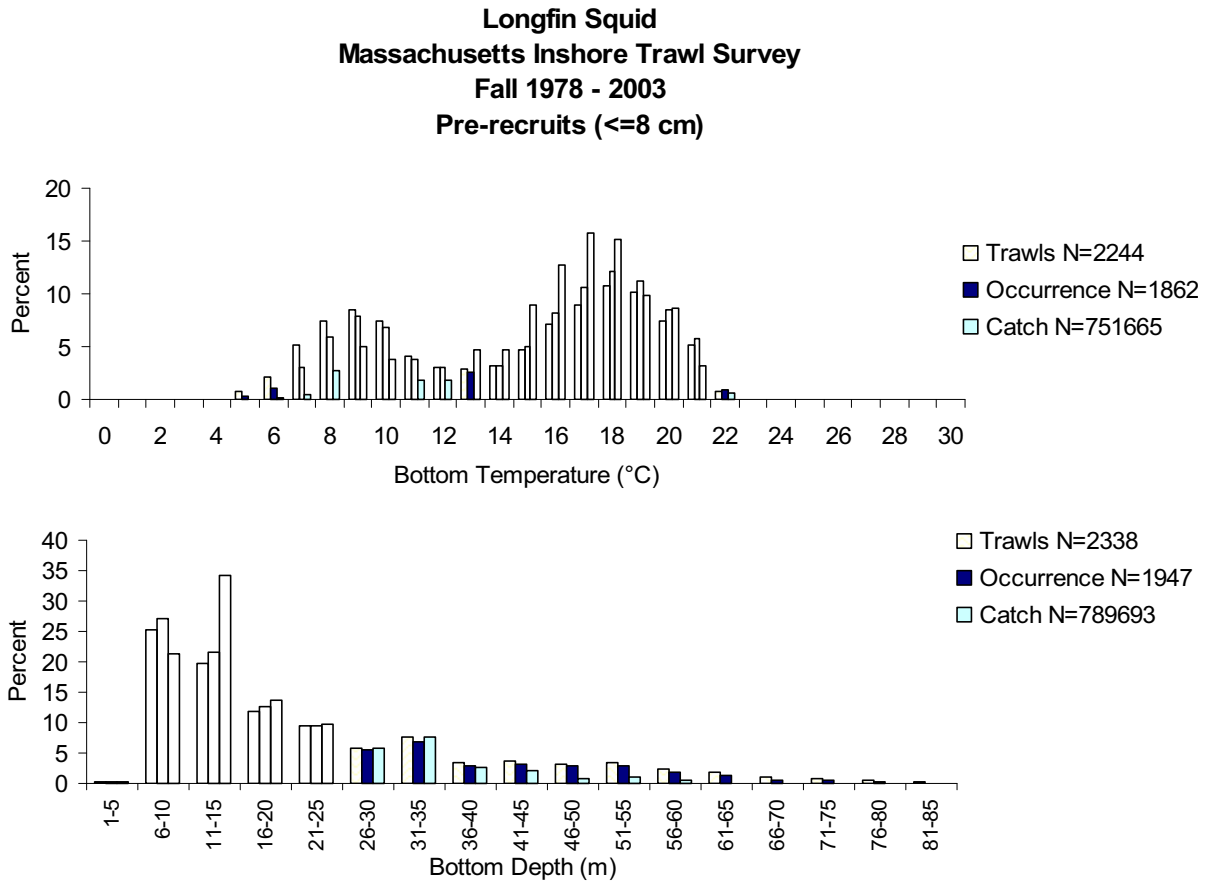

Figure 14. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught.

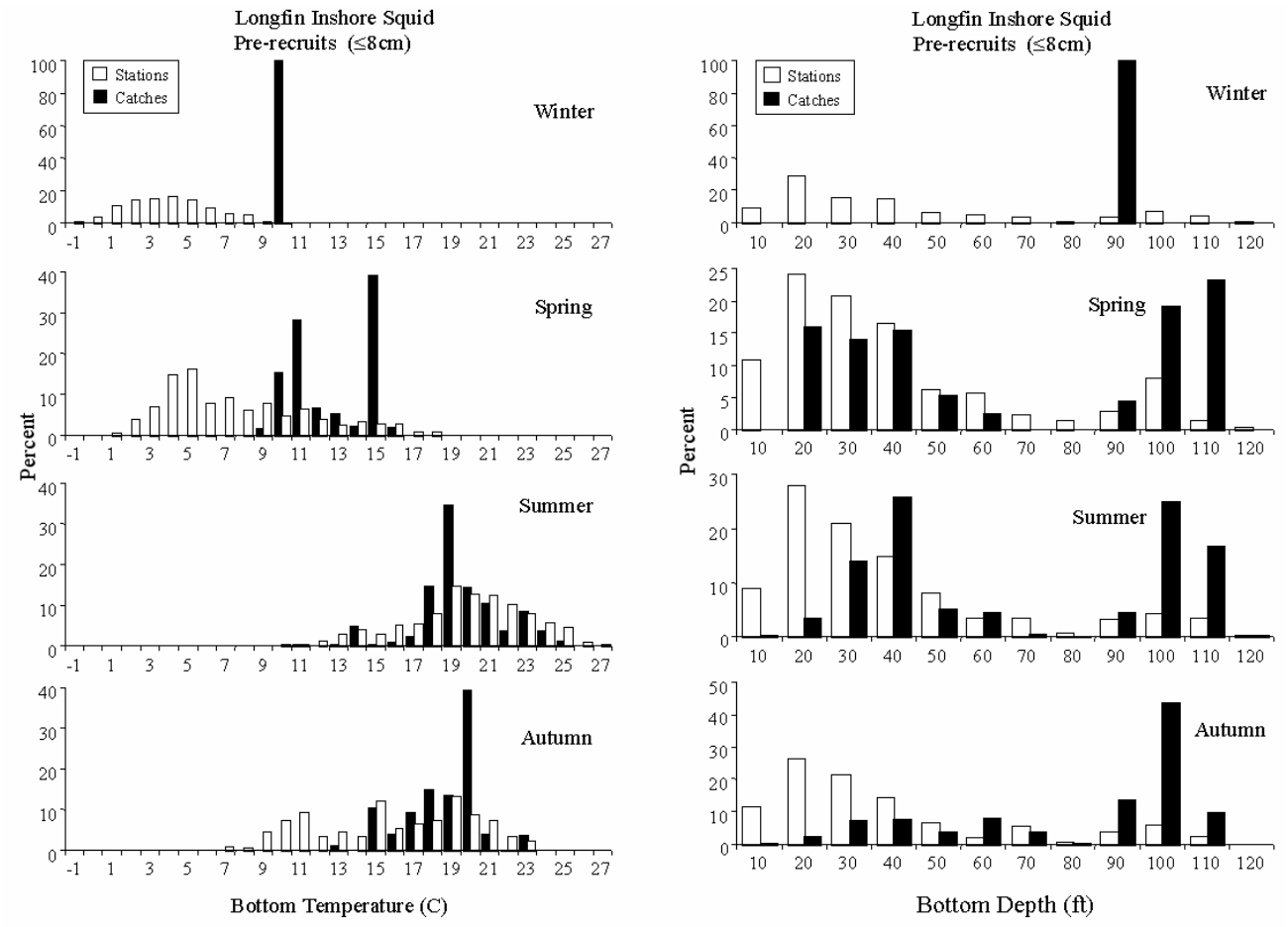

Figure 15. Distributions of longfin inshore squid pre-recruits in Narragansett Bay relative to mean bottom water temperature and bottom depth.
Based on Rhode Island trawl surveys, 1990-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

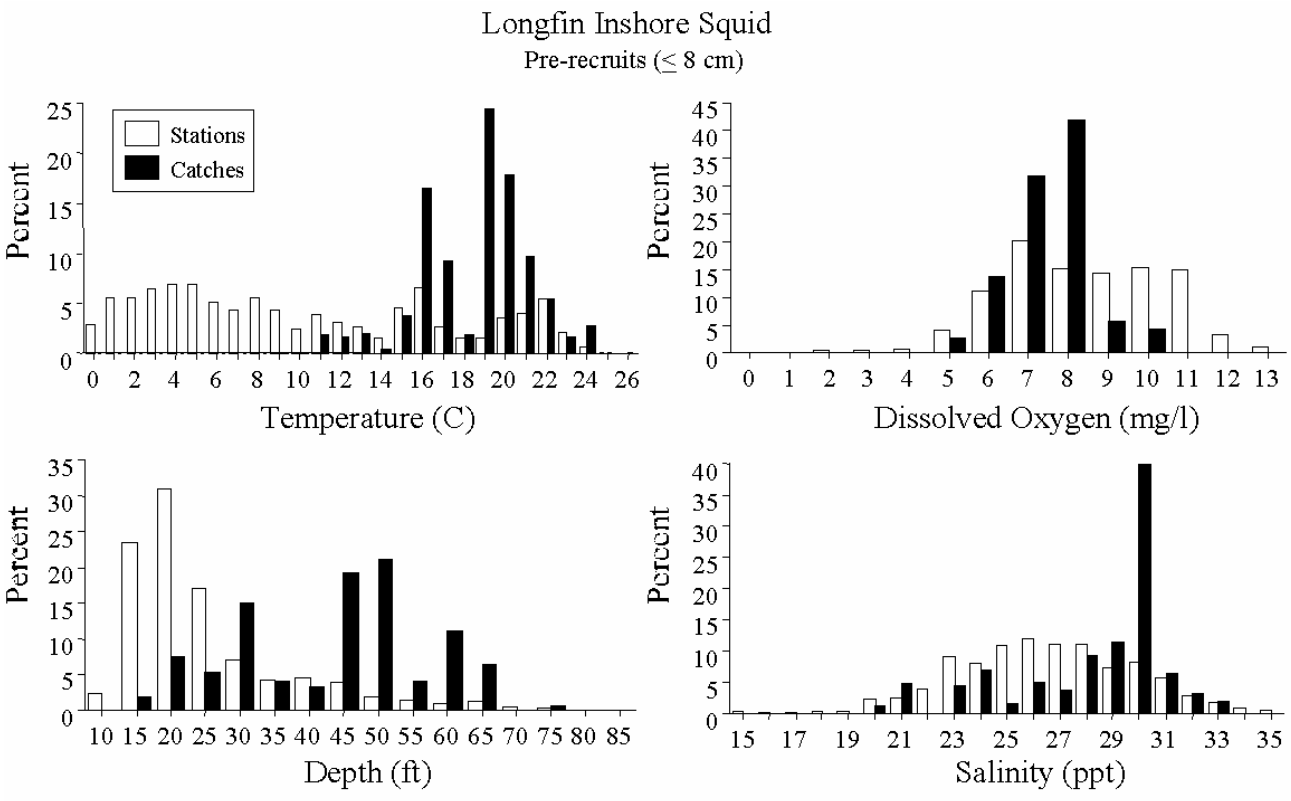

Figure 16. Distributions of longfin inshore squid pre-recruits in the Hudson-Raritan estuary relative to bottom water temperature, depth, dissolved oxygen, and salinity.
Based on NEFSC Hudson-Raritan estuary trawl surveys, 1992-1997, all seasons and years combined. Open bars represent the proportion of all stations surveyed, solid bars represent the proportion of the sum of all standardized catches.

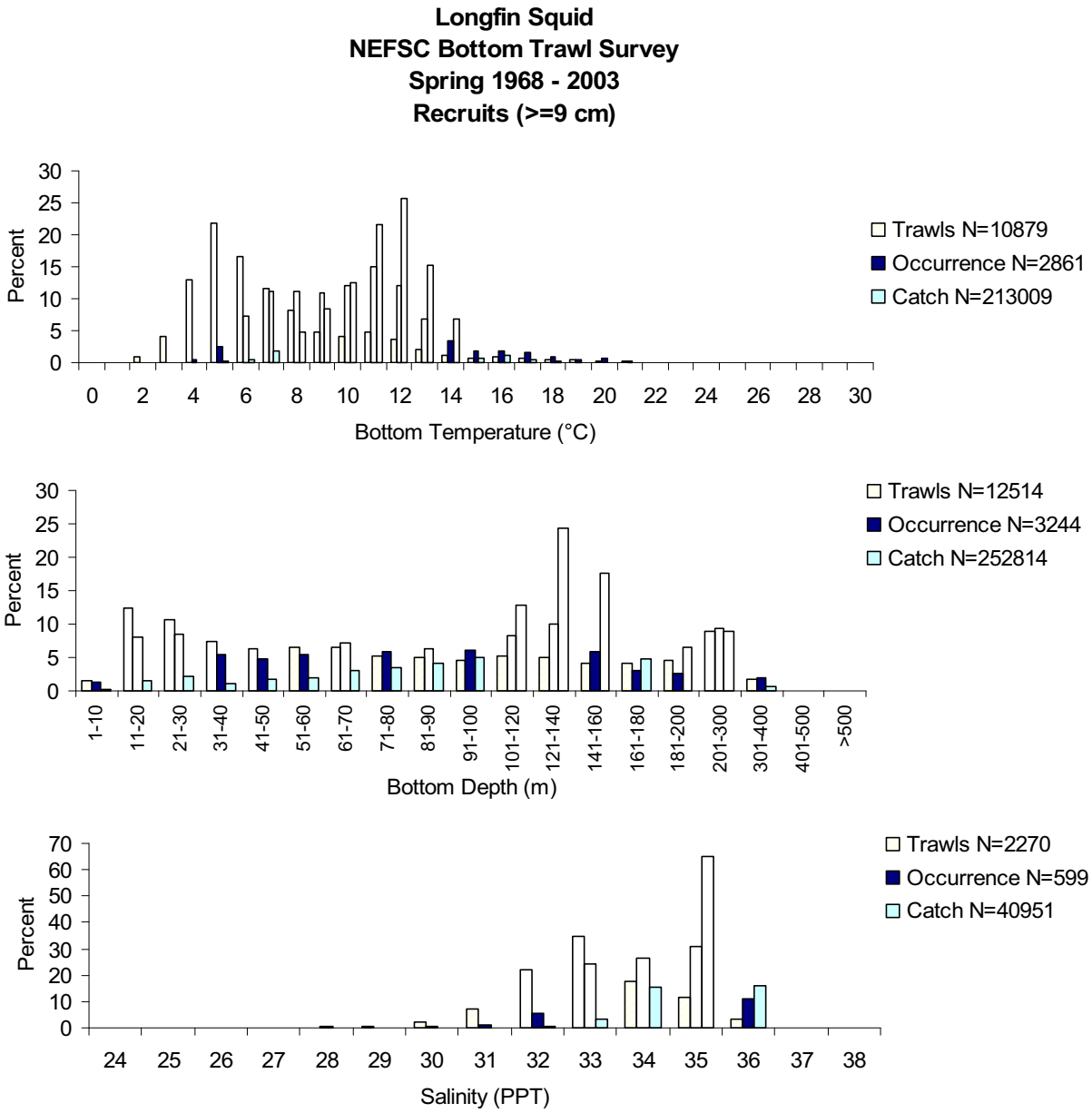

Figure 17. Distributions of recruit longfin inshore squid and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught. Note that the bottom depth interval changes with increasing depth.

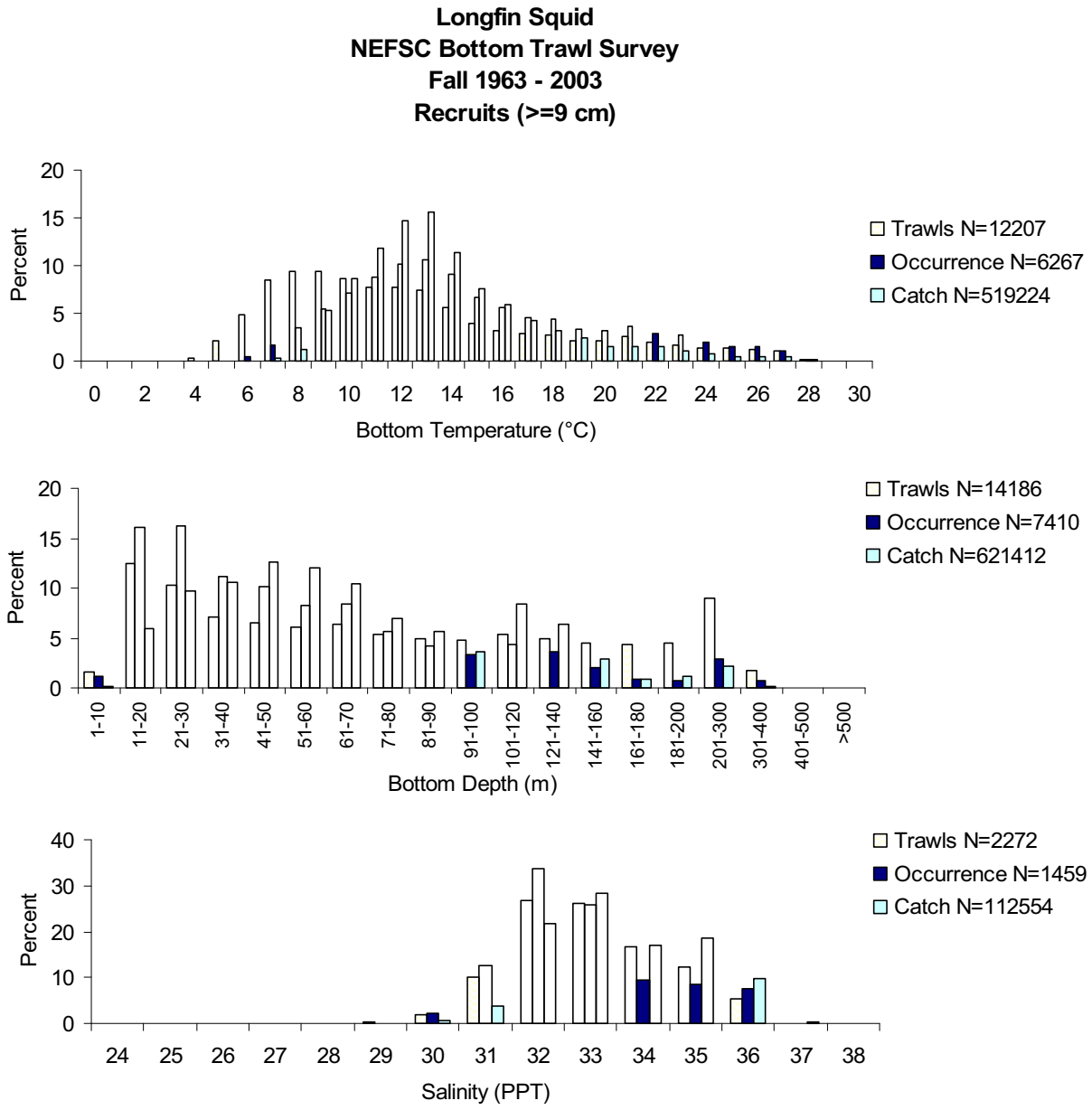

Figure 17. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1967-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught. Note that the bottom depth interval changes with increasing depth.

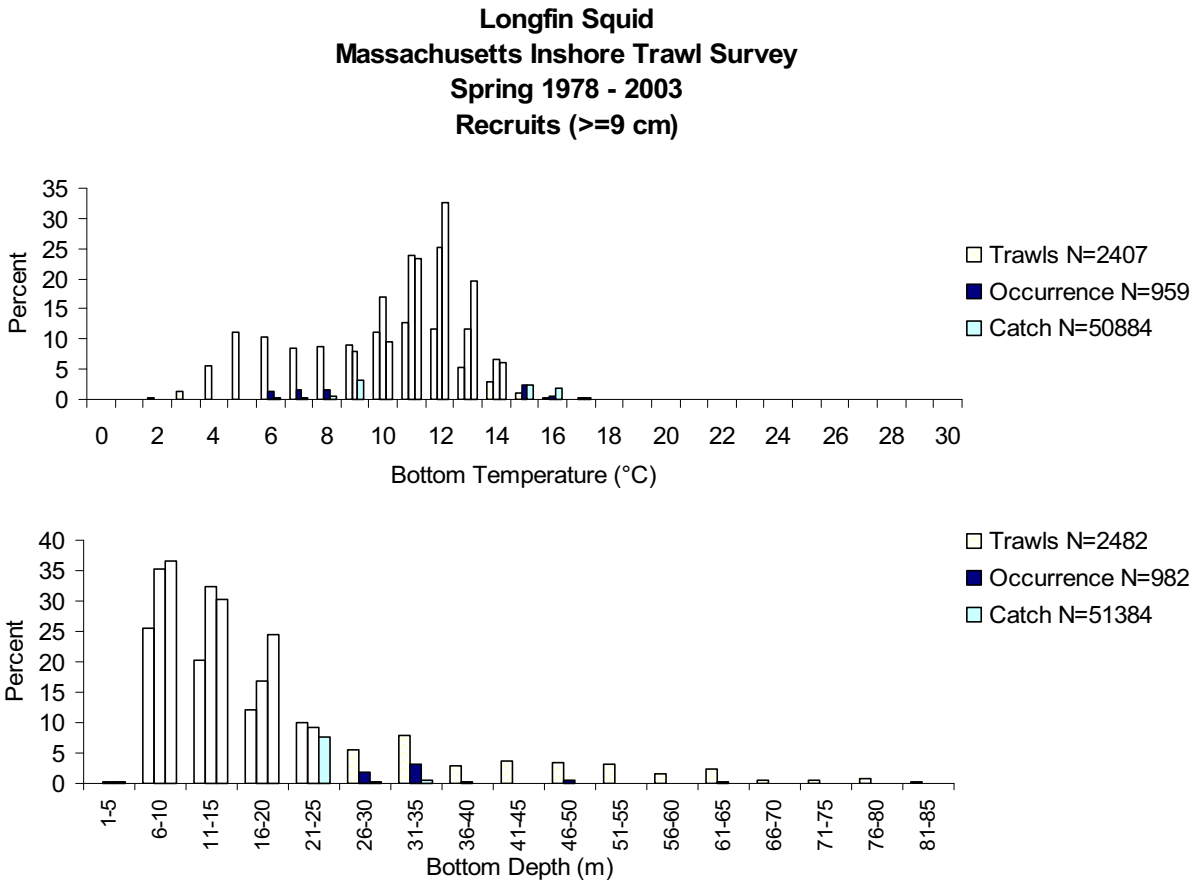

Figure 18. Distributions of recruit longfin inshore squid and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught.

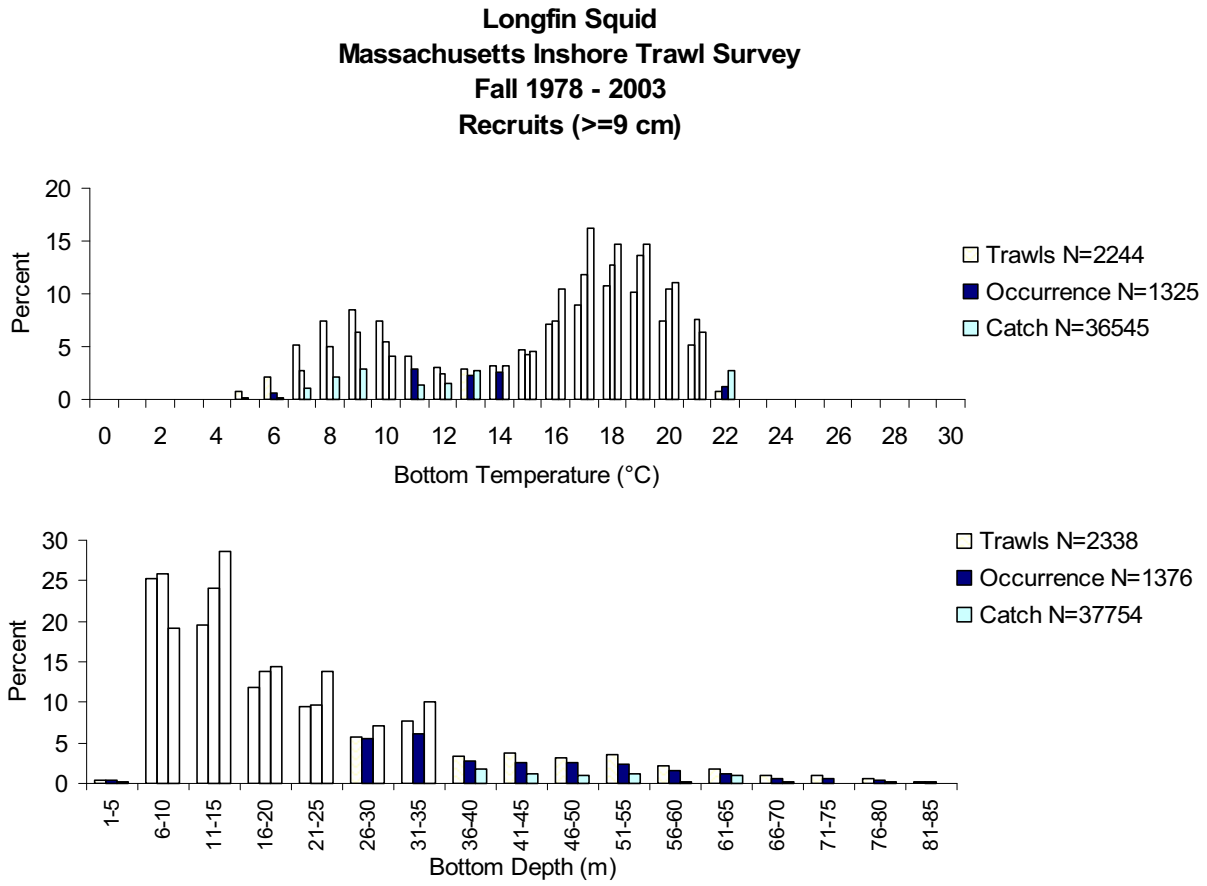

Figure 18. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which longfin inshore squid occurred and medium bars show, within each interval, the percentage of the total number of longfin inshore squid caught.

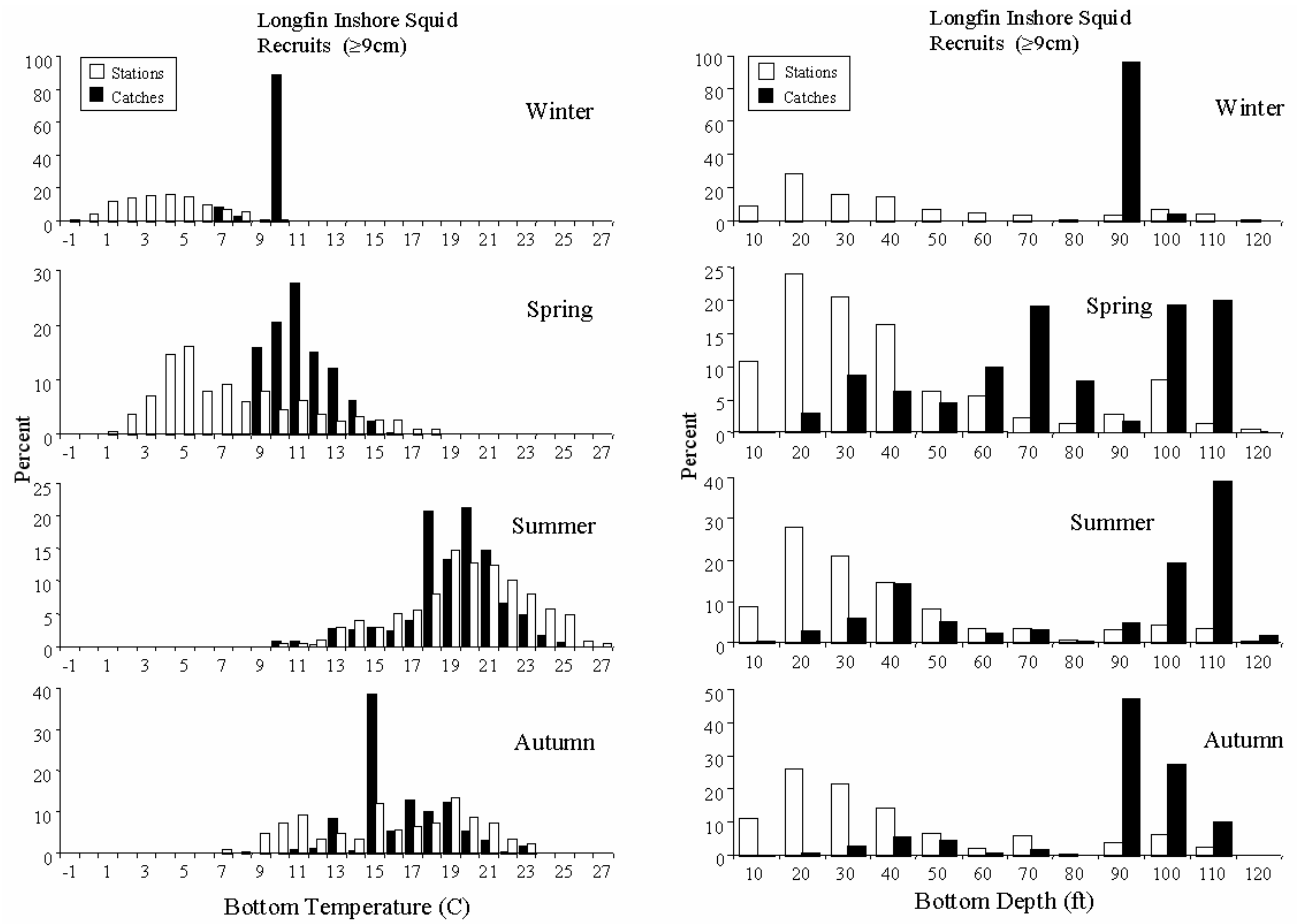

Figure 19. Distributions of longfin inshore squid recruits in Narragansett Bay relative to mean bottom water temperature and bottom depth.
Based on Rhode Island trawl surveys, 1990-1996. Open bars represent the proportion of all stations surveyed, while solid bars represent the proportion of the sum of all catches.

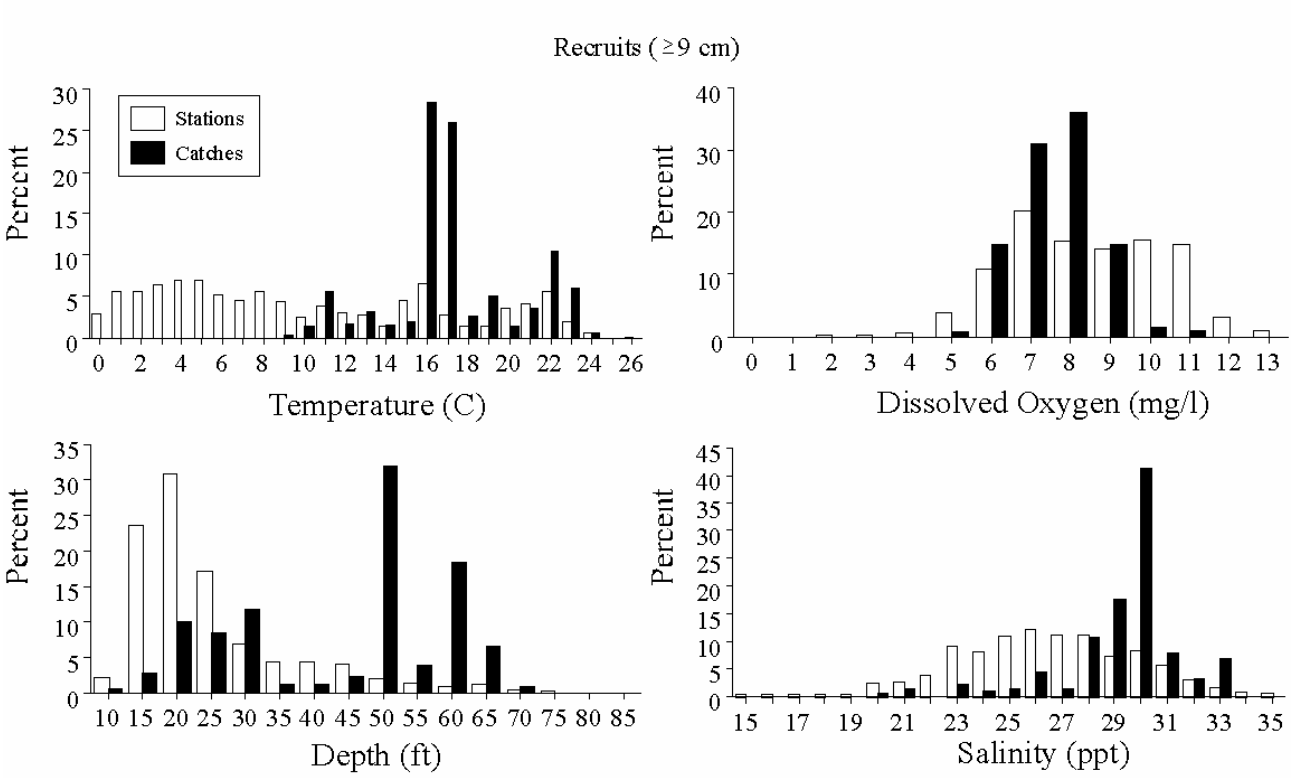

Figure 20. Distributions of longfin inshore squid recruits in the Hudson-Raritan estuary relative to bottom water temperature, depth, dissolved oxygen, and salinity.
Based on NEFSC Hudson-Raritan estuary trawl surveys, 1992-1997, all seasons and years combined. Open bars represent the proportion of all stations surveyed, solid bars represent the proportion of the sum of all standardized catches.

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Essential Fish Habitat Source Document:

Haddock, *Melanogrammus aeglefinus*, Life History and Habitat Characteristics

Second Edition

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Editorial Production

For "Essential Fish Habitat Source Documents" issued in the *NOAA Technical Memorandum NMFS-NE* series, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division largely assume the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production is performed by, and all credit for such production rightfully belongs to, the staff of the Ecosystems Processes Division.

Internet Availability and Information Updating

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Each issue is updated at least every five years. The updated edition will be published as a Web posting only; the replaced edition(s) will be maintained in an online archive for reference purposes.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Nelson *et al*. 2004[a]; Robins *et al.* 1991[b]), mollusks (*i.e.*, Turgeon *et al.* 1998[c]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[d]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[e]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species.

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[a]Nelson, J.S.; Crossman, E.J.; Espinosa-Pérez, H.; Findley, L.T.; Gilbert, C.R.; Lea, R.N.; Williams, J.D. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. 6th ed. *Amer. Fish. Soc. Spec. Publ.* 29; 386 p.

[b]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. World fishes important to North Americans. *Amer. Fish. Soc. Spec. Publ.* 21; 243 p.

[c]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[d]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[e]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

PREFACE TO SECOND EDITION

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NOAA Fisheries to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NOAA Fisheries has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in a series of EFH species reports (plus one consolidated methods report). The EFH species reports are a survey of the important literature as well as original analyses of fishery-independent data sets from NOAA Fisheries and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and understandably are referred to as the "EFH source documents."

NOAA Fisheries provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

The initial series of EFH species source documents were published in 1999 in the *NOAA Technical Memorandum NMFS-NE* series. Updating and review of the EFH components of the councils' Fishery Management Plans is required at least every 5 years by the NOAA Fisheries Guidelines for meeting the Sustainable Fisheries Act/EFH Final Rule. The second editions of these species source documents were written to provide the updated information needed to meet these requirements. The second editions provide new information on life history, geographic distribution, and habitat requirements via recent literature, research, and fishery surveys, and incorporate updated and revised maps and graphs. This second edition of the Haddock EFH source document is based on the original by Luca M. Cargnelli, Sara J. Griesbach, Peter L. Berrien, Wallace W. Morse, and Donna L. Johnson, with a foreword by Jeffrey N. Cross (Cargnelli *et al*. 1999).

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NOAA Fisheries, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

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INTRODUCTION

The haddock, *Melanogrammus aeglefinus*, is a demersal gadid found on both sides of the North Atlantic (Figure 1). In the northwest Atlantic, haddock are distributed from Cape May, New Jersey to the Strait of Belle Isle, Newfoundland (Klein-MacPhee 2002). Six haddock stocks have been identified in the northwest Atlantic from Newfoundland to Georges Bank (Begg 1998). There are two haddock stocks in U.S. waters: Georges Bank and Gulf of Maine. U.S. haddock fisheries are managed by the New England Fishery Management Council under the Northeast Multispecies Fishery Management Plan (NEFMC 1993). The Georges Bank haddock stock is also a transboundary resource, which is co-managed with Canada.

This Essential Fish Habitat Source Document provides up-to-date information on the life history characteristics and habitat requirements of the Georges Bank and Gulf of Maine haddock stocks.

LIFE HISTORY

The life history characteristics of Georges Bank and Gulf of Maine haddock are described in detail by Bigelow and Schroeder (1953) and Klein-MacPhee (2002). Some additional information on early life history stages may be found in Hardy (1978) and Chenoweth *et al.* (1986). Characteristics of egg, larval, juvenile, and adult haddock life history stages are described below.

EGGS

Haddock spawn over various substrates including rocks, gravel, smooth sand, and mud (Klein-MacPhee 2002). Eggs are broadcast and fertilized near the bottom. Fertilized eggs are buoyant and remain in the water column where subsequent development occurs (Hardy 1978; Page *et al.* 1989). Egg size ranges from 1.32-1.60 mm. Incubation time varies with temperature (Laurence and Rogers 1976; Hardy 1978) and can range from 6-42 days (Klein-MacPhee 2002). In temperature-controlled laboratory experiments, haddock eggs averaged about 17-21 days to hatch (Hardy 1978). At water temperatures typical of Georges Bank, haddock eggs hatch in about 15 days (Page and Frank 1989).

LARVAE

Newly-hatched haddock larvae range from 2.0-5.0 mm in length (Klein-MacPhee 2002). Average size at hatch is 4.1 mm for Georges Bank and Gulf of Maine haddock. Length at hatch tends to decrease as the spawning season progresses (Colton and Marak 1969). Larvae absorb their yolk sack within roughly 5 days (Page *et al*. 1999).

Larval survival and growth is influenced by hatching date and oceanographic conditions. Larvae hatched earlier in the spawning season appear to have a survival advantage over those hatched later in the season (Lapolla and Buckley 2005). On Georges Bank, stratified conditions appear to enhance larval survival and growth (Buckley and Lough 1987). Larvae may be advected long distances by ocean currents. In some years, wind-driven currents transport haddock larvae from Georges Bank to the Mid-Atlantic Bight (Polacheck *et al*. 1992). Larval growth appears to be positively correlated with temperatures of about 7-9°C, but may be suppressed at 4 °C (Laurence 1974, 1978). In general, increased temperature has a positive effect on both larval size at age (Green *et al*. 2004) and growth rates (Caldarone 2005). Larval growth generally exceeds 0.2 mm d^{-1} and appears to peak at about 0.5 mm d^{-1} in June (Green *et al*. 2004).

JUVENILES

Larvae metamorphose into juveniles in roughly 30-42 days (Laurence 1978) at lengths of 2-3 cm (Fahay 1983). Small juveniles initially live and feed in the epipelagic zone. Juveniles remain in the upper part of the water column for 3-5 months. After reaching lengths of 3-10 cm (Hardy 1978; Fahay 1983; Mahon and Neilson 1987; Perry and Neilson 1988; Lough and Bolz 1989), juveniles visit the ocean bottom in search of food. Once suitable bottom habitat is located, juveniles settle into a demersal existence (Klein-MacPhee 2002).

ADULTS

Adult haddock are demersal benthivores ranging in size from roughly 30 cm to up to 1 meter. Haddock do not make extensive seasonal migrations. In winter, they prefer deeper waters and tend to move shoreward in summer. When summer water temperatures reach 10-11°C, haddock move to colder, deeper waters. The largest haddock reported from American waters was a 13.6 kg fish (Klein-MacPhee 2002). The oldest haddock documented from Northeast Fisheries Science

Center (NEFSC) surveys during 1963-2002 was a 17 year old fish captured in 1980. Most commercially-caught haddock weigh from 1-3 kg.

REPRODUCTION

Haddock are highly fecund broadcast spawners (Klein-MacPhee 2002). Depending upon their size, adult females produce on the order of hundreds of thousands to millions of eggs per year. Eggs are released near the ocean bottom in batches and fertilized by a courting male. After fertilization, haddock eggs become buoyant and rise to the surface water layer.

Median age and size of maturity differ slightly between the Georges Bank and Gulf of Maine haddock stocks (Table 1). During the late-1980s, Georges Bank haddock matured at younger ages and smaller sizes than Gulf of Maine haddock (O'Brien *et al*. 1993, see also Clark 1959). On Georges Bank, males matured at younger ages and smaller sizes than females. In the Gulf of Maine, median age of maturity for males was greater than for females while male and female sizes at maturity were similar. Size at maturity of Georges Bank haddock has declined in recent years (O'Brien *et al*. 1993; Trippel *et al.* 1997). For example, female median length of maturity was about 40 cm during 1977-1983 but declined to about 34-36 cm in the early-1990s. Density-dependence may explain the apparent decline in median size of maturity since haddock appear to mature at smaller sizes when population density is low (Waiwood and Buzeta 1989; Ross and Nelson 1992).

Georges Bank is the principal haddock spawning area in the northeast U.S. continental shelf ecosystem. Haddock spawning is concentrated on the northeast peak of Georges Bank. The western edge of Georges Bank also supports a smaller spawning concentration (Walford 1938). The two spawning components are persistent and exhibit phenotypic differences in otolith morphometrics (Begg *et al*. 2000). Although the vast majority of reproductive output originates from Georges Bank, some limited spawning activity occurs on Nantucket Shoals (Smith and Morse 1985) and along the South Channel (Colton and Temple 1961). In the Gulf of Maine, Jeffreys Ledge and Stellwagen Bank are the two primary spawning sites (Colton 1972). In addition, Ames (1997) also reported numerous small, isolated spawning areas in inshore Gulf of Maine waters. Based on interviews with retired commercial fishers from Maine and New Hampshire, Ames (1997) identified 100 haddock spawning sites, covering roughly 500 square miles, from Ipswich Bay to Grand Manan Channel.

The timing of haddock spawning activity varies among areas. In general, spawning occurs later in more northerly regions (Page and Frank 1989; Lapolla and Buckley 2005). There is also inter-annual variation in the onset and peak of spawning activity. On Georges Bank, spawning occurs from January to June (Smith and Morse 1985), usually peaking from February to early-April (Smith and Morse 1985; Lough and Bolz 1989; Page and Frank 1989; Brander and Hurley 1992; Lapolla and Buckley 2005) but the timing can vary by a month or more depending upon water temperature (Marak and Livingstone 1970; Page and Frank 1989). In the Gulf of Maine, spawning occurs from early February to May, usually peaking in February to April (Bigelow and Schroeder 1953). Overall, cooler water temperatures tend to delay haddock spawning and may contract the duration of spawning activity (Marak and Livingstone 1970; Page and Frank 1989).

FOOD HABITS

Haddock diet changes with life history stage. Pelagic larvae and small juvenile haddock feed on phytoplankton, copepods, and invertebrate eggs in the upper part of the water column (Kane 1984). Juvenile haddock eat small crustaceans, primarily copepods and euphausiids, as well as polychaetes and small fishes. Juveniles make a transition from pelagic to demersal habitat at ages from 3 to 5 months. During this transition, juvenile diet changes to primarily benthic prey (Mahon and Neilson 1987). Planktonic prey such as copepods and pteropods decrease in importance after juveniles become demersal, while ophiuroids and polychaetes increase in importance. When juveniles reach 8 cm in length, they feed primarily on echinoderms, small decapods, and other benthic prey (Bowman *et al*. 1987). Benthic juveniles above 30 cm and adults feed primarily on crustaceans, polychaetes, mollusks, echinoderms, and some fish (Bowman and Michaels 1984; Mahon and Neilson 1987; Klein-MacPhee 2002). Regional variation in haddock food habits also exists (Bowman *et al*. 2000). Echinoderms are more common prey items in the Gulf of Maine than on Georges Bank. In contrast, polychaetes are more common prey on Georges Bank than in the Gulf of Maine.

Food habits data collected during Northeast Fisheries Science Center (NEFSC) bottom trawl surveys [see Reid *et al.* (1999) and Link and Almeida (2000)] reveal that the species composition of haddock prey varies by haddock size class (Figure 2). Unidentified fish (> 40%), amphipods (> 30%), and well-digested prey (WDP, > 10%) were the most common prey items by weight for small haddock less than 20 cm in length. The diet of haddock between 20 and 50 cm in length was more varied and included WDP (> 20%), amphipods (> 15%), ophiuroids (> 10%), and polychaetes (> 10%). Ophiuroids (> 15%), amphipods (> 10%), WDP (> 10%), and polychaetes (> 10%) were the most common prey items of large

haddock with lengths between 50 and 80 cm. Extra-large haddock over 80 cm in length fed primarily upon clupeids (> 25%), ophiuroids (> 20%), amphipods (> 10%), and scombrids (> 10%). There was more sampling variation in the diet of extra-large haddock due to low sample size. Overall, the NEFSC food habits data show that haddock diet includes more ophiuroids and becomes more varied as fish increase in size. It also shows that amphipods are an important prey item for all demersal life history stages and that fish are an important component of the diet of very large haddock.

LARVAL RETENTION

The retention of haddock larvae in suitable nursery areas is an important factor in determining year class strength of Georges Bank haddock. The clockwise gyre around the main portion of Georges Bank provides a physical mechanism to retain haddock larvae on the Bank. Larvae associated with the interior of the gyre tend to remain on Georges Bank (Smith and Morse 1985) while those associated with the outside of the gyre tend to be transported southwest by prevailing currents towards Nantucket Shoals. Strong year-classes may arise in years when circulation results in either retention of larvae on the Bank (Smith and Morse 1985) or in transport of larvae to nursery grounds to the southwest of the Bank (Colton and Temple 1961; Polacheck *et al.* 1992). Comparisons of water residence times on Georges Bank and spawning locations suggest that haddock select areas and times of the year that enhance the probability of larval retention on the Bank (Page *et al*. 1999).

Lough and Bolz (1989) found that the southerly drift of larvae may be slowed, and retention on the shoals of Georges Bank enhanced, by larvae residing nearer to the bottom in waters shallower than 70 m. In some years, differences in wind stress and associated geostrophic currents alter the pattern of larval retention on the Bank. Wind-driven southwesterly surface currents can alter the pattern of larval retention and transport haddock larvae over hundreds of kilometers into the Mid-Atlantic Bight (Polacheck *et al*. 1992). In contrast, strong episodes of southeastward wind stress are associated with high egg and larval mortalities in some years (Mountain *et al*. 2003). There is limited information on retention of larval haddock in the Gulf of Maine. Ames (1997) suggests that haddock eggs and larvae in coastal Gulf of Maine waters may be retained in suitable habitats by tidal currents.

GEOGRAPHICAL DISTRIBUTION

In the northwest Atlantic, haddock are distributed from Cape Charles, Virginia to Labrador, Canada (Figure 3). Georges Bank, the Scotian Shelf, and the southern Grand Bank have the highest densities of haddock. The distributions of haddock egg, larval, and juvenile and adult stages on Georges Bank and the Gulf of Maine are described below.

EGGS

The distribution of haddock eggs was determined using monthly NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) survey data. During 1978-1987, MARMAP ichthyoplankton surveys caught haddock eggs from New Jersey to southwest Nova Scotia (Figure 4). The highest densities were found on Georges Bank and Browns Bank, which are important haddock spawning areas (Colton and Temple 1961; Laurence and Rogers 1976; Brander and Hurley 1992). Eggs were collected from January through August. The highest concentrations occurred in April, followed by March and May. This pattern is consistent with the timing of peak spawning from March to May (Bigelow and Schroeder 1953; Page and Frank 1989; Brander and Hurley 1992). In particular, the highest mean densities of eggs occurred in April (77.3 eggs/10 m^2) and March (21.1 eggs/10 m^2). By July and August, mean densities had decreased substantially (< 0.1 eggs/10 m^2).

Data from the more recent U.S. GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) showed the highest concentration of eggs to be on the eastern, Canadian side of Georges Bank, with peaks occurring during February-March and into April (Figure 5).

LARVAE

The distribution of haddock larvae was determined using monthly MARMAP survey data. The 1977-1987 MARMAP ichthyoplankton surveys captured haddock larvae from the Delmarva Peninsula to southwest Nova Scotia (Figure 6). Larvae were collected from January through July. The highest mean densities occurred in May (8.3 larvae/10 m^2) and April (8.1 larvae/10 m^2). High densities of larvae were found off southwest Nova Scotia and Georges Bank, spreading southward. Mean densities were low in January and February. Larval densities were highest in April through June and declined substantially by July (< 0.1 larvae/10 m^2). These findings are consistent with the seasonal pattern

of haddock spawning (Smith and Morse 1985; Campana 1989).

Data from the more recent U.S. GLOBEC Georges Bank surveys showed the highest numbers of larvae were in March and April and mostly in southern areas of the Bank between the 50-100m isobath (Figure 7).

JUVENILES AND ADULTS

Seasonal catches of juvenile (≤ 31 cm) and adult haddock (> 31 cm) in NEFSC bottom trawl surveys [see Reid *et al*. (1999) for details] during 1963-2003 show that the distributions of juvenile and adult haddock are generally similar (Figure 8 and Figure 10; note that winter and summer distributions are presented as presence data only, precluding a discussion of abundances). During winter and summer, juveniles and adults (Figure 8 and Figure 10) are found on Georges Bank, throughout the Gulf of Maine, in southern New England, and in the northern section of the Mid-Atlantic (the latter is not true for adults in the summer). During spring, adults are generally found near spawning areas (Figure 10). Dense concentrations of adults are found on the northeast peak of Georges Bank, in the Great South Channel and in coastal waters of the Gulf of Maine. Juvenile distribution during spring is similar to that of adults although more juveniles occur on the southern flank of Georges Bank (Figure 8). In autumn, adults are found throughout the Gulf of Maine, the Great South Channel, and the northern flank and northeast peak of Georges Bank (Figure 10). Juvenile distribution during autumn is generally shallower than adults and in some years, extends south into the Mid-Atlantic Bight, with large numbers around Hudson Canyon (Figure 8).

Information on the inshore distribution of juvenile and adult haddock was collected from Massachusetts inshore bottom trawl surveys during 1978-2003 [see Reid *et al*. (1999) for details]. Juveniles were more abundant in coastal Massachusetts waters than adults (Figure 9 and Figure 11), and were more abundant in autumn than spring. In the spring, juveniles were most abundant north of Cape Ann, in northeastern Massachusetts Bay, and in two aggregations off eastern Cape Cod, but were not widespread in Cape Cod Bay. Another aggregation was found northwest of Provincetown, Cape Cod. Adults were more abundant in spring than in autumn. In spring, adults were most abundant in northeast Massachusetts Bay, and were also found northeast of Cape Ann and around Provincetown. In autumn, juveniles were most abundant directly north and northeast of Cape Ann and in northeastern Massachusetts Bay. They were also found in two aggregations off the east coast of Cape Cod, and in low numbers throughout Cape Cod Bay. In autumn, adults were mostly absent from inshore Massachusetts waters.

The distributions and abundances of juvenile and adult haddock along the coasts of Maine and New Hampshire, based on spring and fall 2000-2004 Maine-New Hampshire inshore groundfish surveys (Sherman *et al*. 2005), are shown in Figure 12. The majority were juveniles, particularly in the fall, with higher numbers of adults seen in the spring (Figure 13). Haddock CPUE along the Maine-New Hampshire coast by region and season/year is shown in Figure 14.

HABITAT CHARACTERISTICS

Detailed information on life history and habitat parameters for Georges Bank and Gulf of Maine haddock were summarized from the literature (Table 2). The habitat characteristics of egg and larval stages as well as juvenile and adult stages are described below.

EGGS AND LARVAE

Haddock egg and larval stages are pelagic. They are usually found at depths of 10-50 m below the surface (Marak 1960; Colton and Temple 1961; Miller *et al.* 1963; Hardy 1978), and in water temperatures of 4-10°C (Laurence and Rogers 1976; Laurence 1978) and salinities of 34-36 ppt (Laurence and Rogers 1976). During the MARMAP surveys, most haddock eggs were collected at temperatures of 4-10°C and depths of 50-130 m while most larvae were collected at 4-14°C and 30-90 m (Figure 15 and Figure 18).

Haddock eggs were sampled at temperatures ranging from 2-10°C. The vast majority were found at 4-10°C (Figure 15), the temperature range at which egg survival is highest (Hardy 1978). In January, the highest densities of eggs were found at 6-7°C , while in February, March, and April, the highest densities occurred at 4-6°C. This is consistent with Colton (1972) and Hardy (1978) who reported that the optimum spawning temperature for haddock is 2-7°C. In May and June, the highest abundance of eggs was at 5-7°C. During July and August almost all eggs were found at 8-10°C. Thus, eggs were found at higher temperatures as the spawning season progressed.

Eggs were sampled at water column depths ranging from 10 m to 450 m. However, the majority were found at 50-130 m (Figure 15). From January to May the highest density of eggs occurred at depths of 70-90 m, while in June the majority of eggs were deeper, at 110-150 m. In July, all eggs were found between 90-110 m, and in August all eggs were found at 50-70 m.

Larvae were captured at temperatures of 2-15°C, a wider range than for eggs. The majority of larvae occurred at 4-14°C (Figure 18). There was monthly variation in the temperatures where larvae were caught.

In January, the majority of larvae were found at temperatures of 8-9°C. During February to April, larvae were at a cooler range of 4-6°C. In May and June, most larvae were caught at 6-9°C. In July, a few larvae were found at 9-11°C and 14°C.

Larvae were captured at water column depths ranging from 10 m to 325 m. However the majority occurred at 30-90 m (Figure 18). From January to June, most larvae were found at 70-90 m, and during July all larvae were found at 30-90 m, with the highest abundance at 30-50 m.

During the more recent GLOBEC Georges Bank survey from January to July 1995-1999, the majority of eggs were found in a narrow temperature range of about 3-4°C in January, and from about 1-3°C from February to May, and at temperatures of 3-6°C in June (Figure 13). Their depth range on Georges Bank during that same period was centered on 61-100 m (Figure 14). Larvae were found at temperatures of 6-7°C in January, mostly from 5-6°C in February and April, and from 4-5°C in March (Figure 16). In May, the majority were found at the lower temperature of 2°C, while in June they were spread over a temperature range of 6-12°C. In July, larvae were caught at 8°C and 10°C. Most were found at depths of 61-100 m from January to April, from 61-80 in May and June, and from 81-120 m in July (Figure 17).

JUVENILES AND ADULTS

Juvenile and adult haddock are demersal. Juveniles and adults are usually found at depths between 40-150 m (Bigelow and Schroeder 1953; Murawski and Finn 1988; Perry and Neilson 1988). Their preferred depth range is from 50-100 m (Scott 1982; Waiwood and Buzeta 1989), but they can sometimes be found as shallow as 10 m (Blacker 1971) or as deep as 200+ m (Colton 1972; Hardy 1978).

Juveniles are commonly found at water temperatures of 4.5-10°C (Murawski and Finn 1988). Adults can be found at a wider range of 0-13°C (Hardy 1978), but prefer temperatures of 2-9°C (Bigelow and Schroeder 1953; Colton 1972; Waiwood and Buzeta 1989). Juvenile and adult haddock are commonly associated with salinities of 31-35 ppt, although 32 ppt is optimal (Bigelow and Schroeder 1953; Scott 1982; Waiwood and Buzeta 1989).

During spring and fall NEFSC trawl surveys (Figure 21 and Figure 23), both juveniles and adults were caught at depths of 21-400 m and temperatures of 2-16°C. During spring and fall Massachusetts inshore trawl surveys (Figure 22 and Figure 24), juveniles were caught at depths of 6-85 m and temperatures of 3-16°C, while adults were caught at 26-85 m and 4-12°C.

During spring NEFSC surveys, most juveniles and adults were captured at temperatures of 4-7°C with peaks at 5-6°C (Figure 21 and Figure 23). The preferred juvenile depth range in spring was 71-140 m while the preferred salinity range was 33 ppt. The preferred adult depth range in spring was 51-120 m while the preferred salinity was 33 ppt. During autumn, the preferred juvenile temperature range was about 6-13°C with a peak at 8°C (Figure 21). Most juveniles were captured at depths of 41-120 m and at salinities of 32-34 ppt. The preferred adult temperature range during autumn was 6-10°C, and with a peak at 7°C (Figure 23). Most adults were found at depths greater than 81 m, with a preferred salinity of 33-34 ppt.

During the Massachusetts spring inshore trawl surveys, juveniles were primarily found at temperatures of 4-8°C and at depths of 31-65 m (Figure 22). Most adults occurred at temperatures of 4-8°C and depths of 46-55 m (Figure 24). In the autumn, juveniles were primarily found at temperatures of 7-10°C and at depths of 31-50 m (Figure 22). Adults were generally absent from inshore waters during autumn (Figure 24); the few that were present occurred at temperatures of 8°C, 10°C, and 12°C and at depths of 61-65 m.

SUBSTRATE

Preferred bottom types include gravel, pebbles, clay, and smooth hard sand, particularly smooth areas between rocky patches (Klein-MacPhee 2002). Juvenile and adult haddock do not frequent ledges, rocks, kelp, or soft oozy mud. The distribution of substrate sediments on Georges Bank and in the Gulf of Maine area show regional differences (Figure 25). Substantial areas of suitable substrate for haddock (i.e., sand, gravelly sand, and gravel) are found on Georges Bank. In contrast, fewer areas of suitable substrate exist in the Gulf of Maine. Consequently, haddock are more abundant on Georges Bank than in the Gulf of Maine. In particular, the principal haddock spawning area on the northeast peak of Georges Bank (Colton and Temple 1961; Lough and Bolz 1989) contains large areas of suitable substrate. Similarly, the two principal spawning areas in the Gulf of Maine, Stellwagen Bank and Jeffreys Ledge (Colton 1972), also contain gravelly sand substrate.

STATUS OF THE STOCKS

The U.S. Sustainable Fisheries Act of 1996 (DOC 1996) requires that fishery conservation and management measures prevent overfishing and rebuild depleted stocks to biomasses consistent with producing maximum sustainable yield (MSY). Overfishing occurs whenever fishing mortality exceeds a threshold that jeopardizes the reproductive capacity of a stock to

produce maximum sustainable yield. Guidelines to the Act also specify that a depleted resource is one that has been reduced below a minimum stock size threshold. For Georges Bank and Gulf of Maine haddock, the minimum stock size threshold is one-half the biomass needed to produce MSY (B_{MSY}). It is possible for a stock to be classified as overfished (due to previous overharvesting) even though the annual harvest rate is below the overfishing threshold. This has been the case for haddock, which have been rebuilding in recent years.

For Georges Bank haddock, spawning biomass and the proxy fishing mortality (F_{MSY}) to produce MSY are B_{MSY} = 250,300 mt and F_{MSY} = 0.26, respectively (Northeast Fisheries Science Center 2002). The overfished threshold for Georges Bank haddock is $B_{THRESHOLD}$ = 125,200 mt. The overfishing threshold for Georges Bank haddock is $F_{THRESHOLD}$ = 0.26. In the last formal assessment of Georges Bank haddock in 2004 (Brodziak *et al*. 2005), spawning biomass was 116,800 mt (93% of $B_{THRESHOLD}$ and 47% of B_{MSY}). Therefore, the Georges Bank haddock stock was overfished in 2004. In 2004, the fishing mortality was 0.24 (92% of $F_{THRESHOLD}$). Therefore, overfishing was not occurring on the Georges Bank haddock stock in 2004.

For Gulf of Maine haddock, the stock biomass index and the proxy exploitation rate index to produce MSY are B_{MSY} = 22.2 kg/tow and F_{MSY} = 0.23 (Northeast Fisheries Science Center 2002). The overfished threshold for Gulf of Maine haddock is $B_{THRESHOLD}$ = 11.1 kg/tow. The overfishing threshold for Gulf of Maine haddock is $F_{THRESHOLD}$ = 0.23. In the last formal assessment of the Gulf of Maine haddock stock in 2004 (Brodziak and Traver 2005), the stock biomass index was 5.8 kg/tow (52% of $B_{THRESHOLD}$ and 26% of B_{MSY}) with a standard error of 1.1 kg/tow. Based on the point estimate of the biomass index, the Gulf of Maine haddock stock was overfished in 2004. In 2004, the exploitation rate index was 0.18 (78% of $F_{THRESHOLD}$). Therefore, overfishing was not occurring on the Gulf of Maine haddock stock in 2004.

Prior to mid-1990s, Georges Bank haddock had been overfished for decades (Brodziak and Link 2002). The stock had experienced long-term declines in spawning biomass and recruitment (Brodziak *et al*. 2001) and was considered by some to have been near collapse in the early 1990s. It was around this time that fishery management actions to recover Georges Bank haddock and other groundfish stocks were initiated.

Fishery management measures implemented since 1994 have decreased fishing mortality (Figure 26a). These measures have included large year-round closed areas, restrictions on fishing effort, increases in trawl mesh size, and other conservation measures (Fogarty and Murawski 1998). Fishing mortality on Georges Bank haddock averaged F=0.35 per year during 1980-1993, or about 36% higher than the current overfishing limit (F_{MSY} =0.26) for this stock. Since 1994, annual fishing mortality for Georges Bank haddock has averaged about F=0.17, about 30% below F_{MSY}.

Stock response to reductions in fishing mortality during the 1990s was dramatic (Figure 26b). Under persistent overfishing in the 1980s, Georges Bank haddock spawning biomass declined from 67,400 mt in 1980 to only 14,600 mt in 1993. Since 1994, spawning biomass has increased substantially as fishing mortality decreased. By 2003, spawning biomass had increased to 131,900 mt, the highest abundance of adult spawners since 1966 and over a 9-fold increase since 1993. Nonetheless, the Georges Bank haddock stock is presently considered to be overfished since spawning biomass is still less than half of the rebuilding target.

Recruitment of Georges Bank haddock has displayed a similar positive response as spawning biomass to reduced fishing mortality (Figure 26c). Recruitment averaged only 8 million age-1 recruits per year during 1980-1993. Since 1994, average recruitment has increased over 10-fold to about 87 million fish. Further, prospects remain positive for continued high recruitment. When Georges Bank haddock spawning stock biomass (SSB) exceeds its 1931-1998 median value of about 82,000 mt, the likelihood of above-average recruitment increases over 20-fold (Brodziak *et al*. 2001). Similarly, the expected magnitude of recruitment increases over 3-fold when SSB exceeds 82,000 mt. Recent U.S. and Canadian assessments and research survey data suggest that the 2003 year class is exceptionally abundant (Figure 26c).

Recruits per spawner data shows that survival ratios for Georges Bank haddock were relatively low from the late-1960s to early-1990s in comparison to historic ratios during the 1930s-1960s (Figure 26d). The impact of the large-scale area closures, reductions in fishing effort, and trawl mesh size increases during the 1990s have had a positive effect on recruits per spawning stock biomass (R/SSB). During 1980-1993, R/SSB averaged about 0.33 recruits per kg. Since 1994, average R/SSB, excluding the exceptional 2003 year class, has increased to 0.46 recruits per kg. Further increases in R/SSB may still occur since, at least historically, the expected value of R/SSB was higher. Overall, the recent increases in R/SSB indicate that survival ratios are approaching the historical average of about 0.76 recruits per kg observed during 1931-1960. If the recent increase in productivity can be sustained, it is possible that historic yields on the order of 50,000 mt per year may be achieved.

The formal rebuilding plan for Georges Bank haddock adopted in Amendment 13 calls for fishing at the overfishing threshold F_{MSY}=0.26 during 2004-2008 (NEFMC 2003). In 2009, the fishing mortality would be reduced marginally to $F_{REBUILD}$=0.245, a value projected to produce at least a 50% chance that spawning biomass will meet or exceed B_{MSY}=250,300 mt in 2014. This rebuilding strategy is subject to change in 2008 if observed progress towards rebuilding

spawning biomass or reducing fishing mortality is not consistent with the projected rebuilding trajectory.

In May, 2004, a formal quota sharing agreement between Canada and the U.S. was implemented to share the harvest of the transboundary eastern Georges Bank haddock management unit (Figure 27). This agreement includes total allowable catch quotas for each country as well as in-season monitoring of the catch of haddock on eastern Georges Bank.

RESEARCH NEEDS

The biology of northwest Atlantic haddock is reasonably well known and the habitat matrix is relatively complete (Table 2). However, more detailed information is needed in certain areas:

- More information is needed on the population genetic structure of haddock stocks. The present stock definitions are based on tagging studies, meristic data, age composition, and growth data (Northeast Fisheries Science Center 1997). Few studies of genetic structure currently exist. Purcell *et al.* (1996) detected significant temporal variation in gene frequencies on Georges Bank, and suggested that spawning on the Bank may not be genetically discrete. However, Zwanenburg *et al.* (1992) found that gene flow among spawning aggregations on five banks in the northwestern Atlantic, including Georges Bank, was restricted and that deep channels can be significant barriers to gene flow. Zwanenburg *et al.* (1992) indicated that additional sampling effort was needed to provide a clearer understanding of haddock population structure.
- A better understanding of the factors affecting recruitment and year-class strength is also needed. Research into obvious factors such as the effects of water temperatures, food levels, and predation on the survival of the early life stages is required. Also, the role of other factors such as hydrographic effects (e.g., tidal and non-tidal currents) which affect the retention and transport of eggs and larvae should be investigated more thoroughly.
- Interactions with other closely related species (e.g., cod) are probably important, and need to be better understood.
- Detailed information on fecundity and spawning behavior is needed. There is limited field data on haddock reproductive biology for either the Georges Bank or the Gulf of Maine stocks.

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Table 1. Median size and age at maturity of haddock.

Stock	Time Period	A_{50} (years) *male*	A_{50} (years) *female*	L_{50} (cm) *Male*	L_{50} (cm) *female*	Reference
Georges Bank	1985-1989	1.3	1.5	26.8	29.7	O'Brien *et al.* 1993
	1986-1989	1.1-1.9	1.8-2.6	24-34	33-41	Trippel *et al.* 1997
	1989-1995	1.1-1.4	1.6-2.0	23-30	34-36	Trippel *et al.* 1997
Gulf of Maine	1985-1989	2.1	1.8	35.0	34.5	O'Brien *et al.* 1993

Table 2. Summary of life history and habitat parameters for haddock.
Based on the pertinent literature. Information that applies to both juveniles and adults is listed under 'Juveniles/Adults.'

Life Stage	Size and Growth	Habitat	Substrate	Temperature
Eggs [1]	Mean size at hatch is 3.33 mm. Largest size at hatch occurs at approximately 8°C; decrease in size at lower and higher temperatures.	Early stage eggs concentrated near the surface; later stages are distributed more uniformly over depth or have a sub-surface maximum. One study shows that stage I, II and III eggs were within the top 20 m, while the center of mass of stage IV eggs was 31 m.	Eggs are spawned over rocks, gravel, smooth sand, and mud. After spawning, eggs become buoyant, rise and float near the surface where subsequent development occurs.	Peak spawning occurs when mean surface temperature is 2-10°C. Incubation duration varies with temperature: 20-32 days at 2°C, 11-23 days at 4°C, 11-17 days at 6°C, 9-13 days at 8°C, and 6-8 days at 11°C. Highest survival rate occurs at 4-10°C (mean 6°C). In temperature-controlled lab, eggs averaged about 17-21 days to hatch.
Larvae [2]	Size at hatch ranges from 2 - 5 mm (mean = 4 mm). Larval growth generally exceeds 0.2 mm d^{-1} and appears to peak at about 0.5 mm d^{-1} in June.	Generally pelagic. Maximum depth approximately 150 m. Majority found at depths of 10-50 m.		Larval growth positively correlated with temperatures of about 7-9°C , but may be suppressed at 4°C. Upper lethal = 10°C; lower lethal = 4°C. Time to metamorphosis: at 9°C = 30 days after hatching; at 4°C = 36-42 days. Growth rates: at 4°C = 3.68 %/day, at 7°C = 5.53, at 9°C = 13.36. On Georges Bank, hatching occurs in 2-3 weeks at normal spring temperatures. Increased temperature has a positive effect on both larval size at age and growth rates.
Juveniles [3]	Metamorphosis of larvae occurs at approximately 3 cm.	Small juveniles found near the surface (10-40 m), more or less stationary in the open sea. Descent to bottom (35-100 m) occurs at age 3-5 months and length 5-10 cm (after metamorphosis). YOY found in nursery area between Nantucket Shoals and Hudson Canyon. Occur on same grounds as adults.	Pebble gravel bottom. See adults also.	Occur at 4.5-11.0°C. Occur at colder temperatures in winter/spring than summer/fall.
Adults [4]	Mean size at maturity (female/male, cm): Georges Bank: 29.7/26.8 Gulf of Maine: 34.5/35.0 Size at maturity positively density dependent.	Occur throughout the Gulf and offshore banks; greatest concentration on Georges Bank. More exclusively a groundfish than cod. Generally below 10 m, most in 40-150 m, few deeper than 200 m. No extreme migrations, only short inshore/offshore movements.	Selective as to type of substrate: chiefly broken ground, gravel, pebbles, smooth hard sand and smooth areas between rocky patches. Avoid ledges, rocks, kelp, or soft mud.	Occur at 0-13°C, but are most abundant at 2-9°C and prefer 4-7°C; mortality at < 1°C; avoid > 10°C. Spawn at 2-7°C, optimum is 4-6°C.
Juveniles/ Adults [5]	Average size at age: 1 - 17.5 cm, 2 - 33.8 cm, 3 - 45.5 cm, 4 - 54.0 cm, 5 - 60.1 cm, 6 - 64.5 cm, 7 - 67.6 cm, 8 - 69.9 cm, 9 - 71.5 cm, 10 - 72.7 cm, 11 - 73. 6cm, 12 - 74.2 cm, 13 - 74.6 cm, 14 - 75.0 cm, 15 - 75.2 cm.			

[1] Bigelow and Schroeder (1953); Miller *et al.* (1963); Laurence and Rogers (1976); Hardy (1978); Lough *et al.* (1989); Page and Frank (1989); Page *et al.* (1989); Waiwood and Buzeta (1989); Klein-MacPhee (2002).

[2] Marak (1960); Colton and Temple (1961); Miller *et al*. (1963); Laurence (1974, 1978); Hardy (1978); Kane (1984); Lough and Bolz (1989); Green *et al*. (2004); Caldarone (2005).

[3] Bigelow and Schroeder (1953); Colton and Temple (1961); Blacker (1971); Colton (1972); Hardy (1978); Mahon and Neilson (1987); Murawski and Finn (1988); Perry and Neilson (1988); Lough and Bolz (1989); Lough *et al.* (1989).

[4] Bigelow and Schroeder (1953); Marak and Livingstone (1970); Colton (1972); Hardy (1978); Scott (1982); Waiwood and Buzeta (1989); O'Brien *et al.* (1993); Klein-MacPhee (2002).

[5] Penttila *et al.* (1989).

Table 2. Cont'd.

Life Stage	Salinity	Currents	Prey
Eggs [1]	Highest egg survival occurs at 34-36 ppt. Egg mortality below 25 ppt; mortality decreases with increasing salinity (26-36 ppt).	SW flow of water off Georges Bank results in a southerly flow of eggs and larvae from the NE spawning center.	
Larvae [2]		Larvae drift with surface currents. Georges Bank larvae may be swept off the Bank to the SW (at 0.65 cm/s), otherwise are retained. Southerly drift of larvae may be slowed, and retention on shoals of Georges Bank enhanced, by larvae residing nearer to the bottom in waters < 70 m. In contrast, strong episodes of southeastward wind stress are associated with high egg and larval mortalities in some years. Eggs and larvae in coastal Gulf of Maine waters may be retained in suitable habitats by tidal currents.	Passive foragers on less motile prey: invertebrate eggs, copepods and phytoplankton. In general, ate most abundant species but restricted to prey of a certain size; for example larvae 4-18 mm fed on larval copepods, > 18 mm fed on adult copepods. Feeding peaks shortly before sunset. Larvae may need prey concentrations of 0.5 - 3.0 plankters/ml for suitable growth.
Juveniles [3]		Tidal current weaker near bottom, for example at Georges Bank, current = 1-5 cm/s at 10 cm above bottom, and 7-24 cm/s at 1 m above bottom.	Indiscriminate consumers of invertebrates. Distinct transition from planktonic to benthic feeding. Planktonic prey declines after becoming demersal: copepods and pteropods decreased, while ophiuroids & polychaetes increased. Major benthic prey items (proportion of diet by weight) are crustaceans (56.5%), polychaetes (15.1%), and fish (1.4%).
Adults [4]	Generally found within 31.5 - 35 ppt; Spawn at 31.5 - 34 ppt.		Indiscriminate consumers of sedentary or slow moving invertebrates: crustaceans, annelids, polychaetes, mollusks and echinoderms. Fish make up small part of diet. Heaviest feeding in June; distinct seasonal changes in diet composition.
Juveniles/ Adults [5]			Omnivorous and highly opportunistic. Prey almost exclusively on benthic invertebrates. Order of importance (proportion of diet by weight): echinoderms, 29.9%; polychaetes, 17.6%; crustaceans, 16.2%; fish eggs, 14.6%; other polychaetes, 12.7%. Prey items by area (Gulf of Maine/ Georges Bank/Scotian Shelf) (% by weight): fish-2.2/28.4/3.8, polychaetes-14.7/23.5/11.8, crustacean-15.2/16.0/14.4, mollusks-1.6/3.8/3.0, echinoderms-51.9/7.8/49.0. Echinoderms more common prey in Gulf of Maine than on Georges Bank; polychaetes more common prey on Georges Bank than in Gulf of Maine. Overall, diet includes more ophiuroids and becomes more varied as fish increase in size; amphipods an important prey item for all demersal life history stages, with other fish an important component of the diet of very large haddock.

[1] Colton and Temple (1961); Laurence and Rogers (1976); Smith and Morse (1985); Page *et al.* (1989).
[2] Marak (1960); Laurence (1974); Hardy (1978); Kane (1984); Smith and Morse (1985); Campana *et al.* (1989); Lough and Bolz (1989); Polacheck *et al*. (1992); Ames (1997); Mountain *et a*l. (2003).
[3] Bigelow and Schroeder (1953); Blacker (1971); Bowman and Michaels (1984); Mahon and Neilson (1987); Perry and Neilson (1988); Lough *et al.* (1989).
[4] Bigelow and Schroeder (1953); Wigley and Theroux (1965); Tyler (1972); Hardy (1978); Scott (1982); Bowman and Michaels (1984); Waiwood and Buzeta (1989)
[5] Langton and Bowman (1980); Bowman and Michaels (1984); Bowman *et a*l. (2000); NEFSC food habits database.

Table 2. Cont'd.

Life Stage	Predators	Spawning	Notes
Eggs [1]	Preyed upon by a wide range of pelagic predators.	Northeast peak of Georges Bank and the Great South Channel are the principle spawning areas. Limited spawning along New England coast. Spawning occurs over all of Georges, but largest concentration is on the northeast peak. Spawning occurs from January to July; delay in peak spawning time as one moves north. Gulf of Maine: Feb.-May, peak varies Feb.-April; Georges Bank: Jan.-June, peak lFeb.-early April.	Egg duration on Georges Bank varied from 10-20 days over 34 year period; mean egg duration during peak spawning was 15.5 days. Haddock embryos less tolerant of temperature and salinity extremes than cod embryos.
Larvae [2]	Preyed upon by a wide range of pelagic predators.	Nursery grounds lie (a) between Georges Bank and Nova Scotia and (b) to the east of Cape Cod.	Young tend to drift under bells of jellyfish (*Cyanea*). Lab results imply that the first weeks after hatching are a critical period for larvae. One study estimated daily mortality rate at 7.1%.
Juveniles [3]	0+ and 1+ fish primarily preyed on by cod, pollock, and silver hake.		1-2 yr old fish particularly abundant on Georges Bank. Vertical migrations may depend on diel light cycle, thermal structure, interspecific competition, prey availability and tidal current speed.
Adults [4]	Preyed upon by seals.	Onset of spawning related to environmental conditions; earlier in years with moderate autumn-winter temperatures than in years with cold autumn/winter. Eggs released at intervals over a 3 week period. Fecundity ranges from 12,000-3,000,000 eggs; varies with size; year to year variation may be correlated with temperature. Median age at maturity (female/male, years): Georges Bank: 1.5/1.3; Gulf of Maine: 1.8/2.1. Evidence that median length at maturity on Georges Bank has decreased (during 1977-1983 was 40/37).	Move into shallower water in spring and summer; coincides with the inshore fishery. Offshore fishery occurs during the winter and early spring. Distribution influenced more by restrictive spawning area and bottom type conditions than by temperature variation.
Juveniles/ Adults [5]			Stock abundance clearly influenced growth rates: higher correlations occurred during time periods of highest stock abundance than at times when stocks were depleted. Stock size was significantly correlated with juvenile growth but not young adult growth.

[1] Walford (1938); Colton and Temple (1961); Marak and Livingstone (1970); Laurence and Rogers (1976); Hardy (1978); Smith and Morse (1985); Perry and Neilson (1988); Campana (1989); Lough and Bolz (1989); Page and Frank (1989).
[2] Laurence (1974); Hardy (1978); Smith *et al.* (1981); Cushing (1986).
[3] Bigelow and Schroeder (1953); Miller *et al.* (1963); Blacker (1971); Murawski and Finn (1988); Perry and Neilson (1988).
[4] Bigelow and Schroeder (1953); Colton (1972); Hardy (1978); Smith *et al.* (1981); O'Brien *et al.* (1993).
[5] Ross and Nelson (1992).

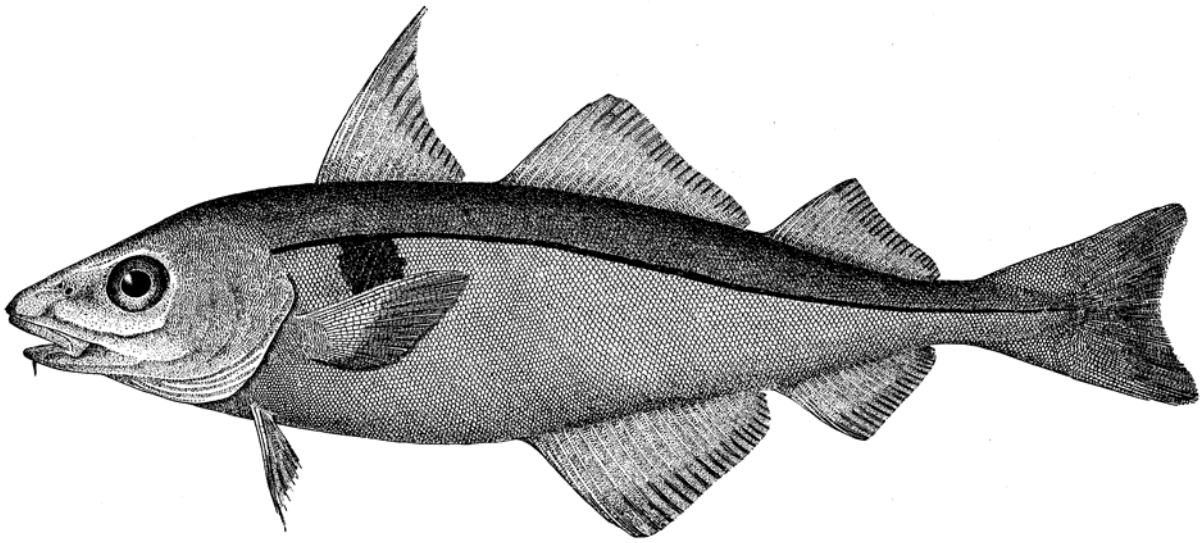


Figure 1. The haddock, *Melanogrammus aeglefinus* (from Goode 1884).

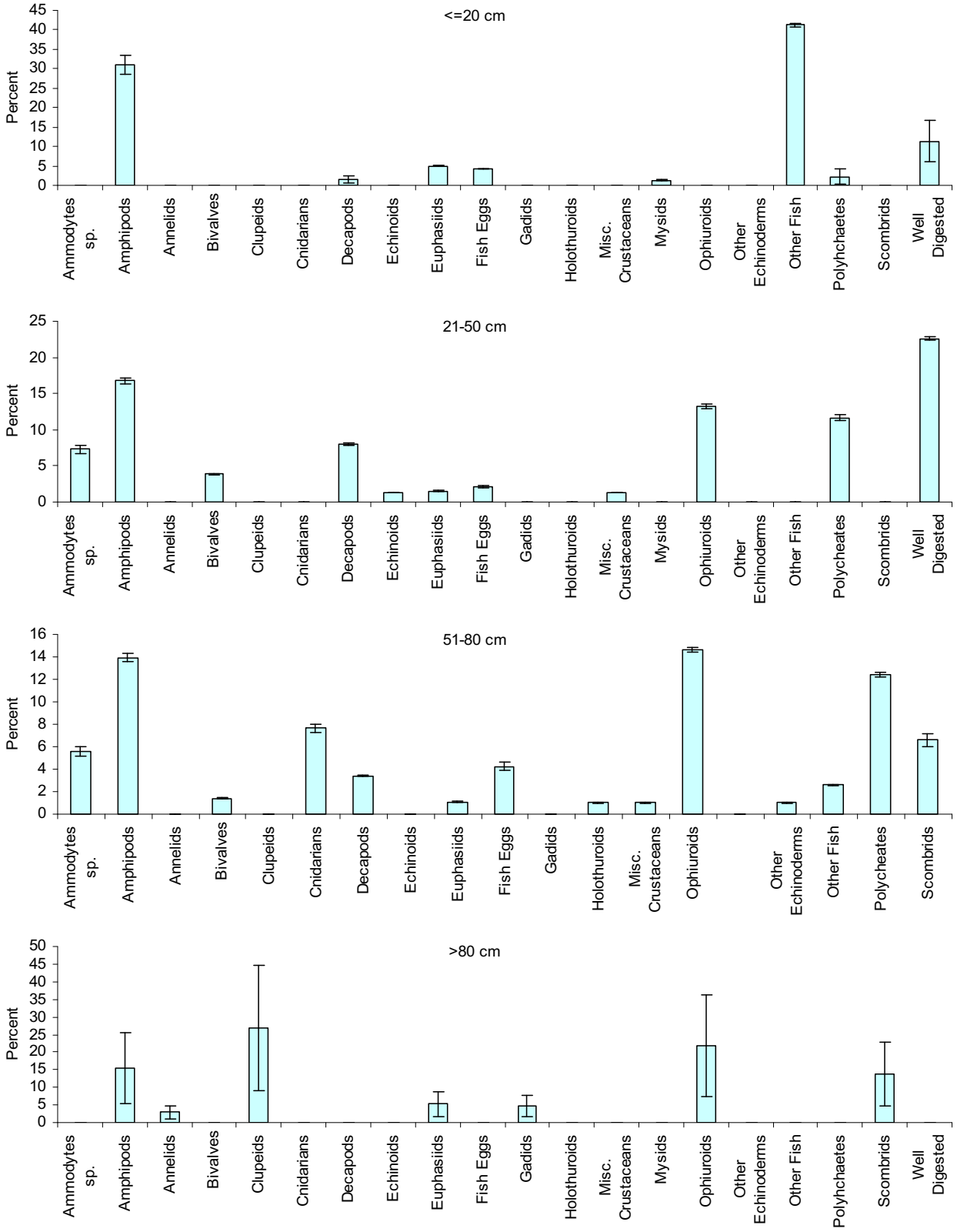


Figure 2. Percent by weight of the major prey items in the diet of four size categories of haddock. Specimens were collected during NEFSC bottom trawl surveys from 1973-2001 (all seasons). For details on NEFSC diet analysis, see Link and Almeida (2000).

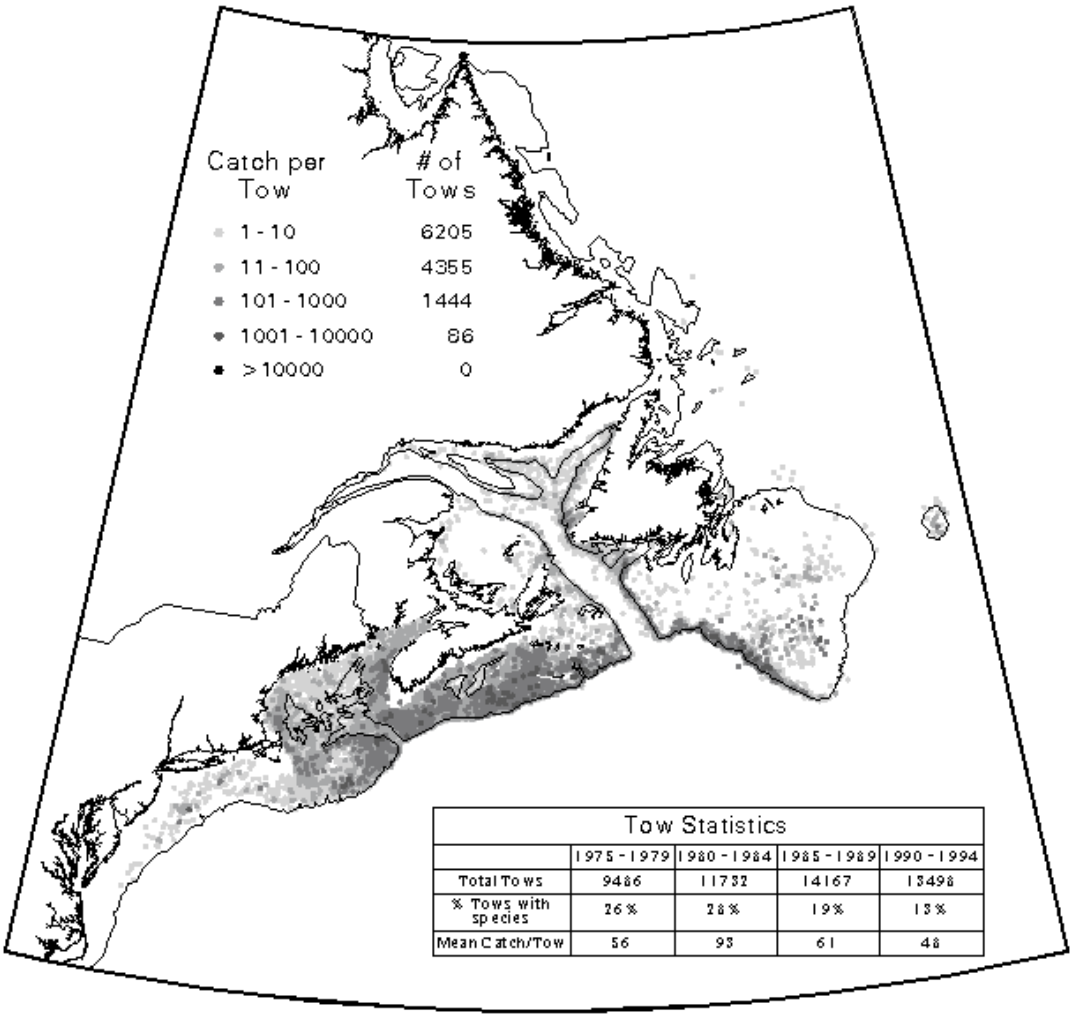


Figure 3. Overall distribution and abundance of haddock in the northwest Atlantic Ocean.
Based on research trawl surveys conducted by Canada (DFO) and the United States (NMFS) from 1975-1994 (http://www-orca.nos.noaa.gov/projects/ecnasap/ecnasap_table1.html).

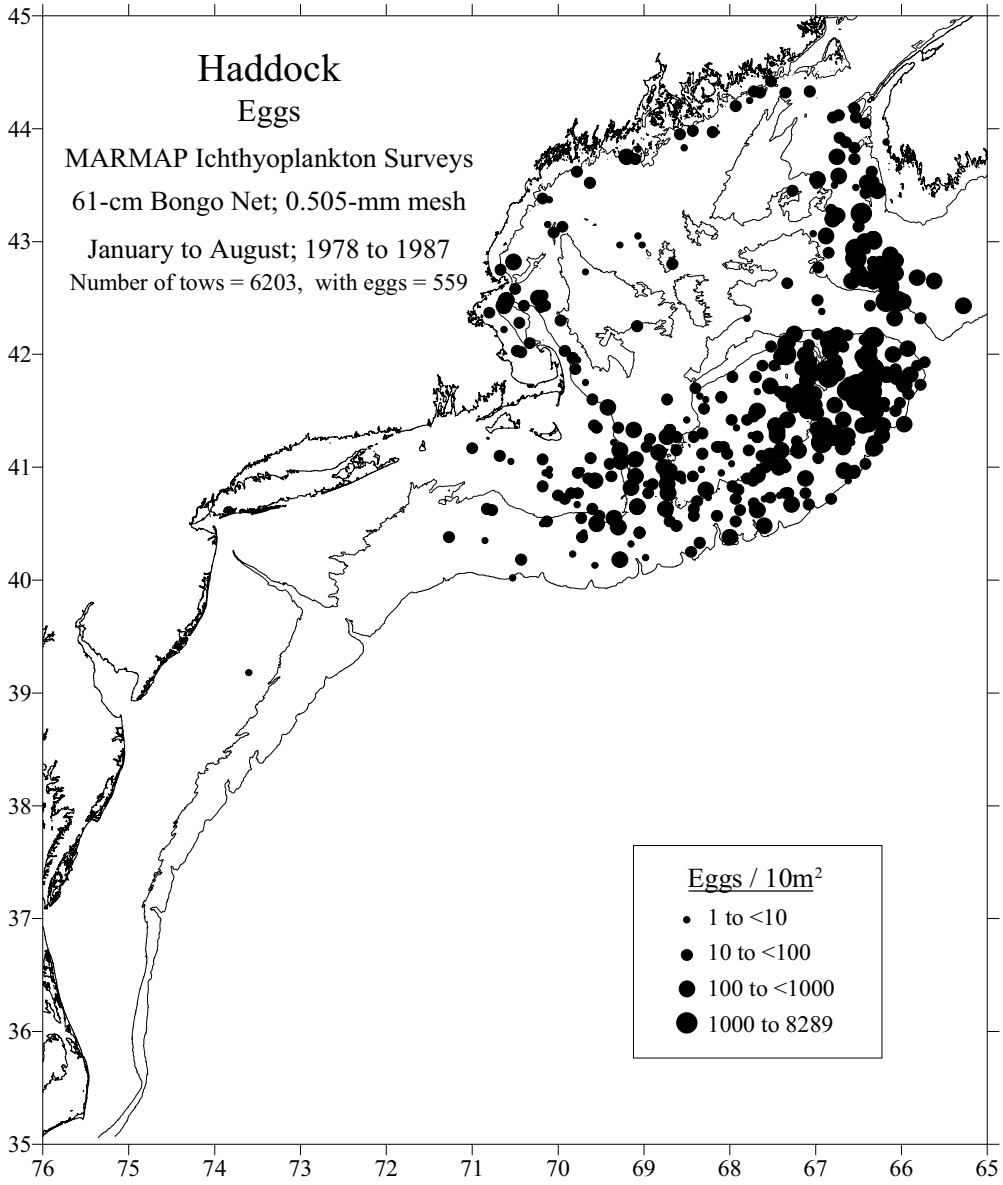


Figure 4. Distributions and abundances of haddock eggs collected during NEFSC MARMAP ichthyoplankton surveys. For all available months and years from 1978 to 1987 combined.

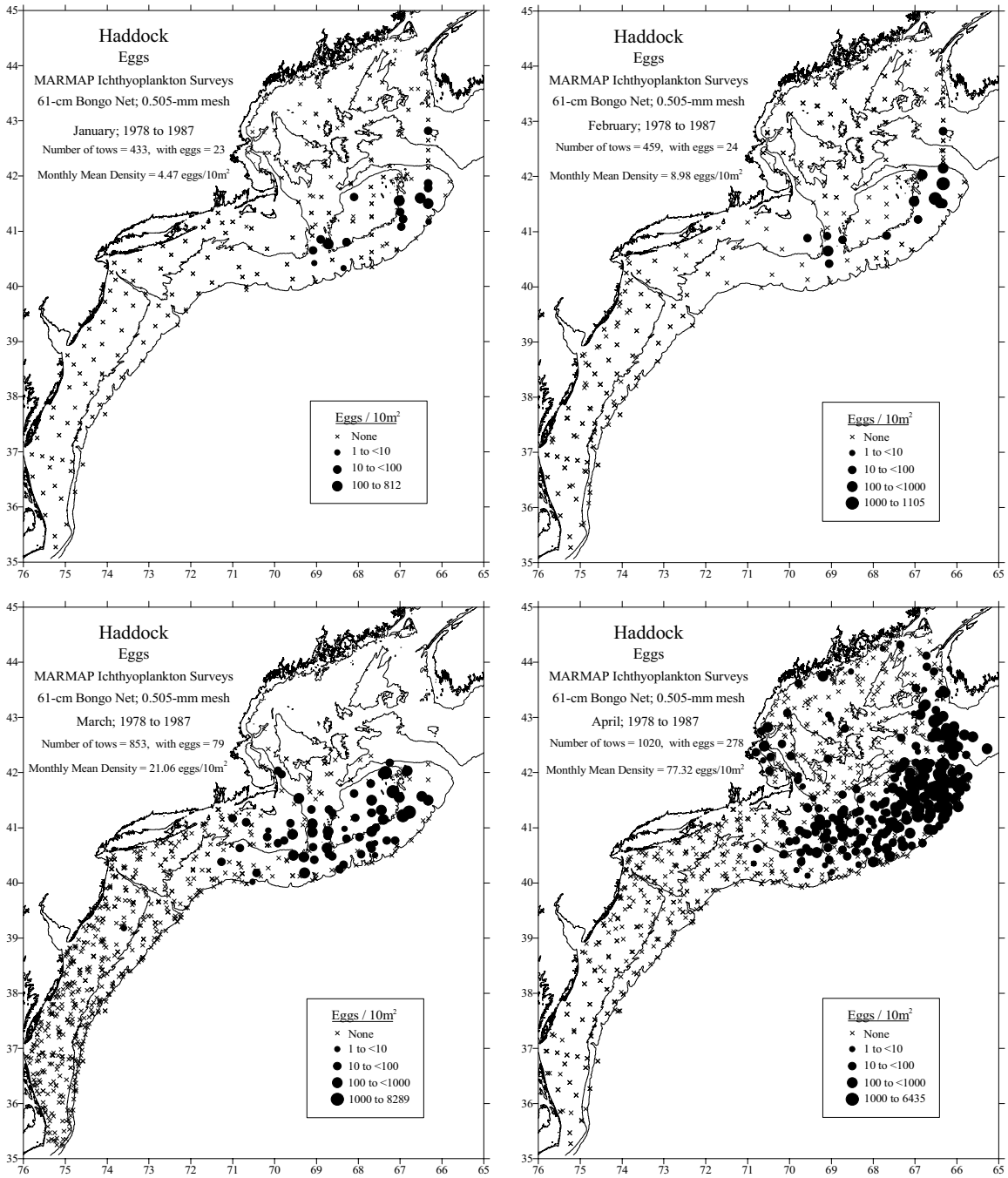


Figure 4. Cont'd.
From MARMAP ichthyoplankton surveys, January through April, 1978-1987.

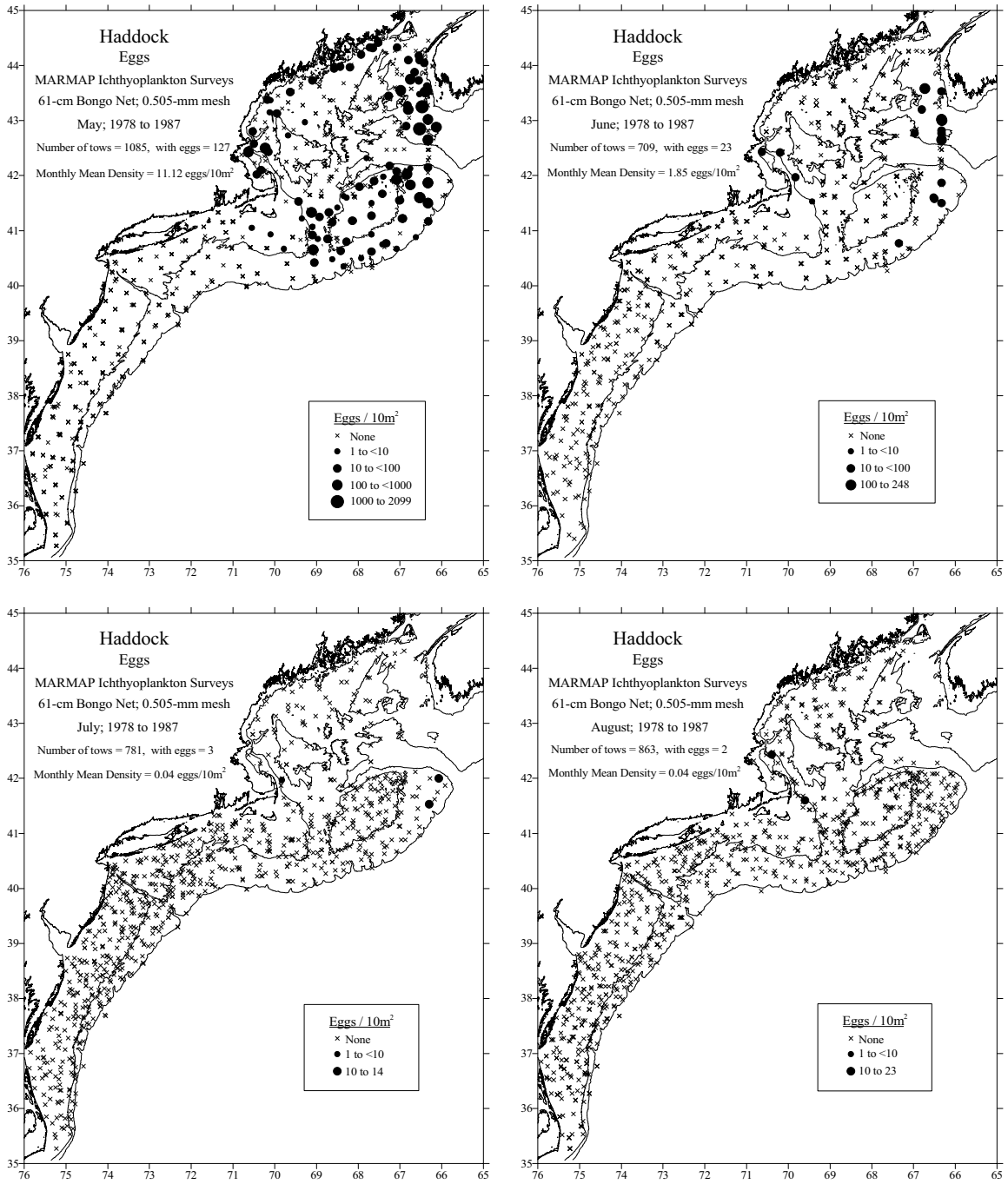


Figure 4. Cont'd.
From MARMAP ichthyoplankton surveys, May through August, 1978-1987.

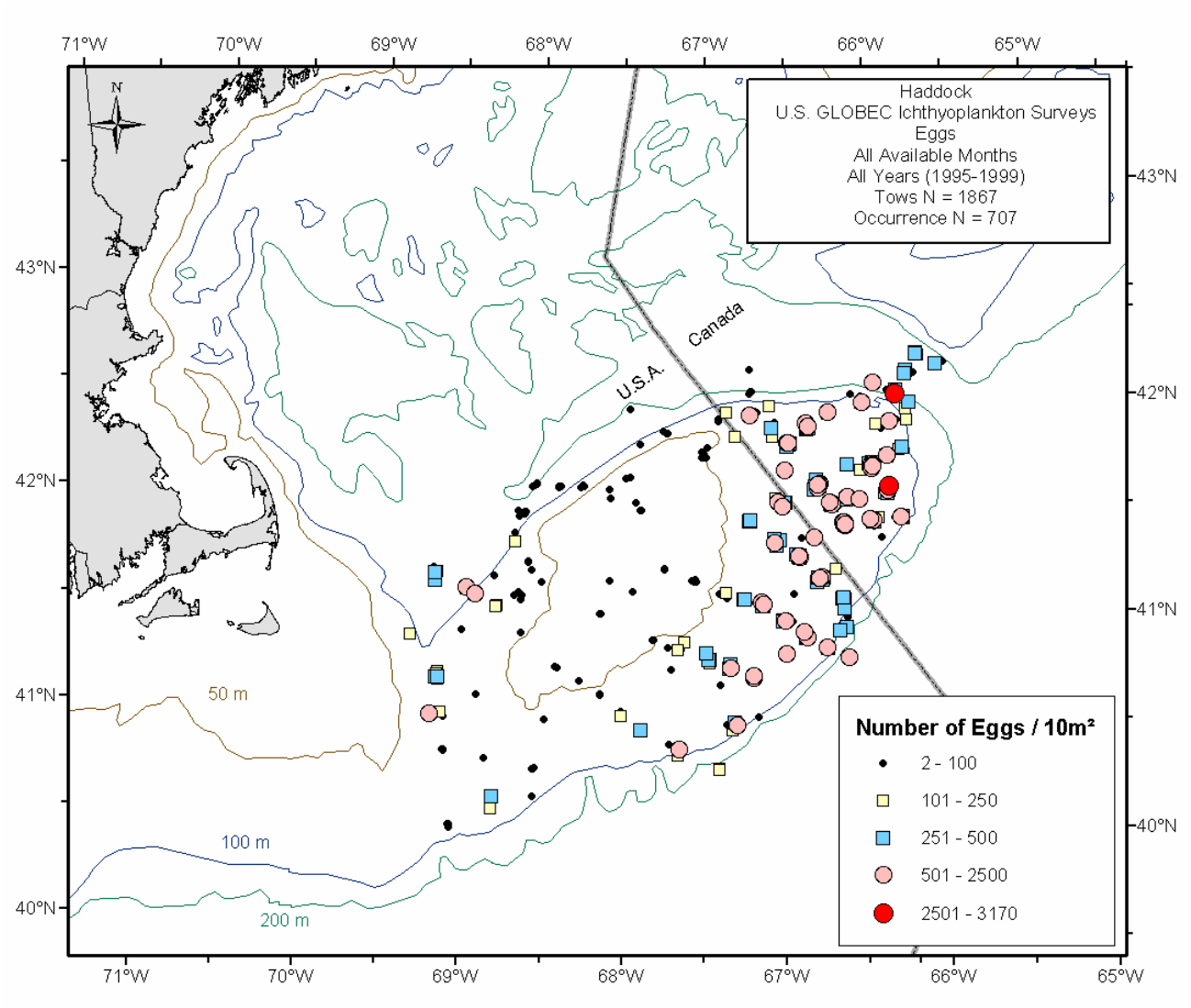
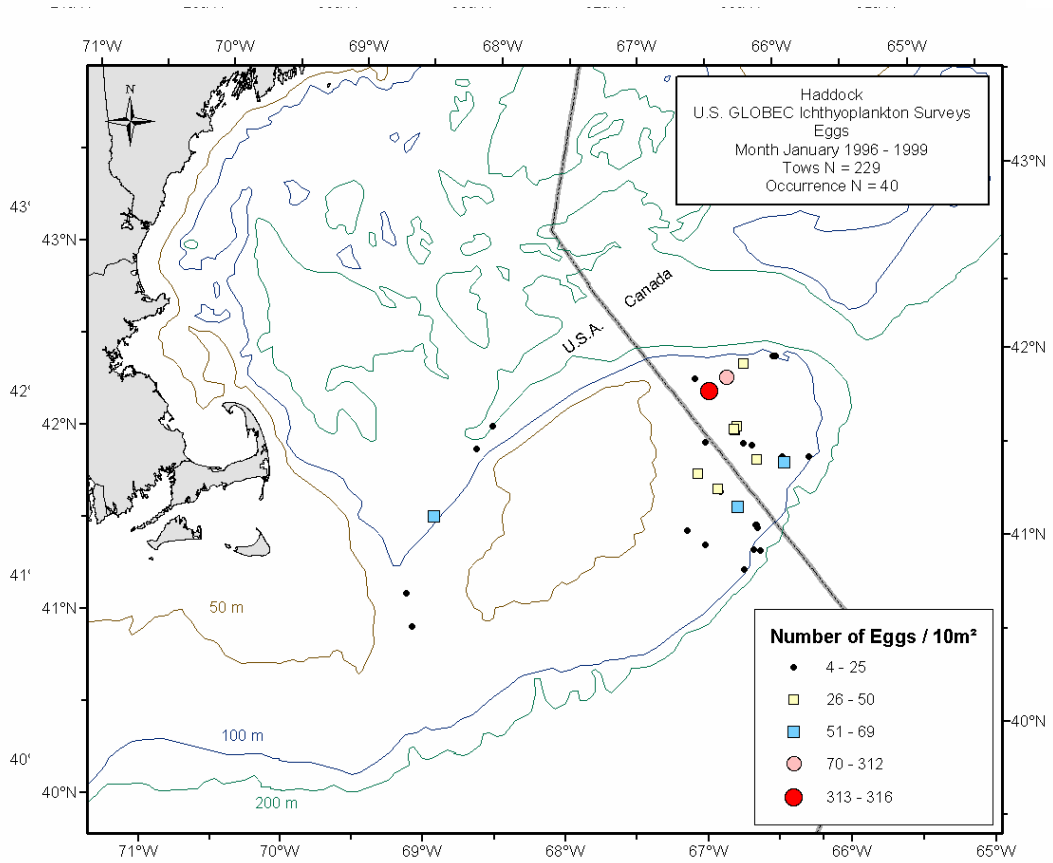


Figure 5. Distributions and abundances of haddock eggs collected during GLOBEC Georges Bank ichthyoplankton surveys.
For all available years (February-July, 1995; January-June, 1996-1999) combined.



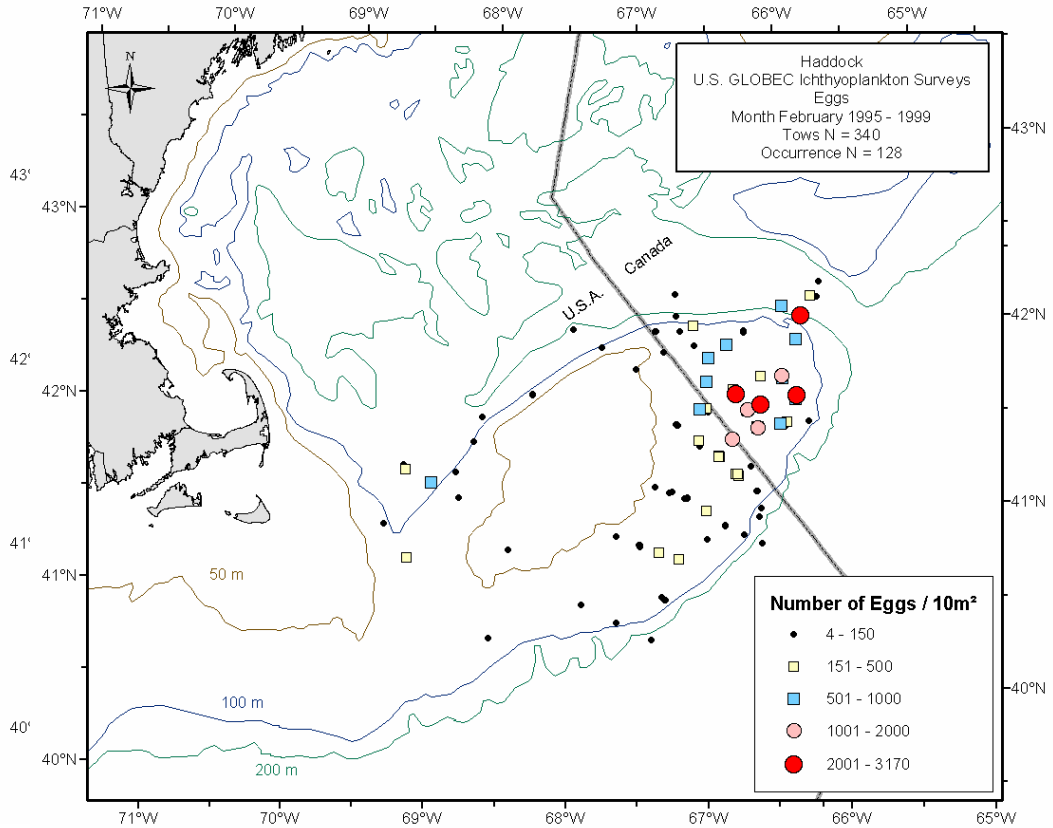
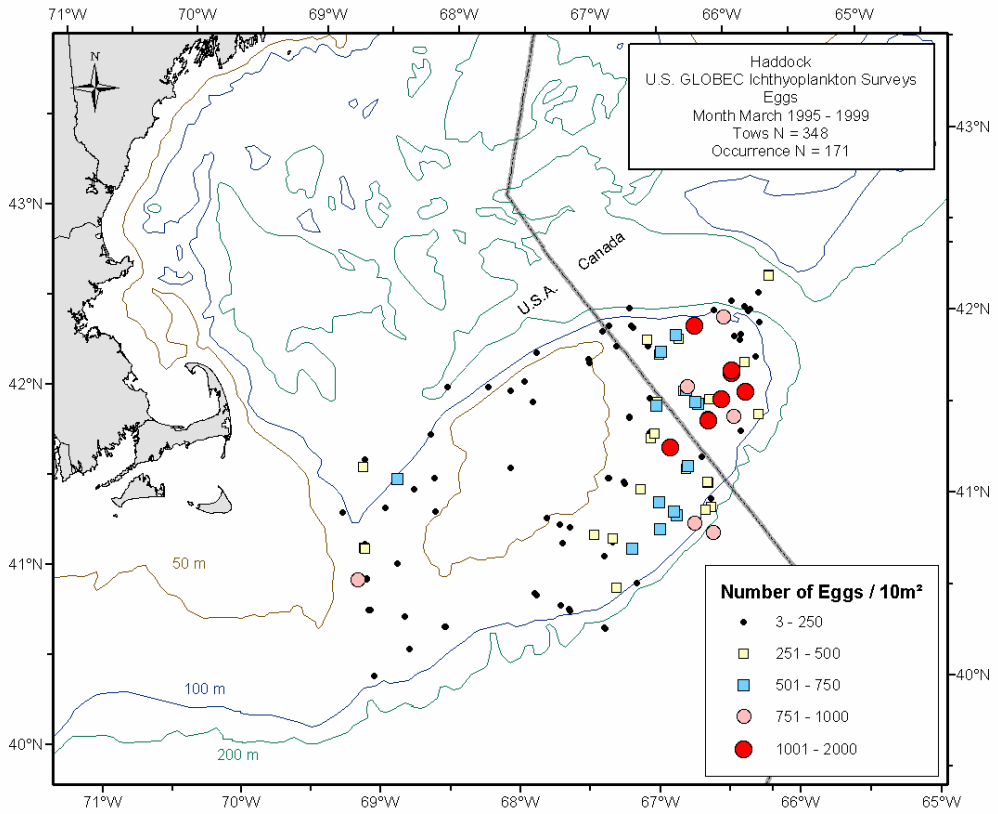


Figure 5. Con
From GLOBEC ichthyoplankton surveys, January and February, for all available years combined.



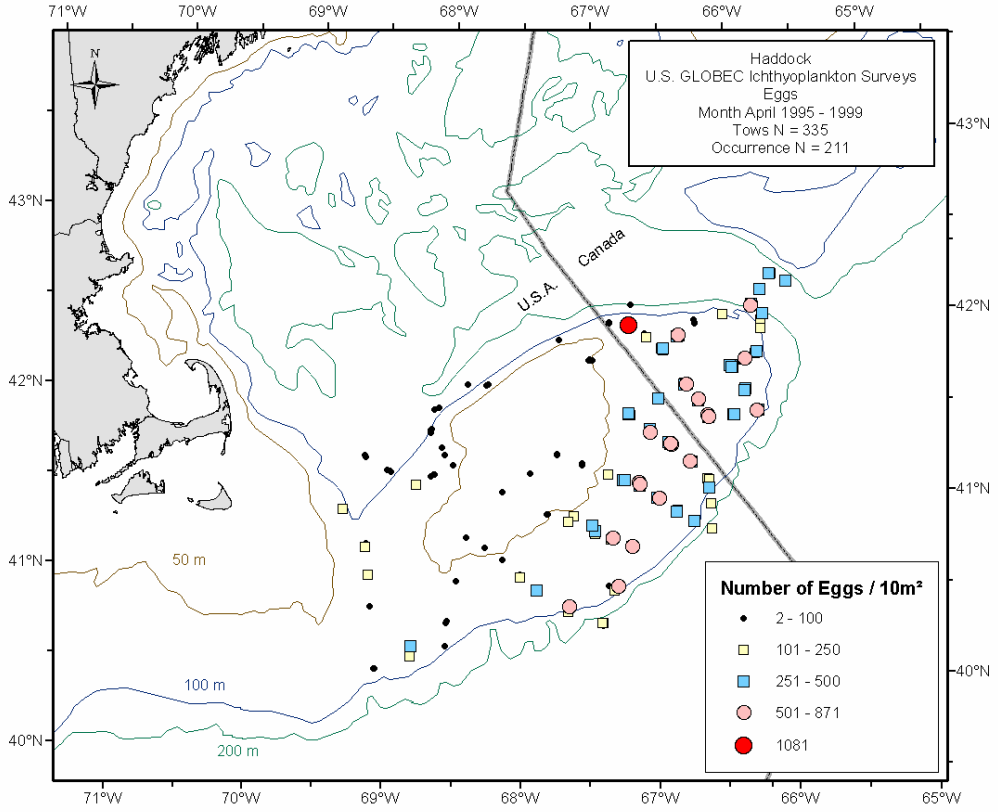


Figure 5. Cont'd.
From GLOBEC ichthyoplankton surveys, March and April, for all available years combined.

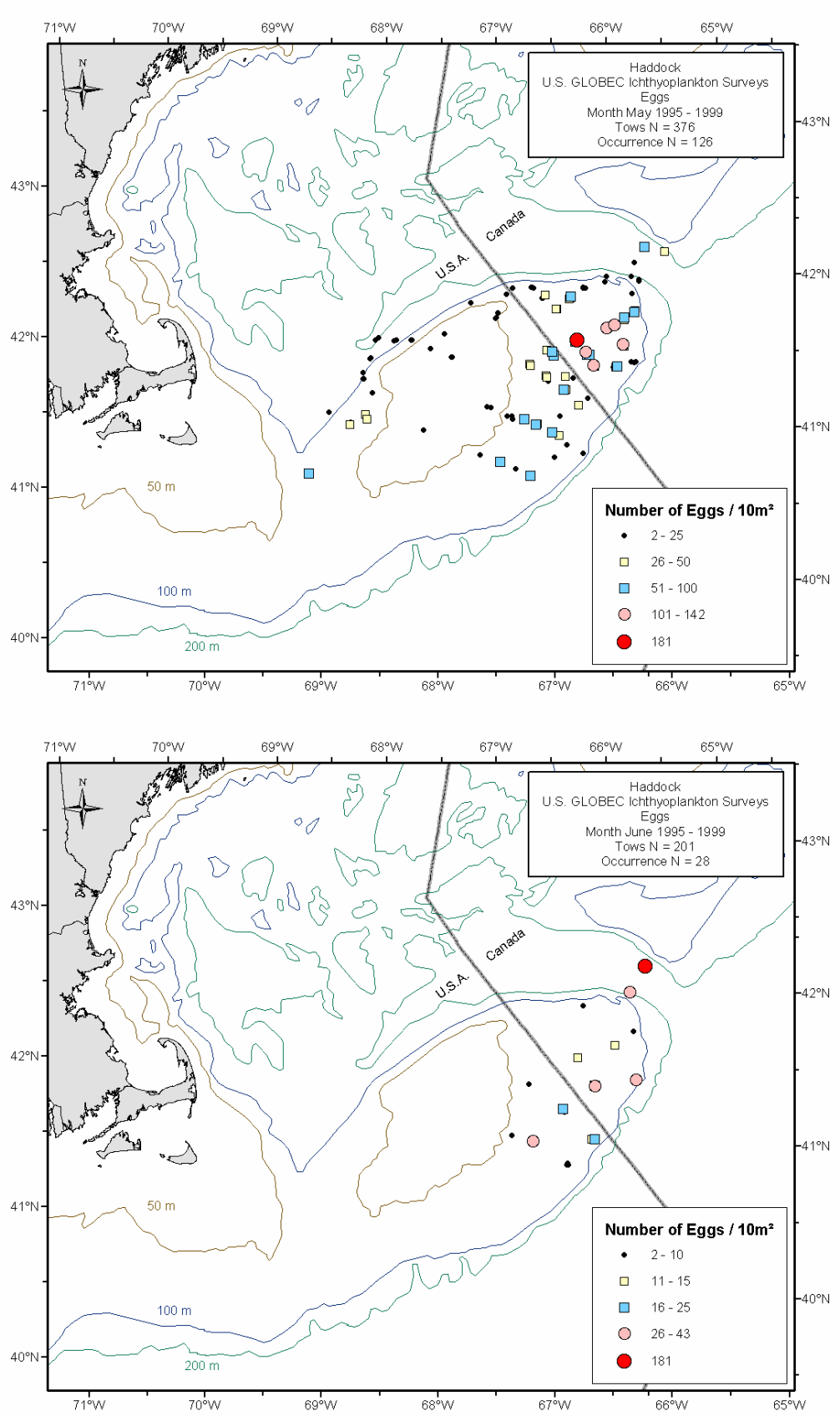


Figure 5. Cont'd.
From GLOBEC ichthyoplankton surveys, May and June, for all available years combined.

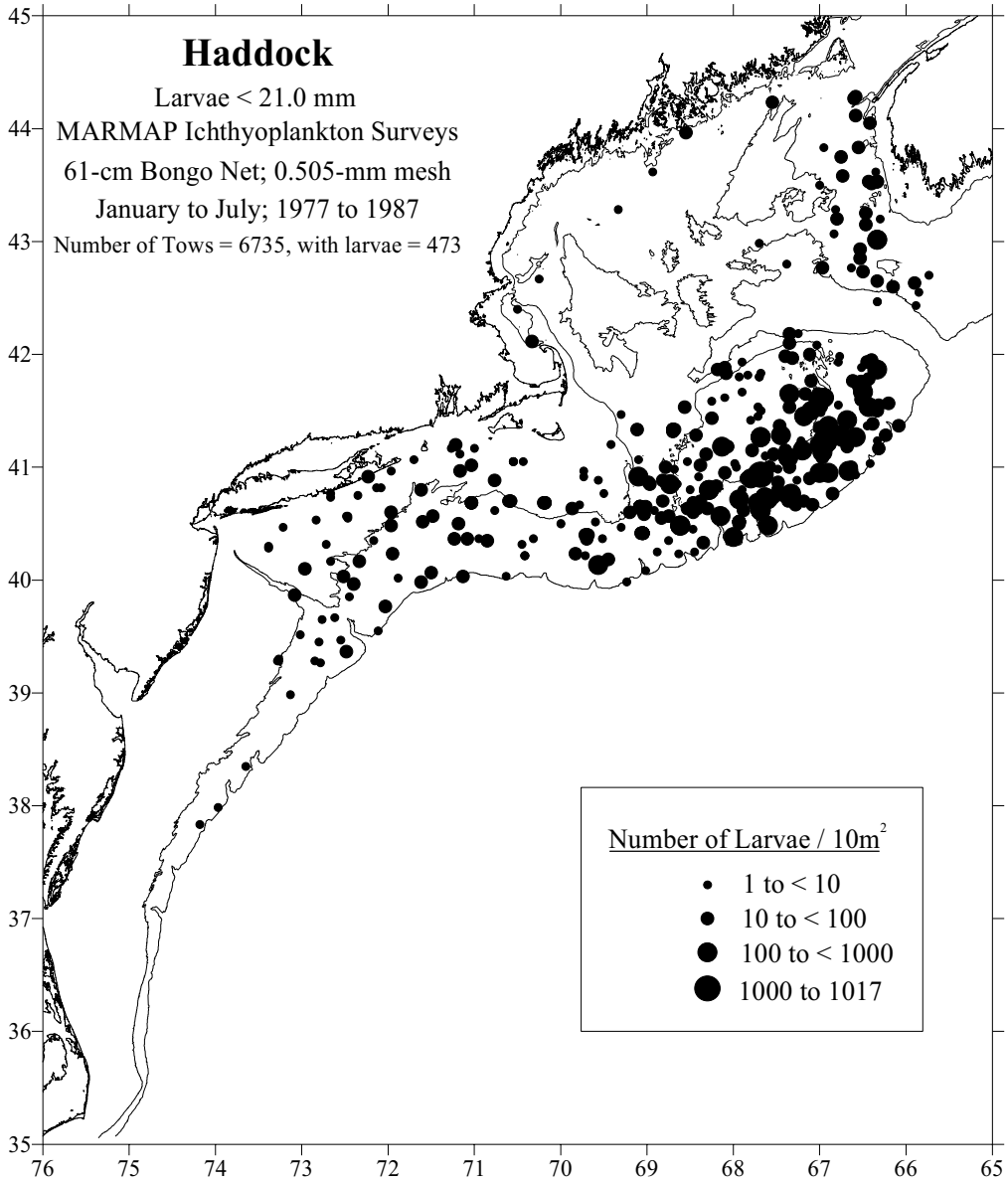


Figure 6. Distributions and abundances of haddock larvae collected during NEFSC MARMAP ichthyoplankton surveys.
For all available months and years from 1977 to 1987 combined.

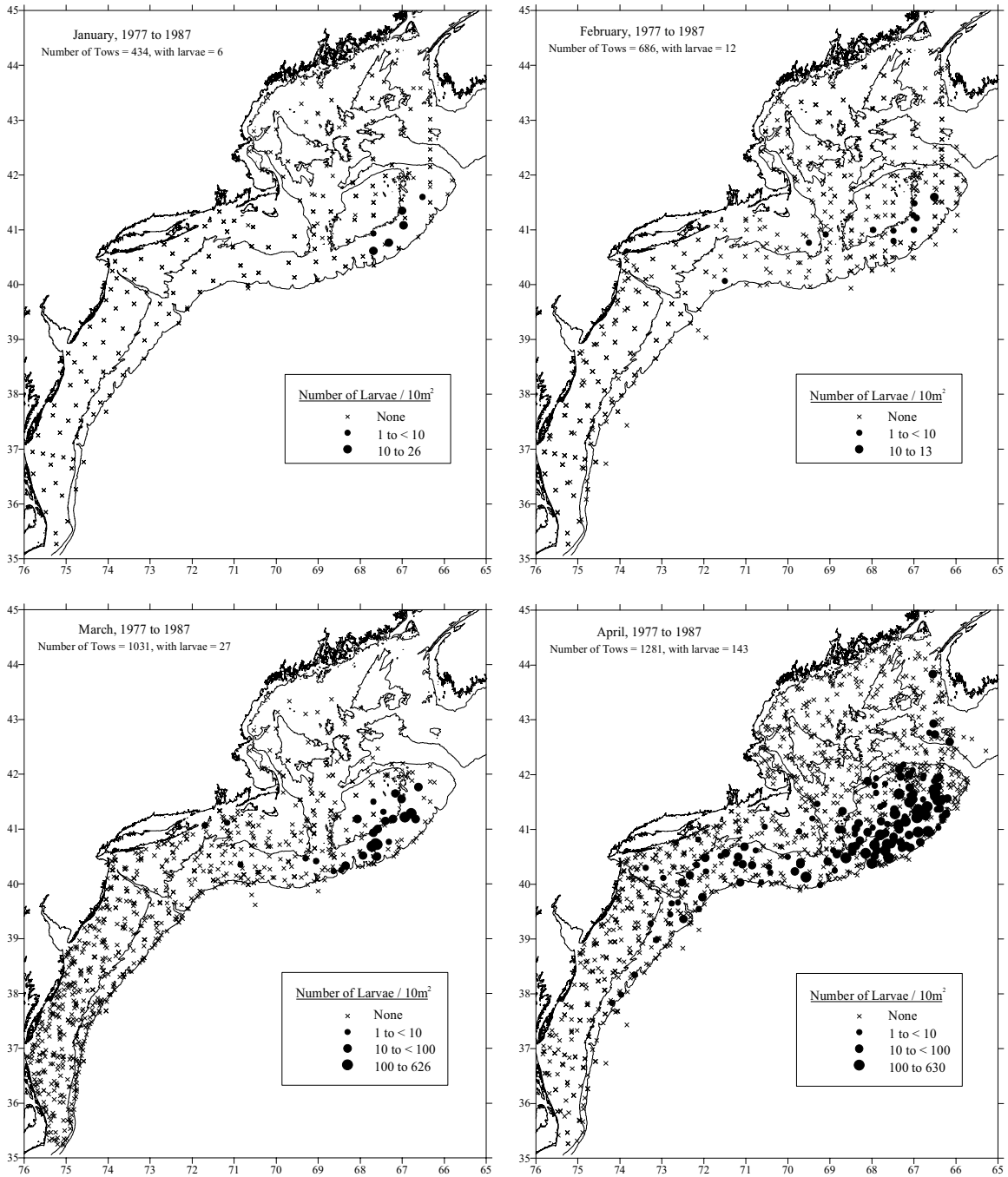


Figure 6. Cont'd.
From MARMAP ichthyoplankton surveys, January through April, 1977-1987.

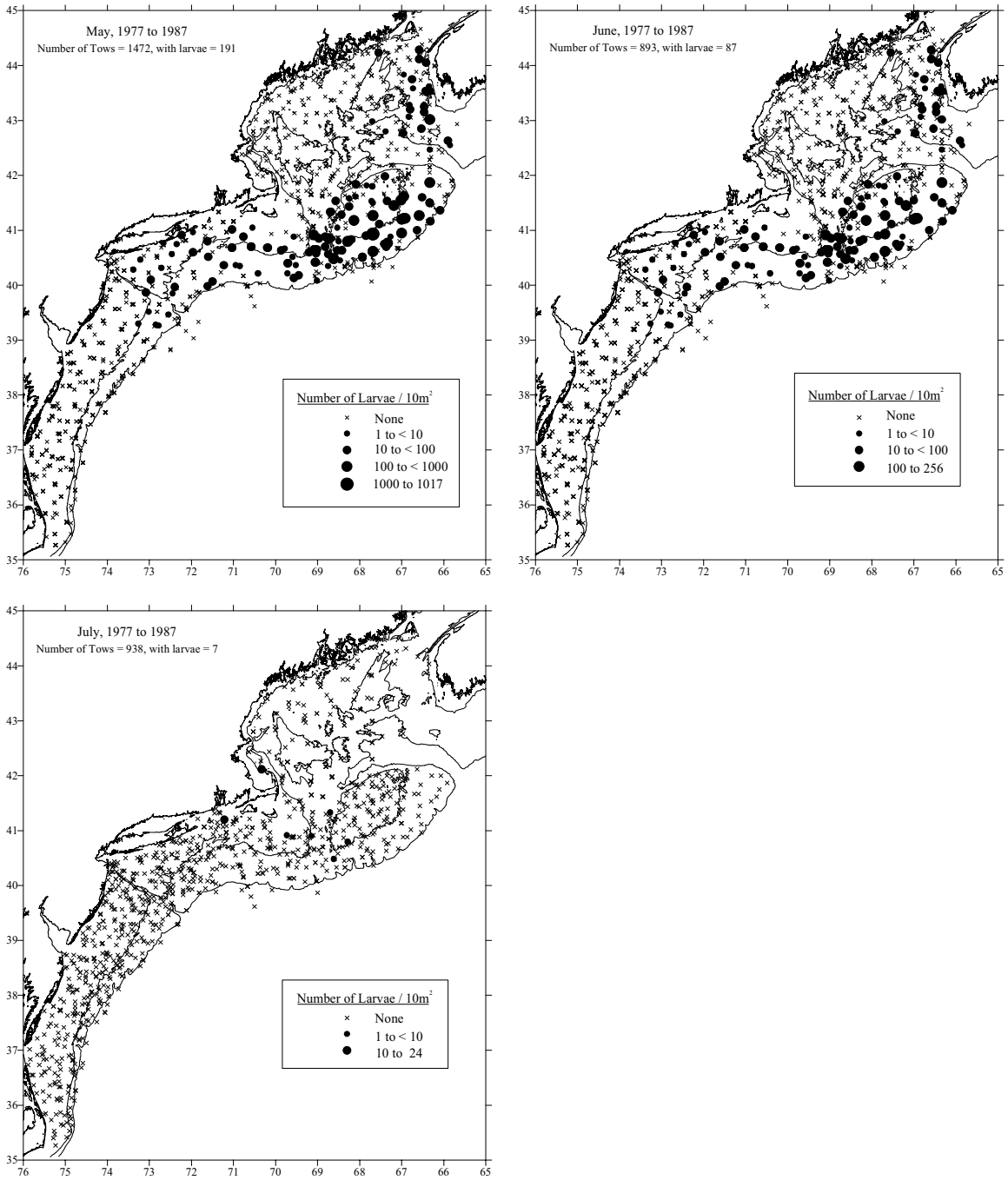


Figure 6. Cont'd.
From MARMAP ichthyoplankton surveys, May through July, 1977-1987.

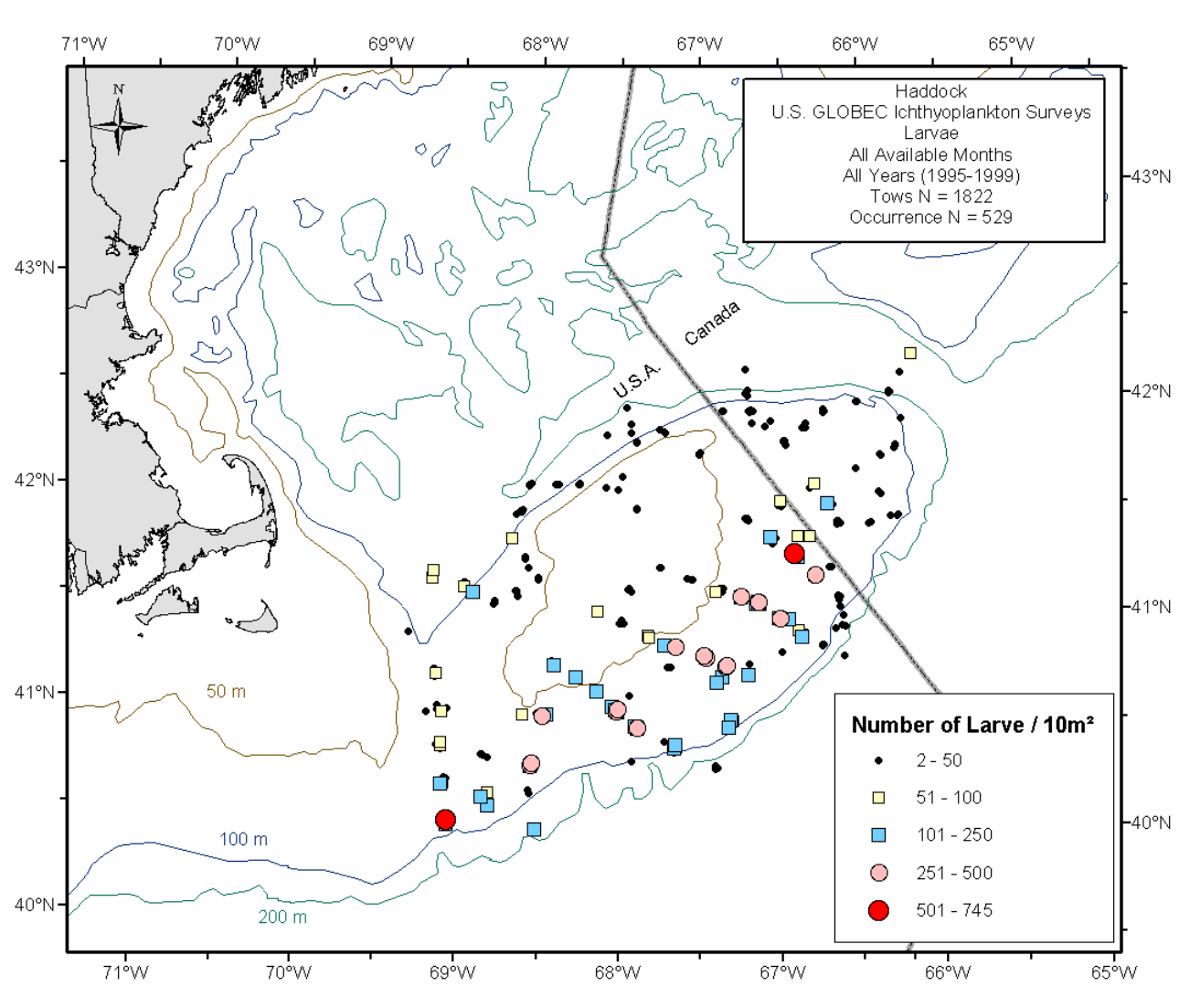
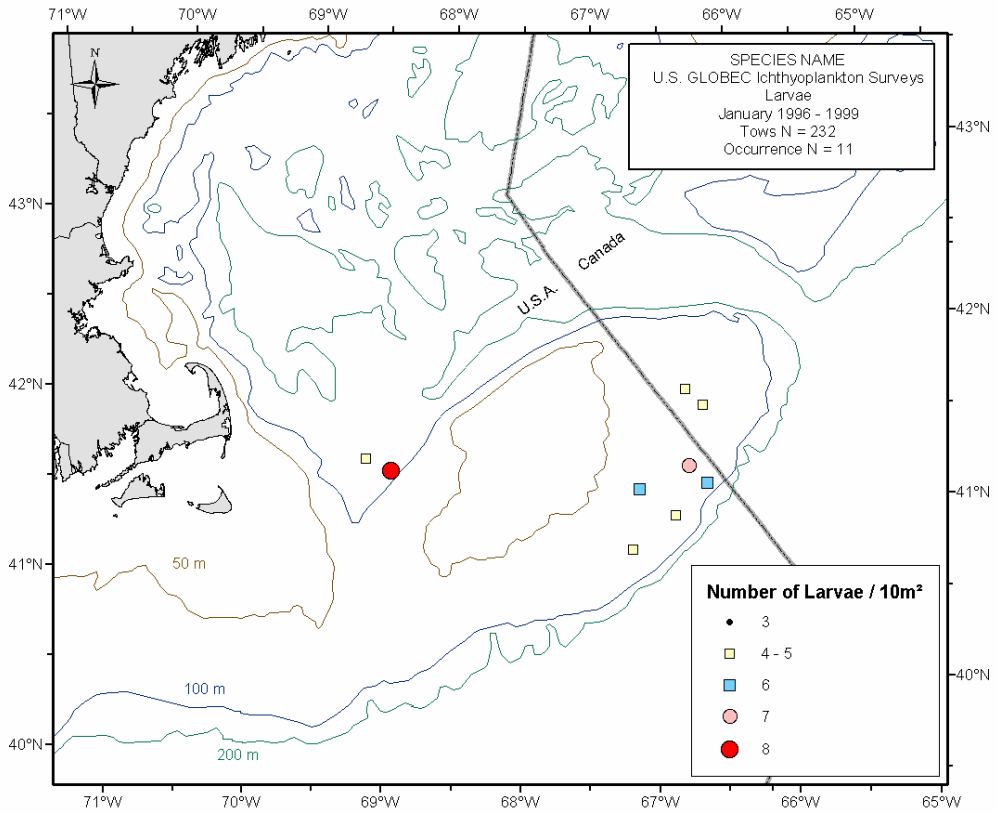


Figure 7. Distributions and abundances of haddock larvae collected during GLOBEC Georges Bank ichthyoplankton surveys.
For all available years (February-July, 1995; January-June, 1996-1999) combined.



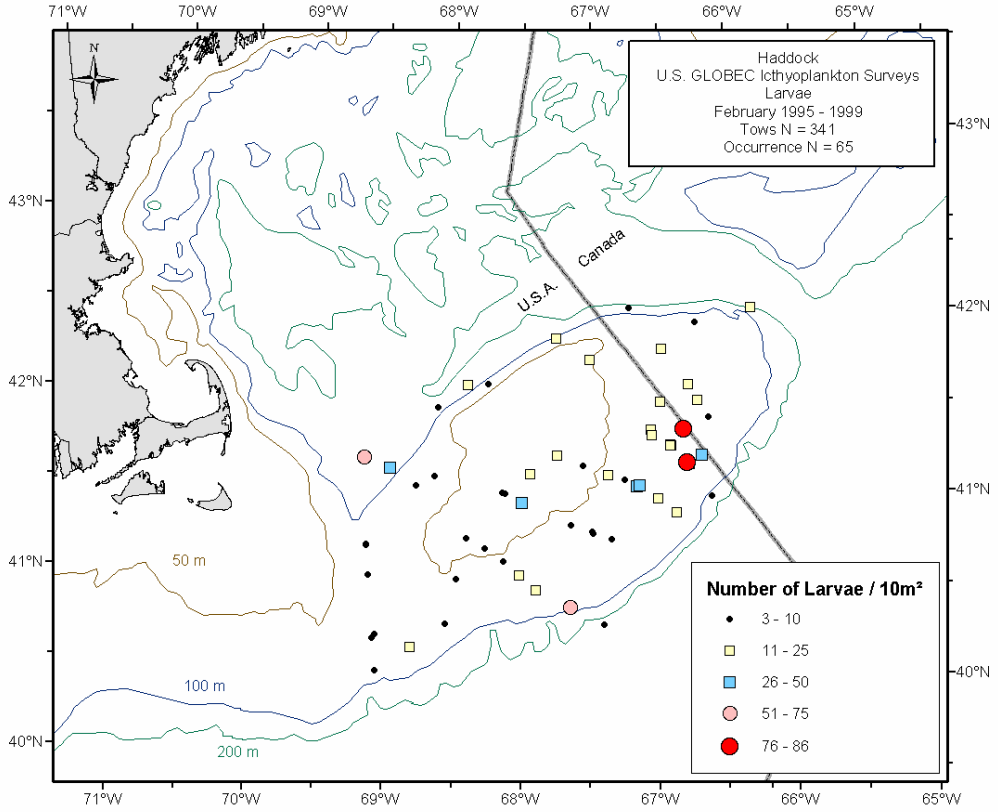


Figure 6. Cont'd.
From GLOBEC ichthyoplankton surveys, January and February, for all available years combined.

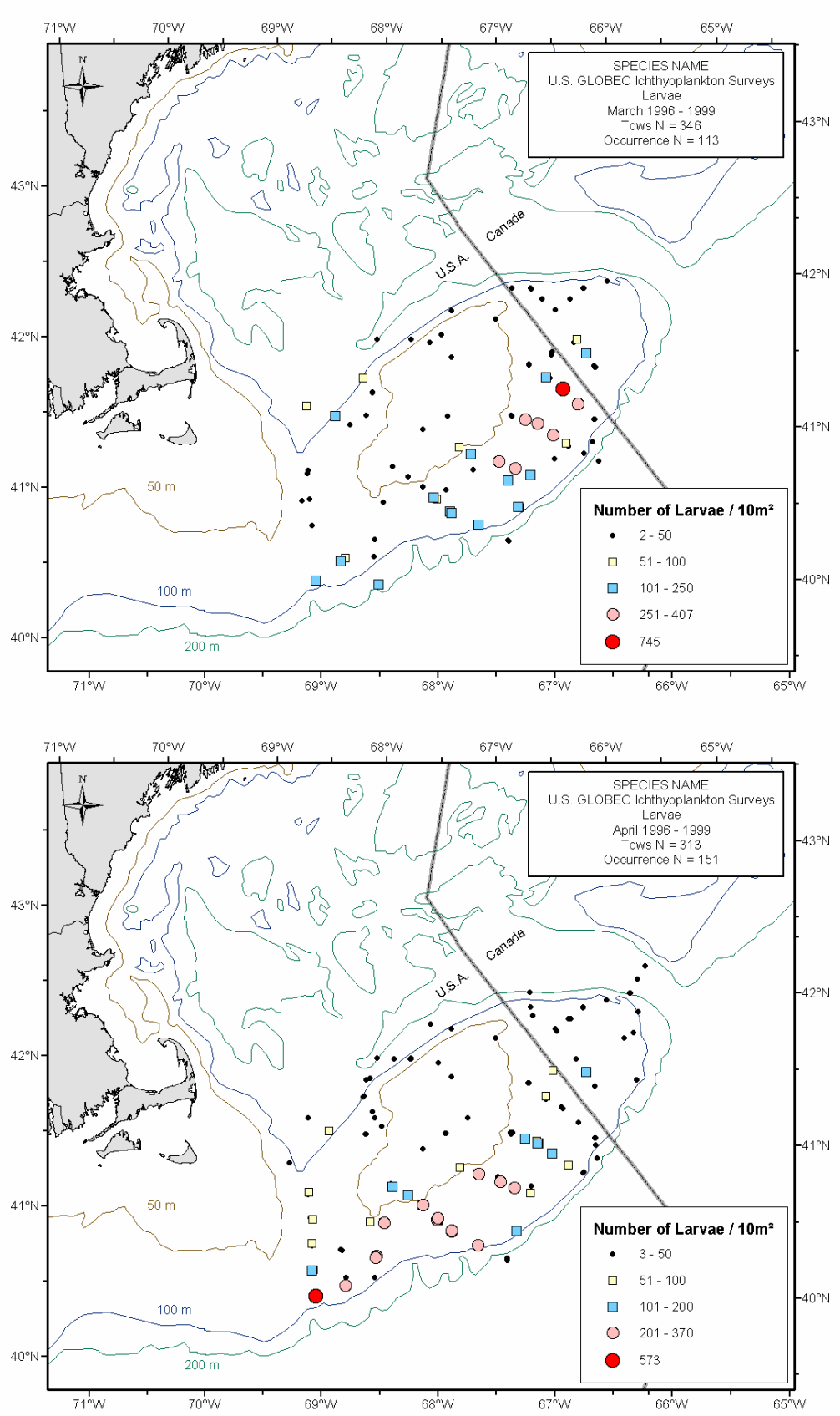


Figure 6. Cont'd.
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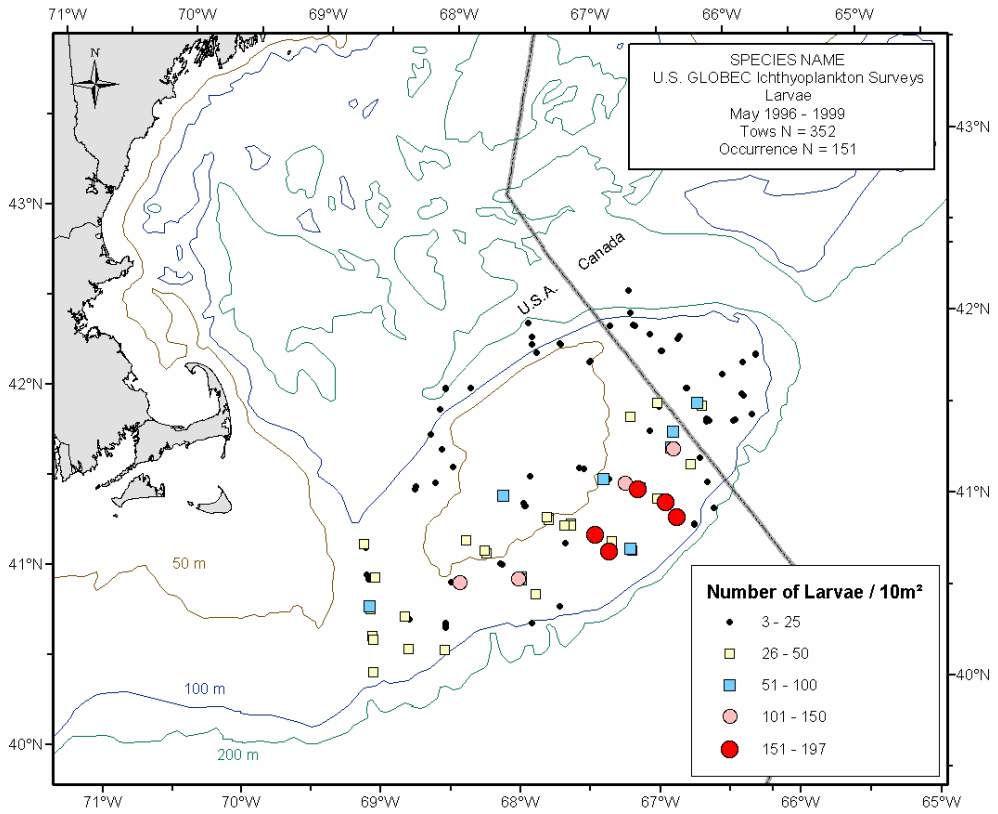

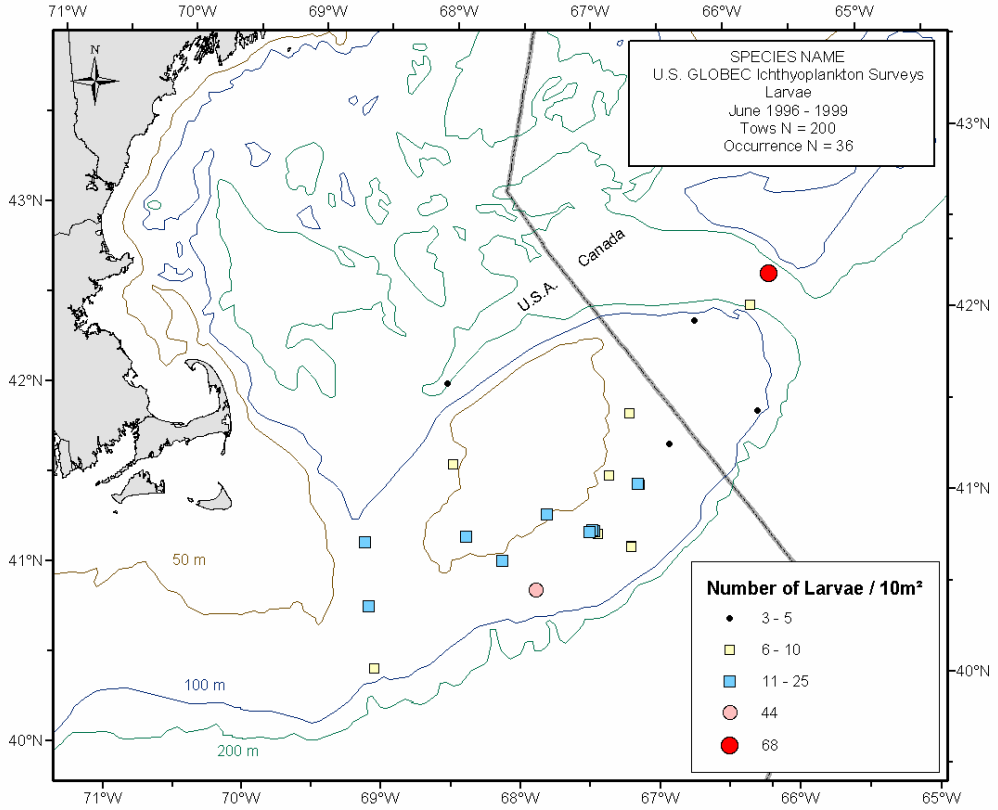

Figure 6. Cont'd.
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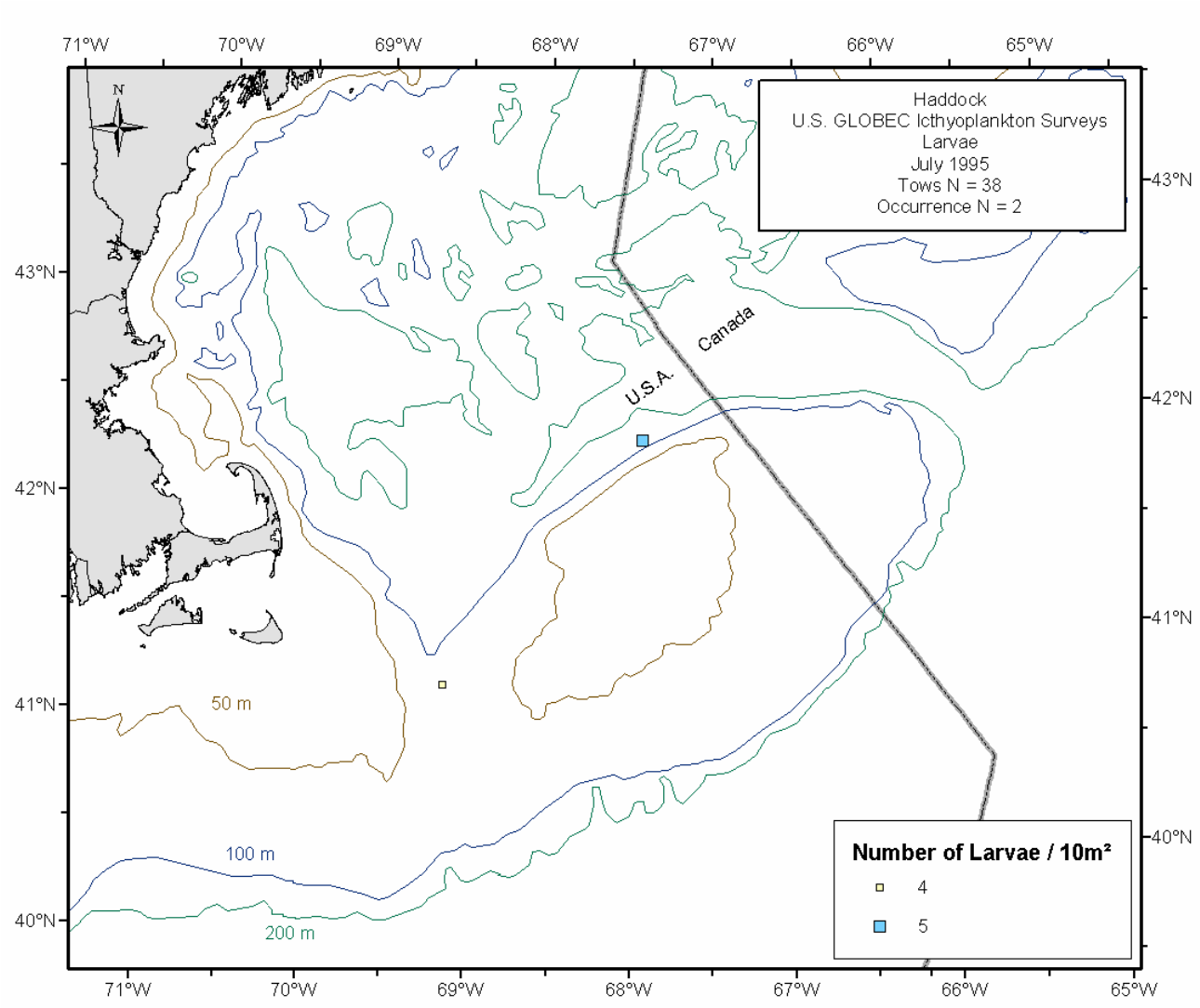

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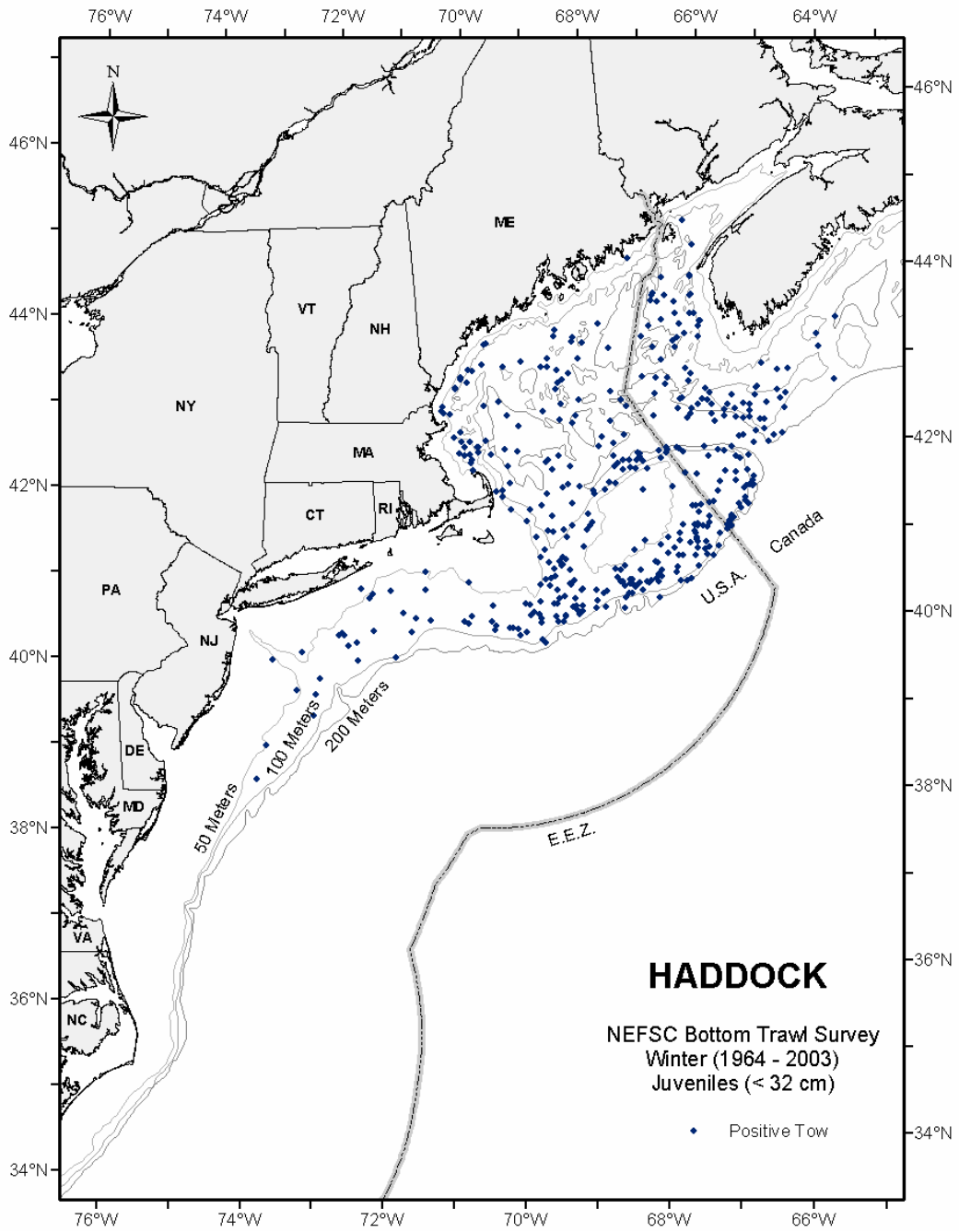


Figure 8. Seasonal distributions and abundances of juvenile haddock collected during NEFSC bottom trawl surveys. From NEFSC winter bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence only.

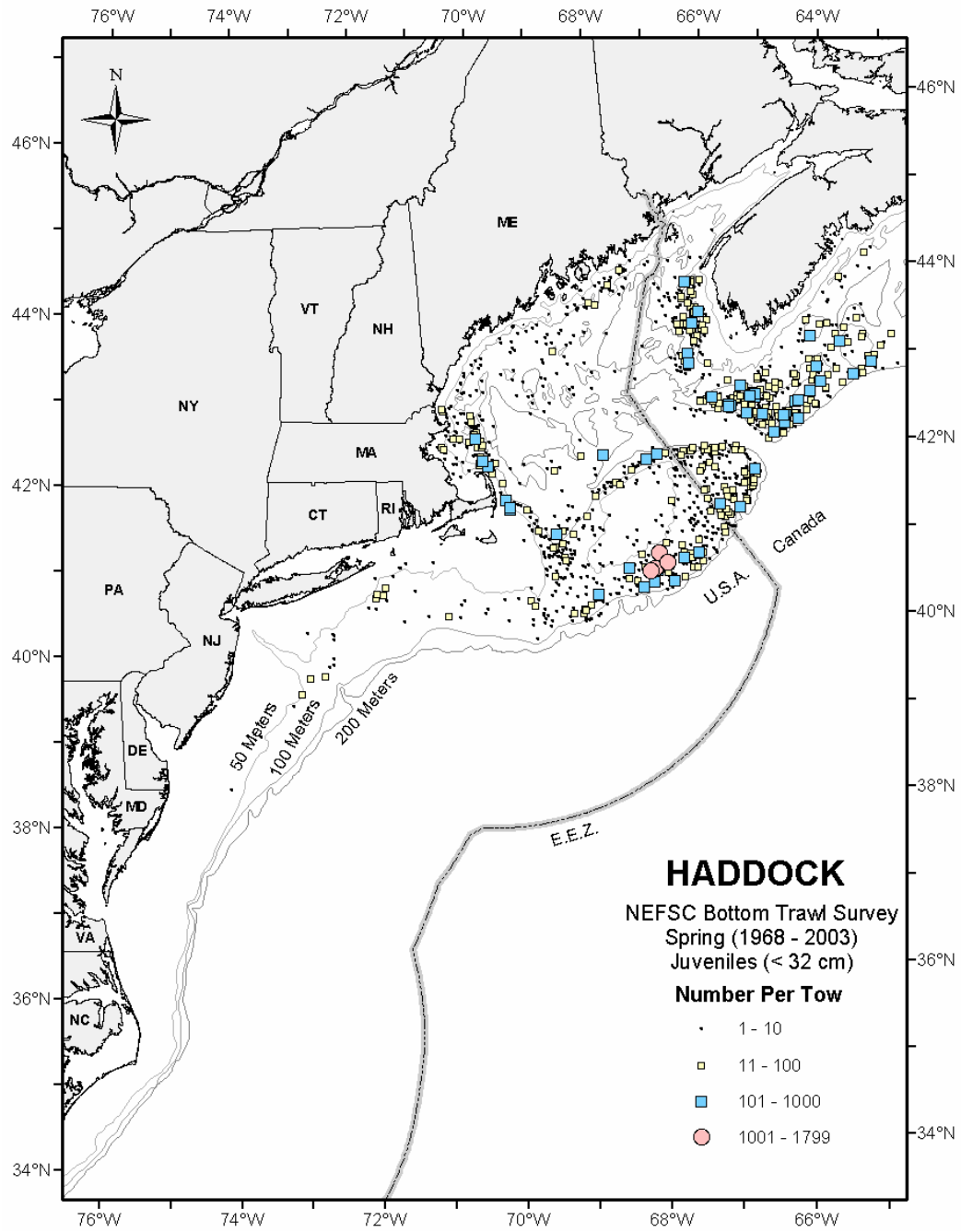


Figure 8. Cont'd.
From NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where juveniles were not found are not shown.

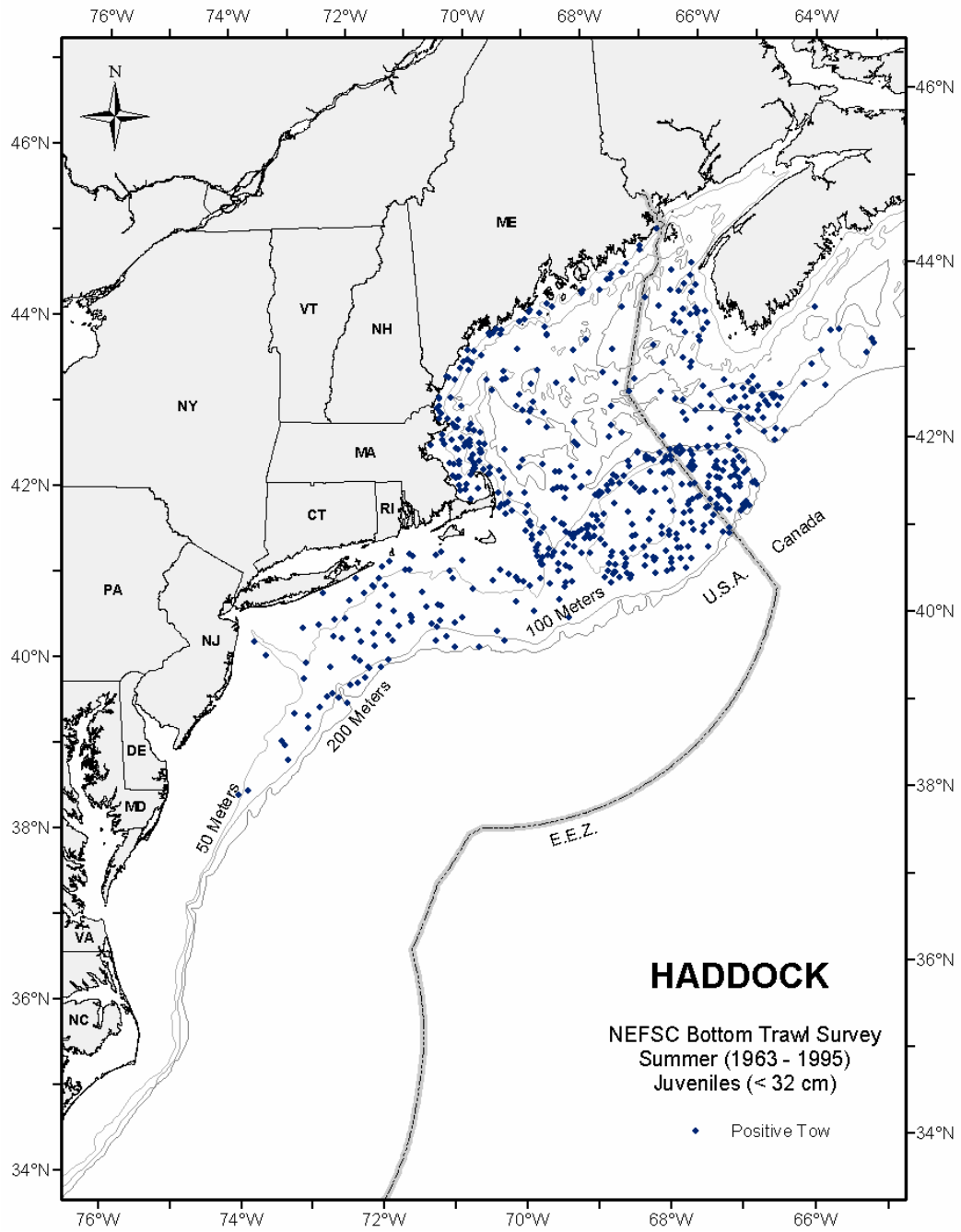


Figure 8. Cont'd.
From NEFSC summer bottom trawl surveys (1963-1995, all years combined). Distributions are displayed as presence only.

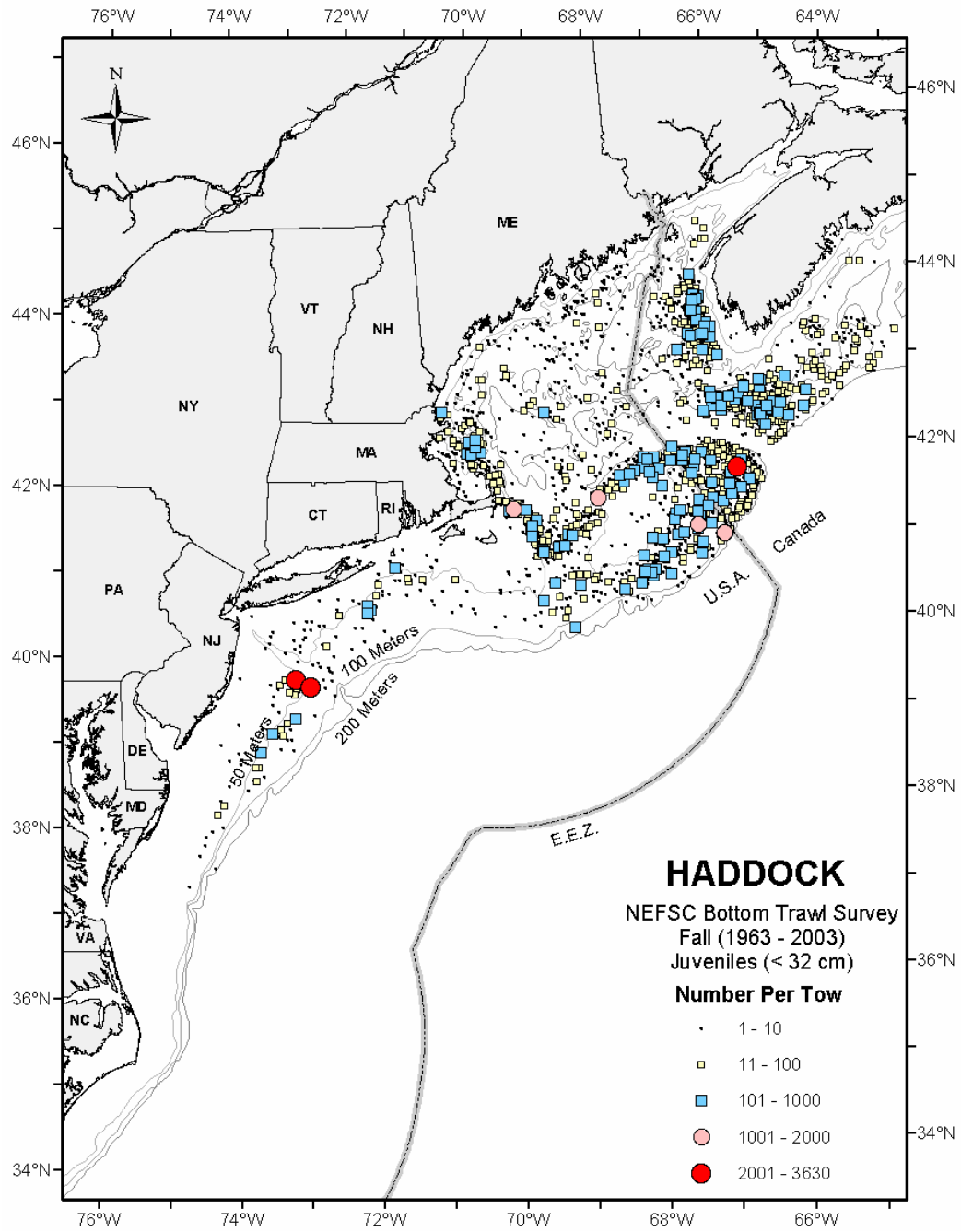


Figure 8. Cont'd.
From NEFSC fall bottom trawl surveys (1963-2003, all years combined). Survey stations where juveniles were not found are not shown.

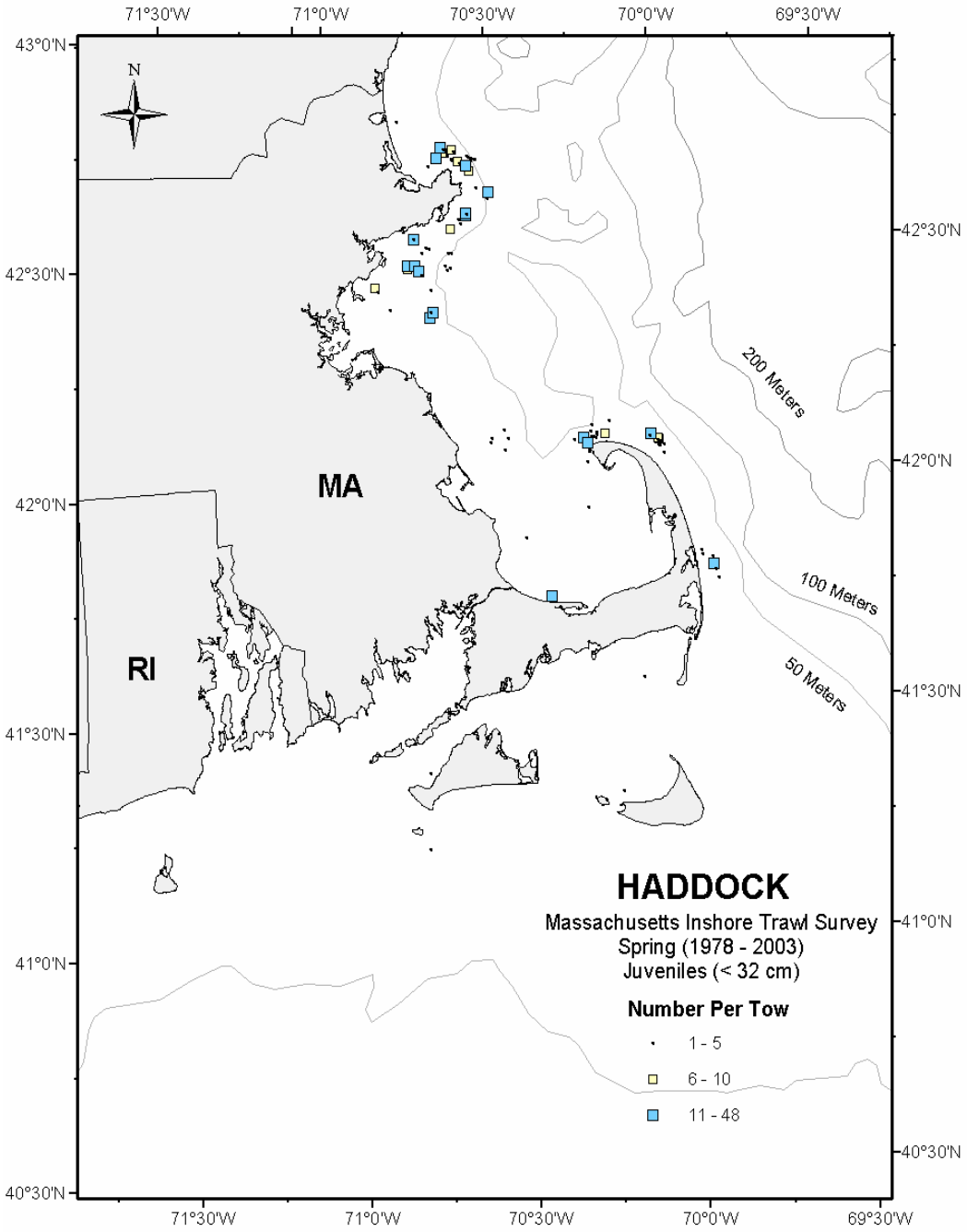


Figure 9. Seasonal distributions and abundances of juvenile haddock in Massachusetts coastal waters. From spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

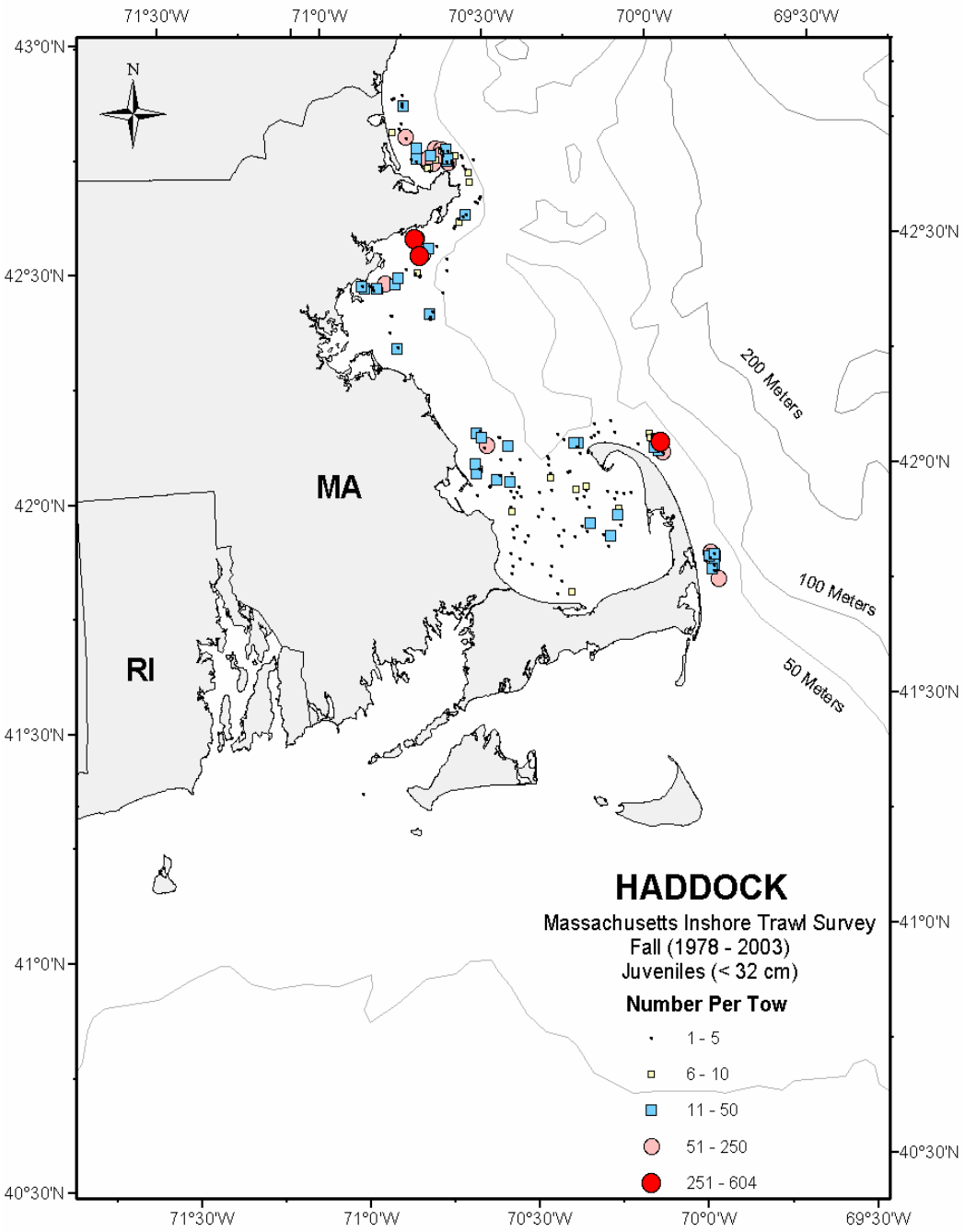


Figure 9. Cont'd.
From fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

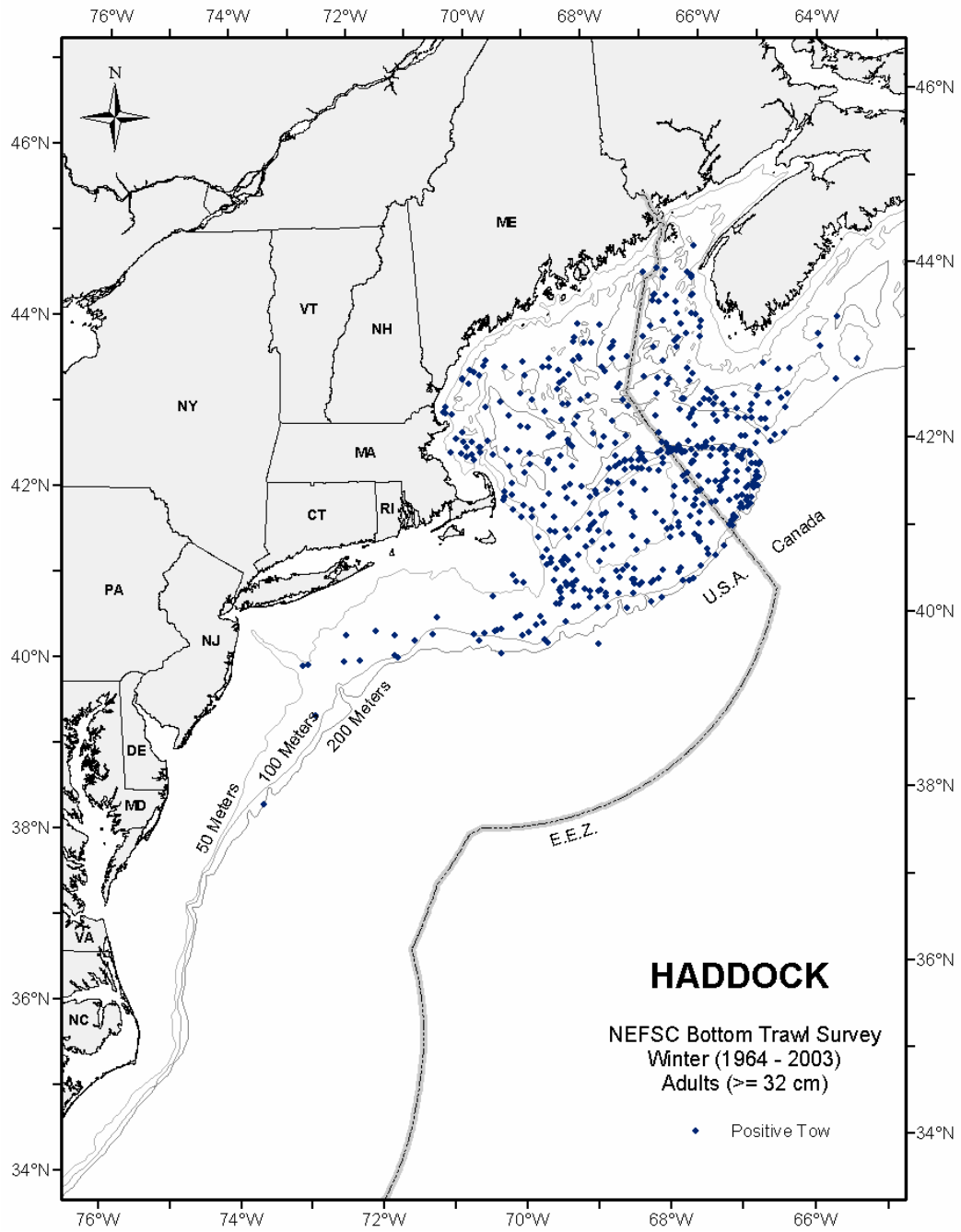


Figure 10. Seasonal distributions and abundances of adult haddock collected during NEFSC bottom trawl surveys. From NEFSC winter bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence only.

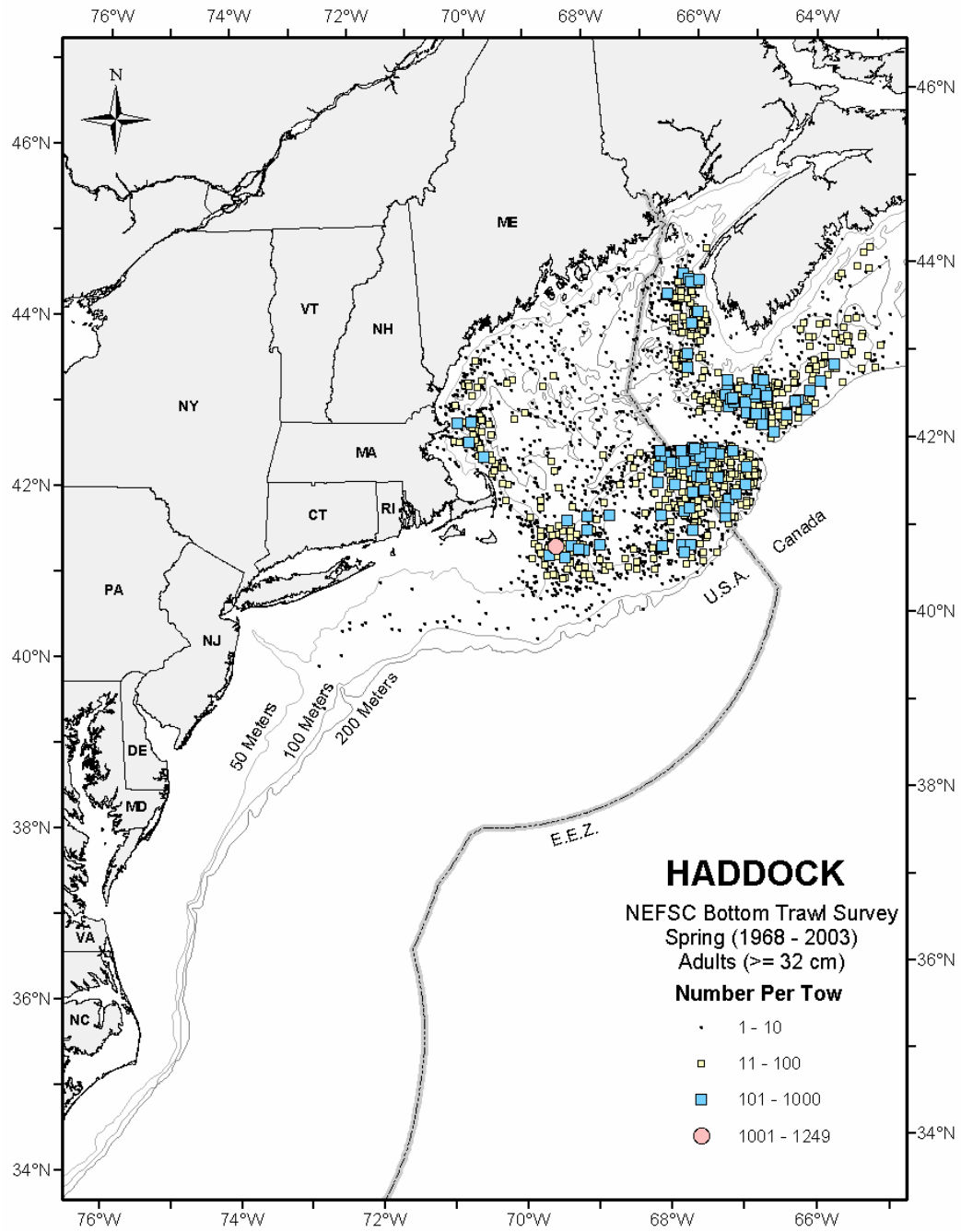


Figure 10. Cont'd.
From NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where adults were not found are not shown.

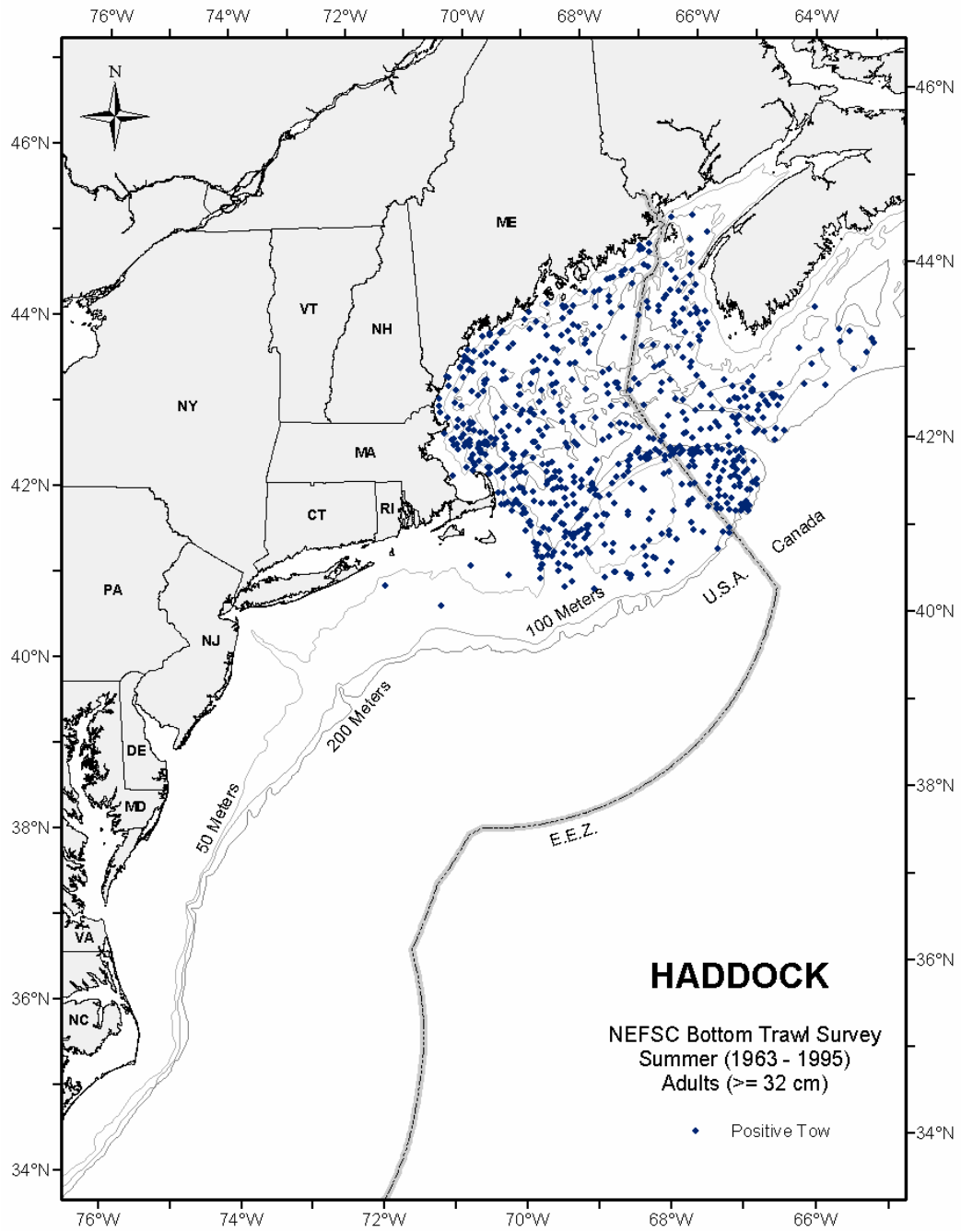


Figure 10. Cont'd.
From NEFSC summer bottom trawl surveys (1963-1995, all years combined). Distributions are displayed as presence only.

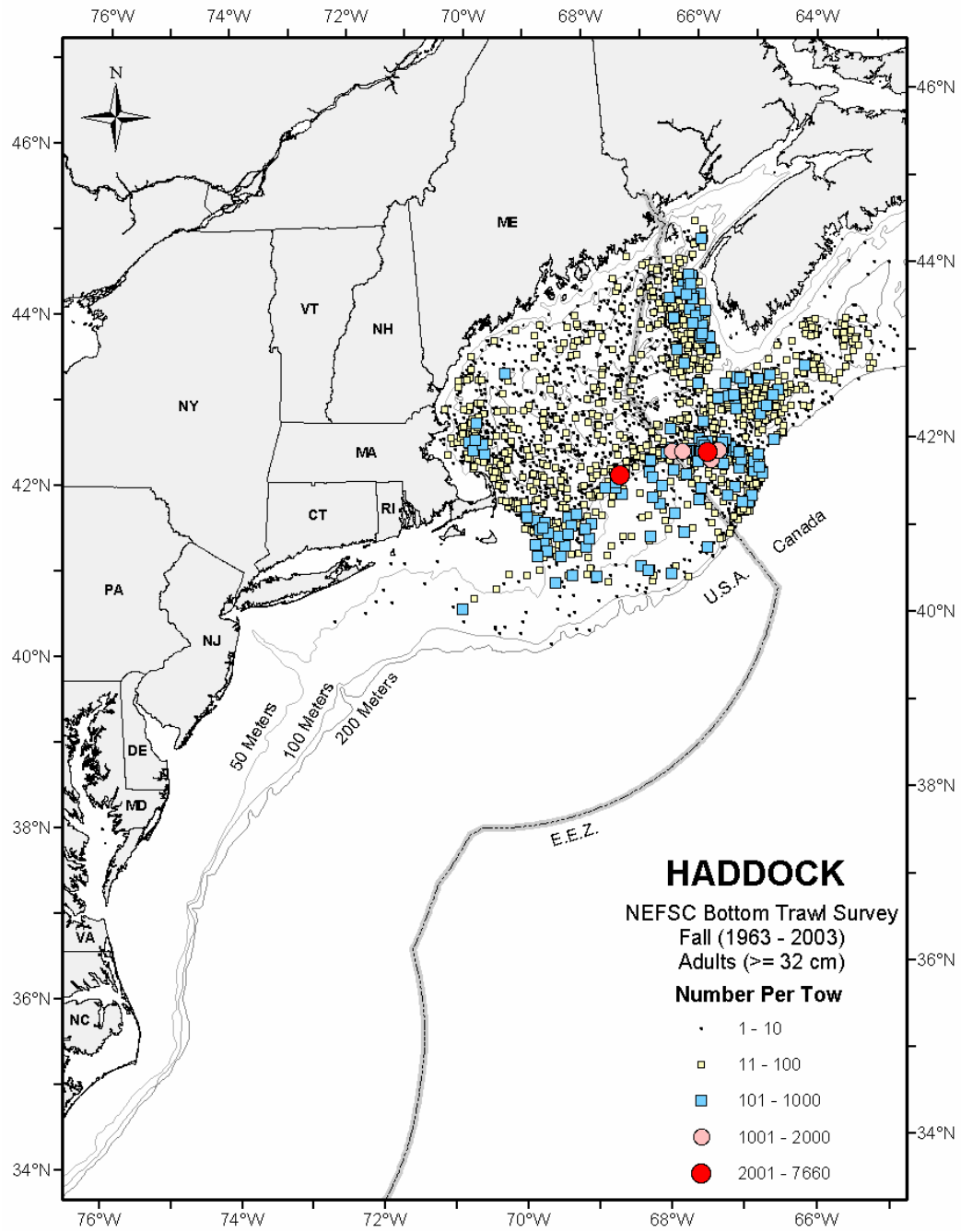


Figure 10. Cont'd.
From NEFSC fall bottom trawl surveys (1963-2003, all years combined). Survey stations where adults were not found are not shown.

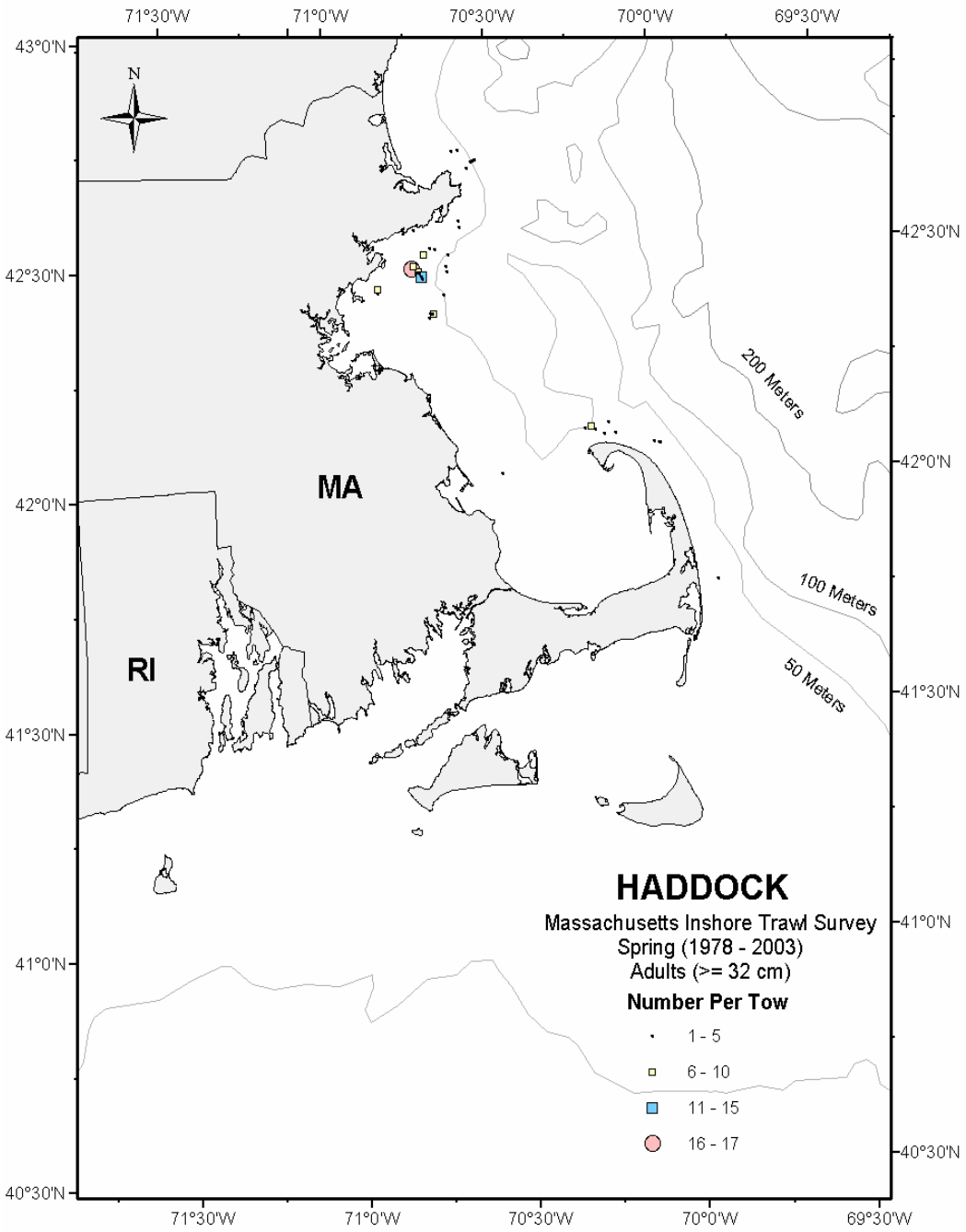


Figure 11. Seasonal distributions and abundances of adult haddock in Massachusetts coastal waters. From spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.

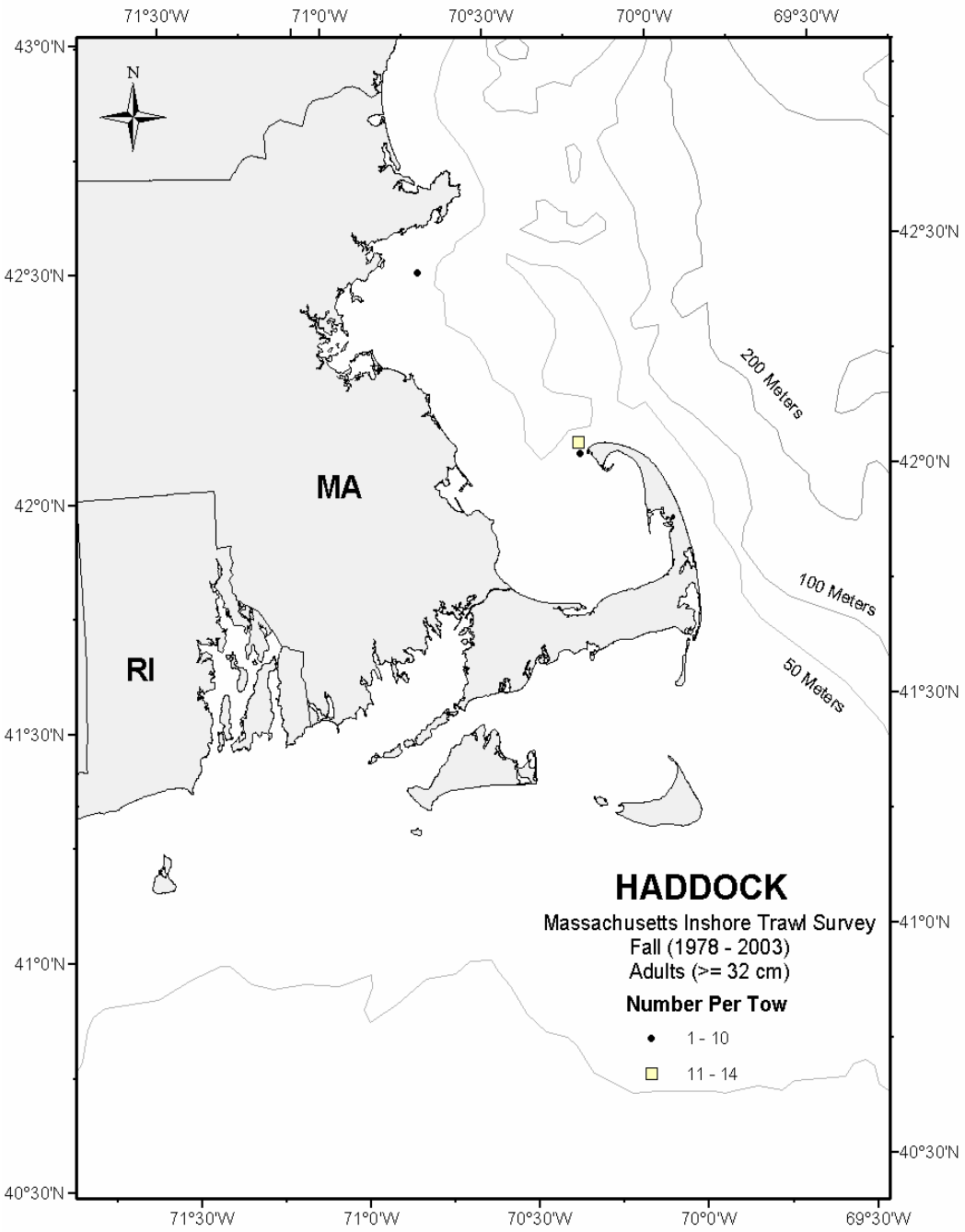


Figure 11. Cont'd.
From fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.

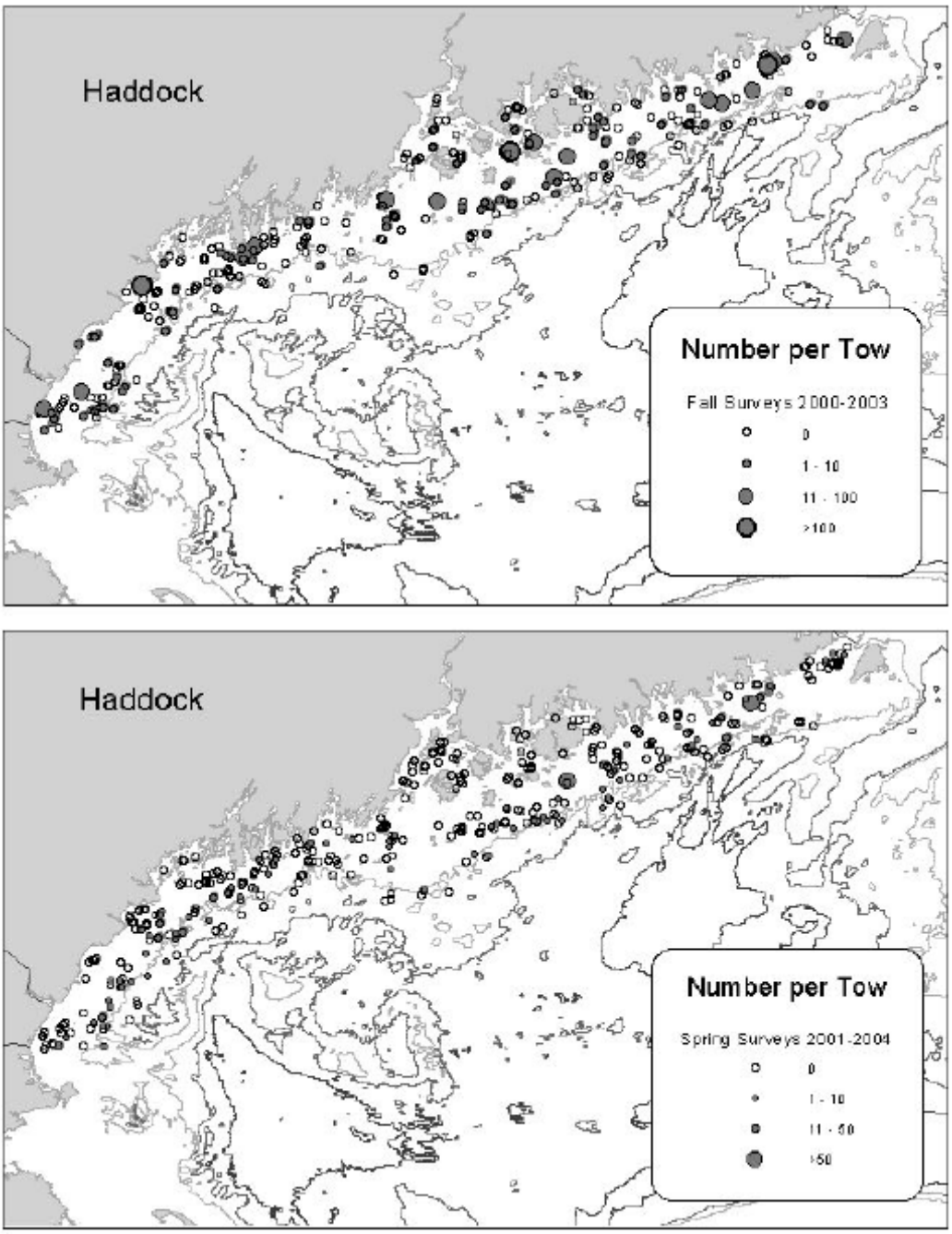


Figure 12. Distribution and abundance of haddock along the coasts of Maine and New Hampshire. From the Maine – New Hampshire spring 2001-2004 and fall 2000-2003 inshore groundfish trawl surveys. For details on the survey, see Sherman *et al*. (2005).

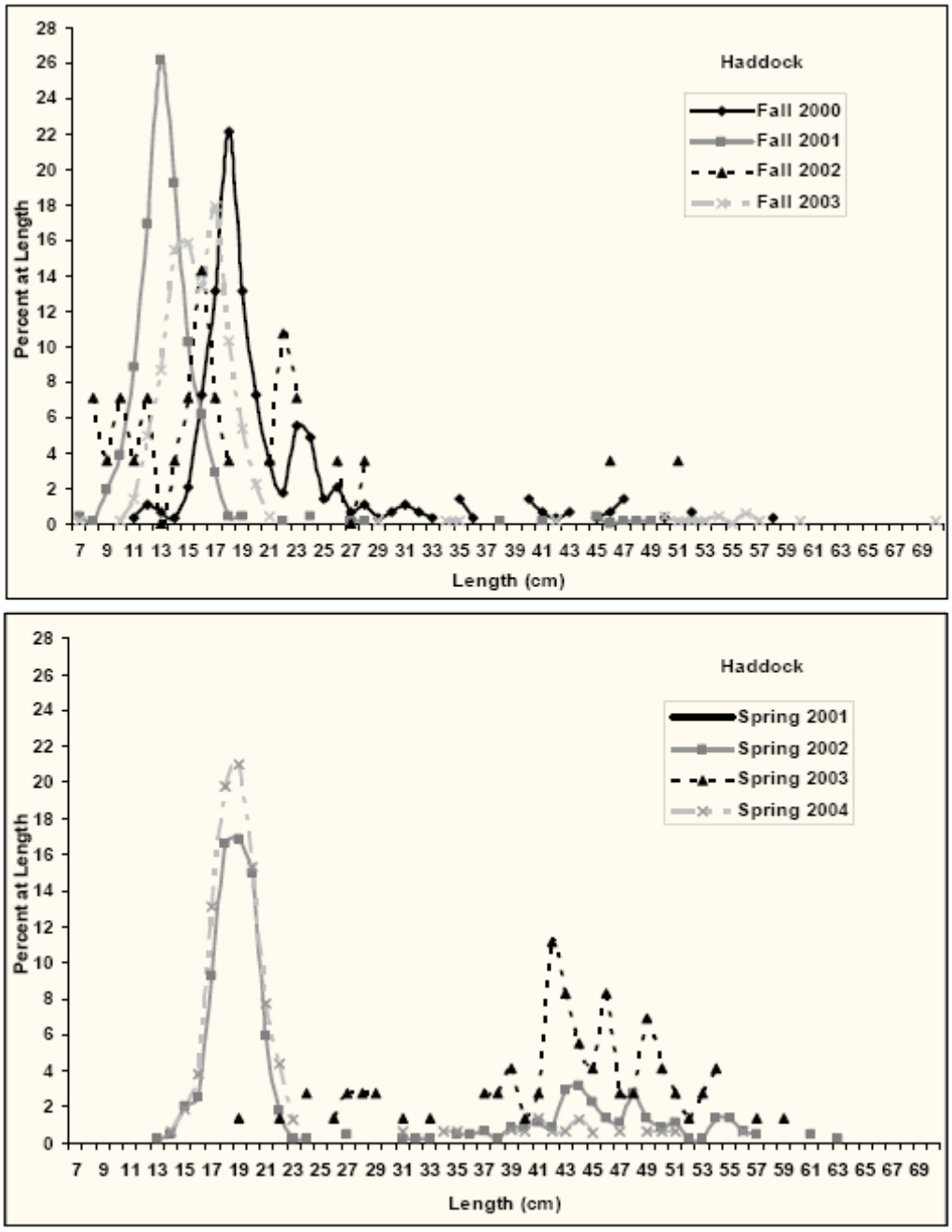
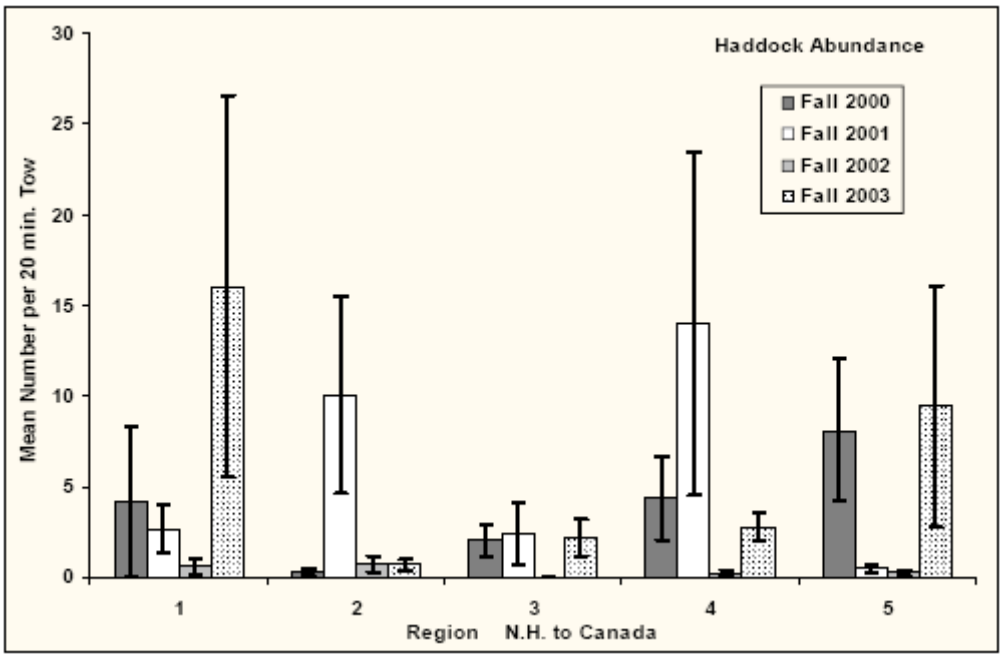


Figure 13. Length frequency plots for haddock caught along the Maine and New Hampshire coasts, by season/year. Based on the Maine – New Hampshire inshore groundfish trawl survey for spring 2001-2004 and fall 2000-2003. Source: Sherman *et al*. (2005).



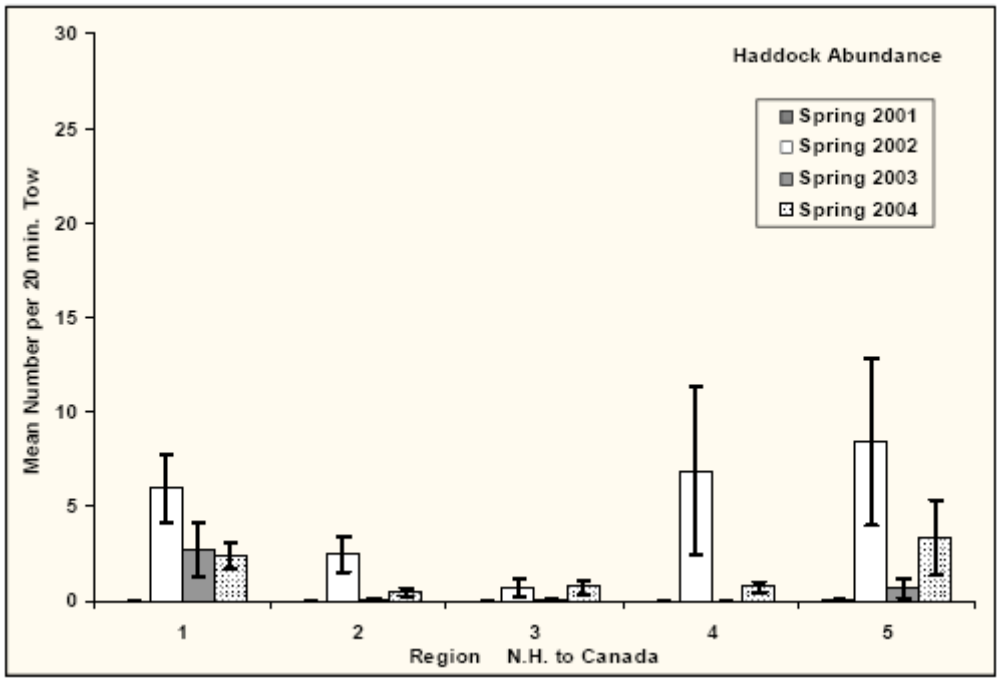


Figure 14. Regional catch-per-unit-effort of haddock caught along the Maine and New Hampshire coasts, by season/year.
Based on the Maine – New Hampshire inshore groundfish trawl survey for spring 2001-2004 and fall 2000-2003. Region 1 = NH–Southern ME; Region 2 = Casco Bay–Midcoast ME; Region 3 = Penobscot Bay, ME; Region 4 = Jerico–Frenchmens Bay, ME; Region 5 = Downeast ME. Source: Sherman *et al*. (2005).

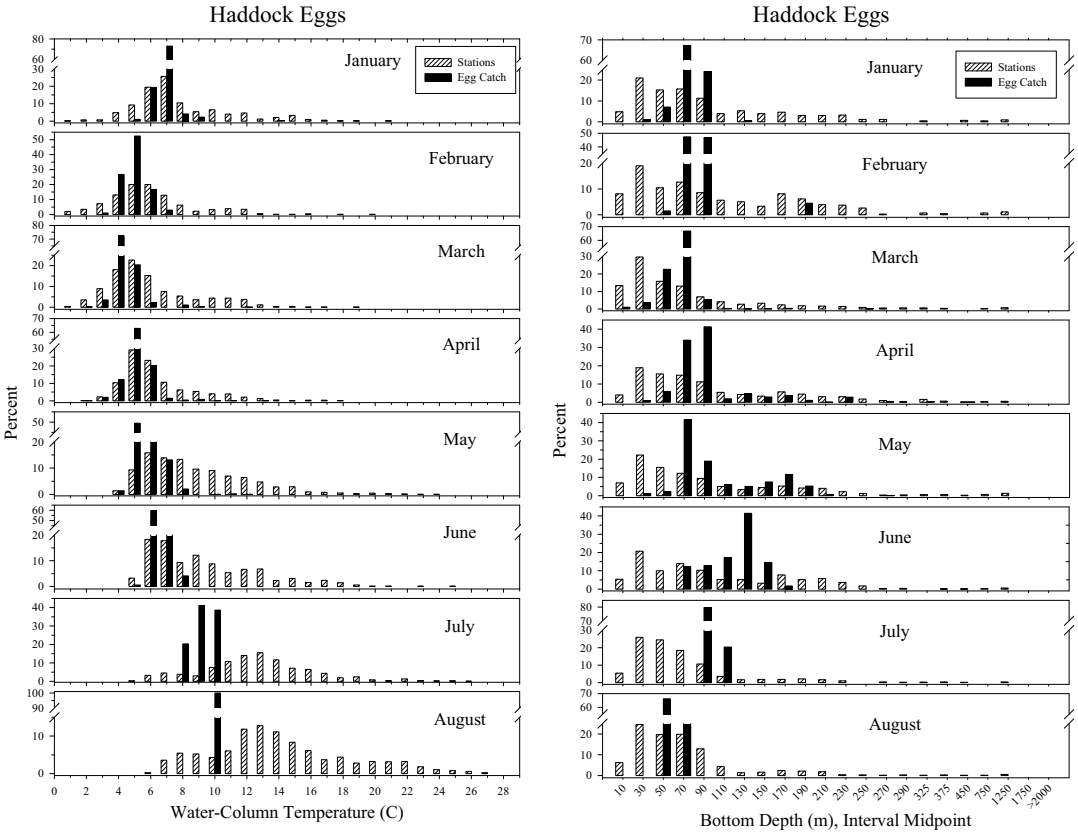


Figure 15. Distributions of haddock eggs collected during NEFSC MARMAP ichthyoplankton surveys relative to water column temperature and bottom depth.
For all available months and years from 1978-1987 combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth interval changes with increasing depth.

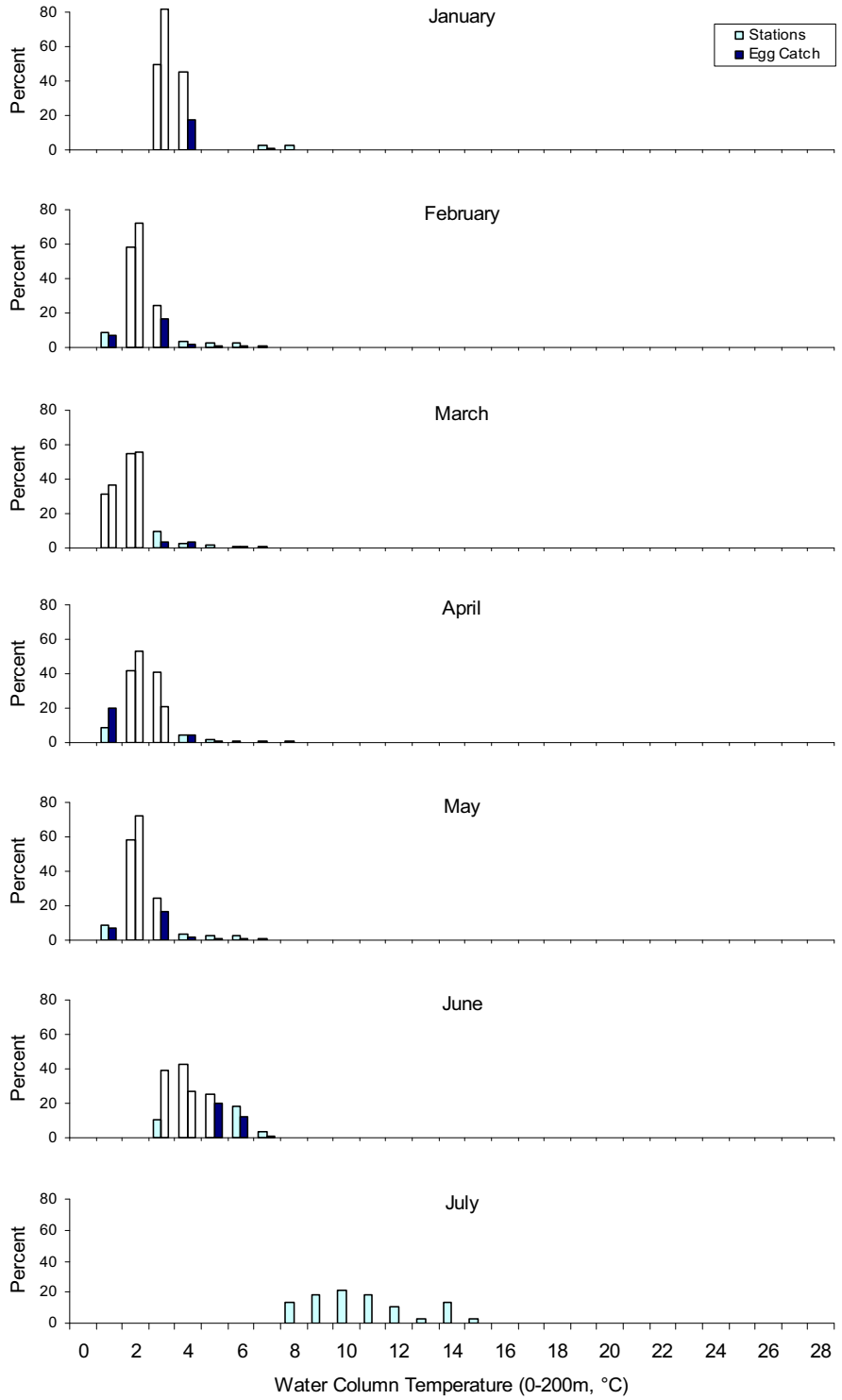


Figure 16. Distributions of haddock eggs collected during GLOBEC ichthyoplankton surveys relative to water column temperature.
From GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10m^2).

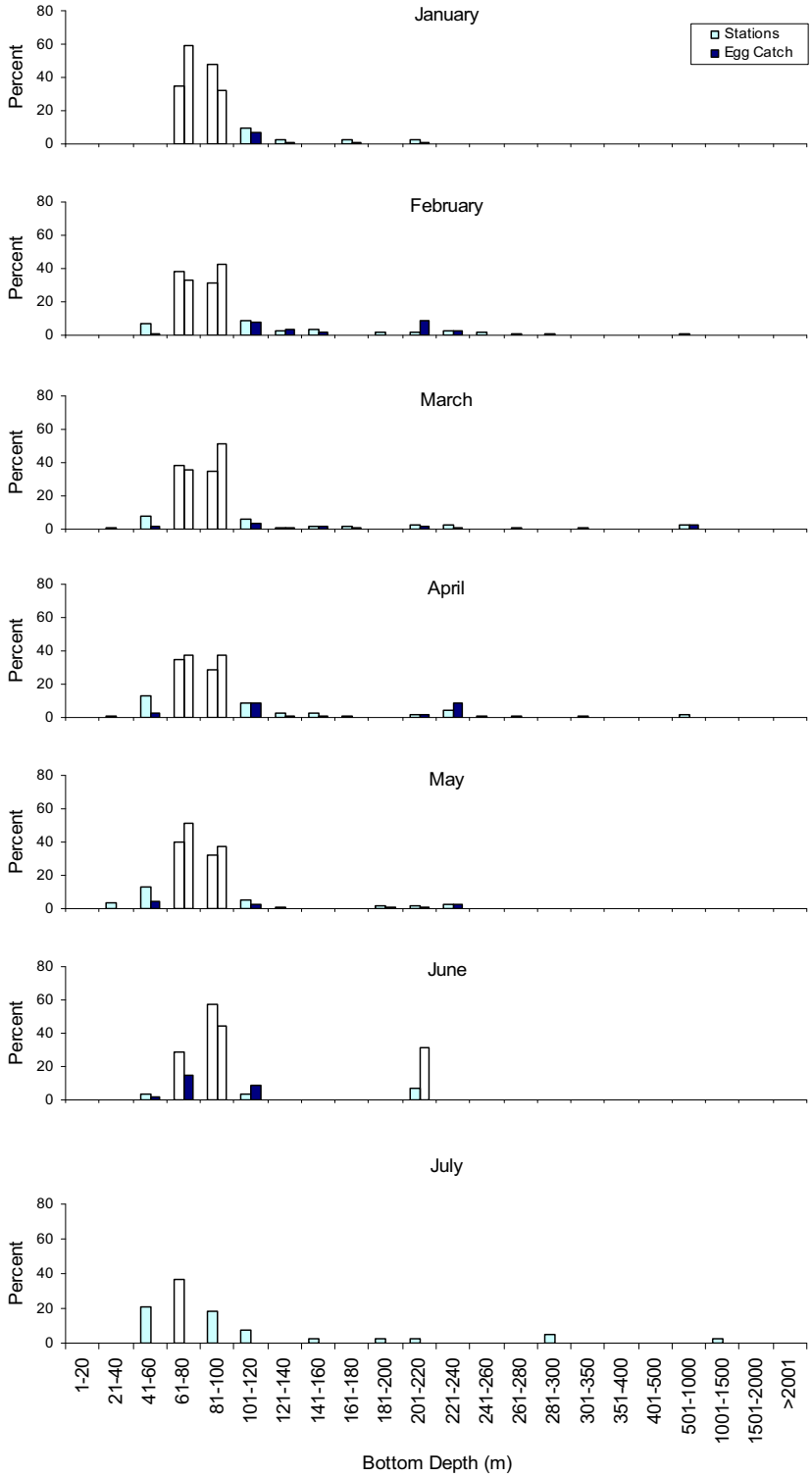


Figure 17. Distributions of haddock eggs collected during GLOBEC ichthyoplankton surveys relative to bottom depth. From GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10m^2). Note that the bottom depth intervals change with depth.

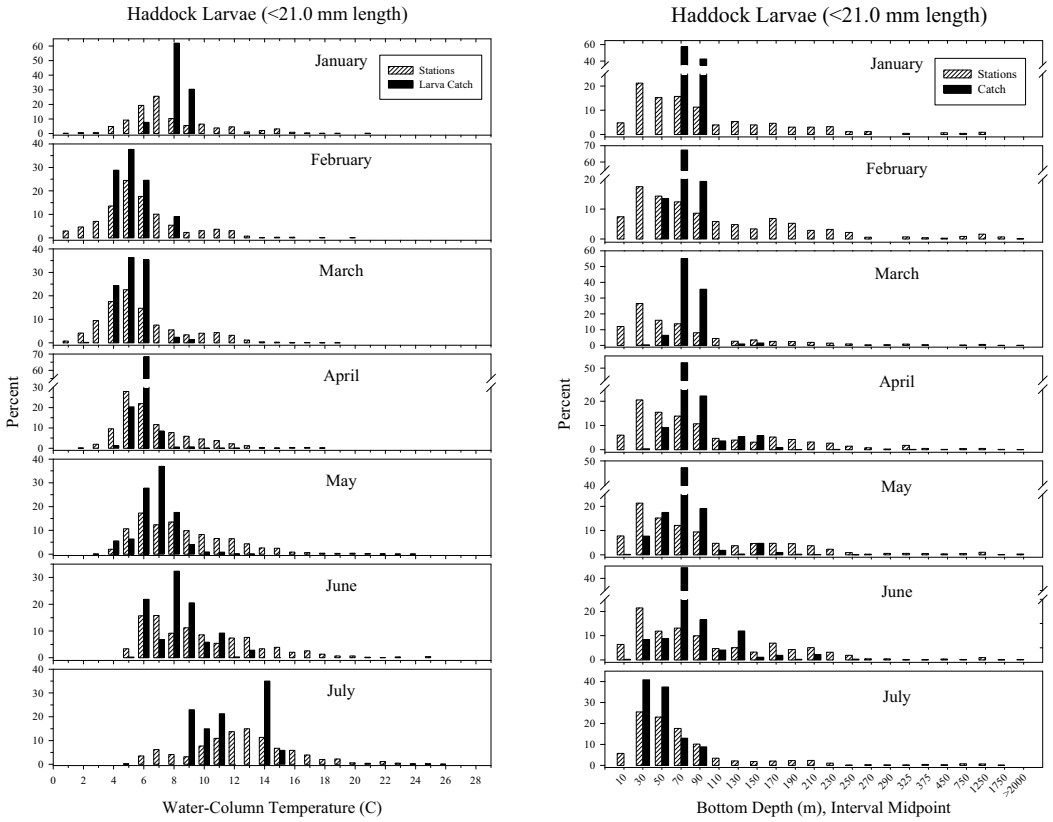


Figure 18. Monthly distributions of haddock larvae collected during NEFSC MARMAP ichthyoplankton surveys relative to water column temperature and bottom depth.
For all available months and years from 1977-1987 combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth interval changes with increasing depth.

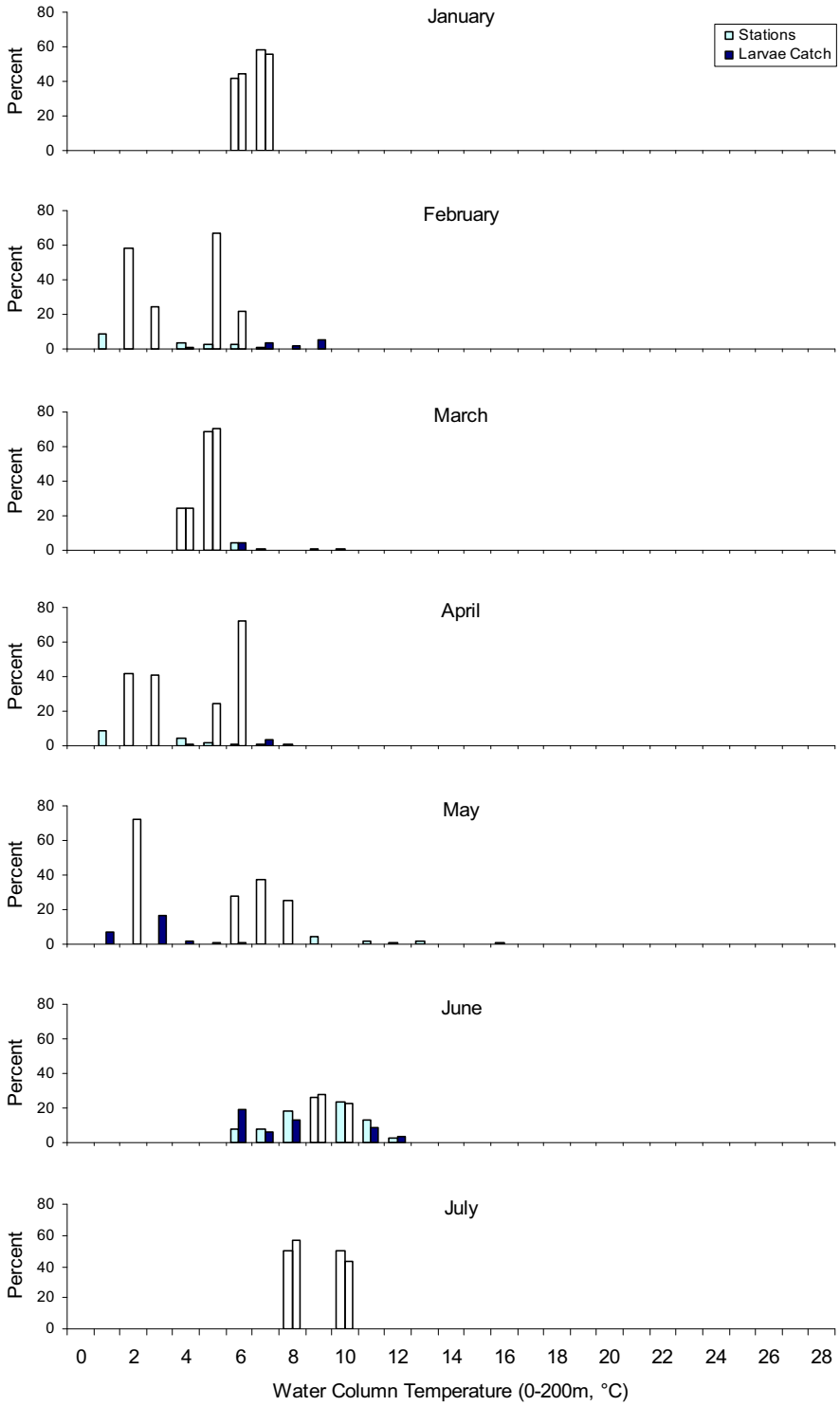


Figure 19. Distributions of haddock larvae collected during GLOBEC ichthyoplankton surveys relative to water column temperature.
From GLOBEC Georges Bank surveys (February-July, 1995, January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10m^2).

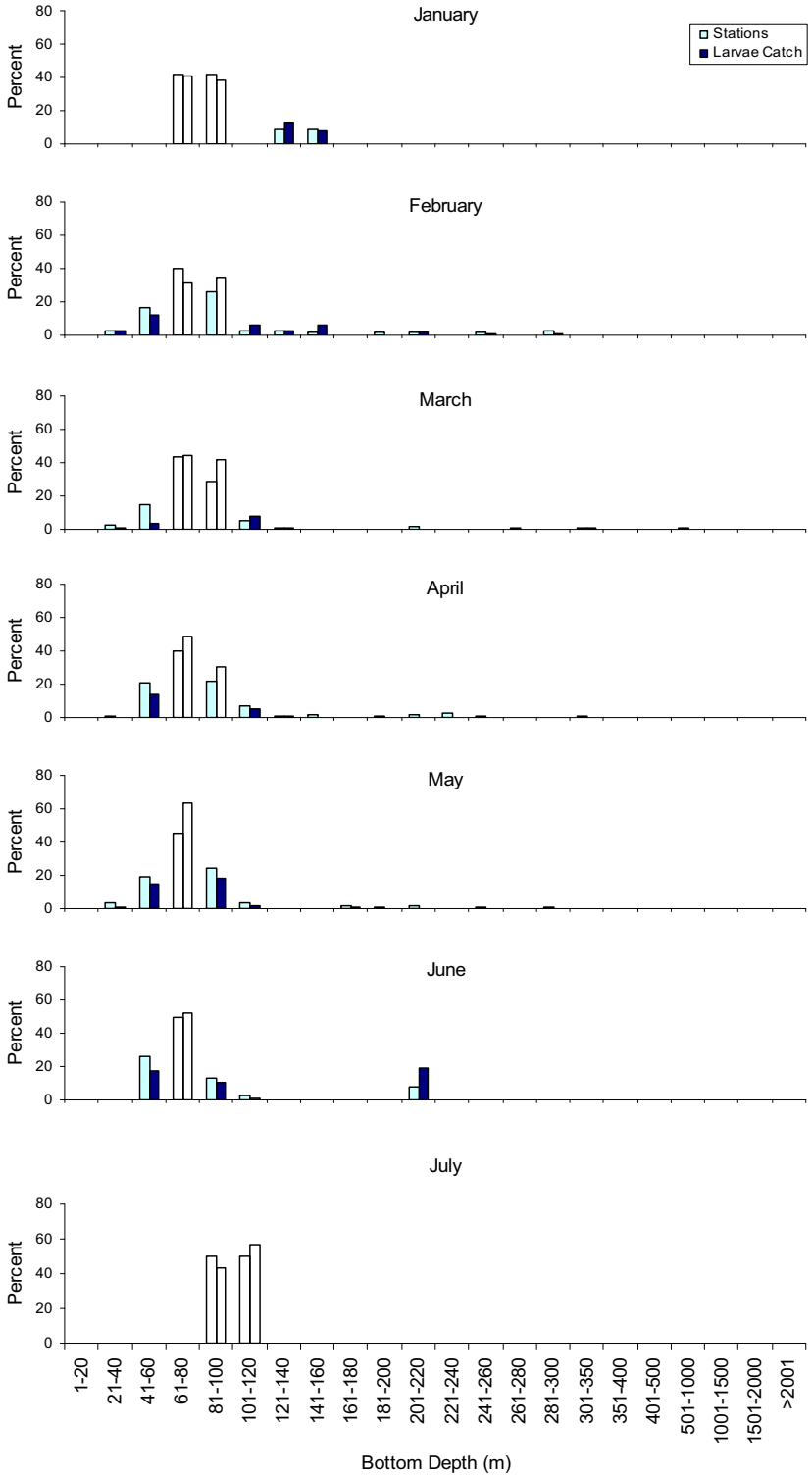


Figure 20. Distributions of haddock larvae collected during GLOBEC ichthyoplankton surveys relative to bottom depth. From GLOBEC Georges Bank surveys (February-July, 1995; January-June, 1996-1999) by month for all available years combined. Light bars represent the proportion of all stations surveyed, while dark bars represent the proportion of the sum of all standardized catches (number/10m^2). Note that the bottom depth intervals change with depth.

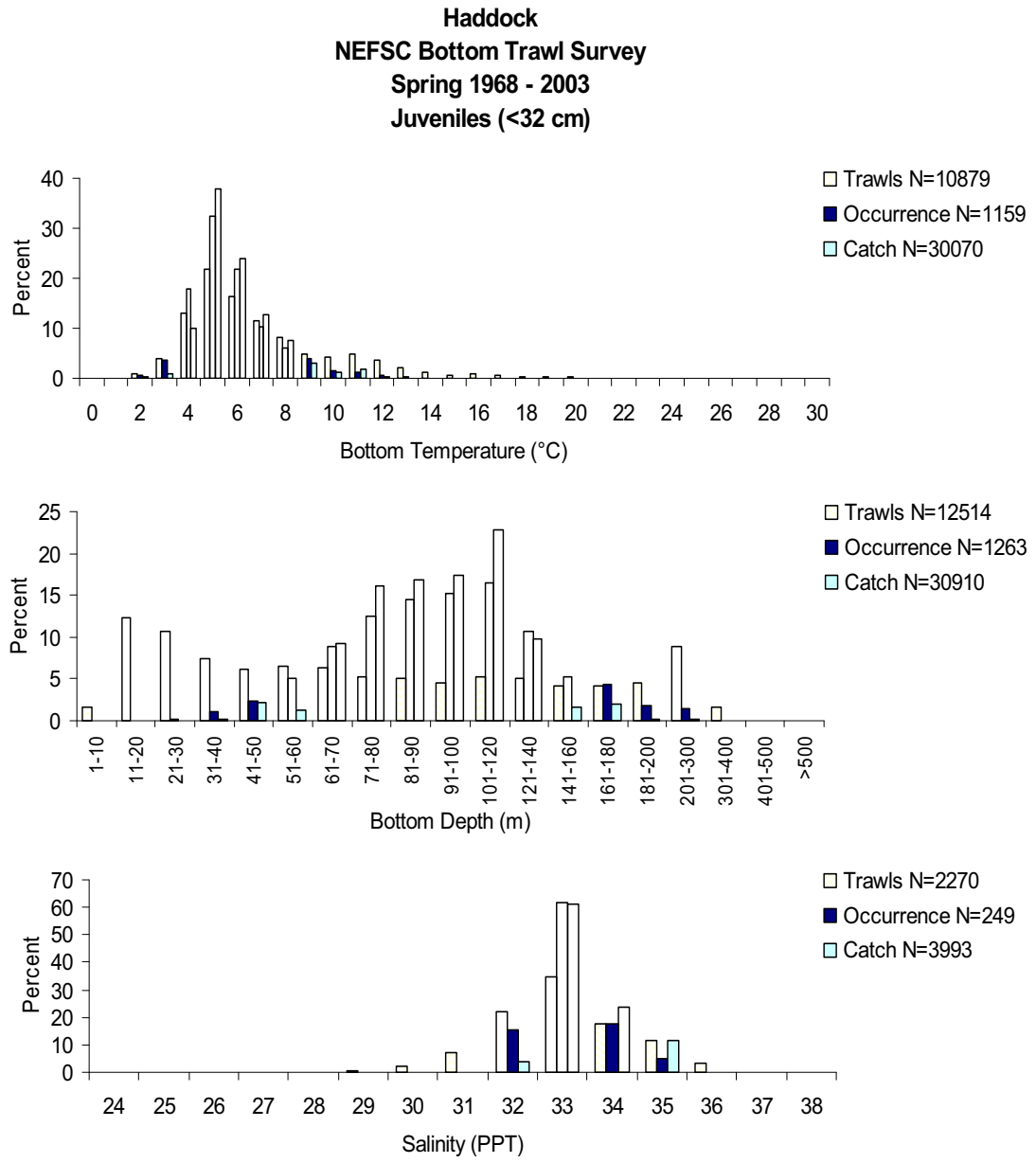


Figure 21. Distributions of juvenile haddock and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught. Note that the bottom depth interval changes with increasing depth.

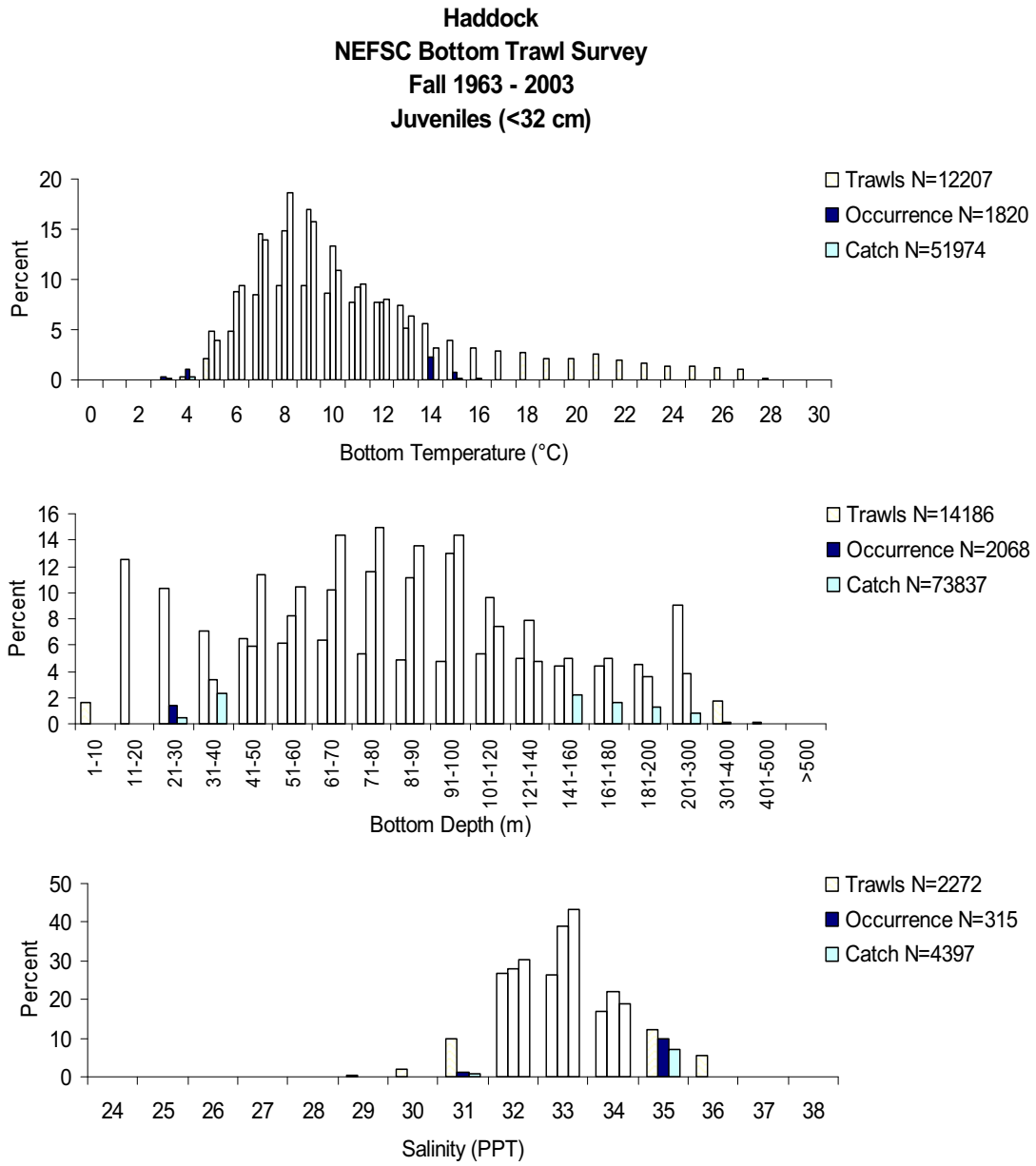


Figure 21. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught. Note that the bottom depth interval changes with increasing depth.

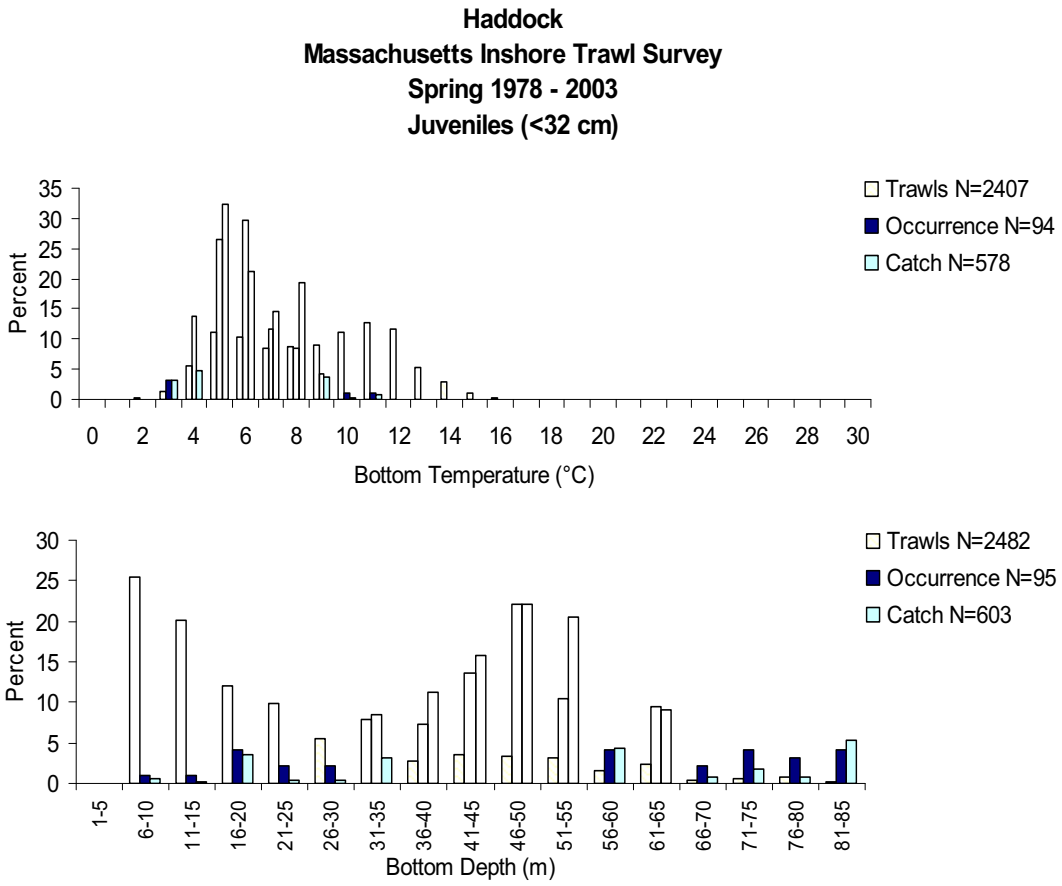


Figure 22. Distributions of juvenile haddock and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught.

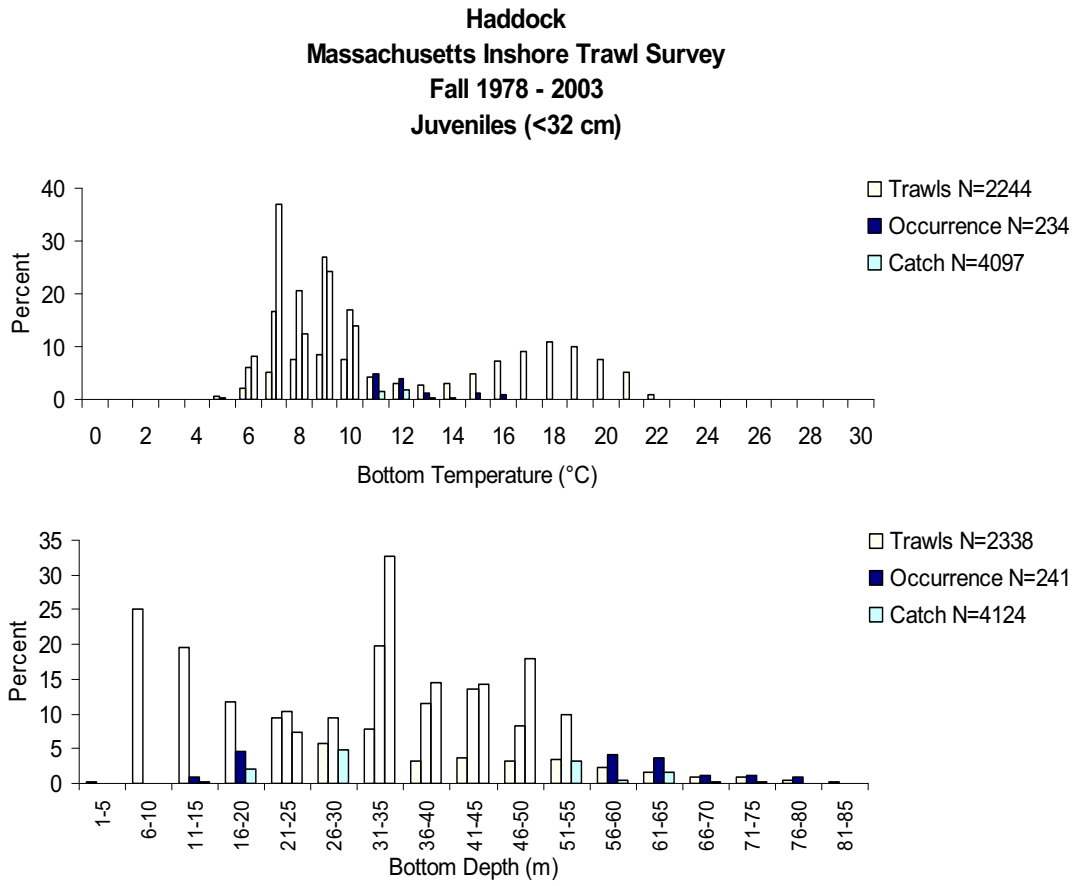


Figure 22. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught.

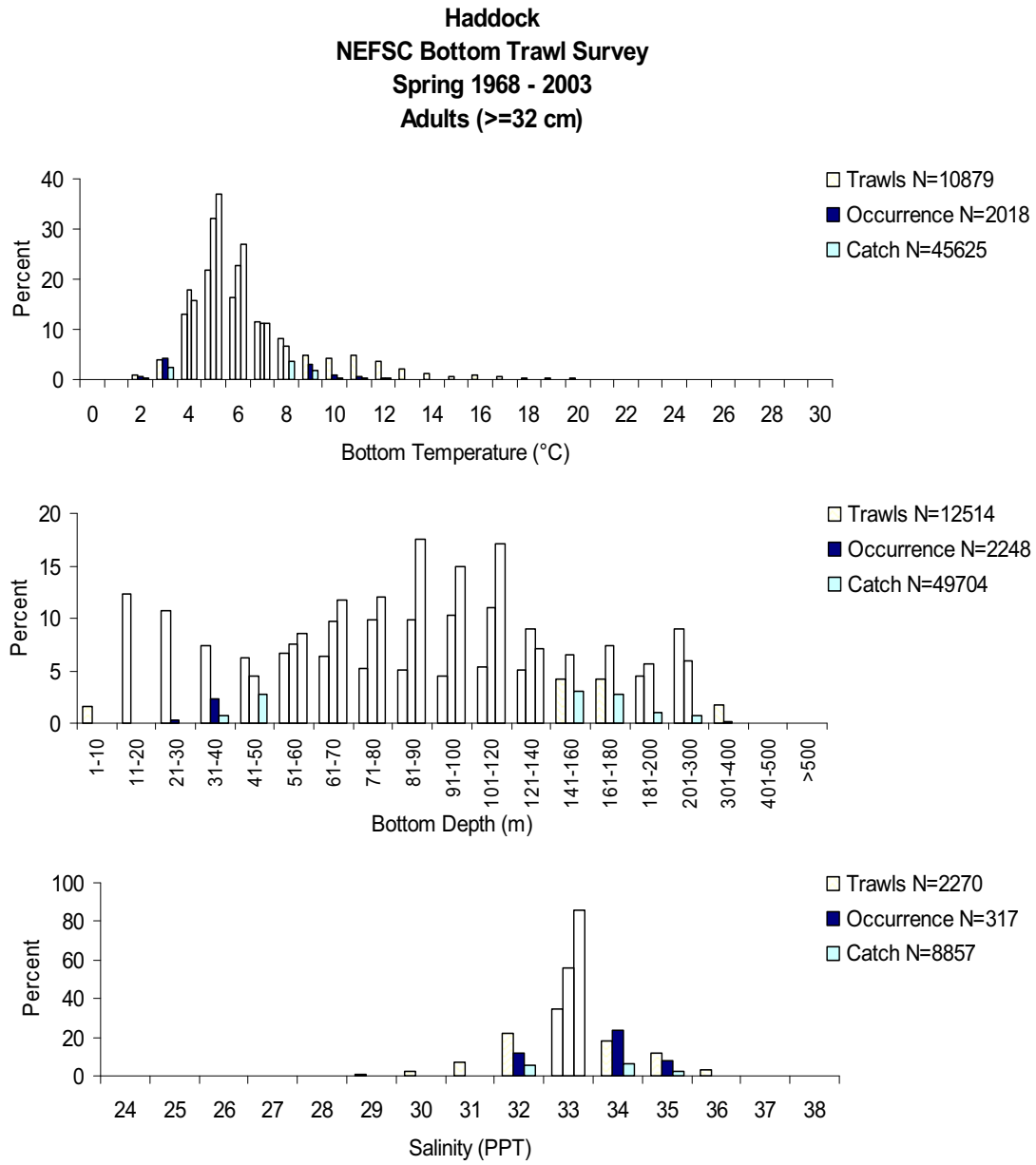


Figure 23. Distributions of adult haddock and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity.
Based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught. Note that the bottom depth interval changes with increasing depth.

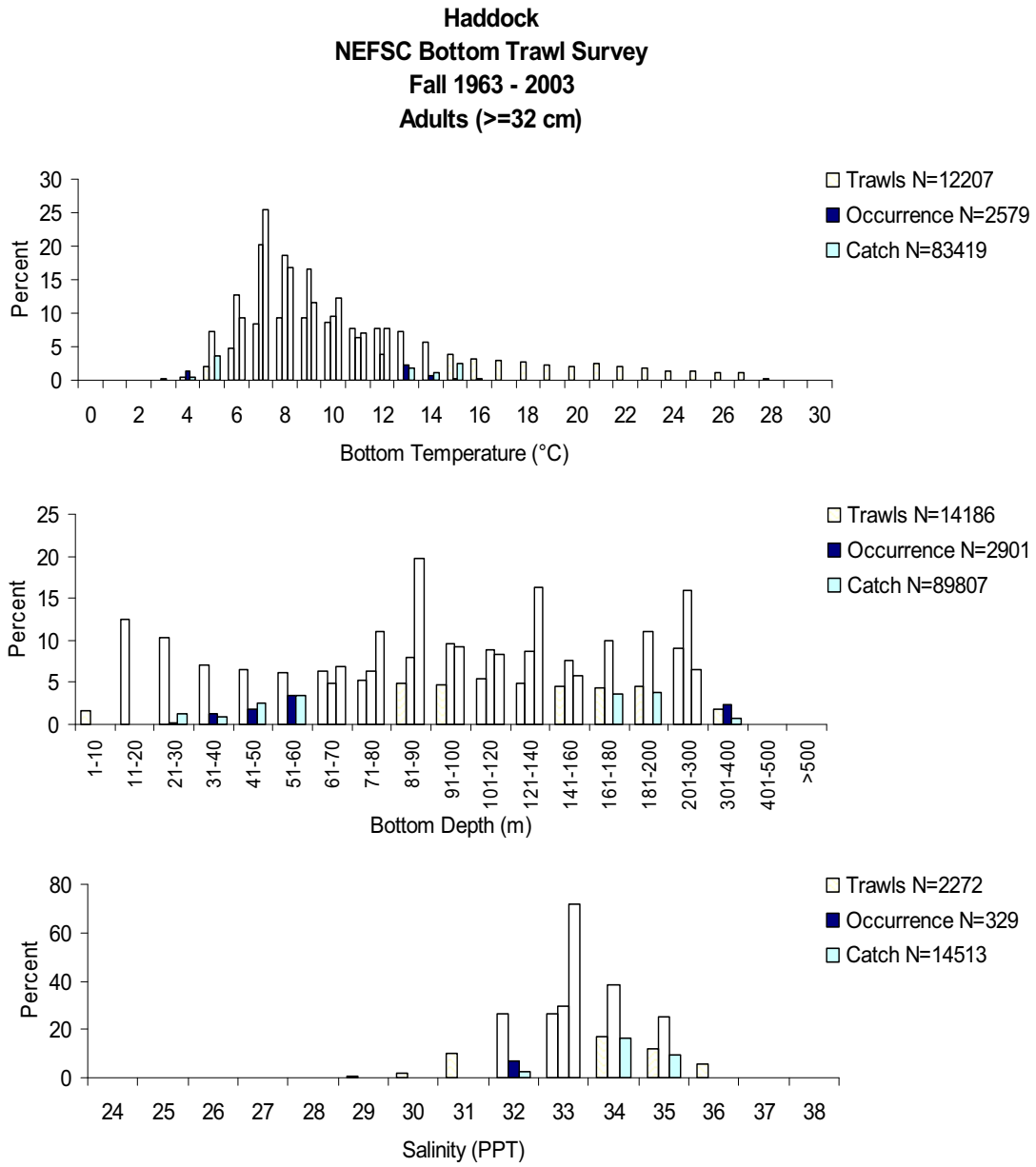


Figure 23. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught. Note that the bottom depth interval changes with increasing depth.

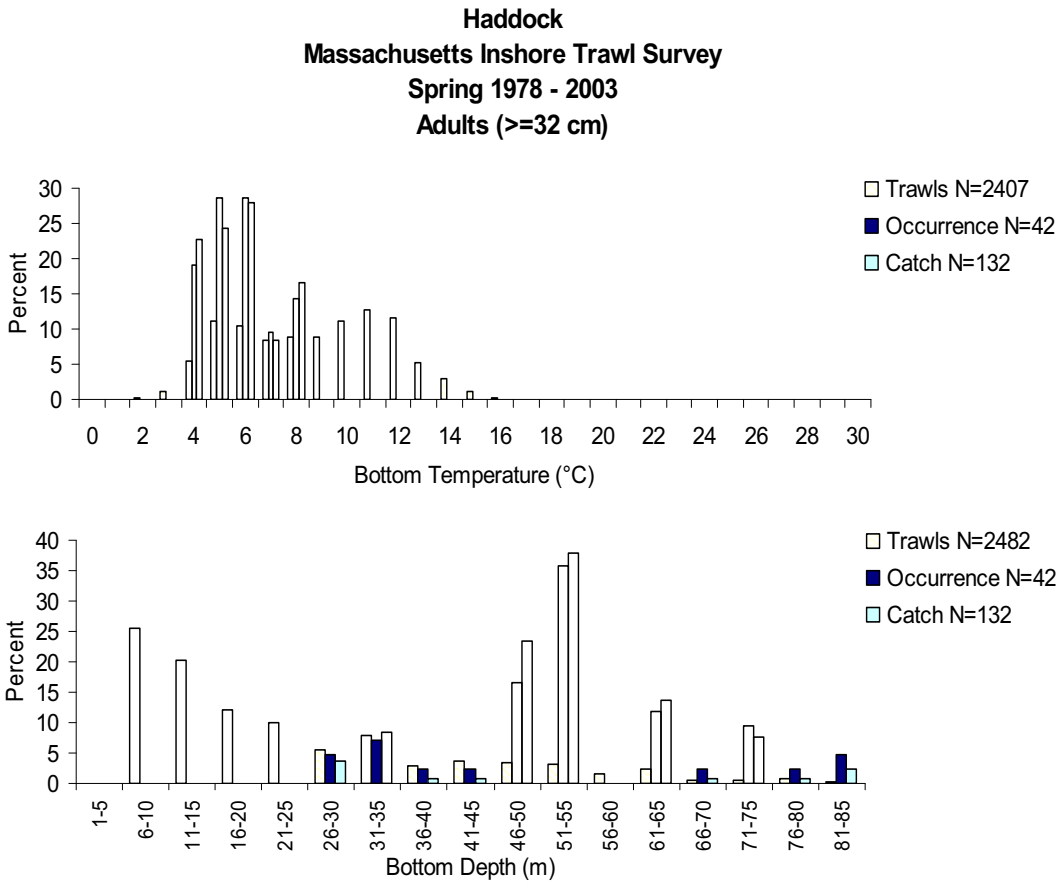


Figure 24. Distributions of adult haddock and trawls in Massachusetts coastal waters relative to bottom water temperature and depth.
Based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught.

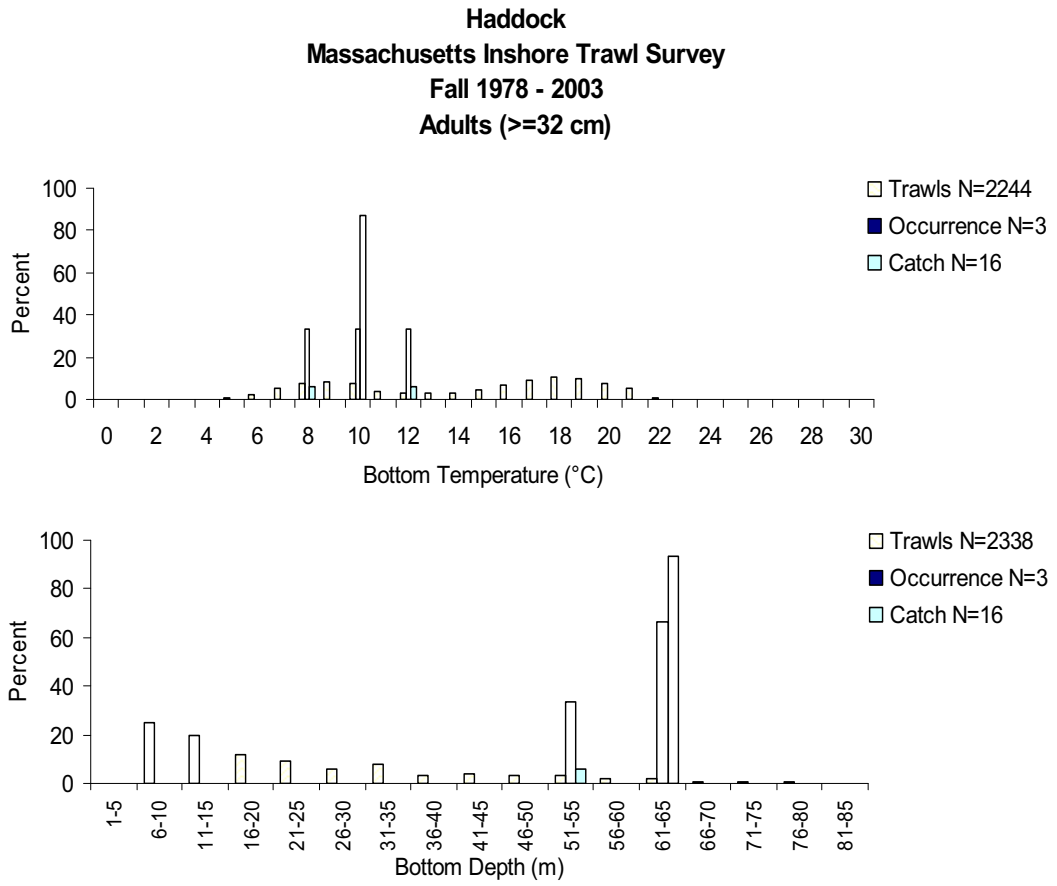


Figure 24. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which haddock occurred and medium bars show, within each interval, the percentage of the total number of haddock caught.

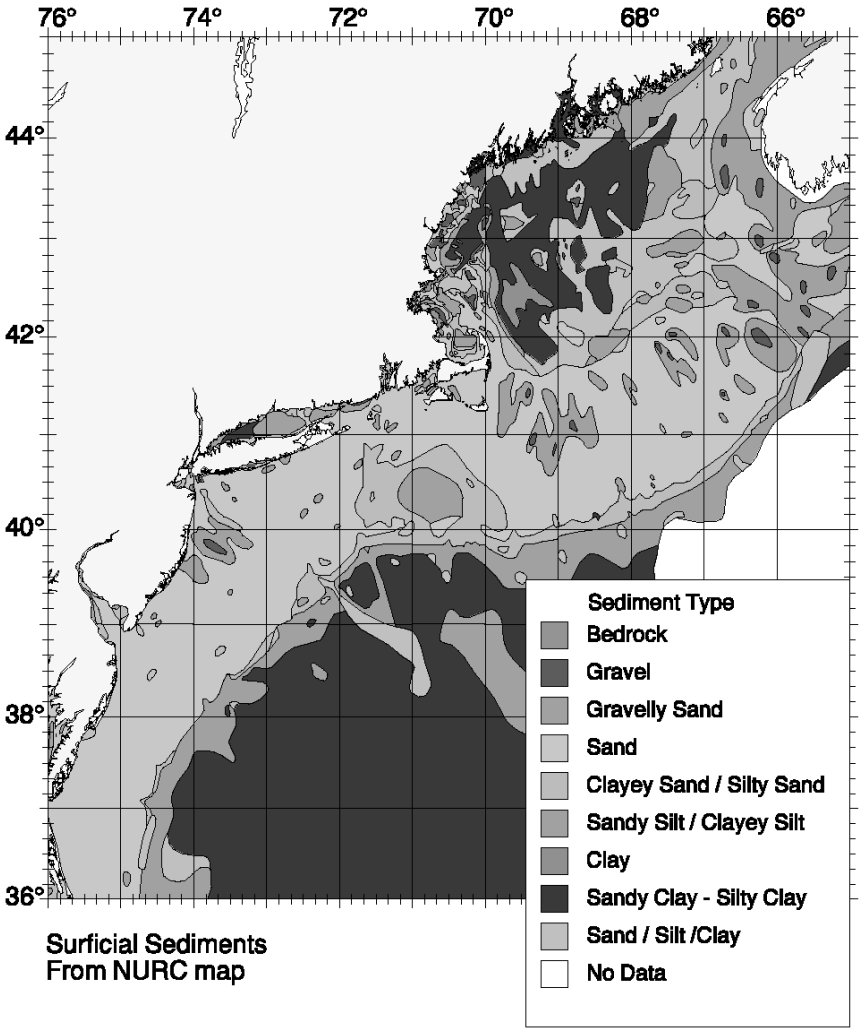


Figure 25. Distribution of surficial sediments along the northeast coast of the United States. Data are from the United States Geological Survey and NOAA.

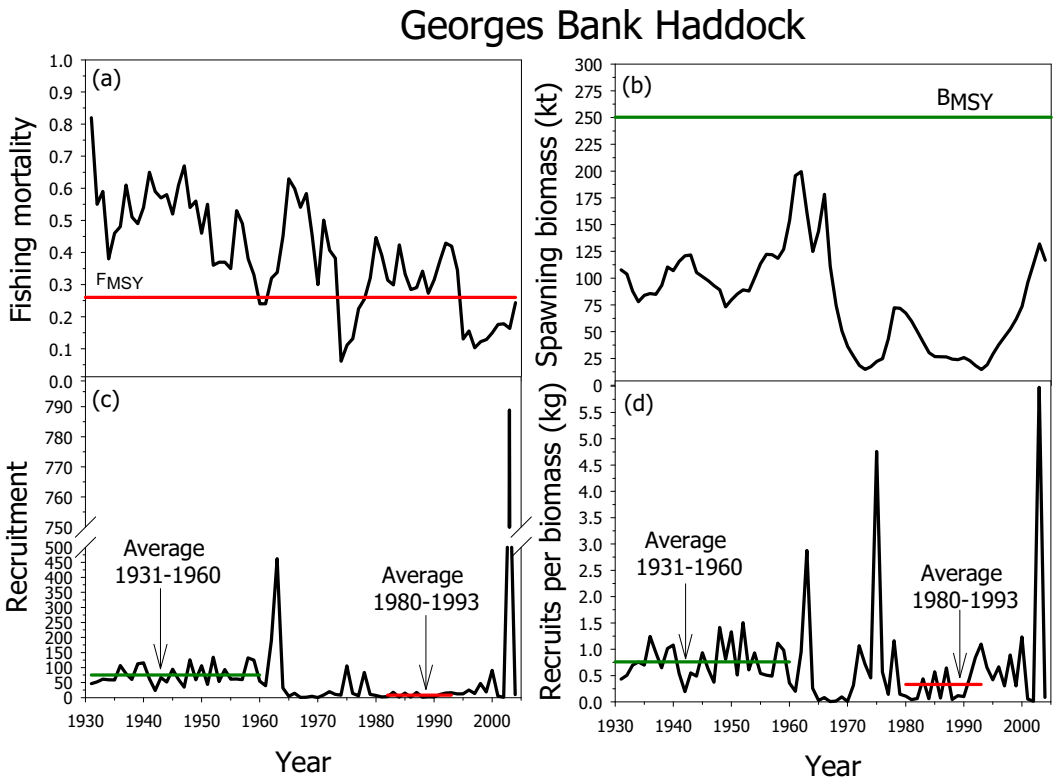


Figure 26. Fishing mortality (a), spawning biomass (b), recruitment (c), and recruits per spawning biomass (d) of Georges Bank haddock during 1931-2004, from Brodziak *et al*. (2005).

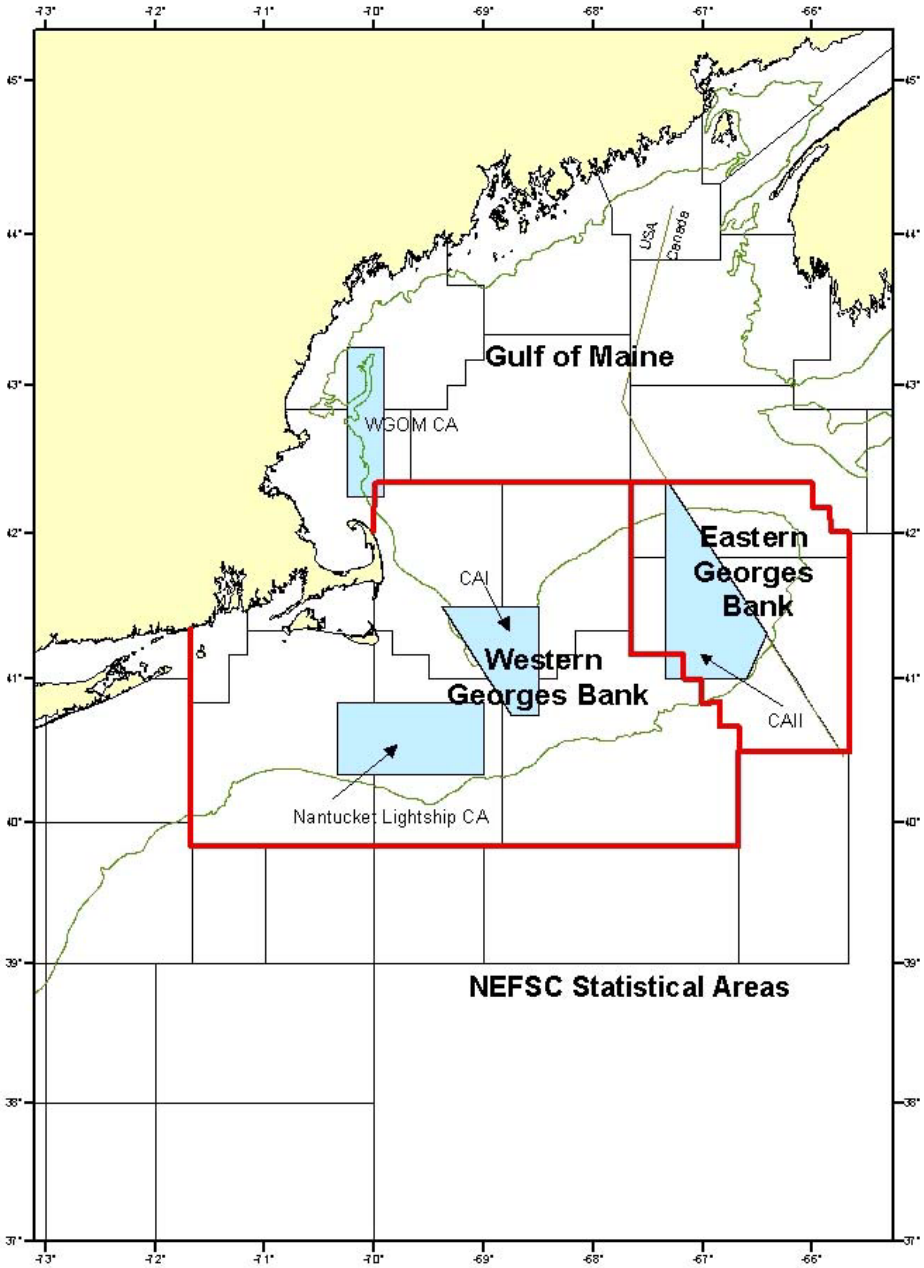


Figure 27. Spatial definition of haddock management units in the Gulf of Maine and Georges Bank region along with locations of the western Gulf of Maine closed area (WGOM CA), Closed Area I (CA I), Closed Area II (CA II), and the Nantucket Lightship closed area (Nantucket Lightship CA).

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NOAA Technical Memorandum NMFS-NE-198

Essential Fish Habitat Source Document:

Bluefish, *Pomatomus saltatrix,* Life History and Habitat Characteristics

Second Edition

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Essential Fish Habitat Source Document:

Bluefish, *Pomatomus saltatrix*, Life History and Habitat Characteristics

Second Edition

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Editorial Notes on "Essential Fish Habitat Source Documents" Issued in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For "Essential Fish Habitat Source Documents" issued in the *NOAA Technical Memorandum NMFS-NE* series, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division largely assume the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production is performed by, and all credit for such production rightfully belongs to, the staff of the Ecosystems Processes Division.

Internet Availability and Information Updating

Each original issue of an "Essential Fish Habitat Source Document" is published both as a paper copy and as a Web posting. The Web posting, which is in "PDF" format, is available at: *http://www.nefsc.noaa.gov/nefsc/habitat/efh*.

Each issue is updated at least every five years. The updated edition will be published as a Web posting only; the replaced edition(s) will be maintained in an online archive for reference purposes.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Nelson *et al*. 2004[a]; Robins *et al.* 1991[b]), mollusks (*i.e.*, Turgeon *et al.* 1998[c]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[d]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[e]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species.

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[a]Nelson, J.S.; Crossman, E.J.; Espinosa-Pérez, H.; Findley, L.T.; Gilbert, C.R.; Lea, R.N.; Williams, J.D. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. 6th ed. *Amer. Fish. Soc. Spec. Publ.* 29; 386 p.

[b]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. World fishes important to North Americans. *Amer. Fish. Soc. Spec. Publ.* 21; 243 p.

[c]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[d]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[e]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

PREFACE TO SECOND EDITION

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NOAA Fisheries to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NOAA Fisheries has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in a series of EFH species reports (plus one consolidated methods report). The EFH species reports are a survey of the important literature as well as original analyses of fishery-independent data sets from NOAA Fisheries and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and understandably are referred to as the "EFH source documents."

NOAA Fisheries provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

The initial series of EFH species source documents were published in 1999 in the *NOAA Technical Memorandum NMFS-NE* series. Updating and review of the EFH components of the councils' Fishery Management Plans is required at least every 5 years by the NOAA Fisheries Guidelines for meeting the Sustainable Fisheries Act/EFH Final Rule. The second editions of these species source documents were written to provide the updated information needed to meet these requirements. The second editions provide new information on life history, geographic distribution, and habitat requirements via recent literature, research, and fishery surveys, and incorporate updated and revised maps and graphs. This second edition of the Bluefish EFH source document is based on the original by Michael P. Fahay, Peter L. Berrien, Donna L. Johnson and Wallace W. Morse, with a foreword by Jeffrey N. Cross (Fahay *et al*. 1999).

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NOAA Fisheries, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

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INTRODUCTION

The bluefish, *Pomatomus saltatrix* (Figure 1), ranges in the western North Atlantic from Nova Scotia and Bermuda to Argentina, but it is rare between southern Florida and northern South America (Robins *et al*. 1986). They travel in schools of like-sized individuals and undertake seasonal migrations, moving into the Middle Atlantic Bight (MAB) during spring and south or farther offshore during fall. Within the MAB they occur in large bays and estuaries as well as across the entire continental shelf. Juvenile stages have been recorded from all estuaries surveyed within the MAB, but eggs and larvae occur in oceanic waters (Able and Fahay 1998). Bluefish growth rates are fast and they may reach a length of 1.1 m (3.5 ft) and a weight of 12.3 kg (27 lbs) (Bigelow and Schroeder 1953). They live to ages 12 and greater (Salerno *et al*. 2001).

A bimodal size distribution of young-of-the-year (YOY) bluefish during the summer in the New York Bight suggests that there are two spawning events along the east coast. Recent studies suggest that spawning is a single, continuous event, but that young are lost from the middle portion resulting in the appearance of a split season. As a result of the bimodal size distribution of juveniles, young are referred to as the *spring-spawned cohort* or *summer-spawned cohort* in the habitat discussion and distribution maps presented below.

LIFE HISTORY

EGGS

Eggs from the MAB are pelagic and spherical with a diameter of 0.95-1.00 mm. They have a smooth, transparent shell and a homogeneous yolk. The single oil globule is 0.26-0.29 mm in diameter and the perivitelline space is narrow (Fahay 1983). Incubation times depend on temperature. At 18.0-22.2^{o}C, hatching occurs after 46-48 h (Deuel *et al.* 1966). Eggs from the South Atlantic Bight (SAB) have not been described.

LARVAE AND PELAGIC-JUVENILES

Larvae are 2.0-2.4 mm long when they hatch; the eyes are unpigmented and the mouth parts are undeveloped. Characteristic pigment includes parallel lines of melanophores along the dorsal fin base, body midline, and anal fin base. Teeth are well developed at 4.3 mm and fin rays are complete at a size of about 13-14 mm (Fahay 1983). Larvae rarely occur deeper in the water column than 15 m; most are concentrated at a depth of about 4 m during the day, but they are about equally distributed between that depth and the surface at night (Kendall and Naplin 1981). The bluefish transforms from a larva to a "pelagic-juvenile" stage that is specially adapted for an oceanic, near-surface existence after completion of fin ray development (Figure 2). This specialized stage is characterized by a silvery, laterally compressed body, with dark blue counter-coloration on the dorsum. This transition occurs at an age of 18-25 d and at a size of 10-12 mm SL (Hare and Cowen 1994). Scales begin to form at about 12 mm on the posterior part of the lateral line region, then proceed forward, until the head is completely scaled at about 37 mm (Silverman 1975). Swimming ability in many fish species dramatically improves during this transformation (e.g. Hunter 1981; Stobutzki and Bellwood 1994; Leis *et al.* 1996) and this improvement presumably applies to bluefish as well. It is during this stage that bluefish arrive at nursery areas in the central part of the MAB, after advection via the Gulf Stream from spawning areas in the SAB and after crossing the Slope Sea (Hare and Cowen 1996; Hare *et al.* 2001) and the continental shelf (Cowen *et al.* 1993). Active larval migration across the shelf is believed to be aided by oceanographic features such as warm-core ring streamers and Gulf-Stream filaments (Hare *et al*. 2001), or Eckman transport (Munch and Conover 2000). This transport (active or passive) is crucial to the recruitment of these progeny to vital estuarine nursery areas, and therefore this life history stage might be considered a critical bottleneck.

JUVENILES (INCLUDING YOUNG-OF-THE-YEAR

Juveniles have a usual fish shape without unusual features. The caudal fin is forked and the body is somewhat laterally compressed, with a silvery, unpatterned color. The mouth is large and oblique and all fin spines are strong. Two distinct dorsal fins touch at their bases; the second dorsal fin is about the same length as the anal fin base (Able and Fahay 1998). The *spring-spawned cohort* is 60-76 d old with a mean size of 60 mm when they recruit to estuarine habitats in the MAB in late May to mid-June (McBride and Conover 1991; Cowen *et al.* 1993). The *summer-spawned cohort* either remains in coastal nursery areas (Kendall and Walford 1979; Able and Fahay 1998; Secor *et al*. 2002; Able *et al*. 2003) or enters estuarine nurseries in mid- to late August when they are 33-47 d old with a mean length of 46 mm (McBride and Conover 1991). Juveniles of both cohorts depart MAB estuaries and coastal areas in October and migrate to waters south of Cape Hatteras, North Carolina. At this time, members of both cohorts range from 4-24 cm long (Able and

Fahay 1998, Able *et al*. 2003). During most years, the *spring-spawned cohort* dominates in the emigrating young-of-the-year, although during the past decade, the summer-spawned cohort was dominant (Conover *et al*. 2003).

ADULTS

Adult bluefish are blue-green above, silvery below, moderately stout-bodied, and armed with stout teeth along both jaws. The snout is pointed and the mouth is large and oblique. The caudal fin is large and forked. The fin ray formulae are first dorsal: 7-9 spines; second dorsal: 1 spine and 23-26 rays; anal: 2-3 spines and 25-28 rays. Vertebrae number 26. The maximum length is about 115 cm and maximum weights are 4.5-6.8 kg, although an occasional heavier fish has been taken. The maximum age is 12 years. The sex ratio is 1:1 for all age groups (Boreman 1982), although Lassiter (1962) reported a ratio of two females per male in North Carolina and Hamer (1959) found a ratio of three females to two males in New Jersey.

REPRODUCTION

A seminal study, based largely on the distribution of eggs and larvae, concluded that there were two discrete spawning events in western Atlantic bluefish. The first occurs during March-May near the edge of the continental shelf of the SAB. The second occurs between June and August in the MAB (Kendall and Walford 1979). Recent studies have re-examined this conclusion and refined our knowledge of a complex reproductive pattern, and support the concept of a single, migratory spawning stock (Hare and Cowen 1993; Smith *et al.* 1994).

Sexual maturity and gonad ripening occur in early spring off Florida, early summer off North Carolina, and late summer off New York (Hare and Cowen 1993). In the New York Bight, gonadosomatic studies indicate that both sexes are ripe or ripening between June and September with a strong peak in July (Chiarella and Conover 1990). Larvae re-occur in the SAB in the fall (Collins and Stender 1987) and there are also indications that gonads reach a second peak in ripeness in fish off Florida in September. Most bluefish are mature by age 2 (Deuel 1964). A recent study using histological methods indicates that bluefish are likely group-synchronous batch spawners (Reiss *et al*. 2002). In South Africa, individuals may spawn repeatedly over a period of 5-6 months (Van der Elst 1976), but there is no comparable information for the U.S. population.

FOOD HABITS

During their oceanic larval stage, bluefish primarily consume copepods. Fish begin to be included in their diet at sizes of 30 mm, and by 40 mm, fish are the major diet item. Soon after this shift in diet, juveniles migrate inshore to occupy estuarine habitats (Marks and Conover 1993).

The results of several studies suggest that bluefish juveniles and adults eat whatever taxa are locally abundant (Table 1). The components of young-of-the-year bluefish diet in Sandy Hook Bay, New Jersey and the effects of those components on condition were studied over a three-year period (Friedland *et al.* 1988). Fish dominated the diet during 1981, while crustaceans and polychaetes were more important during 1983 and 1984. Weight-length relationships indicated that weight at length was significantly greater in 1981 than in the other two years. Thus, not only does the quality of diet differ between estuaries, but the method of foraging may also differ; more benthic foraging was evident in bluefish from Sandy Hook Bay than in bluefish sampled in estuaries in Delaware (Grant 1962) and North Carolina (Lassiter 1962). In the Chesapeake Bay, oyster bar and reef habitats provide an important source of benthic prey, particularly during time periods when preferred small pelagic fish prey are less abundant (Harding and Mann 2001). Depending on age class, diets might change through a season. Spring spawned young-of-the-year prey on invertebrates such as small and shrimp in early summer when the preferred fish prey are less available (Juanes *et al*. 2001). In Chesapeake Bay, diets of three age classes differed through the summer (Table 1), but all three concentrated on *Brevoortia tyrannus* in the fall (Hartman and Brandt 1995a, b).

In ocean habitats, young-of-the-year bluefish switch to piscivory with increasing size, similar to estuarine habitats. By 80-100 mm FL bay anchovy become the primary fish prey along ocean beaches in New Jersey (Able *et al*. 2003). Similar dietary patterns have been observed in juvenile bluefish utilizing ocean habitat in coastal Maryland (Secor *et al*. 2002) and throughout the MAB (Table 1). During offshore residence as larger adults, bluefish target larger schooling species of prey such as squids, clupeids and butterfish (Table 1) (Buckel *et al*. 1999).

PREDATION

Sharks, tunas, and billfishes are the only predators large and fast enough to prey on adult bluefish. They are a major component in the diet of shortfin mako shark, composing 77.5% of the diet by volume (Stillwell and Kohler 1982; Wood 2002). Stillwell and

Kohler (1982) estimated that this shark may consume between 4.3 and 14.5% of the bluefish resource between Georges Bank and Cape Hatteras. Bluefish also ranked fourth in number and occurrence and third in volume in swordfish diets, especially off the Carolinas (Stillwell and Kohler 1985). A study of bluefin tuna diet in New England ranked bluefish as one of the top prey items (Chase 2002). Blue sharks and sandbar sharks also prey on bluefish (Kohler 1988; Medved *et al.* 1985). Young-of-the-year are preyed upon by four oceanic bird species, the Atlantic puffin, Arctic tern, common tern, and roseate tern (Creaser and Perkins 1994; Safina *et al.* 1990). Cannibalism has only rarely been reported, but occurs in age 1 and older year classes in North Carolina (Lassiter 1962), and bluefish compose a minor component of the diet of larger bluefish collected during Northeast Fisheries Science Center (NEFSC) bottom trawl surveys on the continental shelf from the Gulf of Maine to Cape Hatteras [NEFSC food habits database; see Link and Almeida (2000) for details on methodology].

MIGRATIONS

Bluefish are warm water migrants and do not occur in MAB waters at temperatures < 14-16°C (Bigelow and Schroeder 1953). They generally move north in spring-summer to centers of abundance in the New York Bight and southern New England and south in autumn-winter to the waters in the SAB as far as southeastern Florida. There is a trend for larger individuals to occur farther north during the summer (Wilk 1977). Larger adults may limit their southward migration and spend the winter on the outer part of the continental shelf of the MAB, culminating in an aggregation of fish near Cape Hatteras, NC by March. This winter distribution is suggested by the occurrence of bluefish in commercial catches as reported in vessel logbooks (Shepherd *et al*., in press). This conclusion is also supported by historical anecdotal evidence. One report witnessed a single fish landed from about 100 m deep off Martha's Vineyard during mid-January 1950 and several hauls of 80-640 kg from the vicinity of Hudson Canyon during early February of the same year (Bigelow and Schroeder 1953). Another study simply reported "boats engaged in the winter trawl fishery for fluke and scup along the outer margin of the continental shelf often bring in a few bluefish" (Hamer 1959). These reports have been perpetuated since (Lund 1961; Miller 1969; Lund and Maltezos 1970; Hardy 1978). Recent winter trawl surveys indicate the presence of bluefish in the MAB during winter near the shelf edge off Cape Hatteras (see Geographical Distribution).

STOCK STRUCTURE

The bluefish is presently managed as a single stock (MAFMC 1997). Although there is evidence of separate spawning events (see Reproduction), fish from these spawning groups mix extensively during their lives, and recent conclusions have ascertained that bluefish year classes are composed of seasonal cohorts (Chiarella and Conover 1990). Recent studies have re-examined this conclusion and refined our knowledge of a complex reproductive pattern, supporting the concept of a single, migratory spawning stock (Hare and Cowen 1993; Smith *et al.* 1994). A mitochondrial DNA study of *spring*- and *summer-spawned* bluefish also concluded that bluefish along the east coast of the United States comprise a single genetic stock (Graves *et al.* 1992).

GEOGRAPHICAL DISTRIBUTION

EGGS

Spring-spawned cohort: The spring spawning occurs near the edge of the continental shelf in the SAB. However, bluefish eggs have not been collected or identified from this region.

Summer-spawned cohort: Eggs were collected from May to August over the MAB continental shelf during the NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) program surveys [see Reid *et al*. (1999) for methods]. Bluefish eggs were most abundant in July (Figure 3). Eggs were distributed near Cape Hatteras in May and their occurrences expanded rapidly northward during the summer. In July, eggs were distributed as far as southern New England waters with a center of abundance off Delaware Bay and New Jersey (Berrien and Sibunka 1999). Eggs were not collected after August. Bluefish eggs do not occur in estuarine waters. During the NEFSC MARMAP surveys, eggs occurred across the entire shelf, but were most concentrated in mid-shelf depths (Berrien and Sibunka 1999). Eggs in the southern part of the MAB may be advected south and offshore; most (80%) eggs collected in a study off the Chesapeake Bay mouth were > 55 km from shore, with peak spawning occurring in the evening (Norcross *et al.* 1974).

LARVAE

The distribution of all larvae collected in the MAB and SAB is shown in Figure 4. There has been a critical

lack of sampling in the area immediately south of Cape Hatteras.

Spring-spawned cohort: Our understanding of the distribution of larvae in the SAB (corresponding to the *spring-spawned cohort*) is limited. The NEFSC MARMAP ichthyoplankton program sampled there from 1973-1980; bluefish larvae generally were collected in low densities, both in water column sampling with bongo nets (Figure 5) or Isaacs-Kidd midwater trawls (Table 2), and at the surface with two types of neuston net (Figure 6). Most larvae occurred near the 200 m depth contour, placing them close to the Gulf Stream and presumably enhancing their chances of advection to the north as proposed by Kendall and Walford (1979), Powles (1981), and Hare and Cowen (1993, 1996). The collection of bluefish eggs in April and May is consistent with back-calculated birth dates determined from estuarine recruits in the New York Bight (NYB) (see Juveniles). The densest concentrations of larvae in NEFSC MARMAP cruises in the SAB occurred over the outer half of the continental shelf during April and May. Currents there flow toward the northeast and are affected by the Gulf Stream (Lee and Atkinson 1983), while on the inner shelf, wind-driven currents are important in affecting the drift of larvae (Powles 1981; Lee and Atkinson 1983). A secondary concentration of larvae was detected during late summer/early fall of one year (1976) and may indicate the existence of an isolated spawning event (Figure 5). During 1979, all sampling was done by Isaacs-Kidd midwater trawl and was restricted to the shelf area near Charleston, South Carolina between February and August (Table 2). Larvae were collected with this gear in low densities between February and mid-May; two tows in April yielded somewhat higher densities.

Summer-spawned cohort: The distribution of larvae in the MAB is similar to that of the eggs (Figure 7). Larvae < 11 mm (the size when they become pelagic-juveniles) first occurred near Cape Hatteras and along the shelf edge in the Wilmington Canyon area during May, and were present through the summer in increasing numbers throughout the southern and central parts of the MAB. Although larvae are only rarely collected in estuarine waters, they have been reported from a few large systems in the MAB; e.g., one larva, one occurrence in Narragansett Bay (Herman 1963) and several estuaries in New York/New Jersey (Table 3). During June, peak larval abundance occured between Cape Hatteras and Chesapeake Bay and off New Jersey. Larvae are most dense in the central part of the MAB in July and remain dense during August. Few larvae occurred in the MAB during September. Larvae rarely occurred deeper in the water column than 15 m and most are concentrated at a depth of about 4 m during the day, but are about equally distributed between that depth and the surface at night. Neuston sampling, therefore, is likely to drastically undersample bluefish when done during the day.

PELAGIC-JUVENILES (LARVAL TO JUVENILE TRANSITION)

There are no available data that adequately describe the distribution of this transformation stage in bluefish life history; however, limited observations have been made in the NYB (Shima 1989; Hare and Cowen 1996). These observations support the view that temperatures below 13-15°C impede the progress of this stage into MAB estuaries. In early June, these pelagic-juveniles mass at the shelf-slope temperature front, and resume their inshore migration when that front dissipates (Hare and Cowen 1996). Transport of larvae and/or juveniles across the shelf-slope region may be aided by wind-driven surface flow (Munch and Conover 2000).

JUVENILES

It is presently unknown if bluefish are "estuarine dependant" since the distribution of juveniles over the continental shelf has not been described. The distribution and relative abundance of juveniles has been documented for estuaries along the east coast of the United States (Table 3) and for estuaries in Maine (Table 4). In addition to estuaries, juvenile bluefish in the MAB utilize coastal oceanic habitats (Secor *et al*. 2002; Able *et al*. 2003).

A survey of juvenile bluefish published in the early 1970s (Clark 1973) noted that their distribution differed from historical observations (Figure 8). Bluefish were not observed south of Daytona Beach through the 1970s, although juveniles were reported from estuaries as far south as Palm Beach, Florida in the early part of the century (Evermann and Bean 1898; Nichols 1913). This author also suggested that the apparent high densities of juveniles in certain regions (e.g., New Jersey and South Carolina) were due to greater sampling effort. Remaining enigmatic occurrences include those in the freshwaters of the upper Chesapeake Bay (Mansueti 1955; Lund 1961), although the Chesapeake and Delaware Canal may play a role in their presence there.

Several young-of-the-year surveys (or surveys that adequately sample young stages) are conducted within MAB states (Figure 9). Several caveats pertaining to these results prevent these state data from being compared directly. Some surveys are conducted throughout the year, while others are limited in their seasonal extent, and the resultant densities are therefore unequal. Although most results are expressed as "number per tow," tow lengths and gear characteristics vary between states, thus making comparisons among state surveys difficult. Finally, the definition of "juvenile" can vary between states; in some cases, it is

based solely on length frequency distributions, in some cases it is based on an arbitrary length cutoff. In most states, all fish < 30 cm are considered juveniles, although in the Chesapeake Bay region, some of these could be age 1+ if they were collected early in the year (Munch 1997).

Despite these caveats, certain trends are evident in the data. There are signs of strong year classes in each state data set, but these do not necessarily match temporally. In general, abundances are greater in states between Rhode Island and New Jersey, and considerably lower in states in the southern part of the MAB, further emphasizing the importance of the former.

The distributions and abundances of juveniles in Massachusetts coastal waters, based upon the fall 1978-2003 Massachusetts inshore trawl surveys, are shown in Figure 10 (none were found during the spring surveys). They were abundant south of Cape Cod, especially in Buzzards Bay.

The seasonal distributions and abundances of juveniles (< 35 cm) in Narragansett Bay, based upon the 1990-1996 Rhode Island bottom trawl surveys, are shown in Figures 11 and 12. Juveniles were collected in summer and autumn.

The distributions and abundances of both juvenile and adult bluefish in Long Island Sound from April to November 1984-1994, based on the Connecticut Fisheries Division bottom trawl surveys, are shown in Figures 13–19. The following description of bluefish distribution and abundance in Long Island Sound comes from Gottschall *et al*. (2000).

Bluefish first appeared in the survey in May (7% occurrence), but were relatively rare until June when the occurred in 28% of samples (Figure 13D) and were taken throughout the Sound (Figure 14). Bluefish taken in May ranged from 40-76 cm, whereas in June they ranged from 24-78 cm (Figure 15) (Gottschall *et al*. 2000).

Juveniles first appeared in the survey in July. They comprised 46% of the bluefish catch, but only appeared in 8.3% of samples (Figure 16D). Juvenile abundance increased quickly during summer – by August they comprised 94% of the catch and occurred in 63.1% of samples. During the summer period juveniles were primarily distributed on the Connecticut side of the Sound from New Haven to Norwalk (Figure 17), whereas adults appeared to be more abundant in the deeper portions of the Central and Western Basins (Figure 18 and 19C) (Gottschall *et al*. 2000). When abundance peaked in September (Figure 13A), bluefish were found throughout the Sound (93.3% occurrence), although about 93% of the bluefish taken were juveniles. While juvenile abundance decreased rapidly after September (Figure 19A), adult abundance increased to a peak in October before declining (Figure 19A). By November, juveniles only comprised 60% of the bluefish catch, down from a high of 94% in September. The remaining bluefish in November were distributed throughout the Sound (Figure 14) (Gottschall *et al*. 2000).

Most bluefish collected during surveys of the Hudson-Raritan estuary (1992-1997) were juveniles (Figure 20). There were no occurrences during winter, while in summer and fall, juveniles occurred throughout the area. The largest collections were made near navigation channels or in a basin near Graves End Bay.

The New Jersey Department of Environmental Protection assessment survey samples coastal New Jersey inside state waters. Bottom trawling is conducted five times per year and bluefish are encountered primarily in August and October. The fish collected are juveniles and appear as two distinct length modes, presumably the result of the spring and summer cohorts.

The Virginia Institute of Marine Science (VIMS) trawl surveys from 1988-1999 of Chesapeake Bay and its tributaries captured almost exclusively juveniles (Geer 2002). They were caught from May to November, with an increase in catch during October and November as juveniles began to migrate out of the Bay (Figure 21). Catches were concentrated in the main-stem of the Bay with some catches up the tributaries to near the freshwater interface (Figure 22). There was a clear southward movement towards the Bay mouth during the fall months (Figure 22) (Geer 2002).

The VIMS 1994-1999 beach seine surveys of Chesapeake Bay captured only juveniles during every month of sampling (May to October), with June and September being the peak months (Figure 23). Juveniles were captured throughout the brackish range of the survey, with highest catches occurring at the seaside sites and Bay mouth (Figure 24) (Brooks and Geer 2001; Geer 2002).

The Southeast Area Monitoring and Assessment Program (SEAMAP) surveys sampled the coastal region between Cape Hatteras, North Carolina and Cape Canaveral, Florida [see Reid *et al.* (1999) for details]. After an initial several years when gear and methods were not standardized, methodology became synoptic and standardized between 1990 and 1996 (Beatty and Boylan 1997; Boylan *et al.* 1998). Bluefish collected during the latter survey period are shown in Figure 25. Length frequencies of these collections indicate most were young-of-the-year or age 1 (Figure 26). Information on distributions over the offshore portions of the SAB shelf are lacking for any size class. Monthly occurrences of these bluefish are shown in Figure 27. Occurrences decreased during spring, were at low levels during summer, and increased during October beginning in the northern part of the bight, which suggests an influx of migrating young-of-the-year from the MAB.

ADULTS

The distributions and abundances of adults in Massachusetts coastal waters, based upon the spring and fall 1978-2003 Massachusetts inshore trawl surveys, are shown in Figure 28. During spring, a few adults were found south of Cape Cod in the vicinity of Nantucket and Vineyard sounds and in Buzzards Bay. They were slightly more abundant in the fall; a few were also found in Cape Cod Bay.

Adults were rarely collected during summer and autumn in a survey of Narragansett Bay (Figures 29 and 12).

The distribution and abundance of both adults and juveniles in Long Island Sound were discussed previously (Gottschall *et al*. 2000).

Very few adults were collected in the Hudson-Raritan estuary and Sandy Hook Bay. There were no occurrences during winter and only a few adults were collected during spring and summer (Figure 30).

JUVENILES AND ADULTS

Bluefish are migratory and their distribution varies seasonally and according to age and size of individuals composing schools. Length frequencies of trawl-collected bluefish were examined to determine age and size composition of catches in the NEFSC bottom trawl surveys (Figure 31). Modes were separable into spawning cohorts and year classes based on published studies and are the bases for the NEFSC distribution and abundance maps.

The distribution of all lengths during all seasons of the NEFSC surveys indicates that bluefish occurred most densely along the coast of the MAB and through the central part of Georges Bank, although these results may reflect the increased efficiency of the trawl in shallower waters. Winter occurrences during the NEFSC surveys were limited to the outer continental shelf near Cape Hatteras and these few occurrences were larger fish [Figure 32; note that winter and summer distributions are presented as presence data only, precluding a discussion of abundances, see Reid *et al.* (1999) for details]). NEFSC spring collections included *spring-spawned* young-of-the-year off North Carolina, *spring-spawned* age 1 restricted to coastal areas south of Cape Hatteras, age 2 individuals along the continental shelf edge off North Carolina, and older year classes distributed between Cape Hatteras and the Delmarva Peninsula (Figure 33). Figure 34 shows the NEFSC spring distributions and abundances separated into juvenile (< 30 cm) and adult (≥ 30 cm) size classes.

In summer, juveniles were widely distributed along the coast from New York to Cape Hatteras. Adults were less concentrated along the Mid-Atlantic coast, occurring mostly along Long Island, offshore south of Cape Cod, and on Georges Bank (Figure 35). NEFSC fall surveys are most important for measuring relative year-class strength. Young-of-the-year of both *spring-* and *summer-spawned cohorts* and age 1 individuals were abundant along the coast between Long Island and Cape Hatteras. Older year-classes were also found offshore in southern New England and on Georges Bank (Figure 36). Figure 37 shows the fall distributions and abundances separated into juvenile and adult size classes.

HABITAT CHARACTERISTICS

The habitat characteristics for eggs, larvae, pelagic-juveniles, juveniles, and adults based on results of this compendium and pertinent published reports are presented in Table 5. Included are observations of habitat use by young-of-the-year in estuaries. When studies of juvenile abundance have been related to environmental variables, such as eelgrass presence/absence or a substrate type, they have usually been conducted with seines where catch-per-unit-of-effort is difficult to establish. Comparing the results of these studies between locations is usually not possible, and further details of essential habitats are therefore not yet available. Appendix 1 contains more complete data from various studies reported in the literature.

EGGS

Bluefish eggs were collected at near-surface temperatures ranging from about 8-26°C during the NEFSC MARMAP surveys in the months from May to August (Figure 38). During May, 100% of the eggs were found at 22°C, while in June they were found from 13-22°C, with the majority at 13 and 17°C. In July, most were caught over a range of 14-26°C, while in August the majority of eggs were found at 22°C. Their depth range during those months was confined mostly from 30-70 m, with the majority at 30 m.

LARVAE AND PELAGIC JUVENILES

Larvae in the MAB occur in open oceanic waters, near the edge of the continental shelf in the southern Bight and over mid-shelf depths farther north (Norcross *et al.* 1974; Kendall and Walford 1979). They migrate vertically in the water column, occurring near the surface at night, but centered at about 4 m during daylight (Kendall and Naplin 1981). Larvae spawned in

the SAB (*spring-spawned cohort*) are subject to advection north via the Gulf Stream (Hare and Cowen 1996; Kendall and Walford 1979), but some recruit successfully to estuaries in the SAB (Collins and Stender 1987; McBride *et al.* 1993).

During NEFSC MARMAP sampling from May to September, most larvae were collected at surface temperatures between 17-26°C and were concentrated over water depths of about 30-70 m (Figure 39).

The transport of pelagic-juveniles was outlined by Kendall and Walford (1979) and elaborated by Hare and Cowen (1996). Many are found in the vicinity of Cape Hatteras as early as April. In May, several have been collected on the shelf in the SAB (Fahay 1975; Kendall and Walford 1979). By June, they occur in the MAB between the shore and the shelf/slope front, actively crossing the shelf (Hare and Cowen 1996). In both the SAB and MAB, there is a strong negative correlation between fish size and depth indicating an offshore origin and onshore migration with growth. Transport of larvae and/or juveniles across the shelf-slope region may be aided by wind-driven surface flow (Munch and Conover 2000).

Limited observations on pelagic-juveniles by Shima (1989) and Hare and Cowen (1996) have been made in the New York Bight. These observations support the view that temperatures below 13-15°C impede the progress of this stage into MAB estuaries. In early June, these pelagic-juveniles mass at the shelf-slope temperature front, and resume their inshore migration when that front dissipates (Hare and Cowen 1996).

JUVENILES (INCLUDING YOUNG-OF-THE-YEAR)

Juveniles occur in estuaries, bays, and the coastal ocean of the MAB and SAB, where they are less common. They occur in many habitats, but do not use the marsh surface. The range of physical and structural conditions in which they are found is summarized in Table 5. Juveniles begin to depart MAB estuaries in October and migrate south to spend the winter months south of Cape Hatteras.

The spring and fall distributions of juvenile bluefish (< 30 cm) relative to bottom water temperature, depth, and salinity based on 1963-2003 NEFSC bottom trawl surveys from the Gulf of Maine to Cape Hatteras are shown in Figure 40. In the spring, they were found over a temperature range of 8-23°C, with most spread between about 10-19°C. They were found at shallow depths ranging from 1-40 m, with the majority at 1-30 m. Their salinity range was between 33-36 ppt, with a peak in occurrence and catch at 33 ppt. In the fall, the juveniles were spread over a temperature range of 10-28°C, with most between about 17-25°C. They were also found at shallow depths of 1-50 m, with > 60% found at 11-20 m. Their salinity range was between 29-35 ppt, with the majority at 31-32 ppt.

The autumn distributions of juvenile bluefish in Massachusetts coastal waters relative to bottom water temperature and depth based on 1978-2003 Massachusetts inshore trawl surveys are shown in Figure 41. Juveniles were collected at temperatures ranging from about 9-22°C, with the majority between 16-21°C. They were found over depths of 6-45 m, with most at 6-15 m.

The seasonal distributions of juvenile bluefish relative to bottom water temperature and depth based on 1990-1996 Rhode Island Narragansett Bay trawl surveys are shown in Figure 42. The few juveniles that were caught were found in waters from 19-25ºC in summer and 17-23ºC in autumn. The majority were found at 22ºC in summer and 19ºC in the autumn. In summer their depth range was from 10-70 ft (3-21 m) and in the autumn it was from about 20-110 ft (6-34 m). Most were caught at 20-30 (6-9 m) in summer and 20-50 ft (6-15 m) in the autumn.

The distributions and abundances of juveniles in Long Island Sound relative to depth and bottom type, based on the Connecticut Fisheries Division bottom trawl surveys (Gottschall *et al*. 2000), are shown in Figures 13, 16, and 19. Juvenile abundance was highest in depths between 9-27 m over mud bottom in several broad areas in the Sound: the Connecticut side from New Haven to Mattituck. Adult abundance was also high in some these areas, but in contrast with juveniles, abundance tended to generally increase with depth in September, and in October abundance was similar in depths > 9 m (Figure 19C) (Gottschall *et al*. 2000).

The distributions of juvenile bluefish relative to bottom water temperature, dissolved oxygen, depth, and salinity based on 1992-1997 NEFSC Hudson-Raritan estuary trawl surveys are shown in Figure 43. Over the entire survey, juveniles were found in waters ranging from 12-24ºC, with a peak catch of 45%at 21ºC. They were found in dissolved oxygen levels of 5-9 mg/l, with 50% of the catch at 6 mg/l. They were found over a depth range of 15-65 ft (5-20 m), with over 40% found at 20 ft (6 m) and at about 30% found at 40-45 ft (12-14 m). Juveniles were found in salinities ranging from 19-32 ppt, with peaks at 20, 24-26, and at 29 ppt.

The hydrographic preferences of bluefish (almost exclusively juveniles) in Chesapeake Bay and tributaries from the 1988-1999 VIMS trawl surveys are shown in Figure 44 (all years and months combined). According to Brooks and Geer (2001) and Geer (2002), bluefish prefer salinities > 16 ppt and depths between 8-10 m. There appears to be two peaks associated with water temperature, one between 14-18ºC, and the second at 22-26ºC. Most were found where dissolved oxygen levels were 6-9 mg/l. The hydrographic preferences of juveniles caught in the 1994-1999 seine surveys are shown in Figure 45 (all years and months

combined) (Geer 2002). Although captured throughout the sampling range, nearly 90% occur in waters > 18 ppt. Dissolved oxygen is rarely a problem in shallow waters of the Bay (Geer 2002), but the juveniles occurred more at dissolved oxygen levels of 6-8 mg/l. Most juveniles occur at temperatures > 20ºC, with the majority between 24-26ºC. The majority were found at a pH of 8.2.

ADULTS

Adult bluefish occur in the open ocean, large embayments, and most estuarine systems within their range. Although they occur in a wide range of hydrographic conditions, they prefer warmer temperatures and are not found in the MAB when temperatures decline below 14-16°C. See Table 5 for a summary of habitat requirements of adult bluefish.

The spring and fall distributions of adult bluefish relative to bottom water temperature, depth, and salinity based on NEFSC bottom trawl surveys are shown in Figure 46. In the spring, they were found over a temperature range of 8-20°C, with most spread between about 9-16°C. They were found at much deeper depths than the juveniles; they were spread over a depth range of 1-400 m. Their salinity range was between 33-36 ppt, with the majority at 35 ppt. In the fall, the adults were spread over a temperature range of 8-28°C, with most spread between about 14-24°C. They were also found at shallower depths than in the spring: 1-100 m, with most found at 11-30 m. Their salinity range was between 29-35 ppt, with the majority at 31-32 ppt.

The spring and autumn distributions of adults in Massachusetts coastal waters relative to bottom water temperature and depth are shown in Figure 47. The few that were caught in the spring were found in a temperature range of 10-14°C, with a depth range of 6-25 m. In the fall, their temperature range was from 10-22°C, with most between 17-20°C. Their depth range during that season was from about 6-40 m, with the majority at 6-15 m.

The distributions of the few adults found during summer and fall in Narragansett Bay relative to bottom water temperature and depth are shown in Figure 48. They were collected in bottom water temperatures of 15-26°C during summer and 17-21°C in autumn, and depths of 10-70 ft (3-21 m) in summer and 10-110 ft (3-34 m) in autumn.

RESEARCH NEEDS

LIFE HISTORY AND BIOLOGY

We lack information on the reproductive biology of bluefish. Observed patterns of spawning may be based on the population level rather than on information on individual reproductive traits. We presently do not know whether individuals spawn serially, and if so, how many times they are capable of spawning in a year. We also do not know if these reproductive characteristics vary with age. It is apparent that more study of the distribution of older stages needs to be correlated with spawning events. Since bluefish school in like-sized (and supposedly like-aged) groups, we need to know what groups are where and when, and how those aggregations are associated with the observed densities of eggs. Simply describing how many spawning events are occurring can not solve the issue of the number of manageable stocks.

Our understanding of the "pelagic-juvenile" stage is limited despite its obvious importance. We need to better understand the details of transport mechanisms that provide progeny of reproduction in the SAB to nurseries in the MAB. Increased sampling of the neuston or near-surface layers of the ocean between production areas and estuarine nursery areas, associated with appropriate oceanographic observations, would provide much-needed insight into factors affecting transport and estuarine recruitment.

There has been a tight correlation between population size and the contribution of the *spring-spawned cohort* to fall trawl collections in the last three decades. Yet our knowledge of reproduction in the SAB is limited to a brief, under-sampled period in the 1970s when the population was at a relatively low level of abundance. Furthermore, larvae produced in June in the southern part of the MAB appear not to survive [unless recruits to Maine estuaries result from this output, see Creaser and Perkins (1994)], the fate of the remaining MAB summer offspring remains enigmatic.

There is some evidence for spawning during the fall in the Cape Canaveral region of Florida that appears to be discrete, rather than a continuation of spawning in the MAB. This evidence has been demonstrated in this document with larval occurrences and a disjunct autumn distribution of fish between 26 and 40 cm. Hare and Cowen (1993) present gonadosomatic data that suggest the same thing. Admittedly, some of this evidence is weak and based on incomplete sampling, and should be improved to determine the origin of these spawning fish, the magnitude of spawning, and the fate of any progeny.

HABITAT REQUIREMENTS

It is obvious from a review of the literature that we lack data to address the habitat issue at EFH information Level 3 (i.e.; data on habitat-related growth, reproduction, and/or survival by life history stage, as defined in the EFH Technical Manual [NMFS/OHC 1998] and Final Rule to implement the EFH policy [Department of Commerce, National Oceanic and Atmospheric Administration 2002]). Assessing how characteristics of habitat might affect the quality of young-of-the-year is therefore not feasible. Results of biological sampling, in estuaries or continental shelf waters, only rarely report specific characteristics of sampling sites. Therefore, data accruing from these studies are likely to be limited to EFH information Level 1; i.e., "presence/absence" data only (as defined in NMFS/OHC [1998] and Department of Commerce, National Oceanic and Atmospheric Administration [2002]). According to Miller (1984): "We need a reasonable schema of estuaries, emphasizing the factors that have the most significance to the fish. Unfortunately, the necessary physical data are often lacking for an accurate characterization. Many are also temporally unstable. Not even our attempts to classify estuaries recognize their dynamic nature…we need more complete descriptions of how biologically relevant abiotic factors within estuaries affect biologically relevant scales of time and space. Without this, we cannot hope to untangle the biological processes or to compare results from different estuaries. Biologists need to involve more physical oceanographers and meteorologists in our research." Clearly, in the future, more attention needs to be paid to the details of collecting sites, and habitat research supported, such that the linkages between habitat quality and year class success can be made.

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Table 1. Dietary items of bluefish from several study areas.

Source	**Life History Stage and Study Location**	**Diet Items (in order of importance)**
Texas Instruments Incorporated (1976)	Young-of-the-year, Hudson River (tidal)	*Anchoa mitchilli* (dominated diet through summer), Clupeidae, *Microgadus tomcod, Alosa sapidissima, Notropis hudsonius*, Cyprinodontidae
Festa (1979)	11-20 cm, Little Egg Harbor estuary, NJ	*Fundulus* spp., Atherinidae, *Anchoa* spp., *Callinectes sapidus, Brevoortia tyrannus, Crangon septemspinosa*
Friedland *et al.* (1988)	Juvenile, Sandy Hook, NJ	1981: Teleosts, Crustacea, Polychaeta 1982: Crustacea, Teleostei, Polychaeta 1983: Crustacea, Teleostei, Polychaeta (weight at length significantly greater in 1981)
Hartman and Brandt (1995a, b)	Age 0, Age 1, and Age 2, Chesapeake Bay (Diets of all age classes changed through season)	Age 0: *Anchoa mitchilli, Menidia menidia, Brevoortia tyrannus* Age 1: *Leiostomus xanthurus, A. mitchilli, M. menidia, B. tyrannus* Age 2: *Micropogonias undulatus, A. mitchilli, B. tyrannus* (*B. tyrannus* becomes important in diets of all age classes in Sep-Oct.)
Buckel and Conover (1997)	Young-of-the-year, Hudson River estuary	Unidentified fish, *Anchoa mitchilli, Alosa* spp., *Morone saxatilis, Morone americana*
Buckel *et al*. (1999)	Young-of-the-year, Hudson River estuary	*Morone saxatilis*, *Anchoa mitchilli, Menidia menidia, Alosa* spp.
Buckel *et al*. (1999)	Georges Bank and Middle Atlantic Bight continental shelf, Young-of-the-year Adult	1994-1995 Bay anchovy, squid, butterfish, striped anchovy, round herring Squid, butterfish, and clupeids.

Table 1. Continued.

Source	**Life History Stage and Study Location**	**Diet Items (in order of importance)**
Juanes *et al*. (2001)	Young-of-the-year, Great South Bay, NY	Sand shrimp, YOY *Menidia spp*., unidentified fish, menhaden, sand worms
Harding and Mann (2001)	20 – 40 cm Chesapeake Bay	Other fish, polychaete worms, clupeids, unidentified fish, crustacea.
Buckel and McKown (2002)	New York Bight embayments (western Long Island and Staten Island) Young-of-the-year	*Menidia menidia*, *Anchoa mitchelli,* unidentified fish, sand shrimp, mysids, amphipods, polychaete worms, other invertebrates
Able *et al*. (2003)	Coastal NJ, ocean beaches Young-of-the-year	*Anchoa spp.,* unidentified fish, decapods*, Menidia spp.,* copepods, amphipods
NEFSC food habits database [sampling conducted during seasonal surveys on the continental shelf from the Gulf of Maine to Cape Hatteras from 1973 to the present; see Link and Almeida (2000) for methodology]	All ages (mean size 35.6 mm FL), continental shelf, Georges Bank and Middle Atlantic Bight Small (≤ 30 cm FL) Medium (>30 cm to ≤ 70 cm FL) Large (> 70 cm FL)	1973-1980: Unidentified fish, *Illex* spp., *Etrumeus teres, Loligo* spp., *Peprilus triacanthus*, Cephalopoda 1981-2003: *Anchoa spp*., Unidentified fish, *Peprilus triacanthus,* A*mmodytes dubius, Loligo* spp., *Clupea harengus* 1981-2003: *Clupea harengus,* Unidentified fish, squids, *Peprilus triacanthus, Anchoa spp*., 1981-2003: Unidentified fish, squids, *Clupea harengus,* gadids, *Ammodytes spp., Anchoa spp*., flatfish, sculpins, butterfish

Table 2. Sampling in 1979 ("Southern MARMAP") for bluefish larvae in the Charleston Bump area (32°37' N - 32°80' N x 78°42' W - 79°00' W). Isaacs Kidd MWT only.

Date	Sampling Depth	Sampling	Volume Sampled	Bluefish No./10m^2
February 9	15	5	308	
“	37	27	641	
“	84	33	816	
February 28	31	26	693	0.89
“	54	25	1085	
“	110	35	1052	
March 13	30	22	580	
“	74	29	995	
March 17	114	38	1258	0.91
March 18	28	20	700	
March 27	18	20	742	1.16
“	58	27	1002	0.78
“	98	34	1261	
March 28	30	26	965	
April 6	32	25	875	0.71
“	62	25	875	41.48
“	132	40	1400	0.38
April 18	27	20	700	
“	38	21	735	2.22
“	128	33	1155	
April 19	42	22	770	1.45
April 30	28	22	770	36.99
May 1	76	27	945	21.16
“	134	38	1330	
“	50	25	875	3.97
May 16	34	22	770	2.65
“	58	25	875	9.55
“	130	35	1225	0.36
June 5	28	22	770	
“	58	31	1085	
June 30	37	26	910	
July 1	58	29	1015	
“	124	47	1645	
August 12	42	24	890	
August 13	127	31	1150	
“	50	22	816	
“	22	20	742	

Table 3. Distribution of early life history stages of bluefish, *Pomatomus saltatrix*, in estuaries from Maine to Florida. Occurrences are not quantitative and may be based on one or very few specimens. Estimates of relative abundance after Nelson and Monaco (1994), Jury *et al*. (1994), and Stone *et al*. (1994). Some Middle Atlantic Bight estuaries after Able and Fahay (1998).

Estuary	**Eggs**	**Larvae**	**Juveniles**
Passamaquoddy Bay, ME	None	None	Rare
Englishman/Machias Bay, ME	None	None	Rare
Narraguagus Bay, ME	None	None	Rare
Blue Hill Bay, ME	None	None	Rare
Penobscot Bay, ME	None	None	Common
Muscongus Bay, ME	None	None	Common
Damariscotta River, ME	None	None	Common
Sheepscot River, ME	None	None	Common
Kennebec/Androscoggin Rivers, ME	None	None	Common
Casco Bay, ME	None	None	Common
Saco Bay, ME	None	None	Common
Wells Harbor, ME	None	None	Common
Great Bay, ME/NH	None	None	Common
Merrimack River, NH	None	None	Rare
Massachusetts Bay, MA	None	None	Common
Boston Harbor, MA	None	None	Common
Cape Cod Bay, MA	None	None	Common
Nauset Marsh, MA	None	None	None
Buzzards Bay, MA	None	Rare	Abundant
Narragansett Bay, RI	None	Rare/common	Abundant
Connecticut River, CT	None	None	Abundant
Long Island Sound, NY	None	None	Abundant
Gardiners Bay, NY	Rare	Rare	Abundant
Great South Bay, NY	None	None	Abundant
Hudson River, Raritan/Sandy Hook Bays, NY/NJ	Rare	Rare	Abundant
Barnegat Bay, NJ	None	Rare	Abundant
Great Bay, NJ	None	Rare	Common
Southern Inland bays, NJ	None	Rare	Abundant
Delaware Bay, NJ/DE	None	rare	Abundant
Delaware Inland bays, DE	None	None	Common
Eastern Shore, MD/VA	None	Rare	Common
Chesapeake Bay mainstem, MD/VA	None	None	Abundant
Chester River, MD	None	None	Common
Choptank River, MD	None	None	Common

Table 3. Continued.

Estuary	**Eggs**	**Larvae**	**Juveniles**
Patuxent River, MD	None	None	Common
Potomac River, MD/VA	None	None	Abundant
Tangier/Pocomoke Sound, VA	None	None	Abundant
Rappahannock River, VA	None	None	Abundant
York River, VA	None	None	Abundant
James River, VA	None	None	Abundant
Albemarle Sound, NC	None	None	Common
Pamlico Sound, NC	None	None	Abundant
Pungo River, NC	None	None	Common
Neuse River, NC	None	None	Common
Bogue Sound, NC	None	None	Common
New River, NC	None	None	Common
Cape Fear River, NC	None	None	Abundant
Winyah Bay, SC	None	None	Common
Santee Rivers (N&S), SC	None	None	Common
Charleston Harbor, SC	None	None	Common
St. Helena Sound, SC	None	None	Common
Broad River, SC	None	None	Common
Savannah River, SC/GA	None	None	Common
Ossabow Sound, GA	None	None	Common
Sapelo Sound/ St. Catherine, GA	None	None	Common
Altamaha River, GA	None	None	Common
St. Andrew/St. Simon Sound, GA	None	None	Common
St. Johns River, FL	None	None	Common
Indian River, FL	None	None	Rare
Biscayne Bay, FL	None	None	Rare

Table 4. Unpublished records of juvenile bluefish in waters of coastal Maine. Collection locations are ordered from north to south (after Creaser and Perkins 1994).

Location	**Date of Collection**	**O/E[1]**	**Number Collected**	**Size (mm TL)**	**Method[2]**
Marston Pt.	August 25, 1983	O	3	100-130	HW
Seal Island	July 1991	O	1	50	AT
Matinicus Rock	July 24-30, 1991	O	4	50-60	RT
"	July 9-17, 1991	O	14	40-50	AT
"	Mid-July 1990	O	2	30-40	AT
"	July 5, 1989	O	2	85-90	AP
"	July 18, 1986	O	1	77	AP
Foot Bridge (Boothbay Harbor)	Summer 1970-1974	O	---	Juveniles (2 modes)	HS
DMR Dock	July 4, 1984	O	3	40-50	HL
"	August 25, 1978	O	1	86	DN
"	September 14, 1971	O	5	95-105	---
Townsend Gut	September 5, 1985	O	1	Juvenile	HL
Lobster Cove	August 11, 1991	O	4	162-192	HL
"	August 30, 1990	O	1	145	HL
Sheepscot River	August 2, 1989	E	1	140	HL
Sheepscot Falls	August 1967	E	---	150-200	HL
Marsh River	July 17-Sept 17, 1991	E	60	101-217	GN
"	August 1-Sept 26, 1990	E	149	89-218	GN
"	August 8-28, 1989	E	102	92-194	GN
"	August 26, 1987	E	6	129-163	GN
"	August 14, 1986	E	28	93-121	GN
The Eddy	July 9, 1991	E	3	80-85	HS
Cross River	August 8, 1991	E	1	115	HS
Berry Island	September 8, 1974	E	4	125-140	HS
"	August 29, 1973	E	2	132-141	HS
"	August 30, 1972	E	1	112	HS
Kennebec Pt.	August 10-22, 1990	O	29	39-70	HS

Table 4. Continued.

Location	Date of Collection	O/E[1]	Number Collected	Size (mm TL)	Method[2]
Mouth of Abagadasset River	July 18, 1991	E	2	84-94	HS
"	July 3, 1991	E	6	112-115	HS
"	August 3, 1989	E	8	52-76	HS
"	September 11, 1987	E	2	142-150	HS
"	July 17, 1986	E	5	70-77	HS
Mouth of Androscoggin River	August 5, 1983	E	2	82-86	HS
Bath Bridge	Summer 1982	E	90	< 100	OT
Winnegance Bay	Summer 1988-1990	E	---	50-150	HL
Atkins Bay	Summer 1981	E	---	80-90	HS
Howard Point	August 1988	E	3	70-130	FK
Jenny Island	July 16, 1991	E	1	40	CT
Merepoint Bay	September 26, 1991	E	97	150-174	GN
Royal River	Summer 1988	E	---	Juvenile	---
SMVTI Dock	September 1986	O	---	130-150	HL
Union Wharf	September 1984	O	6	150-200	HL
Dunston, Libby, Nonesuch Rivers (confluence)	Summer 1987	E	---	Juvenile	HL
1 mi. off amusement pier, Old Orchard Beach	Summer 1961-1964	O	---	Juvenile	HL
Wells Harbor	August 1991	E	1	68	FN

[1] O = oceanic; E = estuarine
[2] Collection methods: OT = otter trawl; FN = fyke net; HL = hook and line; HS = haul seine; AP = Atlantic puffin; GN = gill net; AT = Arctic tern; DN = dip net; CT = common tern; HW = herring weir; RT = roseate tern

Table 5. Summary of life history and habitat characteristics for bluefish, *Pomatomus saltatrix*. See Appendix 1 for a more complete listing of habitat variables.

Life History Stage	Habitat (Spatial and Temporal)	Temperature	Salinity	Light/Vertical Distribution	Currents/ Circulation	Prey	Estuarine Use
Eggs [1]	*spring cohort*: unknown. *summer cohort*: occurs across continental shelf, southern New England to Cape Hatteras. Most in mid-shelf waters.	*spring cohort*: unknown. *summer cohort*: most in 18-22°C.	*spring cohort*: unknown. *summer cohort*: 31.0 ppt or more (minimum 26.0 ppt).	*spring cohort*: unknown. *summer cohort*: peak spawning in the evening (1900-2100 hrs).	*spring cohort*: unknown. *summer cohort*: in southern MAB, surface currents transport eggs south and offshore.	--	None
Larvae [2]	*spring cohort*: near edge of continental shelf, Cape Hatteras-Cape Canaveral, FL. Peak April-May. *summer cohort*: most 30-70 m depths, May-Sept, peak in July.	*spring cohort*: smallest larvae in > 24°C. *summer cohort*: near Cape Hatteras 22.1-22.4°C; in MAB 18-26°C.	*spring cohort*: smallest larvae in > 35 ppt. *summer cohort*: in MAB in 30-32 ppt.	*spring cohort*: > 4 mm strongly associate with surface. *summer cohort*: near surface at night, mostly at about 4 m during day.	*spring cohort*: subject to northward advection by Gulf Stream. Some retained in SAB by southerly counter-current. *summer cohort*: southwest winds in MAB may facilitate cross-shelf transport.	*summer cohort*: mostly copepod life history stages. Guts full during day.	None
Pelagic Juveniles [3]	*spring cohort*: smallest near 180 m contour; larger near shore. April-May. *summer cohort*: cross MAB shelf from Slope Sea to shore, early- to mid-June.	*spring cohort*: 19.0-24.0°C (or higher well offshore). *summer cohort*: in MAB 15.0-20.0°C (most > 18.0°C). As low as 13.0°C when cross shelf.	*spring cohort*: Near 180 m contour, > 35.0 ppt. *summer cohort*: During June, range 36.0-31.0 ppt.	*both cohorts*: strongly associated with the surface.	*spring cohort*: shoreward movement with growth unless advected north. *summer cohort*: move shoreward with growth. Currents important, but active swimming indicated.	--	*both cohorts*: enter estuarine nurseries during this stage
Juveniles [4] ***(summer cohort only)***	Several estuarine study areas between Narragansett Bay, RI and Delaware Bay and Delaware River. Also coast beaches and surf zones.	In most studies, arrive > 20°C, remain in temperatures up to 30°C, emigrate when declines to 15°C. Can not survive below 10°C or above 34°C. Fall migration in 18-22°C on inner continental shelf.	Usually 23.0-33.0 ppt but can intrude to as low as 3.0 ppt.	Day: usually near shorelines or in tidal creeks. Night: usually in open bay or channel waters.	Can occur in surf zone or clear to turbid back-estuarine zones.	Atlantic silversides, bay anchovy, clupeids, striped bass, sand shrimp, mysids, other fish, invertebrates.	Mostly sand, particularly along coast, but some mud, silt, clay. Also uses *Ulva*, *Zostera* beds, and *Spartina* or *Fucus*. In Chesapeake Bay includes oyster bars and beds.
Adults [5]	Generally oceanic, nearshore to well offshore over continental shelf.	Warm water, usually > 14-16°C. Can tolerate 11.8-30.4°C but are stressed at either extreme.	Oceanic salinities.	--	--	Sight feeders, prey on other fish almost exclusively.	Not uncommon in bays, larger estuaries, as well as coastal waters.

[1] Norcross *et al.* (1974); Berrien and Sibunka (1999); data from present report.
[2] Norcross *et al.* (1974); Kendall and Walford (1979); Kendall and Naplin (1981); Powles (1981); Collins and Stender (1987); Hare and Cowen (1996); data from present report.
[3] Fahay (1975); Kendall and Walford (1979); Powles (1981); Collins and Stender (1987); Hare and Cowen (1996).
[4] Lund and Maltezos (1970); Olla *et al*. (1975); Milstein *et al.* (1977); Nyman and Conover (1988); Rountree and Able (1992a, b); McBride *et al.* (1995); Able *et al.* (1996); Buckel and Conover (1997); Harding and Mann (2001), Buckel and McKown (2002), Secor *et al*. (2002), Able *et al*. (2003).
[5] Bigelow and Schroeder (1953); Olla and Studholme (1971).

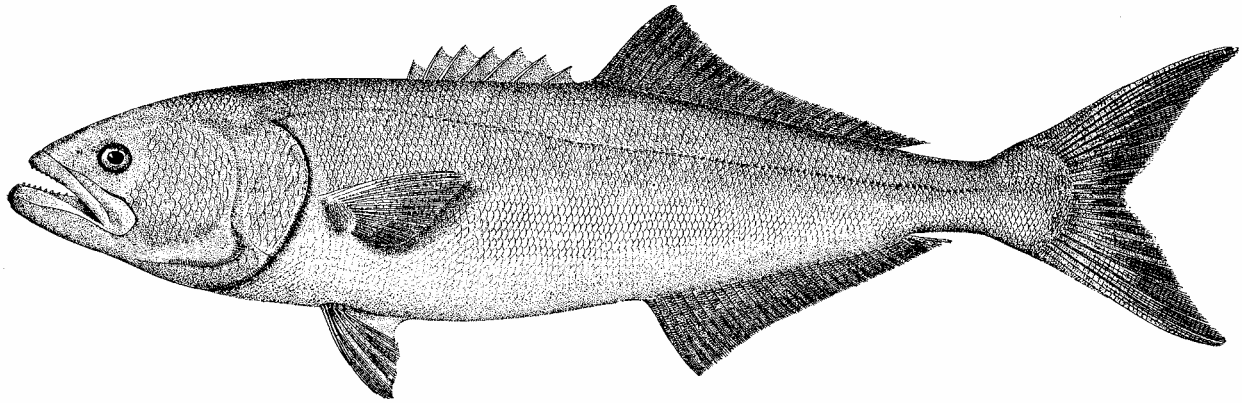


Figure 1. The adult bluefish, *Pomatomus saltatrix* (from Goode 1884).

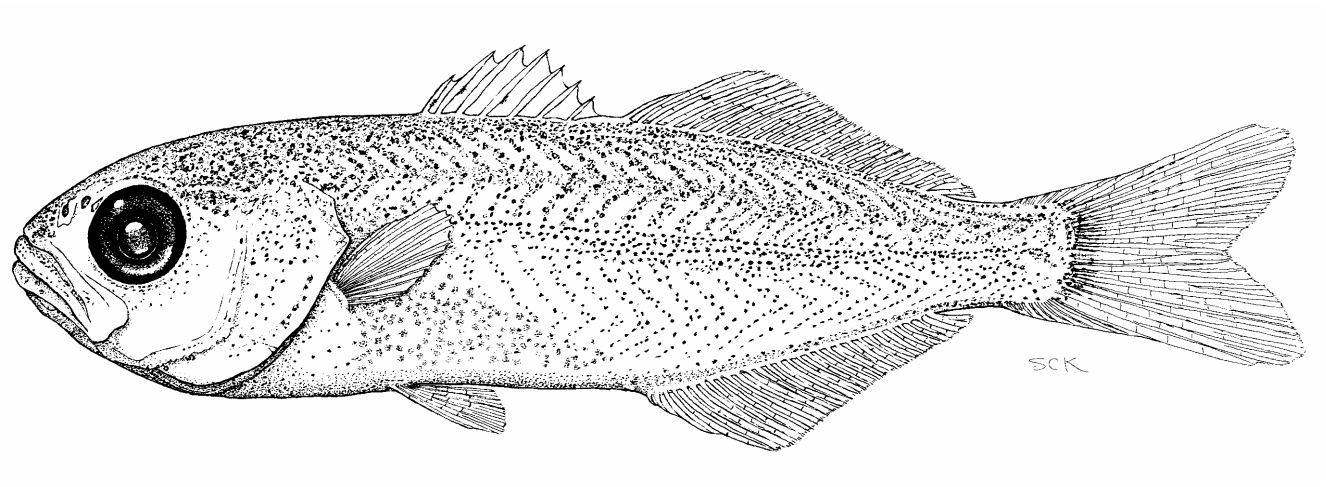


Figure 2. The pelagic juvenile bluefish, 24.3 mm SL (from Able and Fahay 1998).

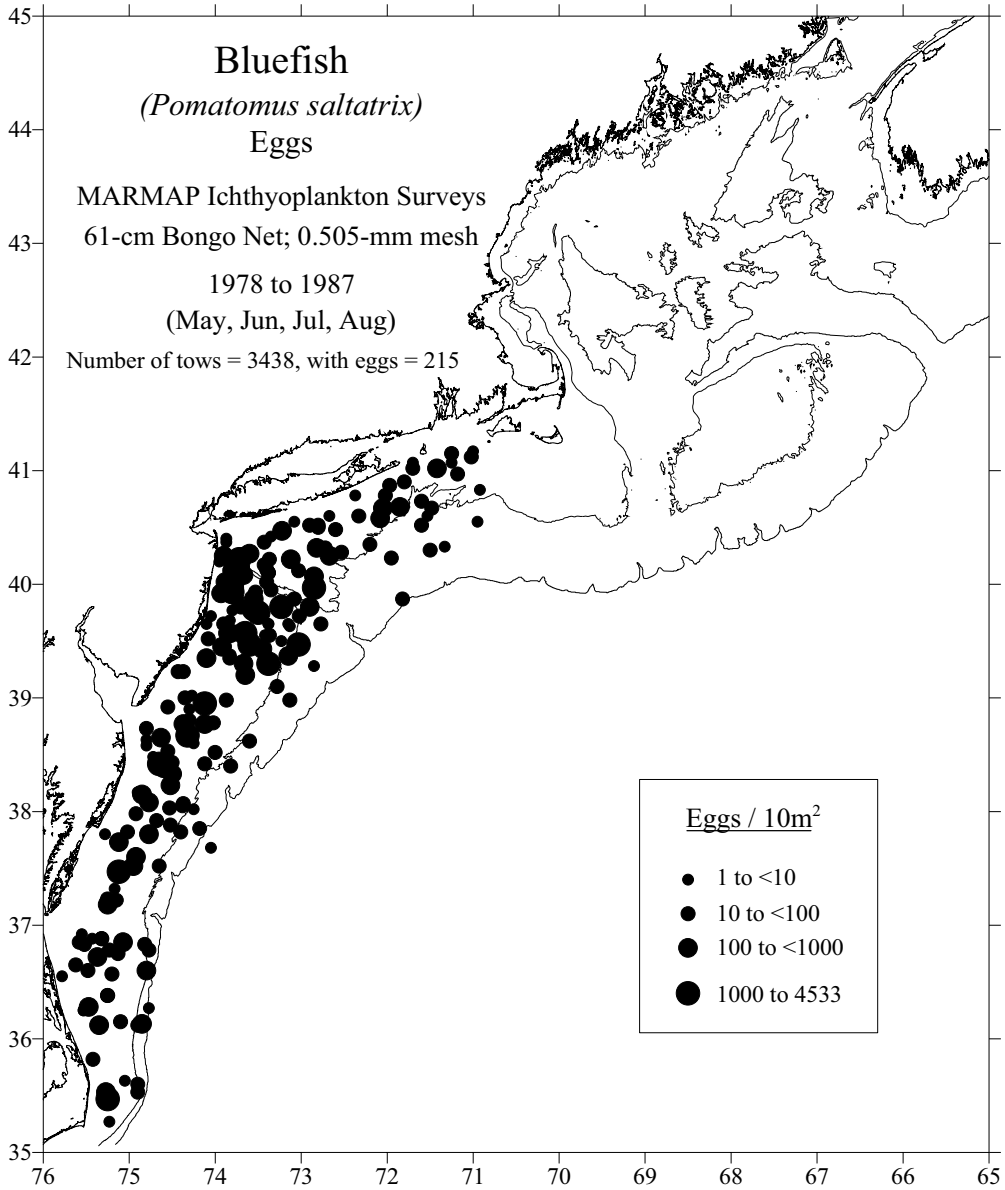


Figure 3. Distribution and abundance of bluefish eggs collected during NEFSC MARMAP ichthyoplankton surveys in the Mid-Atlantic Bight from 1978-1987 [survey also covered the Gulf of Maine and Georges Bank; see Reid *et al.* (1999) for details].

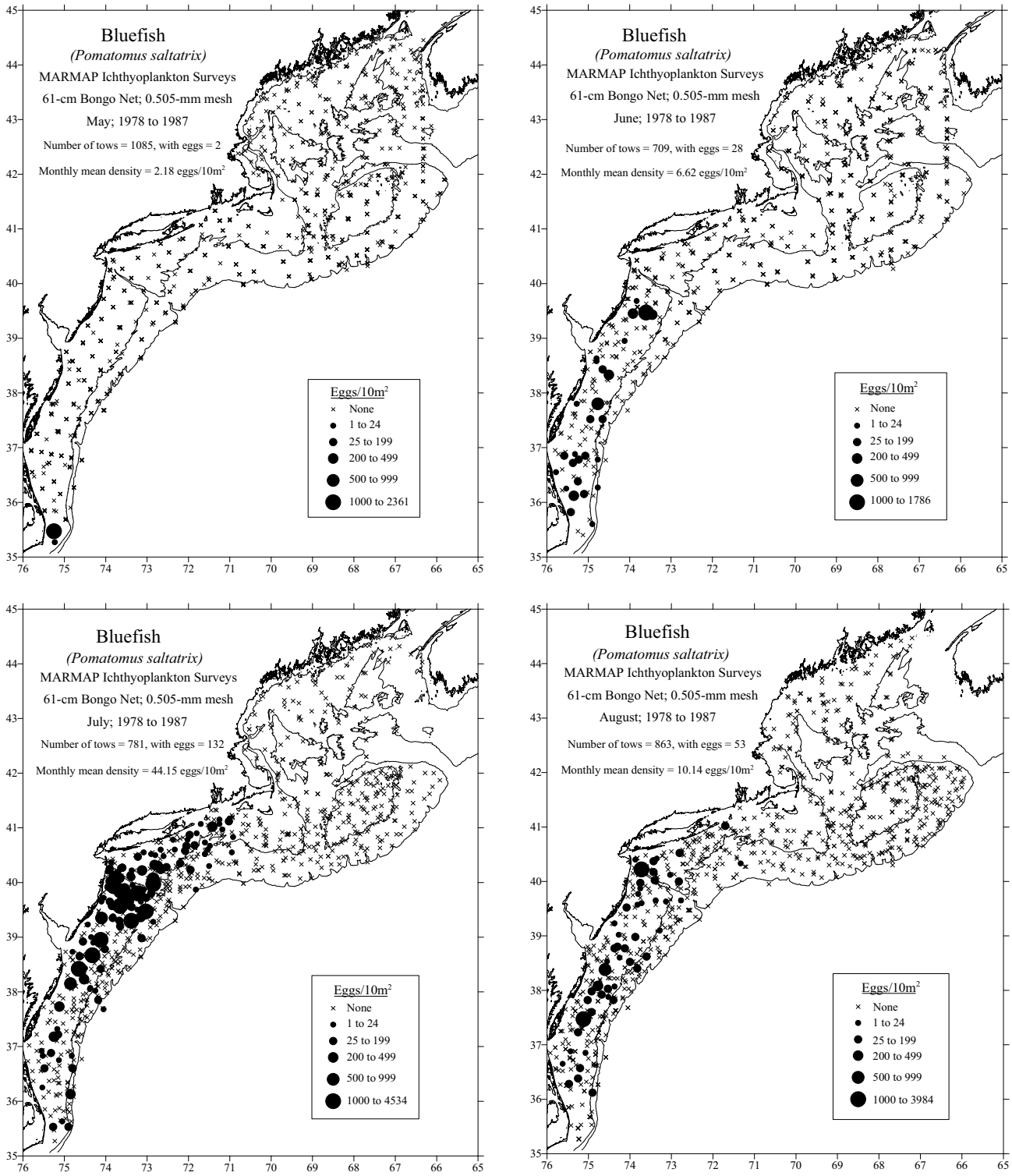


Figure 3. Continued.

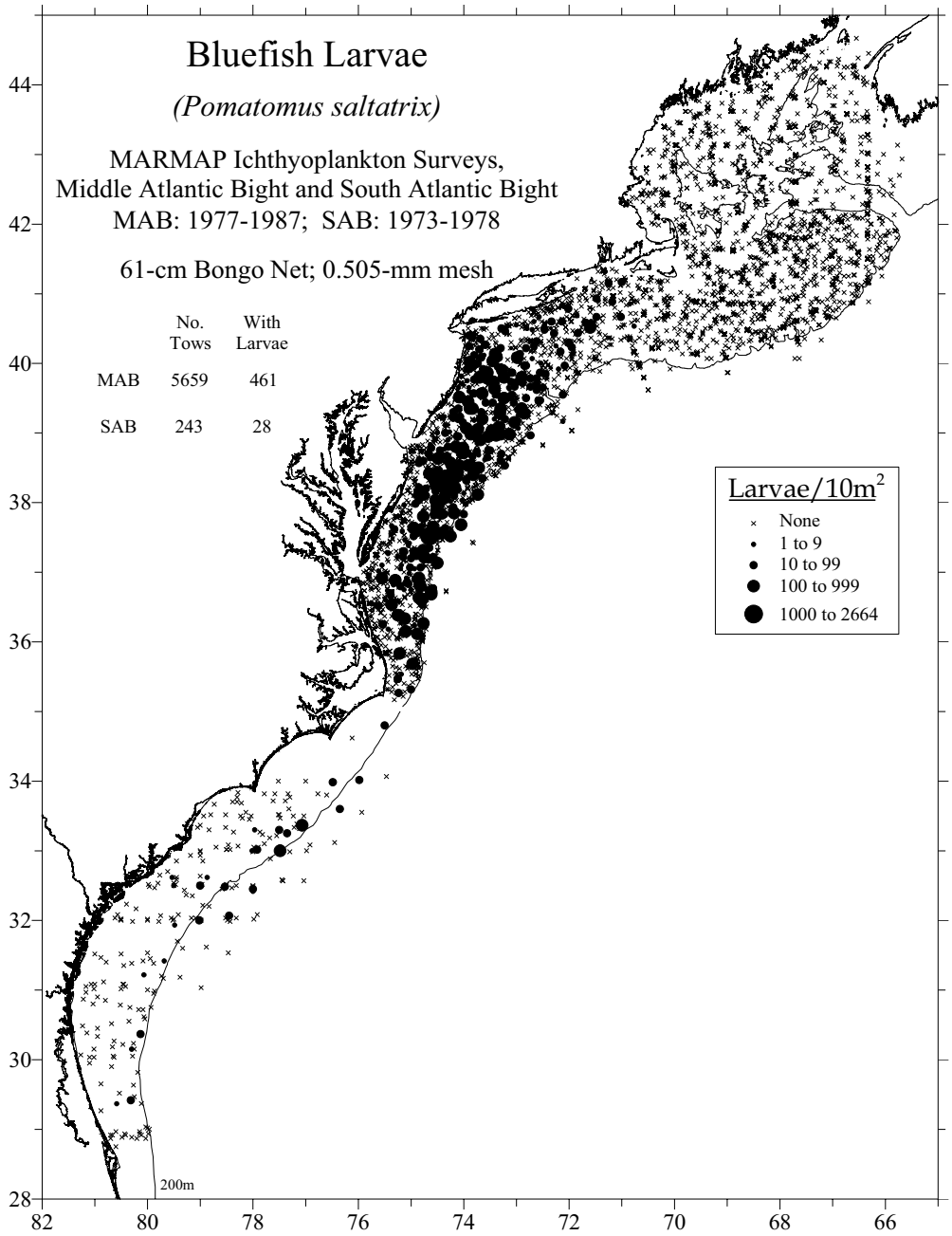


Figure 4. Distribution and abundance of bluefish larvae collected during NEFSC MARMAP ichthyoplankton surveys of both the Mid-Atlantic Bight (1977-1987) and South Atlantic Bight (1973-1978) [survey also covered the Gulf of Maine and Georges Bank; see Reid *et al.* (1999) for details].

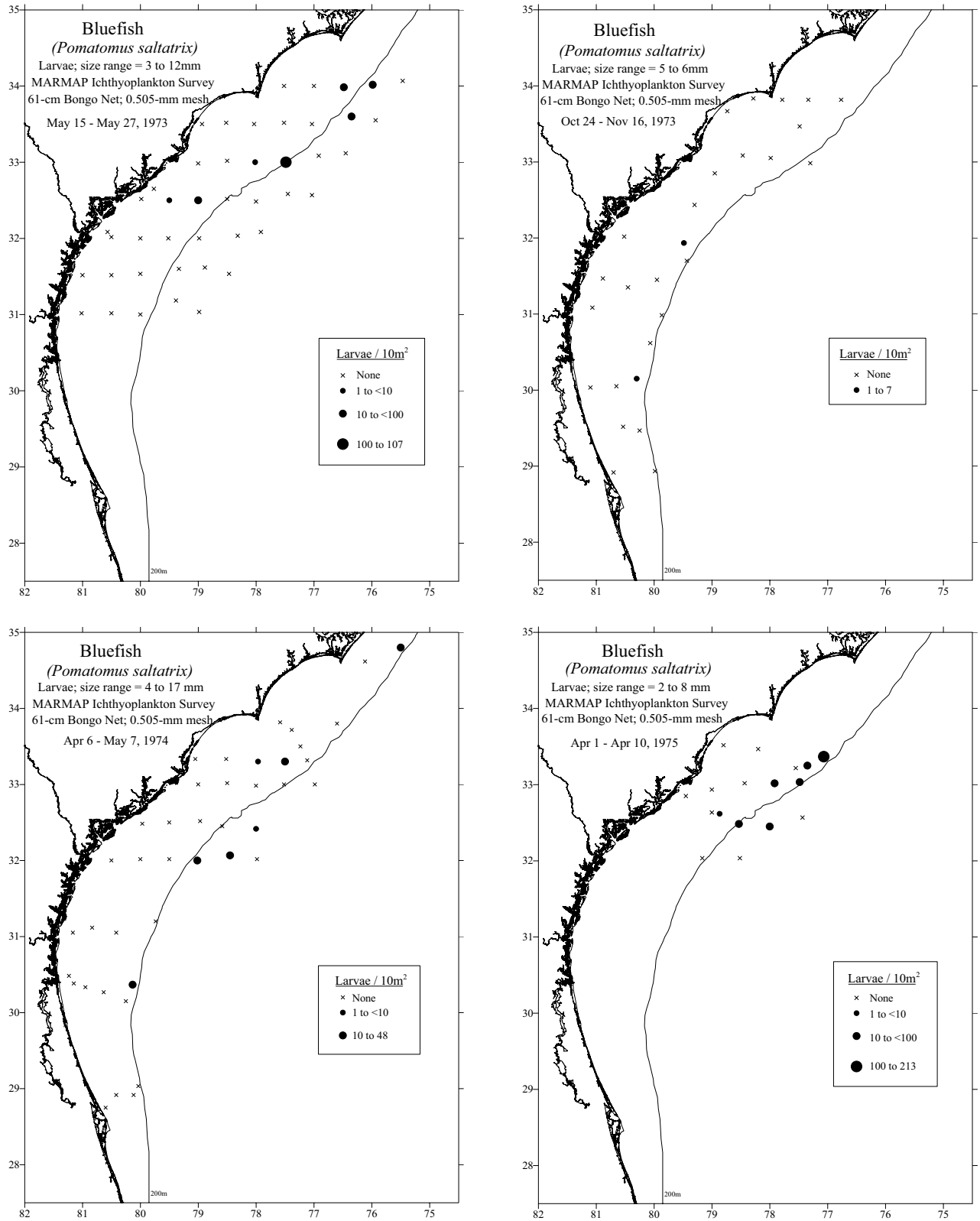
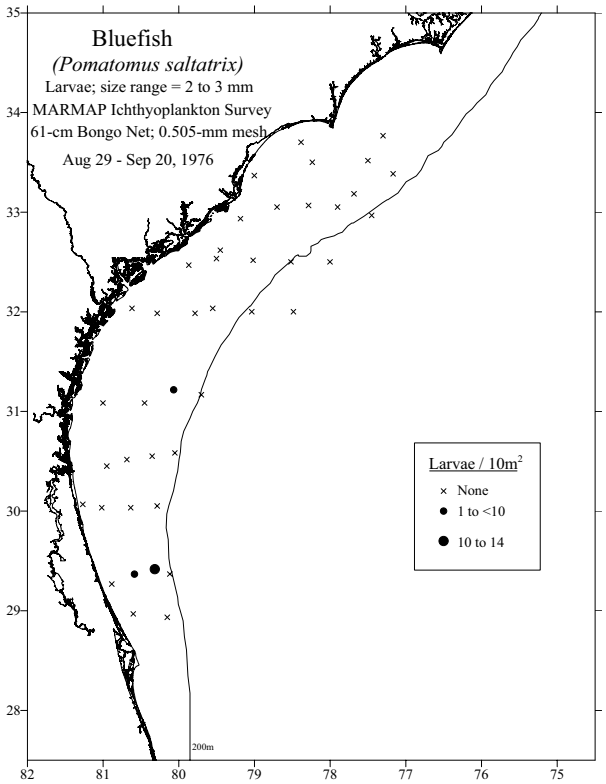
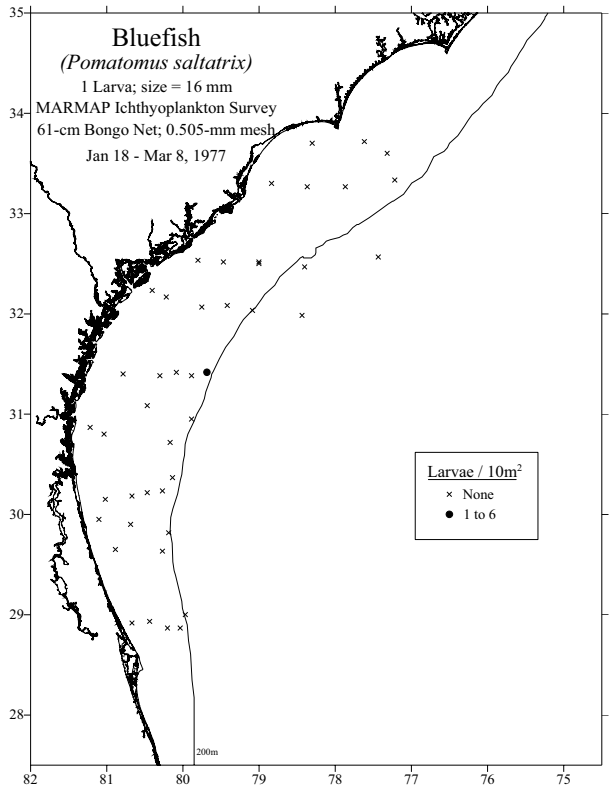


Figure 5. Distribution and abundance of bluefish larvae collected with a bongo net in the South Atlantic Bight during NEFSC MARMAP ichthyoplankton surveys [see Reid *et al.* (1999) for details].





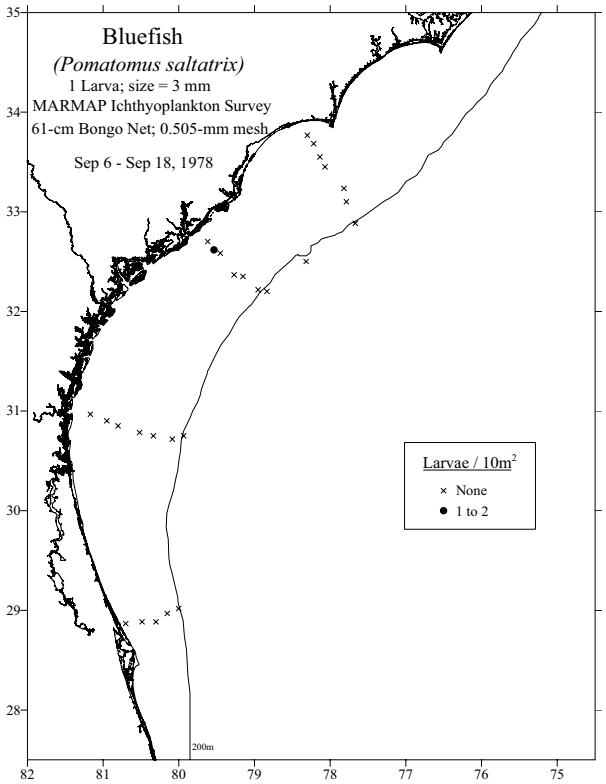


Figure 5. Continued.

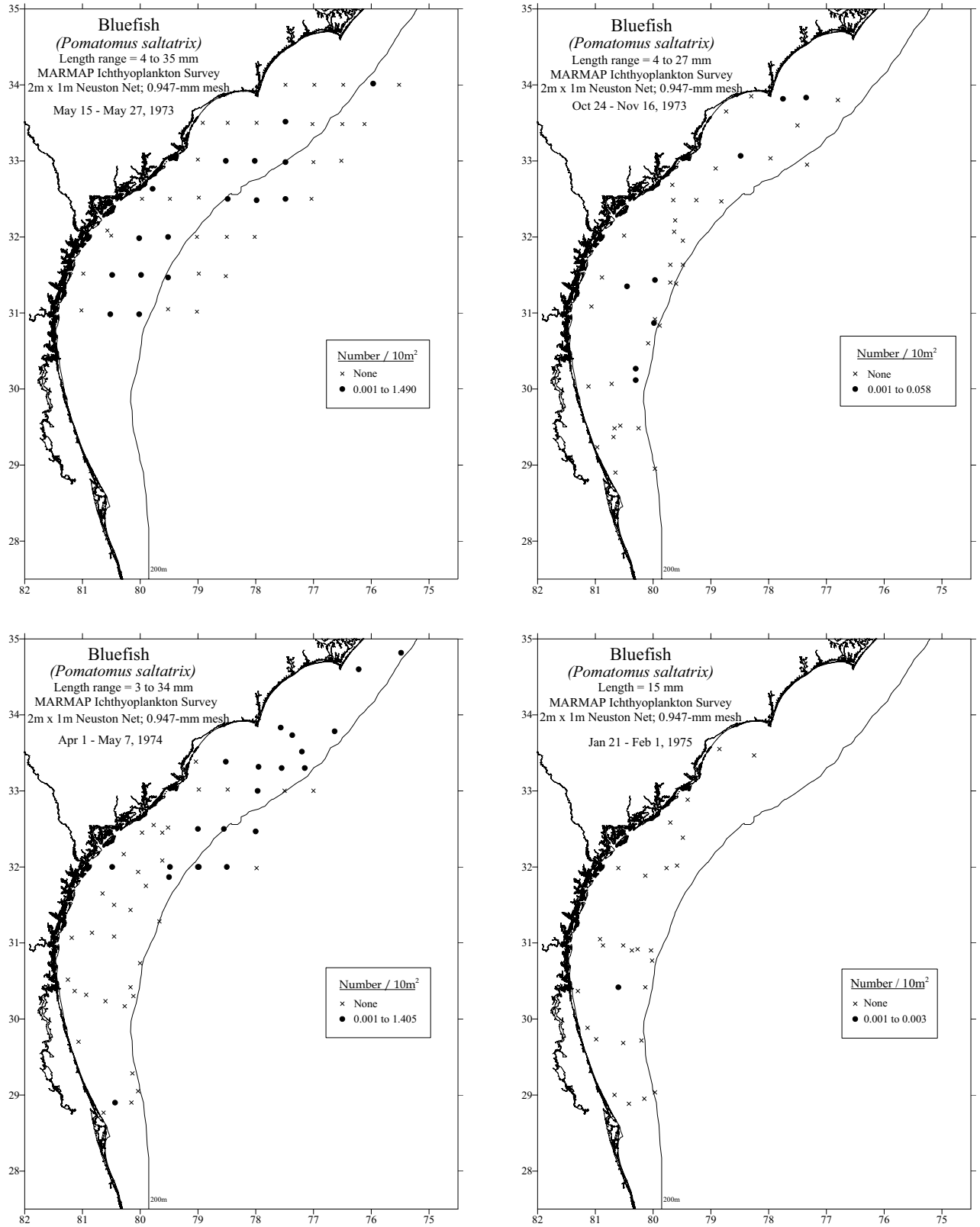


Figure 6. Distribution and abundance of bluefish larvae collected in a neuston net in the South Atlantic Bight during NEFSC MARMAP ichthyoplankton surveys [see Reid *et al.* (1999) for details].

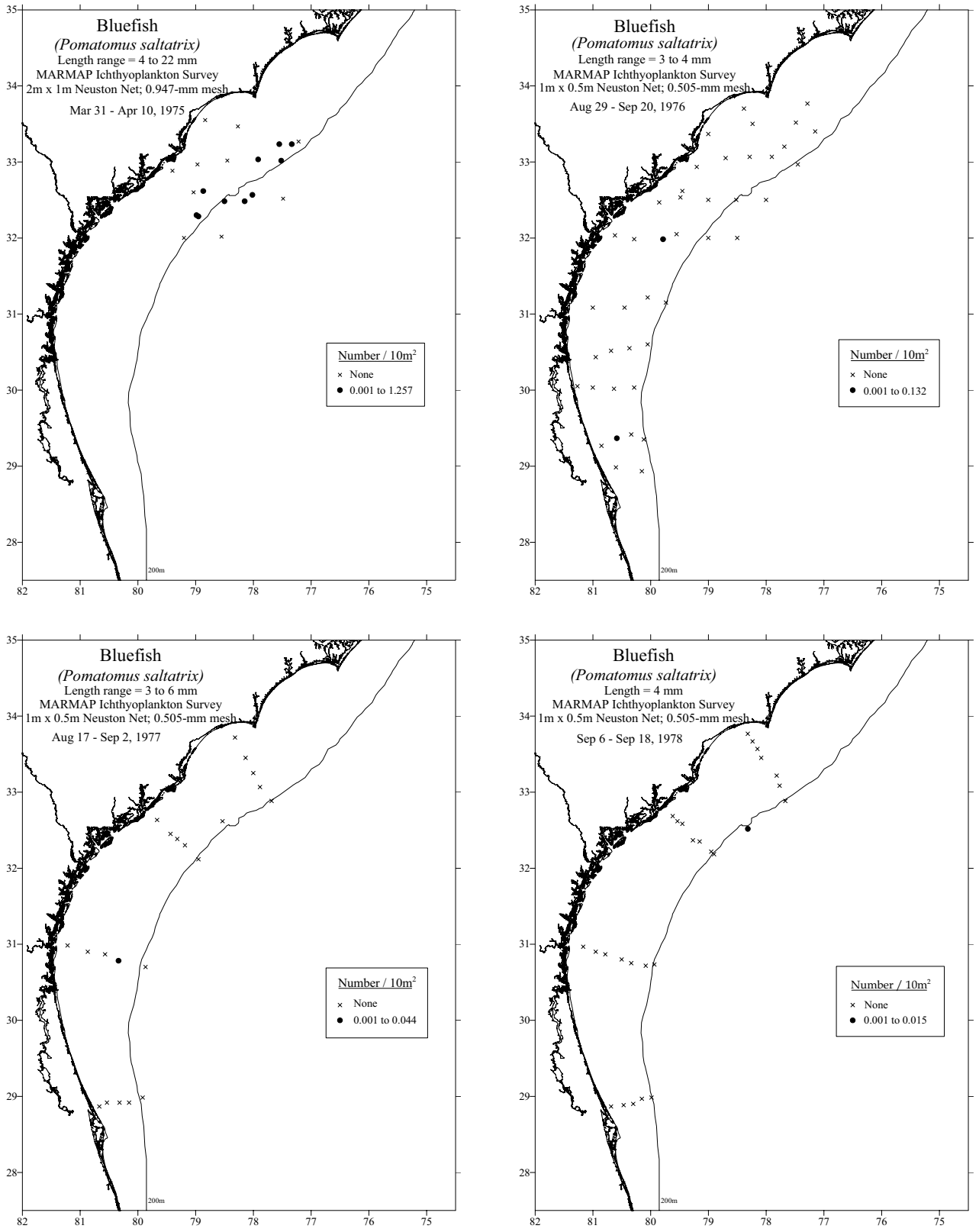


Figure 6. Continued.

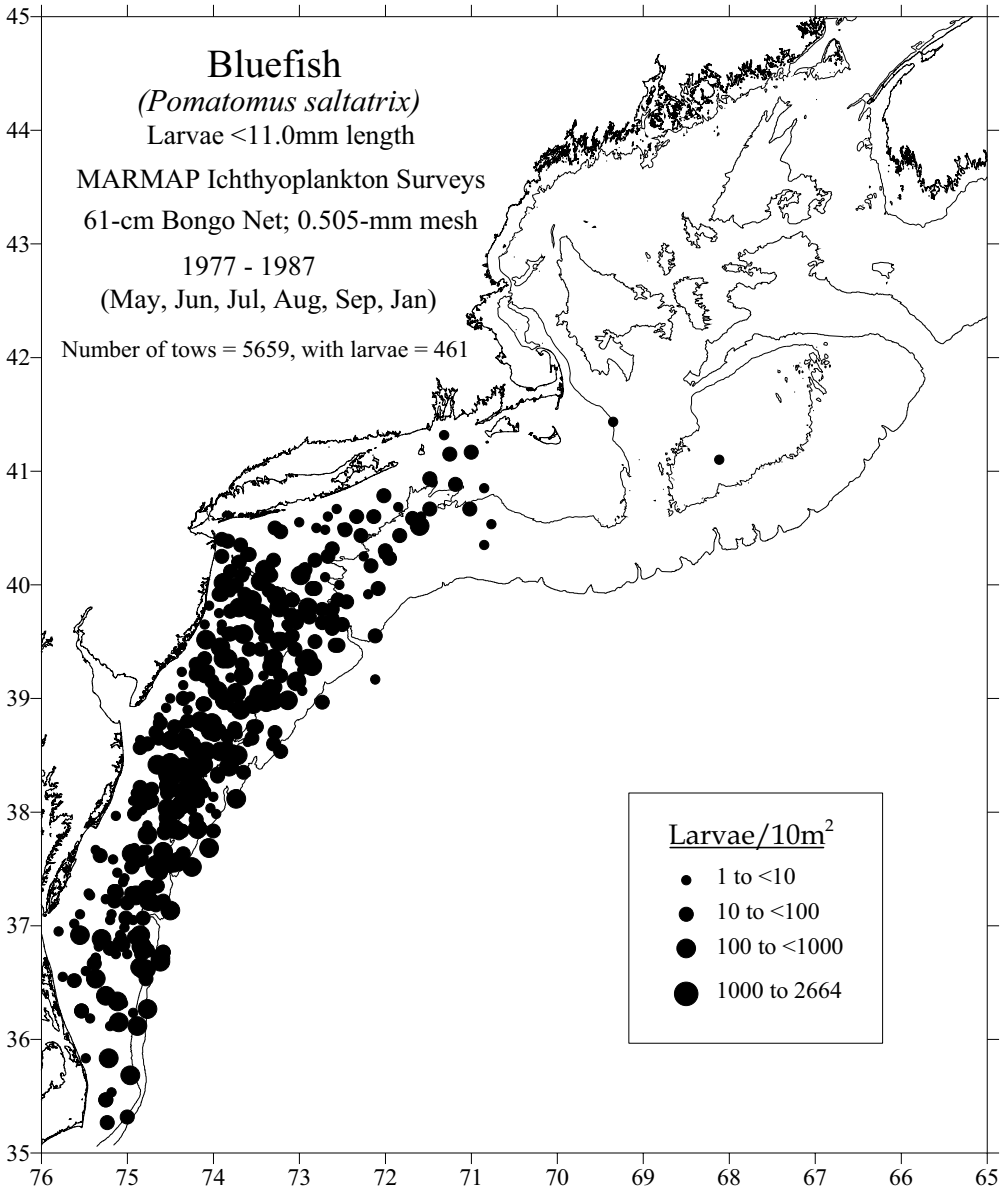


Figure 7. Distribution and abundance of bluefish larvae collected during NEFSC MARMAP ichthyoplankton surveys in the Mid-Atlantic Bight from 1977-1987 [survey also covered the Gulf of Maine and Georges Bank; see Reid *et al.* (1999) for details].

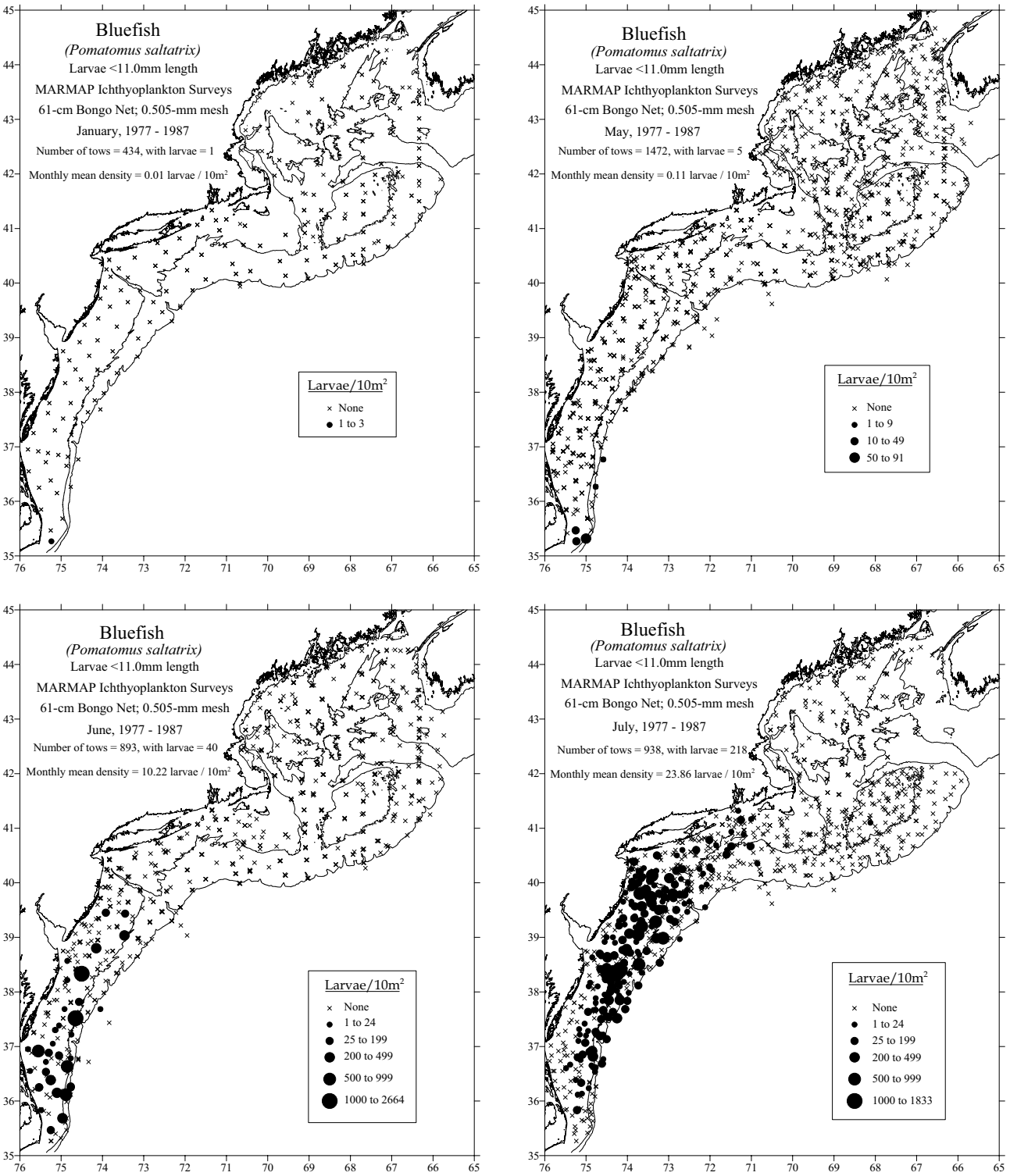


Figure 7. Continued.

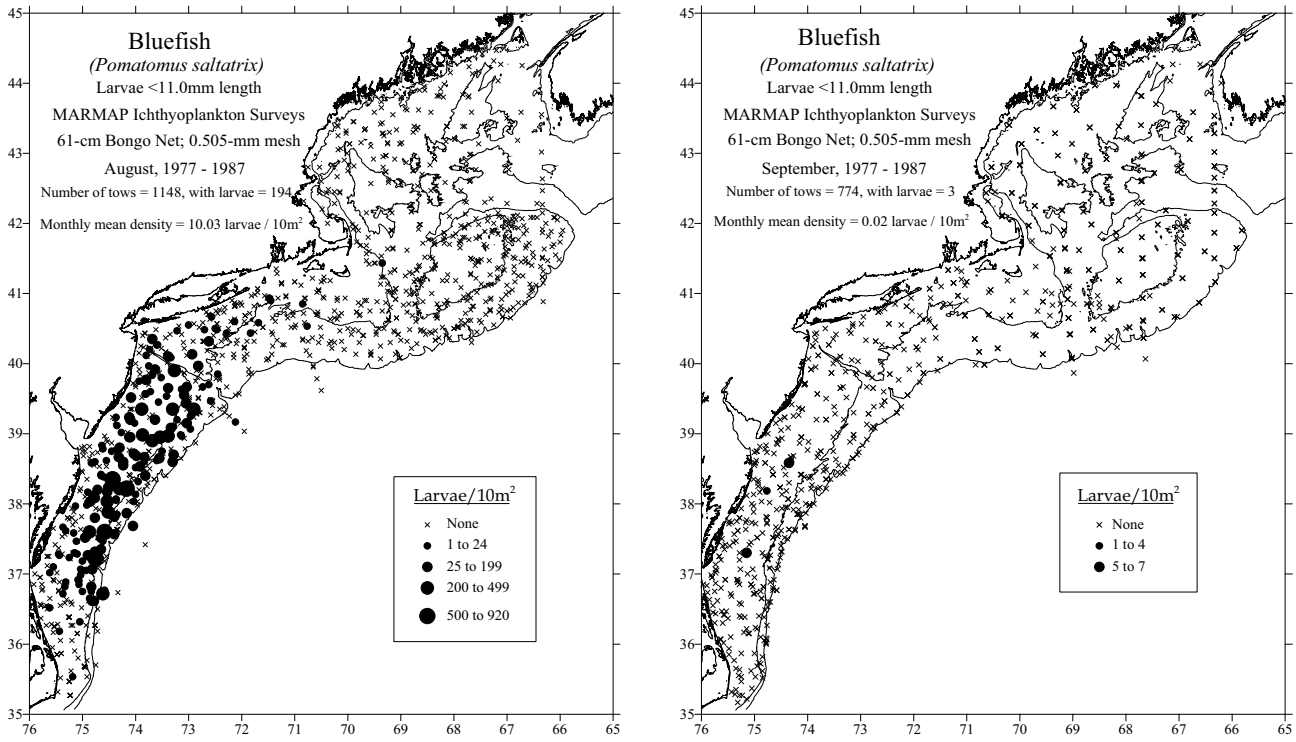


Figure 7. Continued.

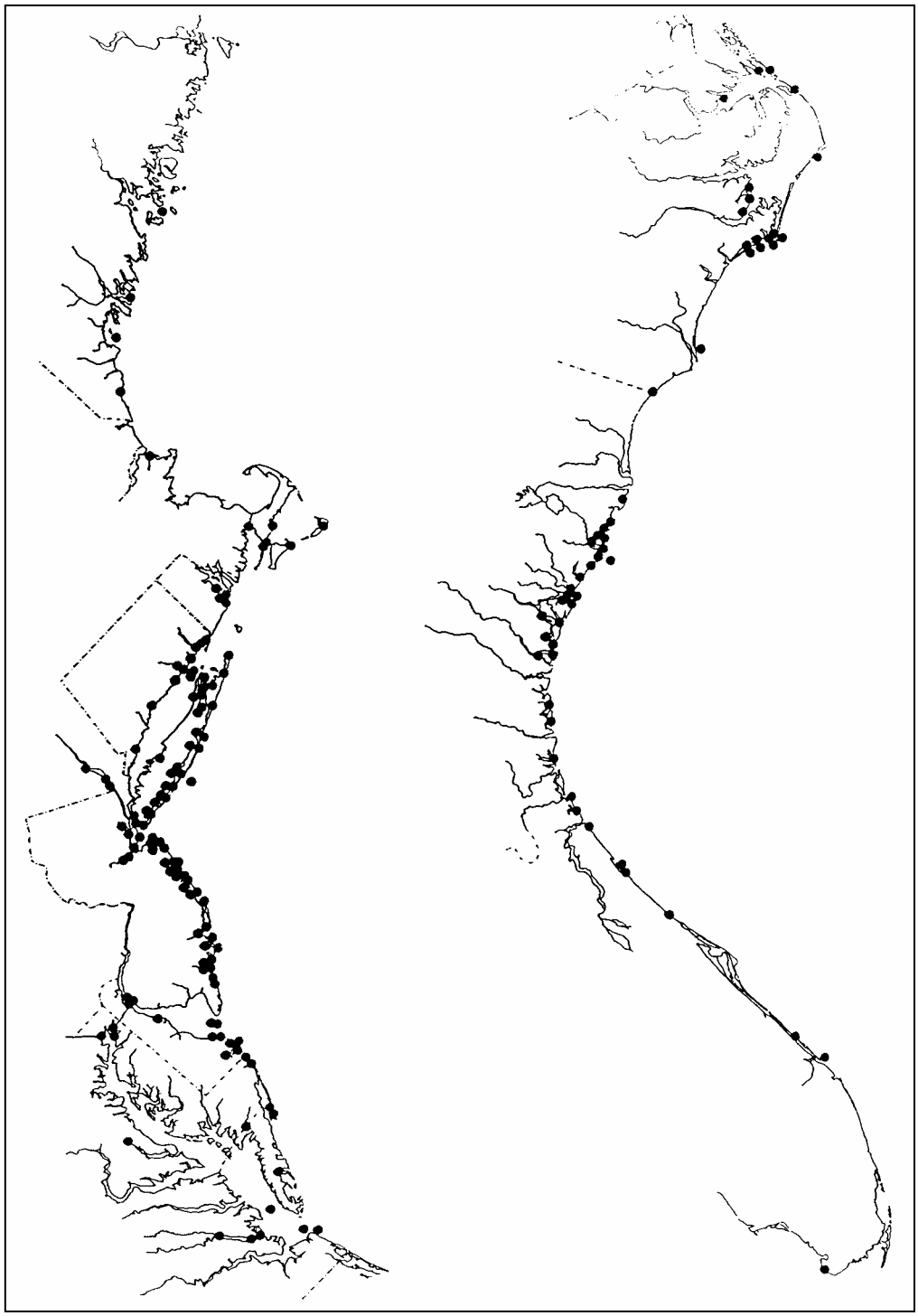


Figure 8. Reported occurrences of juvenile bluefish along the east coast of the United States (Clark 1973).

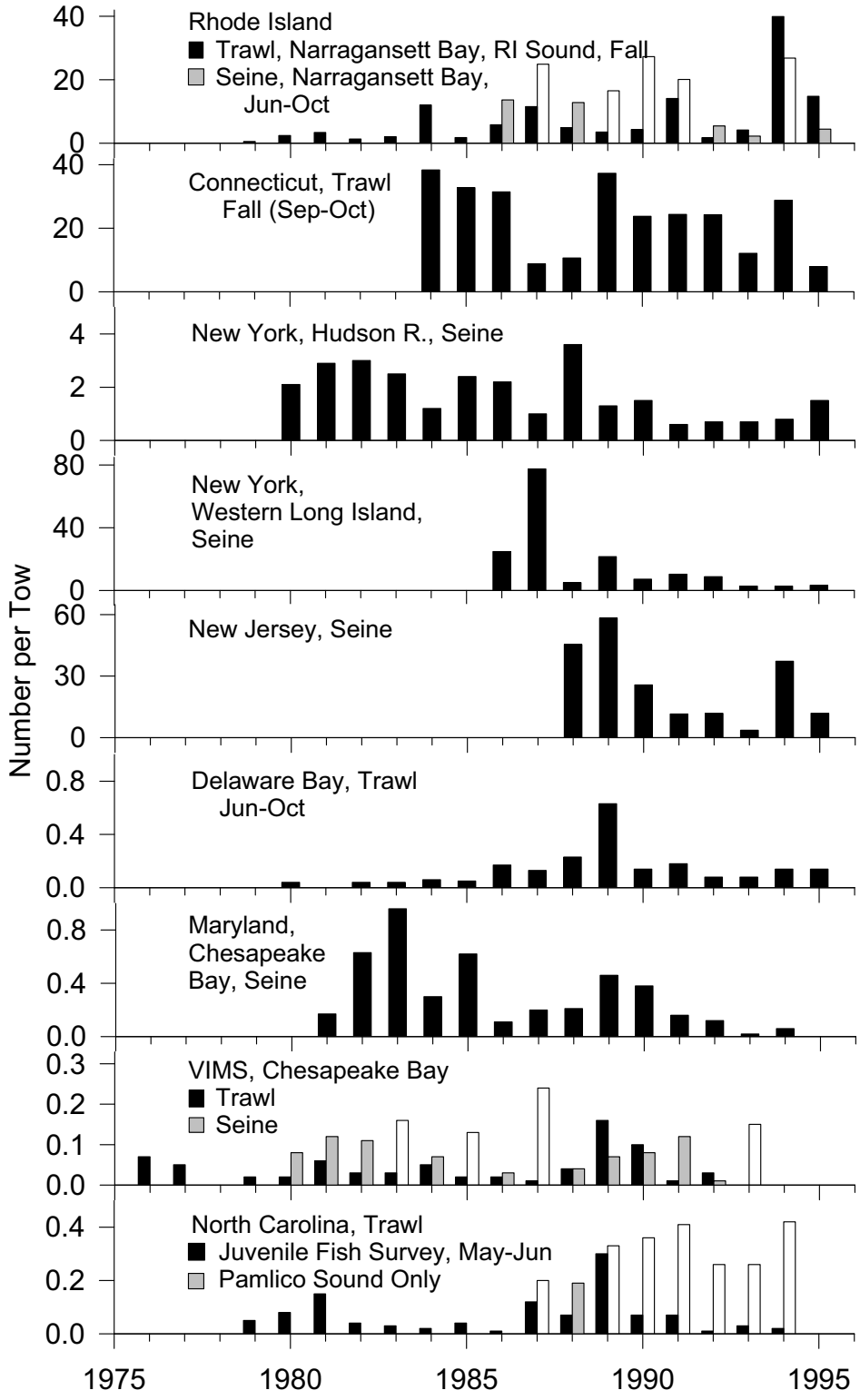


Figure 9. Abundance (number/tow) of young-of-the-year bluefish in seine and trawl surveys by state and by year.

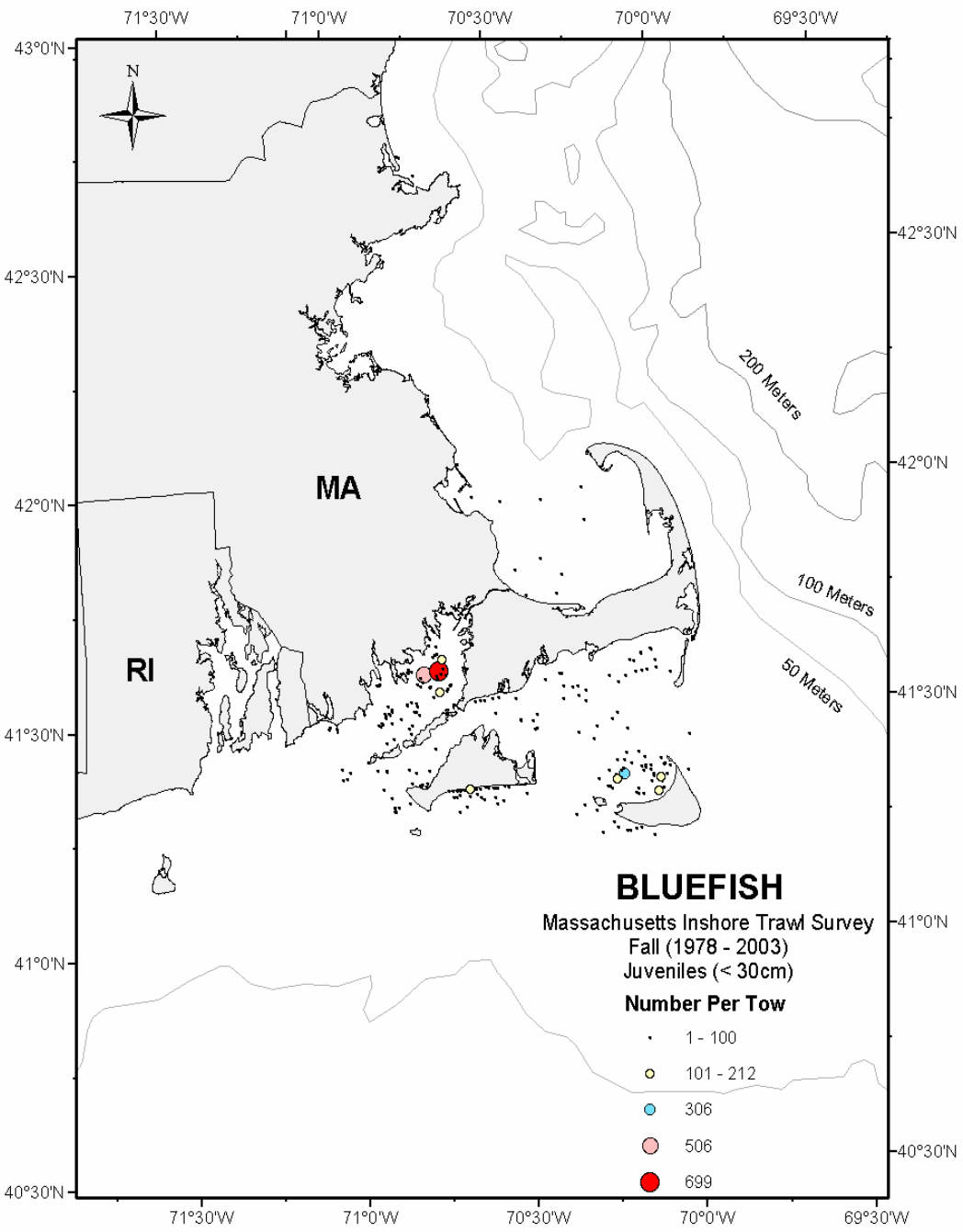


Figure 10. Distributions and abundances of juvenile bluefish in Massachusetts coastal waters collected during the fall Massachusetts inshore trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

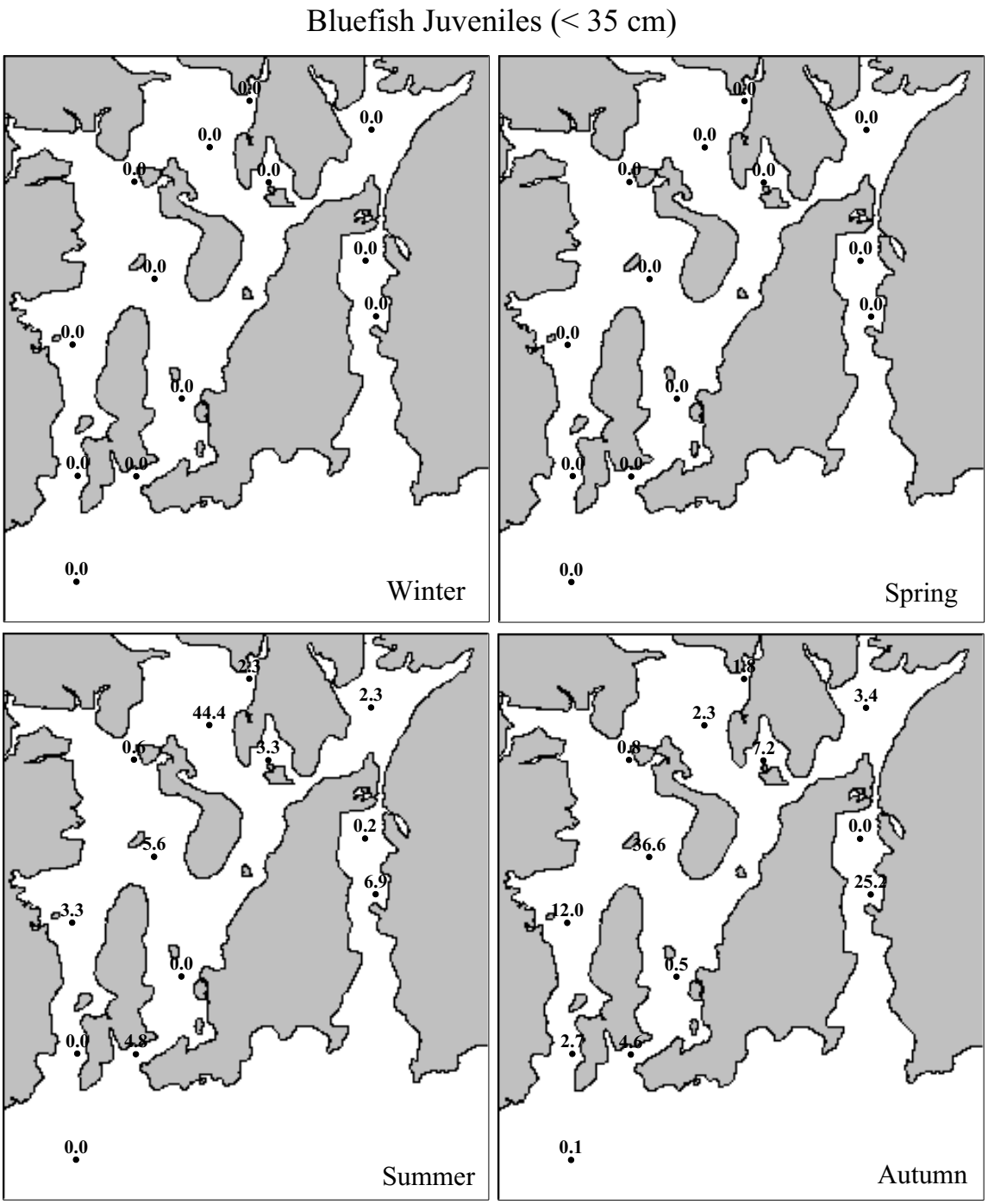


Figure 11. Distributions and abundances of juvenile bluefish collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid et al. (1999) for details].

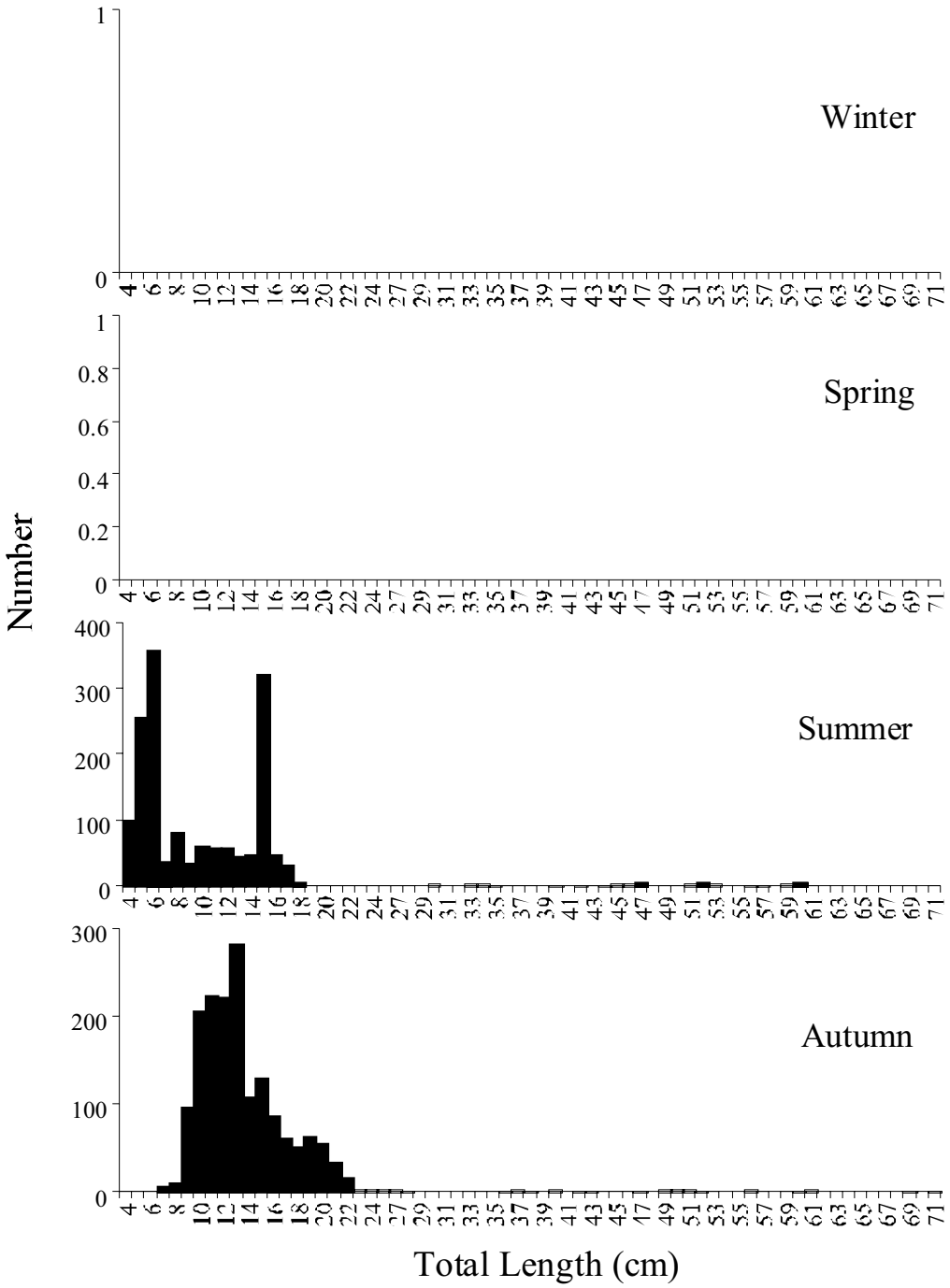


Figure 12. Seasonal length frequency distributions of bluefish collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys [all years combined; see Reid *et al.* (1999) for details].

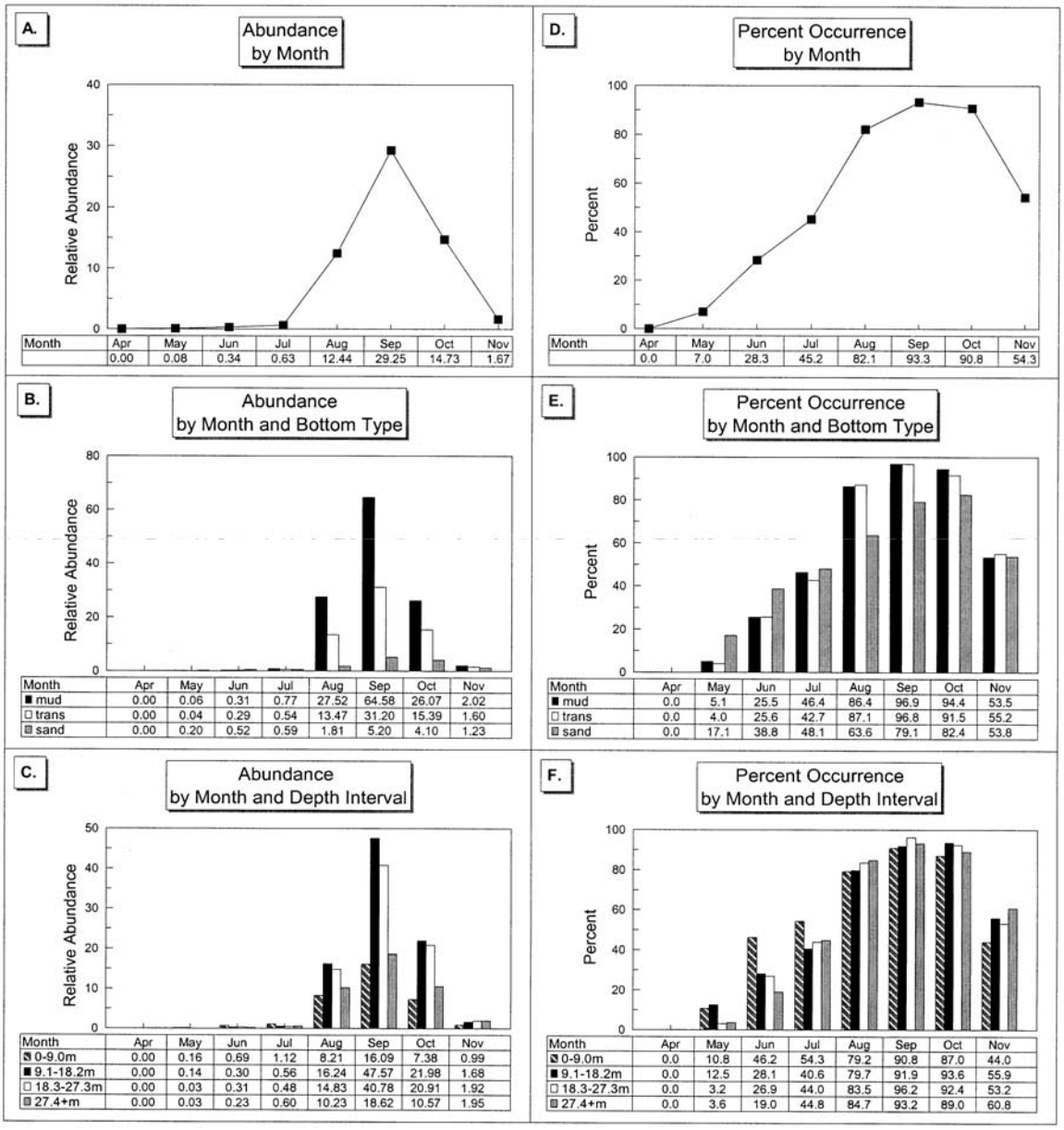


Figure 13. Relative abundance (geometric mean catch/tow) catch/tow and percent occurrence (proportion of samples in which at least one individual was observed) for juvenile and adult bluefish in Long Island Sound, by month, month and bottom type, and month and depth interval. Source: Gottschall *et al.* (2000).

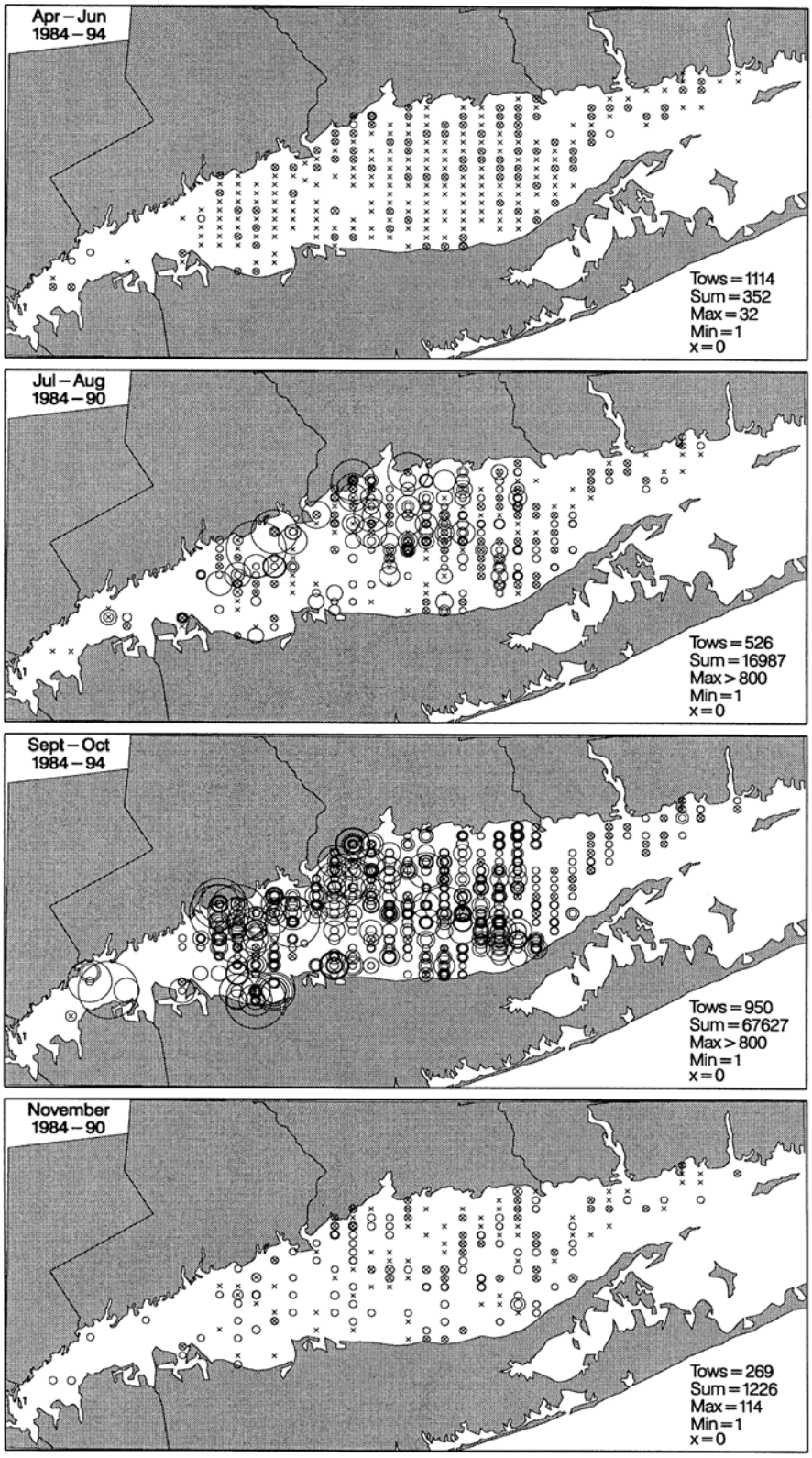


Figure 14. Distributions and abundances of juvenile and adult bluefish in Long Island Sound, based on 86,192 fish taken in 2,859 tows during the finfish surveys of the Connecticut Fisheries Division, 1984-1994. The largest circle size represents a tow with a catch of > 800 bluefish. Collections were made with a 14 m otter trawl at about 40 stations chosen by stratified random design. Source: Gottschall *et al.* (2000).

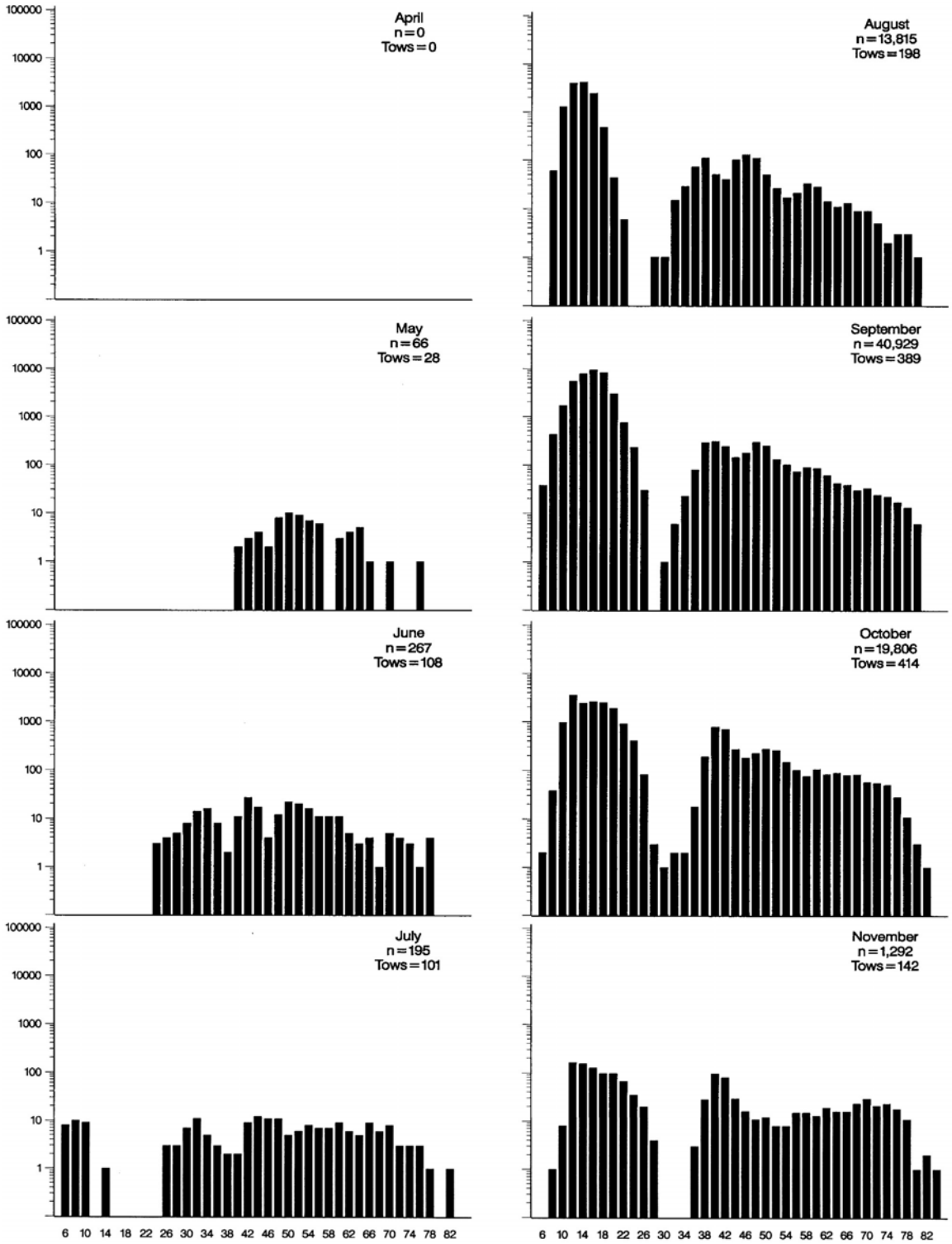


Figure 15. Monthly $\log_{10}$ length frequencies (cm) of juvenile and adult bluefish collected in Long Island Sound, based on 76,370 fish taken in 1,380 tows during the finfish surveys of the Connecticut Fisheries Division between 1989-1994. Source: Gottschall *et al.* (2000).

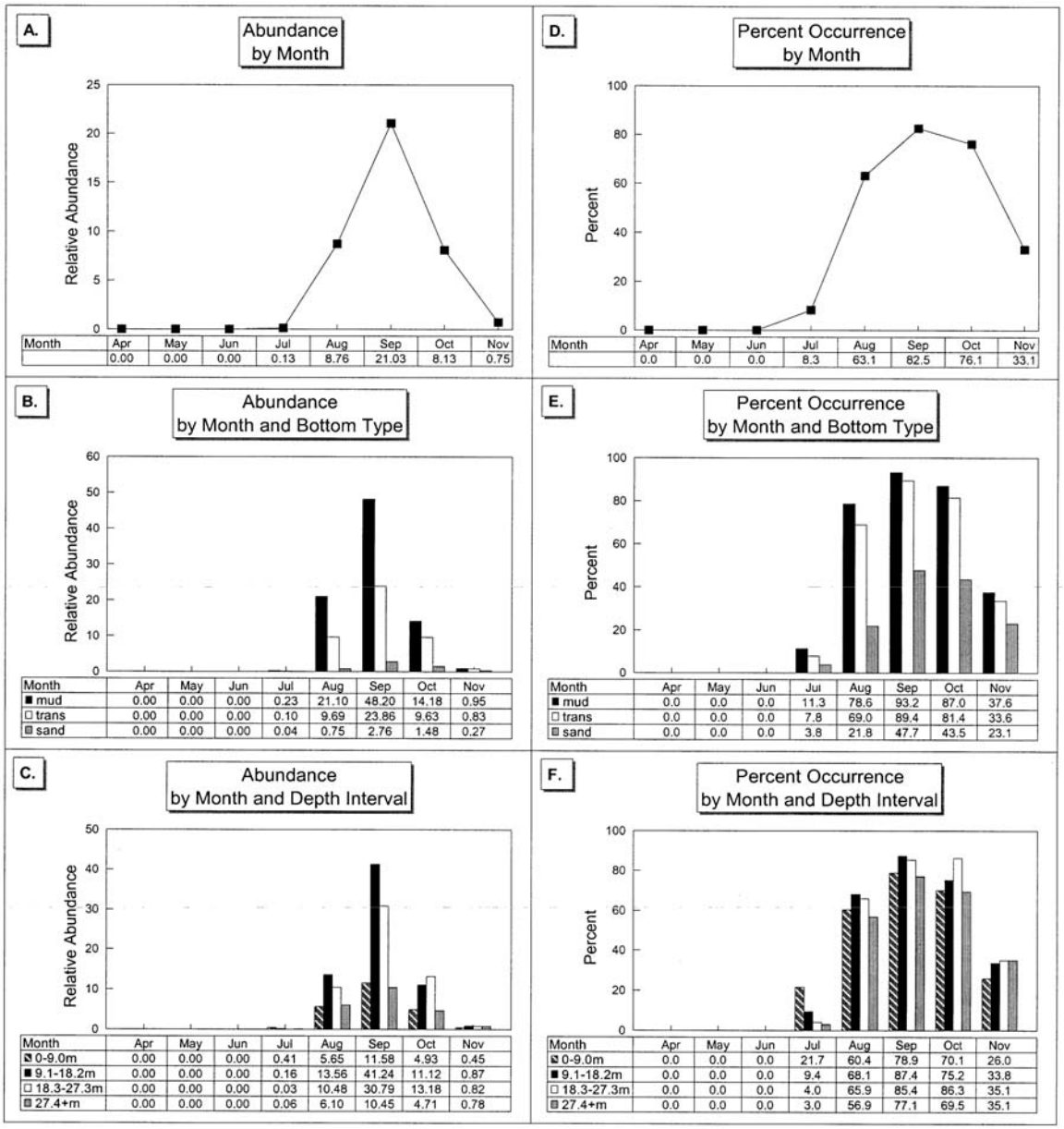


Figure 16. Relative abundance (geometric mean catch/tow) catch/tow and percent occurrence (proportion of samples in which at least one individual was observed) for young-of-year bluefish in Long Island Sound, by month, month and bottom type, and month and depth interval. Source: Gottschall *et al.* (2000).

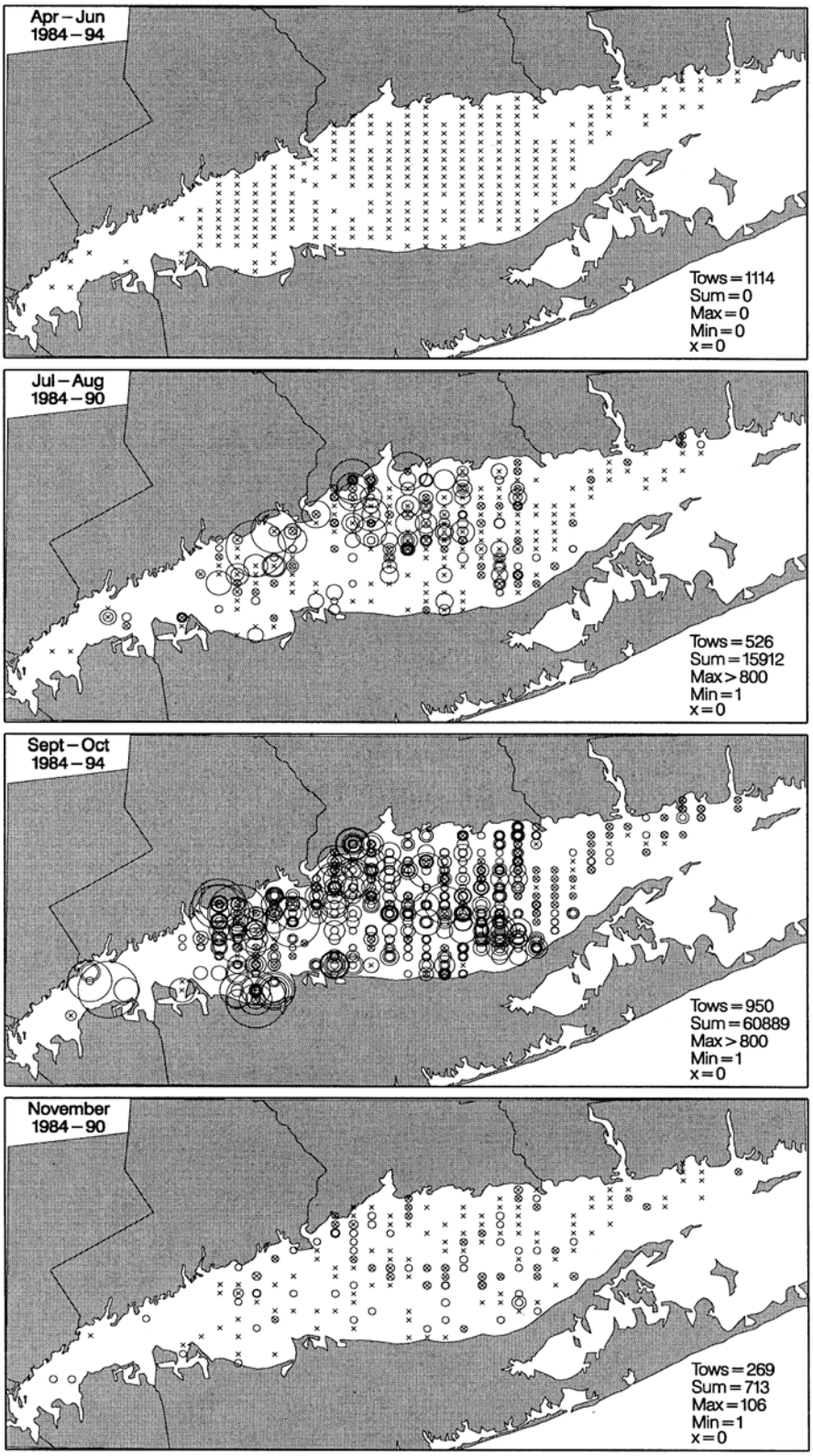


Figure 17. Distributions and abundances of young-of-year bluefish in Long Island Sound, based on 77,514 young-of-year fish taken in 2,859 tows during the finfish surveys of the Connecticut Fisheries Division, 1984-1994. The largest circle size represents a tow with a catch of > 800 bluefish. Collections were made with a 14 m otter trawl at about 40 stations chosen by stratified random design. Source: Gottschall *et al.* (2000).

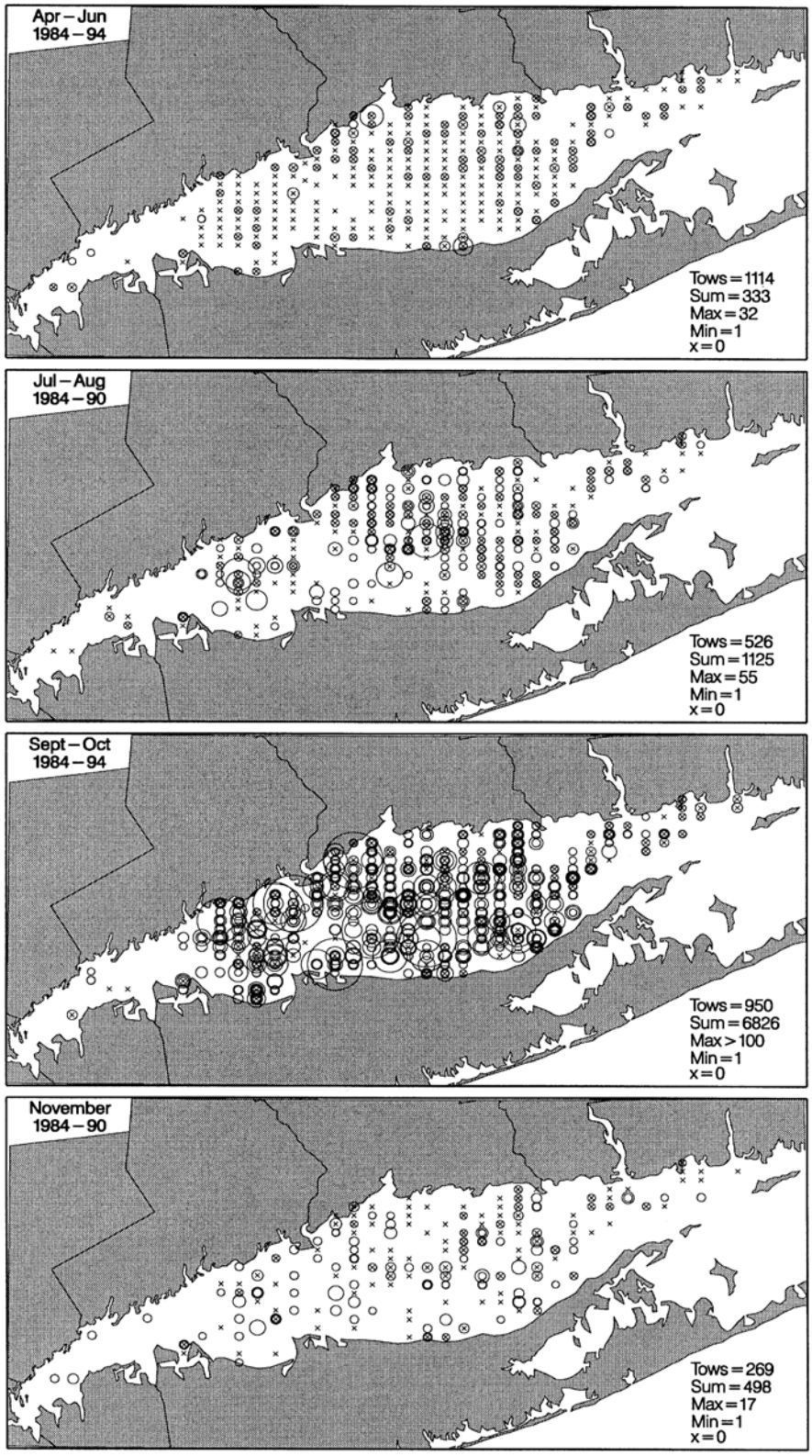


Figure 18. Distributions and abundances of age 1+ bluefish in Long Island Sound, based on 8,782 age 1+ fish taken in 2,859 tows during the finfish surveys of the Connecticut Fisheries Division, 1984-1994. The largest circle size represents a tow with a catch of > 100 bluefish. Collections were made with a 14 m otter trawl at about 40 stations chosen by stratified random design. Source: Gottschall *et al.* (2000).

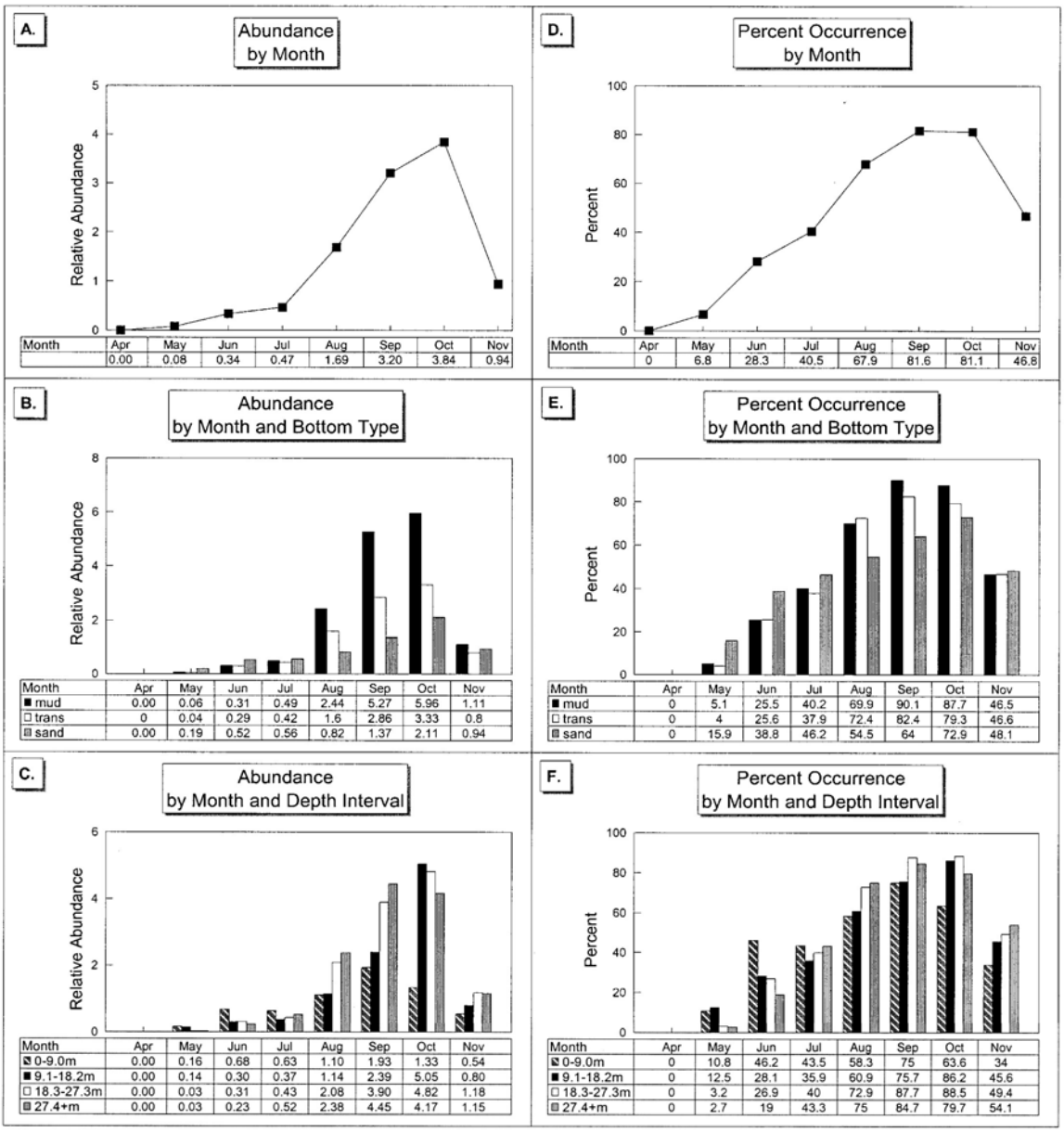


Figure 19. Relative abundance (geometric mean catch/tow) catch/tow and percent occurrence (proportion of samples in which at least one individual was observed) for age 1+ bluefish in Long Island Sound, by month, month and bottom type, and month and depth interval. Source: Gottschall *et al.* (2000).

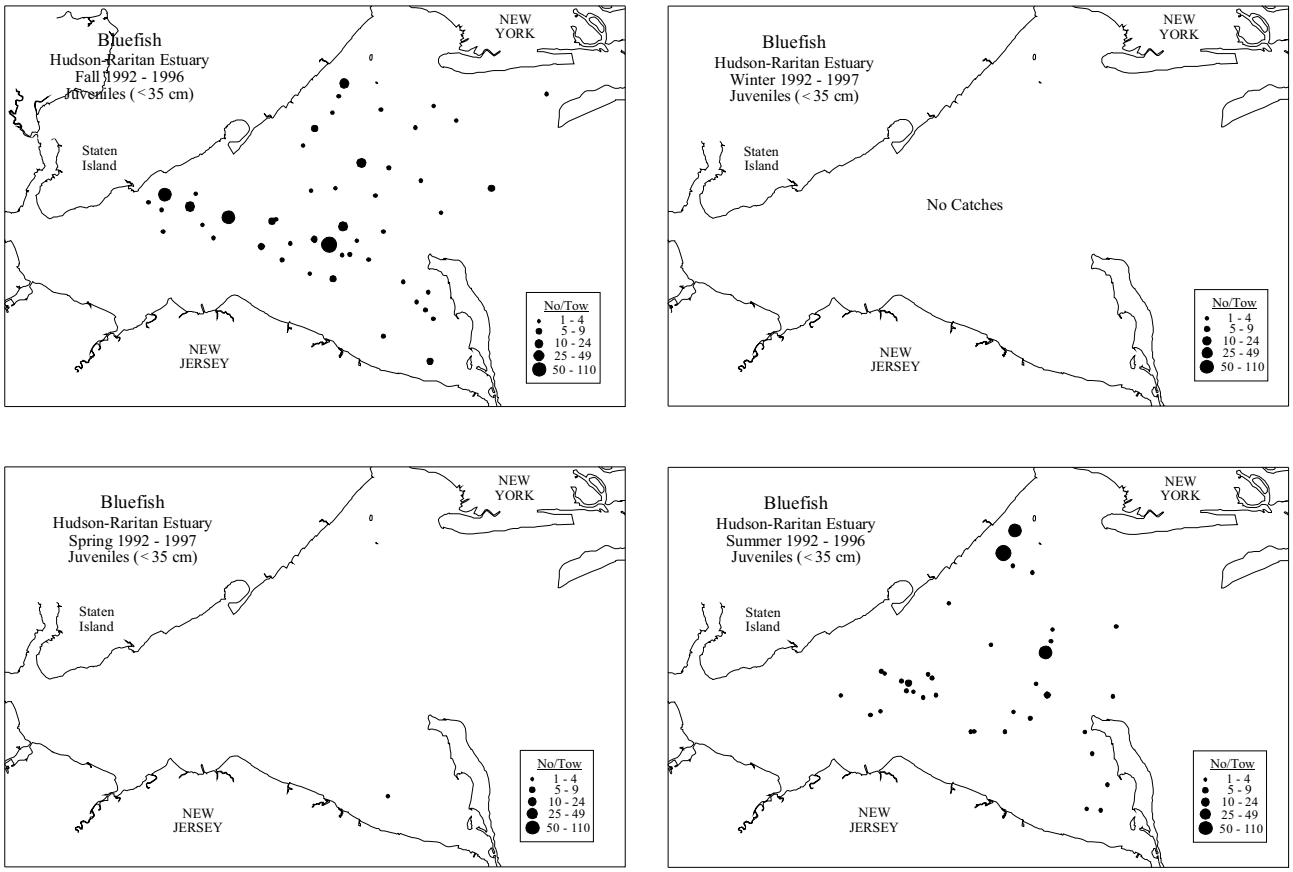


Figure 20. Seasonal distribution and abundance of juvenile bluefish in the Hudson-Raritan estuary collected during Hudson-Raritan estuary trawl surveys, 1992–1997 [see Reid *et al.* (1999) for details].

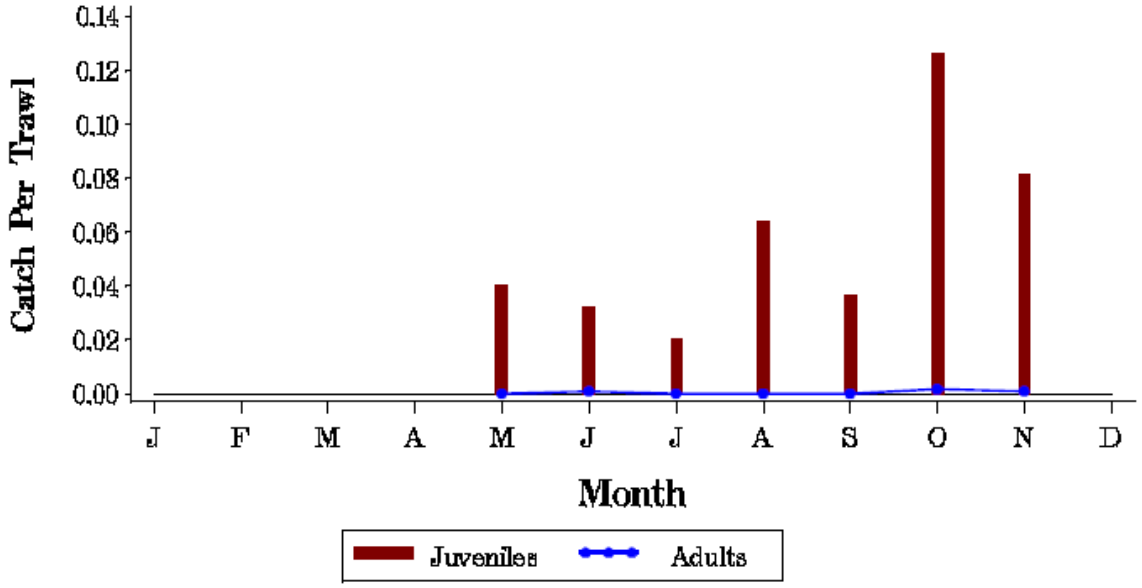


Figure 21. Catch per unit effort for total catch of juvenile and adult bluefish in Chesapeake Bay and tributaries, from the Virginia Institute of Marine Science's (VIMS) trawl surveys, 1988-1999 (all years combined). Source: Geer (2002).

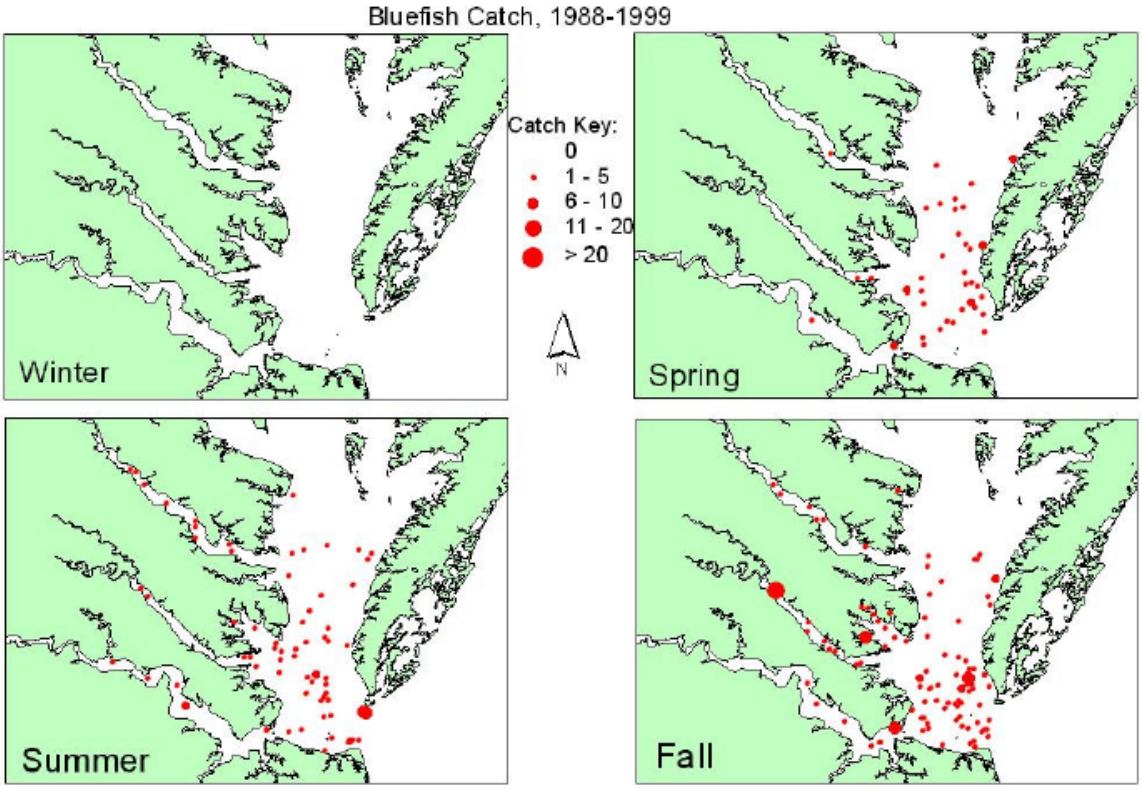


Figure 22. Seasonal distribution and abundance of bluefish in Chesapeake Bay and tributaries, from the VIMS trawl surveys, 1988-1999 (all years combined). Monthly surveys were conducted using a random stratified design of the main stem of the Bay using a 9.1 m semi-balloon otter trawl with 38 mm mesh and 6.4 mm cod end with a tow duration of five minutes. Source: Geer (2002).

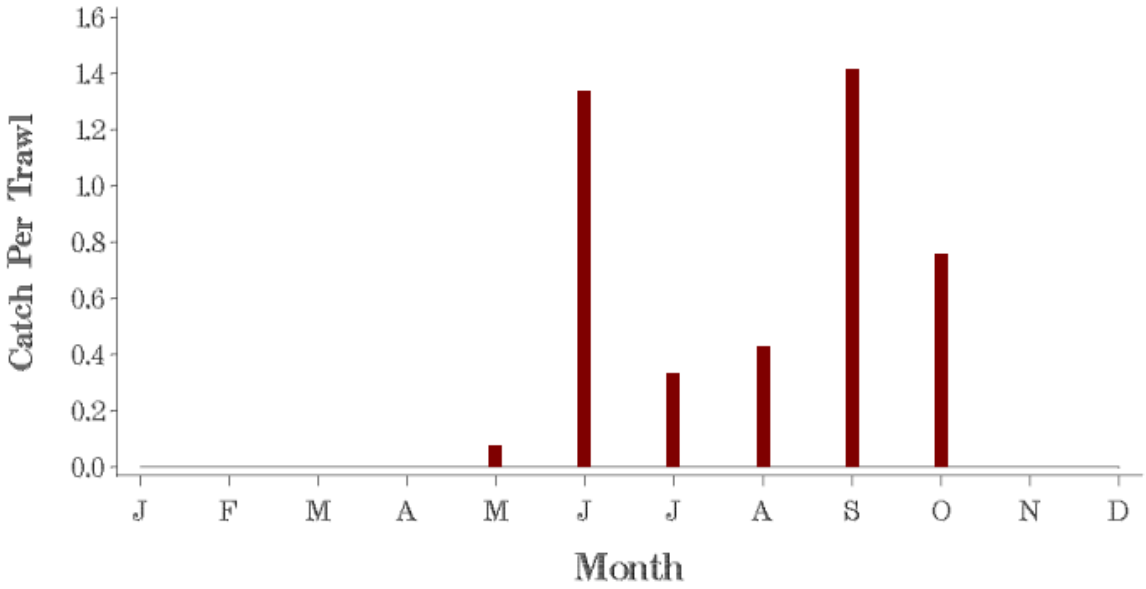


Figure 23. Catch per unit effort for total catch of juvenile bluefish in Chesapeake Bay, from the VIMS seine surveys, 1994-1999 (all years combined). Source: Geer (2002).

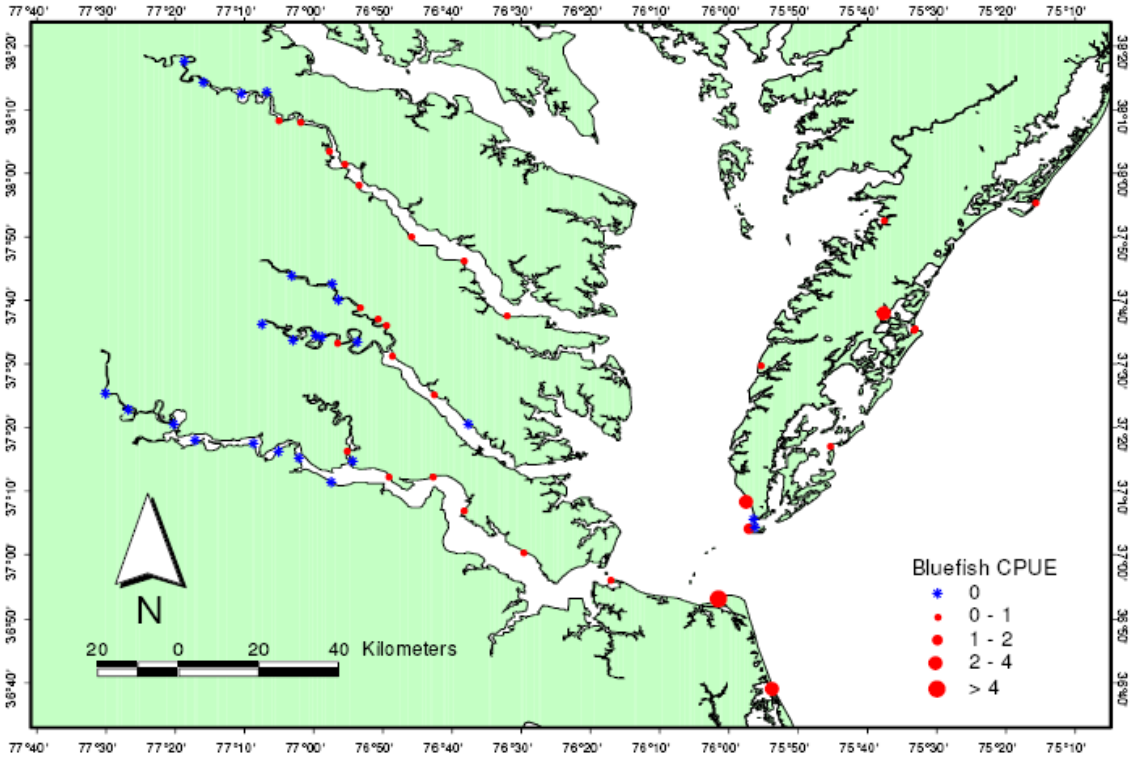


Figure 24. Juvenile bluefish catch per unit effort by site from the VIMS beach seine surveys, 1994-1999 (all years combined). Source: Geer (2002).

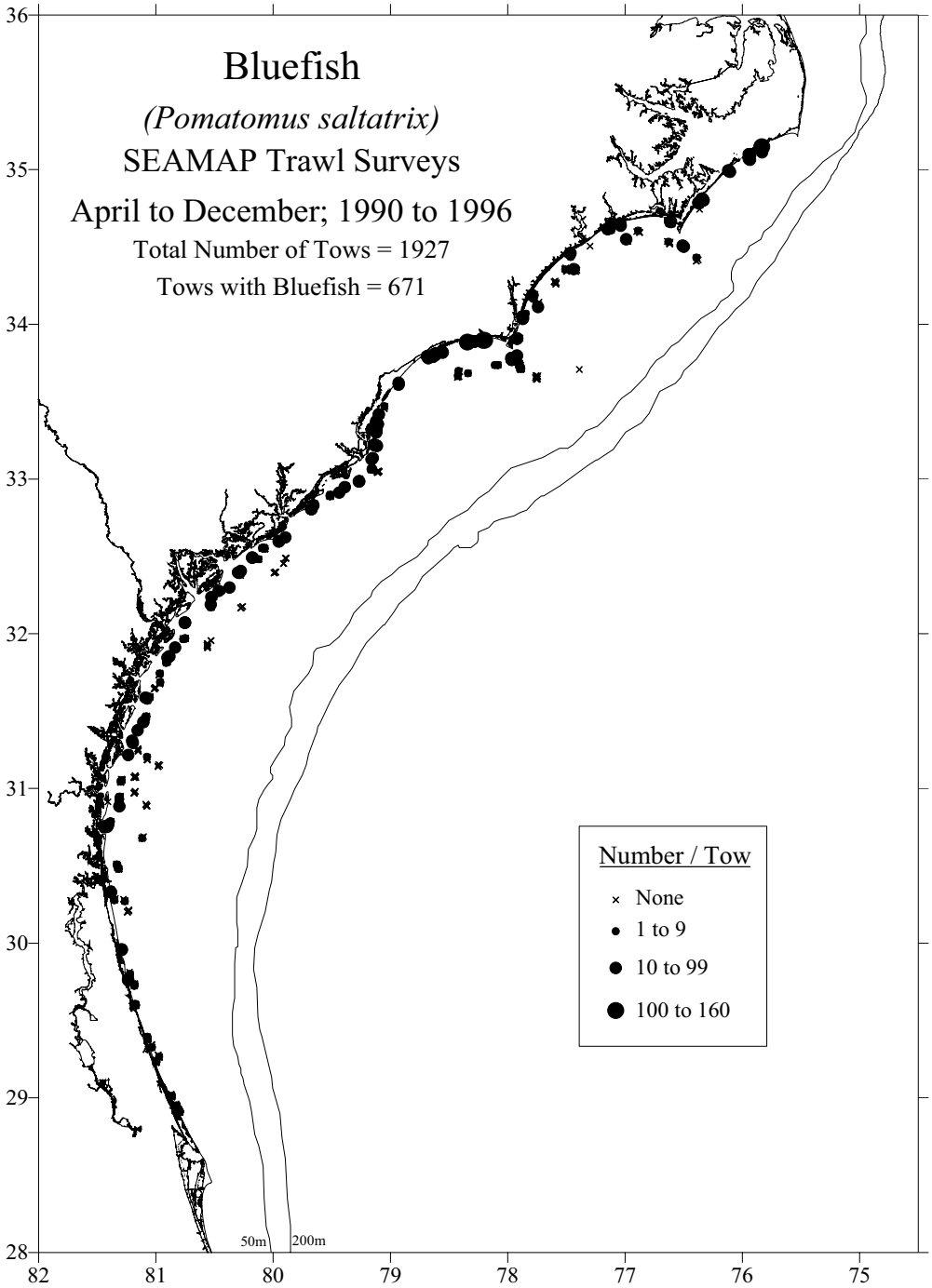


Figure 25. Distribution and abundance of bluefish in the South Atlantic Bight collected during SEAMAP bottom trawl surveys [1990-1996, all years combined; see Reid *et al.* (1999) for details].

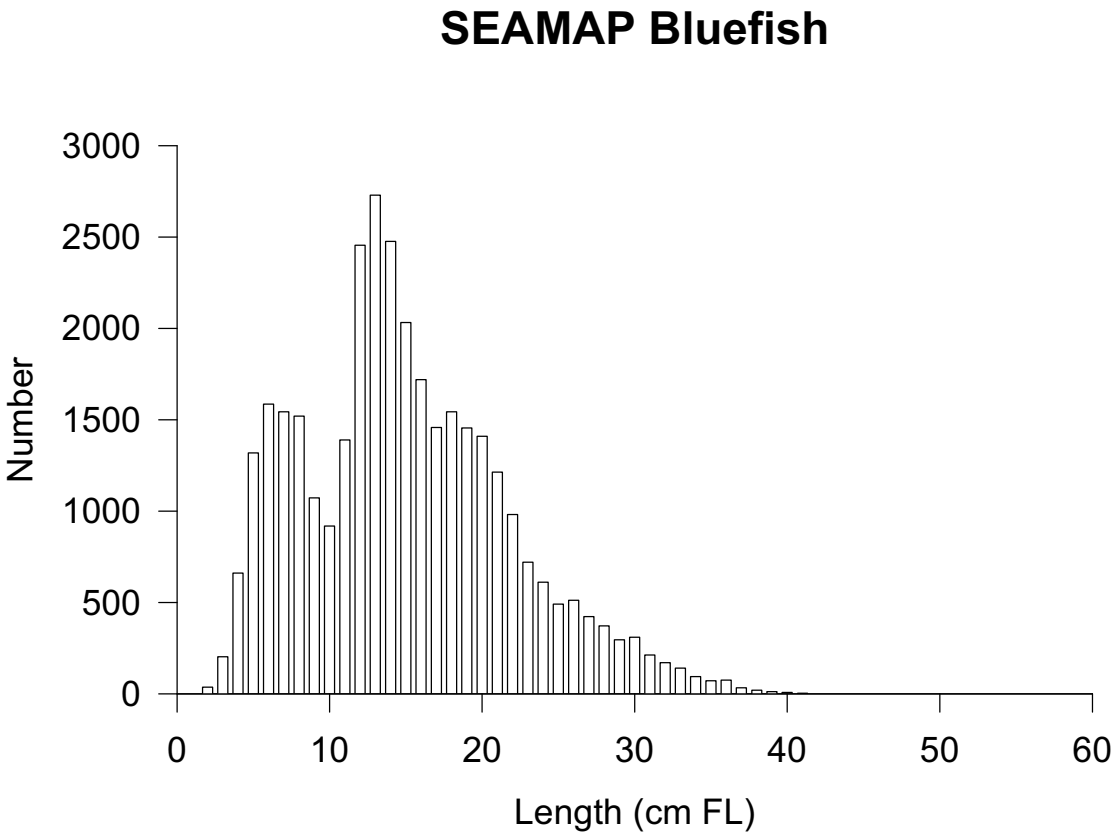


Figure 26. Length frequency distribution of bluefish in the South Atlantic Bight collected during SEAMAP bottom trawl surveys (1990-1996, all years combined).

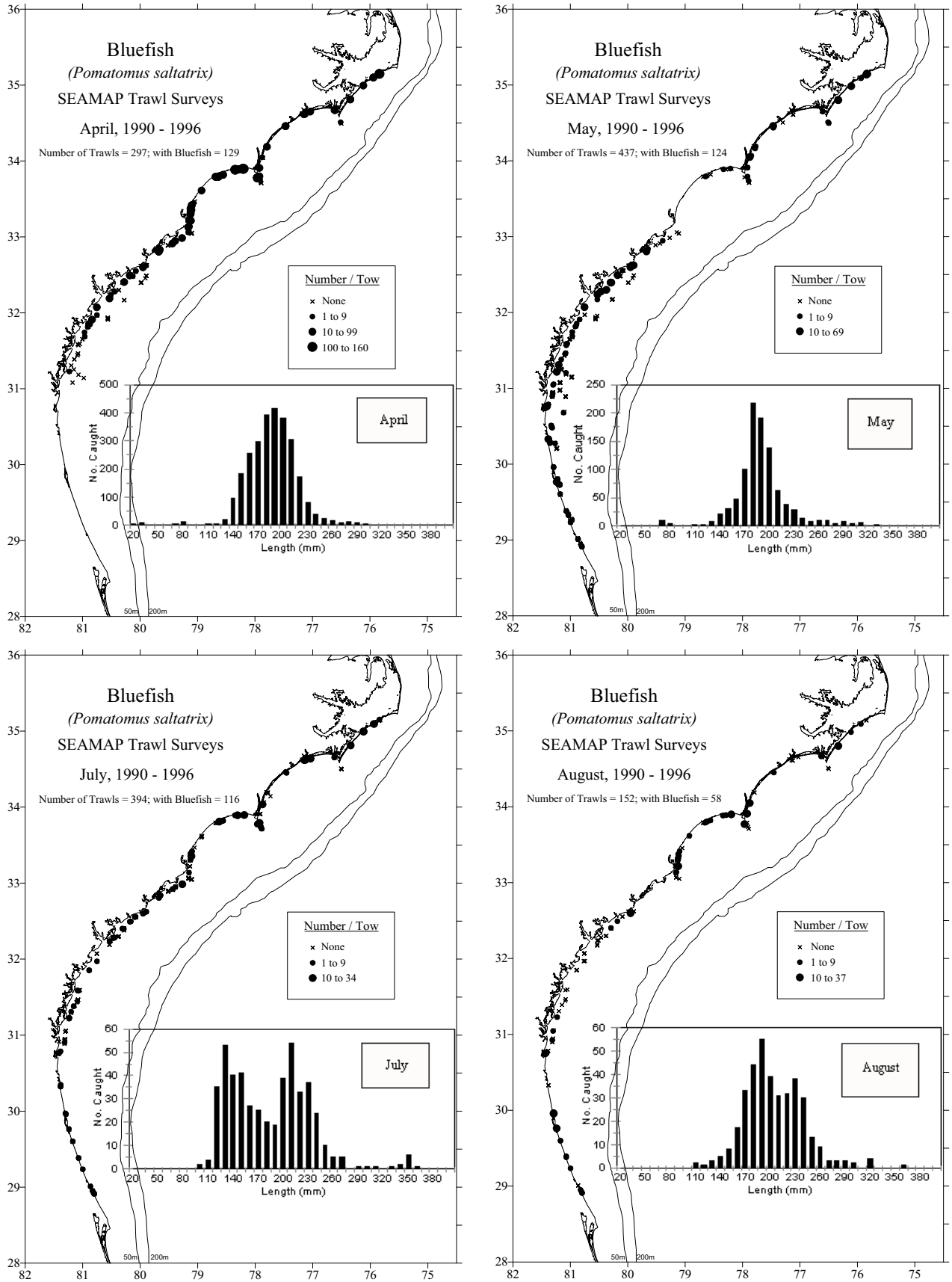


Figure 27. Monthly distribution, abundance, and length frequency distribution of bluefish in the South Atlantic Bight collected during SEAMAP bottom trawl surveys (1990-1996, all years combined).

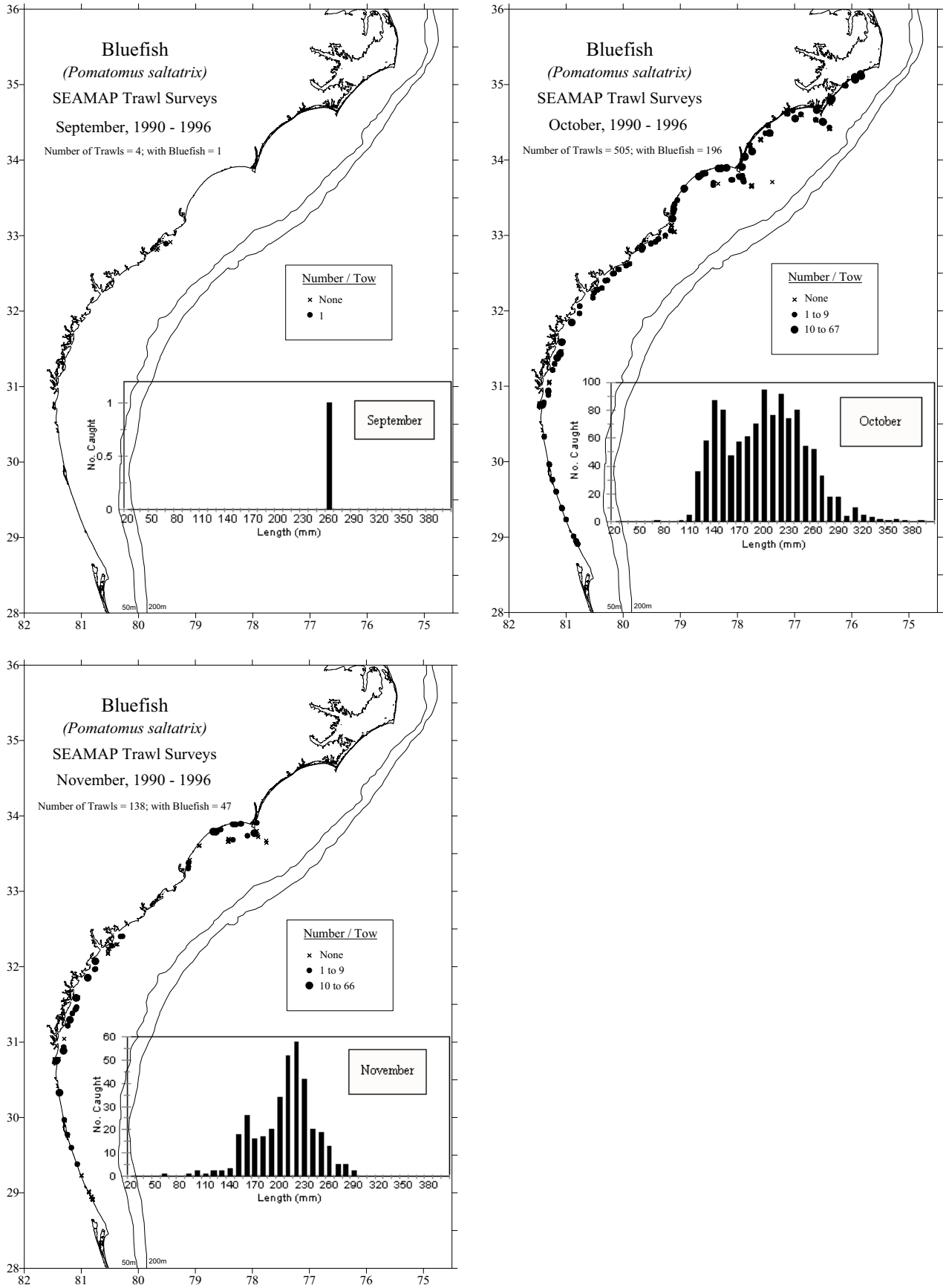


Figure 27. Continued.

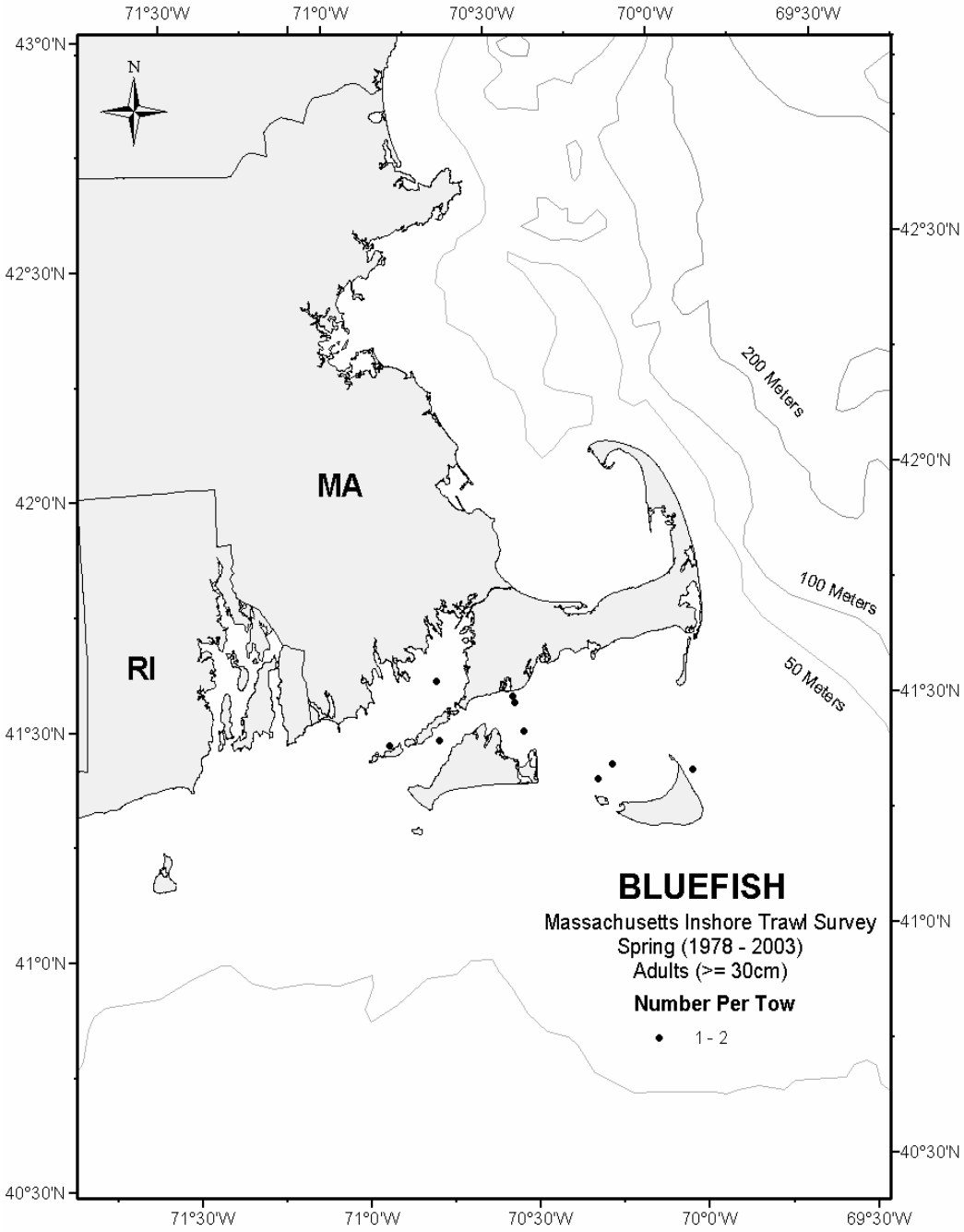


Figure 28. Distributions and abundances of adult bluefish in Massachusetts coastal waters collected during the spring and fall Massachusetts inshore trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.

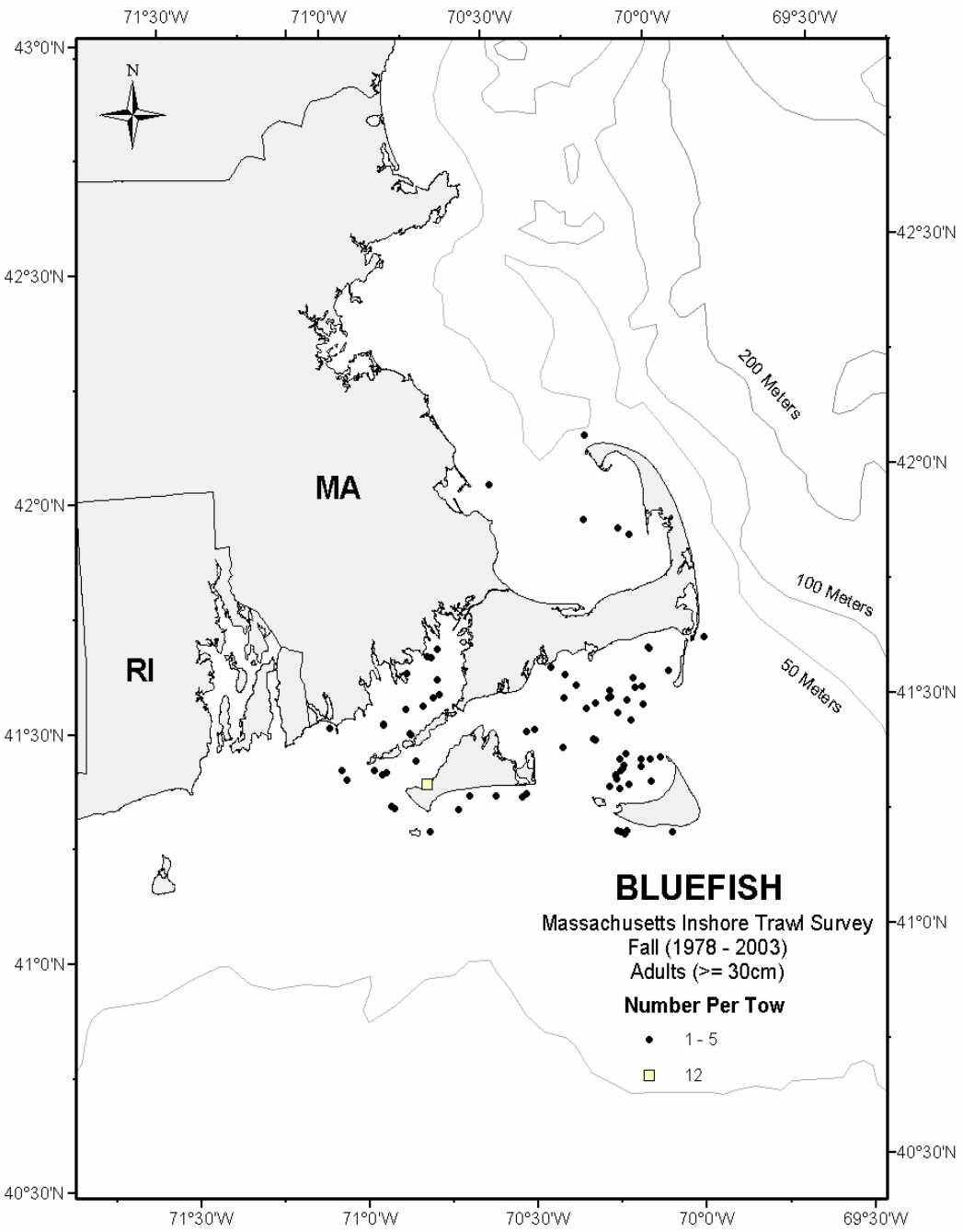


Figure 28. Continued.

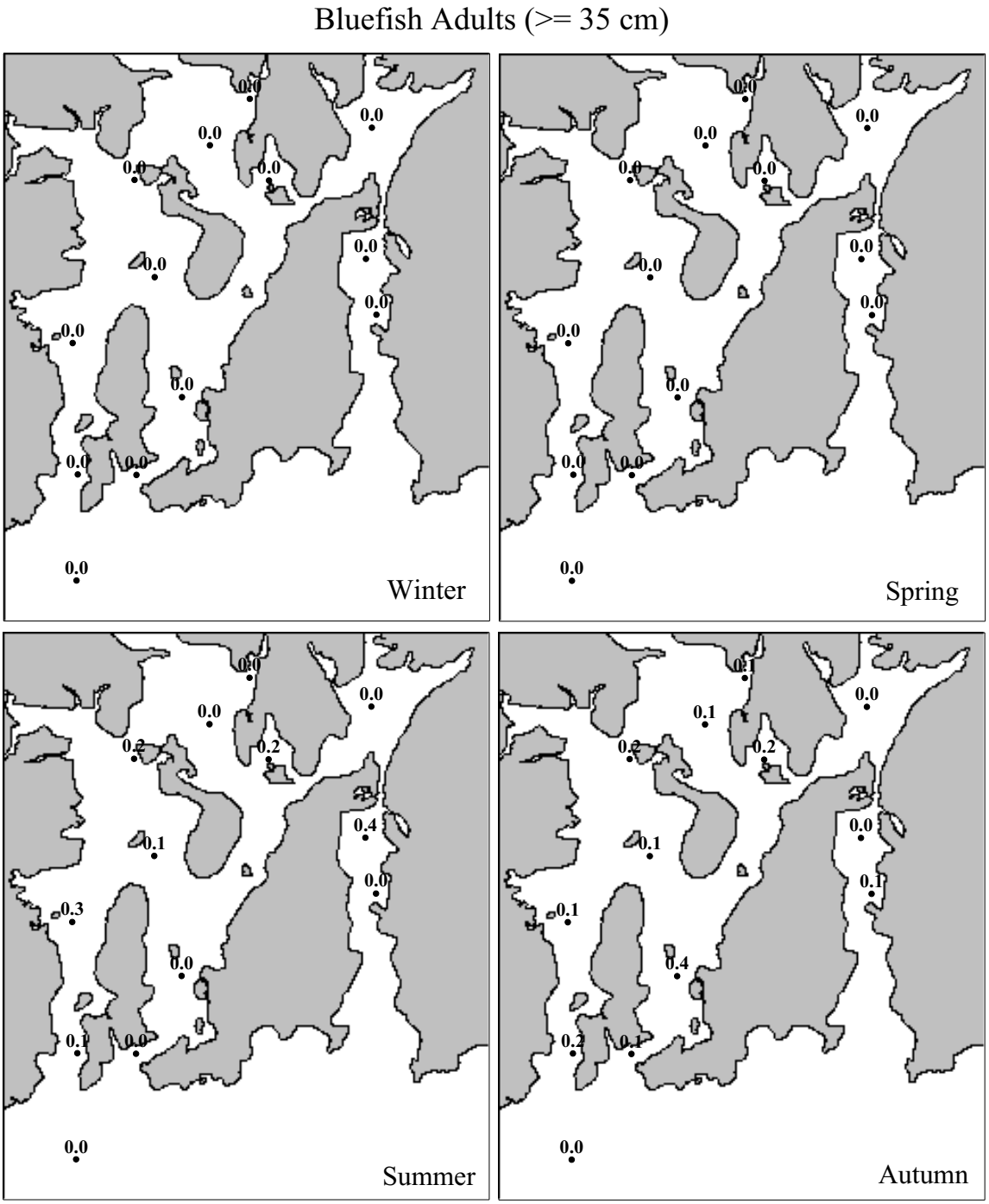


Figure 29. Distributions and abundances of adult bluefish collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid et al. (1999) for details].

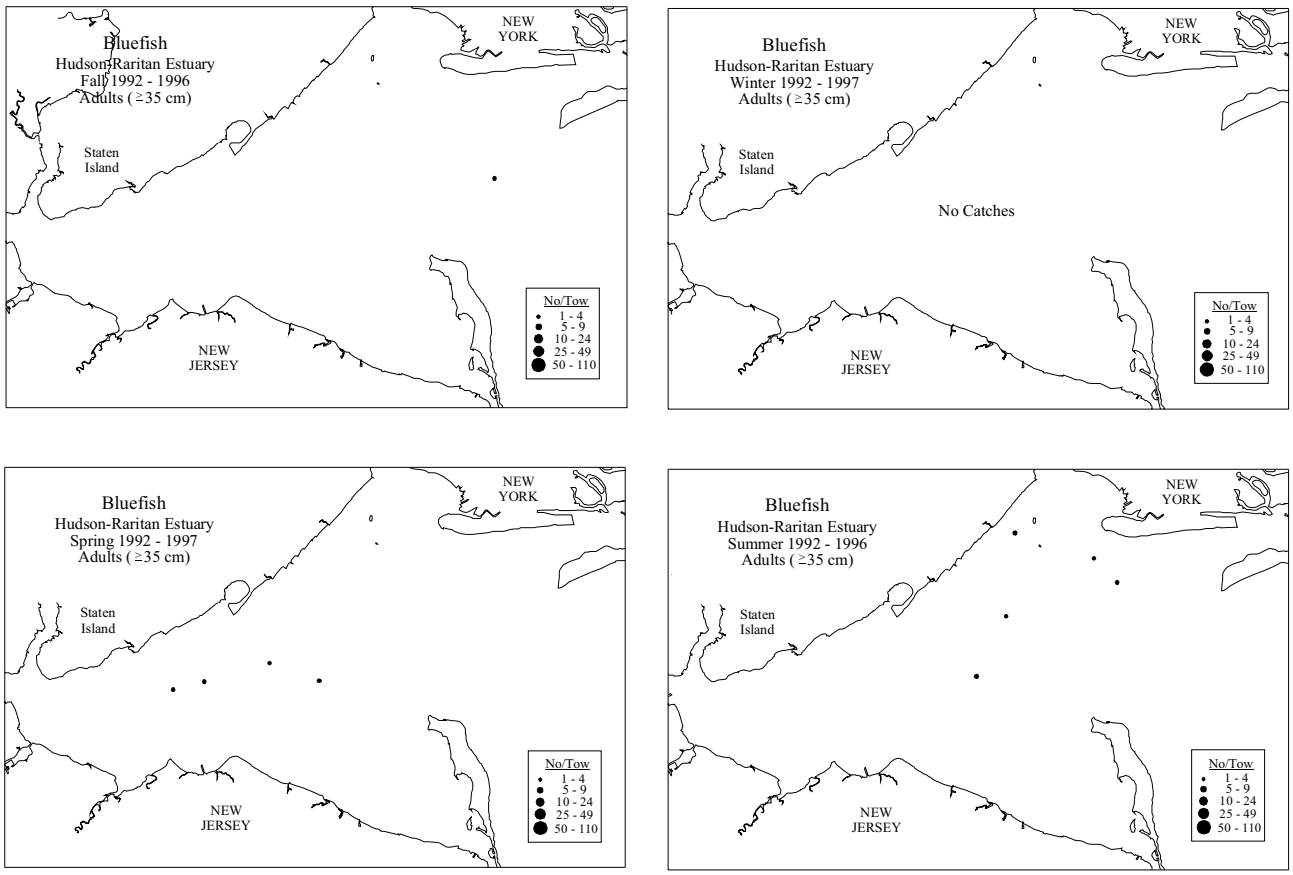


Figure 30. Seasonal distribution and abundance of adult bluefish in the Hudson-Raritan estuary collected during Hudson-Raritan estuary trawl surveys, 1992–1997 [see Reid *et al.* (1999) for details].

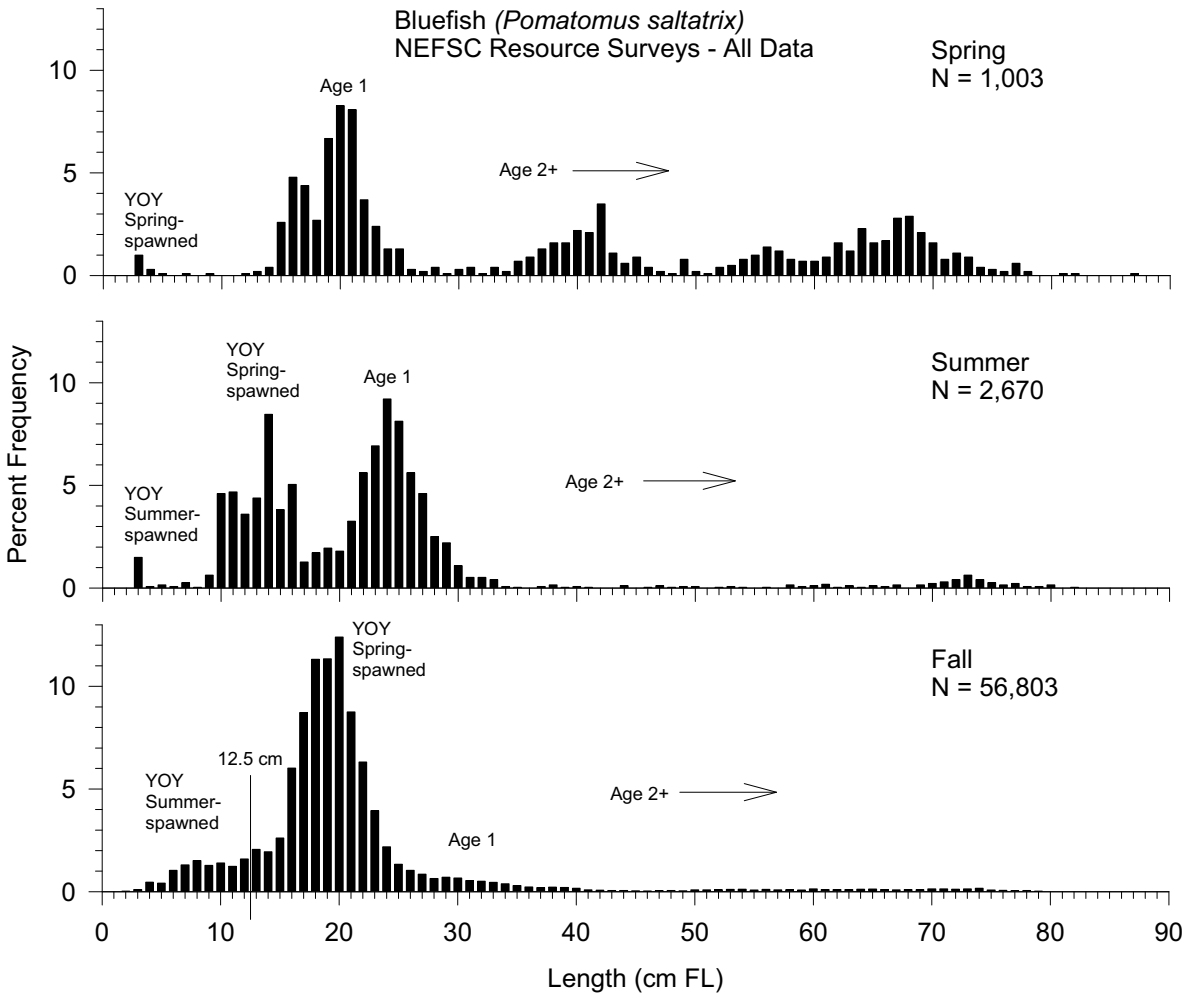


Figure 31. Seasonal length frequency distributions used to determine bluefish size and age cutoffs in NEFSC bottom trawl surveys.

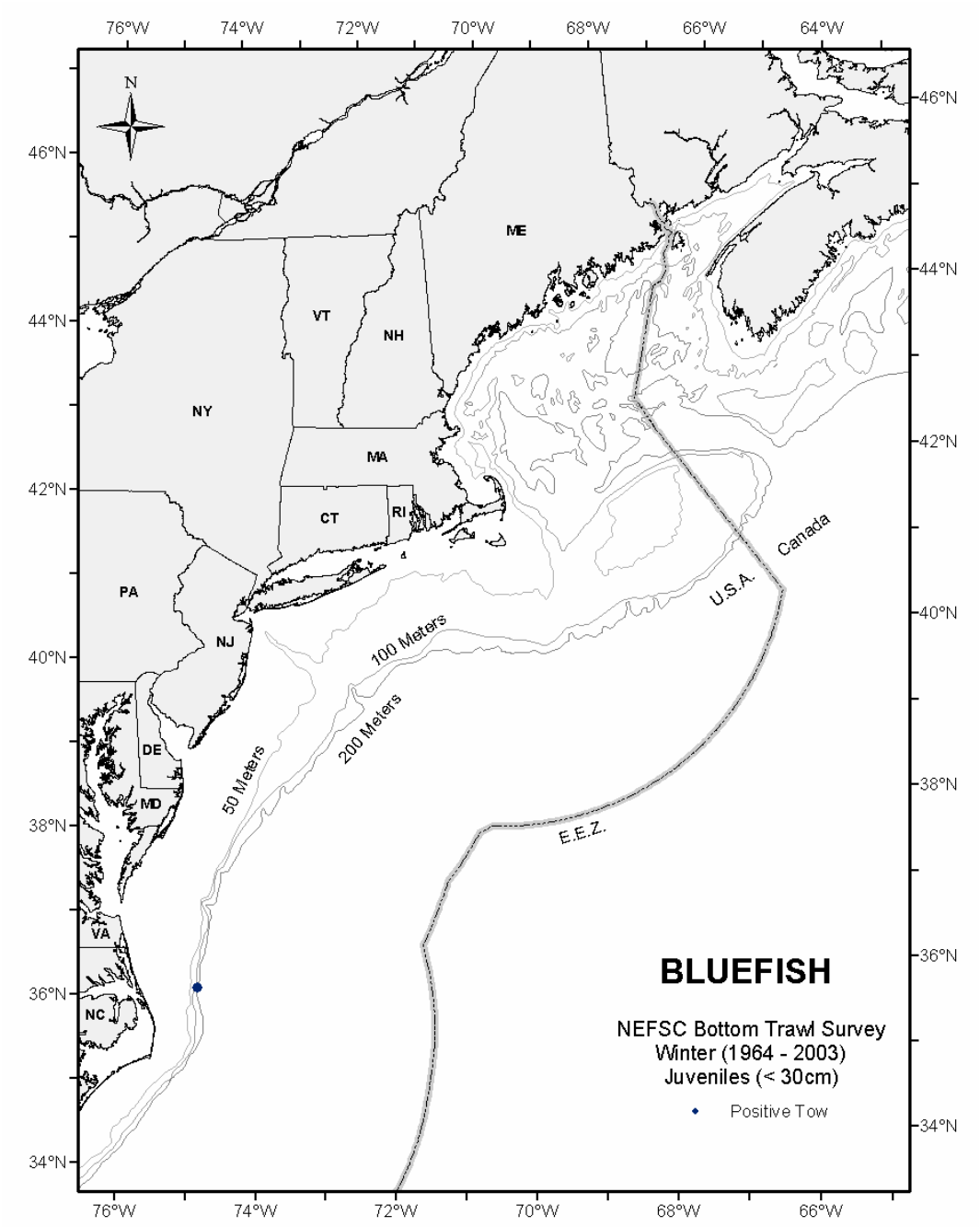


Figure 32. Distributions and abundances of juvenile and adult bluefish collected during winter NEFSC bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence only.

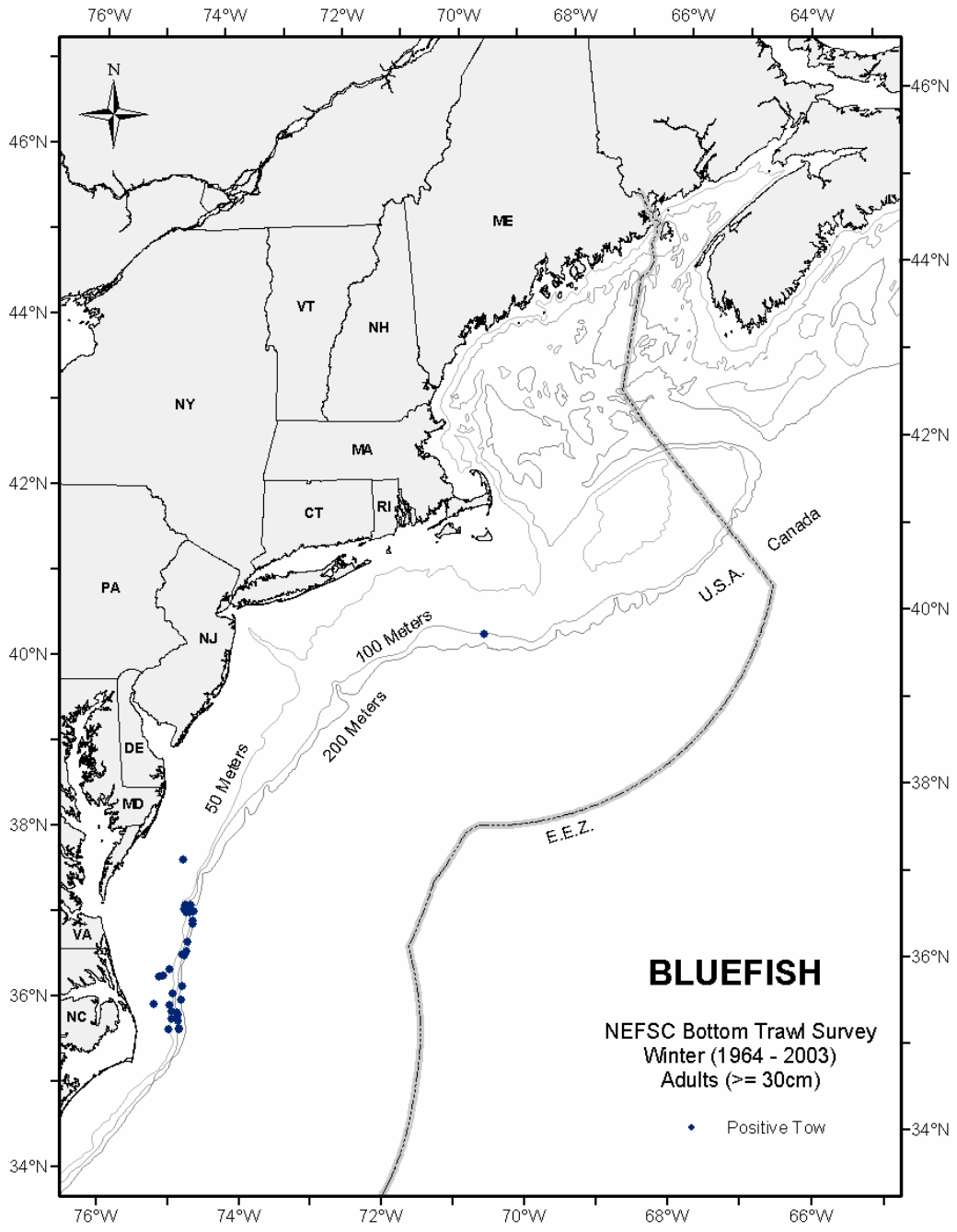


Figure 32. Continued.

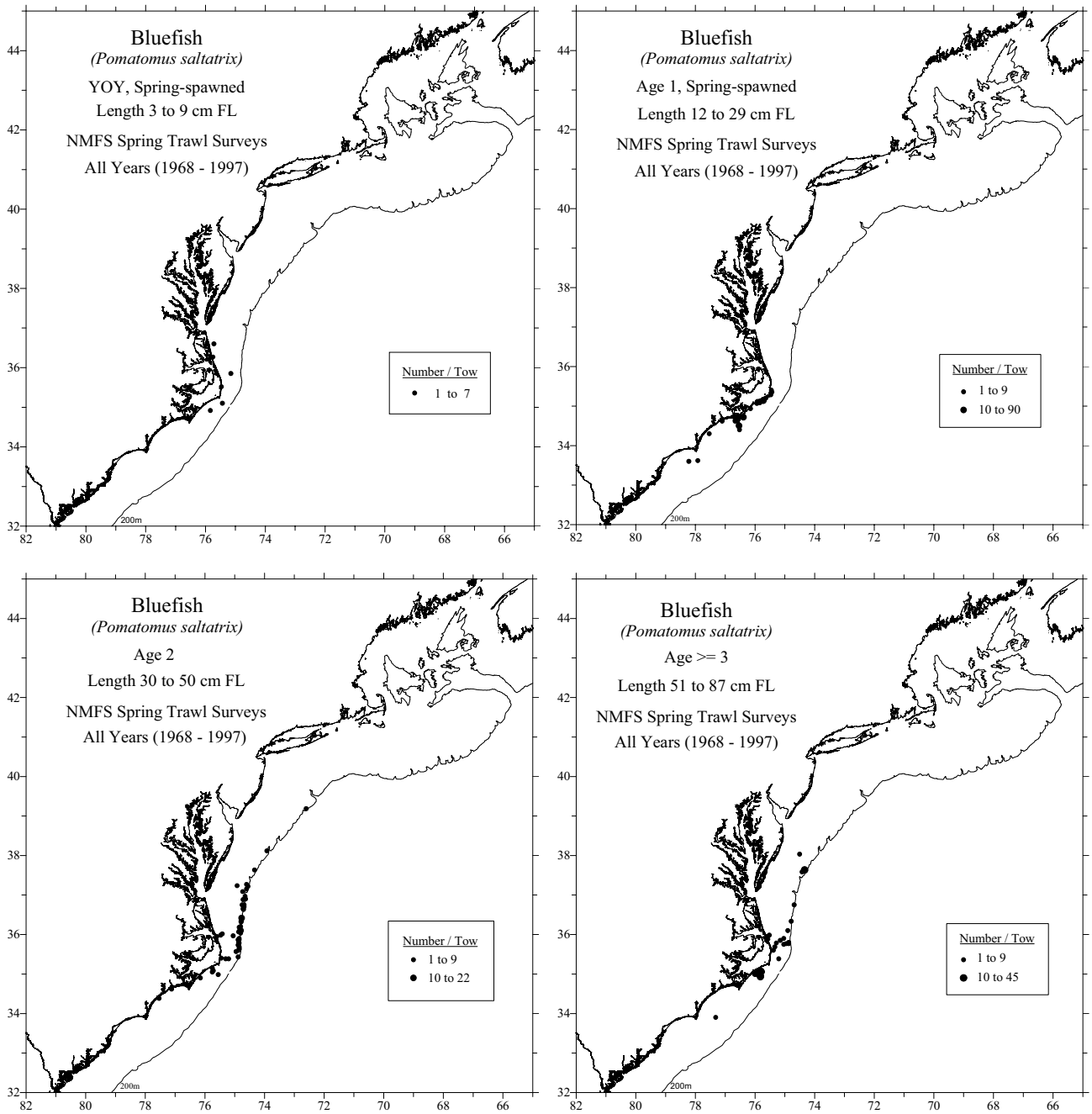


Figure 33. Distributions and abundances of four size classes of bluefish collected during spring NEFSC bottom trawl surveys (1968-1997, all years combined). Survey stations where bluefish were not found are not shown.

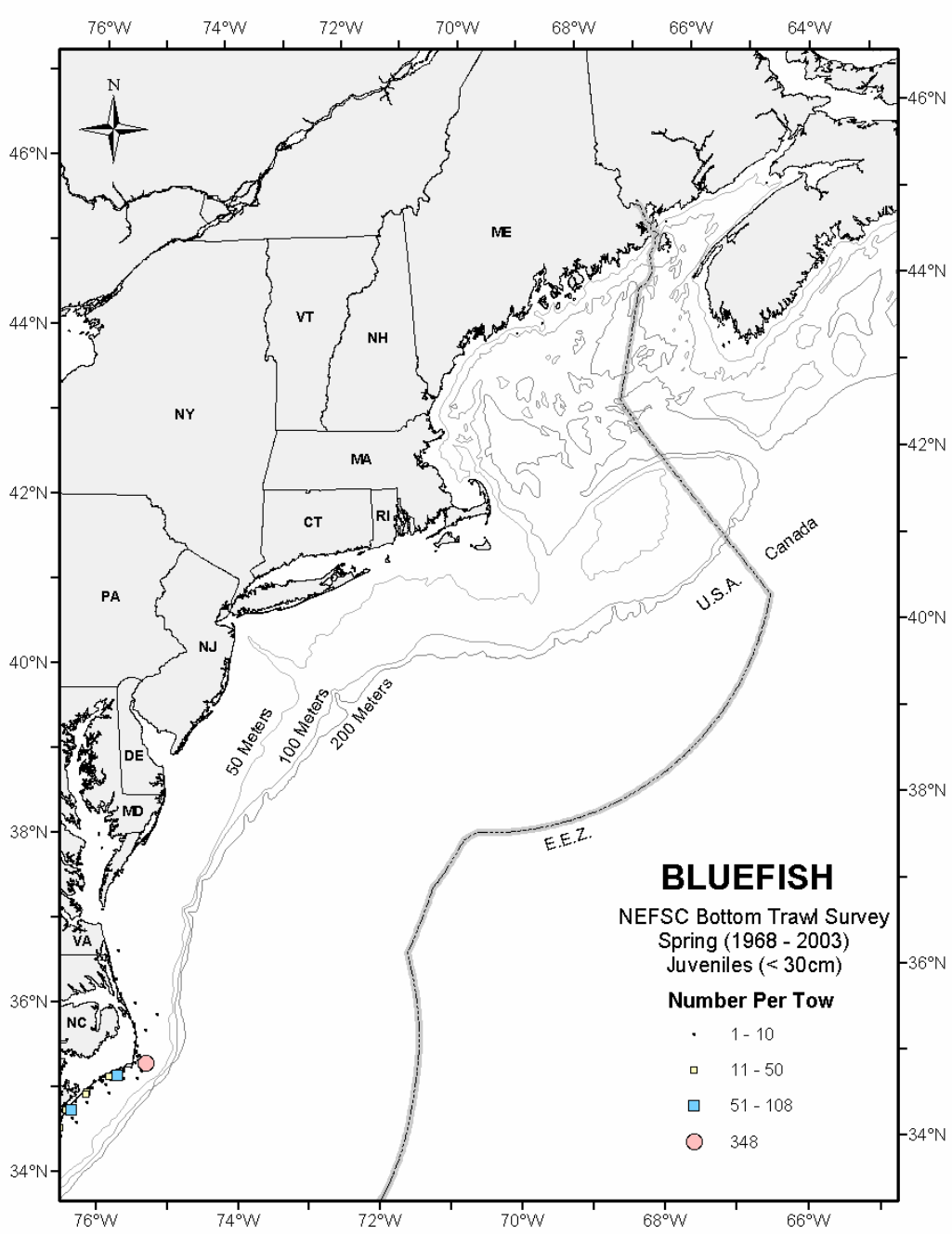


Figure 34. Distributions and abundances of juvenile and adult bluefish collected during spring NEFSC bottom trawl surveys (1968-2003, all years combined). Survey stations where bluefish were not found are not shown.

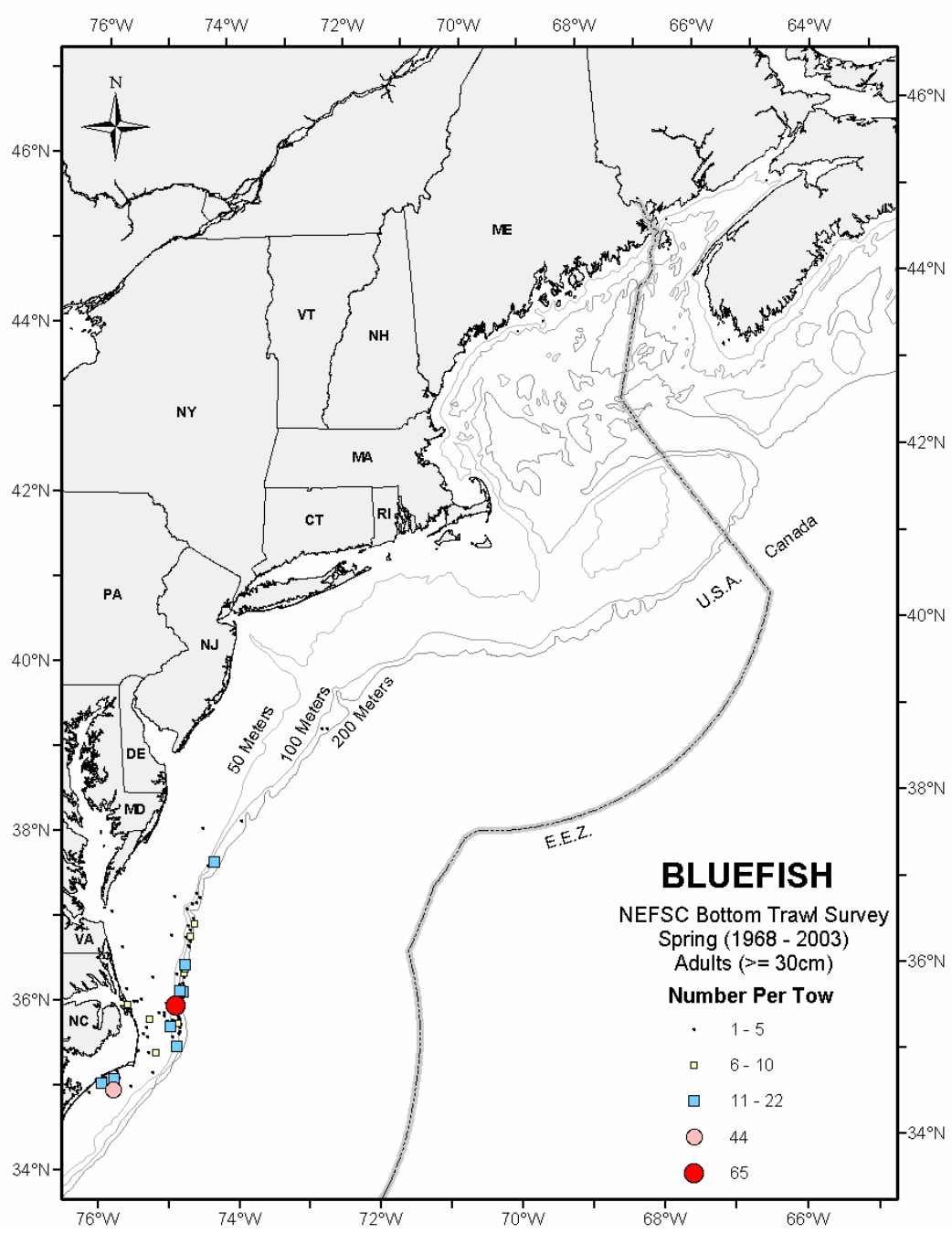


Figure 34. Continued.

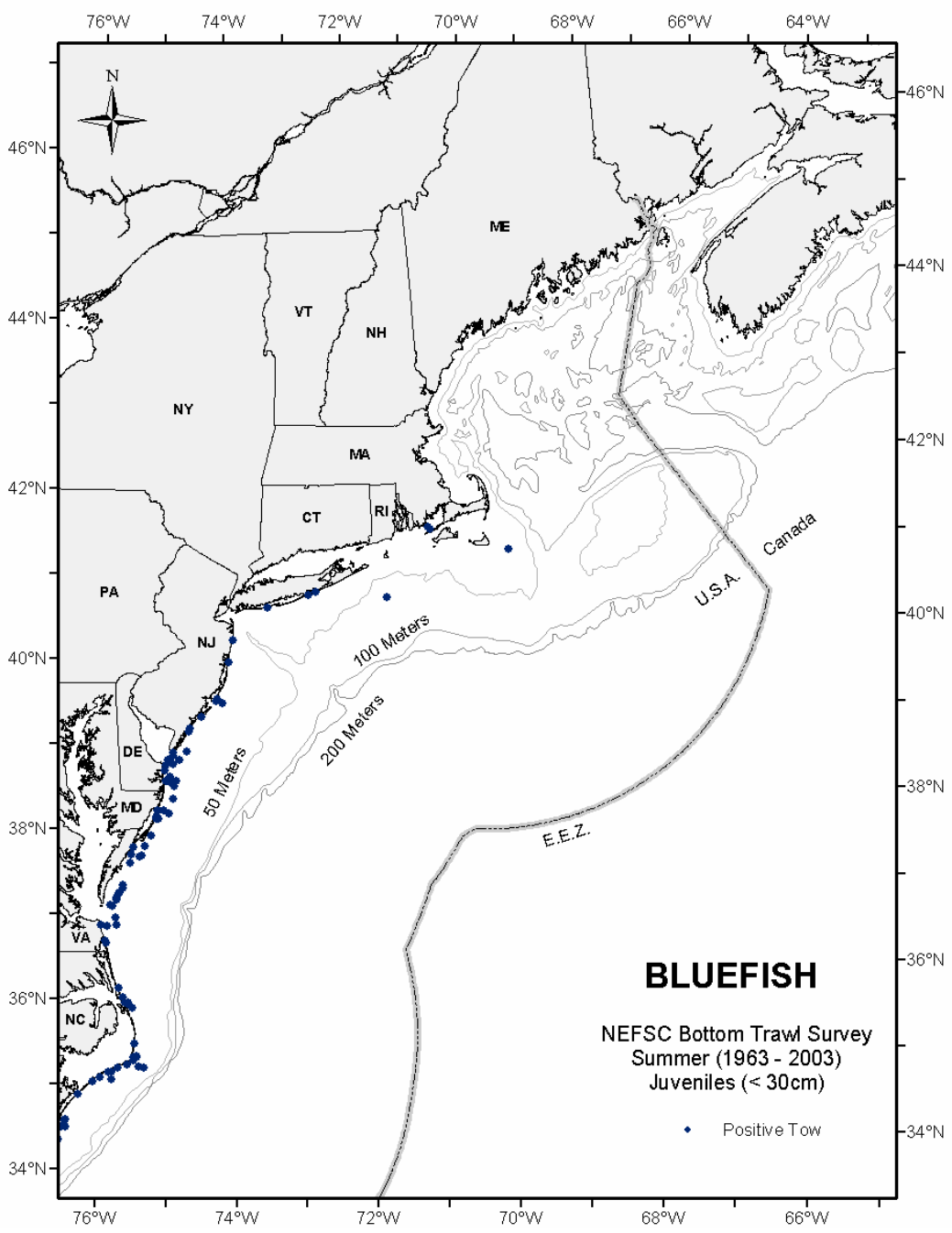


Figure 35. Distributions and abundances of juvenile and adult bluefish collected during summer NEFSC bottom trawl surveys (1963-2003, all years combined). Distributions are displayed as presence only.

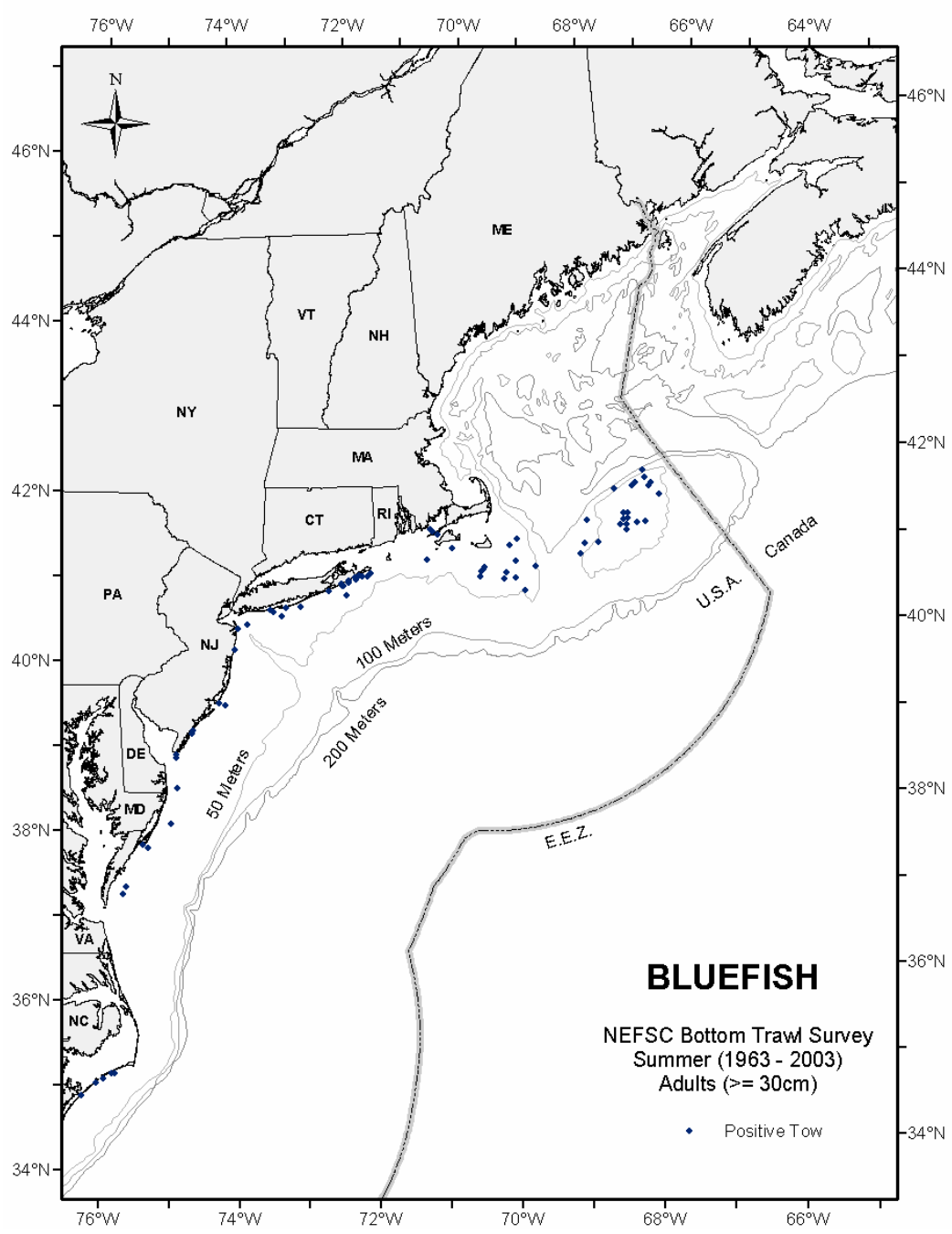


Figure 35. Continued.

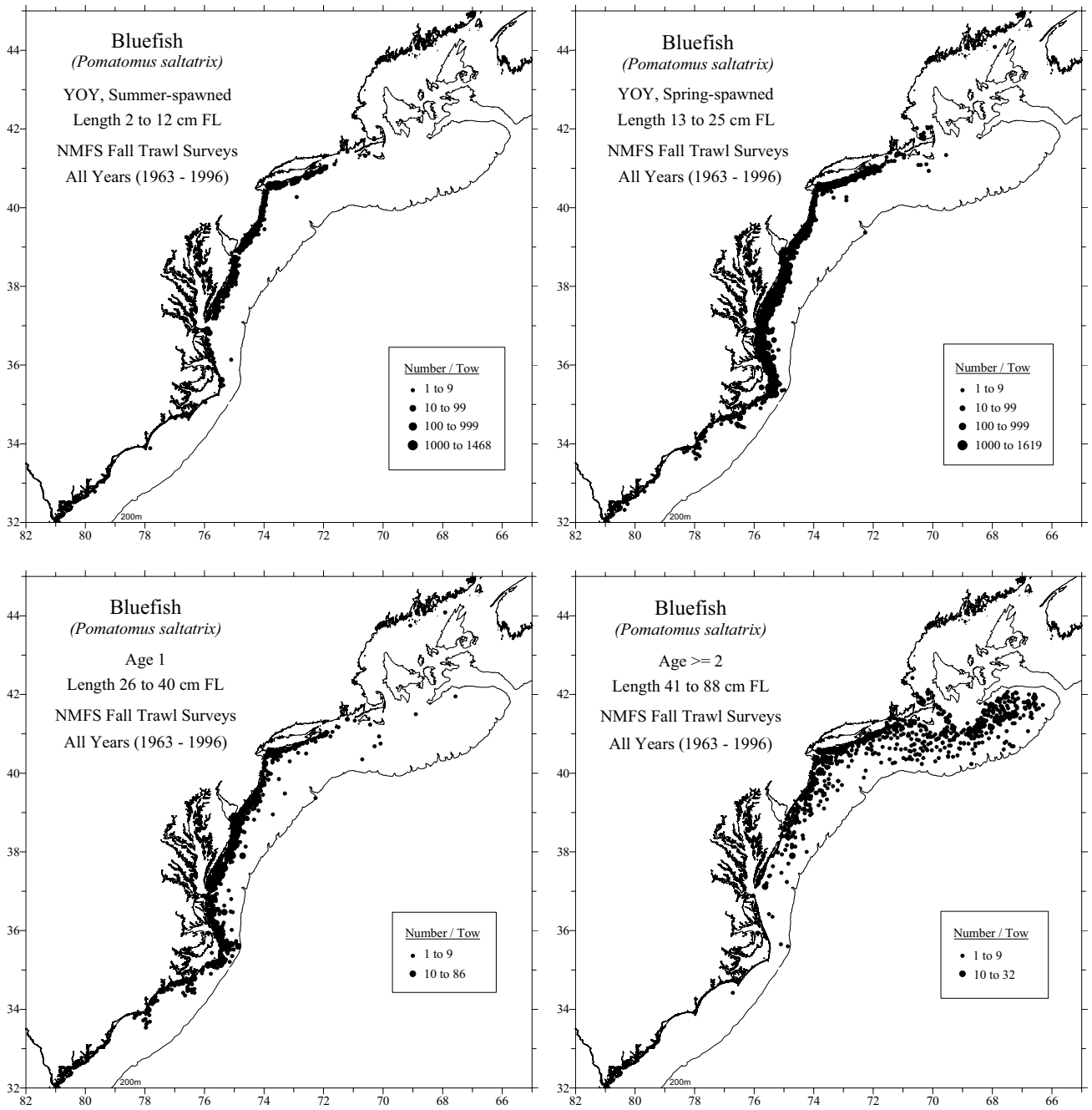


Figure 36. Distributions and abundances of four size classes of bluefish collected during fall NEFSC bottom trawl surveys (1963-1996, all years combined). Survey stations where bluefish were not found are not shown.

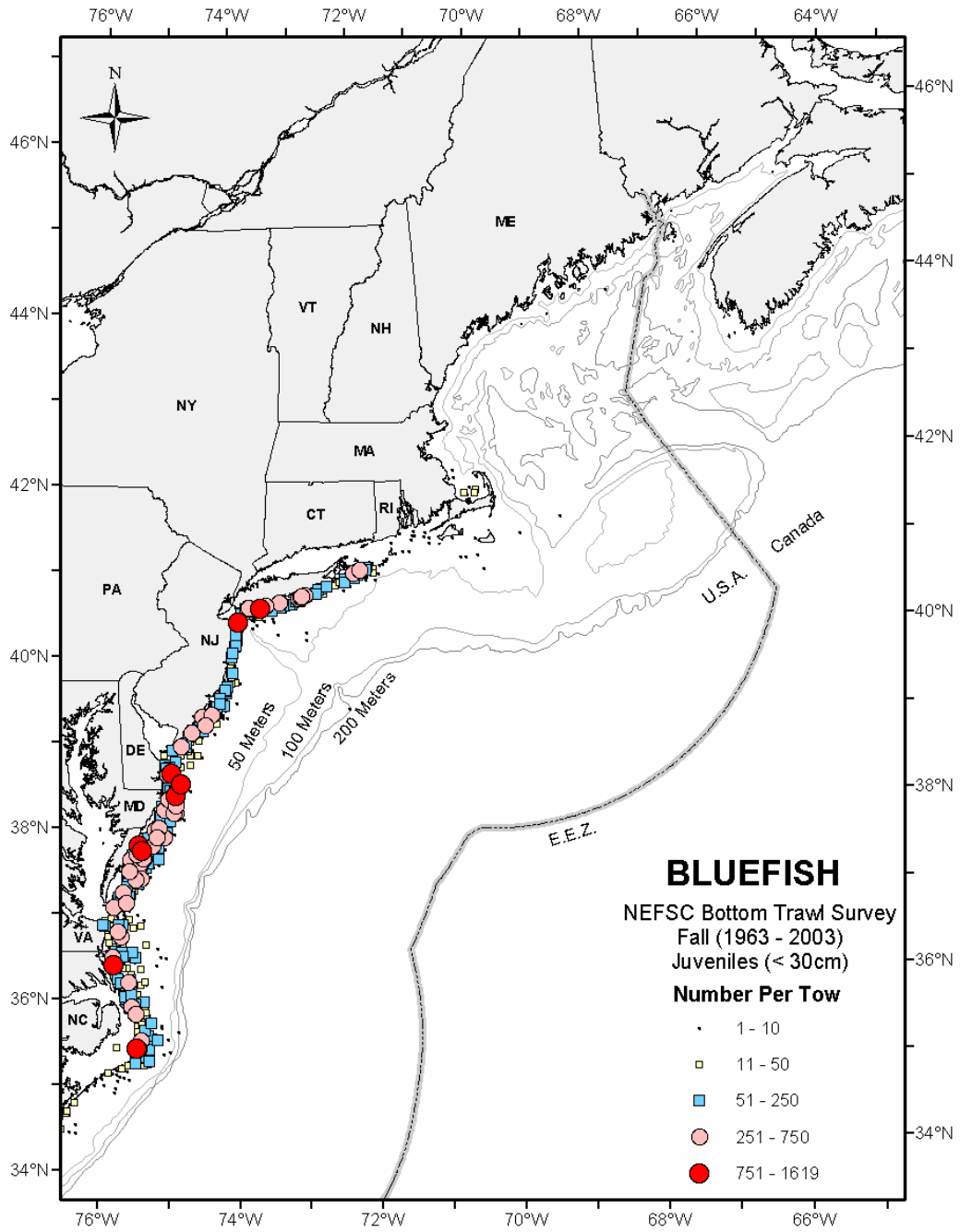


Figure 37. Distributions and abundances of juvenile and adult bluefish collected during fall NEFSC bottom trawl surveys (1963-2003, all years combined). Survey stations where bluefish were not found are not shown.

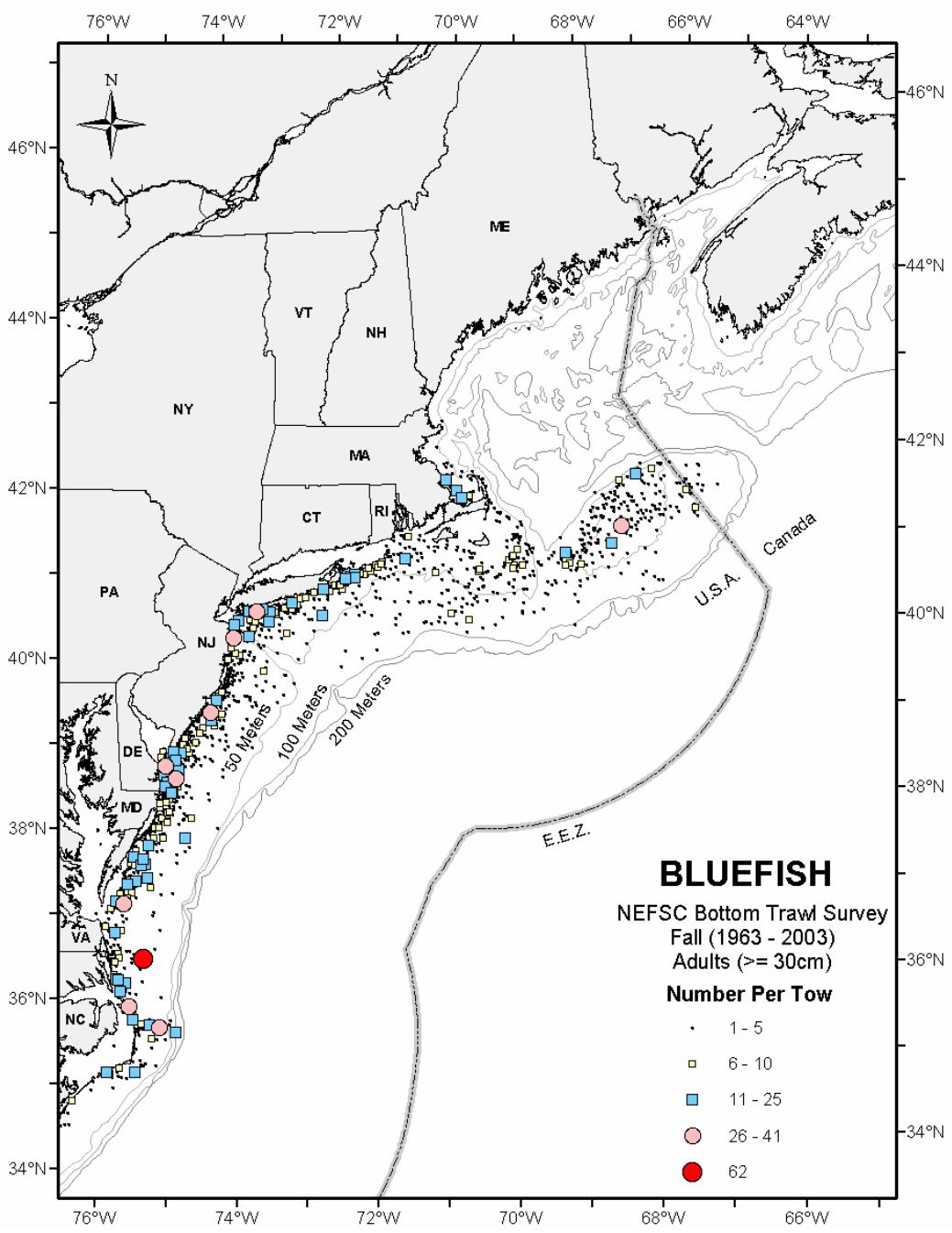


Figure 37. Continued.

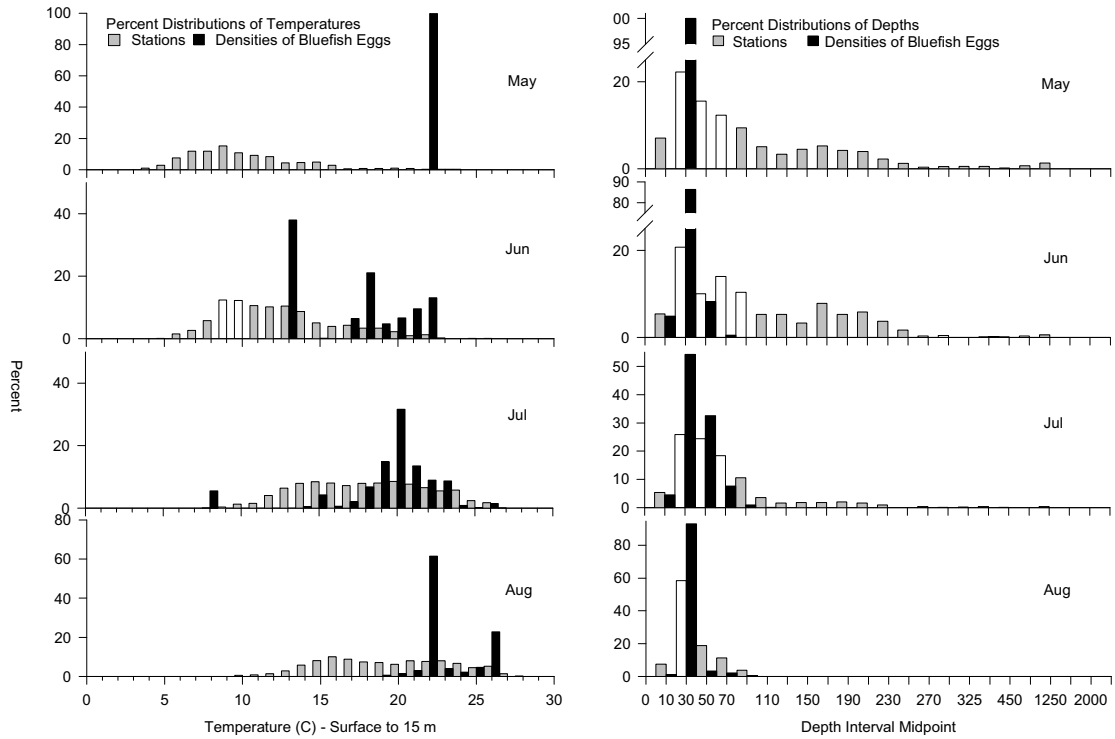


Figure 38. Distributions of bluefish eggs collected during NEFSC MARMAP ichthyoplankton surveys relative to near-surface water column temperature and depth, from May- August 1978-1987, all years combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth interval changes with increasing depth.

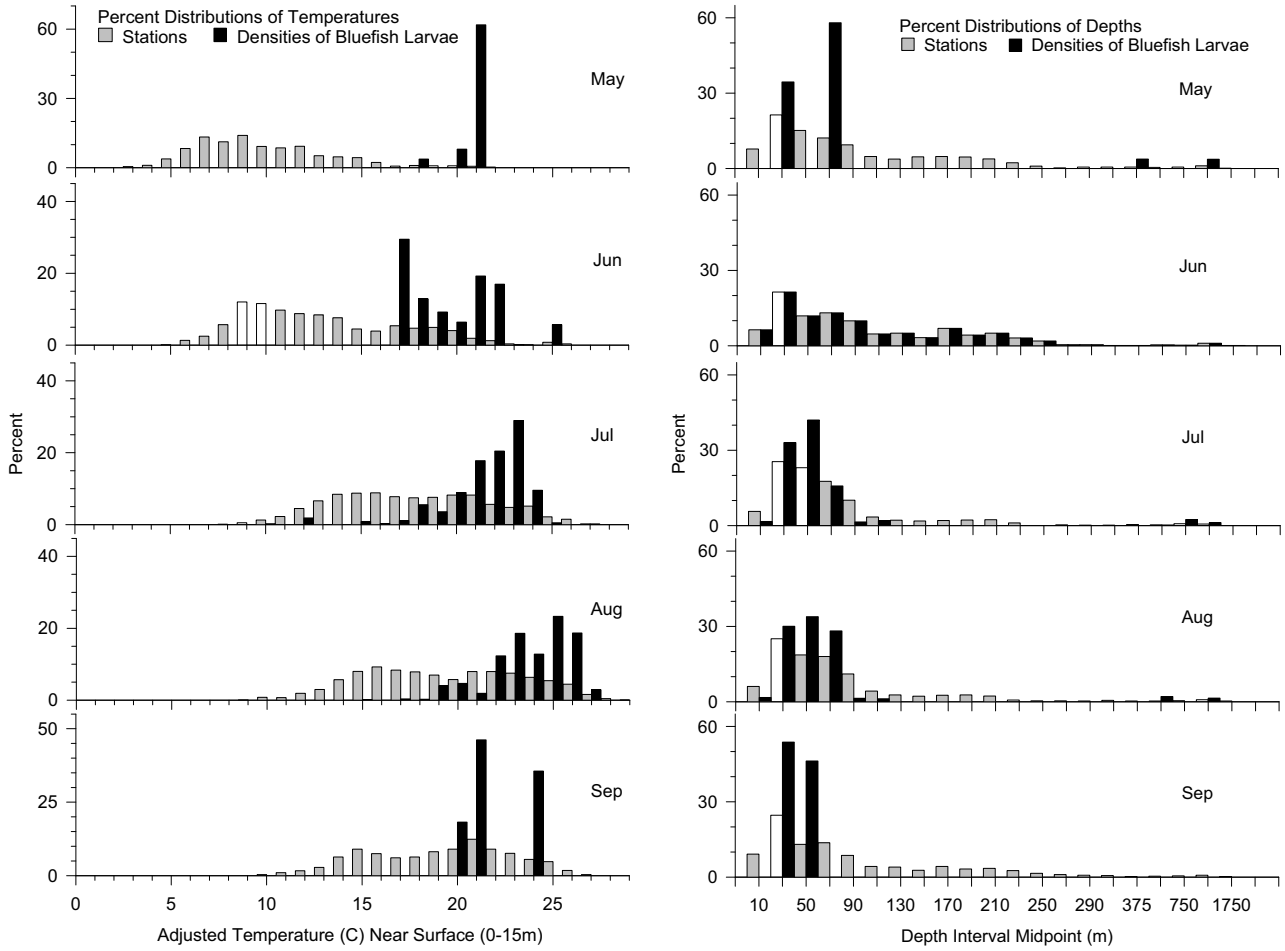


Figure 39. Distributions of bluefish larvae collected during NEFSC MARMAP ichthyoplankton surveys relative to near-surface water column temperature and depth, from May- September 1977-1987, all years combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth interval changes with increasing depth.

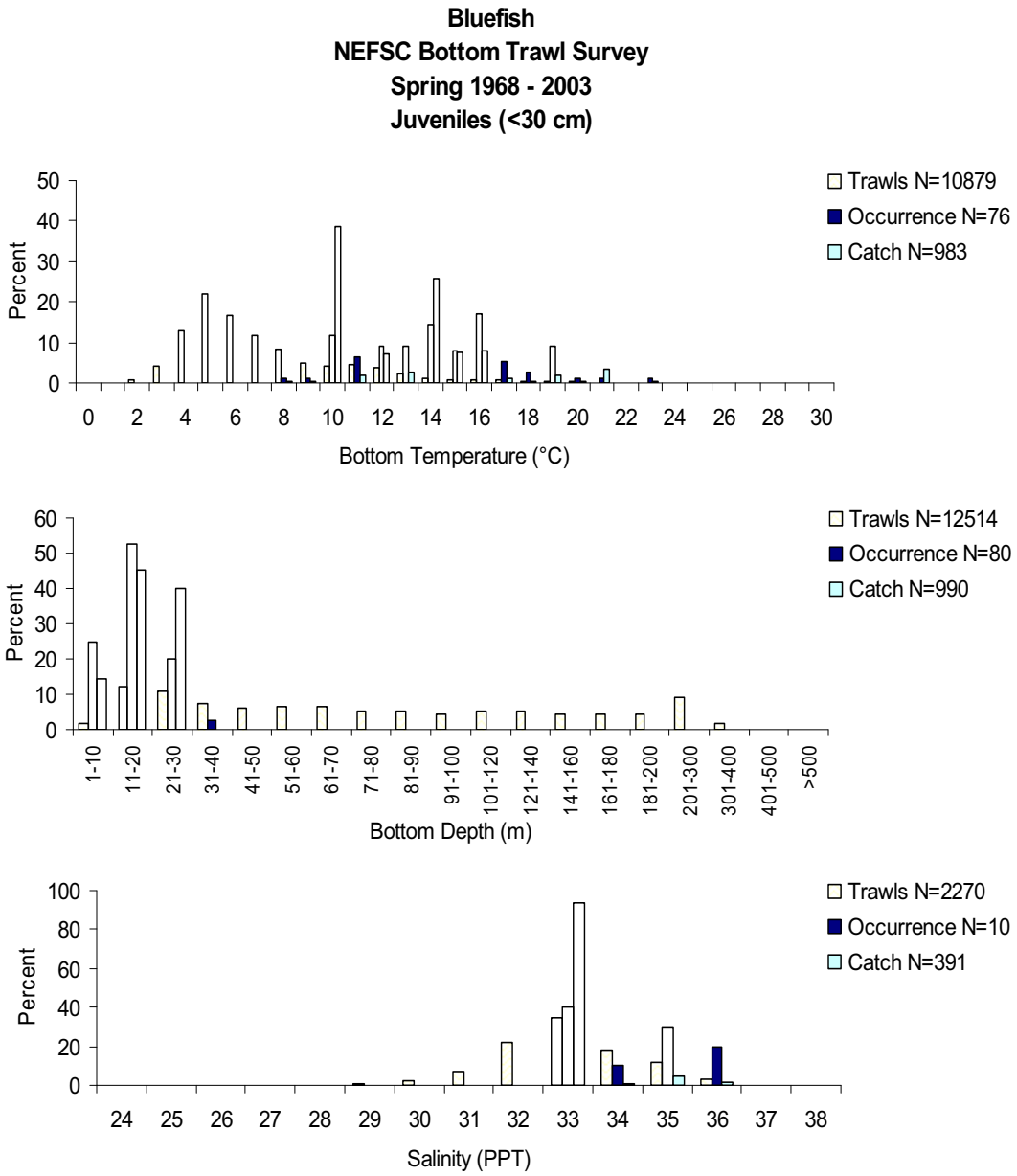


Figure 40. Distributions of juvenile bluefish and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity, based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which bluefish occurred and medium bars show, within each interval, the percentage of the total number of bluefish caught. Note that the bottom depth interval changes with increasing depth.

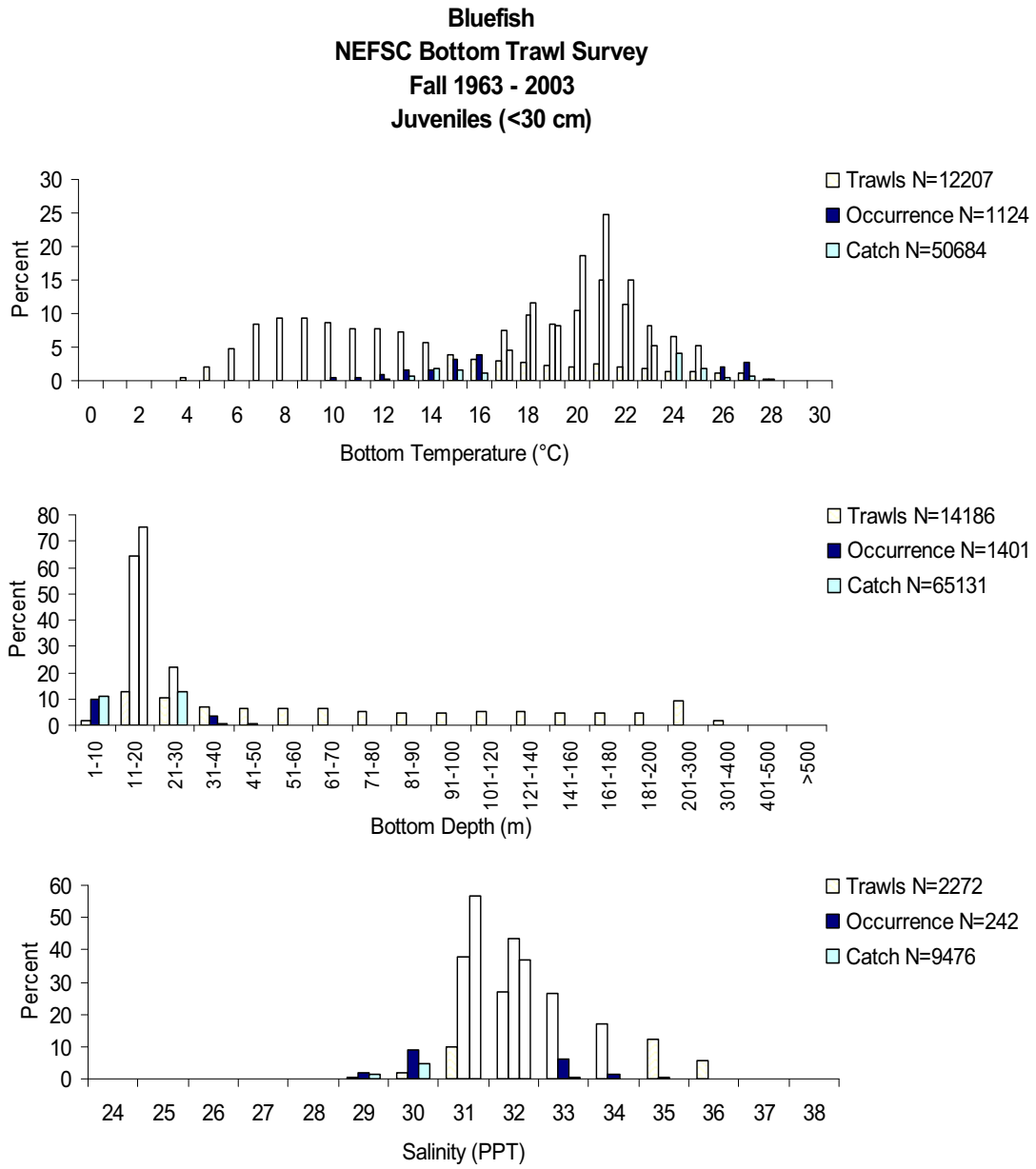


Figure 40. Continued.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which bluefish occurred and medium bars show, within each interval, the percentage of the total number of bluefish caught. Note that the bottom depth interval changes with increasing depth.

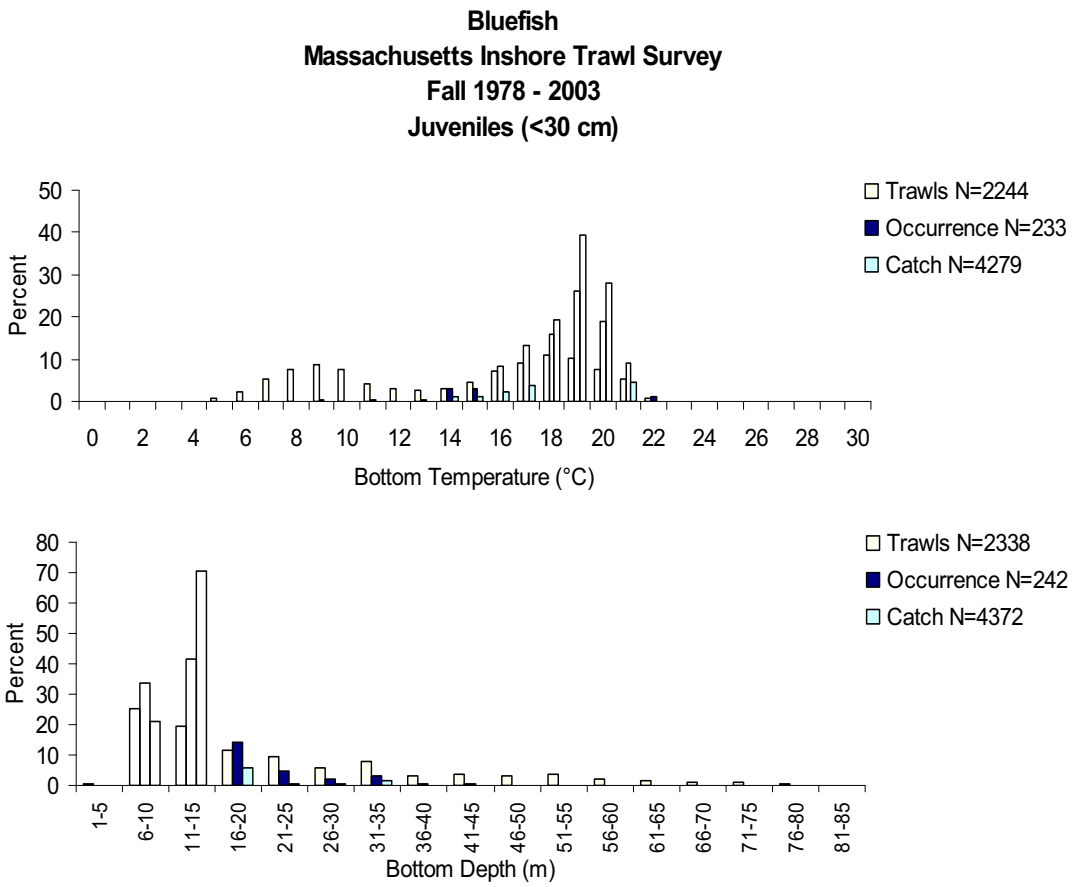


Figure 41. Distributions of juvenile bluefish and trawls in Massachusetts coastal waters relative to bottom water temperature and depth, based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which bluefish occurred and medium bars show, within each interval, the percentage of the total number of bluefish caught.

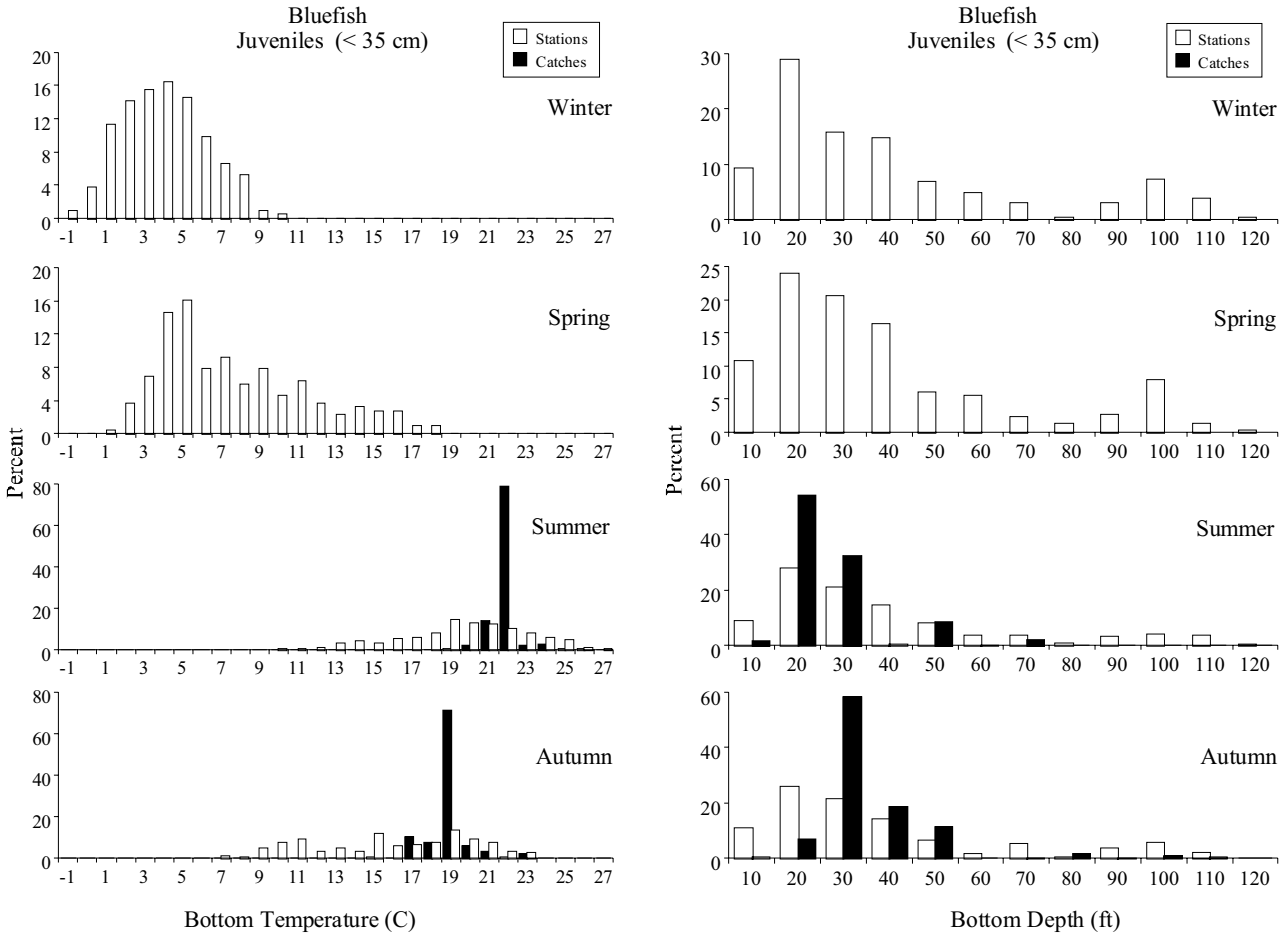


Figure 42. Seasonal distributions of juvenile bluefish and trawls relative to bottom water temperature and depth based on Rhode Island Narragansett Bay trawl surveys (1990-1996; all years combined). White bars give the distribution of all the trawls and black bars represent, within each interval, the percentage of the total number of juveniles caught.

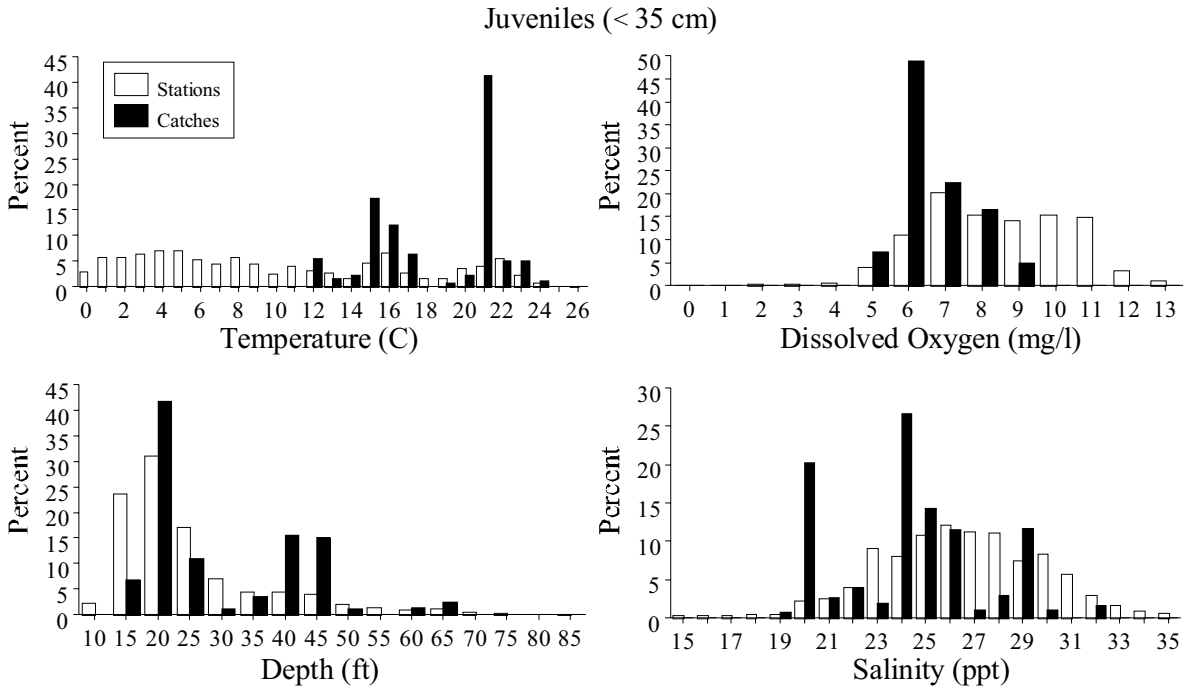


Figure 43. Distributions of juvenile bluefish relative to mean bottom water temperature, dissolved oxygen, depth, and salinity, based on Hudson-Raritan estuary trawl surveys (January 1992 - June 1997, all years combined). Open bars represent stations surveyed and closed bars represent fish collected.

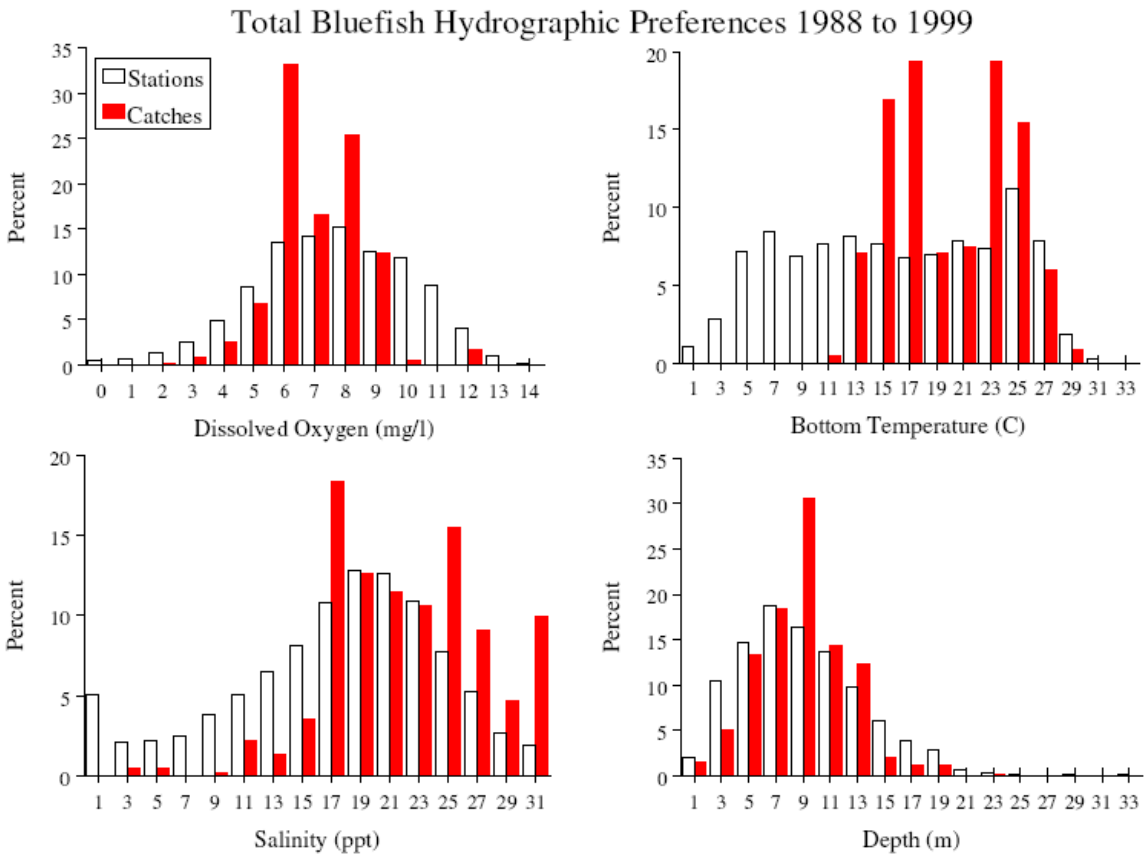


Figure 44. Hydrographic preferences for bluefish in Chesapeake Bay and tributaries, from the VIMS trawl surveys, 1988-1999 (all years combined). Source: Geer (2002).

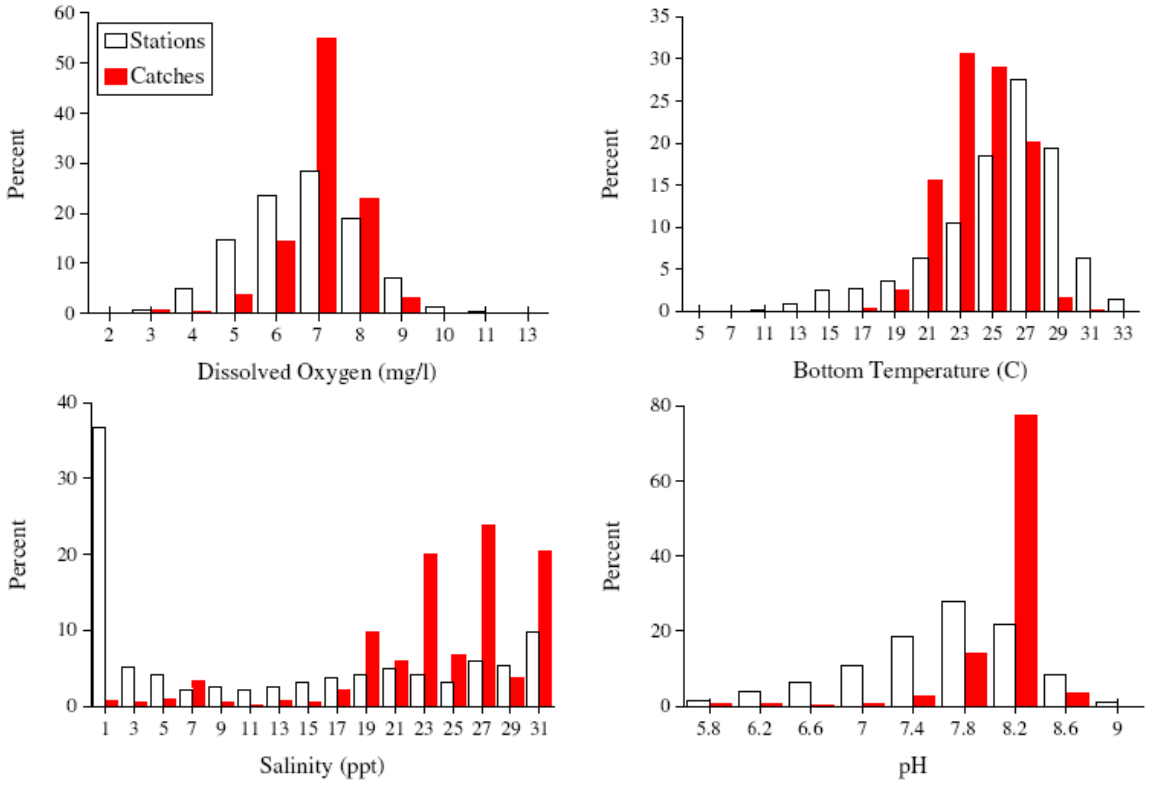


Figure 45. Hydrographic preferences for juvenile bluefish, from the VIMS seine surveys, 1994-1999 (all years combined). Source: Geer (2002).

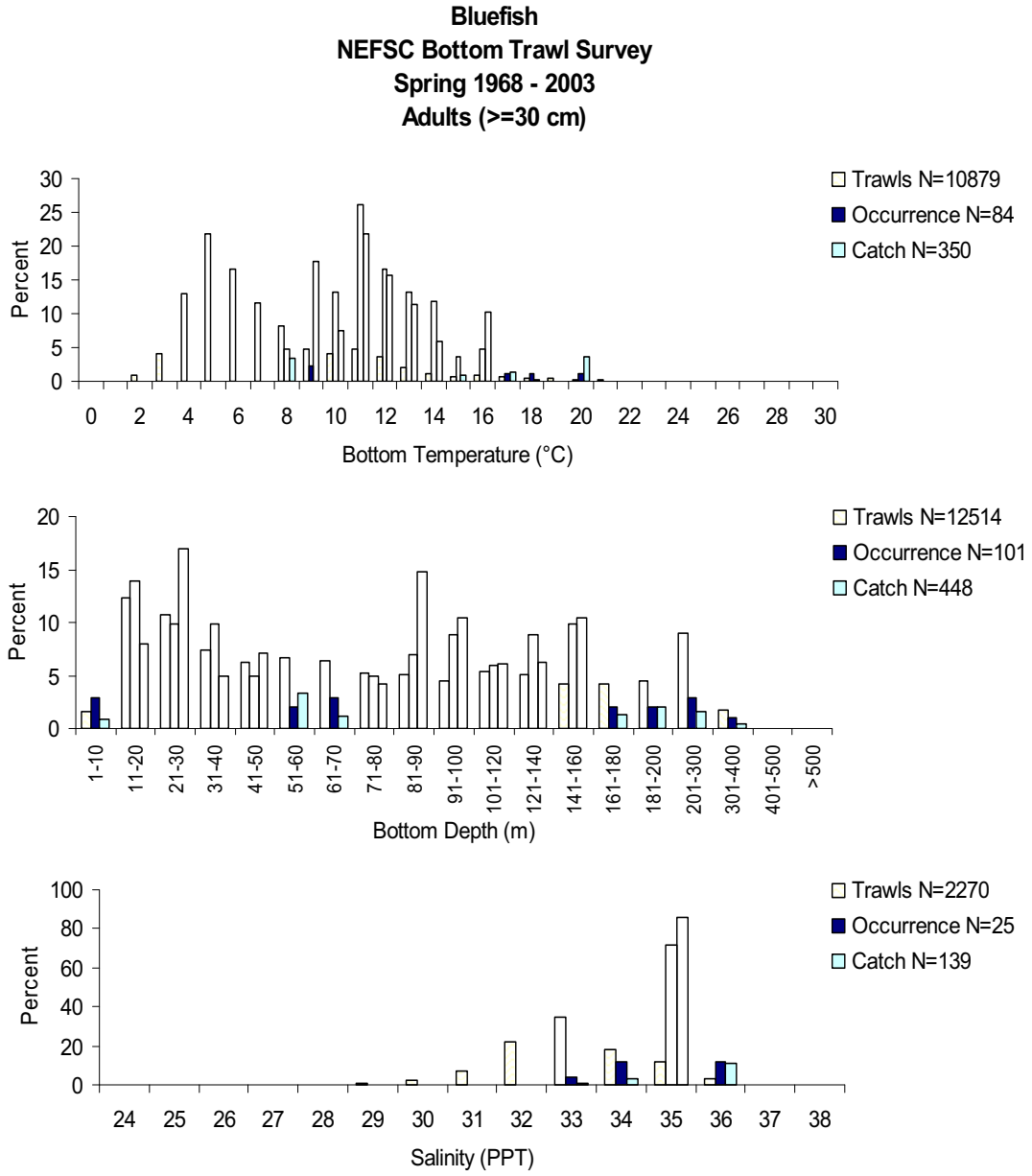


Figure 46. Distributions of adult bluefish and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity, based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which bluefish occurred and medium bars show, within each interval, the percentage of the total number of bluefish caught. Note that the bottom depth interval changes with increasing depth.

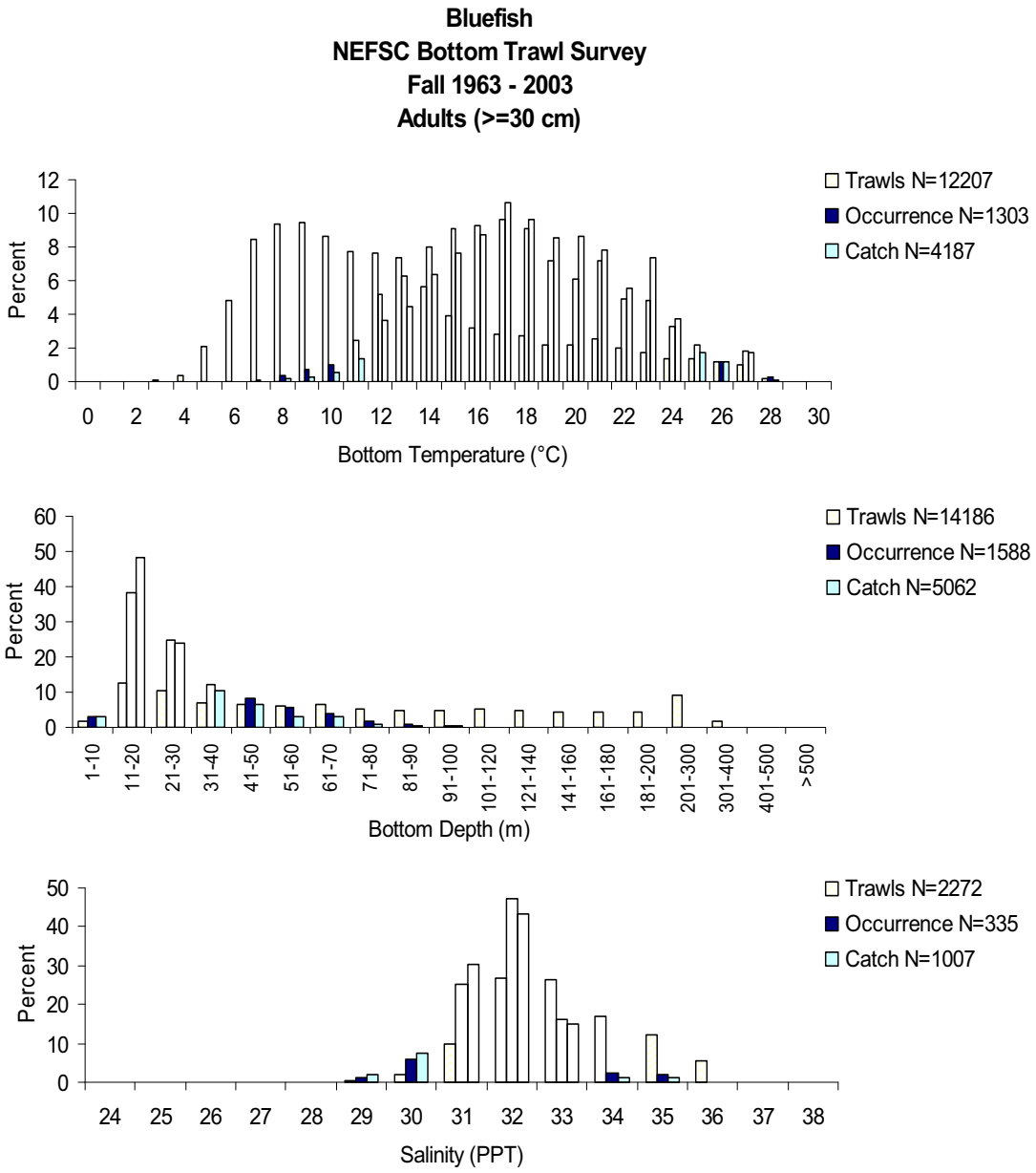


Figure 46. Continued.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which bluefish occurred and medium bars show, within each interval, the percentage of the total number of bluefish caught. Note that the bottom depth interval changes with increasing depth.

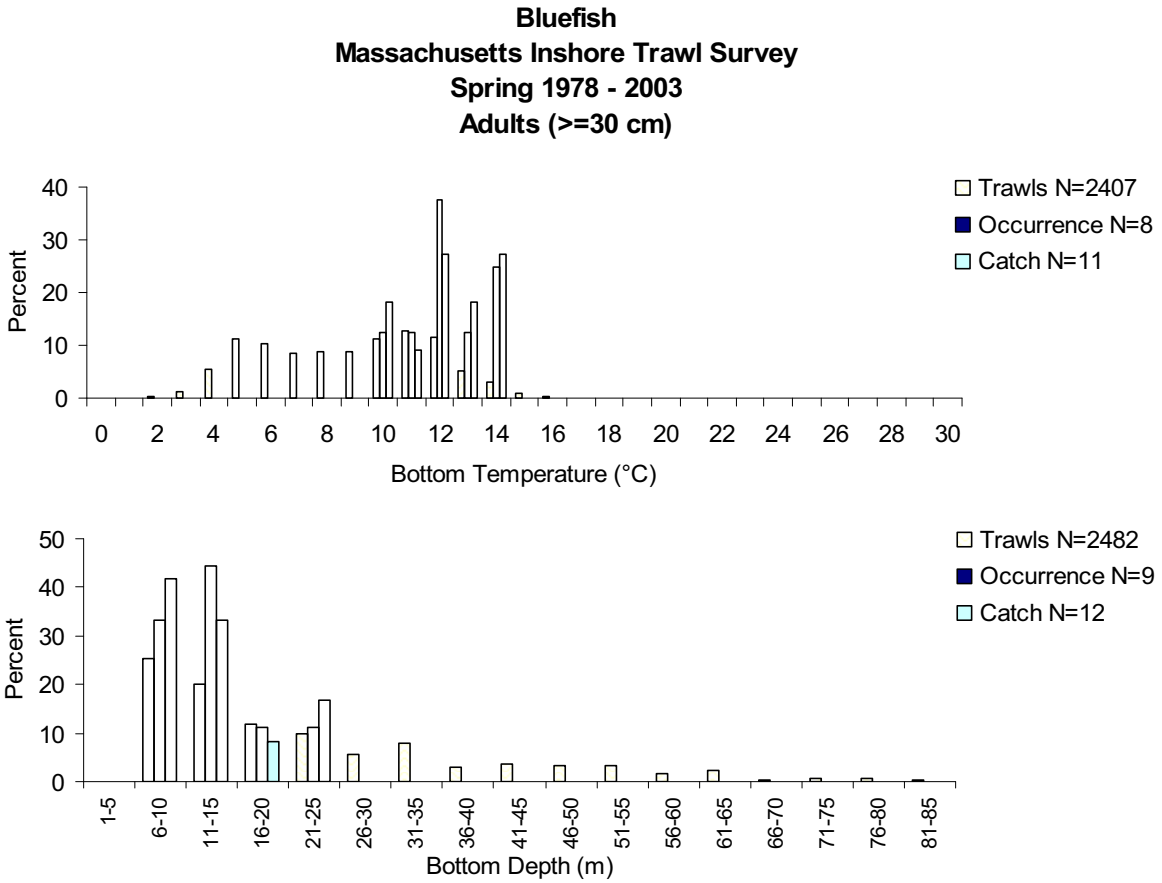


Figure 47. Distributions of adult bluefish and trawls in Massachusetts coastal waters relative to bottom water temperature and depth, based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which bluefish occurred and medium bars show, within each interval, the percentage of the total number of bluefish caught.

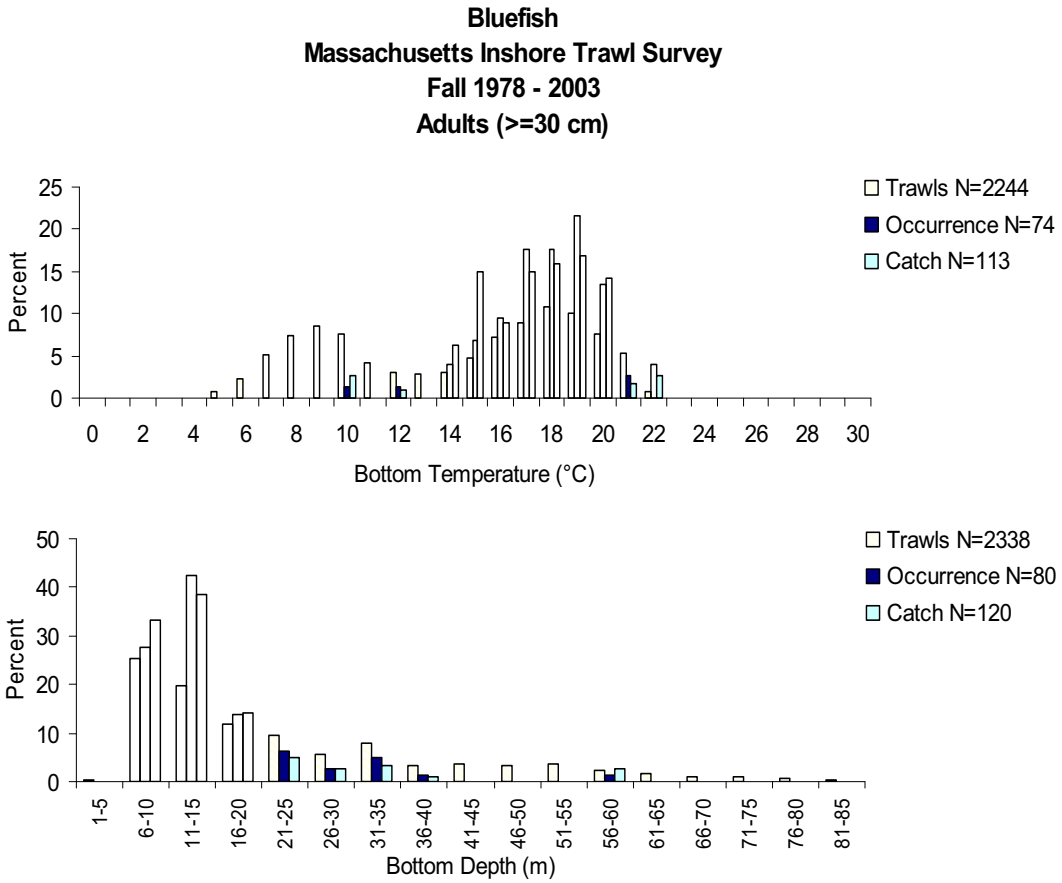


Figure 47. Continued.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which bluefish occurred and medium bars show, within each interval, the percentage of the total number of bluefish caught.

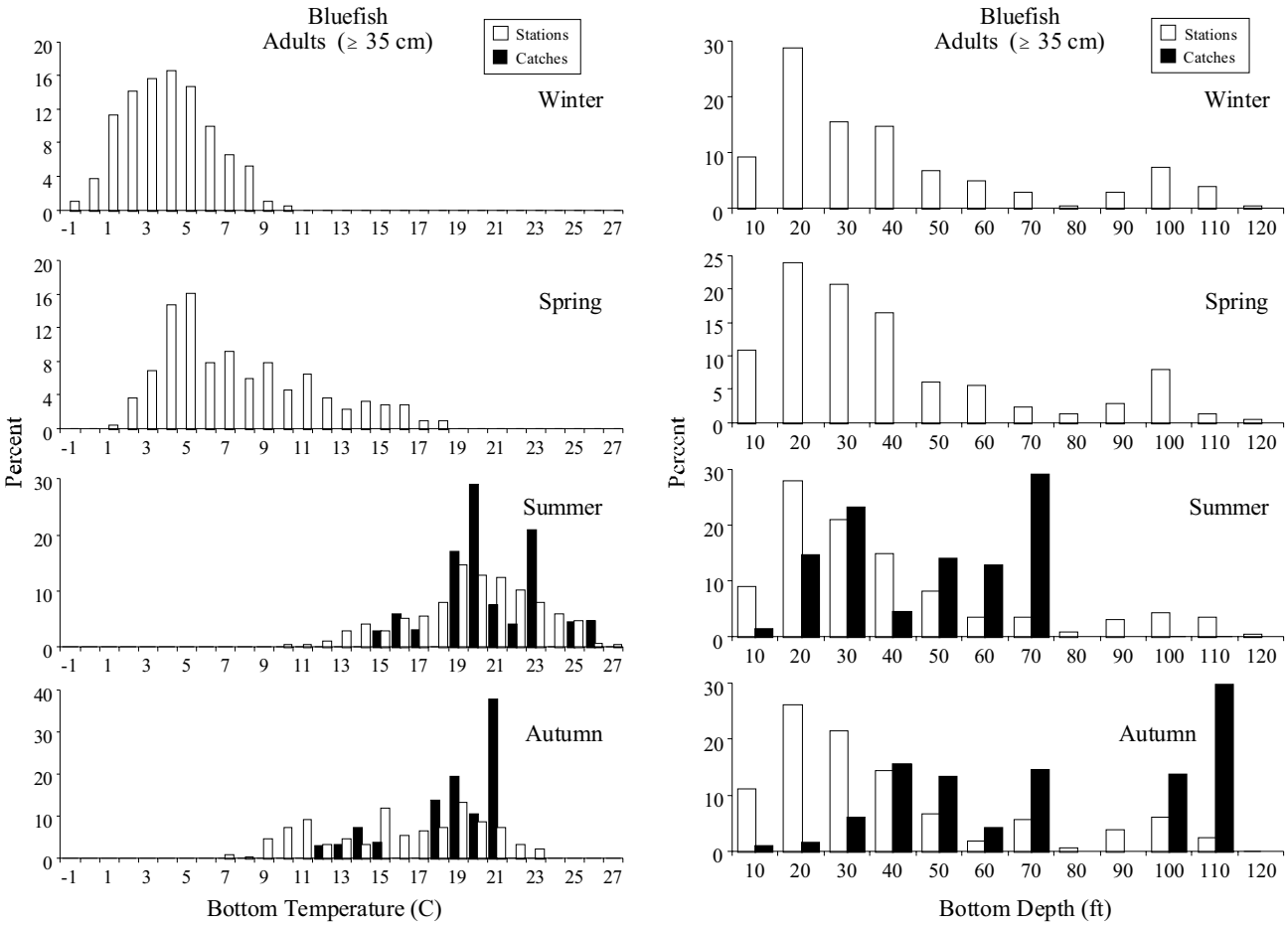


Figure 48. Seasonal distributions of adult bluefish and trawls relative to bottom water temperature and depth based on Rhode Island Narragansett Bay trawl surveys (1990-1996; all years combined). White bars give the distribution of all the trawls and black bars represent, within each interval, the percentage of the total number of adults caught.

Appendix 1. Bluefish habitat characteristics. MAB = Middle Atlantic Bight; SAB = South Atlantic Bight.

EGGS

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents	Light	Prey
Norcross *et al.* (1974)	1960-1962, Continental Shelf waters off Virginia.	Across shelf, from nearshore to shelf edge, but most in outer half of shelf. June through August, peak July.	22°C or more. (Minimum 18°C).	31 ppt or more. (Minimum 26.6 ppt).	---	Prevailing surface currents transport eggs south and offshore.	Peak spawning evening (1900-2100 hrs).	---
Berrien and Sibunka (1999)	1977-1987, Continental Shelf waters, Gulf of Maine to Cape Hatteras.	Occur southern New England to Cape Hatteras across entire shelf. Most in mid-shelf waters of MAB, especially off New Jersey and Delaware Bay. May-August.	---	---	---	---	---	---

Appendix 1. Continued.

LARVAE

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents	Light/Vertical Distribution	Prey
Norcross *et al.* (1974)	1960-1962, Continental Shelf waters off Virginia.	Surface waters, most near edge of shelf.	---	---	---	---	---	---
Kendall and Walford (1979)	1965-1967, Continental Shelf waters between Cape Cod and Palm Beach, Florida.	Late April: in and near Gulf Stream off Cape Hatteras; May: near edge of shelf off Carolinas; August: mid-shelf depths off New Jersey; September: few in New York Bight; October: concentration near shelf edge off Georgia.	C. Hatteras: 22.1-22.4°C; MAB: 18-26°C, SAB: 20-26°C.	MAB: 30-32 ppt, SAB: 35-38 ppt.	---	Larvae from spring spawn advected north via Gulf Stream.	---	---
Kendall and Naplin (1981)	July 1974, outer Continental Shelf off Delaware Bay.	Vertical distribution study. Most larvae within 4 m of surface.	Surface 23°C.	Surface 33 ppt.	---	---	Near surface at night; mostly at 4 m during daylight.	Mostly copepod life history stages. Guts full during day; empty during night.
Powles (1981)	1973-1976, Cape Fear, North Carolina to Cape Canaveral, Florida.	Peaked April-May; smallest near edge of shelf; larger closer to shore or advected north.	Smallest larvae > 24°C.	Smallest larvae > 35 ppt.	---	Ekman drift would impede inshore migration.	Predominately neustonic.	---
Collins and Stender (1987)	1973-1980, Cape Hatteras to Cape Canaveral, Florida.	Mostly in waters > 40 m, primarily in spring, secondarily in late summer.	---	---	---	Southerly counter-current retains larvae in SAB.	> 4 mm strongly associated with surface.	---
Hare and Cowen (1996); Hare *et al*. (2001)	March 1990, 1991; April 1989; June 1991; Water masses off Cape Hatteras.	Larvae occurred March through June; different sizes occurred in different water masses.	March: 20-25°C; April: 18-25°C; June: 21-25°C	March: 36+ ppt; April: 34.5-36.5 ppt; June: 31-36 ppt.	---	SW winds in MAB may facilitate cross-shelf transport of larvae.	---	---

Appendix 1. Continued.

PELAGIC-JUVENILES

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents	Light/Vertical Distribution	Prey
Fahay (1975)	Seasonal, May 1967-Feb. 1968. SAB Continental Shelf.	14 collected between North Carolina and Cape Canaveral, various depths between nearshore and shelf edge. All during May.	19.0-24.0°C	---	---	---	---	---
Kendall and Walford (1979)	1965-1972, East Coast U.S. (MAB and SAB Continental Shelf into Slope Sea).	April (late): many near Cape Hatteras; May: shelf in SAB, largest nearshore; June: MAB between shore and shelf/slope front; Fall: few between Delaware Bay and Cape Hatteras; Winter: few between St. Johns River and Cape Canaveral.	April-May: 22.1-24.0°C, Jun: 15.0-20.0°C (most > 18.0°C), Fall: 15.0-18.0°C, Winter: 13.0-15.0°C.	---	---	Migrate across shelf from shelf/slope front to shore as shelf waters warm.	All collected in near-surface samplers.	---
Powles (1981)	1973-1976; SAB Cape fear-Cape Canaveral.	Smallest collected near 180 m contour; larger near shore.	180 m contour: > 24.0°C.	180 m contour: > 35.0 ppt.	---	Weak association of size with proximity to coast. Most probably advected north.	Strongly associated with the surface.	---
Collins and Stender (1987)	1973-1980, SAB Cape Fear-Cape Canaveral.	Seaward of 40 m isobath, mostly spring, some fall occurrences.	---	---	---	Strong negative correlation of size and depth during spring, indicates shoreward movement with growth.	Strongly associated with the surface.	---
Hare and Cowen (1996)	1988, MAB shelf edge.	Cross shelf from Slope Sea to shore early to mid-June.	13.0-15.0°C.	---	---	Wind-driven flow may be important, but active swimming probably more important.	Surface oriented.	---

Appendix 1. Continued.

JUVENILES AND OLDER

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents/Tide	Substrate/ Vegetation	Light/ Diel	Prey
de Sylva *et al.* (1962)	1958-1960, Delaware Bay and River.	July and August, mostly in shore zone of lower estuary.	---	usually high, but as low as 3.0 ppt.	---	Surf zone, clear to turbid.	Sand.	---	Collected with small clupeids and anchovies.
Smith (1971)	1969-1970, four low-salinity creeks, upper Delaware Bay.	Six YOY occurred in two of the creeks, June and July.	24.5-30.0°C.	0-5.2 ppt.	4.5-7.3.	Ebb/flood.	Sand/gravel.	Day.	---
Milstein *et al.* (1977)	1972-1974, Great Bay, New Jersey.	Several distinct habitats studied; bluefish most abundant in mud-sand, high salinity sites; also sandy beaches.	---	---	---	Slow to moderate, swept by waves.	Mostly sand, some gravel, silt, clay; *Ulva lactuca*, *Spartina alterniflora*, *Fucus* (sometimes).	---	---
Pristas and Trent (1977)	1972, St. Andrews Bay, Florida.	Range of depths sampled with gill nets, 24 hrs. Bluefish most dense in shallowest zone (0.7-1.1 m).	11.4-27.0°C.	25.3-34.6 ppt.	---	---	> 80% sand; vegetation most dense in shallow zone.	Bluefish most abundant at night in shallowest zone.	---
Nyman and Conover (1988)	1985-1986, both shores of Long Island, New York.	Occur in embayments, between late May and October.	Arrive > 20°C; emigrate ca. 15°C.	---	---	---	---	---	---
Rountree and Able (1992a, b).	1988-1989, Great South Bay, New Jersey.	Occur in polyhaline subtidal marsh creeks during summer.	> 20.0°C.	23.0-30.0 ppt.	---	---	---	Day: tidal creeks Night: open bay.	*Menidia menidia.*
McBride *et al.* (1995)	Narragansett Bay, Rhode Island.	June-October, shallow beaches.	18.0-28.0°C.	25.0-34.0 ppt.	---	---	Cobble, gravel, shell, sand; *Ulva* and some *Zostera.*	Day sampling only.	---
Able *et al.* (1996)	Great Bay, New Jersey.	Most bluefish in subtidal creeks.	19.0-28.0°C.	25.0-33.0 ppt.	---	---	0.3-1.2 m depth; *Ulva lactuca.*	---	---

Appendix 1. Continued.

JUVENILES AND OLDER (CONTINUED)

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents/Tide	Substrate/ Vegetation	Light/ Diel	Prey
Buckel and Conover (1997)	1992-1993, Hudson River estuary.	Mid-channel and nearshore day-night occurrence and feeding study.	---	---	---	---	---	Most abundant nearshore during daylight; mid-channel at night and twilight.	Gut fullness highest twilight and day, usually low at night. Prey: striped bass, bay anchovy, clupeids.
Fahay *et al.* (1999)	1964-1997, Continental shelf MAB, south to Cape Fear, Cape Canaveral.	Inner shelf (over depths < 20 m) during summer and fall.	Most 18-22°C.	---	---	---	---	---	---
Harding and Mann (2001)	Chesapeake Bay 1997.	May to September. Oyster reefs, oyster bars, and sandy bottoms.	17°C to 28°C.	11 to 18 ppt.	---	No significant effect on abundance.	More abundant on oyster bars. More diverse diet on bars.	Most abundant in samples at night.	Clupeids, other teleosts, polychaetes and crustaceans.
Buckel and McKown (2002)	New York Bight embayments, 1997 and 1998.	May to November, embayments in western Long Island and Staten Island.	15°C to 26°C.	22 to 27 ppt.	---	---	---	---	Sand shrimp, mysids, *Menidia* spp., *Anchoa* spp., *Fundulus* spp. , amphipods.
Scharf *et al.* (2002)	Navesink River/Sandy Hook Bay.	Shallow estuaries May to October.	---	---	---	Low velocity currents.	Depositional habitat – high turbidity zones.	---	Primarily menhaden large niche overlap between predator and prey.
Fox *et al.* (2002)	Delaware Bay June – Nov 2001.	Marsh creeks in NJ.	---	Range from mesohaline to oligohaline.	---	---	---	---	Menhaden, *Fundulus* spp., *Menidia* spp.

Appendix 1. Continued.

JUVENILES AND OLDER (CONTINUED)

Authors	Study Period and Area	Habitat (Spatial and Temporal)	Temperature	Salinity	Dissolved Oxygen	Currents/Tide	Substrate/ Vegetation	Light/ Diel	Prey
Secor *et al.* (2002)	Chesapeake Bay and MD coastal bays.	Shoal habitats (< 2 m depth) and deeper offshore habitats (4-40 m depth). Concluded that shallow ocean habitat important for YOY in late summer – early fall.	---	---	---	---	---	---	*Menidia* spp. in July, *Anchoa* spp. in August.
Able *et al*. (2003)	Coastal NJ 1995-1998.	Sandy ocean beaches and Great Bay and Little Egg Harbor estuary.	7.7°C to 25.4°C.	27.1 to 33.4 ppt.	---	High wave energy on beaches and 1.4 m tidal range.	Sand.	---	Bay anchovy, *Menidia spp*., amphipods, decapods.

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For spelling of scientific and common names of fishes, mollusks, and decapod crustaceans from the United States and Canada, use *Special Publications* No. 29 (fishes), 26 (mollusks), and 17 (decapod crustaceans) of the American Fisheries Society (Bethesda, MD). For spelling of scientific and common names of marine mammals, use *Special Publication* No. 4 of the Society for Marine Mammalogy (Lawrence, KS). For spelling in general, use the most recent edition of *Webster's Third New International Dictionary of the English Language Unabridged* (Springfield, MA: G.&C. Merriam).

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Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Currently, there are three such media:

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Resource Survey Report (formerly *Fishermen's Report*) -- This information report is a quick-turnaround report on the distribution and relative abundance of selected living marine resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of this report.

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NOAA Technical Memorandum NMFS-NE-200

Essential Fish Habitat Source Document:

Black sea bass, *Centropristis striata*, Life History and Habitat Characteristics

Second Edition

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

February 2007

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NOAA Technical Memorandum NMFS-NE-200

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Essential Fish Habitat Source Document:

Black Sea Bass, *Centropristis striata*, Life History and Habitat Characteristics

Second Edition

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February 2007

Editorial Notes on "Essential Fish Habitat Source Documents" Issued in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For "Essential Fish Habitat Source Documents" issued in the *NOAA Technical Memorandum NMFS-NE* series, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division largely assume the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production is performed by, and all credit for such production rightfully belongs to, the staff of the Ecosystems Processes Division.

Internet Availability and Information Updating

Each original issue of an "Essential Fish Habitat Source Document" is published both as a paper copy and as a Web posting. The Web posting, which is in "PDF" format, is available at: *http://www.nefsc.noaa.gov/nefsc/habitat/efh*.

Each issue is updated at least every five years. The updated edition will be published as a Web posting only; the replaced edition(s) will be maintained in an online archive for reference purposes.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Nelson *et al*. 2004[a]; Robins *et al.* 1991[b]), mollusks (*i.e.*, Turgeon *et al.* 1998[c]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[d]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[e]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species.

---

[a]Nelson, J.S.; Crossman, E.J.; Espinosa-Pérez, H.; Findley, L.T.; Gilbert, C.R.; Lea, R.N.; Williams, J.D. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. 6th ed. *Amer. Fish. Soc. Spec. Publ.* 29; 386 p.

[b]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. World fishes important to North Americans. *Amer. Fish. Soc. Spec. Publ.* 21; 243 p.

[c]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[d]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[e]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

PREFACE TO SECOND EDITION

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NOAA Fisheries to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NOAA Fisheries has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in a series of EFH species reports (plus one consolidated methods report). The EFH species reports are a survey of the important literature as well as original analyses of fishery-independent data sets from NOAA Fisheries and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and understandably are referred to as the "EFH source documents."

NOAA Fisheries provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

The initial series of EFH species source documents were published in 1999 in the *NOAA Technical Memorandum NMFS-NE* series. Updating and review of the EFH components of the councils' Fishery Management Plans is required at least every 5 years by the NOAA Fisheries Guidelines for meeting the Sustainable Fisheries Act/EFH Final Rule. The second editions of these species source documents were written to provide the updated information needed to meet these requirements. The second editions provide new information on life history, geographic distribution, and habitat requirements via recent literature, research, and fishery surveys, and incorporate updated and revised maps and graphs.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NOAA Fisheries, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

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INTRODUCTION

The black sea bass (*Centropristis striata* Linnaeus 1758) (Figure 1) is a warm temperate serranid that ranges from southern Nova Scotia and the Bay of Fundy (Scott 1988) to southern Florida (Bowen and Avise 1990) and into the Gulf of Mexico. Fish have been reported on the Grand Banks of Canada (Brown *et al.* 1996), but are uncommon in cooler waters north of Cape Cod (Scattergood 1952; DeWitt *et al.* 1981). Black sea bass are typically found on the continental shelf in complex habitats such as reefs and shipwrecks, but young of the year (YOY) fish also occur in large numbers in structurally complex estuarine habitats.

LIFE HISTORY

EGGS

Black sea bass eggs are pelagic and the length of the incubation period is inversely temperature dependent (Able and Fahay 1998).

Berrien and Sibunka (1999) showed that in the Mid-Atlantic Bight, areas with high average egg densities were generally located on the continental shelf in the vicinity of large estuaries including Chesapeake Bay, the Delaware River, and the Hudson River. Eggs are collected off Cape Hatteras as early as January but these may be reproductive products transported by the Gulf Stream from spawning areas to the south (Mercer 1978).

Black sea bass eggs also occur infrequently in large bays. They have been reported in Buzzards Bay, MA (Stone *et al*. 1994), with the highest egg concentrations between May and October, but eggs were also collected in January and April. Eggs are rare in Long Island Sound (Merrimann and Sclar 1952; Wheatland 1956; Richards 1959), and absent in Narragansett Bay Rhode Island (Bourne and Govoni 1988) and Delaware Bay (Wang and Kernehan 1979).

LARVAE

Larvae hatch from eggs at 1.5-2.1 mm TL and settle as early juveniles at 10-16 mm TL (Kendall 1972; Fahay 1983; Able *et al.* 1995). Kendall (1972) however, suggested that fish may delay settlement until they reach 25 mm TL.

Gelatinous zooplankton may be important predators of larvae (Arai 1988).

JUVENILES

In the Mid-Atlantic Bight, juveniles migrate in the fall from nearshore summer habitats to over wintering habitats on the outer continental shelf south of Long Island, NY. During warmer winters, juveniles may successfully over winter in deeper waters of lower Chesapeake Bay (MAFMC 1996; Chesapeake Bay Program 1996). The fall offshore migration of juveniles in most of the Mid-Atlantic Bight probably allows fish to avoid temperatures below the lower lethal limit (~2°C, see Habitat Characteristics section) (Hales and Able 2001). However, juveniles in the Gulf of Mexico also disappear in the fall from inshore collections in the lower reaches of Florida west coast estuaries where they are abundant, and appear to over winter in offshore areas (Reid 1954; Joseph and Yerger 1956; Springer and Woodburn 1960; Hastings 1972).

The growth of juvenile black sea bass has been measured in situ by Able and Hales (1997) who used mark recapture techniques in the lower reach of a southern New Jersey estuary to show that growth rates of age-0 and age-1 fish from spring through fall averaged ~ 0.45 mm d (SE=0.04). Juvenile growth was higher during the summer (July-September; 0.74 mm d, SE= 0.05) than during the spring (March-June; 0.29 mm d, SE=0.04) and fall (October-December; 0.39 mm d). Growth estimates for age 1+ fish derived from length frequencies of fish in the same region, but in a different study, were similar (average=0.77 mm/day) (Able *et al.* 1995). In the Hereford Estuary, New Jersey early juveniles ~ 20 mm SL are collected in July but leave the estuary in the fall at sizes > 40 mm TL (Allen *et al.* 1978). Age-1 fish enter this estuary at 60 mm TL but migrate in the fall at ~ 100 mm TL. In eastern Virginia bays juveniles are reported to be ~ 30 mm TL in April but reach 100-182 mm TL by the end of the growing season in November (Schwartz 1961). Juvenile black sea bass appear to allocate metabolic energy toward rapid growth from settlement to ~ 49 mm SL, but then show reduced growth as they begin to store energy as lipid at larger sizes (Guida, NOAA Fisheries, NEFSC, James J. Howard Marine Sciences Laboratory, Highlands, NJ, pers. comm.). Guida (pers. comm.) speculated that this pattern represented a two-phase metabolic program that allows young fish to reduce size dependent predation mortality during and immediately following settlement while allowing for the storage of fats necessary for over wintering survival by larger individuals which are less vulnerable to predators.

In the Mid-Atlantic Bight juveniles form annuli in otoliths in May or June which appears to be the beginning of the growing season for fish after their first winter (Dery and Mayo 1988). Annulus formation occurs earlier in the South Atlantic Bight (April and May) (Cupka *et al.* 1973; Mercer 1978; Waltz *et al.* 1979; Link 1980; Wenner *et al.* 1986).

ADULTS

Black sea bass are strongly associated with structurally complex habitats. Habitats used by adults include rocky reefs, cobble and rock fields, stone coral patches, exposed stiff clay, and mussel beds. In the South Atlantic Bight adult black sea bass are associated with hard or live bottom sponge coral habitat (Struhsaker 1969; Powles and Barans 1980; Grimes *et al.* 1982; Wenner 1983; Chester *et al.* 1984; Sedberry and Van Dolah 1984; Parker and Ross 1986). In the Gulf of Mexico, limestone and coral reefs and other low relief structures are important habitats, but black sea bass are rarely found off deeper ledges (> 25 m) inhabited by larger serranids (Topp 1963; Godcharles 1970; Bortone 1977). In Long Island Sound, adults are generally associated with structurally complex habitats embedded within areas of sandy rather than muddy substratum (Richards 1963b). Black sea bass are usually observed by divers hovering near or above shelters and retreat into them if threatened. Fish appear to remain near complex structures during the day, but may move to adjacent soft-bottom to feed at dawn and dusk (Steimle and Figley 1996). Once black sea bass find suitable summer habitat, they show strong habitat fidelity, and in the Mid-Atlantic Bight, remain until the fall migration (Briggs 1979).

In the Mid-Atlantic Bight adult black sea bass migrate from nearshore continental shelf habitats to outer shelf over wintering areas, south of New Jersey, as bottom temperatures decline in the fall (Musick and Mercer 1977). Offshore migration begins as bottom water temperatures approach 7°C (Nesbit and Neville 1935; June and Reintjes 1957; Colvocoresses and Musick 1984; Chang 1990; Shepherd and Terceiro 1994). Larger fish appear to migrate earlier than smaller fish (Kendall 1977). Tag returns from fish tagged in Nantucket Sound (Massachusetts) suggest that fish migrate south to the outer shelf near Block Canyon (south of Rhode Island) and then move southwest along the outer shelf toward Norfolk Canyon off Virginia (Kolek 1990).

Fish in South Atlantic Bight and Gulf of Mexico appear to be non-migratory and attached to specific reefs throughout the year (Beaumariage 1964; Beaumariage and Wittich 1966; Moe 1966). Most fish using nearshore artificial reef and wreck habitats (< 20 m deep) support commercial and recreational fisheries during the winter (Chee 1977; Mercer 1989; Adams 1993). Sedberry *et al*. (1998) showed that 95% of black sea bass tagged and at large for more than one month in Gray's Reef National Marine Sanctuary were recaptured in the vicinity of the sanctuary. However some fish moved large distances as one individual was recaptured off St. Augustine (Florida), 167 km from Gray's reef. Musick and Mercer (1977) suggested that some adult black sea bass in the Gulf of Mexico may migrate, but tagging studies performed in the northeastern Gulf of Mexico suggest that adult fish become site attached once established on a specific reef (Topp 1963; Beaumariage 1964; Beaumariage and Wittich 1966; Moe 1966).

In the Mid-Atlantic Bight, adult black sea bass move from over wintering habitats on the outer continental shelf to inshore areas as waters warm in the spring. The inshore migration appears to begin in April as temperatures warm to > 7°C (Nesbit and Neville 1935; June and Reintjes 1957; Colvocoresses and Musick 1984; Chang 1990; Shepherd and Terceiro 1994). Primary summer habitats for adults are located on the nearshore continental shelf at depths < 60 m and fish may use complex habitats in the lower reaches of large estuaries which are relatively shallow (~ 5 m).

Adult black sea bass growth appears to vary with latitude. Growth was nearly twice as high for fish collected in Massachusetts than for fish in New York and Virginia (Dery and Mayo 1988; Kolek 1990; Caruso 1995). A similar latitudinal trend was suggested by Mercer (1978) and Wenner *et al.* (1986) who showed fish from the Mid-Atlantic Bight were larger at age and grew faster than fish from the South Atlantic Bight. Adults show linear growth up to age 6 (Wenner *et al.* 1986).

Several studies have suggested that growth rates are sex dependent in adult black sea bass, with females growing more rapidly than males (Lavenda 1949; Mercer 1978; Wilk *et al*. 1978). However, Alexander (1981) used otolith analyses of year 1 and older fish from New York to suggest that males grow faster than females. Shepherd and Idoine (1993) suggested growth was sex dependent for all stages including transitional individuals. However, the sex dependent and geographic differences in growth may be related to site specific differences in exploitation rates, gear selectivity, and other sampling biases (Mercer 1978; Wenner *et al.* 1986).

REPRODUCTION

Black sea bass are protogynous hermaphrodites, with fish changing sex from female to male as they increase in age and size. Age of sexual transition varies with latitude with females maturing and undergoing sexual transition at greater ages in northern latitudes (McGovern *et al*. 2002). Fish in the Mid-Atlantic Bight begin to mature at age 1 (8-17 cm TL) and 50% are mature at 2-3 yrs and ~19 cm SL (O'Brien *et al.* 1993). The majority of fish less < 19 cm are females, while larger fish are transitional individuals or males (Mercer 1978). Detailed studies of sexual development and transition have been performed with individuals collected in the South Atlantic Bight and Gulf of Mexico, where the patterns are similar (Mercer 1978; Link 1980; Wenner *et al.* 1986; Hood *et al.* 1994). In

the South Atlantic Bight, frequency of occurrence for transitional fish is highest at ages 2-5 yrs (Waltz *et al.* 1979; Wenner *et al.* 1986). Fish older than 4-5 yrs and > 210 mm TL are primarily males (Hood *et al*. 1994). Maximum age and size of black sea bass are 7 yrs and 330 mm TL, respectively. The age and size of fish undergoing sexual transition has decreased as a result of increasing fishing pressure (Alexander 1981; Shapiro 1987). The frequency of large mature males also declined. A mark-recapture study of black sea bass in Gray's Reef National Marine Sanctuary, Georgia also showed that size distributions of fish decreased overtime as a result of fishing pressure in the South Atlantic Bight (Sedberry *et al*. 1998). Reproductive potential in black sea bass may be limited by the availability of large males (Shepherd and Idoine 1993). Reproductive output varies with the abundance of large males for other serranids that show strong spawning hierarchies and paired spawning (McGovern *et al*. 1998). However, black sea bass reproductive behavior has not been studied and the participation of non-dominant males in spawning could reduce the possibility that reproductive potential is depressed by the rarity of large dominant males (Shepherd and Idoine 1993).

Fecundity is related to body size and age. Female fish 2-5 years of age in the Mid-Atlantic Bight release between 191,000 and 369,500 eggs (Mercer 1978). In the South Atlantic Bight fecundity ranges from 17,000 for age-2 females (108 mm SL) to 1,050,000 for age 2-3 fish (438 mm SL) (Wenner *et al.* 1986). Frequency of occurrence for individuals in sexual transition may be highest just before spawning.

Primary spawning habitats appear to be located in the nearshore continental shelf at depths of 20-50 m (Breder 1932; Kendall 1972; Musick and Mercer 1977; Wilk and Brown 1980; Eklund and Targett 1990; Berrien and Sibunka 1999). Gravid females are common on the continental shelf and generally not found in estuaries (Allen *et al.* 1978). Fish may spawn on sand bottoms broken by ledges and move to structurally complex habitats in deeper water after spawning (Kolek 1990; MAFMC 1996). Kolek (1990) showed that some tagged black sea bass return to the spawning grounds in Nantucket Sound and suggested that the animals may home to spawning grounds. The population Kolek (1990) studied appeared to spawn earlier and in shallower water than reported for other populations in the Mid-Atlantic Bight (Kendall 1977).

In the Mid-Atlantic Bight, black sea bass spawn from April through October (Able and Fahay 1998; Reiss and McConaugha 1999). Spawning occurs earlier in the year at southern latitudes. In the South Atlantic Bight, spawning occurs from January through June with a peak from March through May (Mercer 1989). Spawning may also occur from September-October (Wenner *et al.* 1986). Fish in the Gulf of Mexico spawn from December through April (Hood *et al*. 1994).

STOCK STRUCTURE

The black sea bass population is currently managed as three separate stocks: Mid-Atlantic, South Atlantic, and Gulf of Mexico. The geographic dividing line for the Mid- and South Atlantic stocks is located at Cape Hatteras, North Carolina. The South Atlantic stock extends to Cape Kennedy, Florida (Ginsburg 1952; Mercer 1978; Shepherd 1991; Klein-MacPhee 2002), while the Gulf of Mexico stock ranges from Cape Kennedy to Texas (Bowen and Avise 1990). Ginsburg (1952) considered fish in the Atlantic and Gulf of Mexico to be separate species (*C. striata* and *C. melana*, respectively) based on meristic characteristics. Miller (1959) analyzed morphometric and meristic data from a larger number of specimens and concluded that the difference between populations warranted only subspecific designations: *C. striata striata* and *C. striata melana*. Miller's subspecific classification has been supported by analyses of osteological differences, allozyme and plasma protein variation, and mtDNA variation (Bortone 1977; Chapman 1977; Bowen and Avise 1990).

Recently, black sea bass year class strength has been strong in the Mid-Atlantic Bight (Atlantic States Marine Fisheries Commission 2004). The 2002 year-class was strong; the fourth highest since 1968; and the 2003 year-class appear to show moderate strength. However, South Atlantic Bight black sea bass stock appears to be declining (Harris and Sedberry 2004). Virtual population analyses (Vaughan *et al.* 1995, 1998) show the South Atlantic Bight stock population decreased from about 4 million individuals during 1979 to about 2.2 million in 1986. This trend was followed by an increase to over 3 million in 1988 and 1989 before the population decreased to 1.4 million in 1995 (Vaughan *et al.* 1995, 1998). Estimates of total mortality ranged from 1.00 in 1979 to 1.76 in 1982 (McGovern *et al*. 2002). In the Gulf of Mexico, black sea bass are federally managed but the status of the stock is unknown, which is why the Florida Fish and Wildlife Conservation Commission is proposing to regulate fishing practices (Florida Fish and Wildlife Conservation Commission 2004).

FOOD HABITS

Following the completion of the yolk sac stage (~ 2-d), larvae starve after three days if not exposed to appropriate prey (microalgae and zooplankton) (Tucker 1989).

Food habits data collected during Northeast Fisheries Science Center (NEFSC) bottom trawl surveys [see Link and Almeida (2000) for methodology] reveal that decapods were the dominant

prey item for all size classes of black sea bass (Figure 2). Juveniles, which are diurnal, visual predators, prey on benthic and epibenthic crustaceans (isopods, amphipods, small crabs, sand shrimp, copepods, mysids) and small fish (Richards 1963a; Kimmel 1973; Allen *et al.* 1978; Link 1980; Werme 1981; Hood *et al.* 1994), and their diets appear to change with body size. Bowman *et al*. (2000), using the same NEFSC food habits database, but only for the years 1977-1980, found that crustaceans dominated the diet for all size classes of juvenile black sea bass (Table 1). Amphipods were among the more important crustacean prey for the smallest juveniles (1-5 cm), and although decapods dominated the diet of fish 11-20 cm, the euphausiid, *Meganyctiphanes norvegica*, was also an important prey item for that size class. Among the important decapod prey for juveniles were *Cancer irroratus* and *Crangon septemspinosa*. Crustaceans are also dominant prey for juveniles in New Jersey coastal and estuarine areas, but fish > 110-180 mm SL incorporate fish prey (anchovy and silversides *Menidia* sp.) in their diets (Allen *et al.* 1978). Large juveniles in New Jersey estuaries also feed on lady (*Ovalipes* sp.), blue and xanthid crabs, as well as caridean shrimp (Festa 1979). In lower Chesapeake Bay eelgrass beds, fish 140-165 mm TL consume juvenile blue crabs (*Callinectes sapidus*) and pipefish (*Syngnathus* sp.), as well as isopods, caprellid amphipods, and shrimp (Orth and Heck 1980). Kimmel (1973) reported a dietary shift in juveniles sampled in Magothy Bay, VA. Fish 30-90 mm SL consumed mysids (55%) and amphipods (15%), while juveniles 91-146 mm SL fed on larger brachyurian and xanthid crabs (35%) as well as mysids (19%), and polychaetes (14%). In nearshore continental shelf habitats in the South Atlantic Bight, amphipods, isopods and decapods are also important prey for juveniles 50-100 mm SL while larger individuals also consume more decapods and small fishes (Sedberry 1988).

Adult black sea bass are generalist carnivores that feed on a variety of infaunal and epibenthic invertebrates, especially crustaceans (including juvenile American lobster *Homarus americanus*, crabs, and shrimp) small fish, and squid (Bigelow and Schroeder 1953; Miller 1959; Richards 1963a; Mack and Bowman 1983; Hood *et al.* 1994; Steimle and Figley 1996). The Bowman *et al*. (2000) study showed that while crustaceans continue to be important diet items for the adults, fish also become more significant (Table 1), particularly for the largest black sea bass (> 40 cm), where sand lance (*Ammodytes dubius*) and scup (*Stenotomus chrysops*) were prominent. Sheepshead minnow (*Cyprinodon variegates*) was a major diet item for adults 36-40 cm. Decapods, and in particular, the crab *Cancer irroratus*, was the major crustacean prey. Squids are notable diet items for black sea bass 21-25 cm.

Regionally, in the Mid-Atlantic Bight, the winter diet of adult black sea bass is poorly known, although Bowman *et al*. (2000) showed that crustaceans, especially decapods, dominated the diet in that region. Other important prey in over wintering habitats may include echinoderms [e.g., sand dollars (*Echinarachnius parma*) and sea stars], mollusks [e.g., razor clams (*Ensis directus*)], and polychaetes; average benthic biomasses are 50-75 g/m^2 wet weight (Wigley and Theroux 1981; Steimle 1990). Squid (*Loligo* sp. and *Illex* sp.) and butterfish are also available during the winter. Species co-occurring with sea bass in over wintering habitats, including scup (*Stenotomus chrysops*), may be competitors for food (Austen *et al*. 1994.) Bowman *et al*. (2000) also showed that crustaceans, and again, especially decapods, dominated the diet in southern New England, Georges Bank, and inshore north of Cape Hatteras. In the South Atlantic Bight, black sea bass diets do not vary with season (Sedberry 1988). Fish, as well as epibenthic reef organisms (amphipods, stomatopods, shrimp, decapods) are dominant prey (Sedberry 1988; Bowman *et al*. 2000). Diets of fish in the Gulf of Mexico are similar to those of the South Atlantic Bight population (Miller 1959; Cupka *et al.* 1973; Link 1980; Sedberry 1988; Hood *et al.* 1994).

CO-OCCURRING SPECIES

During the summer, adult black sea bass in the Mid-Atlantic Bight share complex coastal habitats with other fishes including tautog (*Tautoga onitis*), spotted hake (*Urophycis regia*), red hake (*U. chuss*), conger eel (*Conger oceanicus*), ocean pout (*Macrozoarces americanus*), pinfish (*Lagodon rhomboides*), northern sea robin (*Prionotus carolinus*), and transients such as gray triggerfish (*Balistes capriscus*) (Chee 1977; Musick and Mercer 1977; Eklund and Targett 1991). Butterfish (*Peprilus triacanthus*), smooth dogfish (*Mustelus canis*), round herring (*Etrumeus teres*), and windowpane flounder (*Scophthalmus aquosus*) co-occur in samples with black sea bass in inshore trawl surveys (Phoel 1985; Gabriel 1992; Brown *et al.* 1996). Adult black sea bass in the South Atlantic Bight co-occur with southern porgy and scad (Powles and Barans 1980). Grouper, vermillion snapper, and red porgy occur on reef structures with black sea bass in the Gulf of Mexico (McGovern *et al.* 2002). Competition for food and shelter space with co-occurring species could affect habitat quality for black sea bass on specific reef structures.

Hartman and Brandt (1995) found black sea bass, presumably juveniles, in the summer diets of one year old weakfish (*Cynoscion regalis*) and other predators in Chesapeake Bay.

Resource species that co-occur with black sea bass in soft bottom over wintering habitats include scup,

summer flounder, butterfish, squid, and American lobster (Chang 1990; Able and Kaiser 1994).

GEOGRAPHICAL DISTRIBUTION

EGGS

Black sea bass eggs were collected during the 1978-1987 NEFSC Marine Resources Monitoring, Assessment and Prediction (MARMAP) ichthyoplankton surveys mostly from New Jersey to Cape Hatteras (Figure 3). Eggs first appear in large numbers in June, with the highest mean monthly densities in July, August, and September, and the highest mean monthly density in August (6.63 eggs/10 m^2). Egg numbers decline sharply in October.

LARVAE

During the NEFSC MARMAP surveys, peak months for larval abundance in the Mid-Atlantic were from July-September, with the highest mean monthly density in August (3.36 larvae/10 m^2) (Figure 4). Larvae first appear near Cape Hatteras and occur farther north as the year progresses. A few larvae occur in the Mid Atlantic Bight in November (Kendall 1972; Able *et al.* 1995). Infrequent collections of larvae in deeper water (> 200 m) water may be the result of the cross shelf transport from near shore spawning areas and away from high quality settlement habitats.

Larvae have been reported in high salinity coastal areas of southern New England in August and September (Stone *et al*. 1994). Black sea bass in the near shore coastal larval assemblage were collected within 48 km in the New York Bight during the summer months (Cowen 1993). Larvae are abundant on the inner shelf outside Chesapeake Bay but not in association with estuarine plume water (Reiss and McConaugha 1999). Larvae may be more abundant in subsurface than in surface plankton tows in June near the mouth of Chesapeake Bay (Pearson 1941). Larval black sea bass also occur in surf zone plankton collections from northern New Jersey (Burlas *et al.* 2001).

While black sea bass larvae are collected close to shore on the continental shelf, they rarely occur within estuaries. Larvae are not reported in Delaware Bay (Wang and Kernehan 1979), Great Bay, NJ (Able and Fahay 1998), or the Hudson-Raritan Estuary (Croker 1965; Dovel 1981). Few larvae are collected in Cape Cod Bay (Scherer 1984), Narragansett Bay (Herman 1962; Bourne and Govoni 1988), and other southern New England estuaries (Stone *et al*. 1994). Both eggs and larvae have not been collected in Mystic River estuary (Connecticut) (Pearcy and Richards 1962). Black sea bass larvae occurred in the Indian River estuary (Delaware) during one of three survey years (Pacheco and Grant 1965) but were absent in a subsequent two-year survey of the estuary (Scotton 1970; Derickson and Price 1973; Klein-MacPhee 2002). Able *et al.* (1995) speculated that most larvae settle in near shore continental shelf habitats and then move into estuarine nurseries where post-settlement stage juveniles can be abundant.

JUVENILES

Because black sea bass are generally associated with structurally complex habitats and steep depth gradients, patterns of habitat specific distribution are not well described using standard trawl surveys. Black sea bass also use a variety of man-made habitats including artificial reefs, shipwrecks, bridge abutments, piers, pilings, jetties, groins, submerged pipes and culverts, navigation aids, anchorages, rip-rap barriers, fish and lobster traps, and rough bottom along the sides of navigation channels. The NEFSC and state trawl surveys avoid excessively rough bottom, shipwrecks, and reefs, or use roller gear, and thus under-sample fish that use structurally complex habitats. Furthermore these surveys avoid sampling in shallow coastal habitats where black sea bass may be abundant during juvenile life history stages. Thus habitat specific patterns of distribution derived from trawl survey data should be viewed with caution.

The distributions and abundances of juvenile black sea bass collected during NEFSC bottom trawl surveys from the Gulf of Maine to Cape Hatteras are shown in Figure 5. Note that winter and summer distributions are presented as presence data only. In winter they occurred mostly offshore on the shelf in the Mid-Atlantic and southern New England between the 50-200 m isobaths. In the spring the highest numbers are found off Chesapeake Bay and Cape Hatteras near the 200 m isobath, small numbers also occur inshore. In summer, the few juveniles that were present were found mostly nearshore from Delaware Bay to Cape Hatteras. In the fall, the highest numbers were found nearshore in southern New England around Buzzards Bay, Rhode Island Sound, and the tip of Long Island, as well as at the mouth of the Hudson-Raritan estuary; high numbers were also found in the nearshore Mid-Atlantic from Delaware Bay to Cape Hatteras (Figure 5).

Recently settled juveniles have been reported near the mouths of large estuaries from North Carolina to southern Cape Cod, and occasionally into the southern Gulf of Maine. At many locations, juvenile recruitment shows strong inter-annual variability (Adams 1993; Able *et al.* 1995) which may indicate that

meteorological forcing and other "stochastic" factors strongly affect the transport and recruitment of larvae to specific settlement habitats.

Juveniles appear to be most abundant in oceanic waters and polyhaline regions of many estuaries, but can occur at salinities as low as 8 ppt. Juveniles can be relatively common in estuaries south of Cape Cod, and are found in estuaries such as Narragansett Bay, Long Island Sound, the Hudson-Raritan estuary, Great Bay (NJ), Delaware Bay, Chesapeake Bay and tributaries, as well as many estuaries farther south (Bean 1902; Sherwood and Edwards 1902; Mansueti 1955; Richards 1963a, b; Kimmel 1973; Allen *et al.* 1978; Chesapeake Bay Program 1996; Wilk *et al*. 1997; Able and Fahay 1998; Geer 2002; Gottschall *et al.* 2000).

The distributions and abundances of juveniles in Massachusetts coastal waters, based upon the spring and fall 1978-2003 Massachusetts inshore trawl surveys, are shown in Figure 6. Small numbers were found mostly in Buzzards Bay and around Martha's Vineyard in the spring, in contrast to the fall, where very high numbers were found in the Bay and south of Cape Cod; a large catch was found on the eastern tip of Martha's Vineyard.

The seasonal distributions and abundances of juveniles in Narragansett Bay from 1990-1996, based on the Rhode Island bottom trawl surveys, are shown in Figure 7. They were not very common in the Bay; the largest mean catch (1.3 individuals/tow) occurred in summer in Mount Hope Bay.

The distributions and abundances of both juvenile and adult black sea bass in Long Island Sound from April to November 1984-1994, based on the Connecticut Fisheries Division bottom trawl surveys (Gottschall *et al*. 2000), are shown in Figures 8, 9, and 10. The size range of black sea bass captured in the survey ranged from 5-57 cm (Figure 8), with the majority of juveniles captured in October and November (84% and 57% respectively), many of which were YOY (< 10 cm) (Gottschall *et al*. 2000). Most black sea bass taken from May through August were adults. The following description of their distributions relative to depth and bottom type is taken from Gottschall *et al*. (2000).

During May and June, when black sea bass were most commonly encountered (about 13.6% occurrence), they were mostly captured on the Mattituck Sill and along the Connecticut side of the Sound from Norwalk to Guilford (Figure 9). In contrast, during the summer, sea bass were found almost exclusively among sand wave formations on the Mattituck Sill in depths between 18-27 m. During the fall, they were once again more dispersed; however, during September they were taken only in depths < 27 m, whereas in October and November abundance was highest in depths > 27 m (Figure 10C) (Gottschall *et al*. 2000).

Surveys of the Hudson-Raritan estuary (1992-1997) show that juveniles were found from spring through fall, and the highest numbers were concentrated mainly around the center of Raritan Bay in summer and fall (Figure 11).

The Virginia Institute of Marine Science (VIMS) trawl surveys from 1988-1999 of Chesapeake Bay and its tributaries showed that black sea bass was common in the lower Bay and James River, although they were rarely captured in large numbers (Geer 2002). The trawl survey caught 4,907 juveniles and 1,832 adults, with a size range from 2.0-35.4 cm (mean = 10.9 cm). Juveniles were common throughout the Bay and lower portions of the James and York Rivers during spring and summer (April to July) (Figures 12 and 13). Small juveniles (> 7.0 cm) first recruited to the gear in August, so Geer (2002) considered this month to be the beginning of the biological year. Juveniles migrated offshore in the winter and returned to the Bay the following spring at a maximum length of 11 cm. By July it was assumed that YOY fish are a maximum of 17.5 cm (Geer 2002).

The VIMS 1994-1999 beach seine surveys of Chesapeake Bay showed that juvenile black sea bass was uncommon, with only 98 fish captured, ranging in size from 2.2-15.3 cm (mean = 7.4 cm) (Geer 2002). The catch peaked during May (Figure 14), primarily along the ocean sites (Figure 15).

ADULTS

The distributions and abundances of adult black sea bass collected during NEFSC bottom trawl surveys are shown in Figure 16. Note again that winter and summer distributions are presented as presence data only. In winter they were found offshore near the 200 m isobath from southern New England to Cape Hatteras. High numbers were also found along the 200 m isobath in spring, with comparatively small numbers scattered along the Mid-Atlantic coast. In summer, the adults were found mostly closer to shore from the Delmarva peninsula to Cape Hatteras, In the fall, relatively small numbers were found along the coast of southern New England and Mid-Atlantic, but occurred farther offshore towards the Delmarva peninsula and Cape Hatteras; some higher numbers were found near the 200 m isobath off Virginia.

During the spring 1978-2003 Massachusetts inshore trawl surveys (Figure 17), adults were mostly found south of Cape Cod, around the islands, and in Buzzards Bay, with the highest numbers near Nantucket Island and south of the Cape in Nantucket Sound. Distributions were similar in the fall, with the highest numbers occurring in Nantucket Sound and in Buzzards Bay.

Very few adults were found in Narragansett Bay; none were found in winter (Figure 18).

The distributions and abundances of both juvenile and adult black sea bass in Long Island Sound, based

on Gottschall *et al*. (2000), were discussed previously.

Very few adults were found in the Hudson-Raritan estuary (Figure 19); those few that were present were found mostly around the middle of Raritan Bay. None were found in winter.

The VIMS trawl and beach seine surveys of Chesapeake Bay and tributaries show that adults were more common during the latter part of the summer and into the fall on the eastern side of the Bay (Figures 12 and 20) (Geer 2002).

HABITAT CHARACTERISTICS

EGGS

In the laboratory, the incubation period is 38 h at 23°C (Hoff 1970) and approximately 120 hrs at a temperature of 15°C (Kendall 1972). Eggs are sensitive to high salinity, low pH, high nitrite-nitrate concentrations, and temperature extremes.

During the MARMAP ichthyoplankton surveys, eggs were collected mostly between temperatures of about 10-25°C (Figure 21). During July through September, the months of highest mean monthly densities, most of the eggs were found at increasing temperatures over the three months: for July, about 16-22°C; for August, about 17-24°C; and for September, about 17-21°C. Their depth range over the period of the survey was between 10-375 m (Figure 21); however, overall they were found in relatively shallow depths. During July through September, the majority of eggs were found at 30 m.

LARVAE

Larval growth and development rates are inversely temperature dependant. In the laboratory, larval duration is 24 days at 18°C and 21 days at 22°C (Berlinsky *et al.* 2000). At 22°C, larvae grew from 3.5 ± 0.1 to 12.2 ± 0.6 mm in about 18 days, which was significantly faster than those cultured at 18°C (Berlinsky *et al.* 2000). Growth was significantly higher in greenwater (algae-water) than in cultures without greenwater.

During the MARMAP ichthyoplankton surveys, larvae were collected between temperatures of 11-26°C (Figure 22). During July through September, the months of highest mean monthly densities, most larvae were found at about 15-19°C in July, at 15-20°C in August, and in 17-21°C in September. During the survey period they were found over a depth range between 10 m to > 2000 m (Figure 22); however, as with the eggs, the majority were found in shallow depths. During July through September, most were found at 30-50 m.

JUVENILES

Structural complexity appears to be essential component of juvenile black sea bass habitat in offshore as well as inshore nurseries throughout the species range. In offshore areas, recently settled fish occur in accumulations of shell on sand substrata, complex microtopographies on exposed clay, on rocky reefs, and on wrecks (Able *et al.* 1995). Because eggs and larvae are largely absent in estuaries, Able *et al*. (1995) speculated that primary black sea bass settlement habitats were probably located along the near shore continental shelf in accumulations of the shells of bivalves, including Atlantic surf clams (*Spisula solidissima*). Large numbers of newly settled black sea bass were observed on sandy substrates with shell fragments adjacent to an artificial reef 15 km off the coast of Virginia-North Carolina (Adams 1993). Settlers were also observed on the reef. Within estuaries, young fish use shallow shellfish (oyster and mussel), sponge (including *Microciona prolifera*), amphipod (*Ampelisca abdita*), seagrass beds (especially *Ruppia* sp.), and cobble habitats as well as manmade structures such as wharves, pilings, wrecks, reefs, crab and conch pots (Bean 1888; Moore 1892; Sherwood and Edwards 1902; Hildebrand and Schroeder 1928; Arve 1960; Kendall 1972; Derickson and Price 1973; Musick and Mercer 1977; Clayton *et al.* 1978; Weinstein and Brooks 1983; Feigenbaum *et al.* 1989; Able *et al.* 1995). Early juveniles are rare on un-vegetated sandy intertidal flats and beaches (Allen *et al.* 1978) as well as deeper, muddy bottoms (Richards 1963b). Juveniles are primarily associated with shell bottom throughout the year in the lower reaches of a Georgia estuary (Dahlberg 1972).

Juvenile black sea bass display extremely high site fidelity. Recapture rates of tagged juveniles 34-111mm TL (N = ~ 700) ranged from 20% to 30%, and 99% of recaptured fish occurred within 30 m of a release site in a New Jersey estuary (Able and Hales 1997). Young fish may be territorial and defend structured habitat from con-specifics (Werme 1981; Able and Fahay 1998). Like many reef species, juvenile recruitment strength for black sea bass may be strongly affected by the availability of shelters that serve as predation refuges (Huntsman *et al.* 1983; Richards and Lindeman 1987). Arve (1960) attributed black sea bass stock declines in the late 1950s in Chincoteague Bay, MD to declines in oyster populations that provided important shelter habitat for juveniles. Oysters, once common but now effectively extinct in Raritan Bay, NY and NJ, were once important juvenile black sea bass habitat in that estuary (Nichols and Breder 1927).

In the Mid and South Atlantic Bights, black sea bass nursery habitats occur at depths < 50 m (Sedberry *et al*. 1998). Most nurseries are located at depths < 20 m (Sedberry *et al*. 1998). Juvenile depth distributions appear to increase with age and body size (Kendall 1977; Musick and Mercer 1977). Within estuaries, older juveniles use habitats < 10 m deep but the YOY are collected in shallower shoal habitats (1 m) (Musick and Mercer 1977). Older juveniles use deeper estuarine channels (Bean 1888; de Sylva *et al*. 1962; Richards and Castagna 1970; Zawacki 1976; Allen *et al.* 1978; Szedlmayer and Able 1996), jetties (Schwartz 1964), and bridge abutments (Allen *et al.* 1978).

Laboratory studies show that growth rates of juvenile black sea bass vary with temperature, salinity, dissolved oxygen and prey quality (Berlinsky *et al.* 2000). Several studies have shown that juveniles grow most rapidly at intermediate salinities. Fish exposed to a salinity of 20 ppt showed higher growth than those exposed to 10 and 32 ppt in the laboratory (Berlinskiy *et al.* 2000). Optimal salinities for the growth of fish appear to be similar in the South Atlantic Bight (Cotton *et al*. 2003). Osmoregulatory costs are reduced for fish at intermediate salinities. High growth at polyhaline salinities may indicate that habitat suitability is higher in the lower reaches of estuaries and shelf areas under estuarine influence, than offshore nurseries, but experimental comparisons of habitat suitability in estuarine and continental shelf nursery habitats has not been performed.

In the South Atlantic Bight, fish 20-140 mm SL are most abundant on reefs where salinities exceed 30 ppt, but have been collected in estuarine regions where salinities are as low as 9 ppt (Cupka *et al.* 1973). In the St. John's River, FL, young-of the year black sea bass (28-71 mm TL) are primarily associated with salinities ranging from 15-25 ppt (Tagatz 1967). However, larger juveniles can occur in estuarine reaches where salinities are as low as 8-13 ppt. Juveniles were generally most abundant in the lower reaches of a Georgia estuary where salinities are > 30 ppt (Dahlberg 1972).

Hales and Able (1995) showed that laboratory exposure to short term periods of low dissolved oxygen result in poor growth and significant mortality in age-0 and 1+ black sea bass. In their study fish did not grow and showed respiratory distress and reduced feeding when exposed to oxygen concentrations < 2 ppm. In contrast exposure to ~ 6 ppm produced significantly positive growth rates (0.3% d TL). Fifty percent mortality occurred after short-term exposure to ~1 ppm. The authors speculated that conditions producing episodes of hypoxia near continental shelf settlement habitats could depress juvenile recruitment in some areas.

In the laboratory, juvenile black sea bass showed 100% mortality when exposed to temperatures of 2-3°C in seawater pumped from a New Jersey estuary. Temperatures < 6°C resulted in increased shelter use and burial behavior and feeding decreased dramatically at values < 4°C (Able and Hales 1997). These data are consistent with early observations of juvenile mortality during episodic cold temperatures in shallow nursery areas in southern New England (Baird 1873). The fall migration of juvenile black sea bass from shallow estuarine and coastal nursery habitats to deeper offshore waters in the Mid-Atlantic Bight appears to be triggered by declining temperatures. Juveniles begin to move into deeper warmer offshore water as temperatures decline below 14°C, and few individuals are collected in shallow areas when temperatures fall below 6°C (Able and Fahay 1998; Klein-MacPhee 2002). In the Mid-Atlantic Bight, juveniles return to nearshore and estuarine habitats in the spring and are collected as early as March in the Chesapeake Bay region (Kimmel 1973).

Juveniles (20-140 mm SL) are collected at temperatures ranging from 6-30°C in the South Atlantic Bight (Cupka *et al.* 1973). In North Carolina, young-of the year (30-50 mm SL) are abundant along inshore jetties at temperatures 6-29°C (Link 1980; Schwartz *et al.* 1981). Young of the year fish (28-71 mm FL) are also collected in June and July at temperatures ranging from 26.6-27.4°C in the Saint John's River, Florida (Tagatz 1967). During the winter and spring, larger juveniles (91-176 mm FL) occur at temperatures between 11.0-17.4°C in the estuary.

The spring and fall distributions of juvenile black sea bass relative to bottom water temperature, depth, and salinity based on 1963-2003 NEFSC bottom trawl surveys from the Gulf of Maine to Cape Hatteras are shown in Figure 23. In the spring, they were found over a temperature range of 4-18°C, with most spread between about 8-15°C and a peak in catch at 12°C. They were found at depths ranging from 1-400 m; there were peaks in the catch at 101-140 m. Their salinity range was between 28-36 ppt, with the majority spread between 33-35 ppt. In the fall, the juveniles were spread over a warmer temperature range than in the spring: 7-28°C, with the majority found at temperatures ≥ 15°C. They were also found at shallower depths than in the spring, with a range from 1 m to about 140 m, with most found between 11-40 m. Their salinity range was between 29-36 ppt, with the majority at 31-33 ppt.

The spring and autumn distributions of juvenile black sea bass in Massachusetts coastal waters relative to bottom water temperature and depth based on 1978-2003 Massachusetts inshore trawl surveys are shown in Figure 24. The few that were found in spring were found over a temperature range of 9-12°C and a depth range of 6-35 m. The much larger numbers that were found in the fall were found over a higher temperature range of about 10-22°C, with most between 17-21°C. Their depth range during that season was between 1-35 m, with the majority between 6-15 m.

The seasonal distributions of the few juveniles found in Narragansett Bay, relative to bottom water temperature and depth, based on 1990-1996 Rhode Island Narragansett Bay trawl surveys are shown in

Figure 25. In the spring they were found in 11ºC waters, in summer almost all were found at 24ºC, and in the fall they were found at a temperature range of 14-22ºC. Juvenile black sea bass were found at depths of 30-40 ft (9-12 m) in the spring, 10-30 ft (3-9 m) in the summer, and from 10 ft to about 70 ft (21 m) in the fall, with most found in that latter season at 30-40 ft.

The distributions and abundances of both juveniles and adults in Long Island Sound relative to depth were discussed previously, and can be seen, along with their relation to bottom type, in Figure 10 (Gottschall *et al*. 2000).

The distributions of juvenile black sea bass relative to bottom water temperature, dissolved oxygen, depth, and salinity based on 1992-1997 NEFSC Hudson-Raritan estuary trawl surveys are shown in Figure 26. Over the entire survey, juveniles were found in waters ranging from 3-23ºC, with higher percentages found at temperatures $\geq$ 15ºC. They were found in dissolved oxygen levels of 4-11 mg/l, with most between 5-7 mg/l. They were found over a depth range of 10-75 ft (3-23 m), most were found at relatively shallow depths from approximately 20-50 ft (6-15 m). Juveniles were found in salinities ranging from 20-33 ppt, with the majority found at 25-27 ppt.

The hydrographic preferences of juveniles in Chesapeake Bay and tributaries from the 1988-1999 VIMS trawl surveys are shown in Figure 27 (all years and months combined). According to Geer (2002), most juveniles were caught at dissolved oxygen levels of 5-8 mg/l, at temperatures > 16ºC, at salinities > 18 ppt, and at depths > 8 m, (Figure 27). The hydrographic preferences of juveniles caught in the 1994-1999 seine surveys are shown in Figure 28 (all years and months combined). Geer (2002) suggests that the majority were caught in slighter higher temperatures than that of the trawl survey, which may be due to sampling only during months where water temperatures are fairly warm. Most juveniles were also caught in higher salinity waters, with nearly 90% of the catch occurring in waters > 26 ppt (Figure 28). The majority of juveniles caught in the seine surveys were found at dissolved oxygen levels of both 3 mg/l and 6-7 mg/l, and at pH levels of 7.4-8.2.

ADULTS

As stated previously, black sea bass are strongly associated with structurally complex habitats, including rocky reefs, cobble and rock fields, stone coral patches, exposed stiff clay, and mussel beds (see the Life History section for further discussion).

Over wintering habitats in the Mid-Atlantic Bight appear to occur at depths between 60-150 m (range: 30-410 m) (Musick and Mercer 1977). Some fish may also over winter in deep water (> 80 m) off southern New England (Bigelow and Schroeder 1953; Chang 1990; Kolek 1990). Larger fish, that are generally male, occur in deeper water (Nesbit and Neville 1935; Musick and Mercer 1977; Able *et al*. 1995). Potential over wintering habitat may be defined by bottom water temperatures > 7.5°C (Neville and Talbot 1964; Colvocoresses and Musick 1984). The lowest bottom temperatures recorded in the depth range inhabited by adult black sea bass off South Carolina was 5.6°C (Walford and Wicklund 1968). Adult fish exposed to temperatures near 6°C become inactive and were often found resting in holes and crevices (Adams 1993). Schwartz (1964) showed that adult black sea bass stopped feeding when exposed to a temperature of 8°C (salinity = 15 ppt) and died when temperatures were reduced below 2°C. Fish may not over winter in South Atlantic Bight estuaries in the northern part of the region, except during warm winters. Adult sea bass burrow into soft sediments during particularly cold winters off the coast of North and South Carolina (Parker 1990). Winter association of black sea bass with soft substrata on the continental shelf in the Mid-Atlantic Bight (Wigley and Theroux 1981) could be related to winter burial.

In the South Atlantic Bight, black sea bass occur in habitats 10-120 m deep but are most abundant between 20-60 m and occur at temperatures below 29°C (Struhsaker 1969; Link 1980). In the Gulf of Mexico they occur at depths of 7.3-18.3 m, and are most abundant between Tampa and Apalachee Bay (Godcharles 1970; Powers *et al*. 2003). Larger fish are generally found in deeper habitats than smaller fish (Musick and Mercer 1977). Fish have been collected at relatively low salinities (range: 1-36 ppt) in North Carolina estuaries but are most frequent where values exceed 14 ppt (Link 1980). Salinity ranges for fish in Gulf of Mexico and South Atlantic Bight estuaries are similar (Springer and Woodburn 1960).

Adult black sea bass also appear to be vulnerable to low dissolved oxygen stress. Episodic hypoxia in the New York Bight has resulted in mortality for fish and benthic invertebrates, and avoidance on the nearshore continental shelf (Ogren and Chess 1969; Azarovitz *et al.* 1979; Steimle and Radosh 1979). During such events commercial fishermen and sport divers have reported the disappearance and mortality of black sea bass and other fishes from shipwrecks and artificial reefs near the New Jersey coast. These hypoxic conditions are produced by meteorologically driven upwelling events that are followed by early and strong water column stratification that result in an unusually large dinoflagellate blooms. The transport of nutrients from the Hudson River estuary to the nearshore continental shelf may also be important. The Asbury Park Press (NJ) newspaper reported black sea bass mortality in an area where dissolved oxygen concentrations fell below 2 ppm off the New Jersey coast in June of 1997, which followed coastal upwelling.

The spring and fall distributions of adult black sea bass relative to bottom water temperature, depth, and salinity based on 1963-2003 NEFSC bottom trawl surveys are shown in Figure 29. In the spring, they were found over a temperature range of about 3-21°C, with most at 9-12°C. Their depth range was 1-400 m with higher percentages concentrated between 61-140 m. They were found in a salinity range of 32-36 ppt, with the majority between 34-35 ppt. In the fall, adults were spread over a warmer temperature range of 8-28°C, with most spread between about 16-27°C. Their depth range was shallower than in the spring: from 1m to greater than 160 m, with the majority at 11-40 m. Their salinity range was between 30-36 ppt, with the majority at 31-32 ppt.

The spring and autumn distributions of adults in Massachusetts coastal waters relative to bottom water temperature and depth are shown in Figure 30. In spring they were found over at temperature range of 3-17°C, with the majority at 10-14°C. Their depth range during the spring survey was from 1-65 m, with most between 6-25 m. The adults were found at warmer temperatures in the fall, being found over a range of approximately 8-22°C, with the majority between 16-21°C. Almost all were found between depths of 6-20 m.

The seasonal distributions of the few adults found in Narragansett Bay, relative to bottom water temperature and depth, are shown in Figure 31. In the spring they were mostly found in 13-14ºC waters, in summer they were found in a temperature range of 15-24ºC, with peaks at 91-20ºC, and in the fall the majority were at 19-20ºC. Adults were found mostly at a depth of 100 ft (30 m) in the spring, 20-80 ft (6-24 m) in the summer, and from 30-50 ft (9-15 m) and from 100-110 ft (30-34 m) in the fall.

The distributions and abundances of both juveniles and adults in Long Island Sound relative to depth were discussed previously, and can be seen, along with their relation to bottom type, in Figure 10 (Gottschall *et al*. 2000).

The distributions of the few adults found in the Hudson-Raritan estuary, relative to bottom water temperature, dissolved oxygen, depth, and salinity are shown in Figure 32. Over the entire survey, adults were found in a temperature range of 11-23ºC, in a depth range of about 15-65 ft (5-20 m), and were spread over a salinity range spread 20-33 ppt. The majority were found at a dissolved oxygen level of 7mg/l.

In Chesapeake Bay and its tributaries, adults had similar hydrographic preferences to the juveniles in the VIMS trawl surveys (Figure 33) (Geer 2002).

RESEARCH NEEDS

- Studies examining hydrographic mechanisms and larval behaviors controlling larval transport from adult spawning and settlement habitats, including effects of hydrographic processes on the spatial characteristics of settlement habitats and on inter-annual variation in local early juvenile recruitment
- Studies of the mechanisms determining successful migration from offshore settlement to estuarine nursery grounds.
- Comparative studies of the functional habitat quality of coastal ocean and estuarine nursery grounds.
- All aspects of reproductive biology and behavior including the spatial and environmental characteristics of primary spawning habitats, factors controlling sexual transition, and density dependent reproductive success.

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Table 1. Diet composition of black sea bass by fish length category. Data expressed as percentage of stomach content by weight. Squared brackets indicate major taxon subtotal; parentheses indicate minor taxon subtotal. Source: Bowman *et al*. (2000); from NEFSC groundfish surveys, 1977-1980.

	Length Category (cm)									
Stomach Contents	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	>40	Total
MOLLUSCA	-	[0.5]	[2.4]	[6.7]	[20.4]	[9.2]	[2.5]	[10.5]	[6.7]	[10.2]
Bivalvia	-	(0.5)	(1.8)	(4.2)	(7.4)	(8.0)	(1.1)	(6.9)	(1.3)	(5.2)
Laevicardium sp.	-	-	-	1.7	2.2	6.6	-	-	-	2.6
Ensis directus	-	-	-	-	0.3	-	-	6.9	1.3	0.5
Bivalvia unid.	-	0.5	1.8	2.5	4.9	1.4	1.1	-	-	2.1
Cephalopoda	-	-	-	(1.0)	(12.1)	(0.6)	(0.5)	(3.3)	(2.3)	(3.8)
Loligo sp.	-	-	-	-	4.1	-	-	-	2.2	1.3
Cephalopoda unid.	-	-	-	1.0	8.0	0.6	0.5	3.3	0.1	2.5
Mollusca unid.	-	-	(0.6)	(1.5)	(0.9)	(0.6)	(0.9)	(0.3)	(3.1)	(1.2)
POLYCHAETA	-	[5.8]	[8.3]	[0.2]	[0.7]	[0.2]	[0.4]	[<0.1]	[9.6]	[1.9]
CRUSTACEA	[85.5]	[91.5]	[82.4]	[76.3]	[45.7]	[57.8]	[78.8]	[45.7]	[17.3]	[54.5]
Amphipoda	(43.6)	(19.9)	(0.3)	(<0.1)	(<0.1)	(<0.1)	(7.5)	-	-	(1.2)
Mysidacea	(3.2)	(4.2)	-	(1.1)	(<0.1)	(2.5)	(<0.1)	-	-	(0.9)
Euphausiacea	-	-	(33.8)	(34.2)	(7.3)	-	-	-	-	(6.3)
Meganyctiphanes norvegica	-	-	33.8	34.2	7.3	-	-	-	-	6.3
Decapoda	(35.5)	(44.2)	(46.9)	(40.3)	(38.2)	(54.9)	(70.2)	(45.7)	(17.3)	(45.6)
Dichelopandalus leptocerus	-	7.2	-	<0.1	-	-	-	-	-	<0.1
Crangon septemspinosa	14.5	19.4	0.1	<0.1	0.3	0.3	<0.1	-	0.1	0.2
Paguridae	-	1.9	6.4	2.4	5.8	3.8	0.9	-	2.0	3.4
Munida sp.	-	1.7	-	2.3	0.4	4.5	1.7	-	-	1.9
Cancer borealis	-	-	1.8	-	-	<0.1	7.6	-	-	1.2
Cancer irroratus	-	10.2	23.8	19.6	17.5	40.4	37.2	45.7	7.6	27.0
Ovalipes sp.	-	-	-	-	-	-	15.2	-	4.8	3.0
Decapoda unid.	21.0	3.8	14.8	16.0	14.2	5.9	7.6	-	2.8	8.9
Crustacea unid.	(3.2)	(23.2)	(1.4)	(0.7)	(0.2)	(0.4)	(1.1)	-	-	(0.5)
OSTEICHTHYES	-	[1.8]	[2.6]	[8.4]	[27.8]	[25.0]	[14.7]	[43.5]	[62.9]	[28.5]
Ophichthus cruentifer	-	-	-	-	-	-	-	-	0.3	0.1
Alepocephalidae	-	-	-	-	-	2.0	-	-	-	0.6
Clupea harengus	-	-	-	-	2.3	-	-	-	-	0.6
Anchoa hepsetus	-	-	-	6.8	17.2	-	-	-	9.5	6.4
Anchoa mitchilli	-	-	-	-	-	-	9.6	-	-	1.5
Engraulidae	-	-	-	-	3.7	-	-	-	-	0.9
Cyprinodon variegatus	-	-	-	-	-	-	-	30.4	-	1.3
Hippocampus sp.	-	-	-	-	-	-	1.9	-	-	0.3
Syngnathus fuscus	-	-	-	-	-	-	3.0	-	-	0.5
Myctophidae	-	-	-	-	-	12.8	-	-	-	3.6
Ophidiidae	-	-	-	-	-	2.1	-	-	-	0.6
Ammodytes dubius	-	-	-	-	-	-	-	-	20.6	3.0
Stenotomus chrysops	-	-	-	-	-	3.7	-	-	25.3	4.8
Scophthalmus aquosus	-	-	-	-	-	-	-	-	4.4	0.7
Osteichthyes larvae	-	-	-	-	<0.1	<0.1	-	-	-	<0.1
Osteichthyes unid.	-	1.8	2.6	1.6	4.6	4.4	0.2	13.1	2.8	3.6
ANIMAL REMAINS AND MISC.	[14.5]	[0.4]	[4.3]	[8.4]	[5.4]	[7.8]	[3.6]	[0.3]	[3.5]	[4.9]
Number sampled	9	82	69	142	188	103	49	16	22	680
Number empty	1	11	19	36	64	30	18	11	5	195
Mean stomach content (g)	0.007	0.023	0.223	0.581	0.975	2.033	2.314	1.912	4.983	1.097
Mean fish length (cm)	5	7	13	18	22	27	32	38	45	21

Table 2. Diet composition of black sea bass by geographic area. Data expressed as percentage of stomach content by weight. Squared brackets indicate major taxon subtotal; parentheses indicate minor taxon subtotal. Source: Bowman *et al*. (2000); from NEFSC groundfish surveys, 1977-1980.

	Length Category (cm)									
Stomach Contents	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	>40	Total
MOLLUSCA	-	[0.5]	[2.4]	[6.7]	[20.4]	[9.2]	[2.5]	[10.5]	[6.7]	[10.2]
Bivalvia	-	(0.5)	(1.8)	(4.2)	(7.4)	(8.0)	(1.1)	(6.9)	(1.3)	(5.2)
Laevicardium sp.	-	-	-	1.7	2.2	6.6	-	-	-	2.6
Ensis directus	-	-	-	-	0.3	-	-	6.9	1.3	0.5
Bivalvia unid.	-	0.5	1.8	2.5	4.9	1.4	1.1	-	-	2.1
Cephalopoda	-	-	-	(1.0)	(12.1)	(0.6)	(0.5)	(3.3)	(2.3)	(3.8)
Loligo sp.	-	-	-	-	4.1	-	-	-	2.2	1.3
Cephalopoda unid.	-	-	-	1.0	8.0	0.6	0.5	3.3	0.1	2.5
Mollusca unid.	-	-	(0.6)	(1.5)	(0.9)	(0.6)	(0.9)	(0.3)	(3.1)	(1.2)
POLYCHAETA	-	[5.8]	[8.3]	[0.2]	[0.7]	[0.2]	[0.4]	[<0.1]	[9.6]	[1.9]
CRUSTACEA	[85.5]	[91.5]	[82.4]	[76.3]	[45.7]	[57.8]	[78.8]	[45.7]	[17.3]	[54.5]
Amphipoda	(43.6)	(19.9)	(0.3)	(<0.1)	(<0.1)	(<0.1)	(7.5)	-	-	(1.2)
Mysidacea	(3.2)	(4.2)	-	(1.1)	(<0.1)	(2.5)	(<0.1)	-	-	(0.9)
Euphausiacea	-	-	(33.8)	(34.2)	(7.3)	-	-	-	-	(6.3)
Meganyctiphanes norvegica	-	-	33.8	34.2	7.3	-	-	-	-	6.3
Decapoda	(35.5)	(44.2)	(46.9)	(40.3)	(38.2)	(54.9)	(70.2)	(45.7)	(17.3)	(45.6)
Dichelopandalus leptocerus	-	7.2	-	<0.1	-	-	-	-	-	<0.1
Crangon septemspinosa	14.5	19.4	0.1	<0.1	0.3	0.3	<0.1	-	0.1	0.2
Paguridae	-	1.9	6.4	2.4	5.8	3.8	0.9	-	2.0	3.4
Munida sp.	-	1.7	-	2.3	0.4	4.5	1.7	-	-	1.9
Cancer borealis	-	-	1.8	-	-	<0.1	7.6	-	-	1.2
Cancer irroratus	-	10.2	23.8	19.6	17.5	40.4	37.2	45.7	7.6	27.0
Ovalipes sp.	-	-	-	-	-	-	15.2	-	4.8	3.0
Decapoda unid.	21.0	3.8	14.8	16.0	14.2	5.9	7.6	-	2.8	8.9
Crustacea unid.	(3.2)	(23.2)	(1.4)	(0.7)	(0.2)	(0.4)	(1.1)	-	-	(0.5)
OSTEICHTHYES	-	[1.8]	[2.6]	[8.4]	[27.8]	[25.0]	[14.7]	[43.5]	[62.9]	[28.5]
Ophichthus cruentifer	-	-	-	-	-	-	-	-	0.3	0.1
Alepocephalidae	-	-	-	-	-	2.0	-	-	-	0.6
Clupea harengus	-	-	-	-	2.3	-	-	-	-	0.6
Anchoa hepsetus	-	-	-	6.8	17.2	-	-	-	9.5	6.4
Anchoa mitchilli	-	-	-	-	-	-	9.6	-	-	1.5
Engraulidae	-	-	-	-	3.7	-	-	-	-	0.9
Cyprinodon variegatus	-	-	-	-	-	-	-	30.4	-	1.3
Hippocampus sp.	-	-	-	-	-	-	1.9	-	-	0.3
Syngnathus fuscus	-	-	-	-	-	-	3.0	-	-	0.5
Myctophidae	-	-	-	-	-	12.8	-	-	-	3.6
Ophidiidae	-	-	-	-	-	2.1	-	-	-	0.6
Ammodytes dubius	-	-	-	-	-	-	-	-	20.6	3.0
Stenotomus chrysops	-	-	-	-	-	3.7	-	-	25.3	4.8
Scophthalmus aquosus	-	-	-	-	-	-	-	-	4.4	0.7
Osteichthyes larvae	-	-	-	-	<0.1	<0.1	-	-	-	<0.1
Osteichthyes unid.	-	1.8	2.6	1.6	4.6	4.4	0.2	13.1	2.8	3.6
ANIMAL REMAINS AND MISC.	[14.5]	[0.4]	[4.3]	[8.4]	[5.4]	[7.8]	[3.6]	[0.3]	[3.5]	[4.9]
Number sampled	9	82	69	142	188	103	49	16	22	680
Number empty	1	11	19	36	64	30	18	11	5	195
Mean stomach content (g)	0.007	0.023	0.223	0.581	0.975	2.033	2.314	1.912	4.983	1.097
Mean fish length (cm)	5	7	13	18	22	27	32	38	45	21

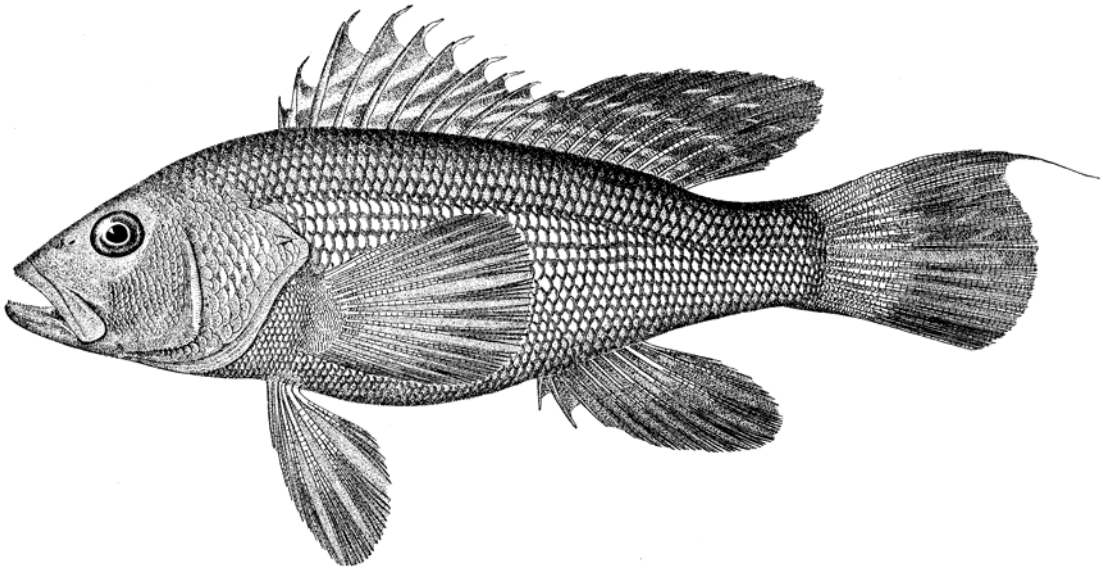

Figure 1. The black sea bass, *Centropristis striata* (from Goode 1884).

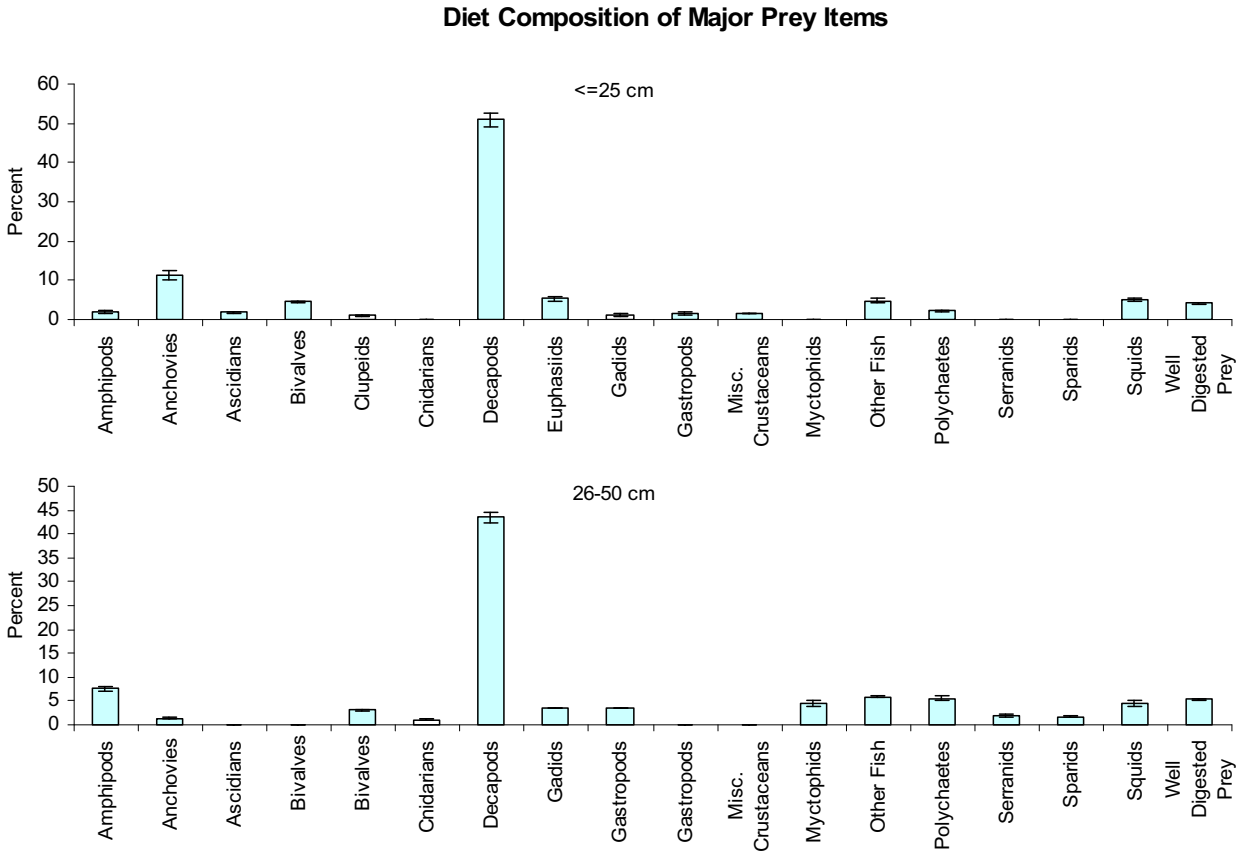

Figure 2. Percent by weight of the major prey items in the diet of two size categories of black sea bass. Specimens were collected during NEFSC bottom trawl surveys from 1973-2001 (all seasons). For details on NEFSC diet analysis, see Link and Almeida (2000).

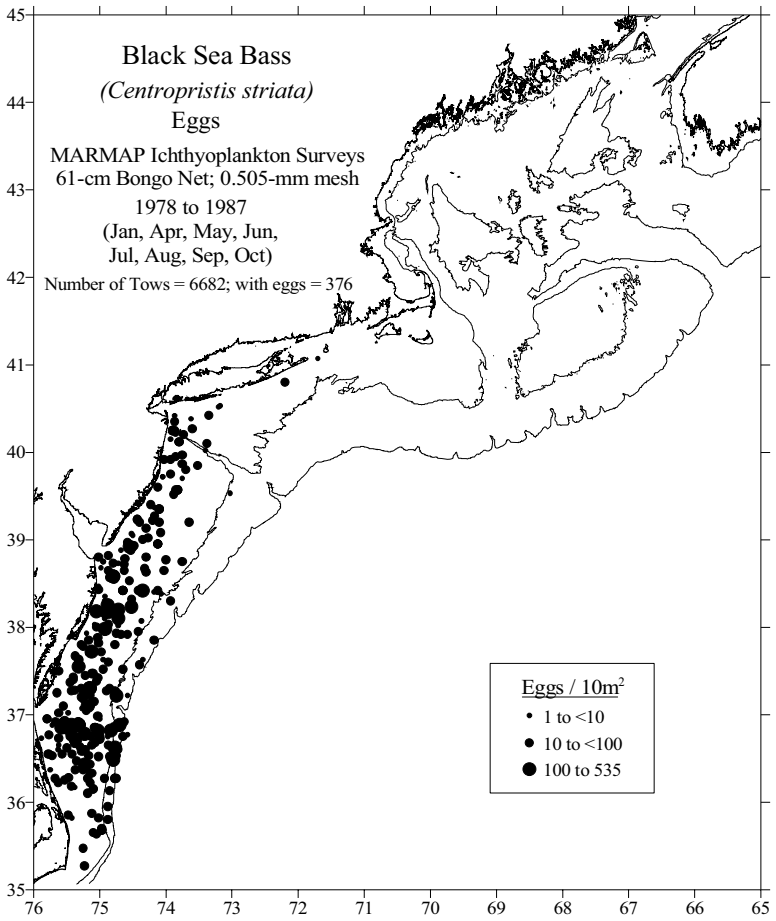

Figure 3. Distributions and abundances of black sea bass eggs collected during NEFSC MARMAP ichthyoplankton surveys, for all available months and years from 1978-1987 combined.

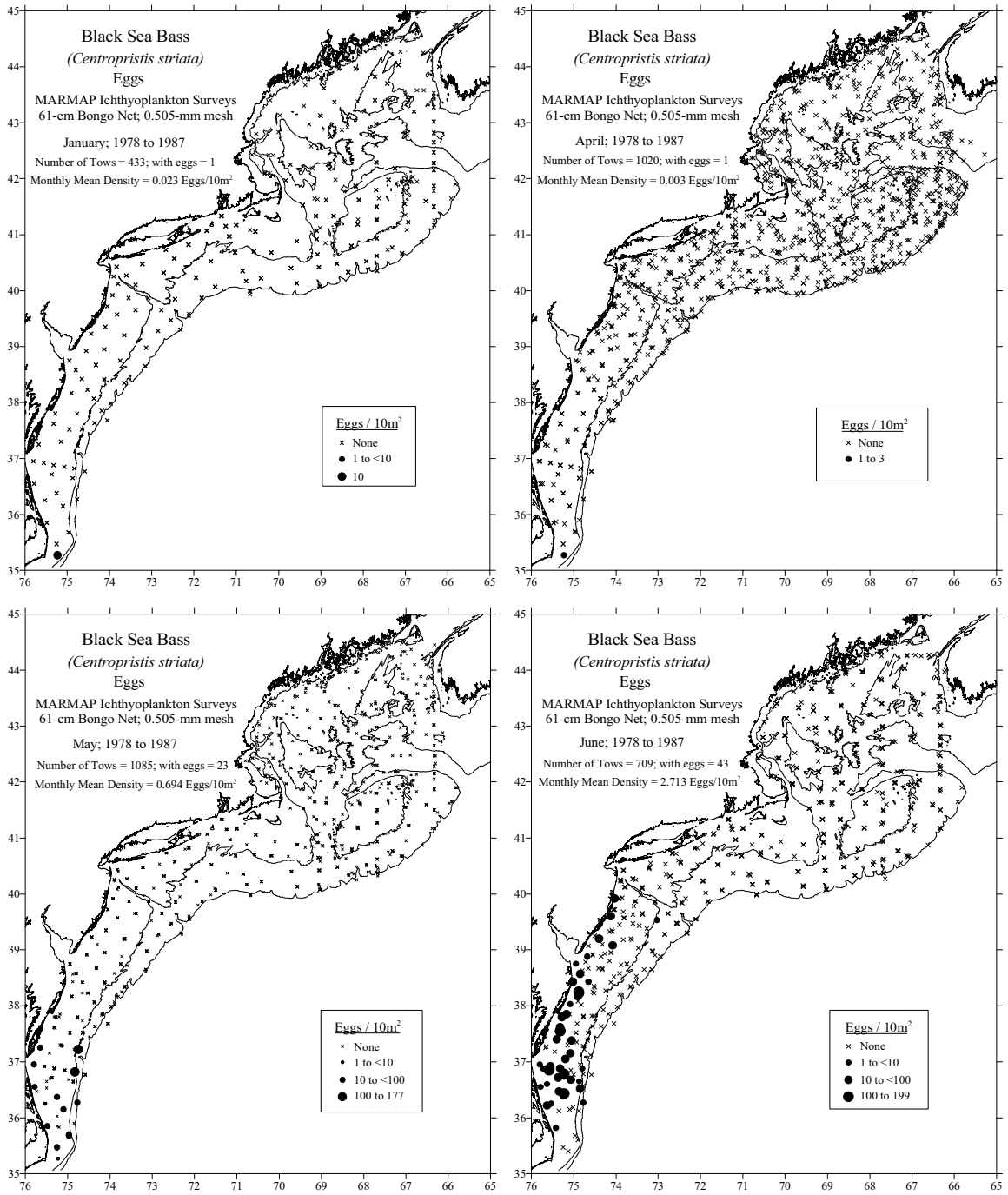

Figure 3. Cont'd.
From MARMAP ichthyoplankton surveys, January, April, May, and June, 1978-1987.

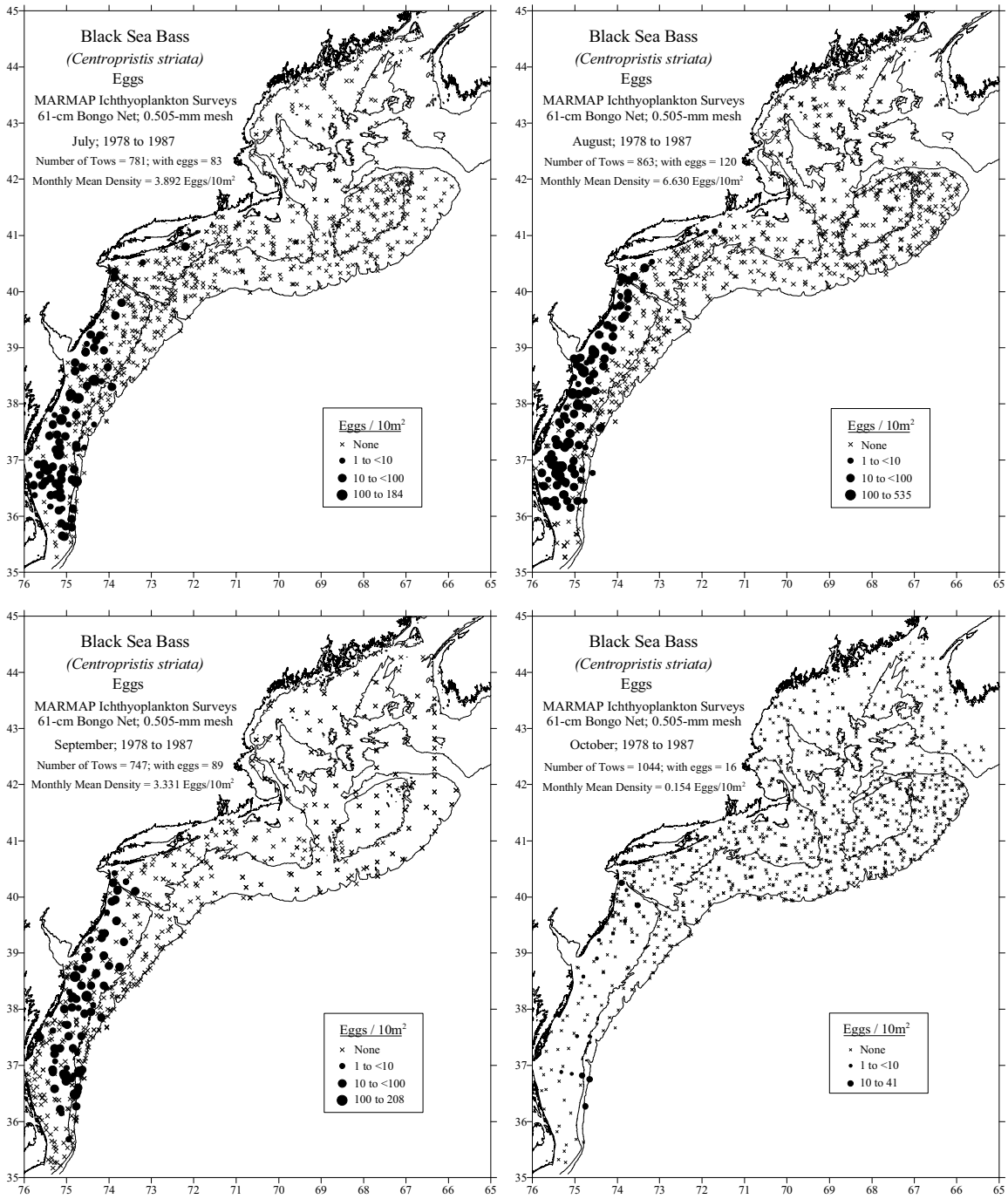

Figure 3. Cont'd.
From MARMAP ichthyoplankton surveys, July through October, 1978-1987.

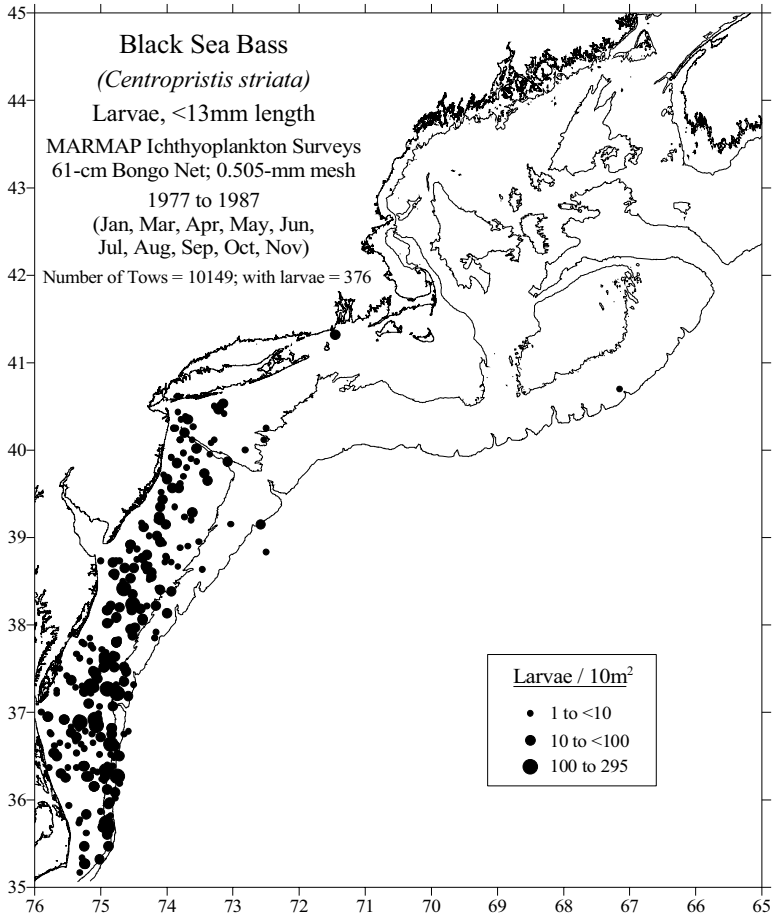

Figure 4. Distributions and abundances of black sea bass larvae collected during NEFSC MARMAP ichthyoplankton surveys, for all available months and years from 1977-1987 combined.

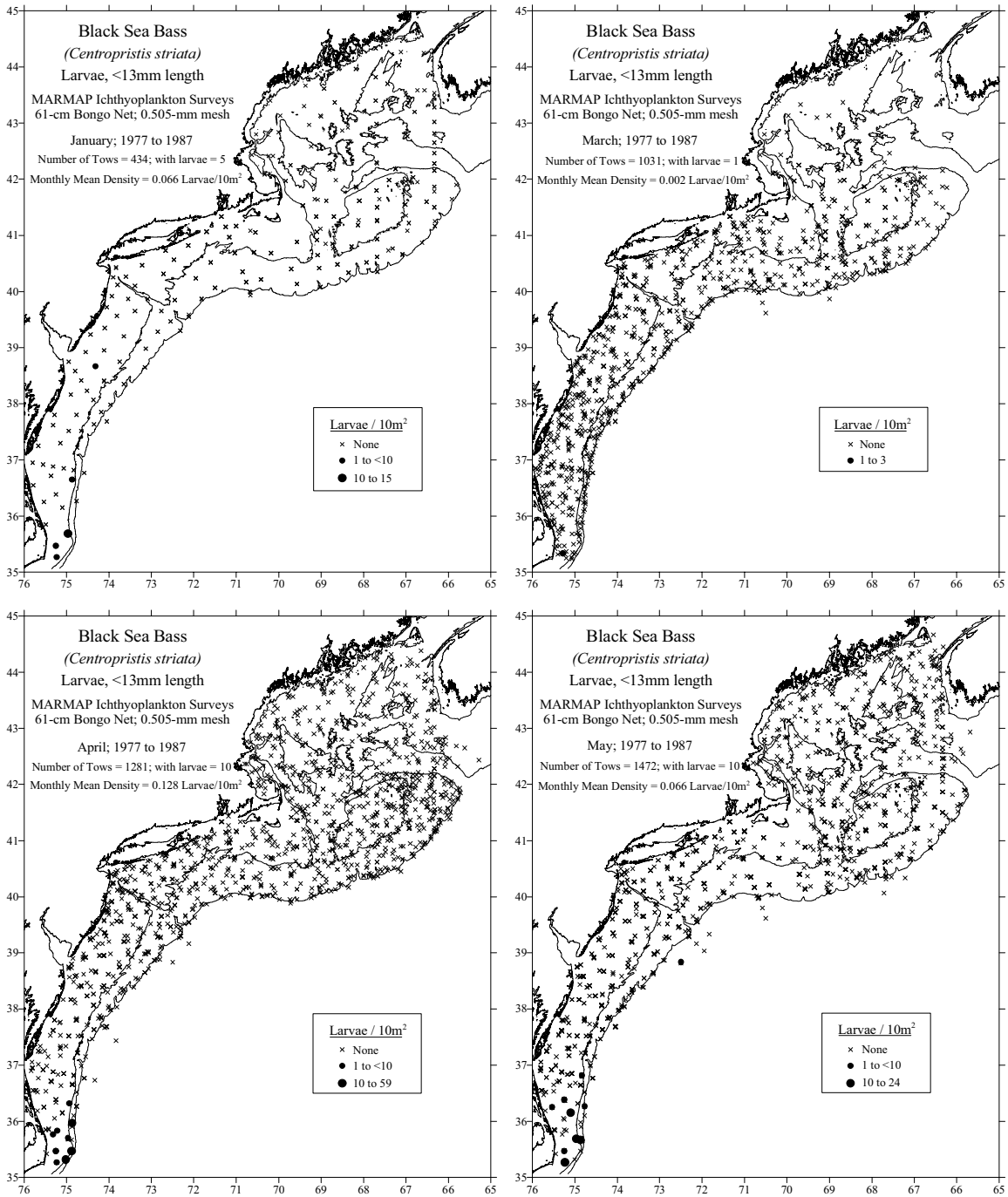

Figure 4. Cont'd.
From MARMAP ichthyoplankton surveys, January, March April, and May, 1977-1987.

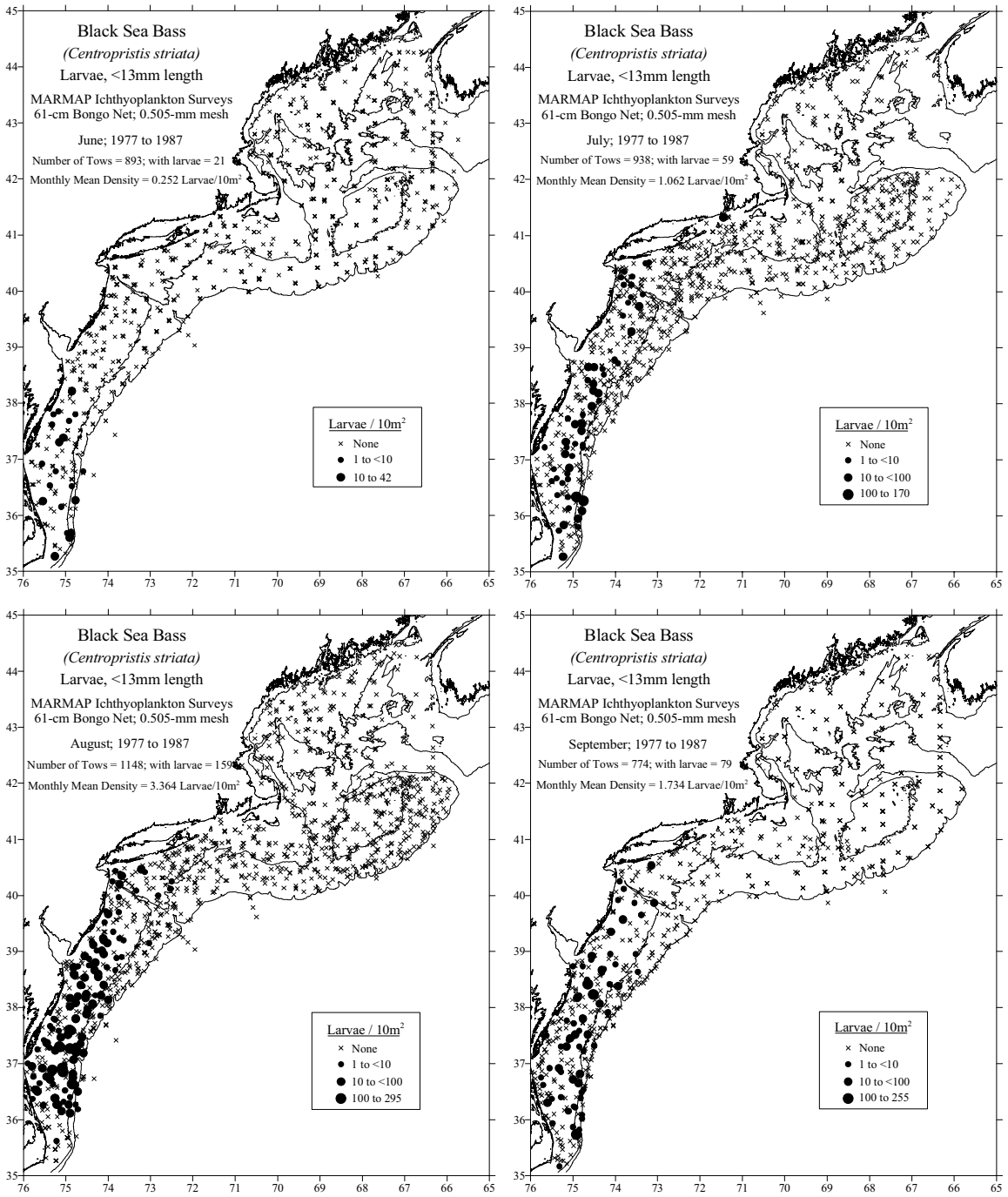

Figure 4. Cont'd.
From MARMAP ichthyoplankton surveys, June through September, 1977-1987.

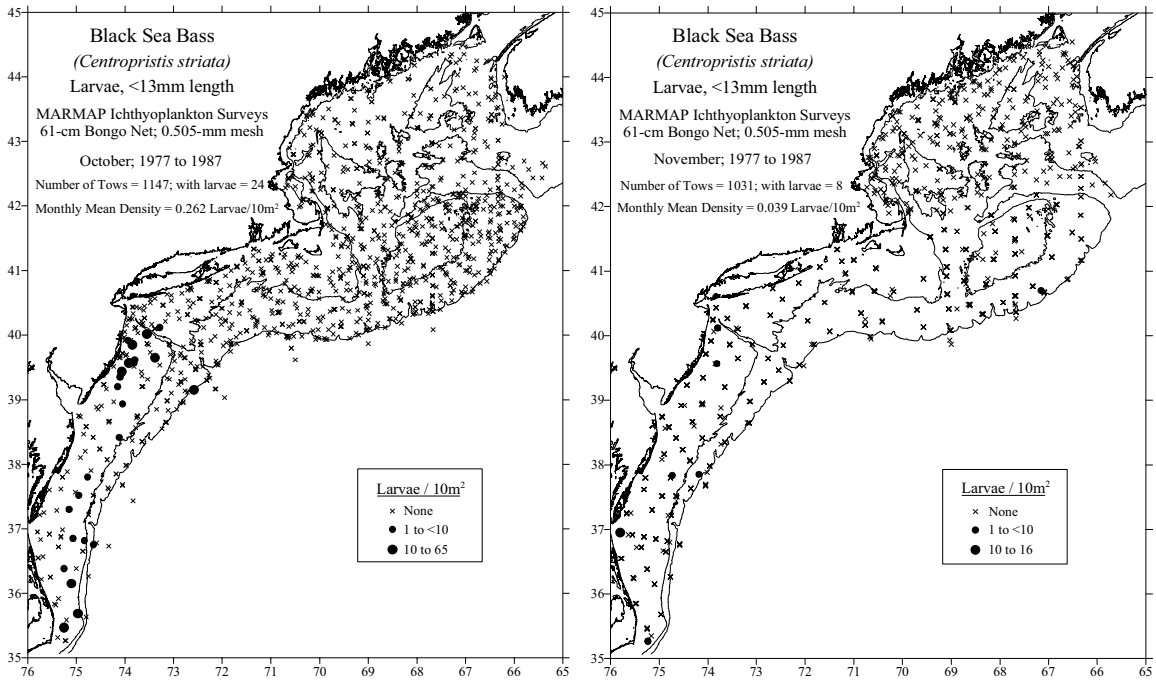

Figure 4. Cont'd.
From MARMAP ichthyoplankton surveys, October and November, 1977-1987.

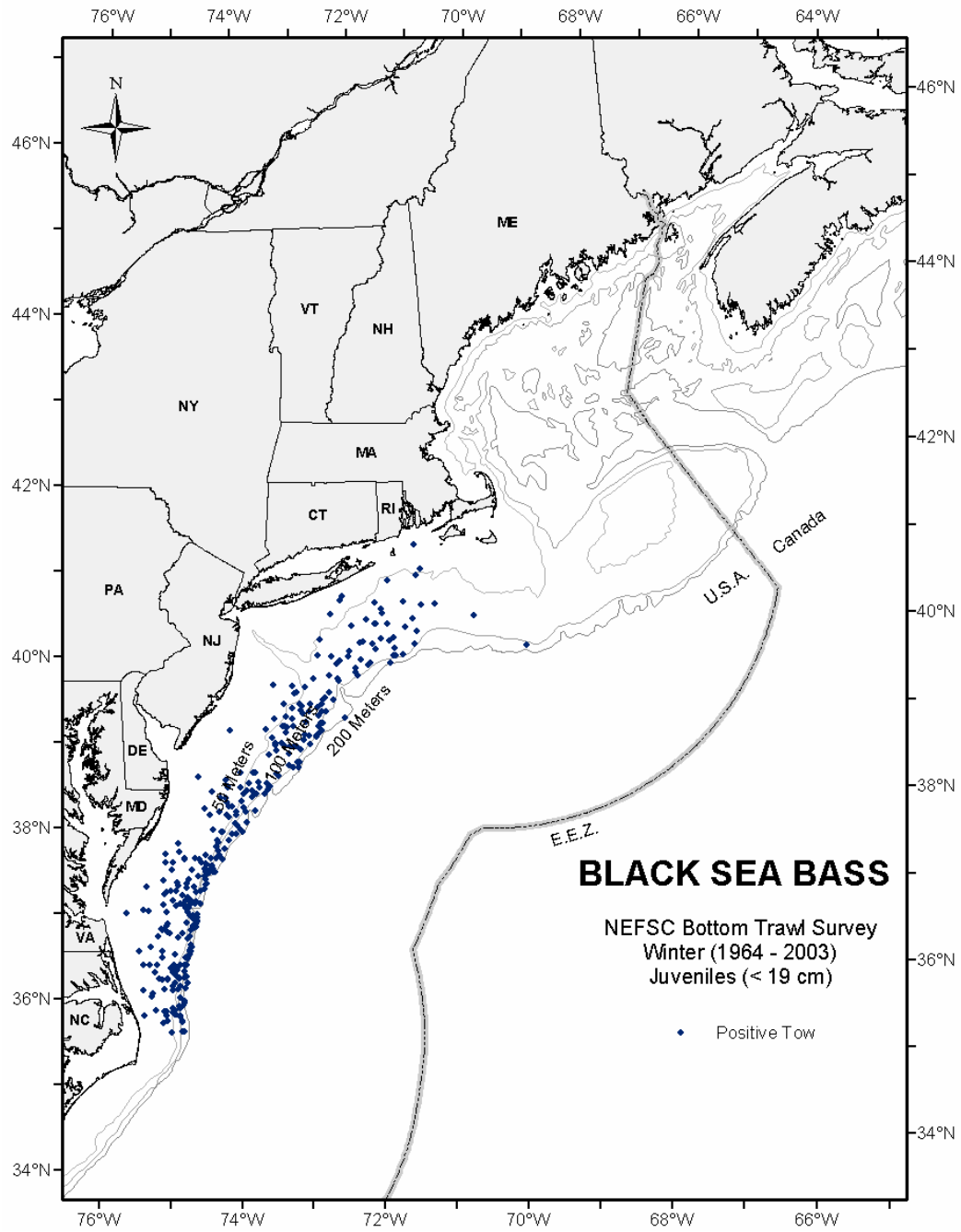

Figure 5. Seasonal distributions and abundances of juvenile black sea bass collected during NEFSC bottom trawl surveys, based on NEFSC winter bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence only.

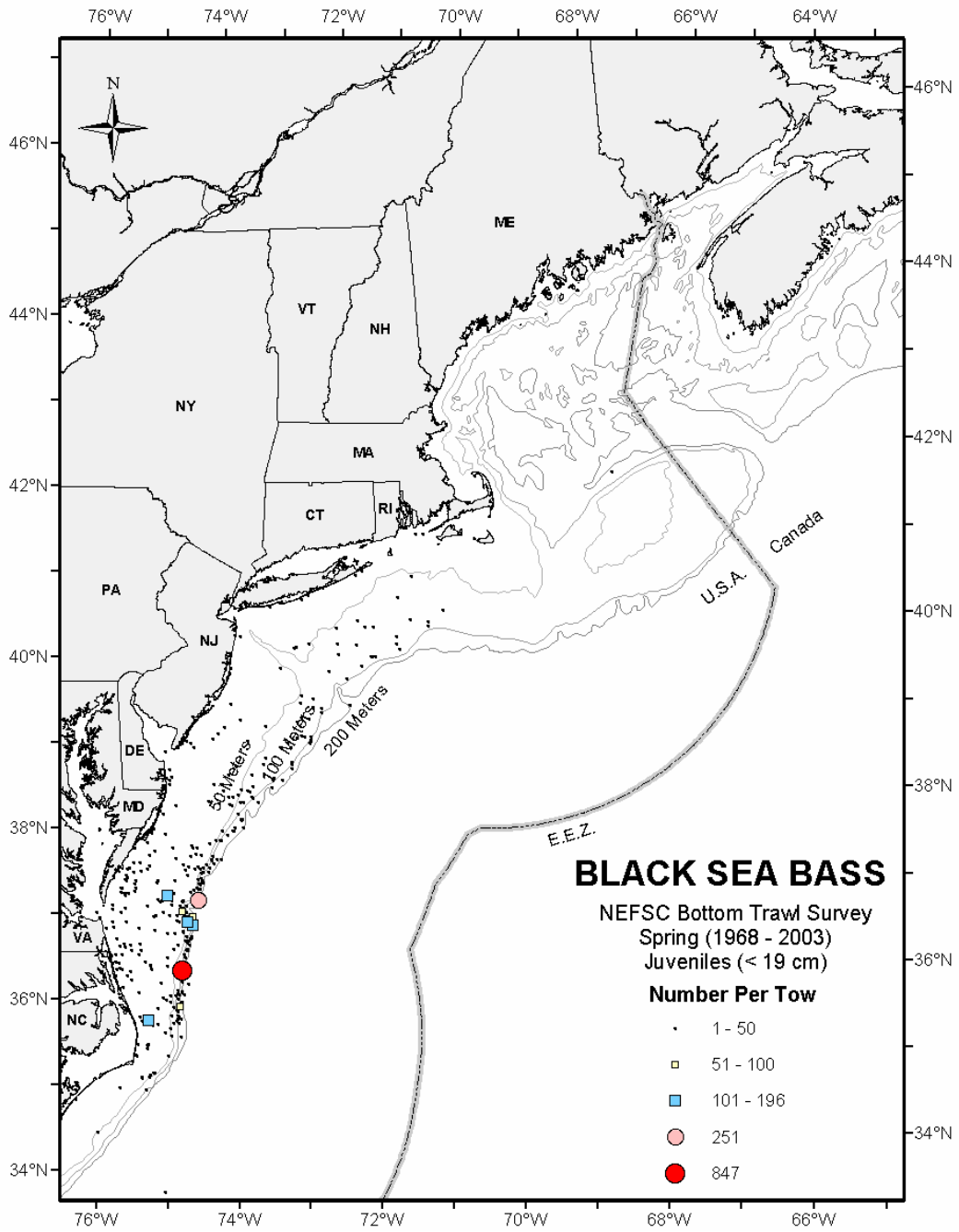

Figure 5. Cont'd.
Based on NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where juveniles were not found are not shown.

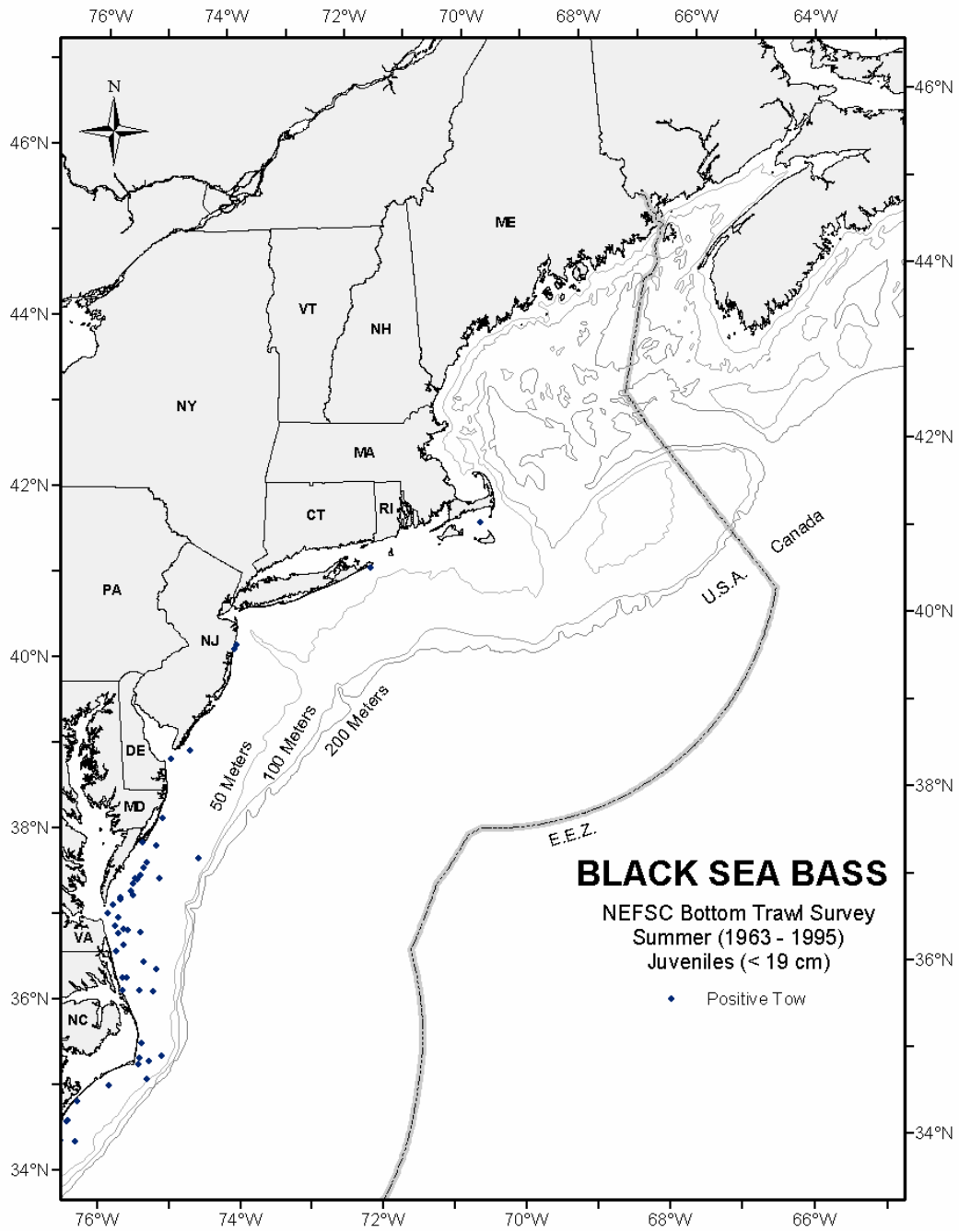

Figure 5. Cont'd.
Based on NEFSC summer bottom trawl surveys (1963-1995, all years combined). Distributions are displayed as presence only.

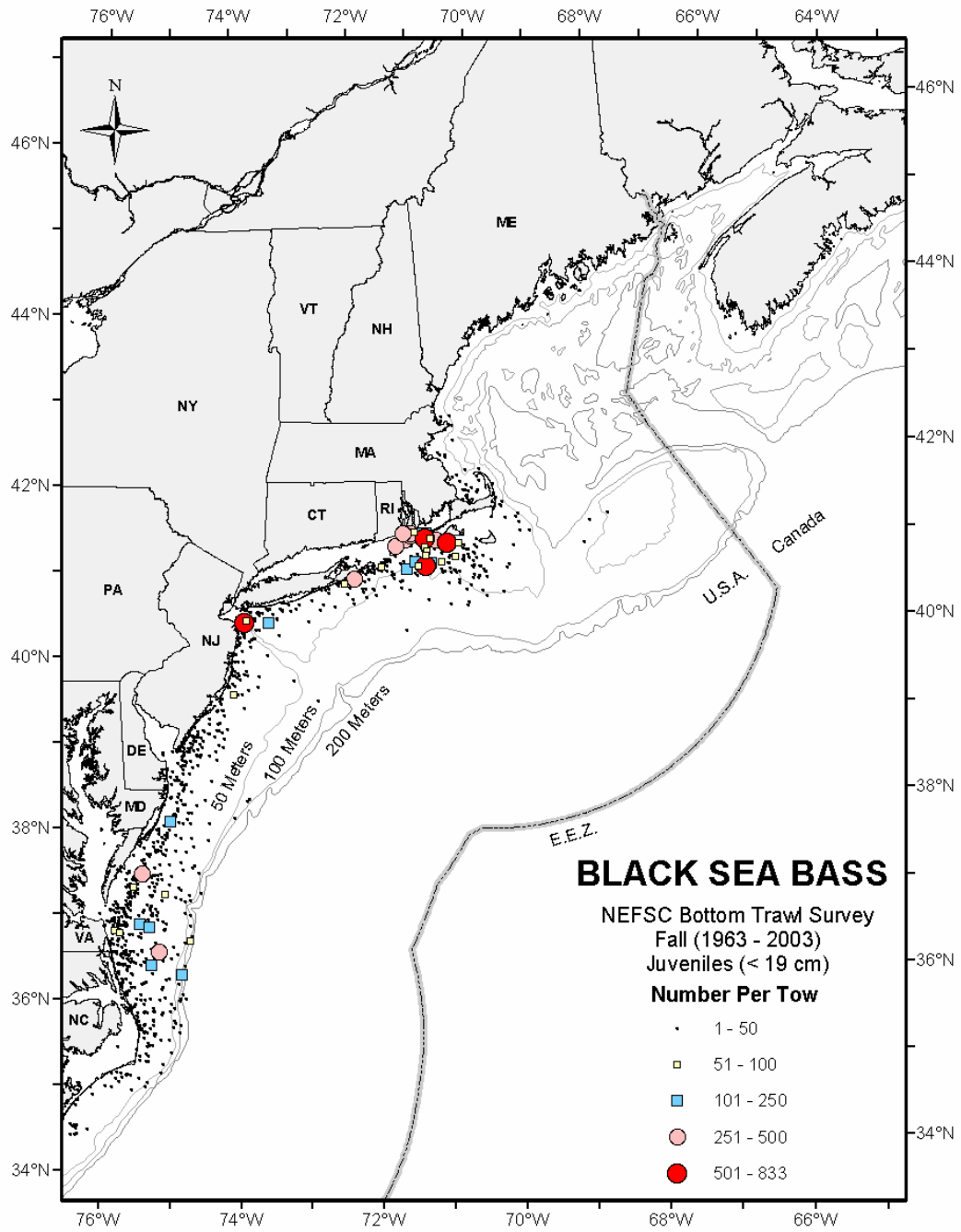

Figure 5. Cont'd.
Based on NEFSC fall bottom trawl surveys (1963-2003, all years combined). Survey stations where juveniles were not found are not shown.

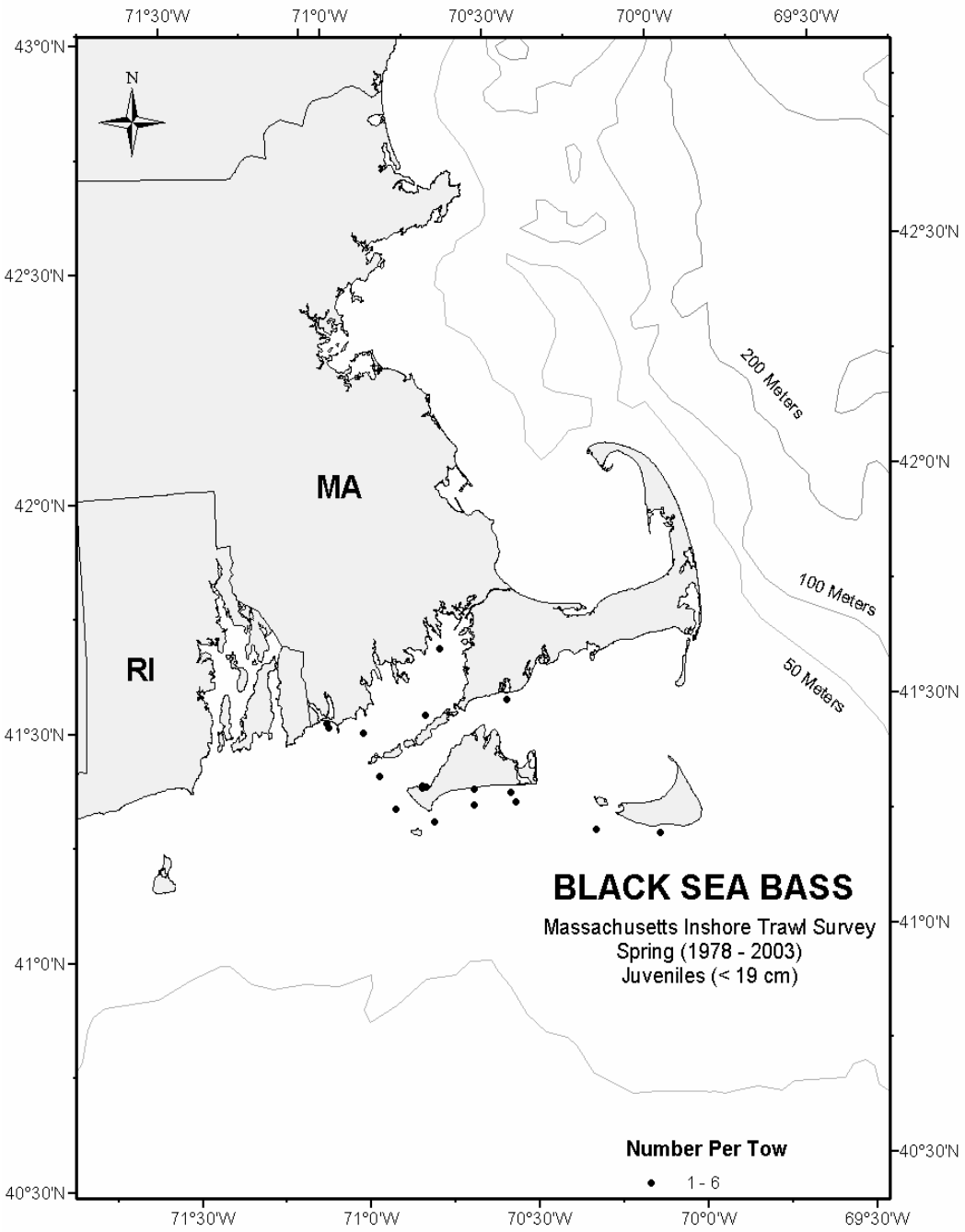

Figure 6. Seasonal distributions and abundances of juvenile black sea bass in Massachusetts coastal waters, based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

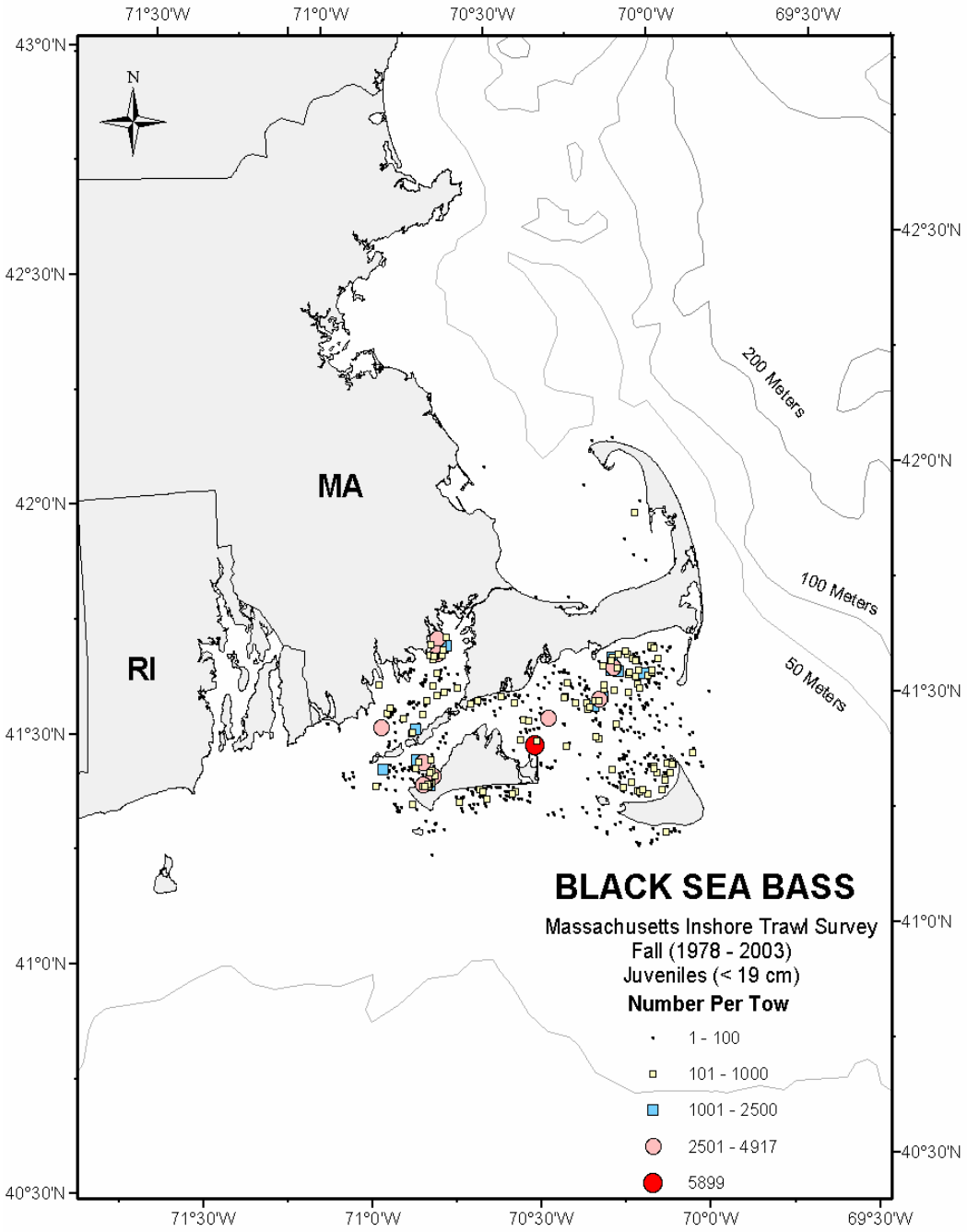

Figure 6. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where juveniles were not found are not shown.

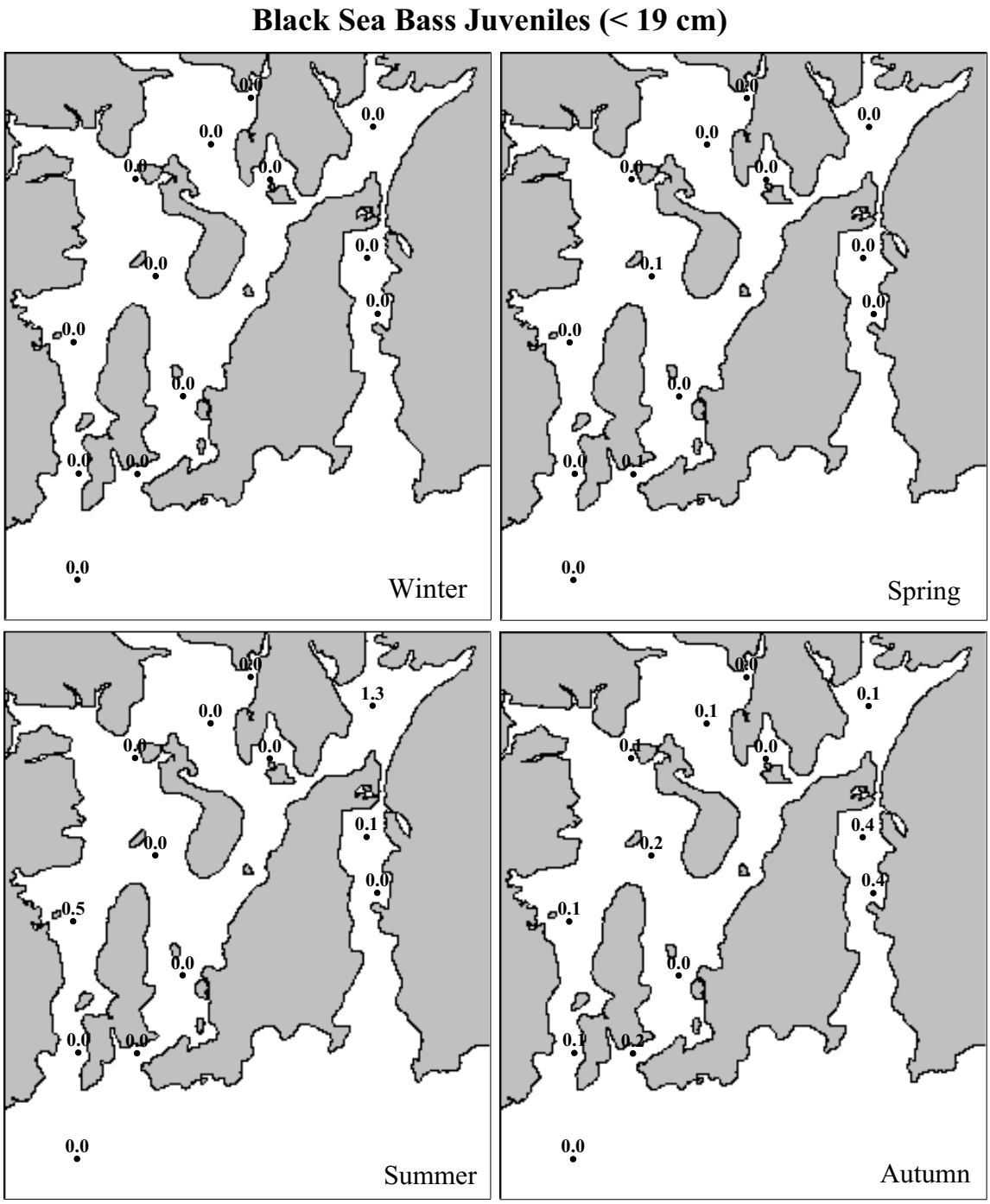

Figure 7. Seasonal distribution and abundance of juvenile black sea bass collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].

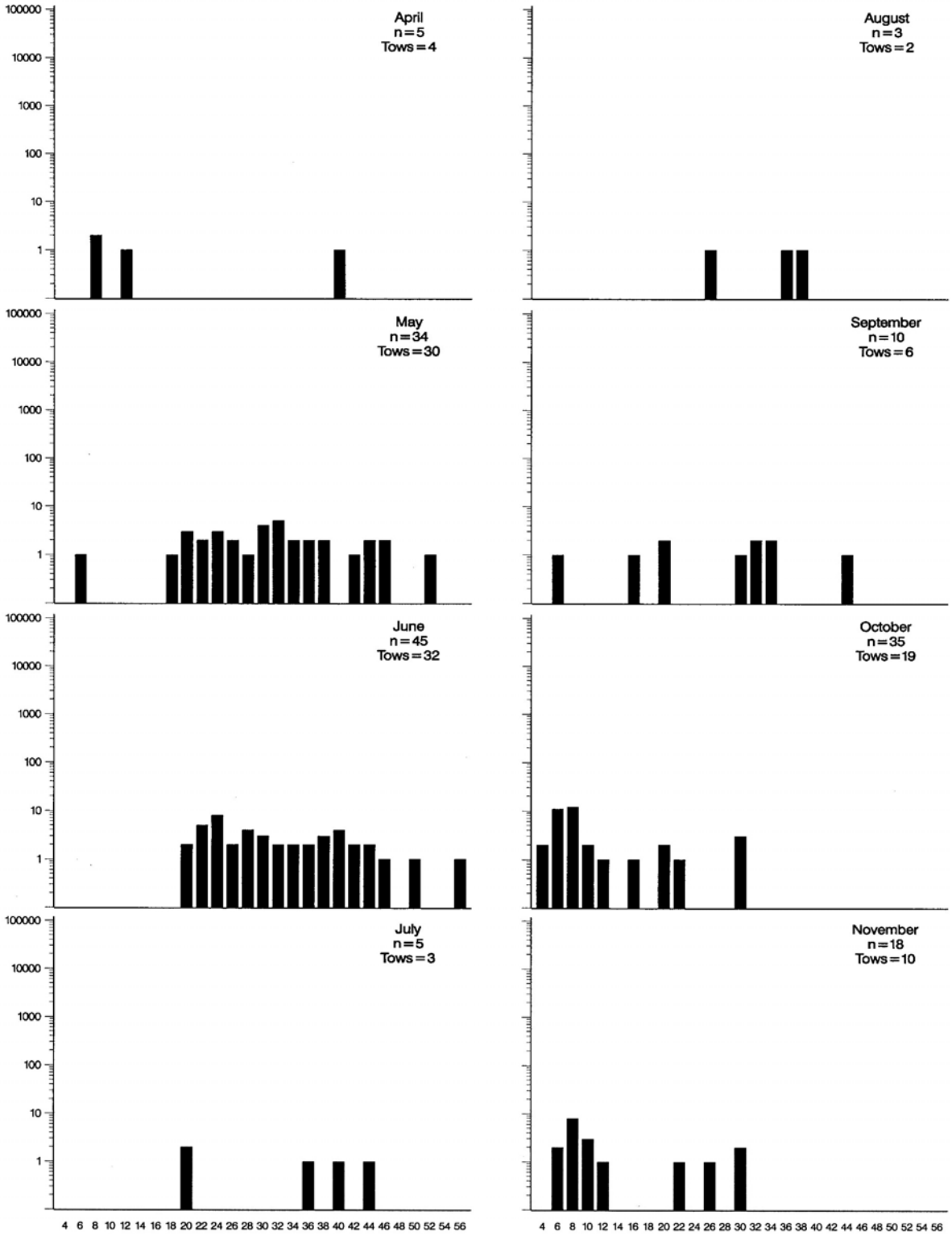

Figure 8. Monthly $\log_{10}$ length frequencies (cm) of juvenile and adult black sea bass collected in Long Island Sound, based on 155 fish taken in 106 tows during the finfish surveys of the Connecticut Fisheries Division between 1989-1994. Source: Gottschall *et al.* (2000).

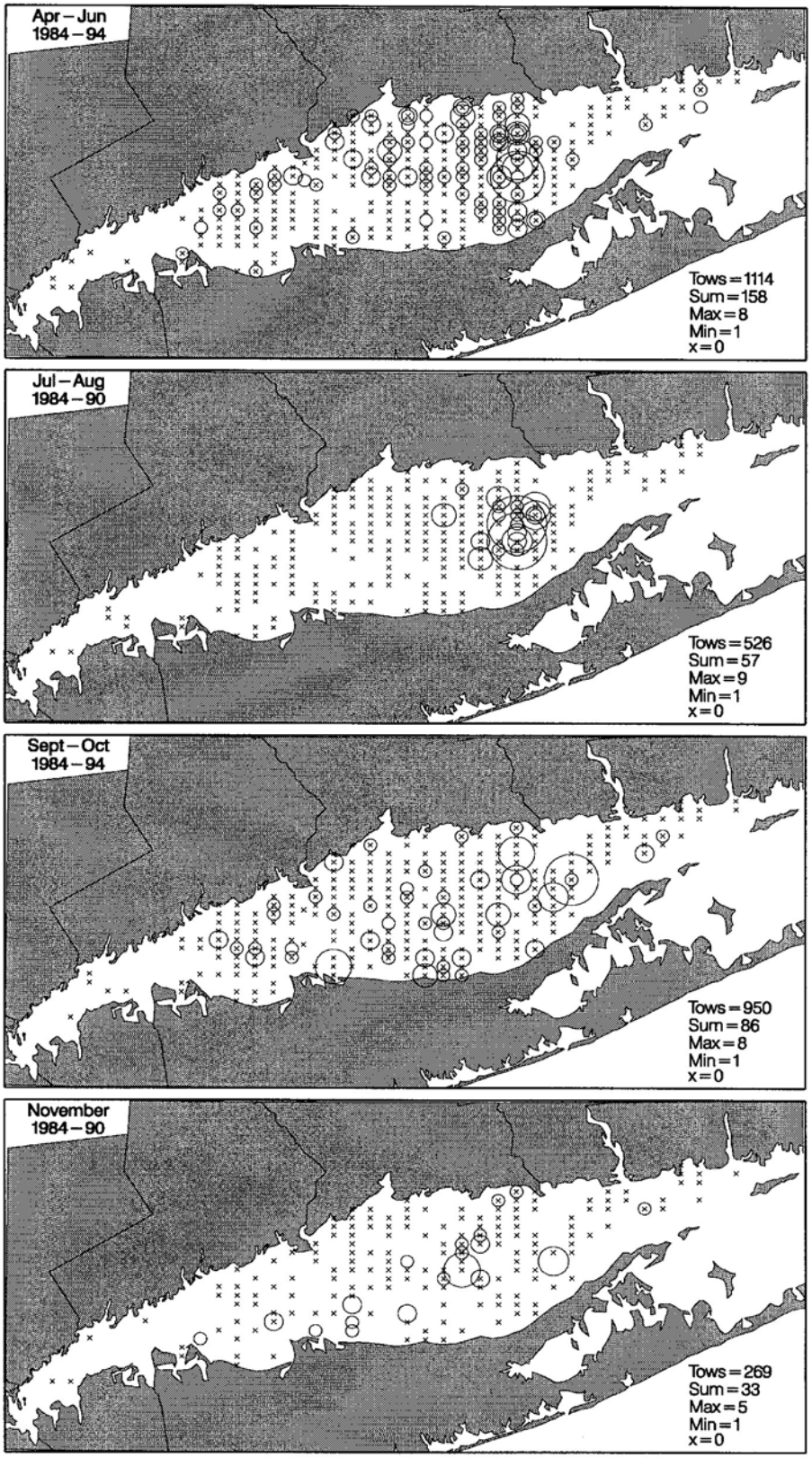

Figure 9. Distribution and abundances of juvenile and adult black sea bass in Long Island Sound, based on 334 fish taken in 2,859 tows during the finfish surveys of the Connecticut Fisheries Division, 1984-1994. The largest circle size represents a tow with a catch of nine black sea bass. Collections were made with a 14 m otter trawl at about 40 stations chosen by stratified random design. Source: Gottschall *et al.* (2000).

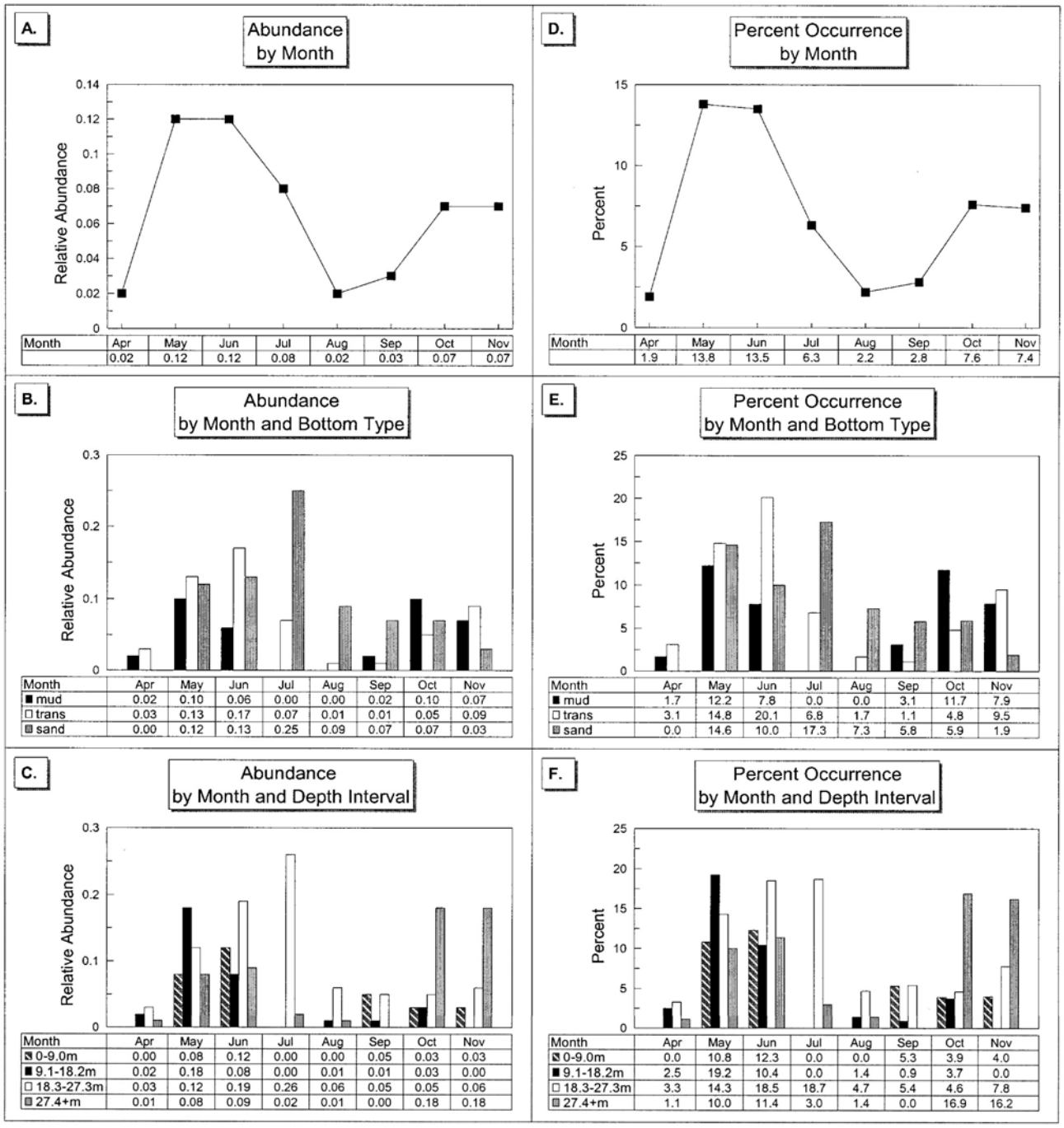

Figure 10. Relative abundance (geometric mean catch/tow) catch/tow and percent occurrence (proportion of samples in which at least one individual was observed) for juvenile and adult black sea bass in Long Island Sound, by month, month and bottom type, and month and depth interval. Source: Gottschall *et al.* (2000).

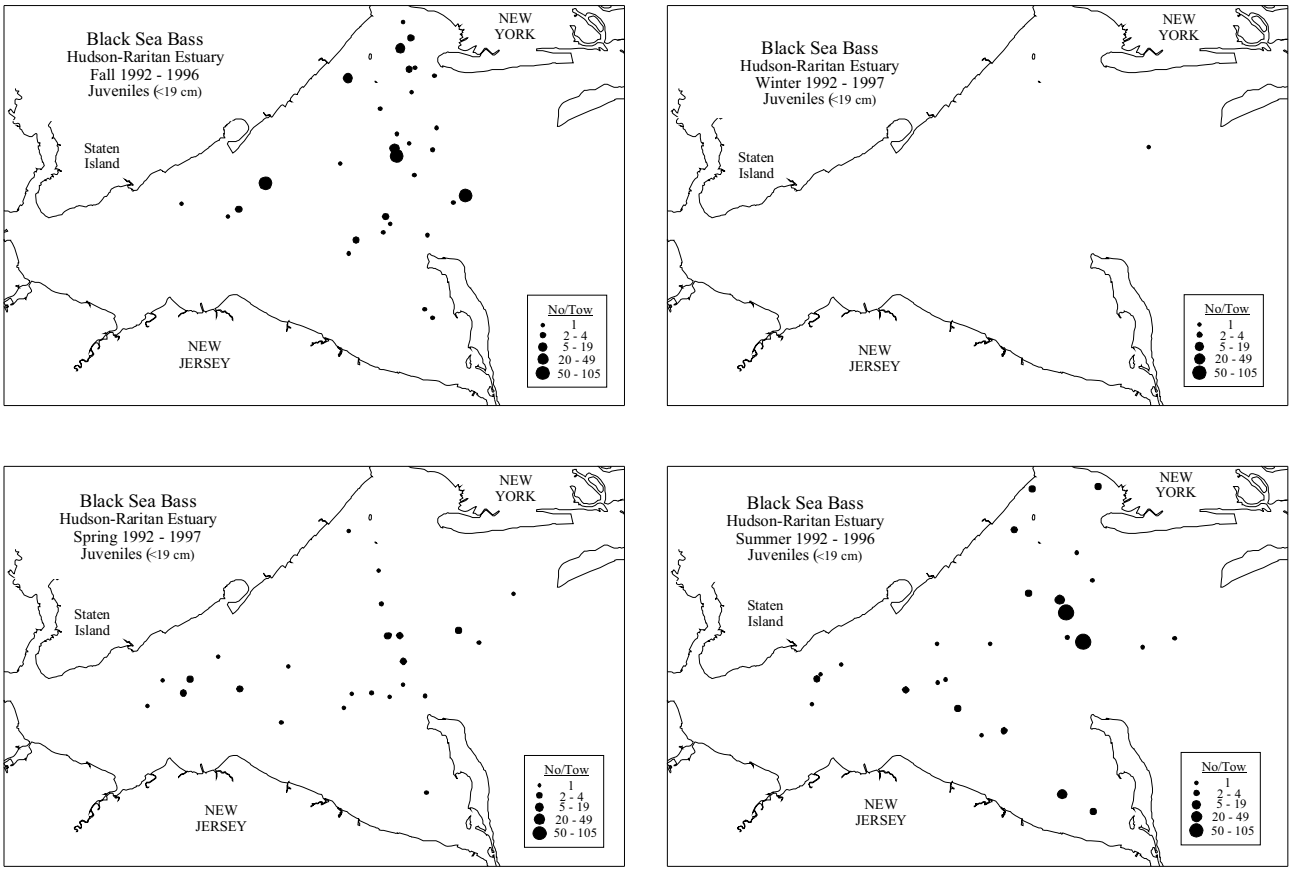

Figure 11. Seasonal distribution and abundance of juvenile black sea bass in the Hudson-Raritan estuary collected during Hudson-Raritan estuary trawl surveys, 1992–1997 [see Reid *et al.* (1999) for details].

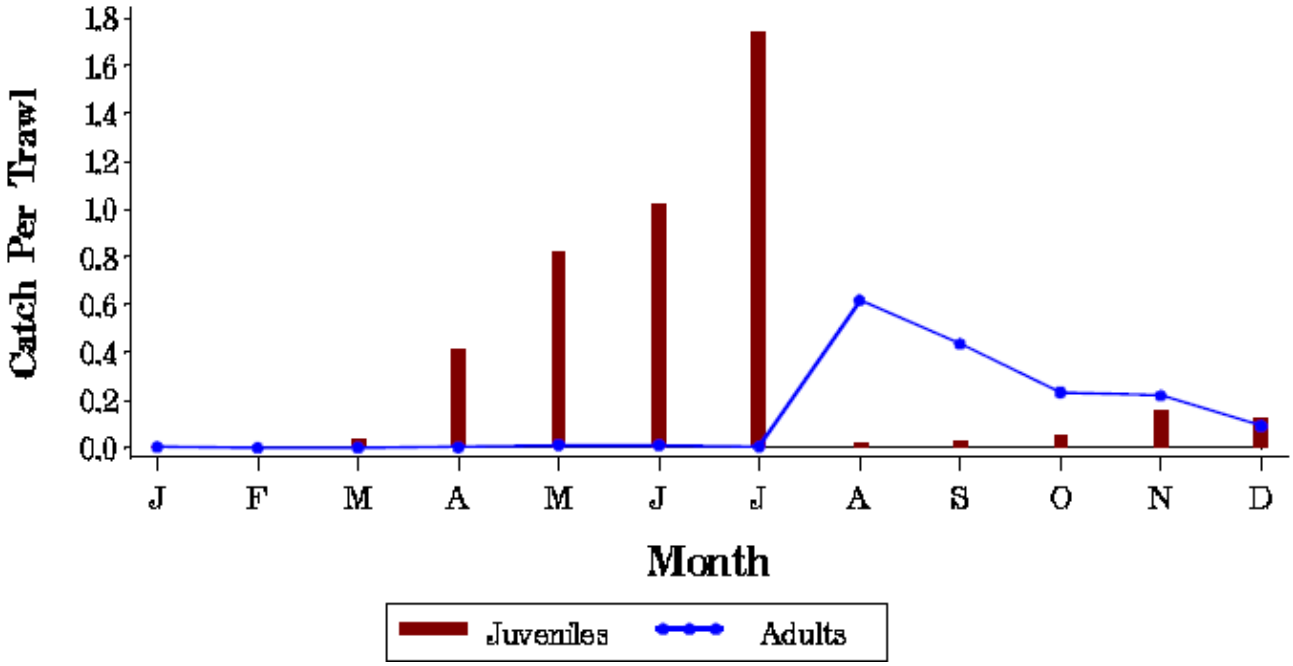

Figure 12. Catch per unit effort for total catch of juvenile and adult black sea bass in Chesapeake Bay and tributaries, from the Virginia Institute of Marine Science's (VIMS) trawl surveys, 1988-1999 (all years combined). Source: Geer (2002).

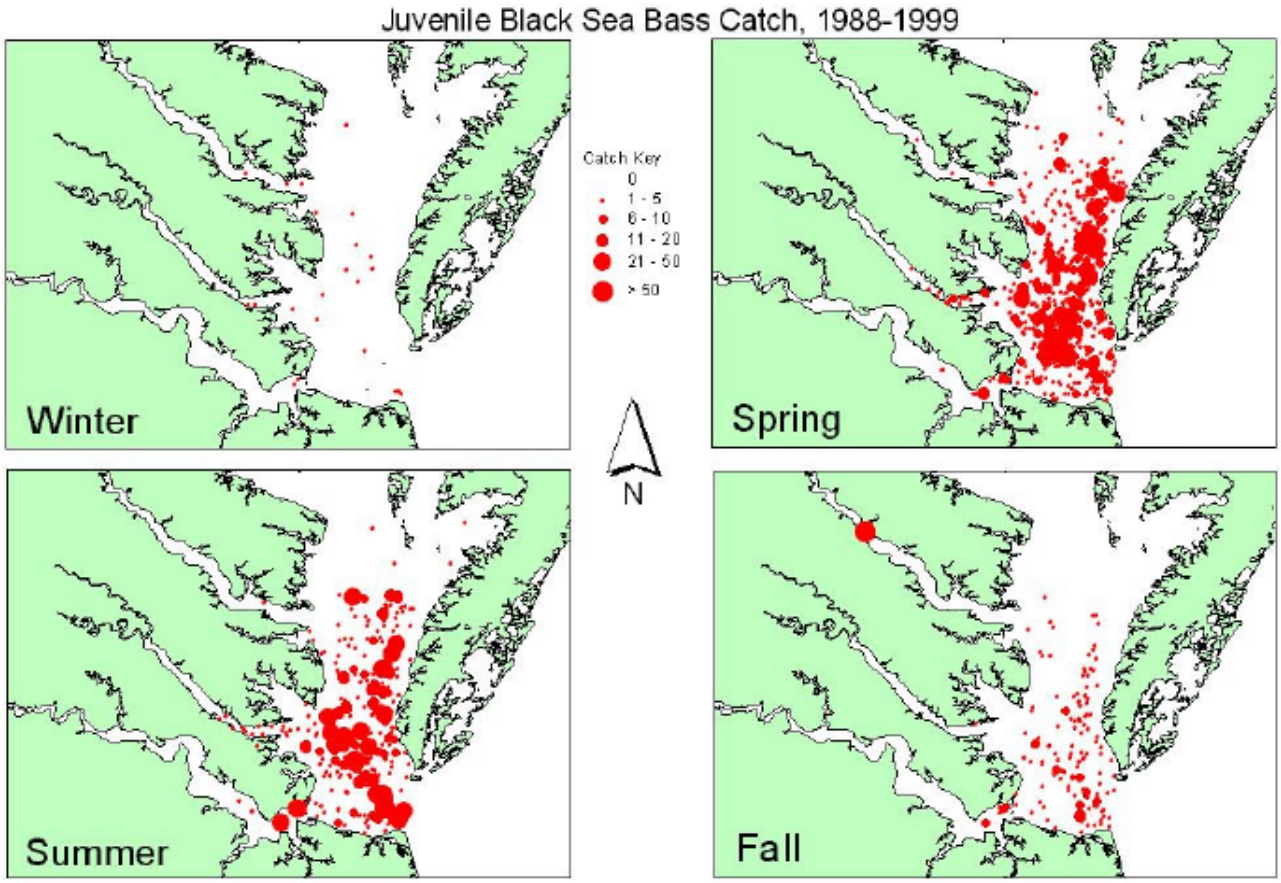

Figure 13. Seasonal distribution and abundance of juvenile black sea bass in Chesapeake Bay and tributaries, from the VIMS trawl surveys, 1988-1999 (all years combined). Monthly surveys were conducted using a random stratified design of the main stem of the Bay using a 9.1 m semi-balloon otter trawl with 38 mm mesh and 6.4 mm cod end with a tow duration of five minutes. Source: Geer (2002).

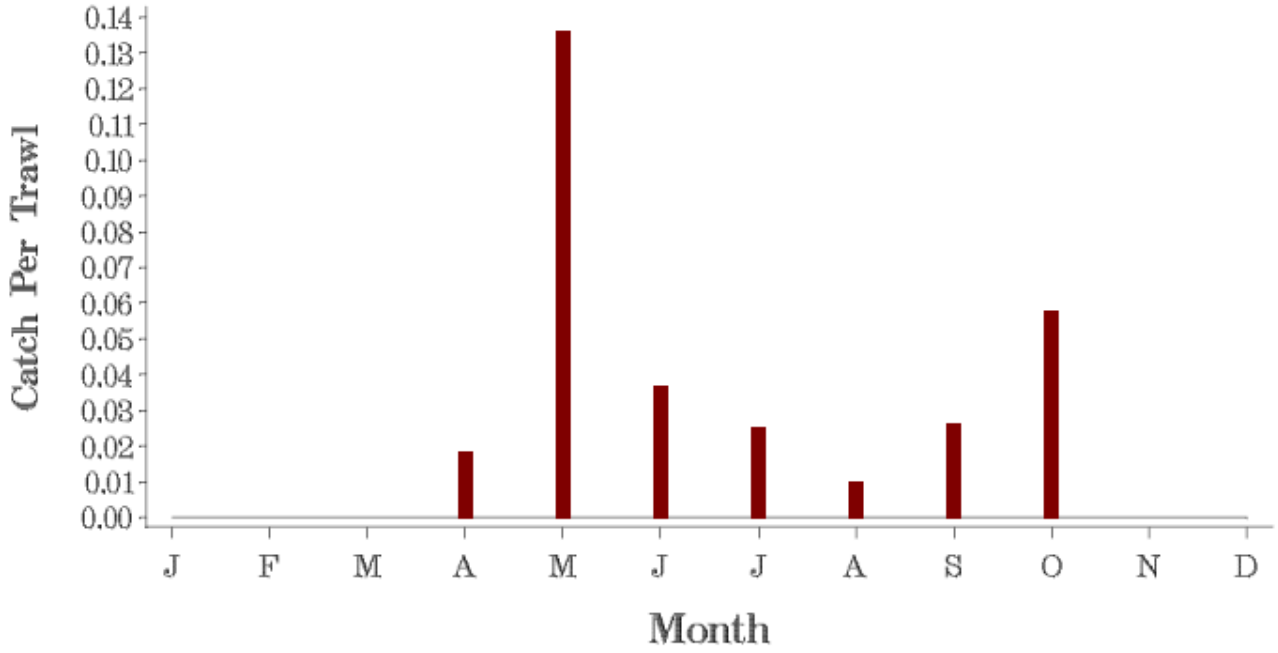

Figure 14. Catch per unit effort for total catch of juvenile black sea bass in Chesapeake Bay, from the VIMS seine surveys, 1994-1999 (all years combined). Source: Geer (2002).

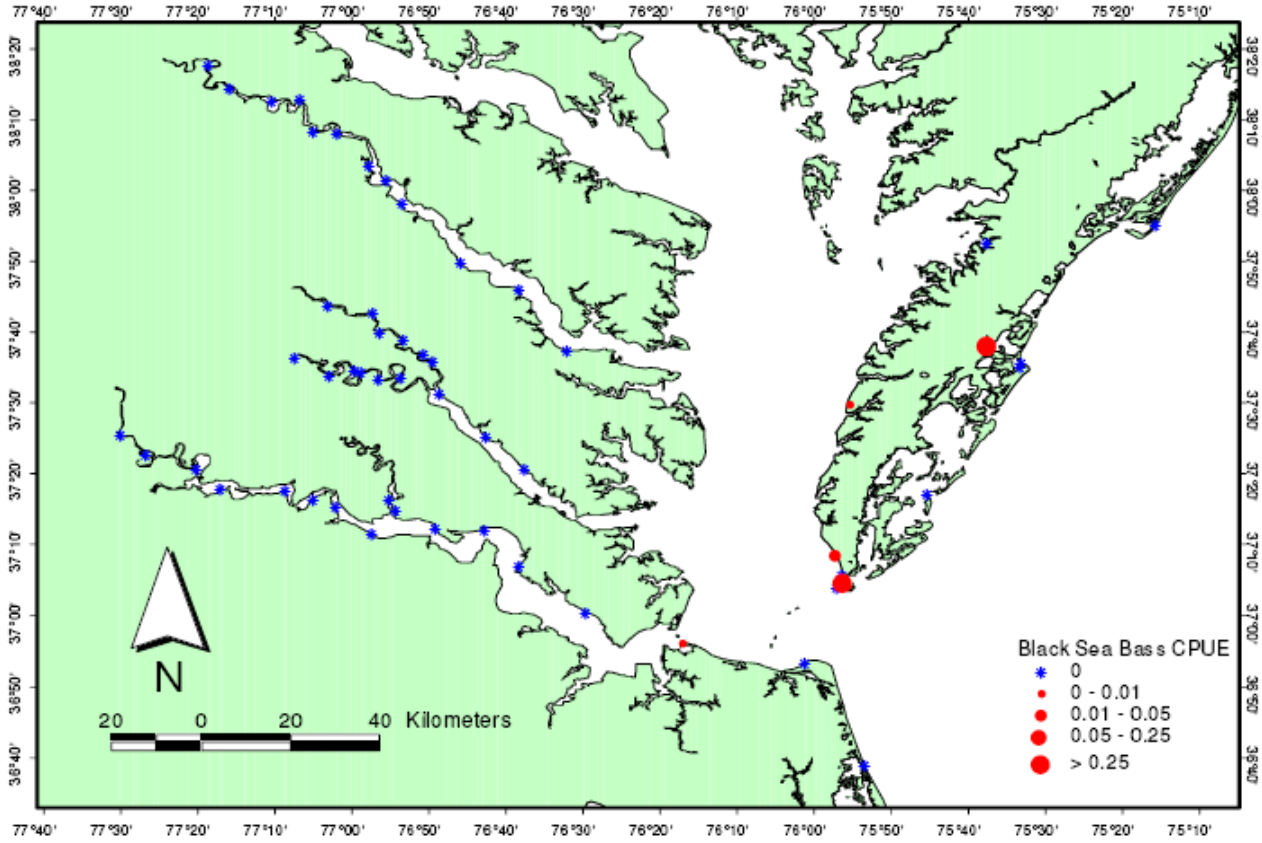

Figure 15. Juvenile black sea bass catch per unit effort by site from the VIMS beach seine surveys, 1994-1999 (all years combined). Source: Geer (2002).

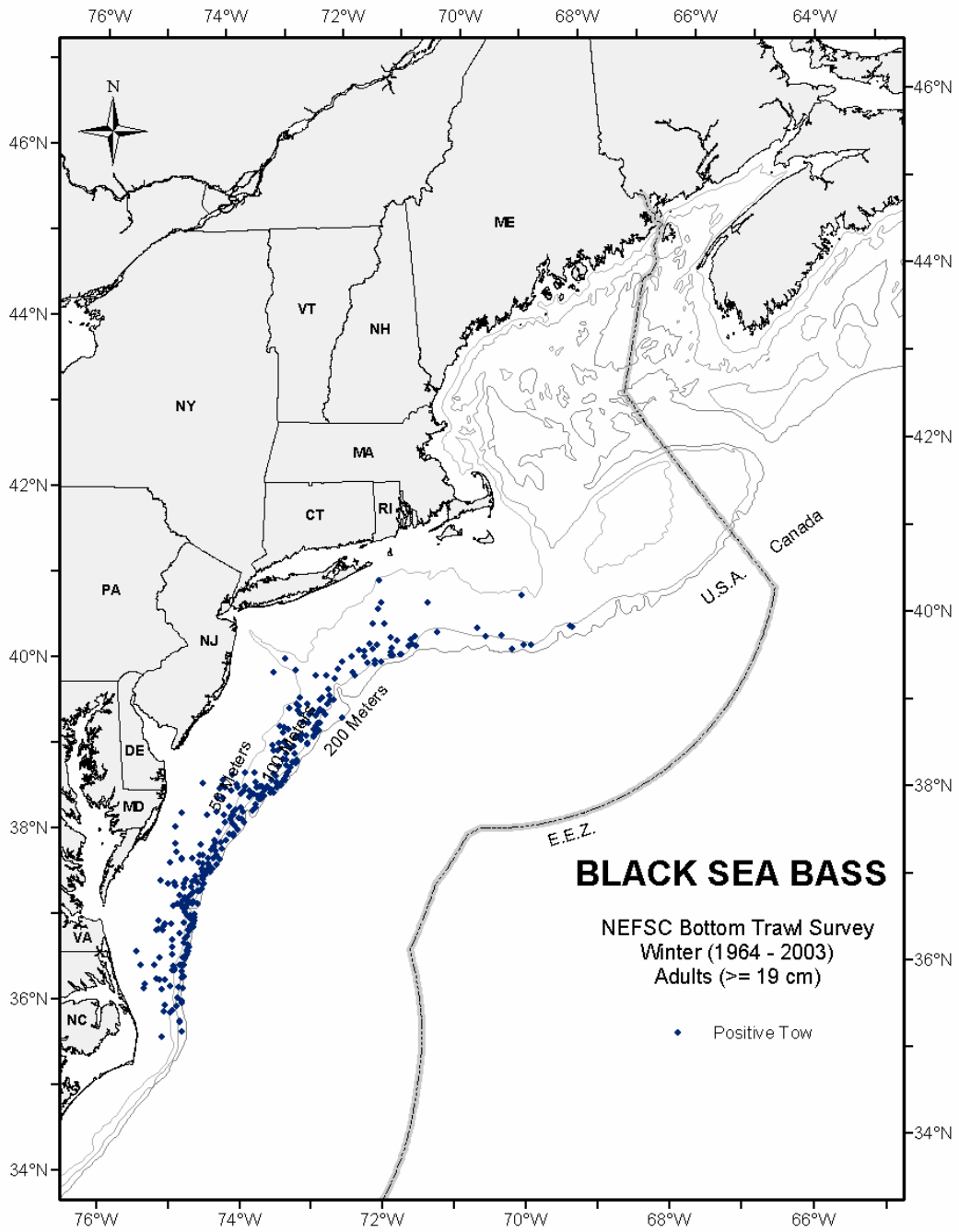

Figure 16. Seasonal distributions and abundances of adult black sea bass collected during NEFSC bottom trawl surveys, based on NEFSC winter bottom trawl surveys (1964-2003, all years combined). Distributions are displayed as presence only.

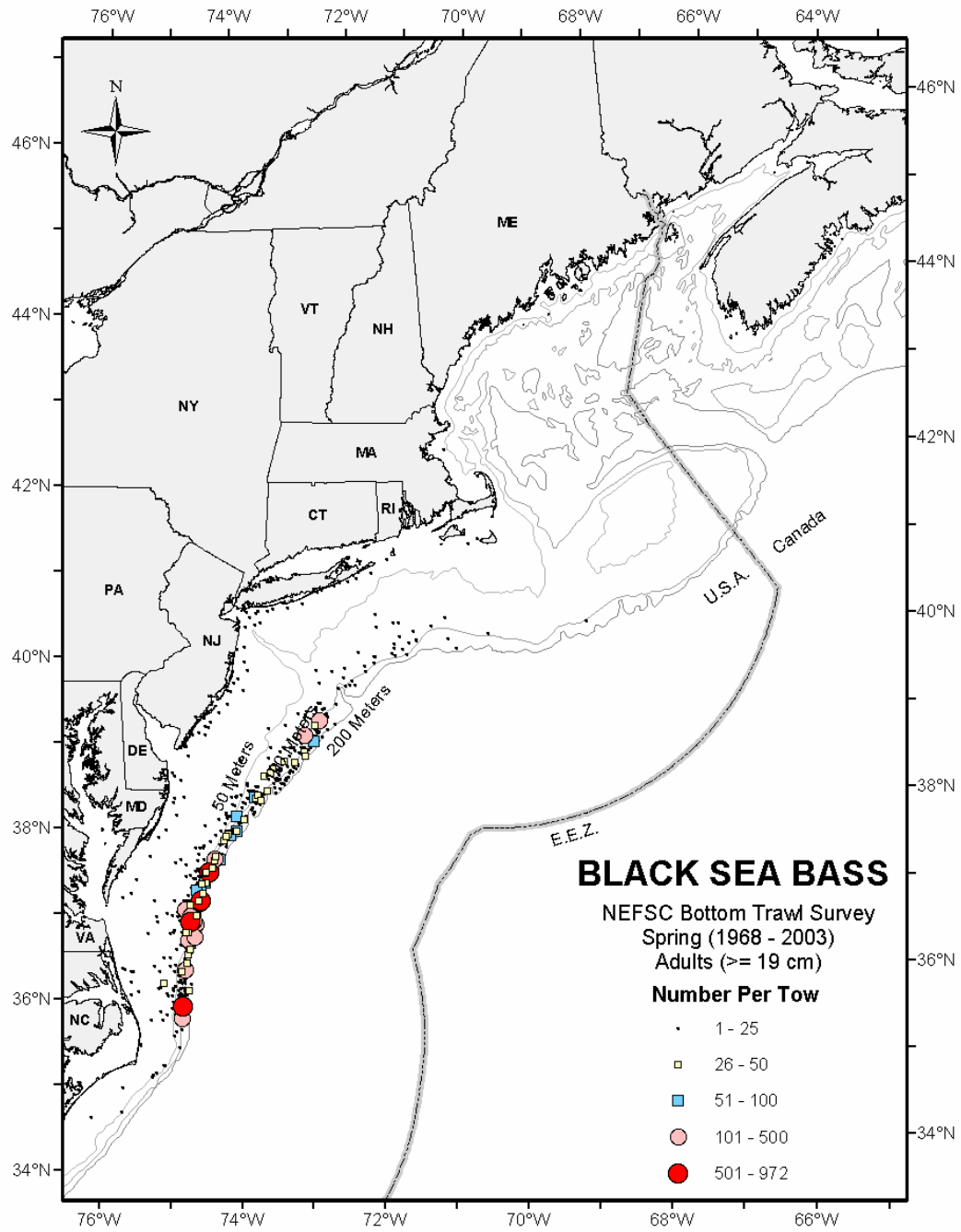

Figure 16. Cont'd.
Based on NEFSC spring bottom trawl surveys (1968-2003, all years combined). Survey stations where adults were not found are not shown.

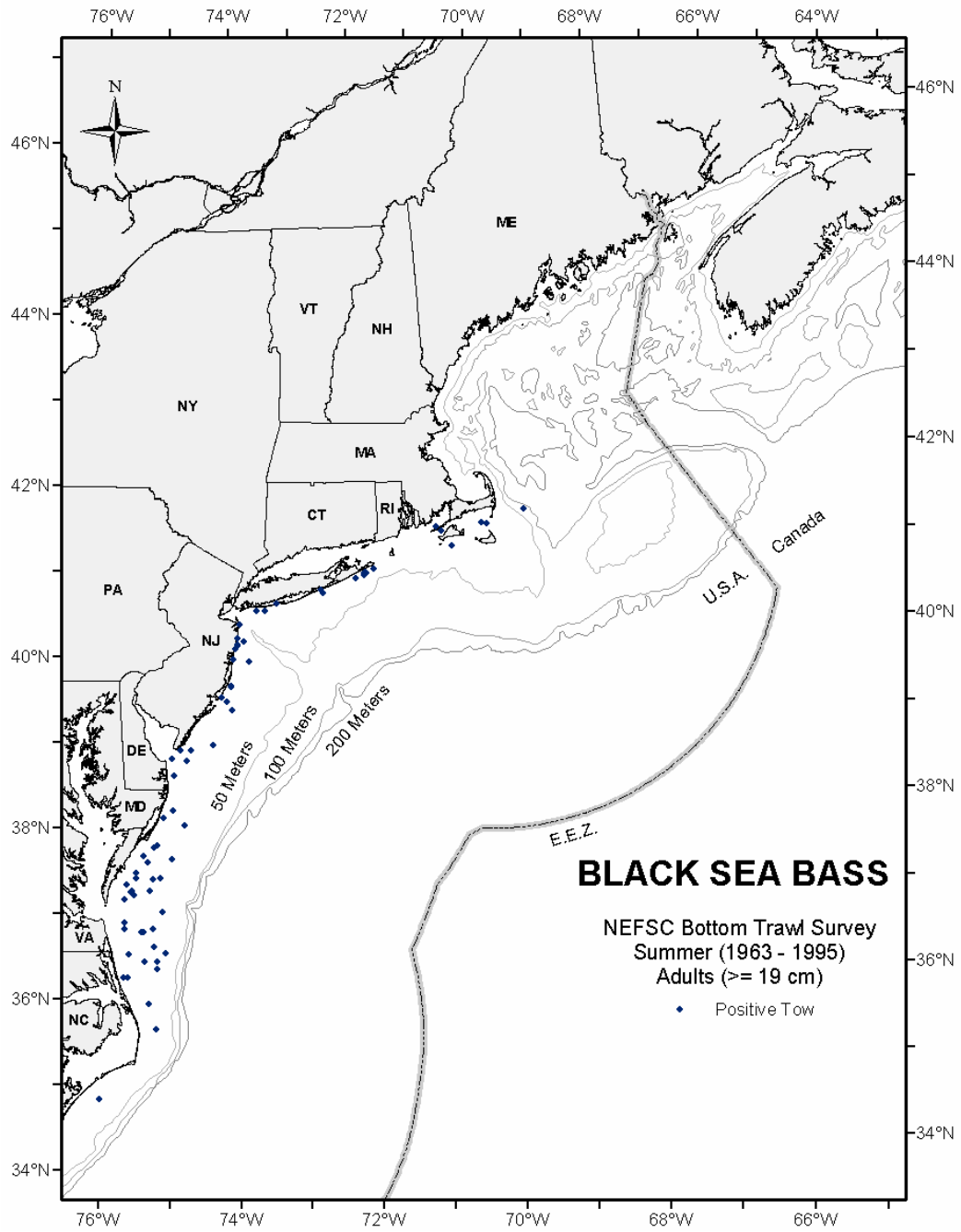

Figure 16. Cont'd.
Based on NEFSC summer bottom trawl surveys (1963-1995, all years combined). Distributions are displayed as presence only.

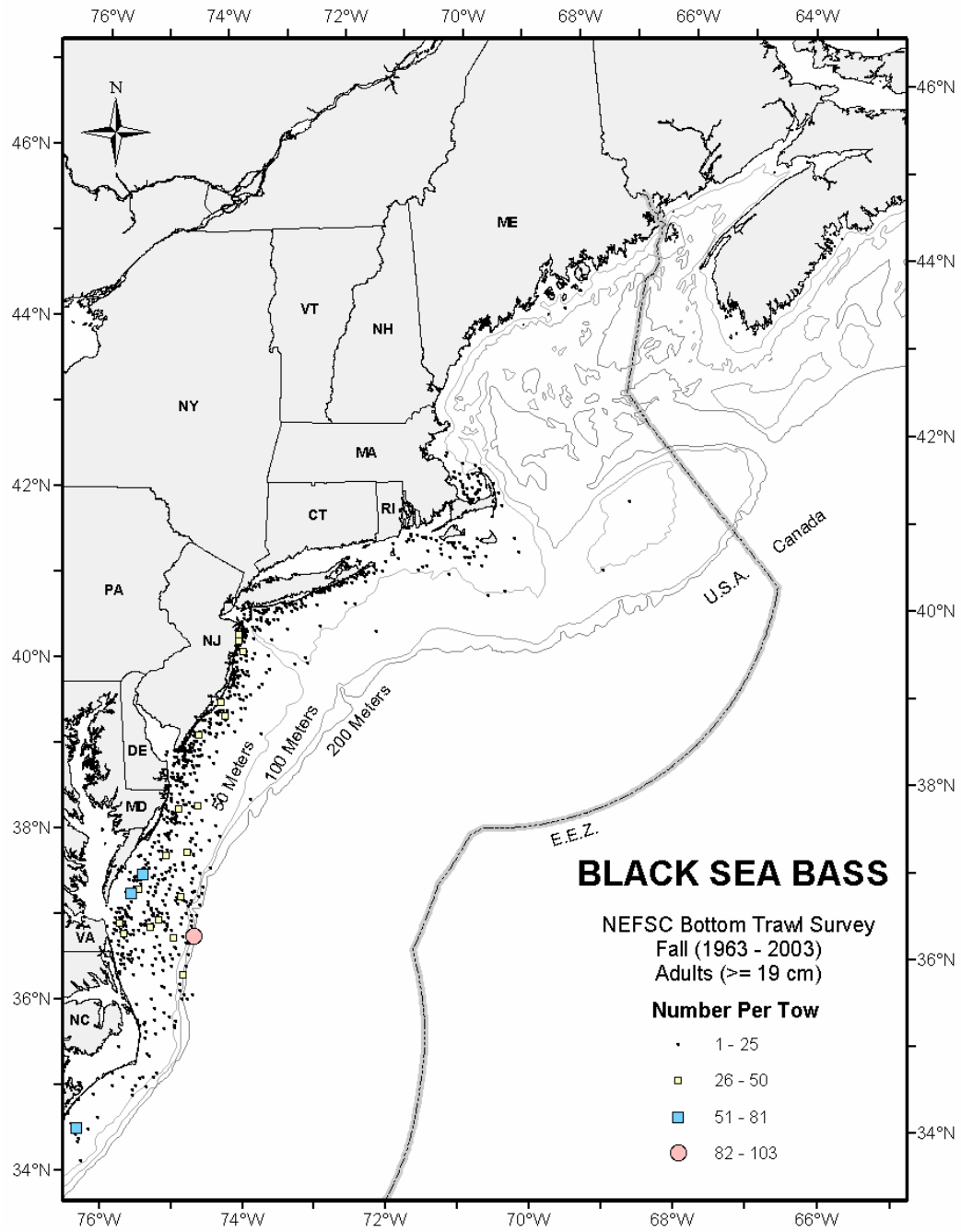

Figure 16. Cont'd.
Based on NEFSC fall bottom trawl surveys (1963-2003, all years combined). Survey stations where adults were not found are not shown.

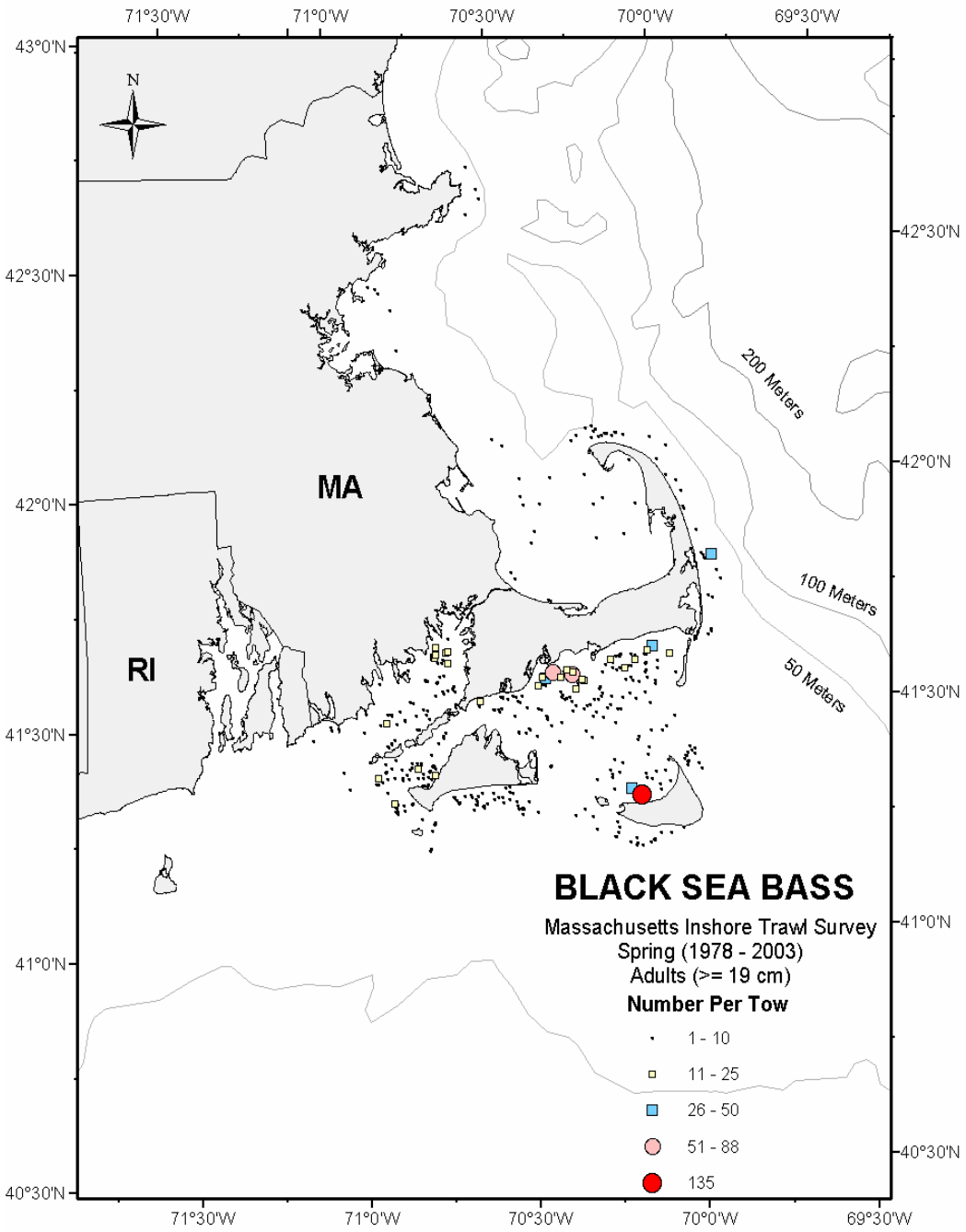

Figure 17. Seasonal distributions and abundances of adult black sea bass in Massachusetts coastal waters, based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.

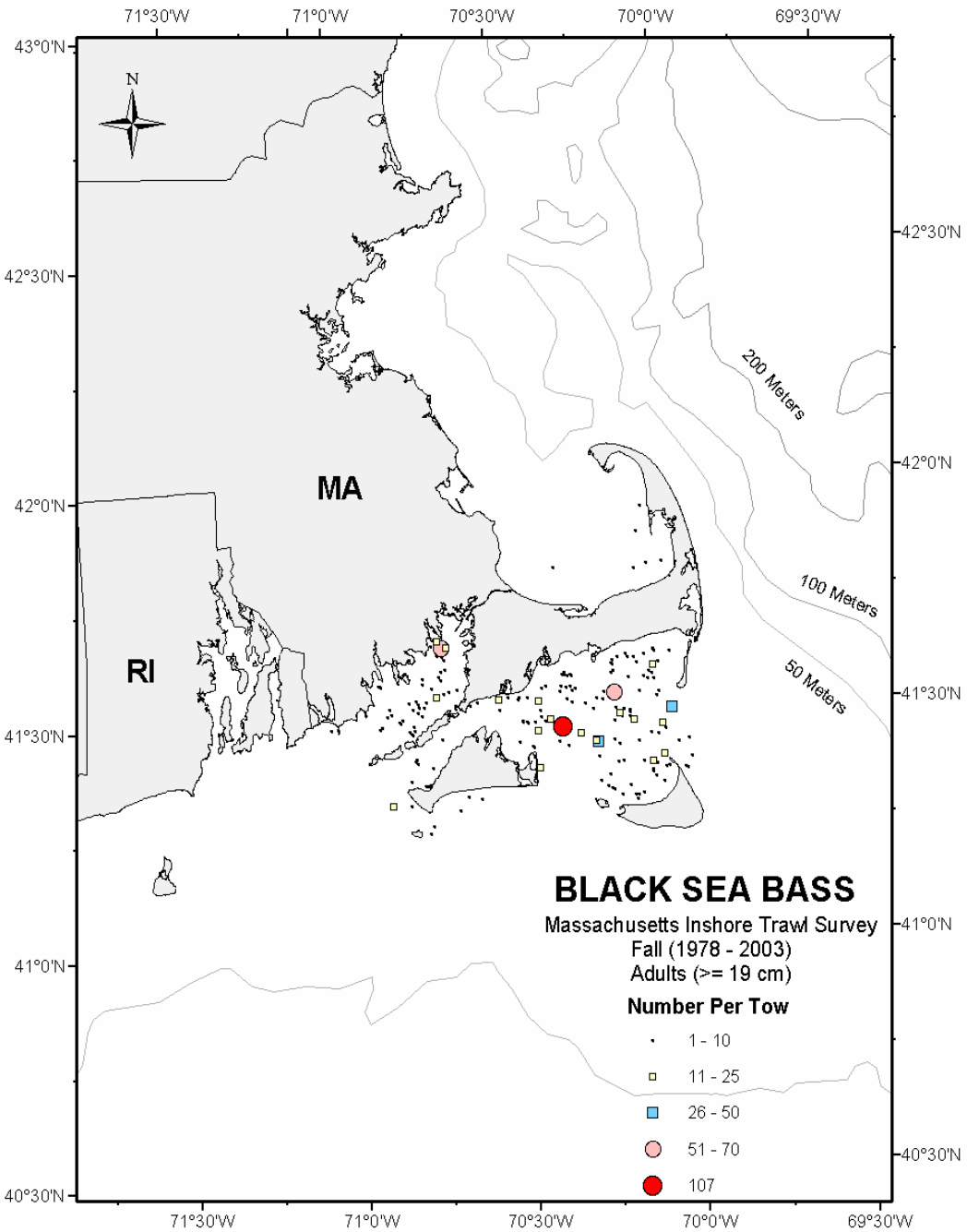

Figure 17. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Survey stations where adults were not found are not shown.

Black Sea Bass Adults (>= 19 cm)

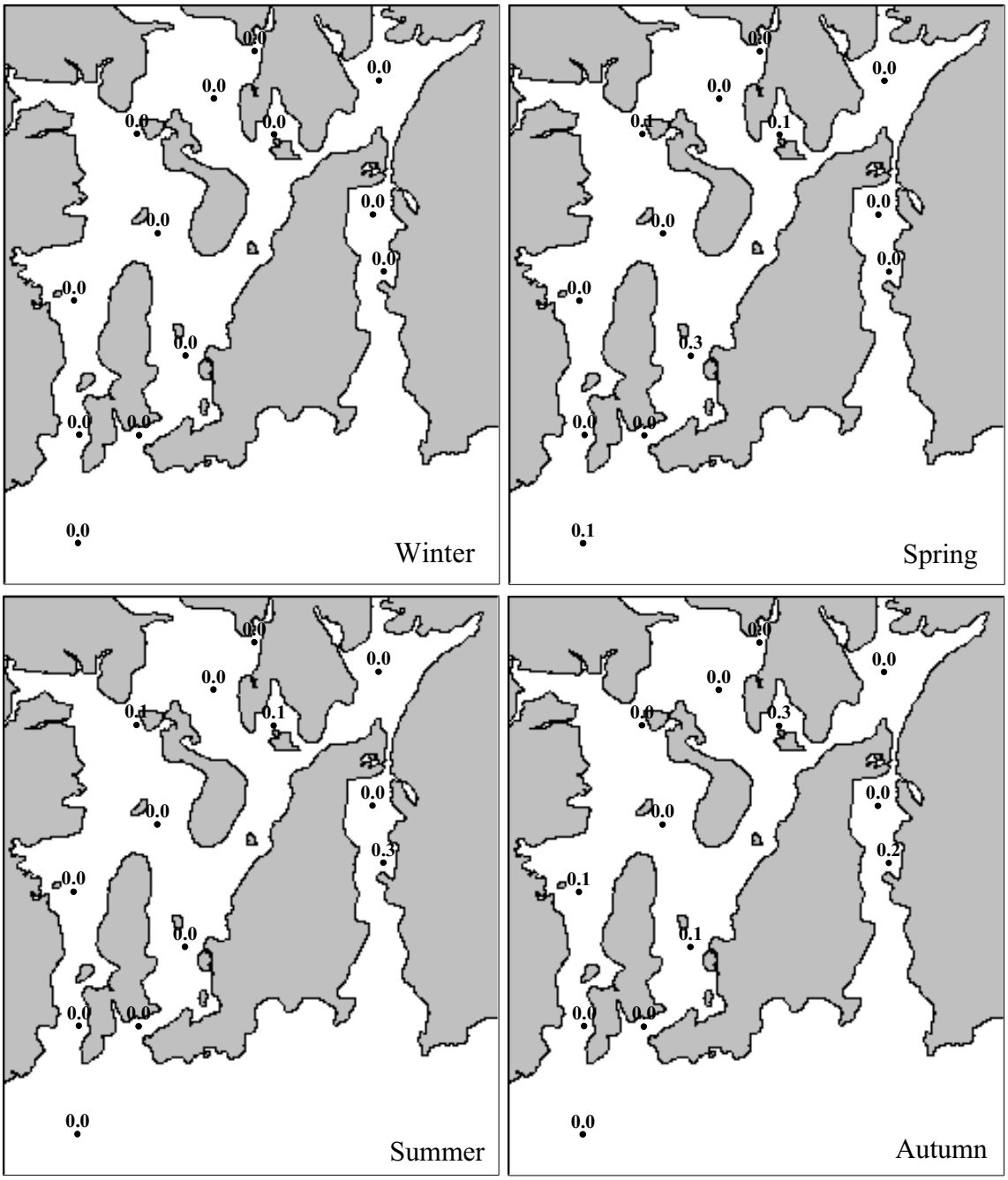

Figure 18. Seasonal distribution and abundance of adult black sea bass collected in Narragansett Bay during 1990-1996 Rhode Island bottom trawl surveys. The numbers shown at each station are the average catch per tow rounded to one decimal place [see Reid *et al.* (1999) for details].

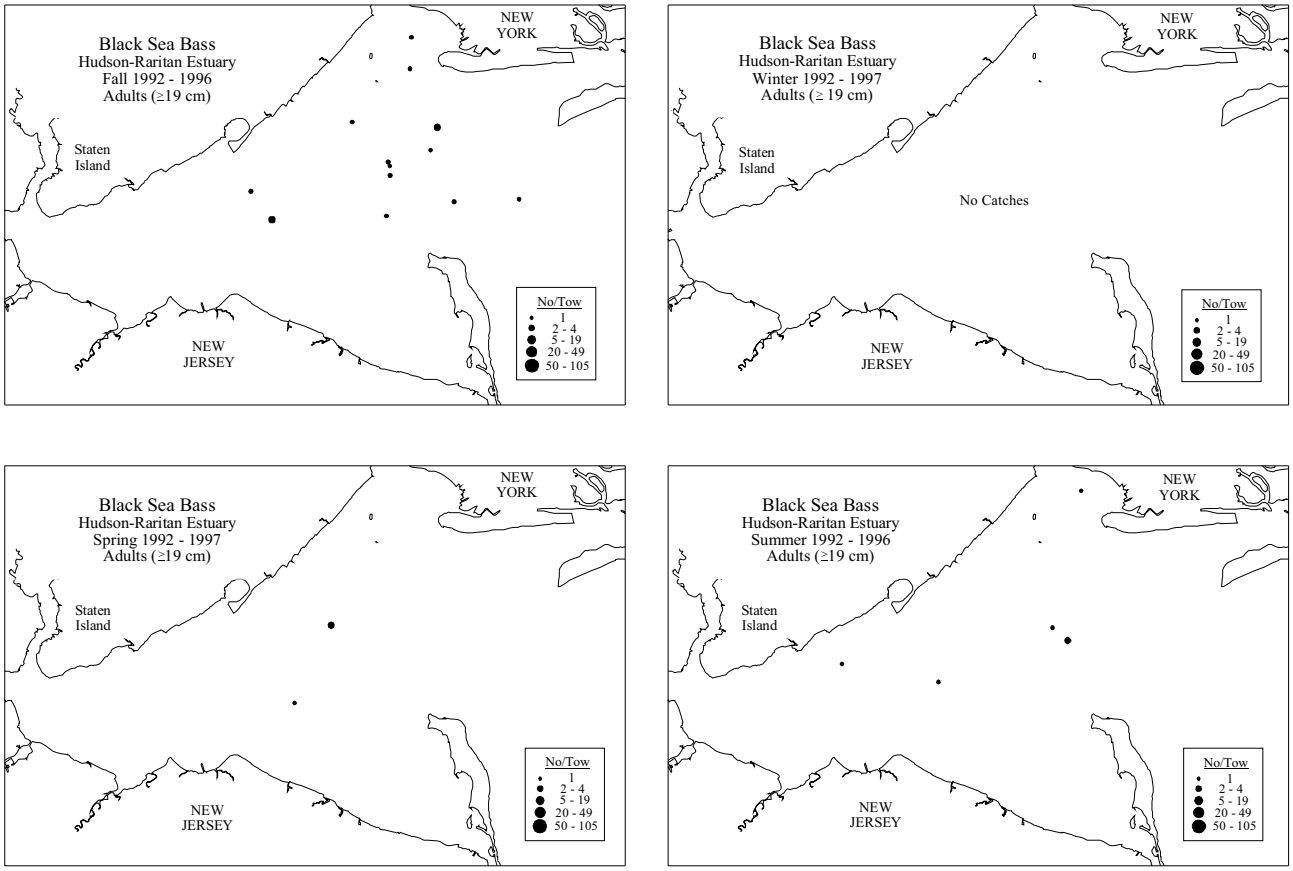

Figure 19. Seasonal distribution and abundance of adult black sea bass in the Hudson-Raritan estuary collected during Hudson-Raritan estuary trawl surveys, 1992–1997 [see Reid *et al.* (1999) for details].

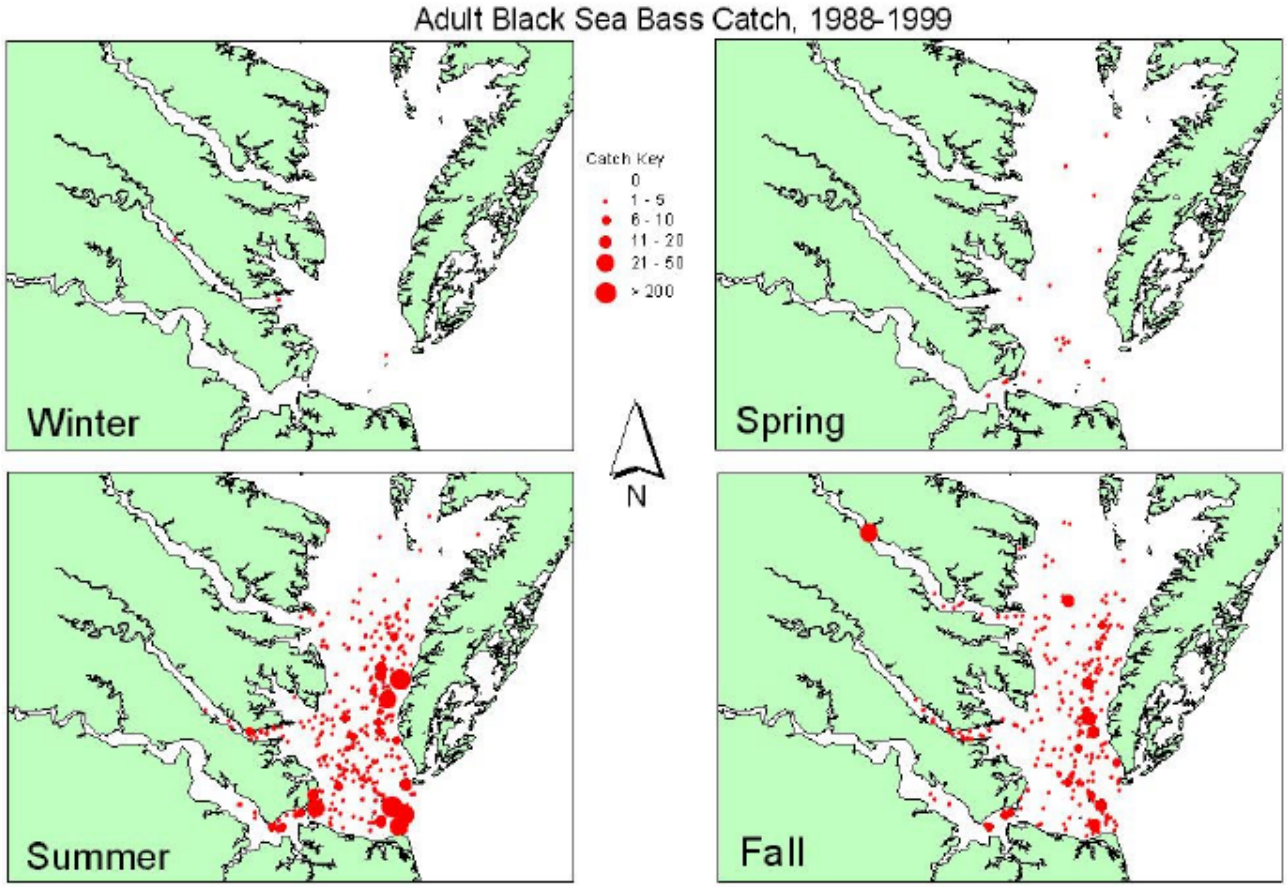

Figure 20. Seasonal distribution and abundance of adult black sea bass in Chesapeake Bay and tributaries, from the VIMS trawl surveys, 1988-1999 (all years combined). Source: Geer (2002).

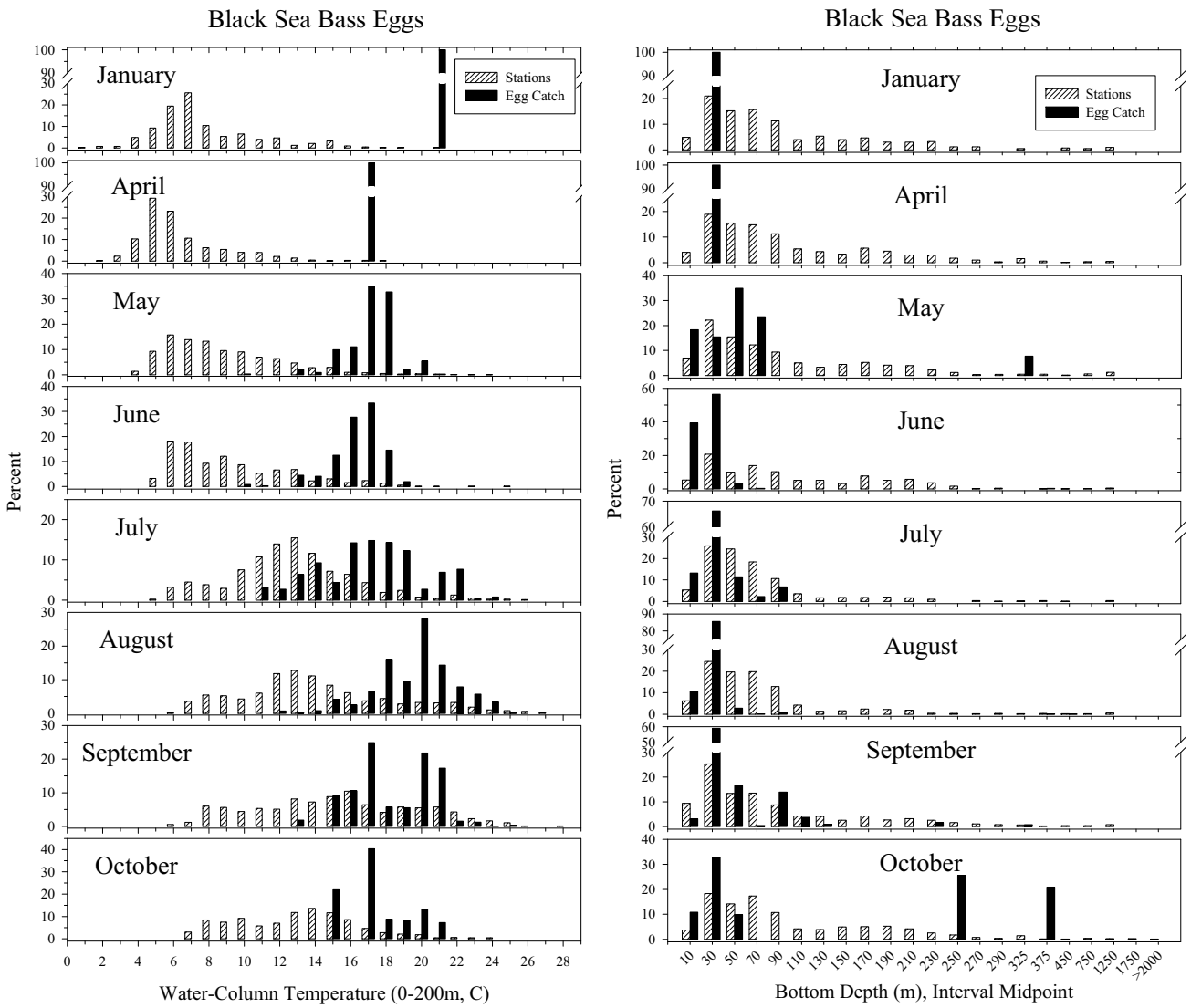

Figure 21. Distributions of black sea bass eggs collected during NEFSC MARMAP icthyoplankton surveys relative to water column temperature and bottom depth, for the years 1978-1987, by month for all years combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth interval changes with increasing depth.

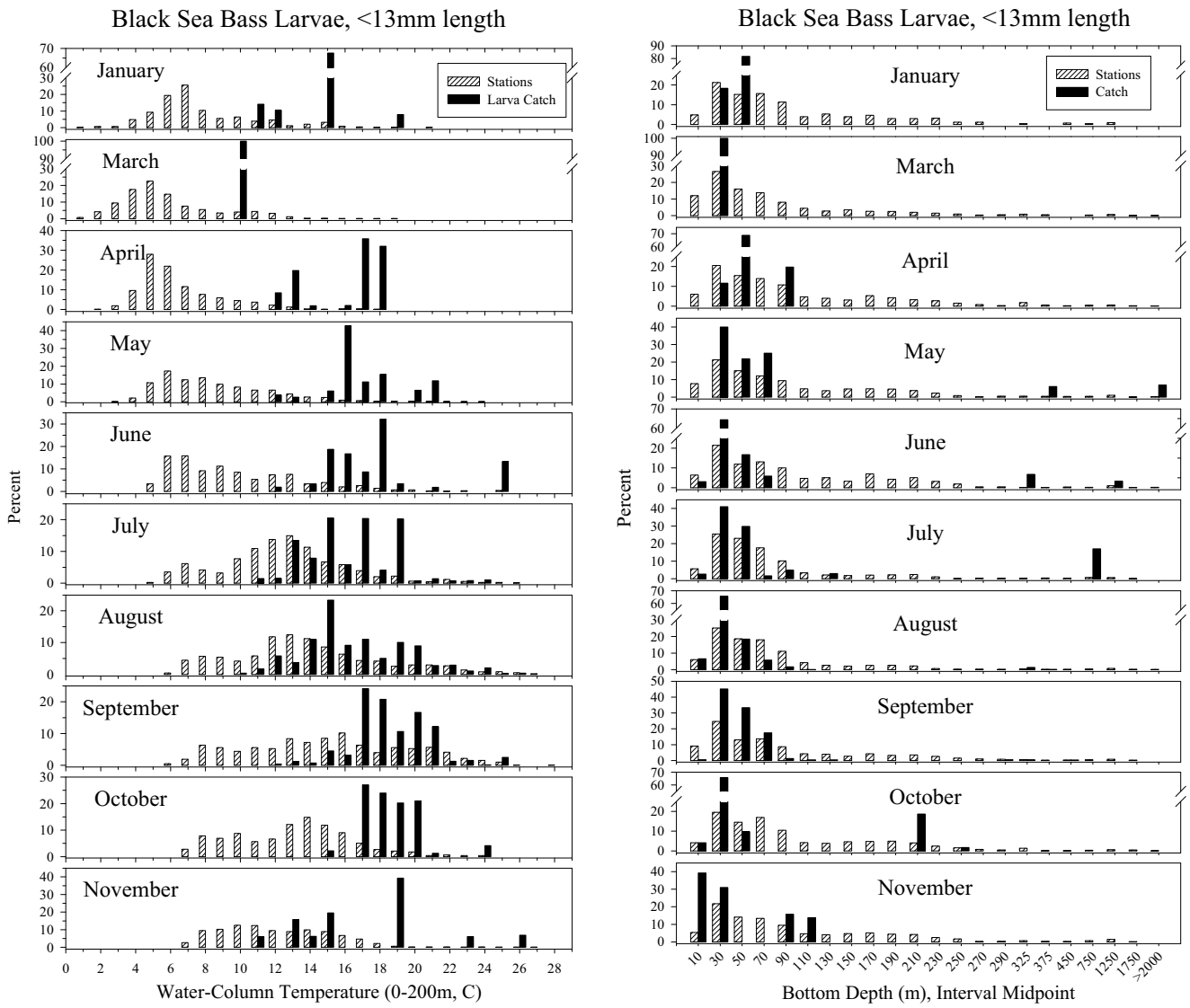

Figure 22. Distributions of black sea bass larvae collected during NEFSC MARMAP icthyoplankton surveys relative to water column temperature and bottom depth, for the years 1977-1987, by month for all years combined. Open bars represent the proportion of all stations which were surveyed, while solid bars represent the proportion of the sum of all standardized catches (number/10 m^2). Note that the bottom depth interval changes with increasing depth.

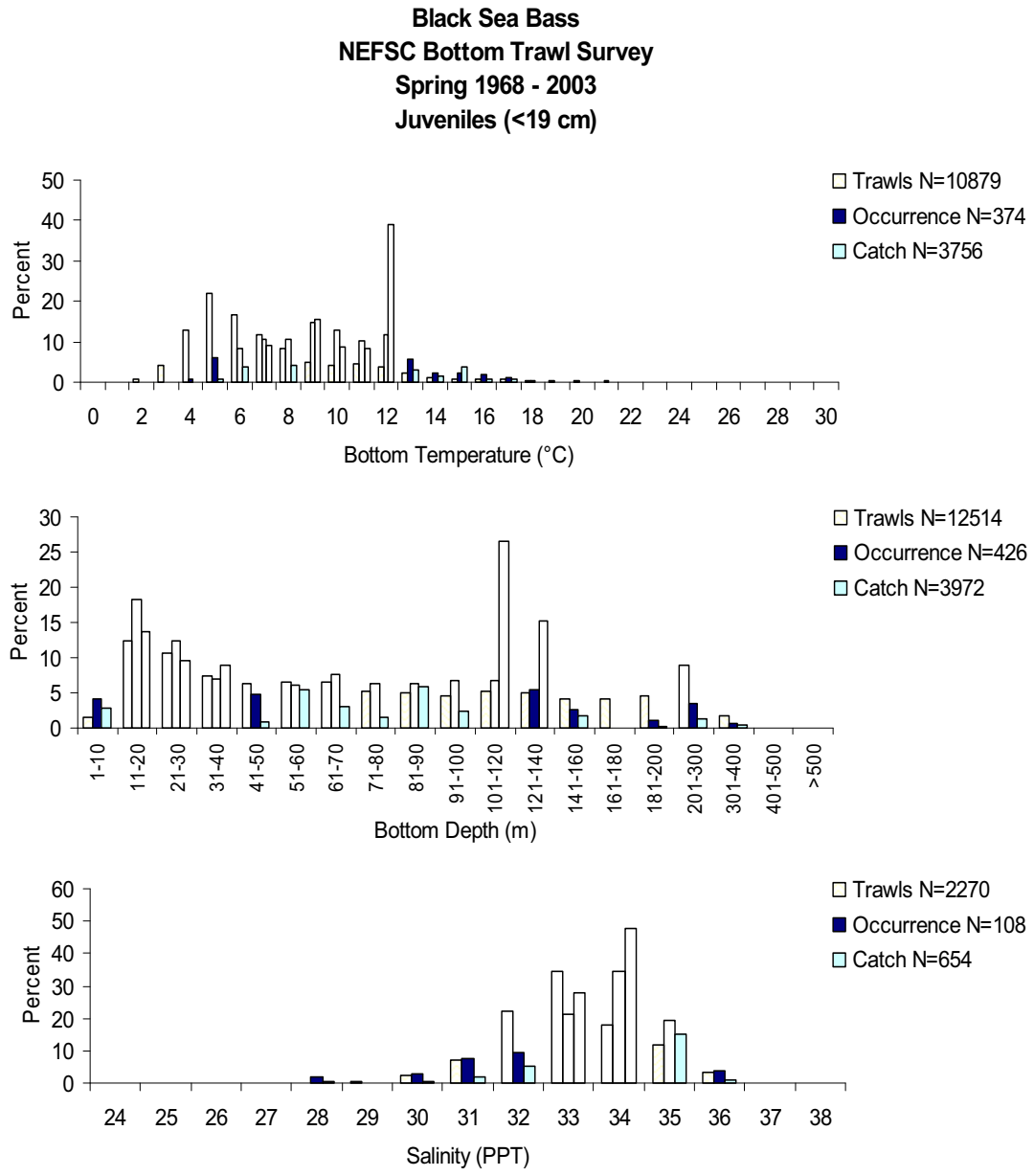

Figure 23. Distributions of juvenile black sea bass and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity, based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which black sea bass occurred and medium bars show, within each interval, the percentage of the total number of black sea bass caught. Note that the bottom depth interval changes with increasing depth.

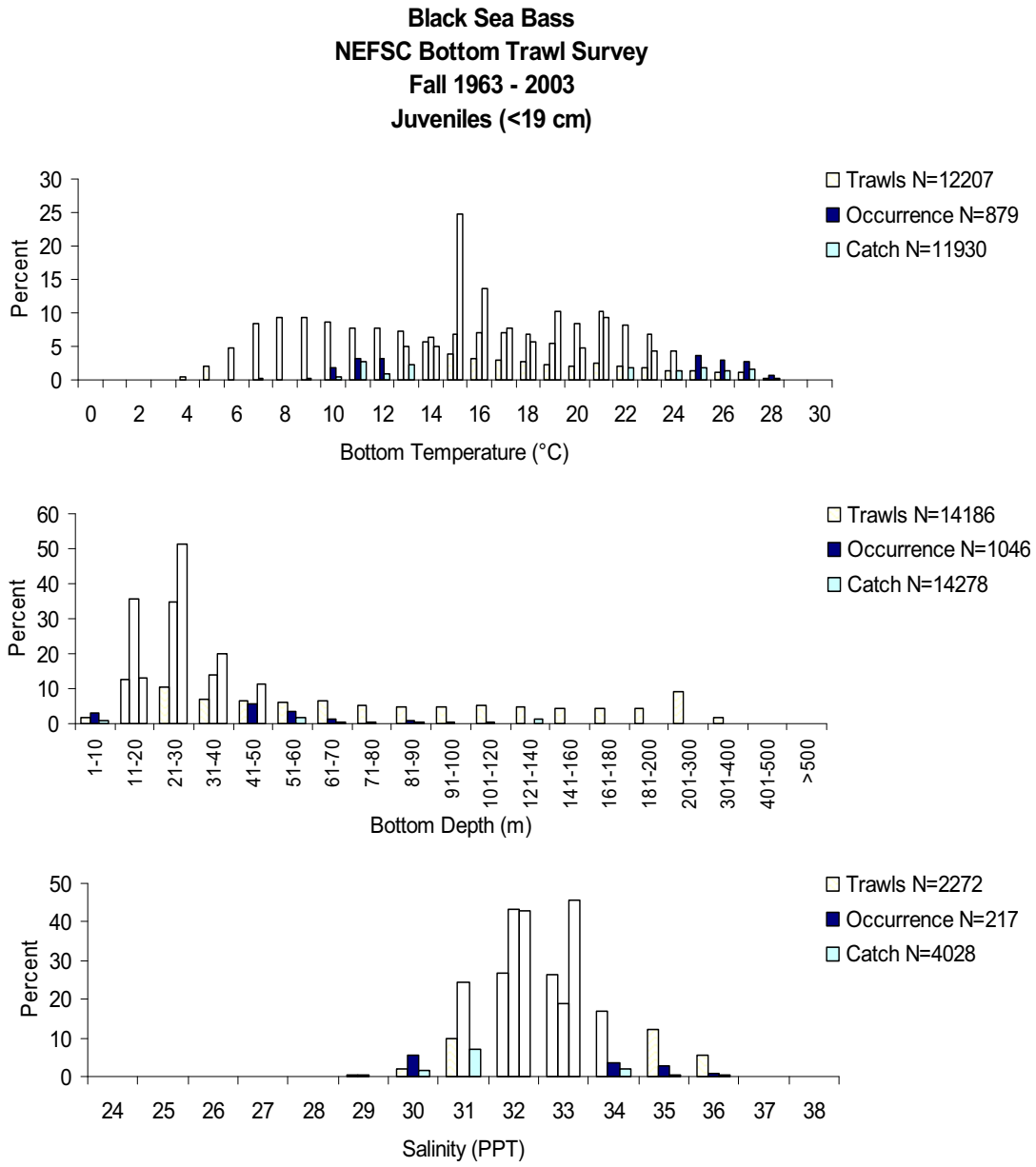

Figure 23. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which black sea bass occurred and medium bars show, within each interval, the percentage of the total number of black sea bass caught. Note that the bottom depth interval changes with increasing depth.

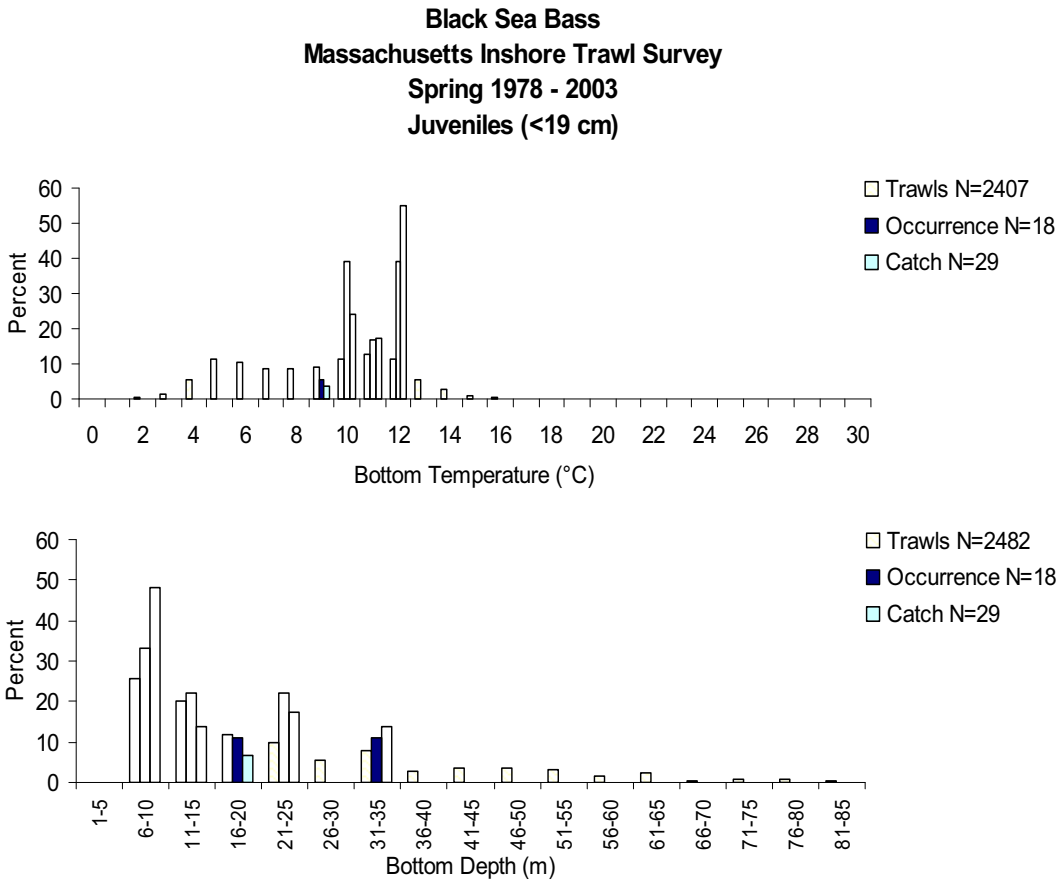

Figure 24. Distributions of juvenile black sea bass and trawls in Massachusetts coastal waters relative to bottom water temperature and depth, based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which black sea bass occurred and medium bars show, within each interval, the percentage of the total number of black sea bass caught.

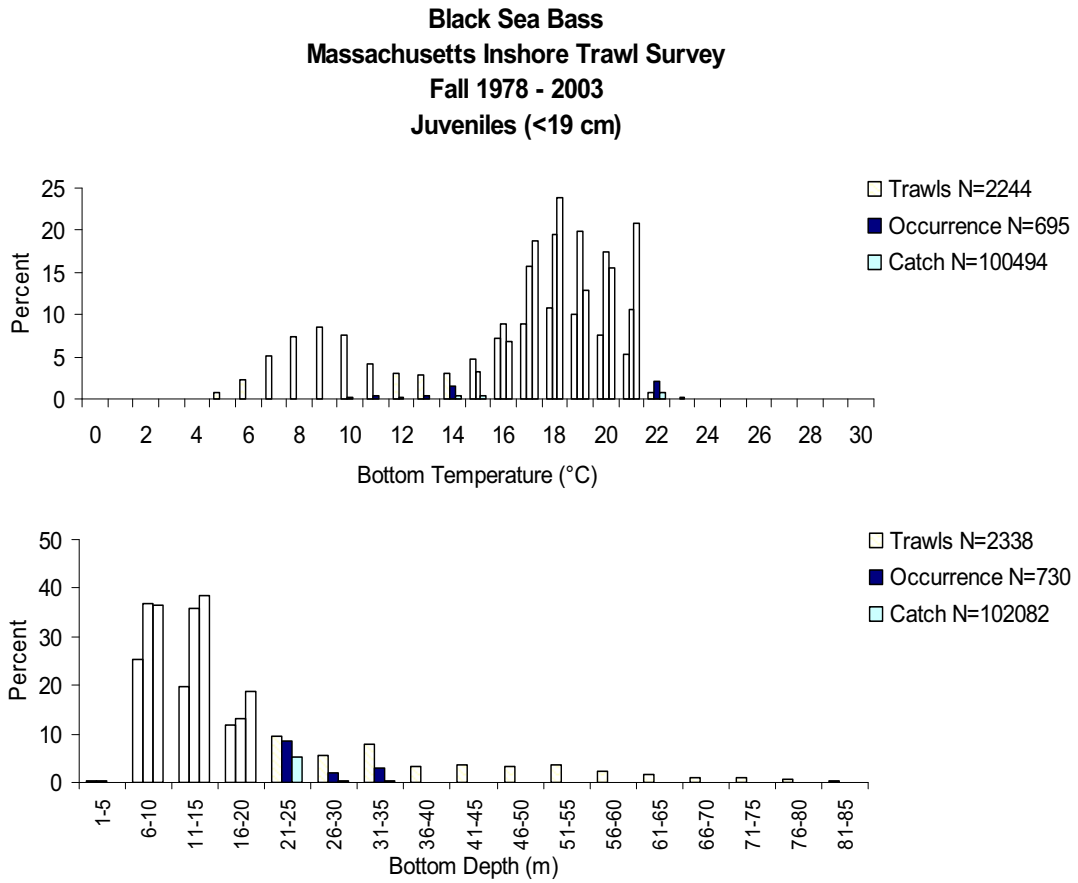

Figure 24. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which black sea bass occurred and medium bars show, within each interval, the percentage of the total number of black sea bass caught.

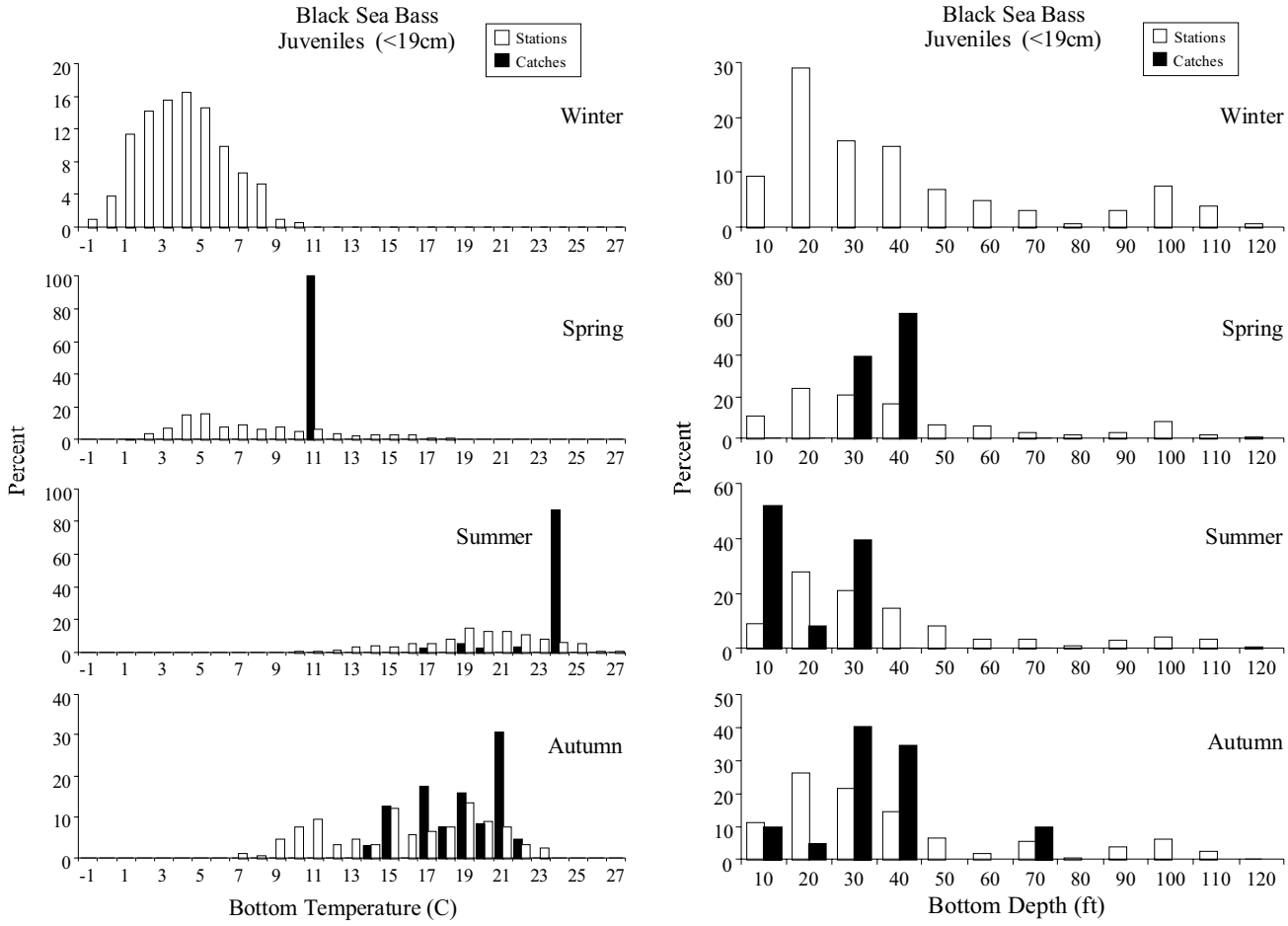

Figure 25. Seasonal distributions of juvenile black sea bass and trawls relative to bottom water temperature and depth, based on Rhode Island Narragansett Bay trawl surveys (1990-1996; all years combined). White bars give the distribution of all the trawls and black bars represent, within each interval, the percentage of the total number of juveniles caught.

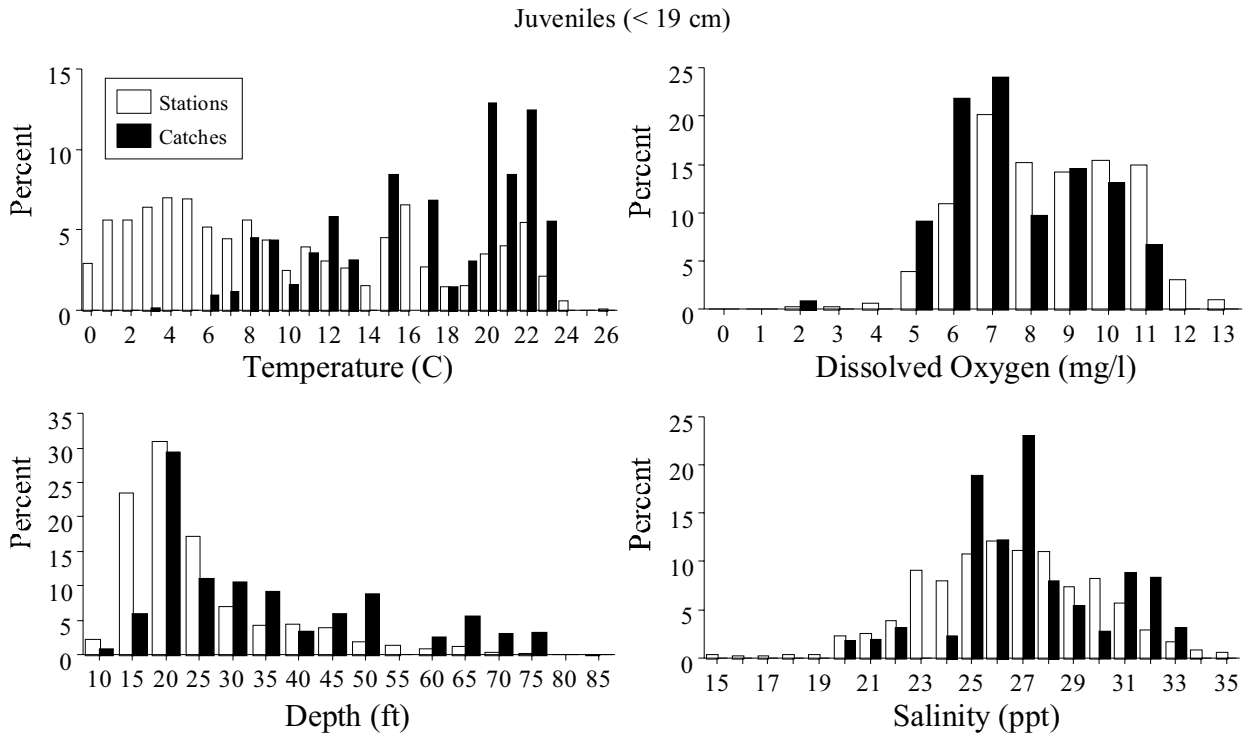

Figure 26. Distributions of juvenile black sea bass relative to mean bottom water temperature, dissolved oxygen, depth, and salinity, based on Hudson-Raritan estuary trawl surveys (January 1992 - June 1997, all years combined). Open bars represent stations surveyed and closed bars represent fish collected.

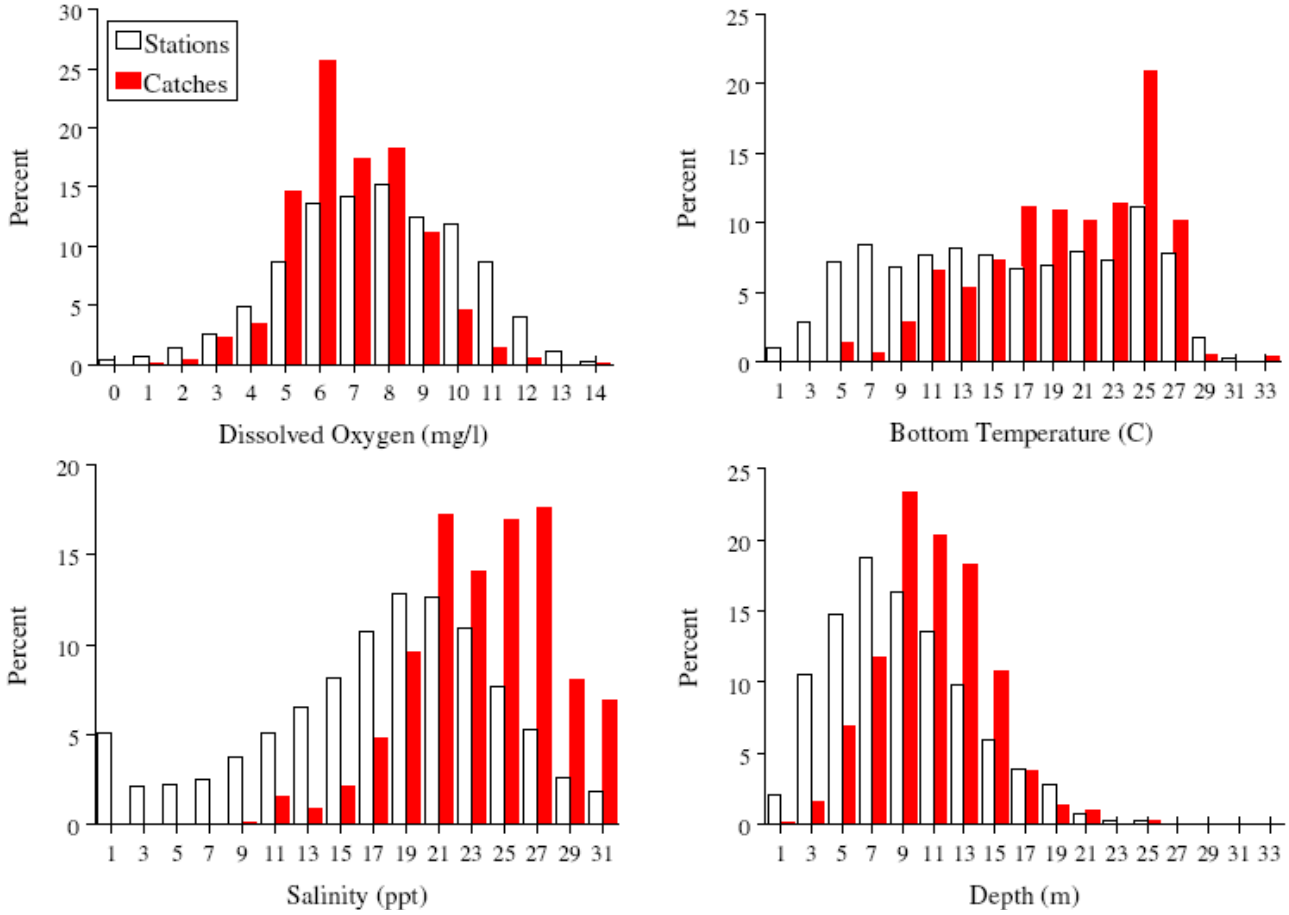

Figure 27. Hydrographic preferences for juvenile black sea bass in Chesapeake Bay and tributaries, from the VIMS trawl surveys, 1988-1999 (all years combined). Source: Geer (2002).

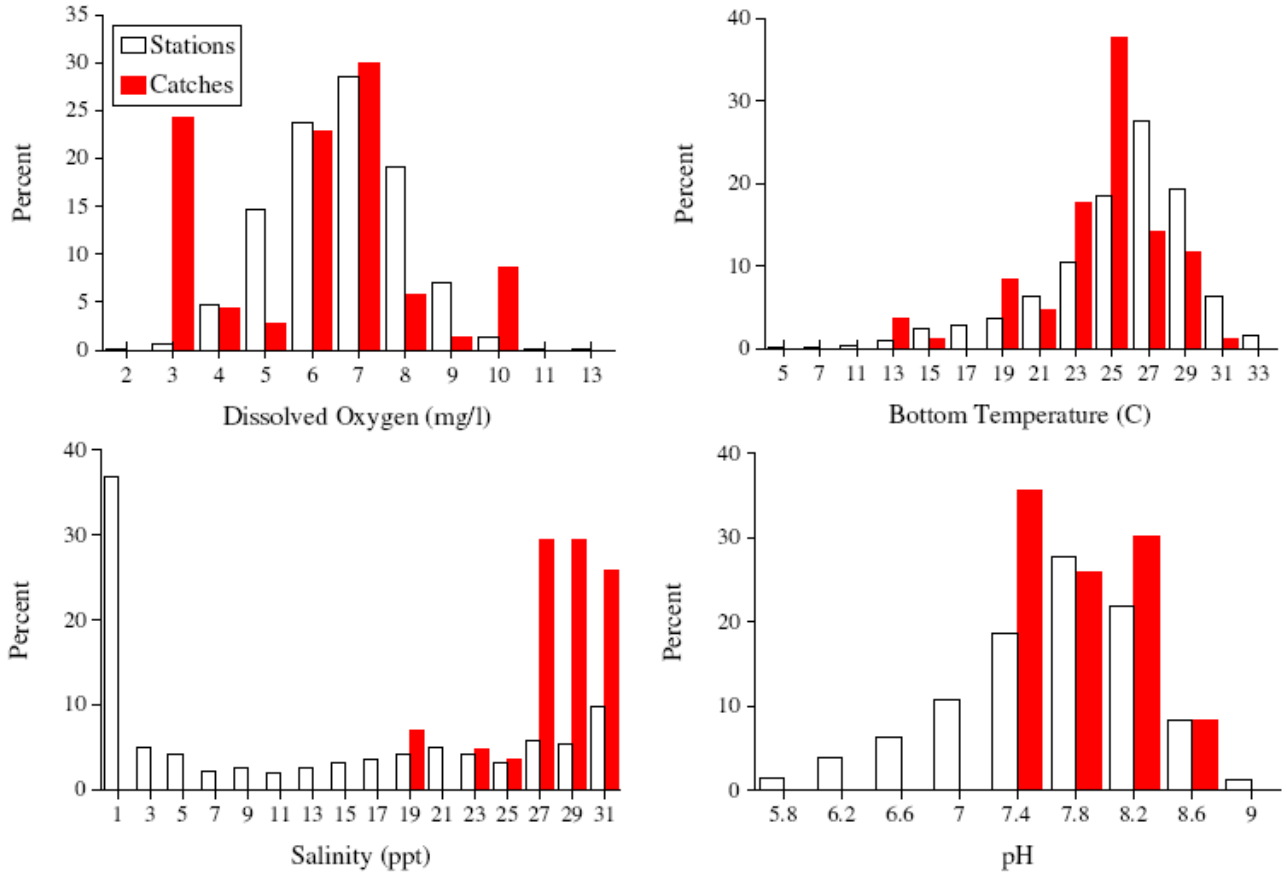

Figure 28. Hydrographic preferences for juvenile black sea bass, from the VIMS seine surveys, 1994-1999 (all years combined). Source: Geer (2002).

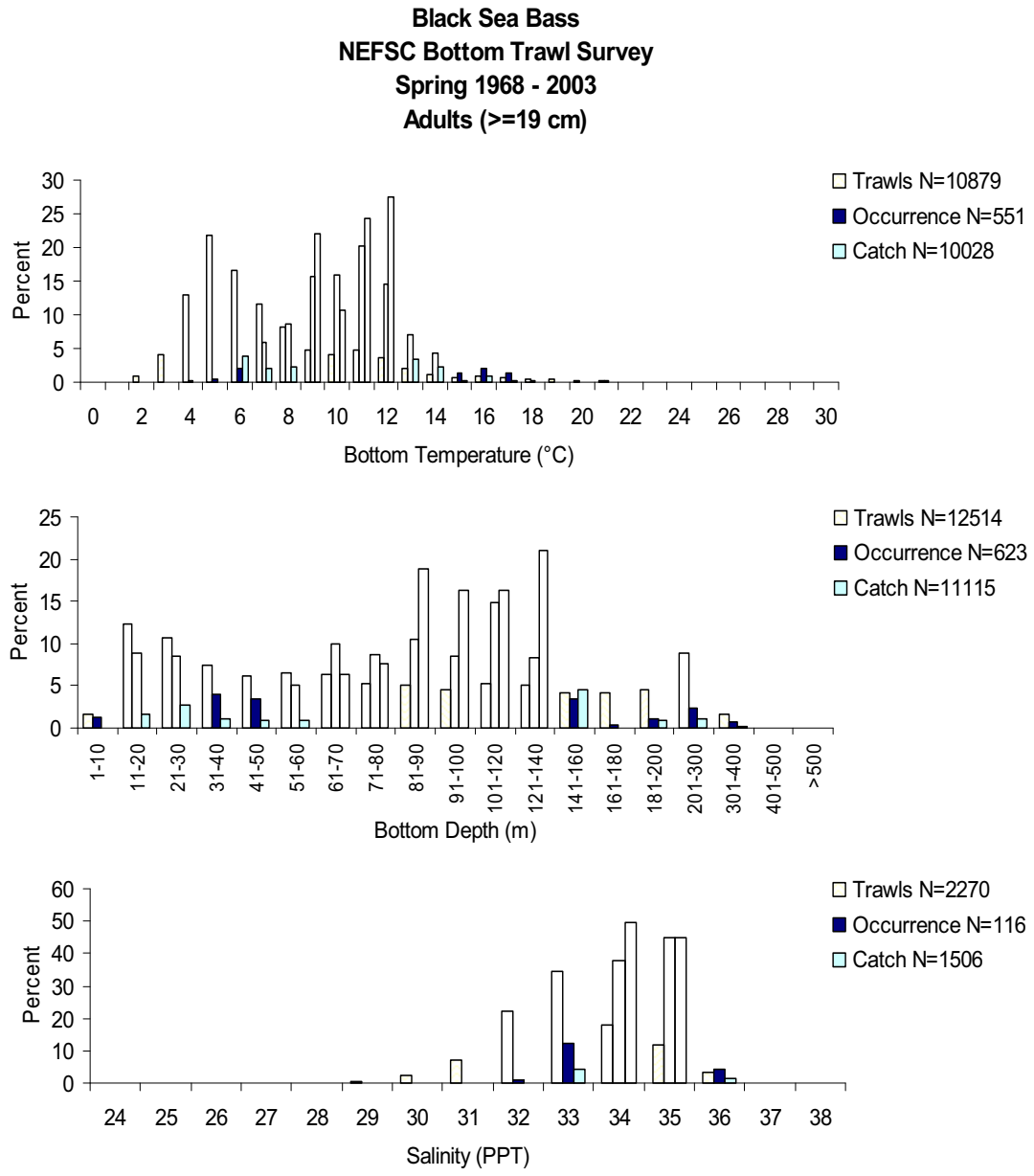

Figure 29. Distributions of adult black sea bass and trawls from NEFSC bottom trawl surveys relative to bottom water temperature, depth, and salinity, based on NEFSC spring bottom trawl surveys (temperature and depth: 1968-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which black sea bass occurred and medium bars show, within each interval, the percentage of the total number of black sea bass caught. Note that the bottom depth interval changes with increasing depth.

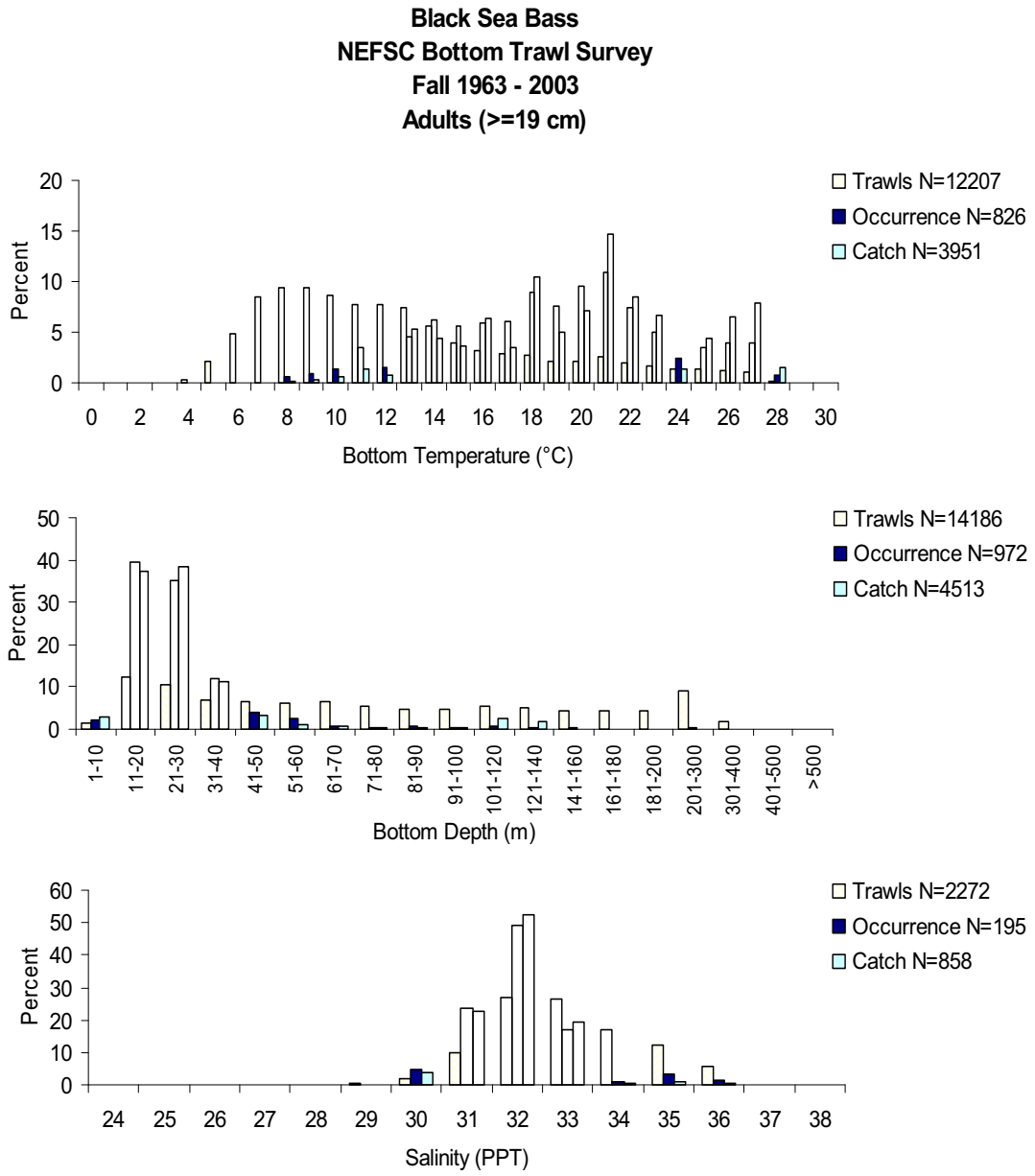

Figure 29. Cont'd.
Based on NEFSC fall bottom trawl surveys (temperature and depth: 1963-2003, all years combined; salinity: 1991-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which black sea bass occurred and medium bars show, within each interval, the percentage of the total number of black sea bass caught. Note that the bottom depth interval changes with increasing depth.

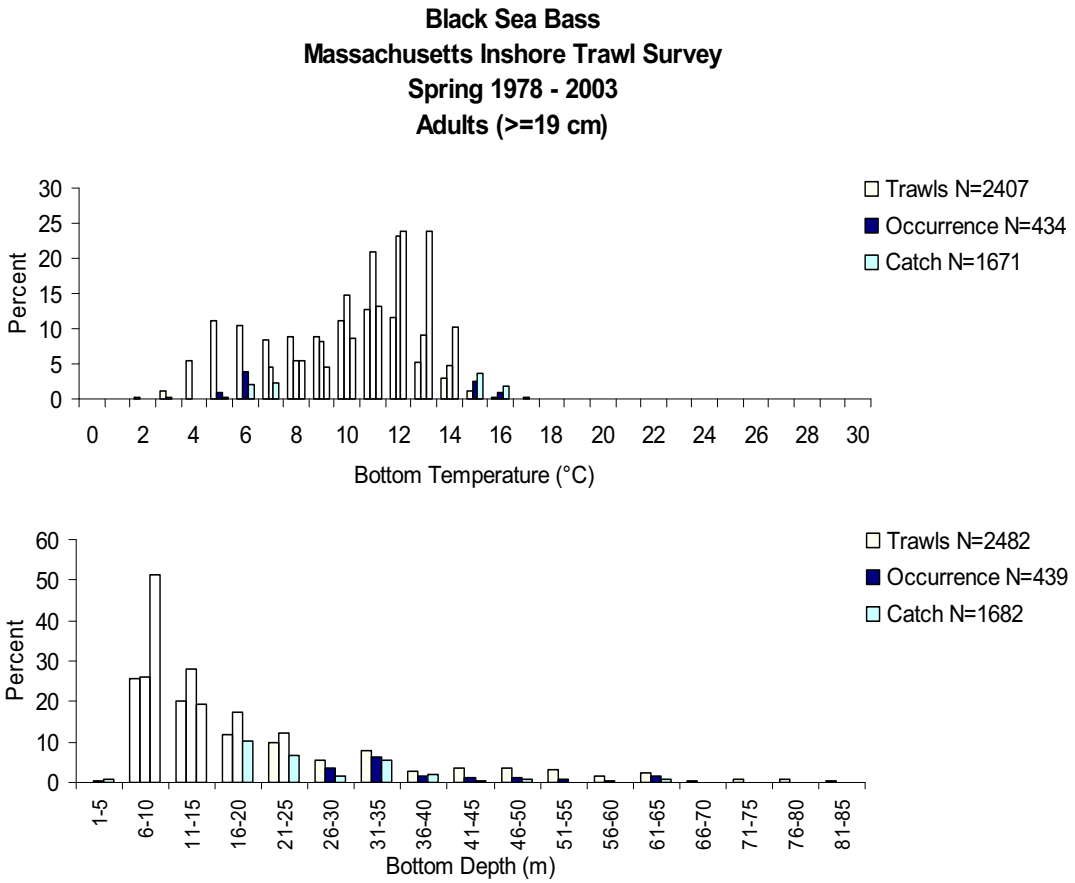

Figure 30. Distributions of adult black sea bass and trawls in Massachusetts coastal waters relative to bottom water temperature and depth, based on spring Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which black sea bass occurred and medium bars show, within each interval, the percentage of the total number of black sea bass caught.

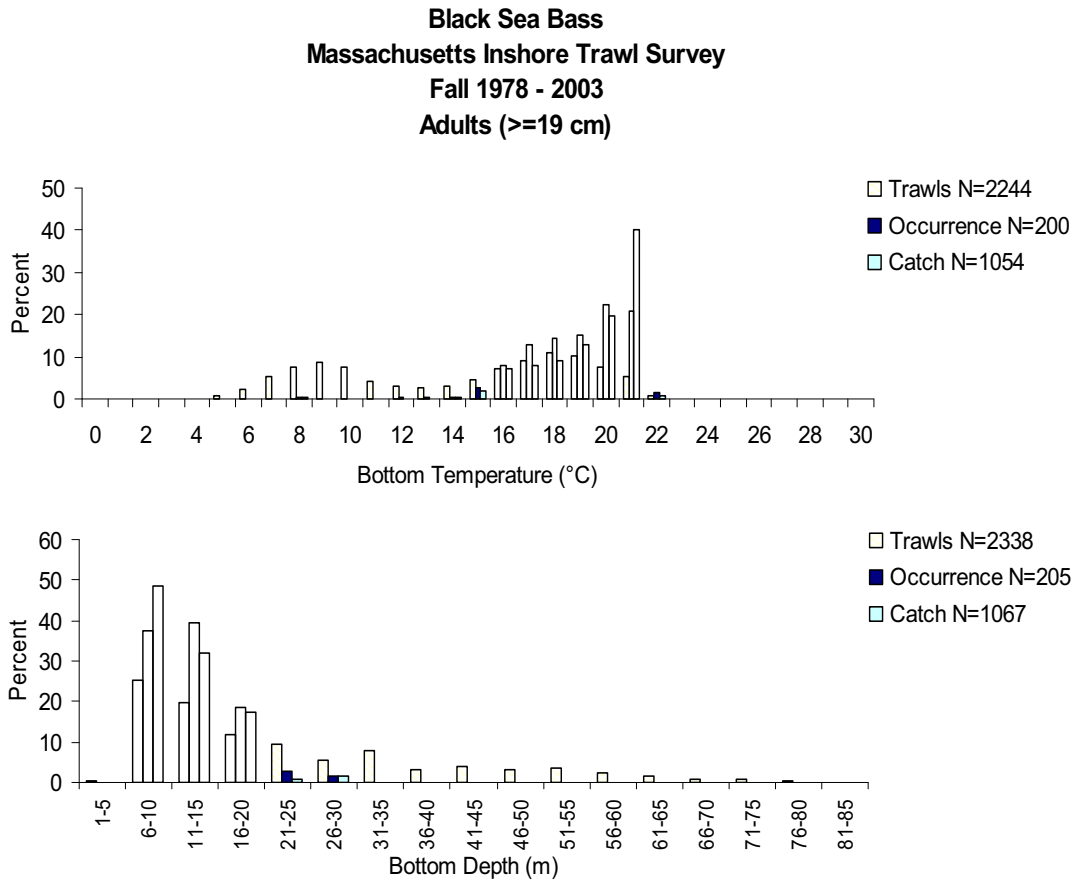

Figure 30. Cont'd.
Based on fall Massachusetts inshore bottom trawl surveys (1978-2003, all years combined). Light bars show the distribution of all the trawls, dark bars show the distribution of all trawls in which black sea bass occurred and medium bars show, within each interval, the percentage of the total number of black sea bass caught.

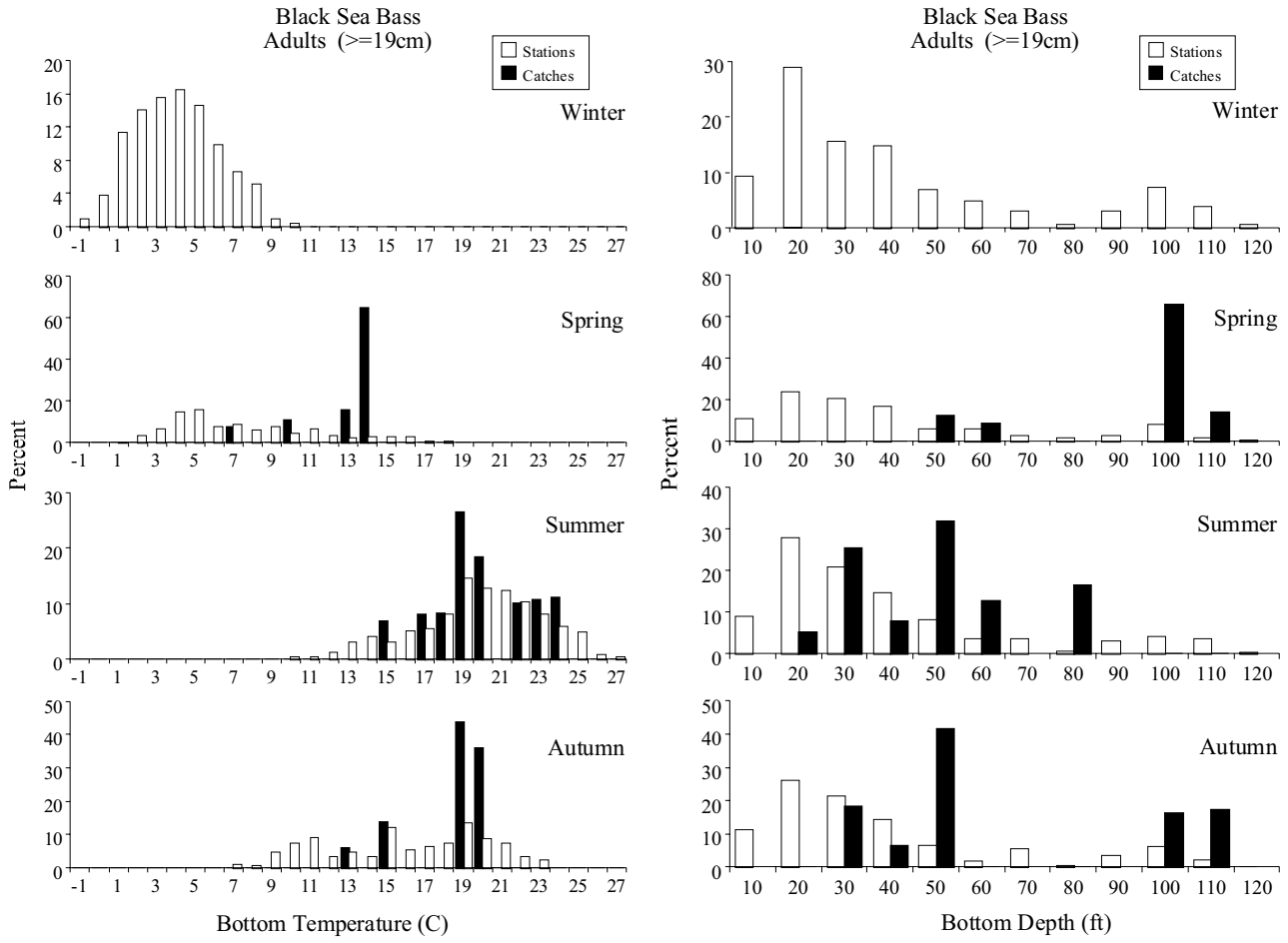

Figure 31. Seasonal distributions of adult black sea bass and trawls relative to bottom water temperature and depth, based on Rhode Island Narragansett Bay trawl surveys (1990-1996; all years combined). White bars give the distribution of all the trawls and black bars represent, within each interval, the percentage of the total number of adults caught.

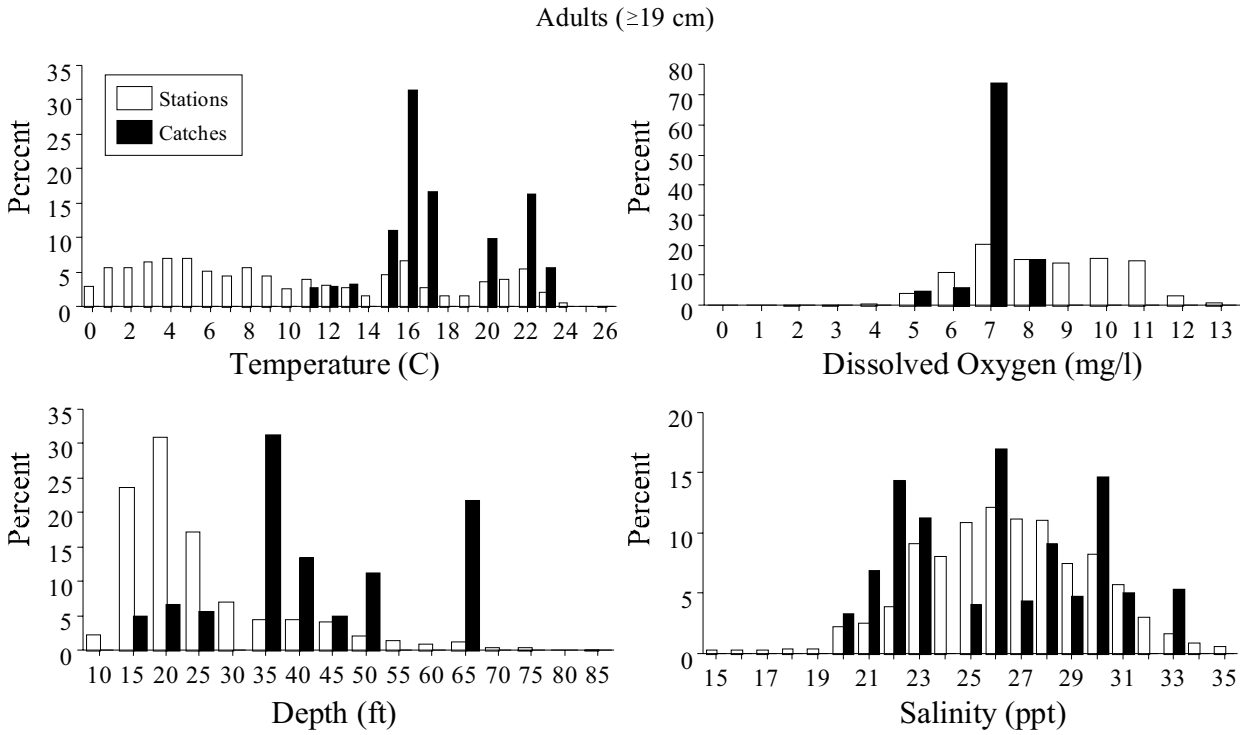

Figure 32. Distributions of adult black sea bass relative to mean bottom water temperature, dissolved oxygen, depth, and salinity, based on Hudson-Raritan estuary trawl surveys (January 1992 - June 1997, all years combined). Open bars represent stations surveyed and closed bars represent fish collected.

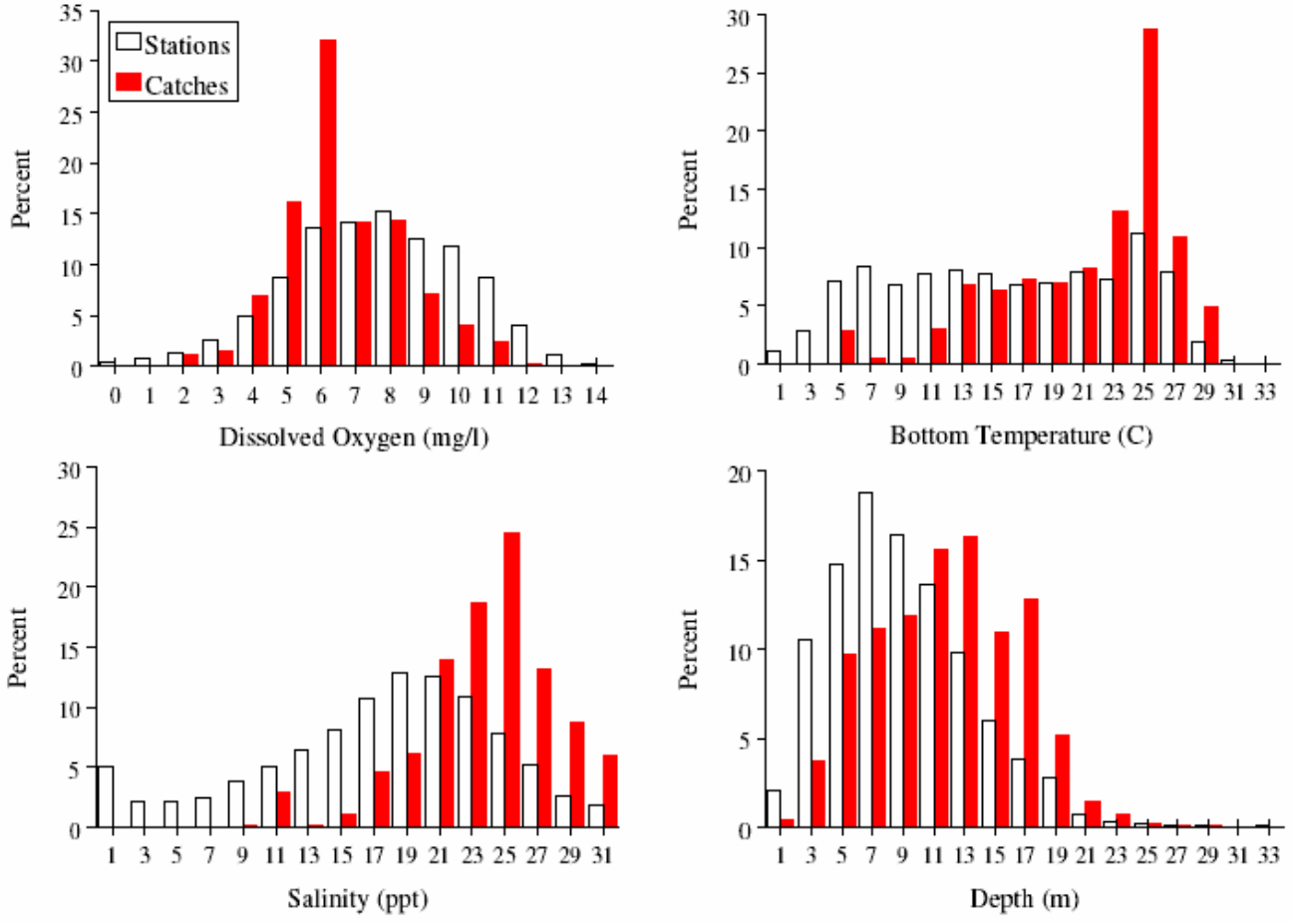

Figure 33. Hydrographic preferences for adult black sea bass in Chesapeake Bay and tributaries, from the VIMS trawl surveys, 1988-1999 (all years combined). Source: Geer (2002).

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NOAA Technical Report NMFS 82 December 1989

Synopsis of Biological Data on the Cobia *Rachycentron canadum* (Pisces: Rachycentridae)

Rosalie Vaught Shaffer
Eugene L. Nakamura

FAO Fisheries
Synopsis 153

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Synopsis of Biological Data on the Cobia *Rachycentron canadum* (Pisces: Rachycentridae)

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December 1989

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Synopsis of Biological Data on the Cobia *Rachycentron canadum* (Pisces: Rachycentridae)

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ABSTRACT

Information on the biology and fisheries of cobia, *Rachycentron canadum*, is compiled and reviewed in the FAO species synopsis style. Topics include taxonomy, morphology, distribution, reproduction, pre-adult and adult stages, food, growth, migration, population characteristics, and various aspects of exploitation. Data and information were obtained from unpublished as well as published sources.

Cobia, the only species in the family Rachycentridae, is a migratory pelagic fish that occurs in tropical and subtropical seas of the world, except in the central and eastern Pacific Ocean. In the western Atlantic Ocean, spawning occurs during the warm months. Eggs and larvae are planktonic. Females grow faster than males: at 1 year, females are 36 cm FL and 0.4 kg; at 4 years, 99 cm and 11 kg; and at 8 years, 137 cm and 31 kg. Comparable data for males are: at 1 year, 31 cm and 0.3 kg; 4 years, 82 cm and 6 kg; and 8 years, 108 cm and 15 kg. Sexual maturity is attained by males at about 52 cm FL in their second year and by females at about 70 cm in their third year. Fecundity for females 100–125 cm FL varies from 1.9 to 5.4 million eggs. Cobia favor crustaceans for food, but will feed on other invertebrates and fishes as well. They attain a maximum size of over 60 kg. Cobia are fished both commercially and recreationally. Commercially, they are usually caught incidentally in both hook-and-line and net fisheries. In the United States, which ranks behind Pakistan, Mexico, and the Philippines in commercial production of cobia, recreational landings exceed commercial landings by more than ten-fold.

1 IDENTITY

1.1 Nomenclature

1.11 Valid name

Rachycentron canadum (Linnaeus 1766) (Fig. 1): Originally described by Linnaeus as *Gasterosteus canadus* in 1766. The type locality was listed as Carolina (Linnaeus 1766; Systema Natura, p. 491).

1.12 Synonymy

The following synonymy is based on the work of Gill (1895), Jordan (1905), and Jordan and Evermann (1896):

Gasterosteus canadus Linnaeus 1766 (type locality, Carolinas)

Scomber niger Bloch 1793

Centronotus gardenii Lacépède 1802 (Carolinas)

Centronotus spinosus Mitchill 1815 (New York)

Rachycentron typus Kaup 1826

Elacate atlantica Cuvier and Valenciennes 1831 (Brazil)

Elacate bivittata Cuvier and Valenciennes 1831 (Molucca)

Elacate malabarica Cuvier and Valenciennes 1831 (Malabar)

Elacate motta Cuvier and Valenciennes 1831 (Orixa)

Elacate pondiceriana Cuvier and Valenciennes 1831 (Pondicherry)

Meladerma nigerrima Swainson 1839

Naucrates niger Swainson 1839

Elacate canada DeKay 1842 (New York)

Elacate falcipinnis Gosse 1851 (Jamaica)

Elacate nigra Günther 1860

Rachycentron canadus Jordan and Evermann 1896

Rachycentron pondicerrianum (*sic*) Jordan 1905

Rachycentron canadum Jordan 1905

1.2 Taxonomy

1.21 Affinities

Suprageneric

Phylum Chordata
  Subphylum Vertebrata
    Superclass Gnathostomata
      Class Osteichthyes
        Superorder Acanthopterygii
          Order Perciformes
            Suborder Percoidei
              Family Rachycentridae

Generic

Genus *Rachycentron* Kaup 1826. Monotypic genus, see 1.22 and 1.3.

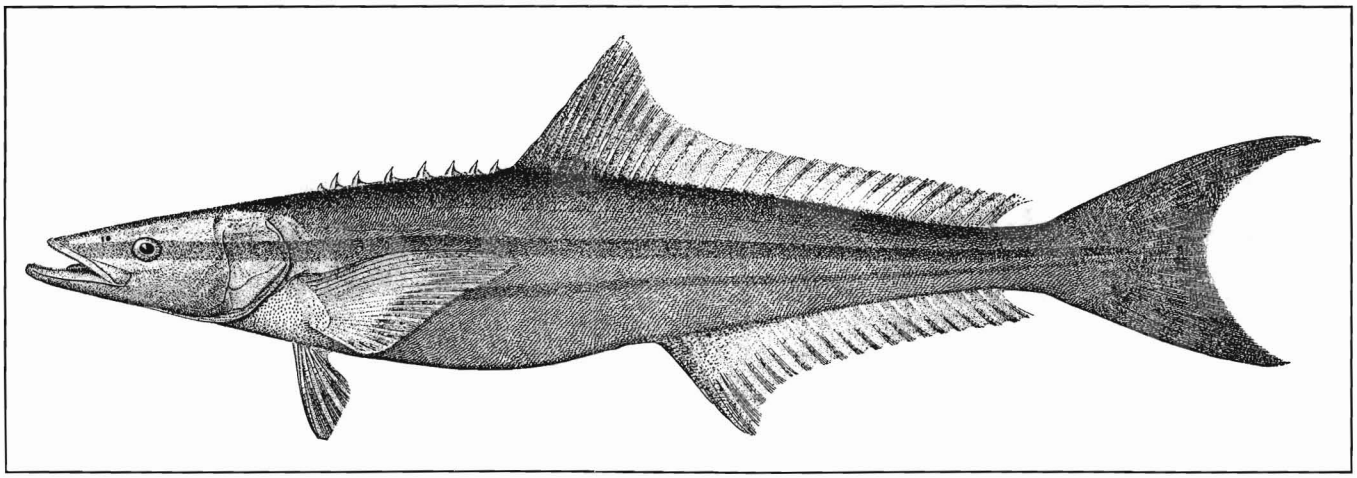

Figure 1
The Cobia, *Rachycentron canadum* (Goode 1884, plate 174).

Specific The following diagnosis of *Rachycentron canadum* is from Collette (1978): "Body elongate, subcylindrical; head broad and depressed. Mouth large, terminal, with projecting lower jaw; villiform teeth in jaws and on roof of mouth and tongue. First dorsal fin with 7–9 (usually 8) short but strong isolated spines, not connected by a membrane; second dorsal fin long, anterior rays somewhat elevated in adults; pectoral fins pointed, becoming more falcate with age; anal fin similar to dorsal, but shorter; caudal fin lunate in adults, upper lobe longer than lower (caudal fin rounded in young, the central rays much prolonged). Scales small, embedded in thick skin; lateral line slightly wavy anteriorly."

1.22 Taxonomic status

Rachycentron canadum is the only species in the family Rachycentridae.

Affinities based on morphology of early life stages as well as adults of species in the families Nematistiidae, Carangidae, Coryphaenidae, Rachycentridae, and Echeneididae are discussed by Johnson (1984). He states that *Rachycentron* and echeneidids have been assumed to be closely related (sister groups) based on similarities in form, color, and fin shape of juveniles of *Rachycentron* and *Echeneis naucrates*, but that osteological examinations reveal a greater likelihood of sister groups between *Rachycentron* and *Coryphaena*. This latter affinity is especially shown in larval morphology of the two genera. He also states, "Three synapomorphies unite the Carangidae, Coryphaenidae, Rachycentridae, and Echeneididae as a monophyletic group. . . Within the carangoids, the Coryphaenidae, Rachycentridae, and Echeneididae form a monophyletic group."

1.23 Subspecies

No subspecies are recognized.

1.24 Standard common names, vernacular names

The accepted common name for *Rachycentron canadum* in the United States is cobia (Robins et al. 1980). The standard FAO common names are: English, cobia; French, mafou; Spanish, cobie (Collette 1978). Other names appearing in the literature are:

United States Ling, sergeant fish, bonito, coalfish (Goode 1884); cabio, crabeater (La Monte 1952); lemonfish (Manooch 1984); black bonito (Hildebrand and Schroeder 1928); lingcod, black salmon (Moe 1970); cubby-yew, flathead (Burgess 1983)

Argentina Bonito negro (Menni et al. 1984)

Australia and India Black kingfish (La Monte 1952, Pillai 1982)

Brazil Bijupirá (Figueiredo and Meneses 1980); ceixupira (Duarte-Bello and Buesa 1973)

Colombia Bacalao (Menni et al. 1984)

Cuba Bacalao (Menni et al. 1984); medregal (Duarte-Bello and Buesa 1973)

Guyanas Cabilo (Org. Econ. Coop. Develop. 1978)

Japan Sugi (Ueno 1965)

Madagascar Sao ambina; poisson-sergent (Fourmanoir 1957)

Mexico Bacalao (La Monte 1952); bonito (Duarte-Bello and Buesa 1973); esmedregal (Sec. Ind. Comer. Mex. 1976)

Pakistan Black kingfish; sanghra; sanglor (Bianchi 1985)

Persian Gulf Sikin (Kuronuma and Abe 1972)

Puerto Rico Bacalao (La Monte 1952, Erdman 1956)

Senegal and Gambia Warangall (Menni et al. 1984)

South Africa Runner; prodigal son (Smith 1965)

Tanzania Runner; songoro (Hatchell 1954)

U.S.S.R. Kobievye; serzhant-ryby (Lindberg and Krasyukova 1971)

Uruguay Bonito; bonito negro (Menni et al. 1984)

Venezuela Bacallao (Menni et al. 1984, Cervigón 1966)

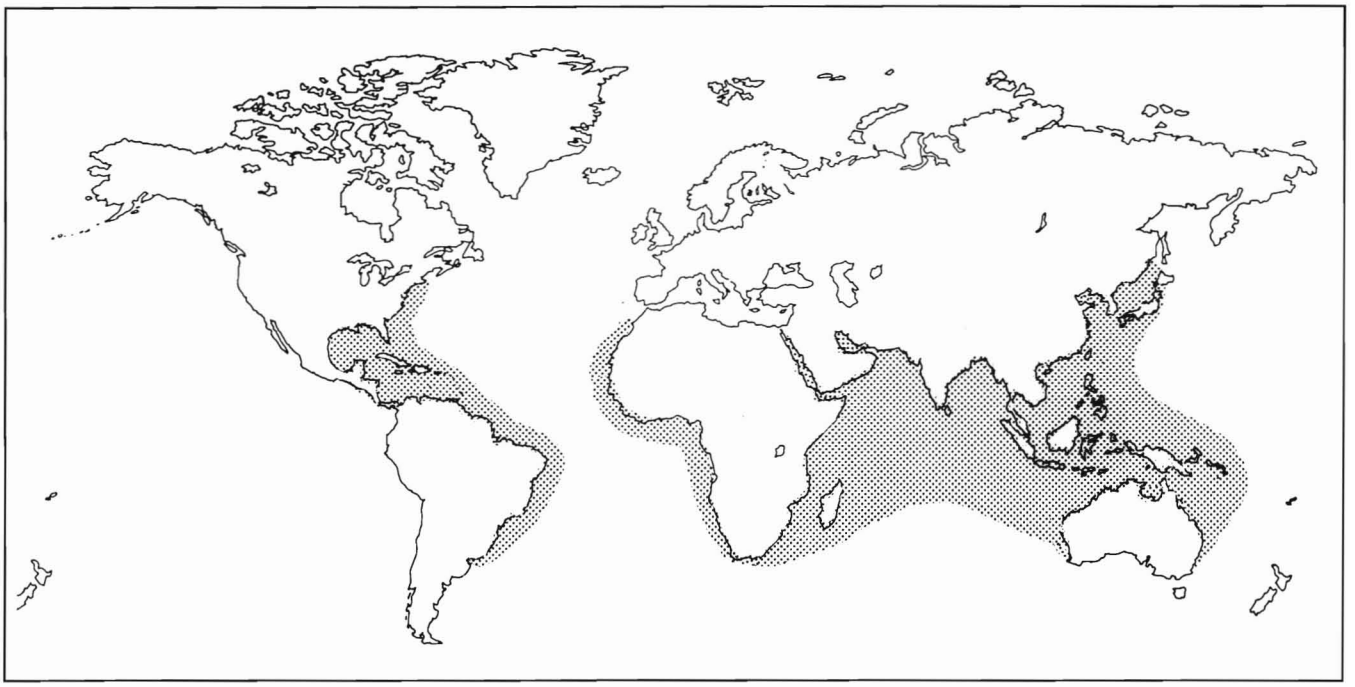

Figure 2
Range of the cobia, *Rachycentron canadum*.

1.3 Morphology

1.31 External morphology

Body elongate, fusiform; head very long, depressed; eye small, interorbital wide, no adipose lid; snout broad, its length 2.45–2.85 in head, eye 4.85–6.35 in head; head 4.05–5.3 in standard length (SL), depth 5.55–8.1; dorsal spines 7–9, each depressible into a groove; dorsal rays 28–33; anal fin with 1–3 spines, 23–27 rays; mouth moderate, lower jaw projecting; maxillary reaching anterior margin of the eye, 2.3–2.6 in head; premaxillaries not protractile; gillrakers short, 7–9 on lower limb of first arch; branchiostegals 7; preopercle and opercle finely serrate marginally; vertebrae 11–14; caudal vertebrae 13 or 14; no air bladder; pyloric appendages branched (Briggs 1974, Fowler 1936, Hardy 1978, Kuronuma and Abe 1972). A detailed study of the cobia lateral-line canal system may be found in Siming and Hongxi (1986). Ueno (1965) gives morphometric data from a Japanese specimen.

Color dark-brown above, a paler brown on sides and below; a black lateral band, as wide as the eye, extending from snout to base of caudal, bordered above and below by paler bands; below this is a narrower dark band. The black lateral band is very pronounced in the juvenile, but tends to become obscured in the adult. Fins mostly all deep or dusky brown; anal and pelvics pale with gray or dusky markings; ventral surface grayish white to silvery (Briggs 1974, Fowler 1936, Hardy 1978, Smith 1907).

2 DISTRIBUTION

2.1 Total area

Cobia are widely distributed, occurring nearly worldwide in tropical, subtropical, and warm temperate waters (Fig. 2). In the western Atlantic, they occur from Massachusetts and Bermuda to the Rio de la Plata, Argentina (Briggs 1958, Menni et al. 1984, Nichols and Breder 1926), with the northern range record of a 42.7-mm SL specimen collected from the Scotian Shelf in Canada (Markle et al. 1980).

In the eastern Atlantic, cobia range from the Atlantic coast of Morocco to South Africa (Monod 1973, Smith 1965). They do not occur in the Mediterranean, except for possible strays from the Red Sea through the Suez Canal (Golani and Ben-Tuvia 1986). Cobia range throughout the Indian Ocean, and in the western Pacific they are reported from Hokkaido, Japan to Australia and the East Indies (Bianchi 1985, Fourmanoir 1957, Grant 1972, Hatchell 1954, Jordan and Seale 1906, La Monte 1952, Lindberg and Krasyukova 1971, Relyea 1981, Ueno 1965). Cobia do not occur in the eastern Pacific.

2.2 Differential distribution

2.21 Spawn, larvae, and juveniles

Most cobia eggs and larvae are found in offshore waters (see 3.16). Early juveniles move inshore and inhabit coastal areas, near beaches, river mouths, barrier islands, lower reaches of bays and inlets, or bays of relatively high salinities (Benson 1982, Hoese and Moore 1977, McClane 1974, Swingle

Table 1
Environmental data from cobia collections.

Location	Date	*N*	Length/wt.	Water temp. (°C)	Salinity (ppt)	References
Western Atlantic						
New Jersey	Aug.*	2	49 mm TL; 51 mm TL	16.8	30.0	Milstein and Thomas 1976
North Carolina–Florida	Sept. 1969–May 1972	10	22–126 cm TL	19.6–25.2	32.0–36.4	Wilk and Silverman 1976
Jupiter Inlet, Florida	Aug. 1960	1	22 cm SL	>30.0	22.5	Christensen 1965
Gulf of Mexico						
Gulf of Mexico	Nov. 1950–Dec. 1952	—	—	23.0–25.0**	—	Springer and Bullis 1956
Buttonwood Canal, Florida	July 1963	2	132 mm TL; 166 mm TL	29.8	44.5	Roessler 1967
Tampa Bay, Florida	July 1958	1	77.0 mm SL	28.0	33.3	Springer and Woodburn 1960
Cedar Key, Florida	Aug. 1950	2	7 kg; 14 kg	28.9	24.6	Reid 1954
Dog Keys Pass, Mississippi	June and July 1967; June 1968	10	12.6–27 mm SL	25.9–32.0	28.9–37.7	Dawson 1971
Eastern Atlantic						
Ivory Coast	Jan. 1983	1	3.8 kg	22.5	35.4	Lhomme 1983

*1972, 1973, or 1974
**Bottom temperatures, trawl-caught samples

1971). Dawson (1971) indicated that small juveniles (13–15 mm) were taken offshore in the Gulf of Mexico, whereas larger specimens (45–140 mm) were most frequently collected from inshore locations.

2.22 Adults

Adult cobia are coastal and continental shelf fish, occasionally entering estuaries (Benson 1982, Collette 1978, Robins and Ray 1986). They are pelagic, but may occur throughout the water column (Freeman and Walford 1976), and have been taken at depths of 50 m, and over waters as deep as 1200 m (Springer and Bullis 1956). They are found in a variety of habitats: Over mud, rock, sand and gravel bottoms; over coral reefs and in mangrove sloughs; inshore around pilings and buoys, and offshore around drifting and stationary objects (Freeman and Walford 1976, Goodson 1985, Hoese and Moore 1977, Relyea 1981, Sonnier et al. 1976, Springer and Bullis 1956).

2.3 Determinants of distribution changes

Temperature The distribution of cobia is greatly affected by temperature. Generally, cobia occur in the cooler portion of their range only during the warm months of the year. Cobia either migrate to warmer waters, or move offshore to deeper waters during the colder months (see 3.51). They have been collected from waters of 16.8–32.0°C (Table 1). Hassler and Rainville (1975) reported 37.7°C to be lethal to juveniles. The juveniles tolerated temperatures down to 17.7°C, although they ceased feeding entirely at 18.3°C. According to Richards (1967), cobia do not appear in the Chesapeake Bay until water temperatures exceed 19°C.

Salinity Cobia generally occur in areas of oceanic or near-oceanic salinities, and can tolerate fairly hypersaline conditions. They have been taken from waters with salinities ranging from 22.5 to 44.5 ppt (Table 1), but they may be able to acclimate to slightly lower salinities. Hassler and Rainville (1975) were able to rear cobia larvae successfully in salinities as low as 19 ppt.

Food Cobia are known to move to areas of high food abundance, particularly abundances of crabs and other crustaceans (Darracott 1977).

2.4 Hybridization

No hybrids of cobia are known (Schwartz 1972, 1981).

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.11 Sexuality

Cobia are gonochoristic. No external sexual dimorphism has been reported.

3.12 Maturity

Male cobia mature at a smaller size than females. Richards (1967) reported that male cobia from the Chesapeake Bay reached earliest maturity in their second year, at 51.8 cm FL and 1.14 kg. Females reached earliest maturity in their third year, at 69.6 cm FL and 3.27 kg.

Table 2

Fecundity estimates of cobia collected from Windmill Point and York Spit, Chesapeake Bay (Richards 1967). Ova measured 0.50–0.90 mm diameter.

Fork length (inches)	Wt. (lbs)	Date (July 1963)	Ovary condition	Total ovarian tissue (g)	Egg count (avg./g)	Estimated total fecundity (10^3 eggs)
49.1	57.75	17	Full	2113	2574	5439
48.8	54.75	17	Full	1877	2316	4347
46.5*	45.50	6**	Partly spent	1121	2497	2799
39.2	26.25	17	Full	506	3825	1935
47.0	45.25	17	Partly spent	769	2866	2204
41.8	33.00	18	Full	1083	2464	2669

*Collected only at York Spit.
**1962

Cobia in other parts of the world may mature earlier. In Indian waters, Rajan et al. (1968) collected a 42.6-cm TL female with ovaries in the third stage of maturity.

3.13 Mating

Cobia form spawning aggregations (Richards 1967).

3.14 Fertilization

Fertilization is probably external, with both eggs and sperm released simultaneously.

3.15 Gonads

Fecundity In the Chesapeake Bay area, Richards (1967) reported that fecundity ranged from 1.9 to 5.4 million eggs for six cobia (Table 2). Richards also gave the relation between fecundity (F), in 10^4 ova, and the body weight (wt) in pounds of four fully-gravid females as $F = 0.98$ (wt) $- 6.39$.

3.16 Spawning

Western North Atlantic The presence of gravid females and appearance of cobia eggs in plankton collections indicated that spawning occurs between mid-June and mid-August in the Atlantic Ocean adjacent to the mouth of the Chesapeake Bay (Joseph et al. 1964). Richards (1967) indicated that cobia spawn from late June through mid-August off Virginia, and that multiple spawning may occur.

Spawning may occur earlier in North Carolina waters. Hassler and Rainville (1975) collected nearly 2000 cobia eggs from 23 May to the end of their sampling period on 28 June in Gulf Stream waters 25–50 km from the coast. Spawning appeared to peak between 10 and 17 June. Off South Carolina, spawning has been recorded as early as mid-May, extending to the end of August in offshore waters, approximately 80 km from the coast (Donald Hammond, S.C. Dep. Wildl. Mar. Resour., P.O. Box 12559, Charleston, SC 29412, pers. commun., 8 Apr. 1987).

Table 3

Cobia larvae collected from Gulf of Mexico waters off the coast of Texas (adapted from Finucane et al. 1978a).

Date	Stn. no.	*N*	Size (mm)	Water depth (m)	Km from coast (est.)
7/6/77	II-3	2	3.8	135	90
9/7/77	IV-3	3	4.0	90	80
9/8/77	III-2	4	6.8	~70	50
9/10/77	I-3	3	5.1	135	85

Gulf of Mexico Finucane et al. (1978a) implied cobia spawning in the Gulf of Mexico from the collection of small larvae (3.8–6.8 mm) off the Texas coast in July and September (Table 3). In an additional study, Finucane et al. (1978b) collected six larvae (5.9–23.0 mm) off the coast of Texas in July. Dawson (1971) reported that cobia less than 30 mm SL were taken from gulf coastal waters between 31 May and 12 July; the smallest specimens (16–19 mm SL) were collected on 5 June. He also noted that the occurrence of small specimens follows the appearance of adults in northern gulf waters in March and April. Baughman (1950) indicated that young cobia were common off Texas in May, June, and July. Observations of what was believed to be spawning by cobia have been made by James M. Barkuloo (U.S. Fish Wildl. Serv., Panama City, FL, pers. commun., 23 March 1988). On 8 and 10 August 1974, while on an oil drilling ship in the Gulf of Mexico about 30 miles southwest of Panama City, Florida, Barkuloo saw as many as nine cobia ranging from 30 to 50 pounds each. The cobia separated into groups of two or more and released eggs ("bubble-like") and sperm ("white cloud") while undergoing changes in body color from uniform brown to a light horizontal-striped pattern on their lateral surfaces.

Caribbean Sea Erdman (1968) indicated that August was the peak month of spawning for cobia in Puerto Rican waters.

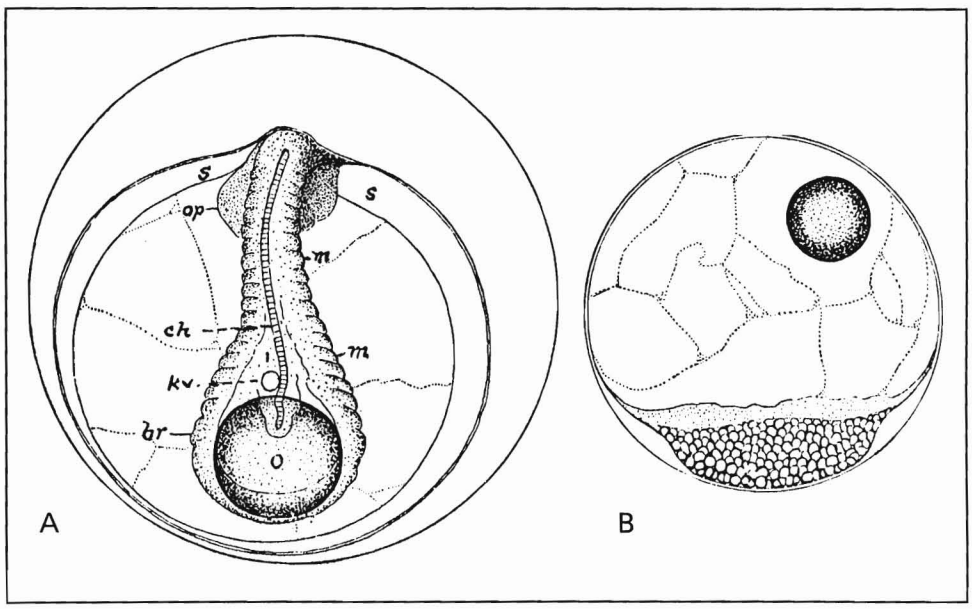

Figure 3

Development of cobia eggs (from Ryder 1887, plate 3): A) Developing egg of *Rachycentron canadum*, showing the spacious cleavage cavity (s), Kupffer's vesicle (kv), the chorda (ch), segments (m) of the embryo, the limbs (br) of the concrescing blastophore, the oil drop (o), and the optic vesicles (op); and B) an earlier phase of the developing egg.

Indian Ocean Little is known regarding cobia spawning in waters other than the western Atlantic. Darracott (1977) indicated that cobia eggs have not yet been recorded from the Indian Ocean, although ripe fish are found year-round. She also indicated that cobia may migrate from the southern Indian Ocean to spawn off coastal areas of the Arabian Sea. Rajan et al. (1968) collected two small juveniles (7 mm TL) in a lagoon of the Bay of Bengal, India, on 25 March 1960. Day (1967) took a ripe female from Indian waters in March. In Pakistan waters, ripe cobia are found in March and April along the Baluchistan coast (Bianchi 1985). A female with maturing eggs was collected from Madagascar waters in October 1964 (Richards 1967).

3.17 Spawn

Unfertilized eggs from female cobia were described by Richards (1967) as having three stages:

Immature Clear, nucleated cells, 0.10–0.30 mm in diameter

Maturing Eggs with a clouded appearance and the oil globule vaguely discernible, 0.36–0.66 mm in diameter

Mature Eggs clear or transparent, 1.09–1.31 mm in diameter (average 1.20 mm), with an oil globule 0.29–0.44 mm in diameter (average 0.37)

Fertilized cobia eggs are pelagic, and can be identified by the distinctively large oil globule. The yolk is segmented. Both the oil globule and the embryo are yellow and mottled with melanin pigment (Hassler and Rainville 1975). Joseph et al. (1964) collected fertilized cobia eggs and described them as ranging from 1.16 to 1.42 mm in diameter (mean 1.27 mm), with a single oil globule ranging from 0.34 to 0.44 mm in diameter (mean 0.38).

3.2 Preadult phase

The preadult phase has been summarized by Hardy (1978).

3.21 Embryonic phase

The development of cobia eggs in the laboratory has been described by Ryder (1887) (Fig. 3). He reported a rapid growth of the blastoderm; within 8 hours from fertilization, the entire vitellus was included and covered by the blastoderm's epibolic growth. Eggs hatched within approximately 36 hours from fertilization (temperature unspecified).

Hassler and Rainville (1975) collected naturally spawned cobia eggs, and found the highest hatching rates to occur in tank water salinities of 33–35 ppt, with a water temperature of approximately 26.5°C.

3.22 Larval and early juvenile phase

The following descriptions were taken from Hassler and Rainville (1975):

Day 1 The 1-day-old larvae are approximately 3 mm long and colorless. Only a light-green tint is to be noted in the area of the developing eye. The larvae have not yet begun to feed actively and the yolksac is large and conspicuous. A single fin extends dorsally from the head and ventrally from the yolksac to the posterior, where it extends around the caudal tip of the body.

Table 4

Measurements (mm) of selected characters of prejuvenile and juvenile *Rachycentron canadum* from the Gulf of Mexico (Dawson 1971).*

Cat. No.	4355	4354	4356	4356	4355	4353	4353	2359	4352	373	373
Standard length	12.6	12.9	13.6	13.7	15.3	16.6	18.2	23.5	27.0	44.3	55.0
Caudal fin length	3.1	2.6	3.0	3.3	3.7	4.3	5.1	7.1	9.3	15.0	16.8
Least caudal peduncle depth	0.7	0.8	0.8	0.8	0.9	0.9	1.0	1.2	1.4	2.4	2.8
Depth at anal fin origin	1.1	1.4	1.4	1.3	1.5	1.6	1.6	2.1	2.7	4.6	5.4
Pectoral fin length	1.6	1.3	1.4	1.6	1.8	2.1	2.4	2.8	4.0	6.1	9.4
Pelvic fin length	0.7	0.7	0.9	1.0	0.7	1.4	1.8	3.1	4.5	8.7	10.1
Pelvic fin insertion to anal fin origin	3.5	3.9	4.1	4.1	4.7	4.5	4.9	6.2	7.3	12.3	15.3
Head length	3.6	3.5	3.8	3.8	—	4.7	—	—	—	—	13.7
Snout length	1.0	0.9	1.1	1.0	—	1.5	—	—	—	—	4.4
Eye diameter	1.1	1.0	1.1	1.1	1.2	1.3	1.5	1.6	1.8	3.1	3.5
Postorbital length	1.5	1.6	1.6	1.7	1.8	1.9	2.1	2.5	2.8	4.8	5.8
Interorbital width	—	0.6	—	0.9	—	1.0	1.1	1.5	1.5	3.2	4.5
Maxillary length	1.3	1.5	1.5	1.4	—	1.6	—	—	—	—	5.2

*All specimens are from the Museum of the Gulf Coast Laboratory, Ocean Springs, MS, except for Cat. no. 2359 collected by the Florida Department of Natural Resources, St. Petersburg, FL.

Day 5 After 5 days, the larvae are 4–5 mm long. Eyes are dark-brown and prominent. The yolksac is absorbed, and development of the eye and mouth permits active feeding. A faint yellow streak extends the length of the body, and scattered blotches of melanin are evident. The fin structure is the same as the day-1 larvae; however, limited swimming is now possible.

Day 10 By the tenth day, definite changes can be noted in the larvae. The mouth, head, and eye are fully developed. Musculature is now apparent throughout the body, permitting prolonged, active swimming. The single finfold persists, and fin rays begin to appear in some areas. Pectoral fins are now present. The larvae are light-brown and 5–10 mm in length.

Day 30 The day-30 juvenile has begun to take on the appearance of the adult fish. Distinct dorsal, anal, caudal, pectoral, and pelvic fins develop. The dorsal fin extends from midbody to a point just anterior to the caudal fin. The [anal] fin also ends just before the caudal fin and begins just behind the anus. The caudal fin is large and fan-shaped. Eight short spines develop just anterior to the dorsal fin. Two color bands run from the head to the posterior tip of the 30-day-old juvenile. The white-to-yellow dorsal band and the black ventral band meet along the lateral line of the juvenile.

Day 59 After 59 days, the juveniles have grown considerably, but their general appearance is similar to the 30-day cobia. The most striking change has occurred in the banding of the fish, which now appears to be black with dorsolateral and ventrolateral gold or white bands. The dorsolateral bands extend anteriorly over the head, just above the eye, and posteriorly to the caudal fin. The ventrolateral band is not as distinct, and extends from under the mouth to the caudal fin. The dorsal, anal, and caudal fins are black with light-yellow tips.

Dawson (1971) gave detailed descriptions of prejuvenile and juvenile cobia, 12.6–55.0 mm SL. His measurements of selected characters are given in Table 4. Illustrations of larval and juvenile cobia are given in Figures 4 and 5.

3.23 Juvenile phase

Joseph et al. (1964) described two juvenile cobia, 108 and 120 mm TL, collected from the mouth of the York River, Virginia. These juveniles differed from adults most notably in color pattern. They displayed a prominent black longitudinal band, extending the full length of the body, bordered above and below by white stripes. The paired fins were black, except for an inconspicuous margin on the pectorals. Dorsal and anal fins were marked with white margins on the anterior portions. The caudal fin was broadly rounded, with white margins on the dorsal and ventral edges (Fig. 6). Hildebrand and Schroeder (1928) indicated that juveniles differ markedly from adults in having a "more elongate body, less strongly depressed head, in having the caudal fin truncate instead of forked, and in being somewhat lighter in color and having a black lateral band, which extends from the snout, through the eye, to the base of the caudal."

Wang and Kernehan (1979) described juvenile cobia 50 mm and larger as resembling the adult, but having a truncate-to-broadly-rounded caudal fin rather than the lunate caudal of the adult. They gave the following characteristics: Head, long and depressed; lower jaw projecting out farther than the upper jaw; all fin rays and spines developed (dorsal fin with 8–9 spines, 30 rays; anal fin with 1 spine, 23 rays); dorsal, pectoral, and anal fins elongate; dark horizontal band extending from tip of snout to base of caudal fin; dorsum, ventrum, and fins darkly pigmented (Fig. 7).

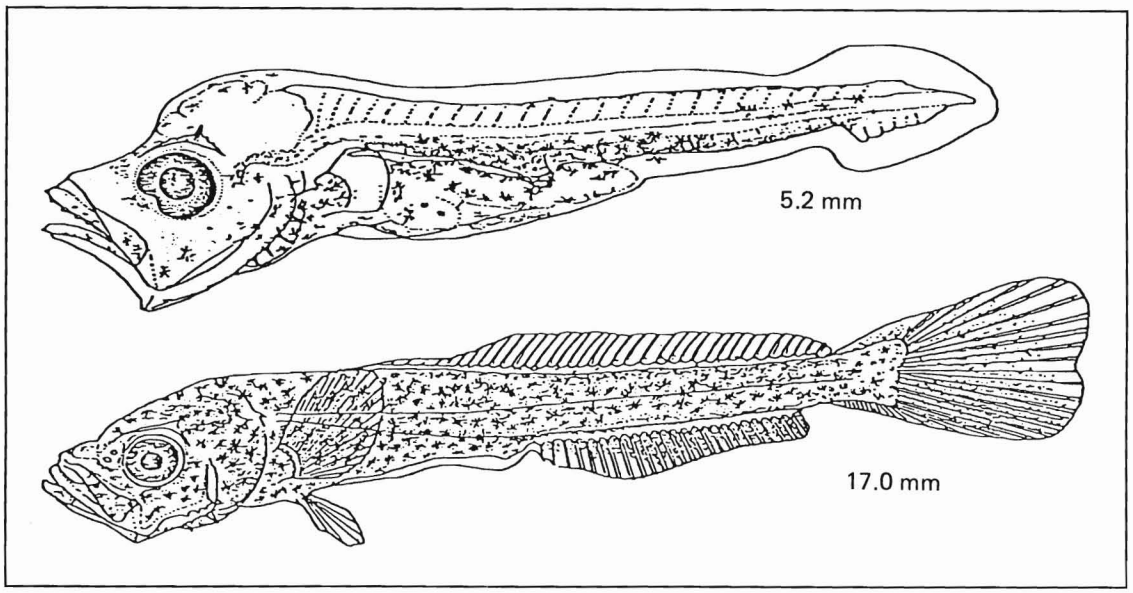

Figure 4

Larval development stages of cobia collected off the Texas outer continental shelf (Finucane et al. 1978a, fig. 146).

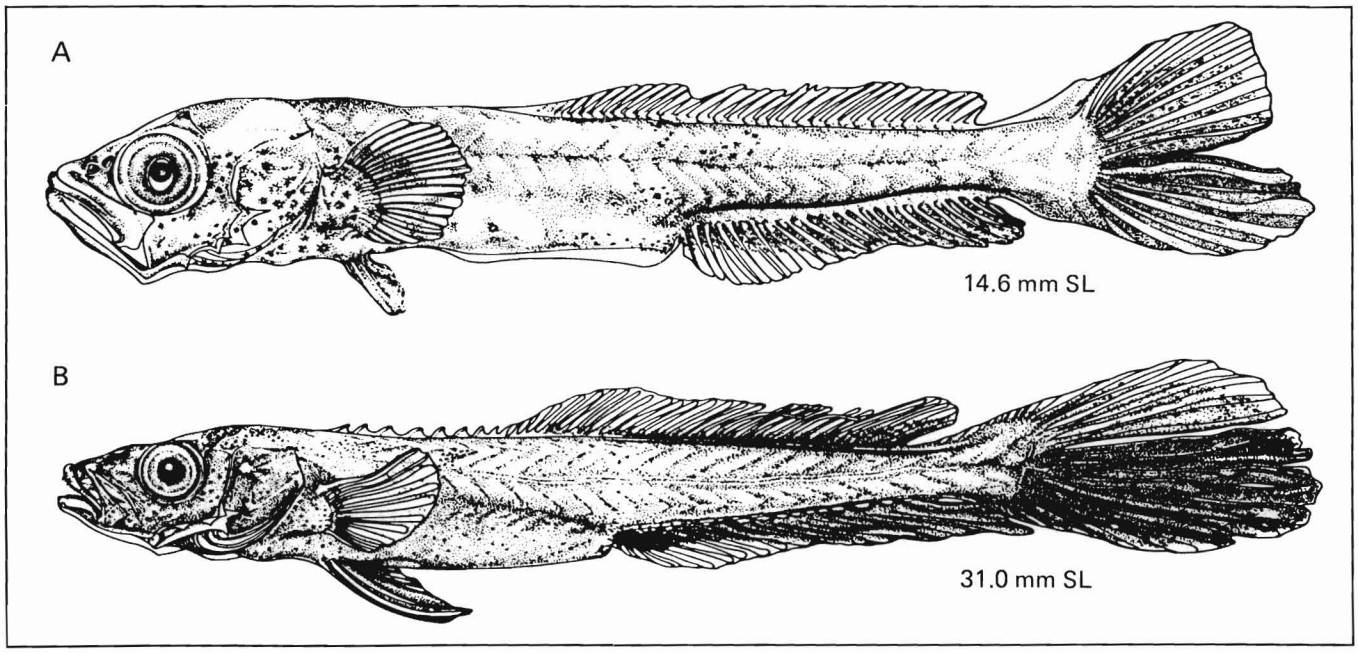

Figure 5

Late larva and juvenile cobia (Hardy 1978, fig. 226): A) Late larva, preopercular spines prominent, preanal finfold still evident; and B) juvenile.

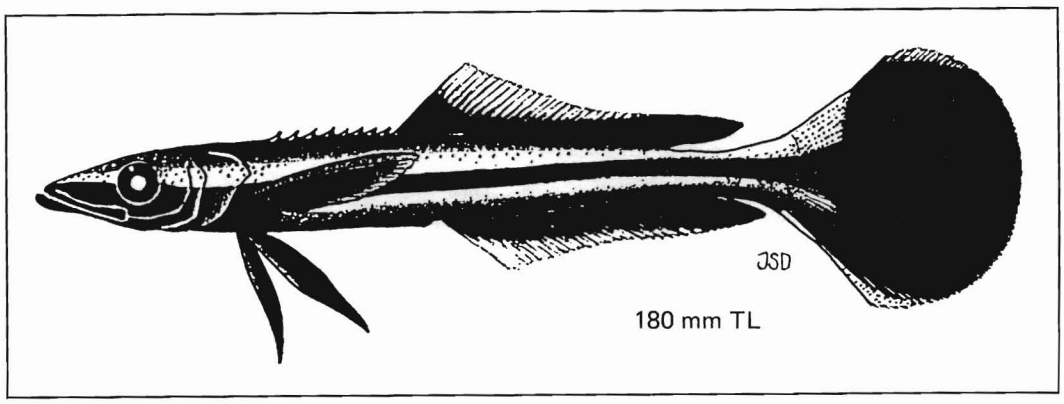

Figure 6
Composite drawing of a juvenile cobia (Joseph et al. 1964, fig. 3).

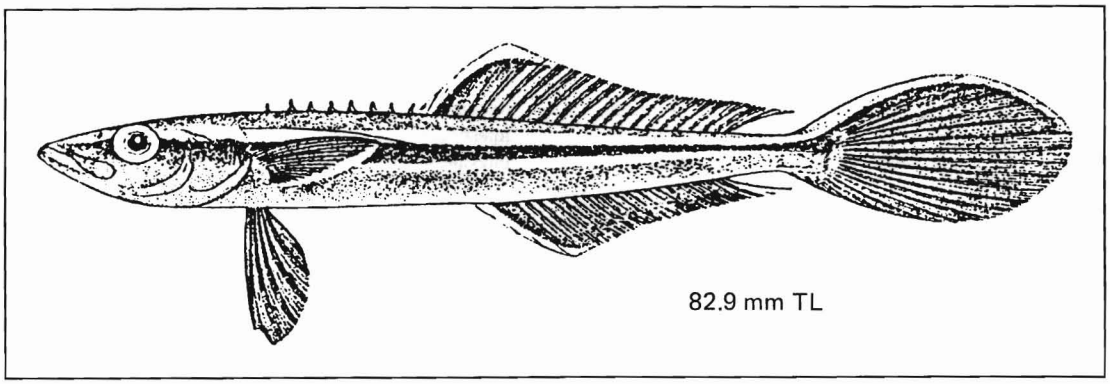

Figure 7
A juvenile cobia (Wang and Kernehan 1979, fig. 75).

3.3 Adult phase

3.31 Longevity

Cobia may reach a length of 2 m (Cadenat 1950). The world hook-and-line weight record for cobia is a 61.5-kg fish from Australian waters in 1985 (Int. Game Fish Assoc. 1988). According to Wheeler (1975), cobia weighing 68 kg have been reported.

Cobia are known to live at least 10 yrs (Richards 1967), and may reach an age of 15 yrs or more (Gulf Mex. S. Atl. Fish. Manage. Counc. 1985).

3.32 Hardiness

Cobia are relatively adaptable to their environment and are able to utilize a variety of habitats and food sources (see 2.2, 2.3, 3.35, 3.42).

3.33 Competitors

No studies have been done regarding the competitors of cobia, but given the wide range of the cobia's habitats and prey species, competition is probably not an important factor in their survival.

3.34 Predators

No studies have been done regarding the predators of cobia, but they are presumably eaten by larger pelagic fishes. Dolphin (*Coryphaena hippurus*) have been reported to prey upon small cobia (Rose 1965).

3.35 Parasites, diseases, and abnormalities

Parasites of cobia include trematodes, monogeneans, cestodes, nematodes, acanthocephalans, and copepods (Table 5). Infections by some parasites appear to be heavy on occasion. Madhavi (1976) reported 30 specimens of the trematode *Stephanostomum pseudoditrematis* from a cobia intestine. Intestinal damage from acanthocephalid worms was severe in cobia examined by George and Nadakal (1981). Rasheed (1965) and Overstreet (Robin Overstreet, Gulf Coast Res. Lab., P.O. Box 7000, Ocean Springs, MS 39564-7000, pers. commun., 12 Aug. 1987) noted that whenever a cobia was dissected for study, the stomach was found to be heavily infected with the nematode *Iheringascaris inquies*.

Some parasites of cobia demonstrate a high degree of host-specificity. The monogenean *Dionchus rachycentris* is reported only from the cobia (Hargis 1957). The closely

Table 5
A partial list of parasites of cobia.

Parasite	Geographic region	Site on host	Reference
Monogeneans			
Dionchus rachycentris	Gulf of Mexico–Texas	Gills	Koratha 1955
(syn. *D. hopkinsi*)	Gulf of Mexico–Florida	—	Hargis 1957
	SW Pacific–Australia	—	Young 1970
Dionchus sp.	SW Pacific–Australia	Gills	Rohde 1978
Digenetic trematodes			
Laruea straightum	Arabian Sea–Pakistan	Intestine	Jahan 1973
Lecithocladium jagannathi	Bay of Bengal–India	Stomach	Ahmad 1981
Sclerodistomum rachycentri	Indian Ocean	—	Parukhin 1978
Stephanostomum cloacum	Bay of Bengal–India	Intestine	Hafeezullah 1978
S. dentatum	NW Atlantic–North Carolina	—	Linton 1905
(syn. *Distomum dentatum*)			
S. imparaspine	Gulf of Mexico–Florida	Rectum	Sogandares-Bernal and Hutton 1959
(syn. *Distomum imparispine*)			
S. microsomum	Bay of Bengal–India	Intestine	Madhavi 1976
S. pseudoditrematis	Bay of Bengal–India	Intestine	Madhavi 1976
Sterrhurus monticelli	NW Atlantic–North Carolina	—	Linton 1905
(syn. *Distomum monticellii*)			
Tormopsolus filiformis	Gulf of Mexico–Florida	Rectum	Sogandares-Bernal and Hutton 1959
	Bay of Bengal–India	Intestine	Madhavi 1976
T. spatulum	Bay of Bengal–India	Intestine	Hafeezullah 1978
Cestodes (metacestode stage)			
Rhinebothrium sp.	NW Atlantic–North Carolina	Alimentary canal	Linton 1905
Rhynchobothrium sp.	NW Atlantic–North Carolina	—	Linton 1905
Scolex polymorphus	NW Atlantic–North Carolina	—	Linton 1905
Tetrarhynchus bisulcatus	NW Atlantic–North Carolina	Stomach wall	Linton 1905
Nematodes			
Goezia pelagia	Gulf of Mexico	Stomach	Deardorff and Overstreet 1980
Iheringascaris inguies	NW Atlantic–North Carolina	—	Linton 1905
(syn. *Ascaris inguies*,	Arabian Sea–Pakistan	Stomach	Rasheed 1965
Thynnascaris inguies,	Arabian Sea–Pakiston	Alimentary canal	Khan and Begum 1971
Neogeozia elacateidae,	Gulf of Mexico	Stomach and pyloric caeca	Overstreet 1978
Contracaecum inguies,	Various	Stomach and pyloric caeca	Deardorff and Overstreet 1981
I. iheringascaris)			
Acanthocephalans			
Serrasentis nadakali	Arabian Sea–India	Intestine and pyloric caeca	George and Nadakal 1981
S. sagittifer	NW Atlantic–North Carolina	Intestine	Linton 1905
(syn. *Echinorhynchus sagittifer*,	E. Atlantic–Senegal	Intestine	Golvan 1956
S. socialis)	Gulf of Mexico	Intestine and pyloric caeca	Overstreet 1978
	Arabian Sea–India	Intestine	Soota and Bhattacharya 1981
Copepods			
Euryphorus nympha	Gulf of Mexico–Texas	—	Causey 1953
(syn. *E. coryphaenae*)			
Lernaeenicus longiventris	Gulf of Mexico–Texas	Fin surface	Causey 1953
Lernaeolophus hemiramphi	Gulf of Mexico–Texas	—	Causey 1953
L. sultanus	Gulf of Mexico–Mississippi	Body surface	Dawson 1969
Parapetalus gunteri	Gulf of Mexico–Texas	Gills	Pearse 1952
	SW Pacific–Australia	Gills	Kabata 1967
	Indian Ocean–India (Trivandrum)	Gills	Pillai 1962
P. occidentalis	NW Atlantic–North Carolina	Inside surface of operculum	Wilson 1908
	Gulf of Mexico	Body surface	Causey 1955
	Indian Ocean–India (Trivandrum)	Gills and inner surface of operculum	Pillai 1962
Tuxophorus caligodes	NW Atlantic–North Carolina	Body surface	Wilson 1908
	Gulf of Mexico–Texas	Body surface	Causey 1953

related *D. remorae* is specific to some remoras. This similarity has been suggested as an indicator of a close phylogenetic relationship between the two fishes (Hargis 1957, Koratha 1955). The adult nematode *Iheringascaris inquies* appears to be restricted to cobia (Deardorff and Overstreet 1981).

A barnacle (*Conchoderma virgatum*) has been found on a cobia from Mississippi waters. It was not attached directly to the fish, but to the parasitic copepod *Lernaeolophus sultanus*, embedded just posterior to the last dorsal fin ray (Dawson 1969).

There is little information in the literature regarding diseases of cobia. Heart abnormalities have been reported. Several cobia hearts examined by Howse et al. (1975) revealed pericardial adhesions, probably resulting from pericarditis. Also, the cobia is reported to be one of the fishes affected by red tide organisms (Galtsoff 1954).

3.36 Chemical composition

The composition of cobia (raw muscle tissue) was reported by Sidwell (1981): Moisture 74.9%, protein 18.9%, fat 5.4%, ash 1.3%, carbohydrates 0%. The caloric content was 124 calories per 100 g.

Moderately high levels of mercury have been found in cobia from Texas offshore waters. Bright and Pequegnat (1974) reported a concentration of 0.71 parts per million of mercury in cobia muscle tissue.

3.4 Nutrition and growth

3.41 Feeding

Cobia are known to be voracious feeders, often engulfing whole prey. Darracott (1977) reported undamaged crustaceans in cobia stomachs. Fisher (1891) compared cobia's feeding with that of the pike. To a large extent, cobia feed near the bottom; however, the presence of pelagic fish in some samples indicates that they also take prey near the surface (Knapp 1951).

Cobia exhibit some degree of commensalism. They are known to associate with rays, sharks, and other large fish, and have been observed in captivity to take in a larger fish's rejected food scraps (Takamatsu 1967, Smith and Merriner 1982). The rays may also stir up benthos upon which the cobia feed (Smith and Merriner 1982).

Feeding appears to decrease with lowered temperatures. Hassler and Rainville (1975) observed that 90-day-old laboratory-reared juvenile cobia ceased feeding when water temperatures were lowered to 18.3°C. Also, cobia may cease feeding during spawning (Richards 1967). No studies have been done regarding the cobia's diurnal feeding habits. Cobia may time their migrations with the availability of important prey species, such as crustaceans (Darracott 1977).

3.42 Food

Cobia are carnivorous, feeding extensively on crabs, other benthic invertebrates, and fish. They have been called the "crabeater" due to the prevalence of this food item in their diet (Randall 1983). Knapp (1951) found a 42% frequency of occurrence of *Callinectes*, and a 46% frequency of occurrence of penaeid shrimp in cobia stomachs. Crustaceans occurred in 100% of the cobia stomachs examined by Darracott (1977). Out of a total of 40 organisms found in cobia stomachs by Miles (1949), 29 were crabs.

Donald Hammond raised cobia from 30 days to 1 yr of age, and found that they did not thrive unless they received crustaceans in their diet (S.C. Dep. Wildl. Mar. Resour., P.O. Box 12559, Charleston, SC 29412, pers. commun., 8 Apr. 1987). Cobia also feed upon squid and a variety of small, particularly demersal fish, such as eels, sea catfish, and sciaenids. Cobia food habit studies are summarized in Table 6.

Little is known regarding the food habits of larval and young juvenile cobia. Hassler and Rainville (1975) successfully fed laboratory-raised cobia a diet of wild zooplankton, dominated by copepods.

3.43 Growth rate

Cobia appear to grow rapidly and have a moderately long life span. Richards (1967, 1977) studied the growth of cobia from the Chesapeake Bay and found that scale annuli were formed in midsummer. His age, length, and weight data are given in Table 7. His growth equations for male and female cobia were:

Males	Females
$FL = 121\ (1-e^{-028(t+0.06)})$	$FL = 164(1-e^{-0.226(t+0.08)})$
$W = 21.3(1-e^{-0.28t})^{3.088}$	$W = 54.5(1-e^{-0.225t})^{3.088}$

where FL = fork length in centimeters, W = weight in kilograms, and t = time in years. Solutions for these equations for 1–8 years are given in Table 8 (Richards 1977). Female cobia appear to grow more rapidly and attain greater size than males (Richards 1967, 1977).

The length-weight relationship for cobia was calculated by Richards (1967) to be: Log W = (3.088 log L) − 3.506, where W = weight in pounds, and L = fork length in inches. The curvilinear relationship was the same for males and females (Fig. 8). Darracott (1977) reported the length-weight relationship of cobia from the Tanzanian area of the Indian Ocean as:

Female $W = -4.57\ L^{2.79}$ (n=9, r=0.97)

Male $W = -5.19\ L^{3.15}$ (n=9, r=0.99)

Total $W = -4.58\ L^{2.83}$ (n=48, r=0.96) (18 could be sexed)

where W = weight in kilograms, and L = length in centimeters.

As scaling parameters in the negative range are unreasonable, it is likely that Darracott (1977) substituted the log parameter values into the non-log form of the equation. Therefore, the correct equations should read:

Table 6
Organisms found in cobia stomachs by various authors.

	Gulf of Mexico					Atlantic Ocean			Indian Ocean	
	Boschung (1957)	Christmas et al. (1974)	Knapp (1951)	Miles (1949)	Reid (1954)	Briggs et al. (1979)	Linton (1905)	Randall (1967)	Chacko (1949)	Darracott (1977)
	Waters of									
	Alabama	Mississippi	Texas	Texas	Florida	New York	North Carolina	West Indies	India	Tanzania
	No. of samples									
Taxonomic group	4	11	24	13	2	1	8	1	1	22
Annelida							x			
Arthropoda	x	x	x	x			x		x	x
Crustacea	x	x	x	x			x		x	x
Penaeidae		x	x	x						
Palinuridae										x
Portunidae	x	x	x	x					x	x
Stomatopoda			x							x
Mollusca			x	x						x
Gastropoda				x						
Cephalopoda			x							x
Chordata	x	x	x	x	x	x	x	x		x
Tunicata			x							
Vertebrata	x	x	x	x	x	x	x	x		x
Pisces	x	x	x	x	x	x	x	x		x
Squaliformes			x							
Anguillidae	x	x	x							x
Synodontidae				x						
Arridae			x	x	x					
Atherinidae						x				
Serranidae			x							
Sciaenidae	x	x	x							
Scombridae			x							
Stromateidae				x						
Triglidae		x								
Bothidae		x								
Cynoglossidae	x									
Ostraciidae					x			x		

$$\text{Female} \quad \text{Log } W = 2.79 \text{ Log } L - 4.57$$

$$\text{Male} \quad \text{Log } W = 3.15 \text{ Log } L - 5.19$$

$$\text{Total} \quad \text{Log } W = 2.83 \text{ Log } L - 4.58$$

(J. Jeffery Isely, Panama City Lab., Southeast Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Panama City, FL 32408, pers. commun., 28 Sept. 1989).

Hassler and Rainville (1975) described exponential weight and length increases in cobia larvae and juveniles older than 10 days with the equations:

$$\text{Log } W = 4.360 \text{ Log } X - 4.318,$$

where W = weight in mg, and X = age in days.

$$\text{Log } L = 1.425 \text{ Log } X - 0.587,$$

where L = length in mm, and X = age in days.

Hassler and Rainville (1975) also described the length-weight relationship of larval and juvenile cobia with the exponential equation: Log W = 2.4035 Log L − 1.3007. Table 9 provides the average weight and length-at-age of cobia to 131 days of age.

Table 7

Calculated fork lengths and average length-weight data for cobia samples from catches within Chesapeake Bay, 1960–64 (Richards 1967).

Age	Sample size	Mean capture weight (lbs)	No. of fish	Mean capture length (in.)	Calculated lengths (inches) at successive annuli									
					1	2	3	4	5	6	7	8	9	10
Males														
I	3	3.3	4	21.4	15.1									
II	32	8.3	37	28.1	14.1	24.6								
III	16	16.7	18	33.2	13.9	22.9	30.1							
IV	9	21.2	10	37.1	13.9	23.6	30.2	34.8						
V	12	26.3	13	39.7	13.9	23.7	30.1	34.7	38.0					
VI	9	30.3	12	40.9	13.4	20.2	27.0	32.3	36.3	39.3				
VII	4	32.0	4	41.4	12.8	19.1	25.4	29.8	33.4	36.8	39.7			
VIII	0	—	0	—										
IX	2	39.1	2	43.0	10.6	16.2	20.5	24.0	29.6	34.0	36.4	39.2	41.6	
X	1	41.8	1	47.0	11.8	20.2	23.7	27.1	32.5	38.2	40.5	42.4	44.3	45.9
Total	88		101	Grand average	13.8	23.1	28.8	32.9	36.2	38.3	39.1	40.3	42.5	45.9
Females														
I	6	4.0	6	22.9	15.3									
II	11	10.2	15	30.7	14.3	25.0								
III	25	24.5	30	37.5	14.0	24.5	34.4							
IV	17	29.2	20	41.0	13.9	23.3	31.6	38.1						
V	34	43.5	39	45.6	14.3	24.2	32.7	38.5	42.8					
VI	19	48.1	22	47.1	14.0	23.0	30.3	35.7	40.8	44.7				
VII	13	55.4	14	49.5	14.7	23.5	30.7	36.2	40.6	44.2	47.4			
VIII	7	62.7	7	51.3	14.2	22.3	28.6	33.5	38.4	42.8	45.8	49.2		
IX	3	67.3	3	52.5	13.3	22.8	31.0	34.5	39.2	42.2	44.6	47.7	50.3	
Total	135		156	Grand average	14.2	23.8	32.0	37.0	41.4	44.1	46.6	48.7	50.3	

Table 8

Length and weight solutions for cobia growth equations (Richards 1977).

t (years)	Females: Fork length in.	Females: Fork length cm	Females: Weight lbs	Females: Weight kg	Males: Fork length in.	Males: Fork length cm	Males: Weight lbs	Males: Weight kg
1	14.0	36	0.85	0.4	12.2	31	0.6	0.3
2	24.2	61	5.2	2.4	20.8	53	3.4	1.5
3	32.3	82	13.3	6.0	27.3	69	8.2	3.7
4	38.8	99	24.0	10.9	32.3	82	13.9	6.3
5	44.0	112	35.7	16.2	36.0	91	19.6	8.9
6	48.1	122	47.5	21.5	38.8	99	24.8	11.2
7	51.4	131	58.6	26.6	40.9	104	29.3	13.3
8	54.0	137	68.7	31.2	42.5	108	33.1	15.0

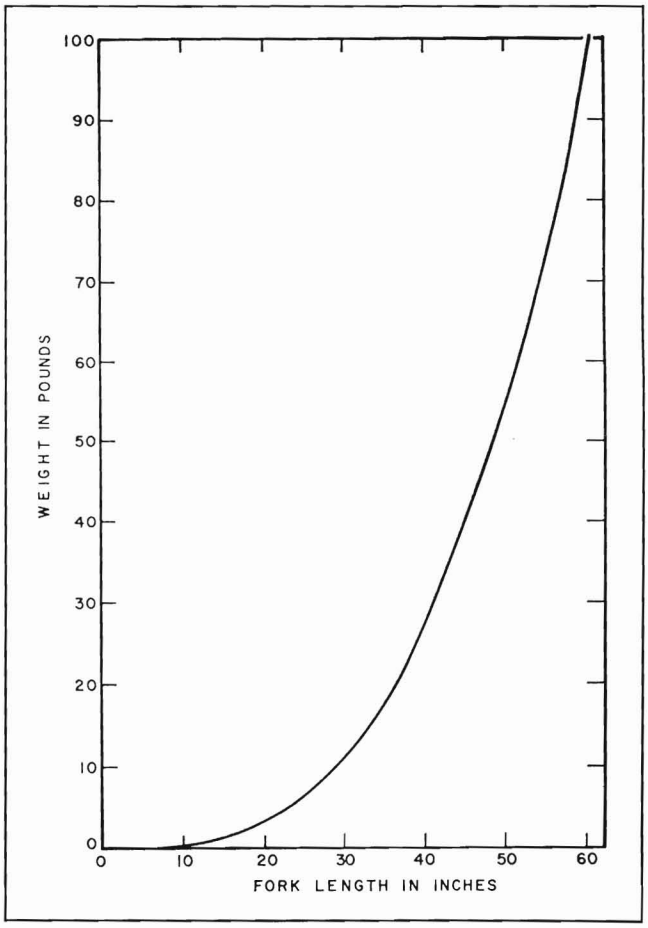

Figure 8
Length-weight relationship for cobia collected from Virginia waters (Richards 1967, fig. 2).

Table 9
Age and average weight and length data of larval and juvenile cobia (modified from Hassler and Rainville 1975).

Age (days)	No. of specimens	Weight (mg) Avg.	Weight (mg) Range	Length (mm) Avg.	Length (mm) Range
1	5	1.0	-	3.0	-
2	5	2.2	2-3	3.6	3.0-4.0
3*	3	1.0	-	3.7	-
4*	3	2.7	2-3	3.7	3.5-4.0
5	3	8.7	8-9	4.7	4.5-5.0
6*	4	9.2	9-10	4.9	4.5-5.0
7*	3	8.0	7-10	4.8	4.5-5.0
8*	3	1.0	-	5.3	5.0-5.5
9	2	7.0	6-8	6.5	6.0-7.0
10	1	10.0	-	9.0	-
10*	1	4.0	-	6.0	-
12*	3	4.0	-	6.7	-
13*	1	9.0	-	9.0	-
14	1	30.0	-	16.0	-
15*	1	8.0	-	9.5	-
18	1	30.0	-	19.0	-
19	7	11.4	20-10	12.1	10.0-15.5
20	1	20.0	-	16.0	-
22	11	42.7	20-90	24.2	16.0-30.0
23	3	41.7	35-50	23.1	22.5-24.0
24	13	46.9	20-120	24.2	19.0-33.0
25	1	90	-	24.5	-
28	1	60	-	29.0	-
30	1	90	-	29.0	-
36	1	920	-	65.0	-
43	1	130	-	34.0	-
51	1	3,750	-	93.0	-
59	8	4,140	1,350- 7,500	98.2	69-120
71	2	19.745	6,900-12,590	138	128-149
73	1	12,480	-	141	-
83	4	10,425	8,900-12,520	142	134-148
88	2	22,865	22,390-23,340	166	165-166
99	1	25,350	-	183	-
102	1	33,610	-	196	-
107	1	43,200	-	201	-
109	1	34,300	-	187	-
110	1	12,000	-	127	-
111	1	25,000	-	178	-
112	1	71,000	-	205	-
120	1	64,000	-	210	-
124	1	74,000	-	225	-
131	1	80,000	-	231	-

*Larvae were reared on *Brachionus plicatilis* and *Artemia salina*.

3.5 Behavior

3.51 Migrations

Western North Atlantic Cobia make seasonal migrations in connection with changes in water temperature and with spawning. In the Chesapeake Bay, cobia were found to enter the bay in late May or early June, and leave by mid-October (Richards 1977). Tagging studies indicated that there was a distinct group that returned to the bay every summer (Richards 1977).

Cobia have long been reported to have a north-south/spring-fall movement pattern along the southeastern United States (Smith 1907, Hardy 1978), and fishermen have been known to track their spring run from Florida to South Carolina (McNally 1985). Recent tagging studies, however, show an inshore-offshore/spring-fall movement by the cobia population off the coast of South Carolina (Donald Hammond, S.C. Dep. Wildl. Mar. Resour., P.O. Box 12559, Charleston, SC 29412, pers. commun., 8 Apr. 1987). A record of extensive migration resulted from that study: A cobia tagged off Charleston in June 1984 was recovered in April 1986 off Biloxi, Mississippi.

Gulf of Mexico In Gulf of Mexico waters, cobia winter in the Florida Keys, and move north and west along the gulf coast in the spring. Fish tagged in the Florida Keys during the winter of 1974 were recovered during the spring and summer of subsequent years from locations ranging from St. Petersburg, Florida, to the Texas-Louisiana border. The following winter, four were recaptured from the original tagging locations (Donald Hammond, pers. commun., see above). More recently, a cobia tagged off Galveston, Texas, in July 1987 was recovered off Sisal, Yucatan, Mexico, in January 1988 (Steve Qualia, P.O. Box 4746, Corpus Christi, TX 78469, pers. commun., 9 Feb. 1988).

Indian Ocean Little information is available on movements of cobia in other parts of the world. Darracott (1977) indicated that cobia from southern Indian Ocean waters may move north to spawn off the coast of Arabia. Smith and Heemstra (1986) reported that cobia migrate to South African waters during the austral summer, occasionally reaching False Bay.

Eastern Atlantic In June, cobia move north along the African coast from the Senegal-Guinea area, returning there in December (Champagnat and Domain 1978).

3.52 Schooling

Cobia may be solitary or travel in small groups or "pods" of 2–8 or more fish (Benson 1982, Burgess 1983, Moe 1970). They form aggregations during the spawning season (Richards 1967).

Associations Cobia associate with larger fish, such as rays and sharks, and sea turtles (Baughman 1950). This behavior has been observed in captivity (Smith and Merriner 1982, Takamatsu 1967) as well as at sea. It is so well known that fishermen often consider schools of large rays to be indicators of cobia (McNally 1985, Moe 1970). In South Africa, cobia are often observed with groups of remoras (Smith and Heemstra 1986). Explanations for the cobia's associations have been proposed, e.g., the increased availability of food (Smith and Merriner 1982, Takamatsu 1967), and as part of the cobia's generalized sheltering behavior (Carr 1987) (see also 3.53).

3.53 Responses to stimuli

Cobia are known to be attracted to inanimate objects in the sea. According to Baughman (1950), "They are found around buoys, under floating debris, around large fish and under sea turtles, to name only a few of the many items with which they have been observed associating." They are also found around pilings, wrecks, and other artificial structures (Hardy 1978, Wickham et al. 1973). Cobia show a strong tendency to lie in the shadow of a boat (Joseph et al. 1964). They appear to be attracted to noise (Goodson 1985, Sasser 1984).

Cobia are a favorite with sport fishermen due to their fighting ability, strength and speed (Henshall 1895, McClane 1974). They are known to make determined runs and leaps when hooked (Grant 1972, Smith 1965).

4 POPULATION

4.1 Structure

4.11 Sex ratio

Richards (1967) found a female-to-male ratio of 1.54:1 for 257 cobia from the Chesapeake Bay region. Of 48 cobia from Tanzanian waters, 9 were identified as male and 9 as female (Darracott 1977). Out of 301 cobia from southeastern U.S. and Gulf of Mexico waters, the female-to-male ratio was 1.20:1 (L. Alan Collins, Panama City Lab., Southeast Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Panama City, FL 32408, pers. commun., 10 Nov. 1987).

4.12 Age composition

The only study on age composition of cobia is that of Richards (1967). He examined 257 fish from Chesapeake Bay area landings, 1960–64, and showed that for males, age-II fish were the most abundant, whereas for females, age-V fish predominated, followed closely by age-III fish (Table 7).

4.13 Size composition

Darracott (1977) reported that the modal length of 48 cobia caught off Tanzania was 75–85 cm FL, and the modal weight was 5–10 kg. Richards (1967) found that females attain greater size than males; the most abundant size range for females was 95–120 cm FL, and 70–85 cm FL for males (Table 7).

4.14 Subpopulations

From tagging studies, Richards (1977) concluded that "Chesapeake Bay cobia may be a distinct group or subpopulation." A separate stock of cobia in the Gulf of Mexico has also been suggested (Jones et al. 1985, Gulf Mex. S. Atl. Fish. Manage. Counc. 1985).

4.2 Abundance and density

Cobia is considered to have low abundance throughout its range. It has relatively higher abundance in the Arabian Sea and in the Gulf of Mexico. See section 5.43.

4.3 Natality and recruitment

4.31 Reproduction rates

See section 3.15.

4.32 Factors affecting reproduction

No studies have been done regarding factors affecting reproduction.

4.33 Recruitment

The rate of recruitment for cobia is considered to be low (Gulf Mex. S. Atl. Fish. Manage. Counc. 1985).

4.4 Mortality

Richards (1977) noted that the total mortality rate for cobia from the Chesapeake Bay area, including both commercial and sport fishing as well as natural mortality, could be excessive. From tagging studies, he calculated a sport fishing mortality for cobia of 0.30 ± 0.21, with a probability of 95%. From his data, an annual survival rate was calculated with 95% confidence limits: $S = 0.66 \pm 0.04$ (Gulf Mex. S. Atl. Fish. Manage. Counc. 1985).

5 EXPLOITATION

5.1 Fishing equipment

Commercial fishery Throughout most of its range, cobia is an incidental catch in the various fisheries. In Pakistan, the world's largest producer of cobia, fishermen catch them with handlines, bottom trawls, driftnets, and floating gillnets (Bianchi 1985). In India, they are usually taken with drift gill nets, handlines, and troll lines from the inshore coastal waters (Pillai 1982). In the Philippines, cobia are caught incidentally in the purse-seine and trawl fisheries (Aprieto 1985, Aprieto and Villoso 1979). In the Persian Gulf, cobia are a common bycatch of the shrimp fishery (Kuronuma and Abe 1972).

In the United States, cobia are caught commercially in pound nets, gill nets, and seines (Manooch 1984). They are also taken incidentally by shrimp trawlers in the Gulf of Mexico, and as a commercial supplement to the Texas charterboat fishery (Gulf Mex. S. Atl. Fish. Manage. Counc. 1985).

Recreational fishery Cobia are highly prized and sought by recreational fishermen, who angle for them from boats, beaches, piers, and jetties. According to McClane (1974), "The most popular tackle for cobia is heavy spinning gear designed to cast 15–25-pound test monofilament lines. Large plugs, similar to those used for striped bass in blue scale or silver-flash finishes, and 1½–3-ounce jigs with white or

yellow skirts are standard baits. A 3-foot wire leader (No. 7–9) or a 60–80-pound test monofilament shock tippet is necessary.'' Other baits used for cobia include a variety of small, live fish, squid, cut bait, large shrimp, and artificial spoons (Daigle 1984, McClane 1974).

5.2 Fishing areas

Cobia are caught incidentally in commercial fisheries throughout their range, particularly in the Gulf of Mexico and the Arabian Sea. The primary recreational fishery for cobia is located in United States waters. They are also fished recreationally in Australia (Grant 1972), southeastern Africa (Hatchell 1954, Smith 1965), and the Caribbean (La Monte 1952). They are usually caught in shallow coastal waters, but have been taken in trawls from waters as deep as 50 m (Springer and Bullis 1956).

5.3 Fishing seasons

Since water temperature influences the movement of cobia, they are generally fished in the cooler portions of their range in the summer and the warmer portions during the winter. In the Chesapeake Bay region, cobia season extends from May to October, with a peak in July (Richards 1965). Along the east coast of the United States, sport fishermen can follow the northward movement of cobia from south Florida in January to the Carolinas in May (McNally 1987). In south Florida, cobia are fished mostly in the winter (Gulf Mex. S. Atl. Fish. Manage. Counc. 1985). In North Carolina waters, cobia are caught from May to August, with a peak in June (Manooch and Laws 1979). In South Carolina, cobia season extends from May to September (Bearden 1961). In the Gulf of Mexico (U.S. waters), cobia are fished in the spring and summer, with a strong ''spring run'' in the northern Gulf from mid-March to May (Burgess 1983, Gulf Mex. S. Atl. Fish. Manage. Counc. 1985).

In Tanzania, anglers catch cobia during August and September (Hatchell 1954), and in Australia from September to November (La Monte 1952).

5.4 Fishing operations and results

5.42 Selectivity

Cobia is generally an incidental catch of various commercial fisheries. Selectivity in the recreational fishery is probably limited to hook size.

5.43 Catches

Cobia is a highly prized food fish, generally sold fresh. It holds up well as a frozen product, and also makes a fine smoked product (Seafood Leader 1987).

Commercial landings of cobia are the highest in Pakistan, Mexico, and the Philippines (Table 10). India is also a major producer of cobia, reporting widely fluctuating landings; e.g., between 1969 and 1980, annual landings ranged from 200 to 880 metric tons (Pillai 1982). Most cobia landed in the United States are taken from Gulf of Mexico waters (Table 11).

Table 10
Commercial landings (metric tons) of cobia by country, 1980–86 (FAO 1983, 1988). (U.S. landings have been revised by NMFS data; see Table 11.)

Country	1980	1981	1982	1983	1984	1985	1986
Pakistan	606	1405	1971	1384	1134	887	769
Mexico	134	385	334	753	626	497	472
Philippines	395	334	298	412	741	378	629
United States	31	45	55	55	73	74	97
United Arab Emirates	—	70	30	36	36	30	30
Bahrain	19	39	44	42	22	19	16
Qatar	—	—	19	21	49	62	37
Saudi Arabia	—	—	—	—	—	—	74
Total	1185	2278	2751	2703	2681	1947	2124

Recreational landings of cobia are not well documented. An estimated 216,000 cobia (2,029,000 lbs or 920 mt) were landed in U.S. waters in 1965 (Deuel and Clark 1968), while 119,000 (900,000 lbs or 408 mt) were landed in 1970 (Deuel 1973). Recreational landings (Table 12) are substantially greater than commercial landings (Table 11) in the United States.

6 PROTECTION AND MANAGEMENT

6.1 Regulatory measures

In the United States, the cobia fishery is managed by the Gulf of Mexico and South Atlantic Fishery Management Councils, and is included in the fishery management plan for coastal migratory pelagic resources (Gulf Mex. S. Atl. Fish. Manage. Counc. 1985). The current regulation consists of a size limit (33 in. or 83.8 cm FL); no allocations or quotas are applied at this time.

7 CULTURE

Few studies have been done on the culture of cobia. However, Hassler and Rainville (1975), in a small-scale study, raised cobia from fertilized eggs to 131-day-old juveniles. They found them to be good potential aquaculture organisms due to their fast growth, ease of handling, and tolerance of variable environmental conditions.

7.1 Procurement of stocks

In May and June of 1974, Hassler and Rainville (1975) collected 1979 naturally spawned cobia eggs in plankton tows off Hatteras Village, North Carolina. Most of the eggs were hatched and larvae reared in 38-liter tanks, although some 76-liter tanks were also used. The seawater was filtered

Table 11
U.S. commercial cobia landings (pounds), 1978–87. (Data from NMFS Southeast and Northeast Fisheries Centers.)

State	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Atlantic										
Massachusetts	—	—	—	—	—	—	—	100	—	—
Maryland	—	—	—	—	100	—	—	100	—	—
Virginia	600	600	1,400	1,400	2,000	900	1,900	2,400	1,180	536
North Carolina	1,928	3,552	5,128	5,260	10,574	4,279	6,701	6,640	18,303	32,672
South Carolina	219	220	1,363	10,137	16,286	11,367	2,523	1,464	3,690	4,718
Georgia	—	168	497	1,126	2,304	1,497	2,570	611	2,561	2,705
East Florida	9,200	7,100	19,971	22,008	13,604	12,936	16,742	15,069	32,588	55,002
Subtotal	11,947	11,640	28,359	39,931	44,868	30,969	30,436	26,384	58,322	95,633
Gulf										
West Florida	40,200	36,900	29,900	42,400	51,300	69,400	103,300	104,895	89,546	99,336
Alabama	3,304	5,700	2,491	1,799	776	3,291	3,604	2,097	11,454	5,169
Mississippi	—	280	250	—	700	100	7,370	5,513	9,940	11,427
Louisiana	359	332	4,718	2,905	153	1,033	3,247	16,873	33,628	39,092
Texas	13,600	7,674	2,200	13,100	24,200	17,200	12,702	6,442	11,628	8,140
Subtotal	57,463	50,886	39,559	60,204	77,129	91,024	130,223	135,820	156,196	163,164
U.S. total										
(pounds)	69,410	62,526	67,918	100,135	121,997	121,993	160,659	162,204	214,518	258,797
(metric tons)	31.5	28.4	30.8	45.4	55.3	55.3	72.9	73.6	97.3	117.4

Table 12
U.S. recreational cobia landings (10^3 lbs) for the years 1981–87. (Data from Marine Recreational Fishing Statistics Survey, NMFS, Wash., D.C.)

Year	Atlantic	Gulf of Mexico	Total
1981	5	2632	2637
1982	336	1106	1442
1983	175	1637	1812
1984	896	778	1674
1985	655	600	1255
1986	542	1250	1792
1987	608	759	1367

before use. Water quality in the tanks was maintained by the use of algae, subgravel filters, and external filters. The tanks were continuously aerated and illuminated. Water exchanges were made when necessary. Most eggs hatched within 12 to 20 hrs after placement in tanks. The hatching percentage ranged from 24 to 76% per tank. Most mortality occurred in the first 10 days. Temperatures were generally held at 26.5°C, salinity at 35 ppt, pH at 8.3, dissolved oxygen above 5.5 mg/L, and nitrite levels below 1 ppm.

7.3 Spawning

Artificial spawning of cobia in the laboratory has not been recorded; however, R.E. Earll reportedly succeeded in artificially fertilizing cobia eggs in 1880 (Goode 1884).

7.4 Rearing

In the Hassler and Rainville (1975) study, cobia larvae were fed wild zooplankton collected from a saltmarsh creek, at the rate of 1.33 food organisms per cubic centimeter of tank capacity per day. The size of the zooplankters, dominated by copepods, was increased as the larvae grew. In three of the tanks, larvae were fed laboratory-raised rotifers (*Brachionus plicatilis*) and brine shrimp (*Artemia salina*) during day-1 to day-14. After eight days of growth, the larvae fed wild zooplankton showed a much greater growth rate, up to twice the growth of the larvae fed laboratory-raised food. After 40 days, juvenile cobia were fed a diet of small mosquito fish (*Gambusia affinis holbrookii*), supplemented by shrimp, cooked bluefish, and ground trout chow. Growth results were given in section 3.43.

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APPENDIX 27

Title 40: Protection of Environment

PART 230—SECTION 404(b)(1) GUIDELINES FOR SPECIFICATION OF DISPOSAL SITES FOR DREDGED OR FILL MATERIAL

Authority: Secs. 404(b) and 501(a) of the Clean Water Act of 1977 (33 U.S.C. 1344(b) and 1361(a)).

Source: 45 FR 85344, Dec. 24, 1980, unless otherwise noted.

Subpart A—General

§ 230.1 Purpose and policy.

(a) The purpose of these Guidelines is to restore and maintain the chemical, physical, and biological integrity of waters of the United States through the control of discharges of dredged or fill material.

(b) Congress has expressed a number of policies in the Clean Water Act. These Guidelines are intended to be consistent with and to implement those policies.

(c) Fundamental to these Guidelines is the precept that dredged or fill material should not be discharged into the aquatic ecosystem, unless it can be demonstrated that such a discharge will not have an unacceptable adverse impact either individually or in combination with known and/or probable impacts of other activities affecting the ecosystems of concern.

(d) From a national perspective, the degradation or destruction of special aquatic sites, such as filling operations in wetlands, is considered to be among the most severe environmental impacts covered by these Guidelines. The guiding principle should be that degradation or destruction of special sites may represent an irreversible loss of valuable aquatic resources.

§ 230.2 Applicability.

(a) These Guidelines have been developed by the Administrator of the Environmental Protection Agency in conjunction with the Secretary of the Army acting through the Chief of Engineers under section 404(b)(1) of the Clean Water Act (33 U.S.C. 1344). The Guidelines are applicable to the specification of disposal sites for discharges of dredged or fill material into waters of the United States. Sites may be specified through:

(1) The regulatory program of the U.S. Army Corps of Engineers under sections 404(a) and (e) of the Act (see 33 CFR Parts 320, 323 and 325);

(2) The civil works program of the U.S. Army Corps of Engineers (see 33 CFR 209.145 and section 150 of Pub. L. 94–587, Water Resources Development Act of 1976);

(3) Permit programs of States approved by the Administrator of the Environmental Protection Agency in accordance with section 404(g) and (h) of the Act (see 40 CFR parts 122, 123 and 124);

(4) Statewide dredged or fill material regulatory programs with best management practices approved under section 208(b)(4)(B) and (C) of the Act (see 40 CFR 35.1560);

(5) Federal construction projects which meet criteria specified in section 404(r) of the Act.

(b) These Guidelines will be applied in the review of proposed discharges of dredged or fill material into navigable waters which lie inside the baseline from which the territorial sea is measured, and the discharge of fill material into the territorial sea, pursuant to the procedures referred to in paragraphs (a)(1) and (2) of this section. The discharge of dredged material into the territorial sea is governed by the Marine Protection, Research, and Sanctuaries Act of 1972, Pub. L. 92–532, and regulations and criteria issued pursuant thereto (40 CFR parts 220 through 228).

(c) Guidance on interpreting and implementing these Guidelines may be prepared jointly by EPA and the Corps at the national or regional level from time to time. No modifications to the basic application, meaning, or intent of these Guidelines will be made without rulemaking by the Administrator under the Administrative Procedure Act (5 U.S.C. 551 *et seq.).*

§ 230.3 Definitions.

For purposes of this part, the following terms shall have the meanings indicated:

(a) The term *Act* means the Clean Water Act (also known as the Federal Water Pollution Control Act or FWPCA) Pub. L. 92–500, as amended by Pub. L. 95–217, 33 U.S.C. 1251, *et seq.*

(b) The term *adjacent* means bordering, contiguous, or neighboring. Wetlands separated from other waters of the United States by man-made dikes or barriers, natural river berms, beach dunes, and the like are “adjacent wetlands.”

(c) The terms *aquatic environment* and *aquatic ecosystem* mean waters of the United States, including wetlands, that serve as habitat for interrelated and interacting communities and populations of plants and animals.

(d) The term *carrier of contaminant* means dredged or fill material that contains contaminants.

(e) The term *contaminant* means a chemical or biological substance in a form that can be incorporated into, onto or be ingested by and that harms aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment, and includes but is not limited to the substances on the 307(a)(1) list of toxic pollutants promulgated on January 31, 1978 (43 FR 4109).

(f)–(g) [Reserved]

(h) The term *discharge point* means the point within the disposal site at which the dredged or fill material is released.

(i) The term *disposal site* means that portion of the "waters of the United States" where specific disposal activities are permitted and consist of a bottom surface area and any overlying volume of water. In the case of wetlands on which surface water is not present, the disposal site consists of the wetland surface area.

(j) [Reserved]

(k) The term *extraction site* means the place from which the dredged or fill material proposed for discharge is to be removed.

(l) [Reserved]

(m) The term *mixing zone* means a limited volume of water serving as a zone of initial dilution in the immediate vicinity of a discharge point where receiving water quality may not meet quality standards or other requirements otherwise applicable to the receiving water. The mixing zone should be considered as a place where wastes and water mix and not as a place where effluents are treated.

(n) The term *permitting authority* means the District Engineer of the U.S. Army Corps of Engineers or such other individual as may be designated by the Secretary of the Army to issue or deny permits under section 404 of the Act; or the State Director of a permit program approved by EPA under section 404(g) and section 404(h) or his delegated representative.

(o) The term *pollutant* means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials not covered by the Atomic Energy Act, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. The legislative history of the Act reflects that "radioactive materials" as included within the definition of "pollutant" in section 502 of the Act means only radioactive materials which are not encompassed in the definition of source, byproduct, or special nuclear materials as defined by the Atomic Energy Act of 1954, as amended, and regulated under the Atomic Energy Act. Examples of radioactive materials not covered by the Atomic Energy Act and, therefore, included within the term "pollutant", are radium and accelerator produced isotopes. See *Train* v. *Colorado Public Interest Research Group, Inc.*, 426 U.S. 1 (1976).

(p) The term *pollution* means the man-made or man-induced alteration of the chemical, physical, biological or radiological integrity of an aquatic ecosystem.

(q) The term *practicable* means available and capable of being done after taking into consideration cost, existing technology, and logistics in light of overall project purposes.

(q-1) *Special aquatic sites* means those sites identified in subpart E. They are geographic areas, large or small, possessing special ecological characteristics of productivity, habitat, wildlife

protection, or other important and easily disrupted ecological values. These areas are generally recognized as significantly influencing or positively contributing to the general overall environmental health or vitality of the entire ecosystem of a region. (See §230.10(a)(3))

(r) The term *territorial sea* means the belt of the sea measured from the baseline as determined in accordance with the Convention on the Territorial Sea and the Contiguous Zone and extending seaward a distance of three miles.

(s) The term *waters of the United States* means:

(1) All waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;

(2) All interstate waters including interstate wetlands;

(3) All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation or destruction of which could affect interstate or foreign commerce including any such waters:

(i) Which are or could be used by interstate or foreign travelers for recreational or other purposes; or

(ii) From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or

(iii) Which are used or could be used for industrial purposes by industries in interstate commerce;

(4) All impoundments of waters otherwise defined as waters of the United States under this definition;

(5) Tributaries of waters identified in paragraphs (s)(1) through (4) of this section;

(6) The territorial sea;

(7) Wetlands adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs (s)(1) through (6) of this section; waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of CWA (other than cooling ponds as defined in 40 CFR 423.11(m) which also meet the criteria of this definition) are not waters of the United States.

Waters of the United States do not include prior converted cropland. Notwithstanding the determination of an area's status as prior converted cropland by any other federal agency, for the

purposes of the Clean Water Act, the final authority regarding Clean Water Act jurisdiction remains with EPA.

(t) The term *wetlands* means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas.

[45 FR 85344, Dec. 24, 1980, as amended at 58 FR 45037, Aug. 25, 1993]

§ 230.4 Organization.

The Guidelines are divided into eight subparts. Subpart A presents those provisions of general applicability, such as purpose and definitions. Subpart B establishes the four conditions which must be satisfied in order to make a finding that a proposed discharge of dredged or fill material complies with the Guidelines. Section 230.11 of subpart B, sets forth factual determinations which are to be considered in determining whether or not a proposed discharge satisfies the subpart B conditions of compliance. Subpart C describes the physical and chemical components of a site and provides guidance as to how proposed discharges of dredged or fill material may affect these components. Subparts D through F detail the special characteristics of particular aquatic ecosystems in terms of their values, and the possible loss of these values due to discharges of dredged or fill material. Subpart G prescribes a number of physical, chemical, and biological evaluations and testing procedures to be used in reaching the required factual determinations. Subpart H details the means to prevent or minimize adverse effects. Subpart I concerns advanced identification of disposal areas.

§ 230.5 General procedures to be followed.

In evaluating whether a particular discharge site may be specified, the permitting authority should use these Guidelines in the following sequence:

(a) In order to obtain an overview of the principal regulatory provisions of the Guidelines, review the restrictions on discharge in §230.10(a) through (d), the measures to minimize adverse impact of subpart H, and the required factual determinations of §230.11.

(b) Determine if a General permit (§230.7) is applicable; if so, the applicant needs merely to comply with its terms, and no further action by the permitting authority is necessary. Special conditions for evaluation of proposed General permits are contained in §230.7. If the discharge is not covered by a General permit:

(c) Examine practicable alternatives to the proposed discharge, that is, not discharging into the waters of the U.S. or discharging into an alternative aquatic site with potentially less damaging consequences (§230.10(a)).

(d) Delineate the candidate disposal site consistent with the criteria and evaluations of §230.11(f).

(e) Evaluate the various physical and chemical components which characterize the non-living environment of the candidate site, the substrate and the water including its dynamic characteristics (subpart C).

(f) Identify and evaluate any special or critical characteristics of the candidate disposal site, and surrounding areas which might be affected by use of such site, related to their living communities or human uses (subparts D, E, and F).

(g) Review Factual Determinations in §230.11 to determine whether the information in the project file is sufficient to provide the documentation required by §230.11 or to perform the pre-testing evaluation described in §230.60, or other information is necessary.

(h) Evaluate the material to be discharged to determine the possibility of chemical contamination or physical incompatibility of the material to be discharged (§230.60).

(i) If there is a reasonable probability of chemical contamination, conduct the appropriate tests according to the section on Evaluation and Testing (§230.61).

(j) Identify appropriate and practicable changes to the project plan to minimize the environmental impact of the discharge, based upon the specialized methods of minimization of impacts in subpart H.

(k) Make and document Factual Determinations in §230.11.

(l) Make and document Findings of Compliance (§230.12) by comparing Factual Determinations with the requirements for discharge of §230.10.

This outline of the steps to follow in using the Guidelines is simplified for purposes of illustration. The actual process followed may be iterative, with the results of one step leading to a reexamination of previous steps. The permitting authority must address all of the relevant provisions of the Guidelines in reaching a Finding of Compliance in an individual case.

§ 230.6 Adaptability.

(a) The manner in which these Guidelines are used depends on the physical, biological, and chemical nature of the proposed extraction site, the material to be discharged, and the candidate disposal site, including any other important components of the ecosystem being evaluated. Documentation to demonstrate knowledge about the extraction site, materials to be extracted, and the candidate disposal site is an essential component of guideline application. These Guidelines allow evaluation and documentation for a variety of activities, ranging from those with large, complex impacts on the aquatic environment to those for which the impact is likely to be innocuous. It is unlikely that the Guidelines will apply in their entirety to any one activity, no matter how complex. It is anticipated that substantial numbers of permit applications will be for minor, routine activities that have little, if any, potential for significant degradation of the aquatic environment. It generally is not intended or expected that extensive testing, evaluation or analysis will be needed to make findings of compliance in such routine cases. Where the

conditions for General permits are met, and where numerous applications for similar activities are likely, the use of General permits will eliminate repetitive evaluation and documentation for individual discharges.

(b) The Guidelines user, including the agency or agencies responsible for implementing the Guidelines, must recognize the different levels of effort that should be associated with varying degrees of impact and require or prepare commensurate documentation. The level of documentation should reflect the significance and complexity of the discharge activity.

(c) An essential part of the evaluation process involves making determinations as to the relevance of any portion(s) of the Guidelines and conducting further evaluation only as needed. However, where portions of the Guidelines review procedure are “short form” evaluations, there still must be sufficient information (including consideration of both individual and cumulative impacts) to support the decision of whether to specify the site for disposal of dredged or fill material and to support the decision to curtail or abbreviate the evaluation process. The presumption against the discharge in §230.1 applies to this decision-making.

(d) In the case of activities covered by General permits or section 208(b)(4)(B) and (C) Best Management Practices, the analysis and documentation required by the Guidelines will be performed at the time of General permit issuance or section 208(b)(4)(B) and (C) Best Management Practices promulgation and will not be repeated when activities are conducted under a General permit or section 208(b)(4)(B) and (C) Best Management Practices control. These Guidelines do not require reporting or formal written communication at the time individual activities are initiated under a General permit or section 208(b)(4)(B) and (C) Best Management Practices. However, a particular General permit may require appropriate reporting.

§ 230.7 General permits.

(a) *Conditions for the issuance of General permits.* A General permit for a category of activities involving the discharge of dredged or fill material complies with the Guidelines if it meets the applicable restrictions on the discharge in §230.10 and if the permitting authority determines that:

(1) The activities in such category are similar in nature and similar in their impact upon water quality and the aquatic environment;

(2) The activities in such category will have only minimal adverse effects when performed separately; and

(3) The activities in such category will have only minimal cumulative adverse effects on water quality and the aquatic environment.

(b) *Evaluation process.* To reach the determinations required in paragraph (a) of this section, the permitting authority shall set forth in writing an evaluation of the potential individual and cumulative impacts of the category of activities to be regulated under the General permit. While some of the information necessary for this evaluation can be obtained from potential permittees

and others through the proposal of General permits for public review, the evaluation must be completed before any General permit is issued, and the results must be published with the final permit.

(1) This evaluation shall be based upon consideration of the prohibitions listed in §230.10(b) and the factors listed in §230.10(c), and shall include documented information supporting each factual determination in §230.11 of the Guidelines (consideration of alternatives in §230.10(a) are not directly applicable to General permits);

(2) The evaluation shall include a precise description of the activities to be permitted under the General permit, explaining why they are sufficiently similar in nature and in environmental impact to warrant regulation under a single General permit based on subparts C through F of the Guidelines. Allowable differences between activities which will be regulated under the same General permit shall be specified. Activities otherwise similar in nature may differ in environmental impact due to their location in or near ecologically sensitive areas, areas with unique chemical or physical characteristics, areas containing concentrations of toxic substances, or areas regulated for specific human uses or by specific land or water management plans (e.g., areas regulated under an approved Coastal Zone Management Plan). If there are specific geographic areas within the purview of a proposed General permit (called a draft General permit under a State 404 program), which are more appropriately regulated by individual permit due to the considerations cited in this paragraph, they shall be clearly delineated in the evaluation and excluded from the permit. In addition, the permitting authority may require an individual permit for any proposed activity under a General permit where the nature or location of the activity makes an individual permit more appropriate.

(3) To predict cumulative effects, the evaluation shall include the number of individual discharge activities likely to be regulated under a General permit until its expiration, including repetitions of individual discharge activities at a single location.

Subpart B—Compliance with the Guidelines

§ 230.10 Restrictions on discharge.

Note: Because other laws may apply to particular discharges and because the Corps of Engineers or State 404 agency may have additional procedural and substantive requirements, a discharge complying with the requirement of these Guidelines will not automatically receive a permit.

Although all requirements in §230.10 must be met, the compliance evaluation procedures will vary to reflect the seriousness of the potential for adverse impacts on the aquatic ecosystems posed by specific dredged or fill material discharge activities.

(a) Except as provided under section 404(b)(2), no discharge of dredged or fill material shall be permitted if there is a practicable alternative to the proposed discharge which would have less adverse impact on the aquatic ecosystem, so long as the alternative does not have other significant adverse environmental consequences.

(1) For the purpose of this requirement, practicable alternatives include, but are not limited to:

(i) Activities which do not involve a discharge of dredged or fill material into the waters of the United States or ocean waters;

(ii) Discharges of dredged or fill material at other locations in waters of the United States or ocean waters;

(2) An alternative is practicable if it is available and capable of being done after taking into consideration cost, existing technology, and logistics in light of overall project purposes. If it is otherwise a practicable alternative, an area not presently owned by the applicant which could reasonably be obtained, utilized, expanded or managed in order to fulfill the basic purpose of the proposed activity may be considered.

(3) Where the activity associated with a discharge which is proposed for a special aquatic site (as defined in subpart E) does not require access or proximity to or siting within the special aquatic site in question to fulfill its basic purpose (i.e., is not “water dependent”), practicable alternatives that do not involve special aquatic sites are presumed to be available, unless clearly demonstrated otherwise. In addition, where a discharge is proposed for a special aquatic site, all practicable alternatives to the proposed discharge which do not involve a discharge into a special aquatic site are presumed to have less adverse impact on the aquatic ecosystem, unless clearly demonstrated otherwise.

(4) For actions subject to NEPA, where the Corps of Engineers is the permitting agency, the analysis of alternatives required for NEPA environmental documents, including supplemental Corps NEPA documents, will in most cases provide the information for the evaluation of alternatives under these Guidelines. On occasion, these NEPA documents may address a broader range of alternatives than required to be considered under this paragraph or may not have considered the alternatives in sufficient detail to respond to the requirements of these Guidelines. In the latter case, it may be necessary to supplement these NEPA documents with this additional information.

(5) To the extent that practicable alternatives have been identified and evaluated under a Coastal Zone Management program, a section 208 program, or other planning process, such evaluation shall be considered by the permitting authority as part of the consideration of alternatives under the Guidelines. Where such evaluation is less complete than that contemplated under this subsection, it must be supplemented accordingly.

(b) No discharge of dredged or fill material shall be permitted if it:

(1) Causes or contributes, after consideration of disposal site dilution and dispersion, to violations of any applicable State water quality standard;

(2) Violates any applicable toxic effluent standard or prohibition under section 307 of the Act;

(3) Jeopardizes the continued existence of species listed as endangered or threatened under the Endangered Species Act of 1973, as amended, or results in likelihood of the destruction or adverse modification of a habitat which is determined by the Secretary of Interior or Commerce, as appropriate, to be a critical habitat under the Endangered Species Act of 1973, as amended. If an exemption has been granted by the Endangered Species Committee, the terms of such exemption shall apply in lieu of this subparagraph;

(4) Violates any requirement imposed by the Secretary of Commerce to protect any marine sanctuary designated under title III of the Marine Protection, Research, and Sanctuaries Act of 1972.

(c) Except as provided under section 404(b)(2), no discharge of dredged or fill material shall be permitted which will cause or contribute to significant degradation of the waters of the United States. Findings of significant degradation related to the proposed discharge shall be based upon appropriate factual determinations, evaluations, and tests required by subparts B and G, after consideration of subparts C through F, with special emphasis on the persistence and permanence of the effects outlined in those subparts. Under these Guidelines, effects contributing to significant degradation considered individually or collectively, include:

(1) Significantly adverse effects of the discharge of pollutants on human health or welfare, including but not limited to effects on municipal water supplies, plankton, fish, shellfish, wildlife, and special aquatic sites.

(2) Significantly adverse effects of the discharge of pollutants on life stages of aquatic life and other wildlife dependent on aquatic ecosystems, including the transfer, concentration, and spread of pollutants or their byproducts outside of the disposal site through biological, physical, and chemical processes;

(3) Significantly adverse effects of the discharge of pollutants on aquatic ecosystem diversity, productivity, and stability. Such effects may include, but are not limited to, loss of fish and wildlife habitat or loss of the capacity of a wetland to assimilate nutrients, purify water, or reduce wave energy; or

(4) Significantly adverse effects of discharge of pollutants on recreational, aesthetic, and economic values.

(d) Except as provided under section 404(b)(2), no discharge of dredged or fill material shall be permitted unless appropriate and practicable steps have been taken which will minimize potential adverse impacts of the discharge on the aquatic ecosystem. Subpart H identifies such possible steps.

§ 230.11 Factual determinations.

The permitting authority shall determine in writing the potential short-term or long-term effects of a proposed discharge of dredged or fill material on the physical, chemical, and biological components of the aquatic environment in light of subparts C through F. Such factual

determinations shall be used in §230.12 in making findings of compliance or non-compliance with the restrictions on discharge in §230.10. The evaluation and testing procedures described in §230.60 and §230.61 of subpart G shall be used as necessary to make, and shall be described in, such determination. The determinations of effects of each proposed discharge shall include the following:

(a) *Physical substrate determinations.* Determine the nature and degree of effect that the proposed discharge will have, individually and cumulatively, on the characteristics of the substrate at the proposed disposal site. Consideration shall be given to the similarity in particle size, shape, and degree of compaction of the material proposed for discharge and the material constituting the substrate at the disposal site, and any potential changes in substrate elevation and bottom contours, including changes outside of the disposal site which may occur as a result of erosion, slumpage, or other movement of the discharged material. The duration and physical extent of substrate changes shall also be considered. The possible loss of environmental values (§230.20) and actions to minimize impact (subpart H) shall also be considered in making these determinations. Potential changes in substrate elevation and bottom contours shall be predicted on the basis of the proposed method, volume, location, and rate of discharge, as well as on the individual and combined effects of current patterns, water circulation, wind and wave action, and other physical factors that may affect the movement of the discharged material.

(b) *Water circulation, fluctuation, and salinity determinations.* Determine the nature and degree of effect that the proposed discharge will have individually and cumulatively on water, current patterns, circulation including downstream flows, and normal water fluctuation. Consideration shall be given to water chemistry, salinity, clarity, color, odor, taste, dissolved gas levels, temperature, nutrients, and eutrophication plus other appropriate characteristics. Consideration shall also be given to the potential diversion or obstruction of flow, alterations of bottom contours, or other significant changes in the hydrologic regime. Additional consideration of the possible loss of environmental values (§§230.23 through 230.25) and actions to minimize impacts (subpart H), shall be used in making these determinations. Potential significant effects on the current patterns, water circulation, normal water fluctuation and salinity shall be evaluated on the basis of the proposed method, volume, location, and rate of discharge.

(c) *Suspended particulate/turbidity determinations.* Determine the nature and degree of effect that the proposed discharge will have, individually and cumulatively, in terms of potential changes in the kinds and concentrations of suspended particulate/turbidity in the vicinity of the disposal site. Consideration shall be given to the grain size of the material proposed for discharge, the shape and size of the plume of suspended particulates, the duration of the discharge and resulting plume and whether or not the potential changes will cause violations of applicable water quality standards. Consideration should also be given to the possible loss of environmental values (§230.21) and to actions for minimizing impacts (subpart H). Consideration shall include the proposed method, volume, location, and rate of discharge, as well as the individual and combined effects of current patterns, water circulation and fluctuations, wind and wave action, and other physical factors on the movement of suspended particulates.

(d) *Contaminant determinations.* Determine the degree to which the material proposed for discharge will introduce, relocate, or increase contaminants. This determination shall consider

the material to be discharged, the aquatic environment at the proposed disposal site, and the availability of contaminants.

(e) *Aquatic ecosystem and organism determinations.* Determine the nature and degree of effect that the proposed discharge will have, both individually and cumulatively, on the structure and function of the aquatic ecosystem and organisms. Consideration shall be given to the effect at the proposed disposal site of potential changes in substrate characteristics and elevation, water or substrate chemistry, nutrients, currents, circulation, fluctuation, and salinity, on the recolonization and existence of indigenous aquatic organisms or communities. Possible loss of environmental values (§230.31), and actions to minimize impacts (subpart H) shall be examined. Tests as described in §230.61 (Evaluation and Testing), may be required to provide information on the effect of the discharge material on communities or populations of organisms expected to be exposed to it.

(f) *Proposed disposal site determinations.* (1) Each disposal site shall be specified through the application of these Guidelines. The mixing zone shall be confined to the smallest practicable zone within each specified disposal site that is consistent with the type of dispersion determined to be appropriate by the application of these Guidelines. In a few special cases under unique environmental conditions, where there is adequate justification to show that widespread dispersion by natural means will result in no significantly adverse environmental effects, the discharged material may be intended to be spread naturally in a very thin layer over a large area of the substrate rather than be contained within the disposal site.

(2) The permitting authority and the Regional Administrator shall consider the following factors in determining the acceptability of a proposed mixing zone:

(i) Depth of water at the disposal site;

(ii) Current velocity, direction, and variability at the disposal site;

(iii) Degree of turbulence;

(iv) Stratification attributable to causes such as obstructions, salinity or density profiles at the disposal site;

(v) Discharge vessel speed and direction, if appropriate;

(vi) Rate of discharge;

(vii) Ambient concentration of constituents of interest;

(viii) Dredged material characteristics, particularly concentrations of constituents, amount of material, type of material (sand, silt, clay, etc.) and settling velocities;

(ix) Number of discharge actions per unit of time;

(x) Other factors of the disposal site that affect the rates and patterns of mixing.

(g) *Determination of cumulative effects on the aquatic ecosystem.* (1) Cumulative impacts are the changes in an aquatic ecosystem that are attributable to the collective effect of a number of individual discharges of dredged or fill material. Although the impact of a particular discharge may constitute a minor change in itself, the cumulative effect of numerous such piecemeal changes can result in a major impairment of the water resources and interfere with the productivity and water quality of existing aquatic ecosystems.

(2) Cumulative effects attributable to the discharge of dredged or fill material in waters of the United States should be predicted to the extent reasonable and practical. The permitting authority shall collect information and solicit information from other sources about the cumulative impacts on the aquatic ecosystem. This information shall be documented and considered during the decision-making process concerning the evaluation of individual permit applications, the issuance of a General permit, and monitoring and enforcement of existing permits.

(h) *Determination of secondary effects on the aquatic ecosystem.* (1) Secondary effects are effects on an aquatic ecosystem that are associated with a discharge of dredged or fill materials, but do not result from the actual placement of the dredged or fill material. Information about secondary effects on aquatic ecosystems shall be considered prior to the time final section 404 action is taken by permitting authorities.

(2) Some examples of secondary effects on an aquatic ecosystem are fluctuating water levels in an impoundment and downstream associated with the operation of a dam, septic tank leaching and surface runoff from residential or commercial developments on fill, and leachate and runoff from a sanitary landfill located in waters of the U.S. Activities to be conducted on fast land created by the discharge of dredged or fill material in waters of the United States may have secondary impacts within those waters which should be considered in evaluating the impact of creating those fast lands.

§ 230.12 Findings of compliance or non-compliance with the restrictions on discharge.

(a) On the basis of these Guidelines (subparts C through G) the proposed disposal sites for the discharge of dredged or fill material must be:

(1) Specified as complying with the requirements of these Guidelines; or

(2) Specified as complying with the requirements of these Guidelines with the inclusion of appropriate and practicable discharge conditions (see subparts H and J) to minimize pollution or adverse effects to the affected aquatic ecosystems; or

(3) Specified as failing to comply with the requirements of these Guidelines where:

(i) There is a practicable alternative to the proposed discharge that would have less adverse effect on the aquatic ecosystem, so long as such alternative does not have other significant adverse environmental consequences; or

(ii) The proposed discharge will result in significant degradation of the aquatic ecosystem under §230.10(b) or (c); or

(iii) The proposed discharge does not include all appropriate and practicable measures to minimize potential harm to the aquatic ecosystem; or

(iv) There does not exist sufficient information to make a reasonable judgment as to whether the proposed discharge will comply with these Guidelines.

(b) Findings under this section shall be set forth in writing by the permitting authority for each proposed discharge and made available to the permit applicant. These findings shall include the factual determinations required by §230.11, and a brief explanation of any adaptation of these Guidelines to the activity under consideration. In the case of a General permit, such findings shall be prepared at the time of issuance of that permit rather than for each subsequent discharge under the authority of that permit.

Subpart C—Potential Impacts on Physical and Chemical Characteristics of the Aquatic Ecosystem

Note: The effects described in this subpart should be considered in making the factual determinations and the findings of compliance or non-compliance in subpart B.

[45 FR 85344, Dec. 24, 1980, as amended at 73 FR 19687, Apr. 10, 2008]

§ 230.20 Substrate.

(a) The substrate of the aquatic ecosystem underlies open waters of the United States and constitutes the surface of wetlands. It consists of organic and inorganic solid materials and includes water and other liquids or gases that fill the spaces between solid particles.

(b) Possible loss of environmental characteristics and values: The discharge of dredged or fill material can result in varying degrees of change in the complex physical, chemical, and biological characteristics of the substrate. Discharges which alter substrate elevation or contours can result in changes in water circulation, depth, current pattern, water fluctuation and water temperature. Discharges may adversely affect bottom-dwelling organisms at the site by smothering immobile forms or forcing mobile forms to migrate. Benthic forms present prior to a discharge are unlikely to recolonize on the discharged material if it is very dissimilar from that of the discharge site. Erosion, slumping, or lateral displacement of surrounding bottom of such deposits can adversely affect areas of the substrate outside the perimeters of the disposal site by changing or destroying habitat. The bulk and composition of the discharged material and the location, method, and timing of discharges may all influence the degree of impact on the substrate.

§ 230.21 Suspended particulates/turbidity.

(a) Suspended particulates in the aquatic ecosystem consist of fine-grained mineral particles, usually smaller than silt, and organic particles. Suspended particulates may enter water bodies as a result of land runoff, flooding, vegetative and planktonic breakdown, resuspension of bottom sediments, and man's activities including dredging and filling. Particulates may remain suspended in the water column for variable periods of time as a result of such factors as agitation of the water mass, particulate specific gravity, particle shape, and physical and chemical properties of particle surfaces.

(b) Possible loss of environmental characteristics and values: The discharge of dredged or fill material can result in greatly elevated levels of suspended particulates in the water column for varying lengths of time. These new levels may reduce light penetration and lower the rate of photosynthesis and the primary productivity of an aquatic area if they last long enough. Sight-dependent species may suffer reduced feeding ability leading to limited growth and lowered resistance to disease if high levels of suspended particulates persist. The biological and the chemical content of the suspended material may react with the dissolved oxygen in the water, which can result in oxygen depletion. Toxic metals and organics, pathogens, and viruses absorbed or adsorbed to fine-grained particulates in the material may become biologically available to organisms either in the water column or on the substrate. Significant increases in suspended particulate levels create turbid plumes which are highly visible and aesthetically displeasing. The extent and persistence of these adverse impacts caused by discharges depend upon the relative increase in suspended particulates above the amount occurring naturally, the duration of the higher levels, the current patterns, water level, and fluctuations present when such discharges occur, the volume, rate, and duration of the discharge, particulate deposition, and the seasonal timing of the discharge.

§ 230.22 Water.

(a) Water is the part of the aquatic ecosystem in which organic and inorganic constituents are dissolved and suspended. It constitutes part of the liquid phase and is contained by the substrate. Water forms part of a dynamic aquatic life-supporting system. Water clarity, nutrients and chemical content, physical and biological content, dissolved gas levels, pH, and temperature contribute to its life-sustaining capabilities.

(b) Possible loss of environmental characteristics and values: The discharge of dredged or fill material can change the chemistry and the physical characteristics of the receiving water at a disposal site through the introduction of chemical constituents in suspended or dissolved form. Changes in the clarity, color, odor, and taste of water and the addition of contaminants can reduce or eliminate the suitability of water bodies for populations of aquatic organisms, and for human consumption, recreation, and aesthetics. The introduction of nutrients or organic material to the water column as a result of the discharge can lead to a high biochemical oxygen demand (BOD), which in turn can lead to reduced dissolved oxygen, thereby potentially affecting the survival of many aquatic organisms. Increases in nutrients can favor one group of organisms such as algae to the detriment of other more desirable types such as submerged aquatic vegetation, potentially causing adverse health effects, objectionable tastes and odors, and other problems.

§ 230.23 Current patterns and water circulation.

(a) Current patterns and water circulation are the physical movements of water in the aquatic ecosystem. Currents and circulation respond to natural forces as modified by basin shape and cover, physical and chemical characteristics of water strata and masses, and energy dissipating factors.

(b) Possible loss of environmental characteristics and values: The discharge of dredged or fill material can modify current patterns and water circulation by obstructing flow, changing the direction or velocity of water flow, changing the direction or velocity of water flow and circulation, or otherwise changing the dimensions of a water body. As a result, adverse changes can occur in: Location, structure, and dynamics of aquatic communities; shoreline and substrate erosion and deposition rates; the deposition of suspended particulates; the rate and extent of mixing of dissolved and suspended components of the water body; and water stratification.

§ 230.24 Normal water fluctuations.

(a) Normal water fluctuations in a natural aquatic system consist of daily, seasonal, and annual tidal and flood fluctuations in water level. Biological and physical components of such a system are either attuned to or characterized by these periodic water fluctuations.

(b) Possible loss of environmental characteristics and values: The discharge of dredged or fill material can alter the normal water-level fluctuation pattern of an area, resulting in prolonged periods of inundation, exaggerated extremes of high and low water, or a static, nonfluctuating water level. Such water level modifications may change salinity patterns, alter erosion or sedimentation rates, aggravate water temperature extremes, and upset the nutrient and dissolved oxygen balance of the aquatic ecosystem. In addition, these modifications can alter or destroy communities and populations of aquatic animals and vegetation, induce populations of nuisance organisms, modify habitat, reduce food supplies, restrict movement of aquatic fauna, destroy spawning areas, and change adjacent, upstream, and downstream areas.

§ 230.25 Salinity gradients.

(a) Salinity gradients form where salt water from the ocean meets and mixes with fresh water from land.

(b) Possible loss of environmental characteristics and values: Obstructions which divert or restrict flow of either fresh or salt water may change existing salinity gradients. For example, partial blocking of the entrance to an estuary or river mouth that significantly restricts the movement of the salt water into and out of that area can effectively lower the volume of salt water available for mixing within that estuary. The downstream migration of the salinity gradient can occur, displacing the maximum sedimentation zone and requiring salinity-dependent aquatic biota to adjust to the new conditions, move to new locations if possible, or perish. In the freshwater zone, discharge operations in the upstream regions can have equally adverse impacts. A significant reduction in the volume of fresh water moving into an estuary below that which is considered normal can affect the location and type of mixing thereby changing the characteristic

salinity patterns. The resulting changed circulation pattern can cause the upstream migration of the salinity gradient displacing the maximum sedimentation zone. This migration may affect those organisms that are adapted to freshwater environments. It may also affect municipal water supplies.

Note: Possible actions to minimize adverse impacts regarding site characteristics can be found in subpart H.

Subpart D—Potential Impacts on Biological Characteristics of the Aquatic Ecosystem

Note: The impacts described in this subpart should be considered in making the factual determinations and the findings of compliance or non-compliance in subpart B.

§ 230.30 Threatened and endangered species.

(a) An endangered species is a plant or animal in danger of extinction throughout all or a significant portion of its range. A threatened species is one in danger of becoming an endangered species in the foreseeable future throughout all or a significant portion of its range. Listings of threatened and endangered species as well as critical habitats are maintained by some individual States and by the U.S. Fish and Wildlife Service of the Department of the Interior (codified annually at 50 CFR 17.11). The Department of Commerce has authority over some threatened and endangered marine mammals, fish and reptiles.

(b) Possible loss of values: The major potential impacts on threatened or endangered species from the discharge of dredged or fill material include:

(1) Covering or otherwise directly killing species;

(2) The impairment or destruction of habitat to which these species are limited. Elements of the aquatic habitat which are particularly crucial to the continued survival of some threatened or endangered species include adequate good quality water, spawning and maturation areas, nesting areas, protective cover, adequate and reliable food supply, and resting areas for migratory species. Each of these elements can be adversely affected by changes in either the normal water conditions for clarity, chemical content, nutrient balance, dissolved oxygen, pH, temperature, salinity, current patterns, circulation and fluctuation, or the physical removal of habitat; and

(3) Facilitating incompatible activities.

(c) Where consultation with the Secretary of the Interior occurs under section 7 of the Endangered Species Act, the conclusions of the Secretary concerning the impact(s) of the discharge on threatened and endangered species and their habitat shall be considered final.

§ 230.31 Fish, crustaceans, mollusks, and other aquatic organisms in the food web.

(a) Aquatic organisms in the food web include, but are not limited to, finfish, crustaceans, mollusks, insects, annelids, planktonic organisms, and the plants and animals on which they feed

and depend upon for their needs. All forms and life stages of an organism, throughout its geographic range, are included in this category.

(b) Possible loss of values: The discharge of dredged or fill material can variously affect populations of fish, crustaceans, mollusks and other food web organisms through the release of contaminants which adversely affect adults, juveniles, larvae, or eggs, or result in the establishment or proliferation of an undesirable competitive species of plant or animal at the expense of the desired resident species. Suspended particulates settling on attached or buried eggs can smother the eggs by limiting or sealing off their exposure to oxygenated water. Discharge of dredged and fill material may result in the debilitation or death of sedentary organisms by smothering, exposure to chemical contaminants in dissolved or suspended form, exposure to high levels of suspended particulates, reduction in food supply, or alteration of the substrate upon which they are dependent. Mollusks are particularly sensitive to the discharge of material during periods of reproduction and growth and development due primarily to their limited mobility. They can be rendered unfit for human consumption by tainting, by production and accumulation of toxins, or by ingestion and retention of pathogenic organisms, viruses, heavy metals or persistent synthetic organic chemicals. The discharge of dredged or fill material can redirect, delay, or stop the reproductive and feeding movements of some species of fish and crustacea, thus preventing their aggregation in accustomed places such as spawning or nursery grounds and potentially leading to reduced populations. Reduction of detrital feeding species or other representatives of lower trophic levels can impair the flow of energy from primary consumers to higher trophic levels. The reduction or potential elimination of food chain organism populations decreases the overall productivity and nutrient export capability of the ecosystem.

§ 230.32 Other wildlife.

(a) Wildlife associated with aquatic ecosystems are resident and transient mammals, birds, reptiles, and amphibians.

(b) Possible loss of values: The discharge of dredged or fill material can result in the loss or change of breeding and nesting areas, escape cover, travel corridors, and preferred food sources for resident and transient wildlife species associated with the aquatic ecosystem. These adverse impacts upon wildlife habitat may result from changes in water levels, water flow and circulation, salinity, chemical content, and substrate characteristics and elevation. Increased water turbidity can adversely affect wildlife species which rely upon sight to feed, and disrupt the respiration and feeding of certain aquatic wildlife and food chain organisms. The availability of contaminants from the discharge of dredged or fill material may lead to the bioaccumulation of such contaminants in wildlife. Changes in such physical and chemical factors of the environment may favor the introduction of undesirable plant and animal species at the expense of resident species and communities. In some aquatic environments lowering plant and animal species diversity may disrupt the normal functions of the ecosystem and lead to reductions in overall biological productivity.

Note: Possible actions to minimize adverse impacts regarding characteristics of biological components of the aquatic ecosystem can be found in subpart H.

Subpart E—Potential Impacts on Special Aquatic Sites

Note: The impacts described in this subpart should be considered in making the factual determinations and the findings of compliance or non-compliance in subpart B. The definition of special aquatic sites is found in §230.3(q–1).

§ 230.40 Sanctuaries and refuges.

(a) Sanctuaries and refuges consist of areas designated under State and Federal laws or local ordinances to be managed principally for the preservation and use of fish and wildlife resources.

(b) Possible loss of values: Sanctuaries and refuges may be affected by discharges of dredged or fill material which will:

(1) Disrupt the breeding, spawning, migratory movements or other critical life requirements of resident or transient fish and wildlife resources;

(2) Create unplanned, easy and incompatible human access to remote aquatic areas;

(3) Create the need for frequent maintenance activity;

(4) Result in the establishment of undesirable competitive species of plants and animals;

(5) Change the balance of water and land areas needed to provide cover, food, and other fish and wildlife habitat requirements in a way that modifies sanctuary or refuge management practices;

(6) Result in any of the other adverse impacts discussed in subparts C and D as they relate to a particular sanctuary or refuge.

§ 230.41 Wetlands.

(a)(1) Wetlands consist of areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

(2) Where wetlands are adjacent to open water, they generally constitute the transition to upland. The margin between wetland and open water can best be established by specialists familiar with the local environment, particularly where emergent vegetation merges with submerged vegetation over a broad area in such places as the lateral margins of open water, headwaters, rainwater catch basins, and groundwater seeps. The landward margin of wetlands also can best be identified by specialists familiar with the local environment when vegetation from the two regions merges over a broad area.

(3) Wetland vegetation consists of plants that require saturated soils to survive (obligate wetland plants) as well as plants, including certain trees, that gain a competitive advantage over others because they can tolerate prolonged wet soil conditions and their competitors cannot. In addition

to plant populations and communities, wetlands are delimited by hydrological and physical characteristics of the environment. These characteristics should be considered when information about them is needed to supplement information available about vegetation, or where wetland vegetation has been removed or is dormant.

(b) Possible loss of values: The discharge of dredged or fill material in wetlands is likely to damage or destroy habitat and adversely affect the biological productivity of wetlands ecosystems by smothering, by dewatering, by permanently flooding, or by altering substrate elevation or periodicity of water movement. The addition of dredged or fill material may destroy wetland vegetation or result in advancement of succession to dry land species. It may reduce or eliminate nutrient exchange by a reduction of the system's productivity, or by altering current patterns and velocities. Disruption or elimination of the wetland system can degrade water quality by obstructing circulation patterns that flush large expanses of wetland systems, by interfering with the filtration function of wetlands, or by changing the aquifer recharge capability of a wetland. Discharges can also change the wetland habitat value for fish and wildlife as discussed in subpart D. When disruptions in flow and circulation patterns occur, apparently minor loss of wetland acreage may result in major losses through secondary impacts. Discharging fill material in wetlands as part of municipal, industrial or recreational development may modify the capacity of wetlands to retain and store floodwaters and to serve as a buffer zone shielding upland areas from wave actions, storm damage and erosion.

§ 230.42 Mud flats.

(a) Mud flats are broad flat areas along the sea coast and in coastal rivers to the head of tidal influence and in inland lakes, ponds, and riverine systems. When mud flats are inundated, wind and wave action may resuspend bottom sediments. Coastal mud flats are exposed at extremely low tides and inundated at high tides with the water table at or near the surface of the substrate. The substrate of mud flats contains organic material and particles smaller in size than sand. They are either unvegetated or vegetated only by algal mats.

(b) Possible loss of values: The discharge of dredged or fill material can cause changes in water circulation patterns which may permanently flood or dewater the mud flat or disrupt periodic inundation, resulting in an increase in the rate of erosion or accretion. Such changes can deplete or eliminate mud flat biota, foraging areas, and nursery areas. Changes in inundation patterns can affect the chemical and biological exchange and decomposition process occurring on the mud flat and change the deposition of suspended material affecting the productivity of the area. Changes may reduce the mud flat's capacity to dissipate storm surge runoff.

§ 230.43 Vegetated shallows.

(a) Vegetated shallows are permanently inundated areas that under normal circumstances support communities of rooted aquatic vegetation, such as turtle grass and eelgrass in estuarine or marine systems as well as a number of freshwater species in rivers and lakes.

(b) Possible loss of values: The discharge of dredged or fill material can smother vegetation and benthic organisms. It may also create unsuitable conditions for their continued vigor by: (1)

Changing water circulation patterns; (2) releasing nutrients that increase undesirable algal populations; (3) releasing chemicals that adversely affect plants and animals; (4) increasing turbidity levels, thereby reducing light penetration and hence photosynthesis; and (5) changing the capacity of a vegetated shallow to stabilize bottom materials and decrease channel shoaling. The discharge of dredged or fill material may reduce the value of vegetated shallows as nesting, spawning, nursery, cover, and forage areas, as well as their value in protecting shorelines from erosion and wave actions. It may also encourage the growth of nuisance vegetation.

§ 230.44 Coral reefs.

(a) Coral reefs consist of the skeletal deposit, usually of calcareous or silicaceous materials, produced by the vital activities of anthozoan polyps or other invertebrate organisms present in growing portions of the reef.

(b) Possible loss of values: The discharge of dredged or fill material can adversely affect colonies of reef building organisms by burying them, by releasing contaminants such as hydrocarbons into the water column, by reducing light penetration through the water, and by increasing the level of suspended particulates. Coral organisms are extremely sensitive to even slight reductions in light penetration or increases in suspended particulates. These adverse effects will cause a loss of productive colonies which in turn provide habitat for many species of highly specialized aquatic organisms.

§ 230.45 Riffle and pool complexes.

(a) Steep gradient sections of streams are sometimes characterized by riffle and pool complexes. Such stream sections are recognizable by their hydraulic characteristics. The rapid movement of water over a coarse substrate in riffles results in a rough flow, a turbulent surface, and high dissolved oxygen levels in the water. Pools are deeper areas associated with riffles. Pools are characterized by a slower stream velocity, a steaming flow, a smooth surface, and a finer substrate. Riffle and pool complexes are particularly valuable habitat for fish and wildlife.

(b) Possible loss of values: Discharge of dredged or fill material can eliminate riffle and pool areas by displacement, hydrologic modification, or sedimentation. Activities which affect riffle and pool areas and especially riffle/pool ratios, may reduce the aeration and filtration capabilities at the discharge site and downstream, may reduce stream habitat diversity, and may retard repopulation of the disposal site and downstream waters through sedimentation and the creation of unsuitable habitat. The discharge of dredged or fill material which alters stream hydrology may cause scouring or sedimentation of riffles and pools. Sedimentation induced through hydrological modification or as a direct result of the deposition of unconsolidated dredged or fill material may clog riffle and pool areas, destroy habitats, and create anaerobic conditions. Eliminating pools and meanders by the discharge of dredged or fill material can reduce water holding capacity of streams and cause rapid runoff from a watershed. Rapid runoff can deliver large quantities of flood water in a short time to downstream areas resulting in the destruction of natural habitat, high property loss, and the need for further hydraulic modification.

Note: Possible actions to minimize adverse impacts on site or material characteristics can be found in subpart H.

Subpart F—Potential Effects on Human Use Characteristics

Note: The effects described in this subpart should be considered in making the factual determinations and the findings of compliance or non-compliance in subpart B.

§ 230.50 Municipal and private water supplies.

(a) Municipal and private water supplies consist of surface water or ground water which is directed to the intake of a municipal or private water supply system.

(b) Possible loss of values: Discharges can affect the quality of water supplies with respect to color, taste, odor, chemical content and suspended particulate concentration, in such a way as to reduce the fitness of the water for consumption. Water can be rendered unpalatable or unhealthy by the addition of suspended particulates, viruses and pathogenic organisms, and dissolved materials. The expense of removing such substances before the water is delivered for consumption can be high. Discharges may also affect the quantity of water available for municipal and private water supplies. In addition, certain commonly used water treatment chemicals have the potential for combining with some suspended or dissolved substances from dredged or fill material to form other products that can have a toxic effect on consumers.

§ 230.51 Recreational and commercial fisheries.

(a) Recreational and commercial fisheries consist of harvestable fish, crustaceans, shellfish, and other aquatic organisms used by man.

(b) Possible loss of values: The discharge of dredged or fill materials can affect the suitability of recreational and commercial fishing grounds as habitat for populations of consumable aquatic organisms. Discharges can result in the chemical contamination of recreational or commercial fisheries. They may also interfere with the reproductive success of recreational and commercially important aquatic species through disruption of migration and spawning areas. The introduction of pollutants at critical times in their life cycle may directly reduce populations of commercially important aquatic organisms or indirectly reduce them by reducing organisms upon which they depend for food. Any of these impacts can be of short duration or prolonged, depending upon the physical and chemical impacts of the discharge and the biological availability of contaminants to aquatic organisms.

§ 230.52 Water-related recreation.

(a) Water-related recreation encompasses activities undertaken for amusement and relaxation. Activities encompass two broad categories of use: consumptive, e.g., harvesting resources by hunting and fishing; and non-consumptive, e.g. canoeing and sight-seeing.

(b) Possible loss of values: One of the more important direct impacts of dredged or fill disposal is to impair or destroy the resources which support recreation activities. The disposal of dredged or fill material may adversely modify or destroy water use for recreation by changing turbidity, suspended particulates, temperature, dissolved oxygen, dissolved materials, toxic materials, pathogenic organisms, quality of habitat, and the aesthetic qualities of sight, taste, odor, and color.

§ 230.53 Aesthetics.

(a) Aesthetics associated with the aquatic ecosystem consist of the perception of beauty by one or a combination of the senses of sight, hearing, touch, and smell. Aesthetics of aquatic ecosystems apply to the quality of life enjoyed by the general public and property owners.

(b) Possible loss of values: The discharge of dredged or fill material can mar the beauty of natural aquatic ecosystems by degrading water quality, creating distracting disposal sites, inducing inappropriate development, encouraging unplanned and incompatible human access, and by destroying vital elements that contribute to the compositional harmony or unity, visual distinctiveness, or diversity of an area. The discharge of dredged or fill material can adversely affect the particular features, traits, or characteristics of an aquatic area which make it valuable to property owners. Activities which degrade water quality, disrupt natural substrate and vegetational characteristics, deny access to or visibility of the resource, or result in changes in odor, air quality, or noise levels may reduce the value of an aquatic area to private property owners.

§ 230.54 Parks, national and historical monuments, national seashores, wilderness areas, research sites, and similar preserves.

(a) These preserves consist of areas designated under Federal and State laws or local ordinances to be managed for their aesthetic, educational, historical, recreational, or scientific value.

(b) Possible loss of values: The discharge of dredged or fill material into such areas may modify the aesthetic, educational, historical, recreational and/or scientific qualities thereby reducing or eliminating the uses for which such sites are set aside and managed.

Note: Possible actions to minimize adverse impacts regarding site or material characteristics can be found in subpart H.

Subpart G—Evaluation and Testing

§ 230.60 General evaluation of dredged or fill material.

The purpose of these evaluation procedures and the chemical and biological testing sequence outlined in §230.61 is to provide information to reach the determinations required by §230.11. Where the results of prior evaluations, chemical and biological tests, scientific research, and experience can provide information helpful in making a determination, these should be used. Such prior results may make new testing unnecessary. The information used shall be

documented. Where the same information applies to more than one determination, it may be documented once and referenced in later determinations.

(a) If the evaluation under paragraph (b) indicates the dredged or fill material is not a carrier of contaminants, then the required determinations pertaining to the presence and effects of contaminants can be made without testing. Dredged or fill material is most likely to be free from chemical, biological, or other pollutants where it is composed primarily of sand, gravel, or other naturally occurring inert material. Dredged material so composed is generally found in areas of high current or wave energy such as streams with large bed loads or coastal areas with shifting bars and channels. However, when such material is discolored or contains other indications that contaminants may be present, further inquiry should be made.

(b) The extraction site shall be examined in order to assess whether it is sufficiently removed from sources of pollution to provide reasonable assurance that the proposed discharge material is not a carrier of contaminants. Factors to be considered include but are not limited to:

(1) Potential routes of contaminants or contaminated sediments to the extraction site, based on hydrographic or other maps, aerial photography, or other materials that show watercourses, surface relief, proximity to tidal movement, private and public roads, location of buildings, municipal and industrial areas, and agricultural or forest lands.

(2) Pertinent results from tests previously carried out on the material at the extraction site, or carried out on similar material for other permitted projects in the vicinity. Materials shall be considered similar if the sources of contamination, the physical configuration of the sites and the sediment composition of the materials are comparable, in light of water circulation and stratification, sediment accumulation and general sediment characteristics. Tests from other sites may be relied on only if no changes have occurred at the extraction sites to render the results irrelevant.

(3) Any potential for significant introduction of persistent pesticides from land runoff or percolation;

(4) Any records of spills or disposal of petroleum products or substances designated as hazardous under section 311 of the Clean Water Act (See 40 CFR part 116);

(5) Information in Federal, State and local records indicating significant introduction of pollutants from industries, municipalities, or other sources, including types and amounts of waste materials discharged along the potential routes of contaminants to the extraction site; and

(6) Any possibility of the presence of substantial natural deposits of minerals or other substances which could be released to the aquatic environment in harmful quantities by man-induced discharge activities.

(c) To reach the determinations in §230.11 involving potential effects of the discharge on the characteristics of the disposal site, the narrative guidance in subparts C through F shall be used along with the general evaluation procedure in §230.60 and, if necessary, the chemical and

biological testing sequence in §230.61. Where the discharge site is adjacent to the extraction site and subject to the same sources of contaminants, and materials at the two sites are substantially similar, the fact that the material to be discharged may be a carrier of contaminants is not likely to result in degradation of the disposal site. In such circumstances, when dissolved material and suspended particulates can be controlled to prevent carrying pollutants to less contaminated areas, testing will not be required.

(d) Even if the §230.60(b) evaluation (previous tests, the presence of polluting industries and information about their discharge or runoff into waters of the U.S., bioinventories, etc.) leads to the conclusion that there is a high probability that the material proposed for discharge is a carrier of contaminants, testing may not be necessary if constraints are available to reduce contamination to acceptable levels within the disposal site and to prevent contaminants from being transported beyond the boundaries of the disposal site, if such constraints are acceptable to the permitting authority and the Regional Administrator, and if the potential discharger is willing and able to implement such constraints. However, even if tests are not performed, the permitting authority must still determine the probable impact of the operation on the receiving aquatic ecosystem. Any decision not to test must be explained in the determinations made under §230.11.

§ 230.61 Chemical, biological, and physical evaluation and testing.

Note: The Agency is today proposing revised testing guidelines. The evaluation and testing procedures in this section are based on the 1975 section 404(b)(1) interim final Guidelines and shall remain in effect until the revised testing guidelines are published as final regulations.

(a) No single test or approach can be applied in all cases to evaluate the effects of proposed discharges of dredged or fill materials. This section provides some guidance in determining which test and/or evaluation procedures are appropriate in a given case. Interim guidance to applicants concerning the applicability of specific approaches or procedures will be furnished by the permitting authority.

(b) *Chemical-biological interactive effects.* The principal concerns of discharge of dredged or fill material that contain contaminants are the potential effects on the water column and on communities of aquatic organisms.

(1) *Evaluation of chemical-biological interactive effects.* Dredged or fill material may be excluded from the evaluation procedures specified in paragraphs (b) (2) and (3) of this section if it is determined, on the basis of the evaluation in §230.60, that the likelihood of contamination by contaminants is acceptably low, unless the permitting authority, after evaluating and considering any comments received from the Regional Administrator, determines that these procedures are necessary. The Regional Administrator may require, on a case-by-case basis, testing approaches and procedures by stating what additional information is needed through further analyses and how the results of the analyses will be of value in evaluating potential environmental effects.

If the General Evaluation indicates the presence of a sufficiently large number of chemicals to render impractical the identification of all contaminants by chemical testing, information may be obtained from bioassays in lieu of chemical tests.

(2) *Water column effects.* (i) Sediments normally contain constituents that exist in various chemical forms and in various concentrations in several locations within the sediment. An elutriate test may be used to predict the effect on water quality due to release of contaminants from the sediment to the water column. However, in the case of fill material originating on land which may be a carrier of contaminants, a water leachate test is appropriate.

(ii) Major constituents to be analyzed in the elutriate are those deemed critical by the permitting authority, after evaluating and considering any comments received from the Regional Administrator, and considering results of the evaluation in §230.60. Elutriate concentrations should be compared to concentrations of the same constituents in water from the disposal site. Results should be evaluated in light of the volume and rate of the intended discharge, the type of discharge, the hydrodynamic regime at the disposal site, and other information relevant to the impact on water quality. The permitting authority should consider the mixing zone in evaluating water column effects. The permitting authority may specify bioassays when such procedures will be of value.

(3) *Effects on benthos.* The permitting authority may use an appropriate benthic bioassay (including bioaccumulation tests) when such procedures will be of value in assessing ecological effects and in establishing discharge conditions.

(c) Procedure for comparison of sites.

(1) When an inventory of the total concentration of contaminants would be of value in comparing sediment at the dredging site with sediment at the disposal site, the permitting authority may require a sediment chemical analysis. Markedly different concentrations of contaminants between the excavation and disposal sites may aid in making an environmental assessment of the proposed disposal operation. Such differences should be interpreted in terms of the potential for harm as supported by any pertinent scientific literature.

(2) When an analysis of biological community structure will be of value to assess the potential for adverse environmental impact at the proposed disposal site, a comparison of the biological characteristics between the excavation and disposal sites may be required by the permitting authority. Biological indicator species may be useful in evaluating the existing degree of stress at both sites. Sensitive species representing community components colonizing various substrate types within the sites should be identified as possible bioassay organisms if tests for toxicity are required. Community structure studies should be performed only when they will be of value in determining discharge conditions. This is particularly applicable to large quantities of dredged material known to contain adverse quantities of toxic materials. Community studies should include benthic organisms such as microbiota and harvestable shellfish and finfish. Abundance, diversity, and distribution should be documented and correlated with substrate type and other appropriate physical and chemical environmental characteristics.

(d) Physical tests and evaluation. The effect of a discharge of dredged or fill material on physical substrate characteristics at the disposal site, as well as on the water circulation, fluctuation, salinity, and suspended particulates content there, is important in making factual determinations in §230.11. Where information on such effects is not otherwise available to make these factual determinations, the permitting authority shall require appropriate physical tests and evaluations as are justified and deemed necessary. Such tests may include sieve tests, settleability tests, compaction tests, mixing zone and suspended particulate plume determinations, and site assessments of water flow, circulation, and salinity characteristics.

Subpart H—Actions To Minimize Adverse Effects

Note: There are many actions which can be undertaken in response to §203.10(d) to minimize the adverse effects of discharges of dredged or fill material. Some of these, grouped by type of activity, are listed in this subpart. Additional criteria for compensation measures are provided in subpart J of this part.

§ 230.70 Actions concerning the location of the discharge.

The effects of the discharge can be minimized by the choice of the disposal site. Some of the ways to accomplish this are by:

(a) Locating and confining the discharge to minimize smothering of organisms;

(b) Designing the discharge to avoid a disruption of periodic water inundation patterns;

(c) Selecting a disposal site that has been used previously for dredged material discharge;

(d) Selecting a disposal site at which the substrate is composed of material similar to that being discharged, such as discharging sand on sand or mud on mud;

(e) Selecting the disposal site, the discharge point, and the method of discharge to minimize the extent of any plume;

(f) Designing the discharge of dredged or fill material to minimize or prevent the creation of standing bodies of water in areas of normally fluctuating water levels, and minimize or prevent the drainage of areas subject to such fluctuations.

§ 230.71 Actions concerning the material to be discharged.

The effects of a discharge can be minimized by treatment of, or limitations on the material itself, such as:

(a) Disposal of dredged material in such a manner that physiochemical conditions are maintained and the potency and availability of pollutants are reduced.

(b) Limiting the solid, liquid, and gaseous components of material to be discharged at a particular site;

(c) Adding treatment substances to the discharge material;

(d) Utilizing chemical flocculants to enhance the deposition of suspended particulates in diked disposal areas.

§ 230.72 Actions controlling the material after discharge.

The effects of the dredged or fill material after discharge may be controlled by:

(a) Selecting discharge methods and disposal sites where the potential for erosion, slumping or leaching of materials into the surrounding aquatic ecosystem will be reduced. These sites or methods include, but are not limited to:

(1) Using containment levees, sediment basins, and cover crops to reduce erosion;

(2) Using lined containment areas to reduce leaching where leaching of chemical constituents from the discharged material is expected to be a problem;

(b) Capping in-place contaminated material with clean material or selectively discharging the most contaminated material first to be capped with the remaining material;

(c) Maintaining and containing discharged material properly to prevent point and nonpoint sources of pollution;

(d) Timing the discharge to minimize impact, for instance during periods of unusual high water flows, wind, wave, and tidal actions.

§ 230.73 Actions affecting the method of dispersion.

The effects of a discharge can be minimized by the manner in which it is dispersed, such as:

(a) Where environmentally desirable, distributing the dredged material widely in a thin layer at the disposal site to maintain natural substrate contours and elevation;

(b) Orienting a dredged or fill material mound to minimize undesirable obstruction to the water current or circulation pattern, and utilizing natural bottom contours to minimize the size of the mound;

(c) Using silt screens or other appropriate methods to confine suspended particulate/turbidity to a small area where settling or removal can occur;

(d) Making use of currents and circulation patterns to mix, disperse and dilute the discharge;

(e) Minimizing water column turbidity by using a submerged diffuser system. A similar effect can be accomplished by submerging pipeline discharges or otherwise releasing materials near the bottom;

(f) Selecting sites or managing discharges to confine and minimize the release of suspended particulates to give decreased turbidity levels and to maintain light penetration for organisms;

(g) Setting limitations on the amount of material to be discharged per unit of time or volume of receiving water.

§ 230.74 Actions related to technology.

Discharge technology should be adapted to the needs of each site. In determining whether the discharge operation sufficiently minimizes adverse environmental impacts, the applicant should consider:

(a) Using appropriate equipment or machinery, including protective devices, and the use of such equipment or machinery in activities related to the discharge of dredged or fill material;

(b) Employing appropriate maintenance and operation on equipment or machinery, including adequate training, staffing, and working procedures;

(c) Using machinery and techniques that are especially designed to reduce damage to wetlands. This may include machines equipped with devices that scatter rather than mound excavated materials, machines with specially designed wheels or tracks, and the use of mats under heavy machines to reduce wetland surface compaction and rutting;

(d) Designing access roads and channel spanning structures using culverts, open channels, and diversions that will pass both low and high water flows, accommodate fluctuating water levels, and maintain circulation and faunal movement;

(e) Employing appropriate machinery and methods of transport of the material for discharge.

§ 230.75 Actions affecting plant and animal populations.

Minimization of adverse effects on populations of plants and animals can be achieved by:

(a) Avoiding changes in water current and circulation patterns which would interfere with the movement of animals;

(b) Selecting sites or managing discharges to prevent or avoid creating habitat conducive to the development of undesirable predators or species which have a competitive edge ecologically over indigenous plants or animals;

(c) Avoiding sites having unique habitat or other value, including habitat of threatened or endangered species;

(d) Using planning and construction practices to institute habitat development and restoration to produce a new or modified environmental state of higher ecological value by displacement of some or all of the existing environmental characteristics. Habitat development and restoration techniques can be used to minimize adverse impacts and to compensate for destroyed habitat. Additional criteria for compensation measures are provided in subpart J of this part. Use techniques that have been demonstrated to be effective in circumstances similar to those under consideration wherever possible. Where proposed development and restoration techniques have not yet advanced to the pilot demonstration stage, initiate their use on a small scale to allow corrective action if unanticipated adverse impacts occur;

(e) Timing discharge to avoid spawning or migration seasons and other biologically critical time periods;

(f) Avoiding the destruction of remnant natural sites within areas already affected by development.

[45 FR 85344, Dec. 24, 1980, as amended at 73 FR 19687, Apr. 10, 2008]

§ 230.76 Actions affecting human use.

Minimization of adverse effects on human use potential may be achieved by:

(a) Selecting discharge sites and following discharge procedures to prevent or minimize any potential damage to the aesthetically pleasing features of the aquatic site (e.g. viewscapes), particularly with respect to water quality;

(b) Selecting disposal sites which are not valuable as natural aquatic areas;

(c) Timing the discharge to avoid the seasons or periods when human recreational activity associated with the aquatic site is most important;

(d) Following discharge procedures which avoid or minimize the disturbance of aesthetic features of an aquatic site or ecosystem;

(e) Selecting sites that will not be detrimental or increase incompatible human activity, or require the need for frequent dredge or fill maintenance activity in remote fish and wildlife areas;

(f) Locating the disposal site outside of the vicinity of a public water supply intake.

§ 230.77 Other actions.

(a) In the case of fills, controlling runoff and other discharges from activities to be conducted on the fill;

(b) In the case of dams, designing water releases to accommodate the needs of fish and wildlife;

(c) In dredging projects funded by Federal agencies other than the Corps of Engineers, maintain desired water quality of the return discharge through agreement with the Federal funding authority on scientifically defensible pollutant concentration levels in addition to any applicable water quality standards;

(d) When a significant ecological change in the aquatic environment is proposed by the discharge of dredged or fill material, the permitting authority should consider the ecosystem that will be lost as well as the environmental benefits of the new system.

Subpart I—Planning To Shorten Permit Processing Time

§ 230.80 Advanced identification of disposal areas.

(a) Consistent with these Guidelines, EPA and the permitting authority, on their own initiative or at the request of any other party and after consultation with any affected State that is not the permitting authority, may identify sites which will be considered as:

(1) Possible future disposal sites, including existing disposal sites and non-sensitive areas; or

(2) Areas generally unsuitable for disposal site specification;

(b) The identification of any area as a possible future disposal site should not be deemed to constitute a permit for the discharge of dredged or fill material within such area or a specification of a disposal site. The identification of areas that generally will not be available for disposal site specification should not be deemed as prohibiting applications for permits to discharge dredged or fill material in such areas. Either type of identification constitutes information to facilitate individual or General permit application and processing.

(c) An appropriate public notice of the proposed identification of such areas shall be issued;

(d) To provide the basis for advanced identification of disposal areas, and areas unsuitable for disposal, EPA and the permitting authority shall consider the likelihood that use of the area in question for dredged or fill material disposal will comply with these Guidelines. To facilitate this analysis, EPA and the permitting authority should review available water resources management data including data available from the public, other Federal and State agencies, and information from approved Coastal Zone Management programs and River Basin Plans;

(e) The permitting authority should maintain a public record of the identified areas and a written statement of the basis for identification.

Subpart J—Compensatory Mitigation for Losses of Aquatic Resources

Source: 73 FR 19687, Apr. 10, 2008, unless otherwise noted.

§ 230.91 Purpose and general considerations.

(a) *Purpose.* (1) The purpose of this subpart is to establish standards and criteria for the use of all types of compensatory mitigation, including on-site and off-site permittee-responsible mitigation, mitigation banks, and in-lieu fee mitigation to offset unavoidable impacts to waters of the United States authorized through the issuance of permits by the U.S. Army Corps of Engineers (Corps) pursuant to section 404 of the Clean Water Act (33 U.S.C. 1344). This subpart implements section 314(b) of the 2004 National Defense Authorization Act (Pub. L. 108–136), which directs that the standards and criteria shall, to the maximum extent practicable, maximize available credits and opportunities for mitigation, provide for regional variations in wetland conditions, functions, and values, and apply equivalent standards and criteria to each type of compensatory mitigation. This subpart is intended to further clarify mitigation requirements established under the Corps and EPA regulations at 33 CFR part 320 and this part, respectively.

(2) This subpart has been jointly developed by the Secretary of the Army, acting through the Chief of Engineers, and the Administrator of the Environmental Protection Agency. From time to time guidance on interpreting and implementing this subpart may be prepared jointly by EPA and the Corps at the national or regional level. No modifications to the basic application, meaning, or intent of this subpart will be made without further joint rulemaking by the Secretary of the Army, acting through the Chief of Engineers and the Administrator of the Environmental Protection Agency, pursuant to the Administrative Procedure Act (5 U.S.C. 551 *et seq.*).

(b) *Applicability.* This subpart does not alter the circumstances under which compensatory mitigation is required or the definition of “waters of the United States,” which is provided at §230.3(s). Use of resources as compensatory mitigation that are not otherwise subject to regulation under section 404 of the Clean Water Act does not in and of itself make them subject to such regulation.

(c) *Sequencing.* (1) Nothing in this section affects the requirement that all DA permits subject to section 404 of the Clean Water Act comply with applicable provisions of this part.

(2) Pursuant to these requirements, the district engineer will issue an individual section 404 permit only upon a determination that the proposed discharge complies with applicable provisions of 40 CFR part 230, including those which require the permit applicant to take all appropriate and practicable steps to avoid and minimize adverse impacts to waters of the United States. Practicable means available and capable of being done after taking into consideration cost, existing technology, and logistics in light of overall project purposes. Compensatory mitigation for unavoidable impacts may be required to ensure that an activity requiring a section 404 permit complies with the Section 404(b)(1) Guidelines.

(3) Compensatory mitigation for unavoidable impacts may be required to ensure that an activity requiring a section 404 permit complies with the Section 404(b)(1) Guidelines. During the 404(b)(1) Guidelines compliance analysis, the district engineer may determine that a DA permit for the proposed activity cannot be issued because of the lack of appropriate and practicable compensatory mitigation options.

(d) *Accounting for regional variations.* Where appropriate, district engineers shall account for regional characteristics of aquatic resource types, functions and services when determining performance standards and monitoring requirements for compensatory mitigation projects.

(e) *Relationship to other guidance documents.* (1) This subpart applies instead of the "Federal Guidance for the Establishment, Use, and Operation of Mitigation Banks," which was issued on November 28, 1995, the "Federal Guidance on the Use of In-Lieu Fee Arrangements for Compensatory Mitigation Under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act," which was issued on November 7, 2000, and Regulatory Guidance Letter 02–02, "Guidance on Compensatory Mitigation Projects for Aquatic Resource Impacts Under the Corps Regulatory Program Pursuant to Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899" which was issued on December 24, 2002. These guidance documents are no longer to be used as compensatory mitigation policy in the Corps Regulatory Program.

(2) In addition, this subpart also applies instead of the provisions relating to the amount, type, and location of compensatory mitigation projects, including the use of preservation, in the February 6, 1990, Memorandum of Agreement (MOA) between the Department of the Army and the Environmental Protection Agency on the Determination of Mitigation Under the Clean Water Act Section 404(b)(1) Guidelines. All other provisions of this MOA remain in effect.

§ 230.92 Definitions.

For the purposes of this subpart, the following terms are defined:

Adaptive management means the development of a management strategy that anticipates likely challenges associated with compensatory mitigation projects and provides for the implementation of actions to address those challenges, as well as unforeseen changes to those projects. It requires consideration of the risk, uncertainty, and dynamic nature of compensatory mitigation projects and guides modification of those projects to optimize performance. It includes the selection of appropriate measures that will ensure that the aquatic resource functions are provided and involves analysis of monitoring results to identify potential problems of a compensatory mitigation project and the identification and implementation of measures to rectify those problems.

Advance credits means any credits of an approved in-lieu fee program that are available for sale prior to being fulfilled in accordance with an approved mitigation project plan. Advance credit sales require an approved in-lieu fee program instrument that meets all applicable requirements including a specific allocation of advance credits, by service area where applicable. The instrument must also contain a schedule for fulfillment of advance credit sales.

Buffer means an upland, wetland, and/or riparian area that protects and/or enhances aquatic resource functions associated with wetlands, rivers, streams, lakes, marine, and estuarine systems from disturbances associated with adjacent land uses.

Compensatory mitigation means the restoration (re-establishment or rehabilitation), establishment (creation), enhancement, and/or in certain circumstances preservation of aquatic resources for the purposes of offsetting unavoidable adverse impacts which remain after all appropriate and practicable avoidance and minimization has been achieved.

Compensatory mitigation project means compensatory mitigation implemented by the permittee as a requirement of a DA permit (i.e., permittee-responsible mitigation), or by a mitigation bank or an in-lieu fee program.

Condition means the relative ability of an aquatic resource to support and maintain a community of organisms having a species composition, diversity, and functional organization comparable to reference aquatic resources in the region.

Credit means a unit of measure (e.g., a functional or areal measure or other suitable metric) representing the accrual or attainment of aquatic functions at a compensatory mitigation site. The measure of aquatic functions is based on the resources restored, established, enhanced, or preserved.

DA means Department of the Army.

Days means calendar days.

Debit means a unit of measure (e.g., a functional or areal measure or other suitable metric) representing the loss of aquatic functions at an impact or project site. The measure of aquatic functions is based on the resources impacted by the authorized activity.

Enhancement means the manipulation of the physical, chemical, or biological characteristics of an aquatic resource to heighten, intensify, or improve a specific aquatic resource function(s). Enhancement results in the gain of selected aquatic resource function(s), but may also lead to a decline in other aquatic resource function(s). Enhancement does not result in a gain in aquatic resource area.

Establishment (creation) means the manipulation of the physical, chemical, or biological characteristics present to develop an aquatic resource that did not previously exist at an upland site. Establishment results in a gain in aquatic resource area and functions.

Fulfillment of advance credit sales of an in-lieu fee program means application of credits released in accordance with a credit release schedule in an approved mitigation project plan to satisfy the mitigation requirements represented by the advance credits. Only after any advance credit sales within a service area have been fulfilled through the application of released credits from an in-lieu fee project (in accordance with the credit release schedule for an approved mitigation project plan), may additional released credits from that project be sold or transferred to permittees. When advance credits are fulfilled, an equal number of new advance credits is restored to the program sponsor for sale or transfer to permit applicants.

Functional capacity means the degree to which an area of aquatic resource performs a specific function.

Functions means the physical, chemical, and biological processes that occur in ecosystems.

Impact means adverse effect.

In-kind means a resource of a similar structural and functional type to the impacted resource.

In-lieu fee program means a program involving the restoration, establishment, enhancement, and/or preservation of aquatic resources through funds paid to a governmental or non-profit natural resources management entity to satisfy compensatory mitigation requirements for DA permits. Similar to a mitigation bank, an in-lieu fee program sells compensatory mitigation credits to permittees whose obligation to provide compensatory mitigation is then transferred to the in-lieu program sponsor. However, the rules governing the operation and use of in-lieu fee programs are somewhat different from the rules governing operation and use of mitigation banks. The operation and use of an in-lieu fee program are governed by an in-lieu fee program instrument.

In-lieu fee program instrument means the legal document for the establishment, operation, and use of an in-lieu fee program.

Instrument means mitigation banking instrument or in-lieu fee program instrument.

Interagency Review Team (IRT) means an interagency group of federal, tribal, state, and/or local regulatory and resource agency representatives that reviews documentation for, and advises the district engineer on, the establishment and management of a mitigation bank or an in-lieu fee program.

Mitigation bank means a site, or suite of sites, where resources (e.g., wetlands, streams, riparian areas) are restored, established, enhanced, and/or preserved for the purpose of providing compensatory mitigation for impacts authorized by DA permits. In general, a mitigation bank sells compensatory mitigation credits to permittees whose obligation to provide compensatory mitigation is then transferred to the mitigation bank sponsor. The operation and use of a mitigation bank are governed by a mitigation banking instrument.

Mitigation banking instrument means the legal document for the establishment, operation, and use of a mitigation bank.

Off-site means an area that is neither located on the same parcel of land as the impact site, nor on a parcel of land contiguous to the parcel containing the impact site.

On-site means an area located on the same parcel of land as the impact site, or on a parcel of land contiguous to the impact site.

Out-of-kind means a resource of a different structural and functional type from the impacted resource.

Performance standards are observable or measurable physical (including hydrological), chemical and/or biological attributes that are used to determine if a compensatory mitigation project meets its objectives.

Permittee-responsible mitigation means an aquatic resource restoration, establishment, enhancement, and/or preservation activity undertaken by the permittee (or an authorized agent or contractor) to provide compensatory mitigation for which the permittee retains full responsibility.

Preservation means the removal of a threat to, or preventing the decline of, aquatic resources by an action in or near those aquatic resources. This term includes activities commonly associated with the protection and maintenance of aquatic resources through the implementation of appropriate legal and physical mechanisms. Preservation does not result in a gain of aquatic resource area or functions.

Re-establishment means the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former aquatic resource. Re-establishment results in rebuilding a former aquatic resource and results in a gain in aquatic resource area and functions.

Reference aquatic resources are a set of aquatic resources that represent the full range of variability exhibited by a regional class of aquatic resources as a result of natural processes and anthropogenic disturbances.

Rehabilitation means the manipulation of the physical, chemical, or biological characteristics of a site with the goal of repairing natural/historic functions to a degraded aquatic resource. Rehabilitation results in a gain in aquatic resource function, but does not result in a gain in aquatic resource area.

Release of credits means a determination by the district engineer, in consultation with the IRT, that credits associated with an approved mitigation plan are available for sale or transfer, or in the case of an in-lieu fee program, for fulfillment of advance credit sales. A proportion of projected credits for a specific mitigation bank or in-lieu fee project may be released upon approval of the mitigation plan, with additional credits released as milestones specified in the credit release schedule are achieved.

Restoration means the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded aquatic resource. For the purpose of tracking net gains in aquatic resource area, restoration is divided into two categories: re-establishment and rehabilitation.

Riparian areas are lands adjacent to streams, rivers, lakes, and estuarine-marine shorelines. Riparian areas provide a variety of ecological functions and services and help improve or maintain local water quality.

Service area means the geographic area within which impacts can be mitigated at a specific mitigation bank or an in-lieu fee program, as designated in its instrument.

Services mean the benefits that human populations receive from functions that occur in ecosystems.

Sponsor means any public or private entity responsible for establishing, and in most circumstances, operating a mitigation bank or in-lieu fee program.

Standard permit means a standard, individual permit issued under the authority of section 404 of the Clean Water Act.

Temporal loss is the time lag between the loss of aquatic resource functions caused by the permitted impacts and the replacement of aquatic resource functions at the compensatory mitigation site. Higher compensation ratios may be required to compensate for temporal loss. When the compensatory mitigation project is initiated prior to, or concurrent with, the permitted impacts, the district engineer may determine that compensation for temporal loss is not necessary, unless the resource has a long development time.

Watershed means a land area that drains to a common waterway, such as a stream, lake, estuary, wetland, or ultimately the ocean.

Watershed approach means an analytical process for making compensatory mitigation decisions that support the sustainability or improvement of aquatic resources in a watershed. It involves consideration of watershed needs, and how locations and types of compensatory mitigation projects address those needs. A landscape perspective is used to identify the types and locations of compensatory mitigation projects that will benefit the watershed and offset losses of aquatic resource functions and services caused by activities authorized by DA permits. The watershed approach may involve consideration of landscape scale, historic and potential aquatic resource conditions, past and projected aquatic resource impacts in the watershed, and terrestrial connections between aquatic resources when determining compensatory mitigation requirements for DA permits.

Watershed plan means a plan developed by federal, tribal, state, and/or local government agencies or appropriate non-governmental organizations, in consultation with relevant stakeholders, for the specific goal of aquatic resource restoration, establishment, enhancement, and preservation. A watershed plan addresses aquatic resource conditions in the watershed, multiple stakeholder interests, and land uses. Watershed plans may also identify priority sites for aquatic resource restoration and protection. Examples of watershed plans include special area management plans, advance identification programs, and wetland management plans.

§ 230.93 General compensatory mitigation requirements.

(a) *General considerations.* (1) The fundamental objective of compensatory mitigation is to offset environmental losses resulting from unavoidable impacts to waters of the United States authorized by DA permits. The district engineer must determine the compensatory mitigation to be required in a DA permit, based on what is practicable and capable of compensating for the aquatic resource functions that will be lost as a result of the permitted activity. When evaluating compensatory mitigation options, the district engineer will consider what would be environmentally preferable. In making this determination, the district engineer must assess the likelihood for ecological success and sustainability, the location of the compensation site relative to the impact site and their significance within the watershed, and the costs of the compensatory mitigation project. In many cases, the environmentally preferable compensatory mitigation may be provided through mitigation banks or in-lieu fee programs because they usually involve consolidating compensatory mitigation projects where ecologically appropriate, consolidating resources, providing financial planning and scientific expertise (which often is not practical for permittee-responsible compensatory mitigation projects), reducing temporal losses of functions, and reducing uncertainty over project success. Compensatory mitigation requirements must be commensurate with the amount and type of impact that is associated with a particular DA permit. Permit applicants are responsible for proposing an appropriate compensatory mitigation option to offset unavoidable impacts.

(2) Compensatory mitigation may be performed using the methods of restoration, enhancement, establishment, and in certain circumstances preservation. Restoration should generally be the first option considered because the likelihood of success is greater and the impacts to potentially ecologically important uplands are reduced compared to establishment, and the potential gains in terms of aquatic resource functions are greater, compared to enhancement and preservation.

(3) Compensatory mitigation projects may be sited on public or private lands. Credits for compensatory mitigation projects on public land must be based solely on aquatic resource functions provided by the compensatory mitigation project, over and above those provided by public programs already planned or in place. All compensatory mitigation projects must comply with the standards in this part, if they are to be used to provide compensatory mitigation for activities authorized by DA permits, regardless of whether they are sited on public or private lands and whether the sponsor is a governmental or private entity.

(b) *Type and location of compensatory mitigation.* (1) When considering options for successfully providing the required compensatory mitigation, the district engineer shall consider the type and location options in the order presented in paragraphs (b)(2) through (b)(6) of this section. In general, the required compensatory mitigation should be located within the same watershed as the impact site, and should be located where it is most likely to successfully replace lost functions and services, taking into account such watershed scale features as aquatic habitat diversity, habitat connectivity, relationships to hydrologic sources (including the availability of water rights), trends in land use, ecological benefits, and compatibility with adjacent land uses. When compensating for impacts to marine resources, the location of the compensatory mitigation site should be chosen to replace lost functions and services within the same marine ecological system (e.g., reef complex, littoral drift cell). Compensation for impacts to aquatic resources in coastal watersheds (watersheds that include a tidal water body) should also be located in a coastal watershed where practicable. Compensatory mitigation projects should not

be located where they will increase risks to aviation by attracting wildlife to areas where aircraft-wildlife strikes may occur (e.g., near airports).

(2) *Mitigation bank credits.* When permitted impacts are located within the service area of an approved mitigation bank, and the bank has the appropriate number and resource type of credits available, the permittee's compensatory mitigation requirements may be met by securing those credits from the sponsor. Since an approved instrument (including an approved mitigation plan and appropriate real estate and financial assurances) for a mitigation bank is required to be in place before its credits can begin to be used to compensate for authorized impacts, use of a mitigation bank can help reduce risk and uncertainty, as well as temporal loss of resource functions and services. Mitigation bank credits are not released for debiting until specific milestones associated with the mitigation bank site's protection and development are achieved, thus use of mitigation bank credits can also help reduce risk that mitigation will not be fully successful. Mitigation banks typically involve larger, more ecologically valuable parcels, and more rigorous scientific and technical analysis, planning and implementation than permittee-responsible mitigation. Also, development of a mitigation bank requires site identification in advance, project-specific planning, and significant investment of financial resources that is often not practicable for many in-lieu fee programs. For these reasons, the district engineer should give preference to the use of mitigation bank credits when these considerations are applicable. However, these same considerations may also be used to override this preference, where appropriate, as, for example, where an in-lieu fee program has released credits available from a specific approved in-lieu fee project, or a permittee-responsible project will restore an outstanding resource based on rigorous scientific and technical analysis.

(3) *In-lieu fee program credits.* Where permitted impacts are located within the service area of an approved in-lieu fee program, and the sponsor has the appropriate number and resource type of credits available, the permittee's compensatory mitigation requirements may be met by securing those credits from the sponsor. Where permitted impacts are not located in the service area of an approved mitigation bank, or the approved mitigation bank does not have the appropriate number and resource type of credits available to offset those impacts, in-lieu fee mitigation, if available, is generally preferable to permittee-responsible mitigation. In-lieu fee projects typically involve larger, more ecologically valuable parcels, and more rigorous scientific and technical analysis, planning and implementation than permittee-responsible mitigation. They also devote significant resources to identifying and addressing high-priority resource needs on a watershed scale, as reflected in their compensation planning framework. For these reasons, the district engineer should give preference to in-lieu fee program credits over permittee-responsible mitigation, where these considerations are applicable. However, as with the preference for mitigation bank credits, these same considerations may be used to override this preference where appropriate. Additionally, in cases where permittee-responsible mitigation is likely to successfully meet performance standards before advance credits secured from an in-lieu fee program are fulfilled, the district engineer should also give consideration to this factor in deciding between in-lieu fee mitigation and permittee-responsible mitigation.

(4) *Permittee-responsible mitigation under a watershed approach.* Where permitted impacts are not in the service area of an approved mitigation bank or in-lieu fee program that has the appropriate number and resource type of credits available, permittee-responsible mitigation is the

only option. Where practicable and likely to be successful and sustainable, the resource type and location for the required permittee-responsible compensatory mitigation should be determined using the principles of a watershed approach as outlined in paragraph (c) of this section.

(5) *Permittee-responsible mitigation through on-site and in-kind mitigation.* In cases where a watershed approach is not practicable, the district engineer should consider opportunities to offset anticipated aquatic resource impacts by requiring on-site and in-kind compensatory mitigation. The district engineer must also consider the practicability of on-site compensatory mitigation and its compatibility with the proposed project.

(6) *Permittee-responsible mitigation through off-site and/or out-of-kind mitigation.* If, after considering opportunities for on-site, in-kind compensatory mitigation as provided in paragraph (b)(5) of this section, the district engineer determines that these compensatory mitigation opportunities are not practicable, are unlikely to compensate for the permitted impacts, or will be incompatible with the proposed project, and an alternative, practicable off-site and/or out-of-kind mitigation opportunity is identified that has a greater likelihood of offsetting the permitted impacts or is environmentally preferable to on-site or in-kind mitigation, the district engineer should require that this alternative compensatory mitigation be provided.

(c) *Watershed approach to compensatory mitigation.* (1) The district engineer must use a watershed approach to establish compensatory mitigation requirements in DA permits to the extent appropriate and practicable. Where a watershed plan is available, the district engineer will determine whether the plan is appropriate for use in the watershed approach for compensatory mitigation. In cases where the district engineer determines that an appropriate watershed plan is available, the watershed approach should be based on that plan. Where no such plan is available, the watershed approach should be based on information provided by the project sponsor or available from other sources. The ultimate goal of a watershed approach is to maintain and improve the quality and quantity of aquatic resources within watersheds through strategic selection of compensatory mitigation sites.

(2) *Considerations.* (i) A watershed approach to compensatory mitigation considers the importance of landscape position and resource type of compensatory mitigation projects for the sustainability of aquatic resource functions within the watershed. Such an approach considers how the types and locations of compensatory mitigation projects will provide the desired aquatic resource functions, and will continue to function over time in a changing landscape. It also considers the habitat requirements of important species, habitat loss or conversion trends, sources of watershed impairment, and current development trends, as well as the requirements of other regulatory and non-regulatory programs that affect the watershed, such as storm water management or habitat conservation programs. It includes the protection and maintenance of terrestrial resources, such as non-wetland riparian areas and uplands, when those resources contribute to or improve the overall ecological functioning of aquatic resources in the watershed. Compensatory mitigation requirements determined through the watershed approach should not focus exclusively on specific functions (e.g., water quality or habitat for certain species), but should provide, where practicable, the suite of functions typically provided by the affected aquatic resource.

(ii) Locational factors (e.g., hydrology, surrounding land use) are important to the success of compensatory mitigation for impacted habitat functions and may lead to siting of such mitigation away from the project area. However, consideration should also be given to functions and services (e.g., water quality, flood control, shoreline protection) that will likely need to be addressed at or near the areas impacted by the permitted impacts.

(iii) A watershed approach may include on-site compensatory mitigation, off-site compensatory mitigation (including mitigation banks or in-lieu fee programs), or a combination of on-site and off-site compensatory mitigation.

(iv) A watershed approach to compensatory mitigation should include, to the extent practicable, inventories of historic and existing aquatic resources, including identification of degraded aquatic resources, and identification of immediate and long-term aquatic resource needs within watersheds that can be met through permittee-responsible mitigation projects, mitigation banks, or in-lieu fee programs. Planning efforts should identify and prioritize aquatic resource restoration, establishment, and enhancement activities, and preservation of existing aquatic resources that are important for maintaining or improving ecological functions of the watershed. The identification and prioritization of resource needs should be as specific as possible, to enhance the usefulness of the approach in determining compensatory mitigation requirements.

(v) A watershed approach is not appropriate in areas where watershed boundaries do not exist, such as marine areas. In such cases, an appropriate spatial scale should be used to replace lost functions and services within the same ecological system (e.g., reef complex, littoral drift cell).

(3) *Information Needs.* (i) In the absence of a watershed plan determined by the district engineer under paragraph (c)(1) of this section to be appropriate for use in the watershed approach, the district engineer will use a watershed approach based on analysis of information regarding watershed conditions and needs, including potential sites for aquatic resource restoration activities and priorities for aquatic resource restoration and preservation. Such information includes: Current trends in habitat loss or conversion; cumulative impacts of past development activities, current development trends, the presence and needs of sensitive species; site conditions that favor or hinder the success of compensatory mitigation projects; and chronic environmental problems such as flooding or poor water quality.

(ii) This information may be available from sources such as wetland maps; soil surveys; U.S. Geological Survey topographic and hydrologic maps; aerial photographs; information on rare, endangered and threatened species and critical habitat; local ecological reports or studies; and other information sources that could be used to identify locations for suitable compensatory mitigation projects in the watershed.

(iii) The level of information and analysis needed to support a watershed approach must be commensurate with the scope and scale of the proposed impacts requiring a DA permit, as well as the functions lost as a result of those impacts.

(4) *Watershed Scale.* The size of watershed addressed using a watershed approach should not be larger than is appropriate to ensure that the aquatic resources provided through compensation

activities will effectively compensate for adverse environmental impacts resulting from activities authorized by DA permits. The district engineer should consider relevant environmental factors and appropriate locally-developed standards and criteria when determining the appropriate watershed scale in guiding compensation activities.

(d) *Site selection.* (1) The compensatory mitigation project site must be ecologically suitable for providing the desired aquatic resource functions. In determining the ecological suitability of the compensatory mitigation project site, the district engineer must consider, to the extent practicable, the following factors:

(i) Hydrological conditions, soil characteristics, and other physical and chemical characteristics;

(ii) Watershed-scale features, such as aquatic habitat diversity, habitat connectivity, and other landscape scale functions;

(iii) The size and location of the compensatory mitigation site relative to hydrologic sources (including the availability of water rights) and other ecological features;

(iv) Compatibility with adjacent land uses and watershed management plans;

(v) Reasonably foreseeable effects the compensatory mitigation project will have on ecologically important aquatic or terrestrial resources (e.g., shallow sub-tidal habitat, mature forests), cultural sites, or habitat for federally- or state-listed threatened and endangered species; and

(vi) Other relevant factors including, but not limited to, development trends, anticipated land use changes, habitat status and trends, the relative locations of the impact and mitigation sites in the stream network, local or regional goals for the restoration or protection of particular habitat types or functions (e.g., re-establishment of habitat corridors or habitat for species of concern), water quality goals, floodplain management goals, and the relative potential for chemical contamination of the aquatic resources.

(2) District engineers may require on-site, off-site, or a combination of on-site and off-site compensatory mitigation to replace permitted losses of aquatic resource functions and services.

(3) Applicants should propose compensation sites adjacent to existing aquatic resources or where aquatic resources previously existed.

(e) *Mitigation type.* (1) In general, in-kind mitigation is preferable to out-of-kind mitigation because it is most likely to compensate for the functions and services lost at the impact site. For example, tidal wetland compensatory mitigation projects are most likely to compensate for unavoidable impacts to tidal wetlands, while perennial stream compensatory mitigation projects are most likely to compensate for unavoidable impacts to perennial streams. Thus, except as provided in paragraph (e)(2) of this section, the required compensatory mitigation shall be of a similar type to the affected aquatic resource.

(2) If the district engineer determines, using the watershed approach in accordance with paragraph (c) of this section that out-of-kind compensatory mitigation will serve the aquatic resource needs of the watershed, the district engineer may authorize the use of such out-of-kind compensatory mitigation. The basis for authorization of out-of-kind compensatory mitigation must be documented in the administrative record for the permit action.

(3) For difficult-to-replace resources (e.g., bogs, fens, springs, streams, Atlantic white cedar swamps) if further avoidance and minimization is not practicable, the required compensation should be provided, if practicable, through in-kind rehabilitation, enhancement, or preservation since there is greater certainty that these methods of compensation will successfully offset permitted impacts.

(f) *Amount of compensatory mitigation.* (1) If the district engineer determines that compensatory mitigation is necessary to offset unavoidable impacts to aquatic resources, the amount of required compensatory mitigation must be, to the extent practicable, sufficient to replace lost aquatic resource functions. In cases where appropriate functional or condition assessment methods or other suitable metrics are available, these methods should be used where practicable to determine how much compensatory mitigation is required. If a functional or condition assessment or other suitable metric is not used, a minimum one-to-one acreage or linear foot compensation ratio must be used.

(2) The district engineer must require a mitigation ratio greater than one-to-one where necessary to account for the method of compensatory mitigation (e.g., preservation), the likelihood of success, differences between the functions lost at the impact site and the functions expected to be produced by the compensatory mitigation project, temporal losses of aquatic resource functions, the difficulty of restoring or establishing the desired aquatic resource type and functions, and/or the distance between the affected aquatic resource and the compensation site. The rationale for the required replacement ratio must be documented in the administrative record for the permit action.

(3) If an in-lieu fee program will be used to provide the required compensatory mitigation, and the appropriate number and resource type of released credits are not available, the district engineer must require sufficient compensation to account for the risk and uncertainty associated with in-lieu fee projects that have not been implemented before the permitted impacts have occurred.

(g) *Use of mitigation banks and in-lieu fee programs.* Mitigation banks and in-lieu fee programs may be used to compensate for impacts to aquatic resources authorized by general permits and individual permits, including after-the-fact permits, in accordance with the preference hierarchy in paragraph (b) of this section. Mitigation banks and in-lieu fee programs may also be used to satisfy requirements arising out of an enforcement action, such as supplemental environmental projects.

(h) *Preservation.* (1) Preservation may be used to provide compensatory mitigation for activities authorized by DA permits when all the following criteria are met:

(i) The resources to be preserved provide important physical, chemical, or biological functions for the watershed;

(ii) The resources to be preserved contribute significantly to the ecological sustainability of the watershed. In determining the contribution of those resources to the ecological sustainability of the watershed, the district engineer must use appropriate quantitative assessment tools, where available;

(iii) Preservation is determined by the district engineer to be appropriate and practicable;

(iv) The resources are under threat of destruction or adverse modifications; and

(v) The preserved site will be permanently protected through an appropriate real estate or other legal instrument (e.g., easement, title transfer to state resource agency or land trust).

(2) Where preservation is used to provide compensatory mitigation, to the extent appropriate and practicable the preservation shall be done in conjunction with aquatic resource restoration, establishment, and/or enhancement activities. This requirement may be waived by the district engineer where preservation has been identified as a high priority using a watershed approach described in paragraph (c) of this section, but compensation ratios shall be higher.

(i) *Buffers.* District engineers may require the restoration, establishment, enhancement, and preservation, as well as the maintenance, of riparian areas and/or buffers around aquatic resources where necessary to ensure the long-term viability of those resources. Buffers may also provide habitat or corridors necessary for the ecological functioning of aquatic resources. If buffers are required by the district engineer as part of the compensatory mitigation project, compensatory mitigation credit will be provided for those buffers.

(j) *Relationship to other federal, tribal, state, and local programs.* (1) Compensatory mitigation projects for DA permits may also be used to satisfy the environmental requirements of other programs, such as tribal, state, or local wetlands regulatory programs, other federal programs such as the Surface Mining Control and Reclamation Act, Corps civil works projects, and Department of Defense military construction projects, consistent with the terms and requirements of these programs and subject to the following considerations:

(i) The compensatory mitigation project must include appropriate compensation required by the DA permit for unavoidable impacts to aquatic resources authorized by that permit.

(ii) Under no circumstances may the same credits be used to provide mitigation for more than one permitted activity. However, where appropriate, compensatory mitigation projects, including mitigation banks and in-lieu fee projects, may be designed to holistically address requirements under multiple programs and authorities for the same activity.

(2) Except for projects undertaken by federal agencies, or where federal funding is specifically authorized to provide compensatory mitigation, federally-funded aquatic resource restoration or conservation projects undertaken for purposes other than compensatory mitigation, such as the

Wetlands Reserve Program, Conservation Reserve Program, and Partners for Wildlife Program activities, cannot be used for the purpose of generating compensatory mitigation credits for activities authorized by DA permits. However, compensatory mitigation credits may be generated by activities undertaken in conjunction with, but supplemental to, such programs in order to maximize the overall ecological benefits of the restoration or conservation project.

(3) Compensatory mitigation projects may also be used to provide compensatory mitigation under the Endangered Species Act or for Habitat Conservation Plans, as long as they comply with the requirements of paragraph (j)(1) of this section.

(k) *Permit conditions.* (1) The compensatory mitigation requirements for a DA permit, including the amount and type of compensatory mitigation, must be clearly stated in the special conditions of the individual permit or general permit verification (see 33 CFR 325.4 and 330.6(a)). The special conditions must be enforceable.

(2) For an individual permit that requires permittee-responsible mitigation, the special conditions must:

(i) Identify the party responsible for providing the compensatory mitigation;

(ii) Incorporate, by reference, the final mitigation plan approved by the district engineer;

(iii) State the objectives, performance standards, and monitoring required for the compensatory mitigation project, unless they are provided in the approved final mitigation plan; and

(iv) Describe any required financial assurances or long-term management provisions for the compensatory mitigation project, unless they are specified in the approved final mitigation plan.

(3) For a general permit activity that requires permittee-responsible compensatory mitigation, the special conditions must describe the compensatory mitigation proposal, which may be either conceptual or detailed. The general permit verification must also include a special condition that states that the permittee cannot commence work in waters of the United States until the district engineer approves the final mitigation plan, unless the district engineer determines that such a special condition is not practicable and not necessary to ensure timely completion of the required compensatory mitigation. To the extent appropriate and practicable, special conditions of the general permit verification should also address the requirements of paragraph (k)(2) of this section.

(4) If a mitigation bank or in-lieu fee program is used to provide the required compensatory mitigation, the special conditions must indicate whether a mitigation bank or in-lieu fee program will be used, and specify the number and resource type of credits the permittee is required to secure. In the case of an individual permit, the special condition must also identify the specific mitigation bank or in-lieu fee program that will be used. For general permit verifications, the special conditions may either identify the specific mitigation bank or in-lieu fee program, or state that the specific mitigation bank or in-lieu fee program used to provide the required compensatory mitigation must be approved by the district engineer before the credits are secured.

(l) *Party responsible for compensatory mitigation.* (1) For permittee-responsible mitigation, the special conditions of the DA permit must clearly indicate the party or parties responsible for the implementation, performance, and long-term management of the compensatory mitigation project.

(2) For mitigation banks and in-lieu fee programs, the instrument must clearly indicate the party or parties responsible for the implementation, performance, and long-term management of the compensatory mitigation project(s). The instrument must also contain a provision expressing the sponsor's agreement to assume responsibility for a permittee's compensatory mitigation requirements, once that permittee has secured the appropriate number and resource type of credits from the sponsor and the district engineer has received the documentation described in paragraph (l)(3) of this section.

(3) If use of a mitigation bank or in-lieu fee program is approved by the district engineer to provide part or all of the required compensatory mitigation for a DA permit, the permittee retains responsibility for providing the compensatory mitigation until the appropriate number and resource type of credits have been secured from a sponsor and the district engineer has received documentation that confirms that the sponsor has accepted the responsibility for providing the required compensatory mitigation. This documentation may consist of a letter or form signed by the sponsor, with the permit number and a statement indicating the number and resource type of credits that have been secured from the sponsor. Copies of this documentation will be retained in the administrative records for both the permit and the instrument. If the sponsor fails to provide the required compensatory mitigation, the district engineer may pursue measures against the sponsor to ensure compliance.

(m) *Timing.* Implementation of the compensatory mitigation project shall be, to the maximum extent practicable, in advance of or concurrent with the activity causing the authorized impacts. The district engineer shall require, to the extent appropriate and practicable, additional compensatory mitigation to offset temporal losses of aquatic functions that will result from the permitted activity.

(n) *Financial assurances.* (1) The district engineer shall require sufficient financial assurances to ensure a high level of confidence that the compensatory mitigation project will be successfully completed, in accordance with applicable performance standards. In cases where an alternate mechanism is available to ensure a high level of confidence that the compensatory mitigation will be provided and maintained (e.g., a formal, documented commitment from a government agency or public authority) the district engineer may determine that financial assurances are not necessary for that compensatory mitigation project.

(2) The amount of the required financial assurances must be determined by the district engineer, in consultation with the project sponsor, and must be based on the size and complexity of the compensatory mitigation project, the degree of completion of the project at the time of project approval, the likelihood of success, the past performance of the project sponsor, and any other factors the district engineer deems appropriate. Financial assurances may be in the form of performance bonds, escrow accounts, casualty insurance, letters of credit, legislative appropriations for government sponsored projects, or other appropriate instruments, subject to

the approval of the district engineer. The rationale for determining the amount of the required financial assurances must be documented in the administrative record for either the DA permit or the instrument. In determining the assurance amount, the district engineer shall consider the cost of providing replacement mitigation, including costs for land acquisition, planning and engineering, legal fees, mobilization, construction, and monitoring.

(3) If financial assurances are required, the DA permit must include a special condition requiring the financial assurances to be in place prior to commencing the permitted activity.

(4) Financial assurances shall be phased out once the compensatory mitigation project has been determined by the district engineer to be successful in accordance with its performance standards. The DA permit or instrument must clearly specify the conditions under which the financial assurances are to be released to the permittee, sponsor, and/or other financial assurance provider, including, as appropriate, linkage to achievement of performance standards, adaptive management, or compliance with special conditions.

(5) A financial assurance must be in a form that ensures that the district engineer will receive notification at least 120 days in advance of any termination or revocation. For third-party assurance providers, this may take the form of a contractual requirement for the assurance provider to notify the district engineer at least 120 days before the assurance is revoked or terminated.

(6) Financial assurances shall be payable at the direction of the district engineer to his designee or to a standby trust agreement. When a standby trust is used (*e.g.* , with performance bonds or letters of credit) all amounts paid by the financial assurance provider shall be deposited directly into the standby trust fund for distribution by the trustee in accordance with the district engineer's instructions.

(o) *Compliance with applicable law.* The compensatory mitigation project must comply with all applicable federal, state, and local laws. The DA permit, mitigation banking instrument, or in-lieu fee program instrument must not require participation by the Corps or any other federal agency in project management, including receipt or management of financial assurances or long-term financing mechanisms, except as determined by the Corps or other agency to be consistent with its statutory authority, mission, and priorities.

§ 230.94 Planning and documentation.

(a) *Pre-application consultations.* Potential applicants for standard permits are encouraged to participate in pre-application meetings with the Corps and appropriate agencies to discuss potential mitigation requirements and information needs.

(b) *Public review and comment.* (1) For an activity that requires a standard DA permit pursuant to section 404 of the Clean Water Act, the public notice for the proposed activity must contain a statement explaining how impacts associated with the proposed activity are to be avoided, minimized, and compensated for. This explanation shall address, to the extent that such information is provided in the mitigation statement required by 33 CFR 325.1(d)(7), the

proposed avoidance and minimization and the amount, type, and location of any proposed compensatory mitigation, including any out-of-kind compensation, or indicate an intention to use an approved mitigation bank or in-lieu fee program. The level of detail provided in the public notice must be commensurate with the scope and scale of the impacts. The notice shall not include information that the district engineer and the permittee believe should be kept confidential for business purposes, such as the exact location of a proposed mitigation site that has not yet been secured. The permittee must clearly identify any information being claimed as confidential in the mitigation statement when submitted. In such cases, the notice must still provide enough information to enable the public to provide meaningful comment on the proposed mitigation.

(2) For individual permits, district engineers must consider any timely comments and recommendations from other federal agencies; tribal, state, or local governments; and the public.

(3) For activities authorized by letters of permission or general permits, the review and approval process for compensatory mitigation proposals and plans must be conducted in accordance with the terms and conditions of those permits and applicable regulations including the applicable provisions of this part.

(c) *Mitigation plan.* (1) *Preparation and Approval.* (i) For individual permits, the permittee must prepare a draft mitigation plan and submit it to the district engineer for review. After addressing any comments provided by the district engineer, the permittee must prepare a final mitigation plan, which must be approved by the district engineer prior to issuing the individual permit. The approved final mitigation plan must be incorporated into the individual permit by reference. The final mitigation plan must include the items described in paragraphs (c)(2) through (c)(14) of this section, but the level of detail of the mitigation plan should be commensurate with the scale and scope of the impacts. As an alternative, the district engineer may determine that it would be more appropriate to address any of the items described in paragraphs (c)(2) through (c)(14) of this section as permit conditions, instead of components of a compensatory mitigation plan. For permittees who intend to fulfill their compensatory mitigation obligations by securing credits from approved mitigation banks or in-lieu fee programs, their mitigation plans need include only the items described in paragraphs (c)(5) and (c)(6) of this section, and the name of the specific mitigation bank or in-lieu fee program to be used.

(ii) For general permits, if compensatory mitigation is required, the district engineer may approve a conceptual or detailed compensatory mitigation plan to meet required time frames for general permit verifications, but a final mitigation plan incorporating the elements in paragraphs (c)(2) through (c)(14) of this section, at a level of detail commensurate with the scale and scope of the impacts, must be approved by the district engineer before the permittee commences work in waters of the United States. As an alternative, the district engineer may determine that it would be more appropriate to address any of the items described in paragraphs (c)(2) through (c)(14) of this section as permit conditions, instead of components of a compensatory mitigation plan. For permittees who intend to fulfill their compensatory mitigation obligations by securing credits from approved mitigation banks or in-lieu fee programs, their mitigation plans need include only the items described in paragraphs (c)(5) and (c)(6) of this section, and either the name of the specific mitigation bank or in-lieu fee program to be used or a statement indicating

that a mitigation bank or in-lieu fee program will be used (contingent upon approval by the district engineer).

(iii) Mitigation banks and in-lieu fee programs must prepare a mitigation plan including the items in paragraphs (c)(2) through (c)(14) of this section for each separate compensatory mitigation project site. For mitigation banks and in-lieu fee programs, the preparation and approval process for mitigation plans is described in §230.98.

(2) *Objectives.* A description of the resource type(s) and amount(s) that will be provided, the method of compensation (i.e., restoration, establishment, enhancement, and/or preservation), and the manner in which the resource functions of the compensatory mitigation project will address the needs of the watershed, ecoregion, physiographic province, or other geographic area of interest.

(3) *Site selection.* A description of the factors considered during the site selection process. This should include consideration of watershed needs, on-site alternatives where applicable, and the practicability of accomplishing ecologically self-sustaining aquatic resource restoration, establishment, enhancement, and/or preservation at the compensatory mitigation project site. (See §230.93(d).)

(4) *Site protection instrument.* A description of the legal arrangements and instrument, including site ownership, that will be used to ensure the long-term protection of the compensatory mitigation project site (see §230.97(a)).

(5) *Baseline information.* A description of the ecological characteristics of the proposed compensatory mitigation project site and, in the case of an application for a DA permit, the impact site. This may include descriptions of historic and existing plant communities, historic and existing hydrology, soil conditions, a map showing the locations of the impact and mitigation site(s) or the geographic coordinates for those site(s), and other site characteristics appropriate to the type of resource proposed as compensation. The baseline information should also include a delineation of waters of the United States on the proposed compensatory mitigation project site. A prospective permittee planning to secure credits from an approved mitigation bank or in-lieu fee program only needs to provide baseline information about the impact site, not the mitigation bank or in-lieu fee project site.

(6) *Determination of credits.* A description of the number of credits to be provided, including a brief explanation of the rationale for this determination. (See §230.93(f).)

(i) For permittee-responsible mitigation, this should include an explanation of how the compensatory mitigation project will provide the required compensation for unavoidable impacts to aquatic resources resulting from the permitted activity.

(ii) For permittees intending to secure credits from an approved mitigation bank or in-lieu fee program, it should include the number and resource type of credits to be secured and how these were determined.

(7) *Mitigation work plan.* Detailed written specifications and work descriptions for the compensatory mitigation project, including, but not limited to, the geographic boundaries of the project; construction methods, timing, and sequence; source(s) of water, including connections to existing waters and uplands; methods for establishing the desired plant community; plans to control invasive plant species; the proposed grading plan, including elevations and slopes of the substrate; soil management; and erosion control measures. For stream compensatory mitigation projects, the mitigation work plan may also include other relevant information, such as planform geometry, channel form (e.g., typical channel cross-sections), watershed size, design discharge, and riparian area plantings.

(8) *Maintenance plan.* A description and schedule of maintenance requirements to ensure the continued viability of the resource once initial construction is completed.

(9) *Performance standards.* Ecologically-based standards that will be used to determine whether the compensatory mitigation project is achieving its objectives. (See §230.95.)

(10) *Monitoring requirements.* A description of parameters to be monitored in order to determine if the compensatory mitigation project is on track to meet performance standards and if adaptive management is needed. A schedule for monitoring and reporting on monitoring results to the district engineer must be included. (See §230.96.)

(11) *Long-term management plan.* A description of how the compensatory mitigation project will be managed after performance standards have been achieved to ensure the long-term sustainability of the resource, including long-term financing mechanisms and the party responsible for long-term management. (See §230.97(d).)

(12) *Adaptive management plan.* A management strategy to address unforeseen changes in site conditions or other components of the compensatory mitigation project, including the party or parties responsible for implementing adaptive management measures. The adaptive management plan will guide decisions for revising compensatory mitigation plans and implementing measures to address both foreseeable and unforeseen circumstances that adversely affect compensatory mitigation success. (See §230.97(c).)

(13) *Financial assurances.* A description of financial assurances that will be provided and how they are sufficient to ensure a high level of confidence that the compensatory mitigation project will be successfully completed, in accordance with its performance standards (see §230.93(n)).

(14) *Other information.* The district engineer may require additional information as necessary to determine the appropriateness, feasibility, and practicability of the compensatory mitigation project.

§ 230.95 Ecological performance standards.

(a) The approved mitigation plan must contain performance standards that will be used to assess whether the project is achieving its objectives. Performance standards should relate to the objectives of the compensatory mitigation project, so that the project can be objectively

evaluated to determine if it is developing into the desired resource type, providing the expected functions, and attaining any other applicable metrics (e.g., acres).

(b) Performance standards must be based on attributes that are objective and verifiable. Ecological performance standards must be based on the best available science that can be measured or assessed in a practicable manner. Performance standards may be based on variables or measures of functional capacity described in functional assessment methodologies, measurements of hydrology or other aquatic resource characteristics, and/or comparisons to reference aquatic resources of similar type and landscape position. The use of reference aquatic resources to establish performance standards will help ensure that those performance standards are reasonably achievable, by reflecting the range of variability exhibited by the regional class of aquatic resources as a result of natural processes and anthropogenic disturbances. Performance standards based on measurements of hydrology should take into consideration the hydrologic variability exhibited by reference aquatic resources, especially wetlands. Where practicable, performance standards should take into account the expected stages of the aquatic resource development process, in order to allow early identification of potential problems and appropriate adaptive management.

§ 230.96 Monitoring.

(a) *General.* (1) Monitoring the compensatory mitigation project site is necessary to determine if the project is meeting its performance standards, and to determine if measures are necessary to ensure that the compensatory mitigation project is accomplishing its objectives. The submission of monitoring reports to assess the development and condition of the compensatory mitigation project is required, but the content and level of detail for those monitoring reports must be commensurate with the scale and scope of the compensatory mitigation project, as well as the compensatory mitigation project type. The mitigation plan must address the monitoring requirements for the compensatory mitigation project, including the parameters to be monitored, the length of the monitoring period, the party responsible for conducting the monitoring, the frequency for submitting monitoring reports to the district engineer, and the party responsible for submitting those monitoring reports to the district engineer.

(2) The district engineer may conduct site inspections on a regular basis (e.g., annually) during the monitoring period to evaluate mitigation site performance.

(b) *Monitoring period.* The mitigation plan must provide for a monitoring period that is sufficient to demonstrate that the compensatory mitigation project has met performance standards, but not less than five years. A longer monitoring period must be required for aquatic resources with slow development rates (e.g., forested wetlands, bogs). Following project implementation, the district engineer may reduce or waive the remaining monitoring requirements upon a determination that the compensatory mitigation project has achieved its performance standards. Conversely the district engineer may extend the original monitoring period upon a determination that performance standards have not been met or the compensatory mitigation project is not on track to meet them. The district engineer may also revise monitoring requirements when remediation and/or adaptive management is required.

(c) *Monitoring reports.* (1) The district engineer must determine the information to be included in monitoring reports. This information must be sufficient for the district engineer to determine how the compensatory mitigation project is progressing towards meeting its performance standards, and may include plans (such as as-built plans), maps, and photographs to illustrate site conditions. Monitoring reports may also include the results of functional, condition, or other assessments used to provide quantitative or qualitative measures of the functions provided by the compensatory mitigation project site.

(2) The permittee or sponsor is responsible for submitting monitoring reports in accordance with the special conditions of the DA permit or the terms of the instrument. Failure to submit monitoring reports in a timely manner may result in compliance action by the district engineer.

(3) Monitoring reports must be provided by the district engineer to interested federal, tribal, state, and local resource agencies, and the public, upon request.

§ 230.97 Management.

(a) *Site protection.* (1) The aquatic habitats, riparian areas, buffers, and uplands that comprise the overall compensatory mitigation project must be provided long-term protection through real estate instruments or other available mechanisms, as appropriate. Long-term protection may be provided through real estate instruments such as conservation easements held by entities such as federal, tribal, state, or local resource agencies, non-profit conservation organizations, or private land managers; the transfer of title to such entities; or by restrictive covenants. For government property, long-term protection may be provided through federal facility management plans or integrated natural resources management plans. When approving a method for long-term protection of non-government property other than transfer of title, the district engineer shall consider relevant legal constraints on the use of conservation easements and/or restrictive covenants in determining whether such mechanisms provide sufficient site protection. To provide sufficient site protection, a conservation easement or restrictive covenant should, where practicable, establish in an appropriate third party (e.g., governmental or non-profit resource management agency) the right to enforce site protections and provide the third party the resources necessary to monitor and enforce these site protections.

(2) The real estate instrument, management plan, or other mechanism providing long-term protection of the compensatory mitigation site must, to the extent appropriate and practicable, prohibit incompatible uses (e.g., clear cutting or mineral extraction) that might otherwise jeopardize the objectives of the compensatory mitigation project. Where appropriate, multiple instruments recognizing compatible uses (e.g., fishing or grazing rights) may be used.

(3) The real estate instrument, management plan, or other long-term protection mechanism must contain a provision requiring 60-day advance notification to the district engineer before any action is taken to void or modify the instrument, management plan, or long-term protection mechanism, including transfer of title to, or establishment of any other legal claims over, the compensatory mitigation site.

(4) For compensatory mitigation projects on public lands, where Federal facility management plans or integrated natural resources management plans are used to provide long-term protection, and changes in statute, regulation, or agency needs or mission results in an incompatible use on public lands originally set aside for compensatory mitigation, the public agency authorizing the incompatible use is responsible for providing alternative compensatory mitigation that is acceptable to the district engineer for any loss in functions resulting from the incompatible use.

(5) A real estate instrument, management plan, or other long-term protection mechanism used for site protection of permittee-responsible mitigation must be approved by the district engineer in advance of, or concurrent with, the activity causing the authorized impacts.

(b) *Sustainability.* Compensatory mitigation projects shall be designed, to the maximum extent practicable, to be self-sustaining once performance standards have been achieved. This includes minimization of active engineering features (e.g., pumps) and appropriate siting to ensure that natural hydrology and landscape context will support long-term sustainability. Where active long-term management and maintenance are necessary to ensure long-term sustainability (e.g., prescribed burning, invasive species control, maintenance of water control structures, easement enforcement), the responsible party must provide for such management and maintenance. This includes the provision of long-term financing mechanisms where necessary. Where needed, the acquisition and protection of water rights must be secured and documented in the permit conditions or instrument.

(c) *Adaptive management.* (1) If the compensatory mitigation project cannot be constructed in accordance with the approved mitigation plans, the permittee or sponsor must notify the district engineer. A significant modification of the compensatory mitigation project requires approval from the district engineer.

(2) If monitoring or other information indicates that the compensatory mitigation project is not progressing towards meeting its performance standards as anticipated, the responsible party must notify the district engineer as soon as possible. The district engineer will evaluate and pursue measures to address deficiencies in the compensatory mitigation project. The district engineer will consider whether the compensatory mitigation project is providing ecological benefits comparable to the original objectives of the compensatory mitigation project.

(3) The district engineer, in consultation with the responsible party (and other federal, tribal, state, and local agencies, as appropriate), will determine the appropriate measures. The measures may include site modifications, design changes, revisions to maintenance requirements, and revised monitoring requirements. The measures must be designed to ensure that the modified compensatory mitigation project provides aquatic resource functions comparable to those described in the mitigation plan objectives.

(4) Performance standards may be revised in accordance with adaptive management to account for measures taken to address deficiencies in the compensatory mitigation project. Performance standards may also be revised to reflect changes in management strategies and objectives if the new standards provide for ecological benefits that are comparable or superior to the approved

compensatory mitigation project. No other revisions to performance standards will be allowed except in the case of natural disasters.

(d) *Long-term management.* (1) The permit conditions or instrument must identify the party responsible for ownership and all long-term management of the compensatory mitigation project. The permit conditions or instrument may contain provisions allowing the permittee or sponsor to transfer the long-term management responsibilities of the compensatory mitigation project site to a land stewardship entity, such as a public agency, non-governmental organization, or private land manager, after review and approval by the district engineer. The land stewardship entity need not be identified in the original permit or instrument, as long as the future transfer of long-term management responsibility is approved by the district engineer.

(2) A long-term management plan should include a description of long-term management needs, annual cost estimates for these needs, and identify the funding mechanism that will be used to meet those needs.

(3) Any provisions necessary for long-term financing must be addressed in the original permit or instrument. The district engineer may require provisions to address inflationary adjustments and other contingencies, as appropriate. Appropriate long-term financing mechanisms include non-wasting endowments, trusts, contractual arrangements with future responsible parties, and other appropriate financial instruments. In cases where the long-term management entity is a public authority or government agency, that entity must provide a plan for the long-term financing of the site.

(4) For permittee-responsible mitigation, any long-term financing mechanisms must be approved in advance of the activity causing the authorized impacts.

§ 230.98 Mitigation banks and in-lieu fee programs.

(a) *General considerations.* (1) All mitigation banks and in-lieu fee programs must have an approved instrument signed by the sponsor and the district engineer prior to being used to provide compensatory mitigation for DA permits.

(2) To the maximum extent practicable, mitigation banks and in-lieu fee project sites must be planned and designed to be self-sustaining over time, but some active management and maintenance may be required to ensure their long-term viability and sustainability. Examples of acceptable management activities include maintaining fire dependent habitat communities in the absence of natural fire and controlling invasive exotic plant species.

(3) All mitigation banks and in-lieu fee programs must comply with the standards in this part, if they are to be used to provide compensatory mitigation for activities authorized by DA permits, regardless of whether they are sited on public or private lands and whether the sponsor is a governmental or private entity.

(b) *Interagency Review Team.* (1) The district engineer will establish an Interagency Review Team (IRT) to review documentation for the establishment and management of mitigation banks

and in-lieu fee programs. The district engineer or his designated representative serves as Chair of the IRT. In cases where a mitigation bank or in-lieu fee program is proposed to satisfy the requirements of another federal, tribal, state, or local program, in addition to compensatory mitigation requirements of DA permits, it may be appropriate for the administering agency to serve as co-Chair of the IRT.

(2) In addition to the Corps, representatives from the U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, NOAA Fisheries, the Natural Resources Conservation Service, and other federal agencies, as appropriate, may participate in the IRT. The IRT may also include representatives from tribal, state, and local regulatory and resource agencies, where such agencies have authorities and/or mandates directly affecting, or affected by, the establishment, operation, or use of the mitigation bank or in-lieu fee program. The district engineer will seek to include all public agencies with a substantive interest in the establishment of the mitigation bank or in-lieu fee program on the IRT, but retains final authority over its composition.

(3) The primary role of the IRT is to facilitate the establishment of mitigation banks or in-lieu fee programs through the development of mitigation banking or in-lieu fee program instruments. The IRT will review the prospectus, instrument, and other appropriate documents and provide comments to the district engineer. The district engineer and the IRT should use a watershed approach to the extent practicable in reviewing proposed mitigation banks and in-lieu fee programs. Members of the IRT may also sign the instrument, if they so choose. By signing the instrument, the IRT members indicate their agreement with the terms of the instrument. As an alternative, a member of the IRT may submit a letter expressing concurrence with the instrument. The IRT will also advise the district engineer in assessing monitoring reports, recommending remedial or adaptive management measures, approving credit releases, and approving modifications to an instrument. In order to ensure timely processing of instruments and other documentation, comments from IRT members must be received by the district engineer within the time limits specified in this section. Comments received after these deadlines will only be considered at the discretion of the district engineer to the extent that doing so does not jeopardize the deadlines for district engineer action.

(4) The district engineer will give full consideration to any timely comments and advice of the IRT. The district engineer alone retains final authority for approval of the instrument in cases where the mitigation bank or in-lieu fee program is used to satisfy compensatory mitigation requirements of DA permits.

(5) *MOAs with other agencies.* The district engineer and members of the IRT may enter into a memorandum of agreement (MOA) with any other federal, state or local government agency to perform all or some of the IRT review functions described in this section. Such MOAs must include provisions for appropriate federal oversight of the review process. The district engineer retains sole authority for final approval of instruments and other documentation required under this section.

(c) *Compensation planning framework for in-lieu fee programs.* (1) The approved instrument for an in-lieu fee program must include a compensation planning framework that will be used to select, secure, and implement aquatic resource restoration, establishment, enhancement, and/or

preservation activities. The compensation planning framework must support a watershed approach to compensatory mitigation. All specific projects used to provide compensation for DA permits must be consistent with the approved compensation planning framework. Modifications to the framework must be approved as a significant modification to the instrument by the district engineer, after consultation with the IRT.

(2) The compensation planning framework must contain the following elements:

(i) The geographic service area(s), including a watershed-based rationale for the delineation of each service area;

(ii) A description of the threats to aquatic resources in the service area(s), including how the in-lieu fee program will help offset impacts resulting from those threats;

(iii) An analysis of historic aquatic resource loss in the service area(s);

(iv) An analysis of current aquatic resource conditions in the service area(s), supported by an appropriate level of field documentation;

(v) A statement of aquatic resource goals and objectives for each service area, including a description of the general amounts, types and locations of aquatic resources the program will seek to provide;

(vi) A prioritization strategy for selecting and implementing compensatory mitigation activities;

(vii) An explanation of how any preservation objectives identified in paragraph (c)(2)(v) of this section and addressed in the prioritization strategy in paragraph (c)(2)(vi) satisfy the criteria for use of preservation in §230.93(h);

(viii) A description of any public and private stakeholder involvement in plan development and implementation, including, where appropriate, coordination with federal, state, tribal and local aquatic resource management and regulatory authorities;

(ix) A description of the long-term protection and management strategies for activities conducted by the in-lieu fee program sponsor;

(x) A strategy for periodic evaluation and reporting on the progress of the program in achieving the goals and objectives in paragraph (c)(2)(v) of this section, including a process for revising the planning framework as necessary; and

(xi) Any other information deemed necessary for effective compensation planning by the district engineer.

(3) The level of detail necessary for the compensation planning framework is at the discretion of the district engineer, and will take into account the characteristics of the service area(s) and the scope of the program. As part of the in-lieu fee program instrument, the compensation planning

framework will be reviewed by the IRT, and will be a major factor in the district engineer's decision on whether to approve the instrument.

(d) *Review process.* (1) The sponsor is responsible for preparing all documentation associated with establishment of the mitigation bank or in-lieu fee program, including the prospectus, instrument, and other appropriate documents, such as mitigation plans for a mitigation bank. The prospectus provides an overview of the proposed mitigation bank or in-lieu fee program and serves as the basis for public and initial IRT comment. For a mitigation bank, the mitigation plan, as described in §230.94(c), provides detailed plans and specifications for the mitigation bank site. For in-lieu fee programs, mitigation plans will be prepared as in-lieu fee project sites are identified after the instrument has been approved and the in-lieu fee program becomes operational. The instrument provides the authorization for the mitigation bank or in-lieu fee program to provide credits to be used as compensatory mitigation for DA permits.

(2) *Prospectus.* The prospectus must provide a summary of the information regarding the proposed mitigation bank or in-lieu fee program, at a sufficient level of detail to support informed public and IRT comment. The review process begins when the sponsor submits a complete prospectus to the district engineer. For modifications of approved instruments, submittal of a new prospectus is not required; instead, the sponsor must submit a written request for an instrument modification accompanied by appropriate documentation. The district engineer must notify the sponsor within 30 days whether or not a submitted prospectus is complete. A complete prospectus includes the following information:

(i) The objectives of the proposed mitigation bank or in-lieu fee program.

(ii) How the mitigation bank or in-lieu fee program will be established and operated.

(iii) The proposed service area.

(iv) The general need for and technical feasibility of the proposed mitigation bank or in-lieu fee program.

(v) The proposed ownership arrangements and long-term management strategy for the mitigation bank or in-lieu fee project sites.

(vi) The qualifications of the sponsor to successfully complete the type(s) of mitigation project(s) proposed, including information describing any past such activities by the sponsor.

(vii) For a proposed mitigation bank, the prospectus must also address:

(A) The ecological suitability of the site to achieve the objectives of the proposed mitigation bank, including the physical, chemical, and biological characteristics of the bank site and how that site will support the planned types of aquatic resources and functions; and

(B) Assurance of sufficient water rights to support the long-term sustainability of the mitigation bank.

(viii) For a proposed in-lieu fee program, the prospectus must also include:

(A) The compensation planning framework (see paragraph (c) of this section); and

(B) A description of the in-lieu fee program account required by paragraph (i) of this section.

(3) *Preliminary review of prospectus.* Prior to submitting a prospectus, the sponsor may elect to submit a draft prospectus to the district engineer for comment and consultation. The district engineer will provide copies of the draft prospectus to the IRT and will provide comments back to the sponsor within 30 days. Any comments from IRT members will also be forwarded to the sponsor. This preliminary review is optional but is strongly recommended. It is intended to identify potential issues early so that the sponsor may attempt to address those issues prior to the start of the formal review process.

(4) *Public review and comment.* Within 30 days of receipt of a complete prospectus or an instrument modification request that will be processed in accordance with paragraph (g)(1) of this section, the district engineer will provide public notice of the proposed mitigation bank or in-lieu fee program, in accordance with the public notice procedures at 33 CFR 325.3. The public notice must, at a minimum, include a summary of the prospectus and indicate that the full prospectus is available to the public for review upon request. For modifications of approved instruments, the public notice must instead summarize, and make available to the public upon request, whatever documentation is appropriate for the modification (e.g., a new or revised mitigation plan). The comment period for public notice will be 30 days, unless the district engineer determines that a longer comment period is appropriate. The district engineer will notify the sponsor if the comment period is extended beyond 30 days, including an explanation of why the longer comment period is necessary. Copies of all comments received in response to the public notice must be distributed to the other IRT members and to the sponsor within 15 days of the close of the public comment period. The district engineer and IRT members may also provide comments to the sponsor at this time, and copies of any such comments will also be distributed to all IRT members. If the construction of a mitigation bank or an in-lieu fee program project requires a DA permit, the public notice requirement may be satisfied through the public notice provisions of the permit processing procedures, provided all of the relevant information is provided.

(5) *Initial evaluation.* (i) After the end of the comment period, the district engineer will review the comments received in response to the public notice, and make a written initial evaluation as to the potential of the proposed mitigation bank or in-lieu fee program to provide compensatory mitigation for activities authorized by DA permits. This initial evaluation letter must be provided to the sponsor within 30 days of the end of the public notice comment period.

(ii) If the district engineer determines that the proposed mitigation bank or in-lieu fee program has potential for providing appropriate compensatory mitigation for activities authorized by DA permits, the initial evaluation letter will inform the sponsor that he/she may proceed with preparation of the draft instrument (see paragraph (d)(6) of this section).

(iii) If the district engineer determines that the proposed mitigation bank or in-lieu fee program does not have potential for providing appropriate compensatory mitigation for DA permits, the initial evaluation letter must discuss the reasons for that determination. The sponsor may revise the prospectus to address the district engineer's concerns, and submit the revised prospectus to the district engineer. If the sponsor submits a revised prospectus, a revised public notice will be issued in accordance with paragraph (d)(4) of this section.

(iv) This initial evaluation procedure does not apply to proposed modifications of approved instruments.

(6) *Draft instrument.* (i) After considering comments from the district engineer, the IRT, and the public, if the sponsor chooses to proceed with establishment of the mitigation bank or in-lieu fee program, he must prepare a draft instrument and submit it to the district engineer. In the case of an instrument modification, the sponsor must prepare a draft amendment (e.g., a specific instrument provision, a new or modified mitigation plan), and submit it to the district engineer. The district engineer must notify the sponsor within 30 days of receipt, whether the draft instrument or amendment is complete. If the draft instrument or amendment is incomplete, the district engineer will request from the sponsor the information necessary to make the draft instrument or amendment complete. Once any additional information is submitted, the district engineer must notify the sponsor as soon as he determines that the draft instrument or amendment is complete. The draft instrument must be based on the prospectus and must describe in detail the physical and legal characteristics of the mitigation bank or in-lieu fee program and how it will be established and operated.

(ii) For mitigation banks and in-lieu fee programs, the draft instrument must include the following information:

(A) A description of the proposed geographic service area of the mitigation bank or in-lieu fee program. The service area is the watershed, ecoregion, physiographic province, and/or other geographic area within which the mitigation bank or in-lieu fee program is authorized to provide compensatory mitigation required by DA permits. The service area must be appropriately sized to ensure that the aquatic resources provided will effectively compensate for adverse environmental impacts across the entire service area. For example, in urban areas, a U.S. Geological Survey 8-digit hydrologic unit code (HUC) watershed or a smaller watershed may be an appropriate service area. In rural areas, several contiguous 8-digit HUCs or a 6-digit HUC watershed may be an appropriate service area. Delineation of the service area must also consider any locally-developed standards and criteria that may be applicable. The economic viability of the mitigation bank or in-lieu fee program may also be considered in determining the size of the service area. The basis for the proposed service area must be documented in the instrument. An in-lieu fee program or umbrella mitigation banking instrument may have multiple service areas governed by its instrument (e.g., each watershed within a State or Corps district may be a separate service area under the instrument); however, all impacts and compensatory mitigation must be accounted for by service area;

(B) Accounting procedures;

(C) A provision stating that legal responsibility for providing the compensatory mitigation lies with the sponsor once a permittee secures credits from the sponsor;

(D) Default and closure provisions;

(E) Reporting protocols; and

(F) Any other information deemed necessary by the district engineer.

(iii) For a mitigation bank, a complete draft instrument must include the following additional information:

(A) Mitigation plans that include all applicable items listed in §230.94(c)(2) through (14); and

(B) A credit release schedule, which is tied to achievement of specific milestones. All credit releases must be approved by the district engineer, in consultation with the IRT, based on a determination that required milestones have been achieved. The district engineer, in consultation with the IRT, may modify the credit release schedule, including reducing the number of available credits or suspending credit sales or transfers altogether, where necessary to ensure that all credits sales or transfers remain tied to compensatory mitigation projects with a high likelihood of meeting performance standards;

(iv) For an in-lieu fee program, a complete draft instrument must include the following additional information:

(A) The compensation planning framework (see paragraph (c) of this section);

(B) Specification of the initial allocation of advance credits (see paragraph (n) of this section) and a draft fee schedule for these credits, by service area, including an explanation of the basis for the allocation and draft fee schedule;

(C) A methodology for determining future project-specific credits and fees; and

(D) A description of the in-lieu fee program account required by paragraph (i) of this section.

(7) *IRT review* . Upon receipt of notification by the district engineer that the draft instrument or amendment is complete, the sponsor must provide the district engineer with a sufficient number of copies of the draft instrument or amendment to distribute to the IRT members. The district engineer will promptly distribute copies of the draft instrument or amendment to the IRT members for a 30 day comment period. The 30-day comment period begins 5 days after the district engineer distributes the copies of the draft instrument or amendment to the IRT. Following the comment period, the district engineer will discuss any comments with the appropriate agencies and with the sponsor. The district engineer will seek to resolve issues using a consensus based approach, to the extent practicable, while still meeting the decision-making time frames specified in this section. Within 90 days of receipt of the complete draft instrument or amendment by the IRT members, the district engineer must notify the sponsor of the status of

the IRT review. Specifically, the district engineer must indicate to the sponsor if the draft instrument or amendment is generally acceptable and what changes, if any, are needed. If there are significant unresolved concerns that may lead to a formal objection from one or more IRT members to the final instrument or amendment, the district engineer will indicate the nature of those concerns.

(8) *Final instrument* . The sponsor must submit a final instrument to the district engineer for approval, with supporting documentation that explains how the final instrument addresses the comments provided by the IRT. For modifications of approved instruments, the sponsor must submit a final amendment to the district engineer for approval, with supporting documentation that explains how the final amendment addresses the comments provided by the IRT. The final instrument or amendment must be provided directly by the sponsor to all members of the IRT. Within 30 days of receipt of the final instrument or amendment, the district engineer will notify the IRT members whether or not he intends to approve the instrument or amendment. If no IRT member objects, by initiating the dispute resolution process in paragraph (e) of this section within 45 days of receipt of the final instrument or amendment, the district engineer will notify the sponsor of his final decision and, if the instrument or amendment is approved, arrange for it to be signed by the appropriate parties. If any IRT member initiates the dispute resolution process, the district engineer will notify the sponsor. Following conclusion of the dispute resolution process, the district engineer will notify the sponsor of his final decision, and if the instrument or amendment is approved, arrange for it to be signed by the appropriate parties. For mitigation banks, the final instrument must contain the information items listed in paragraphs (d)(6)(ii), and (iii) of this section. For in-lieu fee programs, the final instrument must contain the information items listed in paragraphs (d)(6)(ii) and (iv) of this section. For the modification of an approved instrument, the amendment must contain appropriate information, as determined by the district engineer. The final instrument or amendment must be made available to the public upon request.

(e) *Dispute resolution process* . (1) Within 15 days of receipt of the district engineer's notification of intent to approve an instrument or amendment, the Regional Administrator of the U.S. EPA, the Regional Director of the U.S. Fish and Wildlife Service, the Regional Director of the National Marine Fisheries Service, and/or other senior officials of agencies represented on the IRT may notify the district engineer and other IRT members by letter if they object to the approval of the proposed final instrument or amendment. This letter must include an explanation of the basis for the objection and, where feasible, offer recommendations for resolving the objections. If the district engineer does not receive any objections within this time period, he may proceed to final action on the instrument or amendment.

(2) The district engineer must respond to the objection within 30 days of receipt of the letter. The district engineer's response may indicate an intent to disapprove the instrument or amendment as a result of the objection, an intent to approve the instrument or amendment despite the objection, or may provide a modified instrument or amendment that attempts to address the objection. The district engineer's response must be provided to all IRT members.

(3) Within 15 days of receipt of the district engineer's response, if the Regional Administrator or Regional Director is not satisfied with the response he may forward the issue to the Assistant

Administrator for Water of the U.S. EPA, the Assistant Secretary for Fish and Wildlife and Parks of the U.S. FWS, or the Undersecretary for Oceans and Atmosphere of NOAA, as appropriate, for review and must notify the district engineer by letter via electronic mail or facsimile machine (with copies to all IRT members) that the issue has been forwarded for Headquarters review. This step is available only to the IRT members representing these three federal agencies, however, other IRT members who do not agree with the district engineer's final decision do not have to sign the instrument or amendment or recognize the mitigation bank or in-lieu fee program for purposes of their own programs and authorities. If an IRT member other than the one filing the original objection has a new objection based on the district engineer's response, he may use the first step in this procedure (paragraph (e)(1) of this section) to provide that objection to the district engineer.

(4) If the issue has not been forwarded to the objecting agency's Headquarters, then the district engineer may proceed with final action on the instrument or amendment. If the issue has been forwarded to the objecting agency's Headquarters, the district engineer must hold in abeyance the final action on the instrument or amendment, pending Headquarters level review described below.

(5) Within 20 days from the date of the letter requesting Headquarters level review, the Assistant Administrator for Water, the Assistant Secretary for Fish and Wildlife and Parks, or the Undersecretary for Oceans and Atmosphere must either notify the Assistant Secretary of the Army (Civil Works) (ASA(CW)) that further review will not be requested, or request that the ASA(CW) review the final instrument or amendment.

(6) Within 30 days of receipt of the letter from the objecting agency's Headquarters request for ASA(CW)'s review of the final instrument, the ASA(CW), through the Director of Civil Works, must review the draft instrument or amendment and advise the district engineer on how to proceed with final action on that instrument or amendment. The ASA(CW) must immediately notify the Assistant Administrator for Water, the Assistant Secretary for Fish and Wildlife and Parks, and/or the Undersecretary for Oceans and Atmosphere of the final decision.

(7) In cases where the dispute resolution procedure is used, the district engineer must notify the sponsor of his final decision within 150 days of receipt of the final instrument or amendment.

(f) *Extension of deadlines* . (1) The deadlines in paragraphs (d) and (e) of this section may be extended by the district engineer at his sole discretion in cases where:

(i) Compliance with other applicable laws, such as consultation under section 7 of the Endangered Species Act or section 106 of the National Historic Preservation Act, is required;

(ii) It is necessary to conduct government-to-government consultation with Indian tribes;

(iii) Timely submittal of information necessary for the review of the proposed mitigation bank or in-lieu fee program or the proposed modification of an approved instrument is not accomplished by the sponsor; or

(iv) Information that is essential to the district engineer's decision cannot be reasonably obtained within the specified time frame.

(2) In such cases, the district engineer must promptly notify the sponsor in writing of the extension and the reason for it. Such extensions shall be for the minimum time necessary to resolve the issue necessitating the extension.

(g) *Modification of instruments* . (1) *Approval of an amendment to an approved instrument* . Modification of an approved instrument, including the addition and approval of umbrella mitigation bank sites or in-lieu fee project sites or expansions of previously approved mitigation bank or in-lieu fee project sites, must follow the appropriate procedures in paragraph (d) of this section, unless the district engineer determines that the streamlined review process described in paragraph (g)(2) of this section is warranted.

(2) *Streamlined review process* . The streamlined modification review process may be used for the following modifications of instruments: changes reflecting adaptive management of the mitigation bank or in-lieu fee program, credit releases, changes in credit releases and credit release schedules, and changes that the district engineer determines are not significant. If the district engineer determines that the streamlined review process is warranted, he must notify the IRT members and the sponsor of this determination and provide them with copies of the proposed modification. IRT members and the sponsor have 30 days to notify the district engineer if they have concerns with the proposed modification. If IRT members or the sponsor notify the district engineer of such concerns, the district engineer shall attempt to resolve those concerns. Within 60 days of providing the proposed modification to the IRT, the district engineer must notify the IRT members of his intent to approve or disapprove the proposed modification. If no IRT member objects, by initiating the dispute resolution process in paragraph (e) of this section, within 15 days of receipt of this notification, the district engineer will notify the sponsor of his final decision and, if the modification is approved, arrange for it to be signed by the appropriate parties. If any IRT member initiates the dispute resolution process, the district engineer will so notify the sponsor. Following conclusion of the dispute resolution process, the district engineer will notify the sponsor of his final decision, and if the modification is approved, arrange for it to be signed by the appropriate parties.

(h) *Umbrella mitigation banking instruments* . A single mitigation banking instrument may provide for future authorization of additional mitigation bank sites. As additional sites are selected, they must be included in the mitigation banking instrument as modifications, using the procedures in paragraph (g)(1) of this section. Credit withdrawal from the additional bank sites shall be consistent with paragraph (m) of this section.

(i) *In-lieu fee program account* . (1) The in-lieu fee program sponsor must establish a program account after the instrument is approved by the district engineer, prior to accepting any fees from permittees. If the sponsor accepts funds from entities other than permittees, those funds must be kept in separate accounts. The program account must be established at a financial institution that is a member of the Federal Deposit Insurance Corporation. All interests and earnings accruing to the program account must remain in that account for use by the in-lieu fee program for the purposes of providing compensatory mitigation for DA permits. The program account may only

be used for the selection, design, acquisition, implementation, and management of in-lieu fee compensatory mitigation projects, except for a small percentage (as determined by the district engineer in consultation with the IRT and specified in the instrument) that can be used for administrative costs.

(2) The sponsor must submit proposed in-lieu fee projects to the district engineer for funding approval. Disbursements from the program account may only be made upon receipt of written authorization from the district engineer, after the district engineer has consulted with the IRT. The terms of the program account must specify that the district engineer has the authority to direct those funds to alternative compensatory mitigation projects in cases where the sponsor does not provide compensatory mitigation in accordance with the time frame specified in paragraph (n)(4) of this section.

(3) The sponsor must provide annual reports to the district engineer and the IRT. The annual reports must include the following information:

(i) All income received, disbursements, and interest earned by the program account;

(ii) A list of all permits for which in-lieu fee program funds were accepted. This list shall include: the Corps permit number (or the state permit number if there is no corresponding Corps permit number, in cases of state programmatic general permits or other regional general permits), the service area in which the authorized impacts are located, the amount of authorized impacts, the amount of required compensatory mitigation, the amount paid to the in-lieu fee program, and the date the funds were received from the permittee;

(iii) A description of in-lieu fee program expenditures from the account, such as the costs of land acquisition, planning, construction, monitoring, maintenance, contingencies, adaptive management, and administration;

(iv) The balance of advance credits and released credits at the end of the report period for each service area; and

(v) Any other information required by the district engineer.

(4) The district engineer may audit the records pertaining to the program account. All books, accounts, reports, files, and other records relating to the in-lieu fee program account shall be available at reasonable times for inspection and audit by the district engineer.

(j) *In-lieu fee project approval* . (1) As in-lieu fee project sites are identified and secured, the sponsor must submit mitigation plans to the district engineer that include all applicable items listed in §230.94(c)(2) through (14). The mitigation plan must also include a credit release schedule consistent with paragraph (o)(8) of this section that is tied to achievement of specific performance standards. The review and approval of in-lieu fee projects will be conducted in accordance with the procedures in paragraph (g)(1) of this section, as modifications of the in-lieu fee program instrument. This includes compensatory mitigation projects conducted by another party on behalf of the sponsor through requests for proposals and awarding of contracts.

(2) If a DA permit is required for an in-lieu fee project, the permit should not be issued until all relevant provisions of the mitigation plan have been substantively determined, to ensure that the DA permit accurately reflects all relevant provisions of the approved mitigation plan, such as performance standards.

(k) *Coordination of mitigation banking instruments and DA permit issuance* . In cases where initial establishment of the mitigation bank, or the development of a new project site under an umbrella banking instrument, involves activities requiring DA authorization, the permit should not be issued until all relevant provisions of the mitigation plan have been substantively determined. This is to ensure that the DA permit accurately reflects all relevant provisions of the final instrument, such as performance standards.

(l) *Project implementation* . (1) The sponsor must have an approved instrument prior to collecting funds from permittees to satisfy compensatory mitigation requirements for DA permits.

(2) Authorization to sell credits to satisfy compensatory mitigation requirements in DA permits is contingent on compliance with all of the terms of the instrument. This includes constructing a mitigation bank or in-lieu fee project in accordance with the mitigation plan approved by the district engineer and incorporated by reference in the instrument. If the aquatic resource restoration, establishment, enhancement, and/or preservation activities cannot be implemented in accordance with the approved mitigation plan, the district engineer must consult with the sponsor and the IRT to consider modifications to the instrument, including adaptive management, revisions to the credit release schedule, and alternatives for providing compensatory mitigation to satisfy any credits that have already been sold.

(3) An in-lieu fee program sponsor is responsible for the implementation, long-term management, and any required remediation of the restoration, establishment, enhancement, and/or preservation activities, even though those activities may be conducted by other parties through requests for proposals or other contracting mechanisms.

(m) *Credit withdrawal from mitigation banks* . The mitigation banking instrument may allow for an initial debiting of a percentage of the total credits projected at mitigation bank maturity, provided the following conditions are satisfied: the mitigation banking instrument and mitigation plan have been approved, the mitigation bank site has been secured, appropriate financial assurances have been established, and any other requirements determined to be necessary by the district engineer have been fulfilled. The mitigation banking instrument must provide a schedule for additional credit releases as appropriate milestones are achieved (see paragraph (o)(8) of this section). Implementation of the approved mitigation plan shall be initiated no later than the first full growing season after the date of the first credit transaction.

(n) *Advance credits for in-lieu fee programs* . (1) The in-lieu fee program instrument may make a limited number of advance credits available to permittees when the instrument is approved. The number of advance credits will be determined by the district engineer, in consultation with the IRT, and will be specified for each service area in the instrument. The number of advance credits will be based on the following considerations:

(i) The compensation planning framework;

(ii) The sponsor's past performance for implementing aquatic resource restoration, establishment, enhancement, and/or preservation activities in the proposed service area or other areas; and

(iii) The projected financing necessary to begin planning and implementation of in-lieu fee projects.

(2) To determine the appropriate number of advance credits for a particular service area, the district engineer may require the sponsor to provide confidential supporting information that will not be made available to the general public. Examples of confidential supporting information may include prospective in-lieu fee project sites.

(3) As released credits are produced by in-lieu fee projects, they must be used to fulfill any advance credits that have already been provided within the project service area before any remaining released credits can be sold or transferred to permittees. Once previously provided advance credits have been fulfilled, an equal number of advance credits is re-allocated to the sponsor for sale or transfer to fulfill new mitigation requirements, consistent with the terms of the instrument. The number of advance credits available to the sponsor at any given time to sell or transfer to permittees in a given service area is equal to the number of advance credits specified in the instrument, minus any that have already been provided but not yet fulfilled.

(4) Land acquisition and initial physical and biological improvements must be completed by the third full growing season after the first advance credit in that service area is secured by a permittee, unless the district engineer determines that more or less time is needed to plan and implement an in-lieu fee project. If the district engineer determines that there is a compensatory mitigation deficit in a specific service area by the third growing season after the first advance credit in that service area is sold, and determines that it would not be in the public interest to allow the sponsor additional time to plan and implement an in-lieu fee project, the district engineer must direct the sponsor to disburse funds from the in-lieu fee program account to provide alternative compensatory mitigation to fulfill those compensation obligations.

(5) The sponsor is responsible for complying with the terms of the in-lieu fee program instrument. If the district engineer determines, as a result of review of annual reports on the operation of the in-lieu fee program (see paragraphs (p)(2) and (q)(1) of this section), that it is not performing in compliance with its instrument, the district engineer will take appropriate action, which may include suspension of credit sales, to ensure compliance with the in-lieu fee program instrument (see paragraph (o)(10) of this section). Permittees that secured credits from the in-lieu fee program are not responsible for in-lieu fee program compliance.

(o) *Determining credits.* (1) *Units of measure.* The principal units for credits and debits are acres, linear feet, functional assessment units, or other suitable metrics of particular resource types. Functional assessment units or other suitable metrics may be linked to acres or linear feet.

(2) *Assessment.* Where practicable, an appropriate assessment method (e.g., hydrogeomorphic approach to wetlands functional assessment, index of biological integrity) or other suitable

metric must be used to assess and describe the aquatic resource types that will be restored, established, enhanced and/or preserved by the mitigation bank or in-lieu fee project.

(3) *Credit production.* The number of credits must reflect the difference between pre- and post-compensatory mitigation project site conditions, as determined by a functional or condition assessment or other suitable metric.

(4) *Credit value.* Once a credit is debited (sold or transferred to a permittee), its value cannot change.

(5) *Credit costs.* (i) The cost of compensatory mitigation credits provided by a mitigation bank or in-lieu fee program is determined by the sponsor.

(ii) For in-lieu fee programs, the cost per unit of credit must include the expected costs associated with the restoration, establishment, enhancement, and/or preservation of aquatic resources in that service area. These costs must be based on full cost accounting, and include, as appropriate, expenses such as land acquisition, project planning and design, construction, plant materials, labor, legal fees, monitoring, and remediation or adaptive management activities, as well as administration of the in-lieu fee program. The cost per unit credit must also take into account contingency costs appropriate to the stage of project planning, including uncertainties in construction and real estate expenses. The cost per unit of credit must also take into account the resources necessary for the long-term management and protection of the in-lieu fee project. In addition, the cost per unit credit must include financial assurances that are necessary to ensure successful completion of in-lieu fee projects.

(6) *Credits provided by preservation.* These credits should be specified as acres, linear feet, or other suitable metrics of preservation of a particular resource type. In determining the compensatory mitigation requirements for DA permits using mitigation banks or in-lieu fee programs, the district engineer should apply a higher mitigation ratio if the requirements are to be met through the use of preservation credits. In determining this higher ratio, the district engineer must consider the relative importance of both the impacted and the preserved aquatic resources in sustaining watershed functions.

(7) *Credits provided by riparian areas, buffers, and uplands.* These credits should be specified as acres, linear feet, or other suitable metrics of riparian area, buffer, and uplands respectively. Non-aquatic resources can only be used as compensatory mitigation for impacts to aquatic resources authorized by DA permits when those resources are essential to maintaining the ecological viability of adjoining aquatic resources. In determining the compensatory mitigation requirements for DA permits using mitigation banks and in-lieu fee programs, the district engineer may authorize the use of riparian area, buffer, and/or upland credits if he determines that these areas are essential to sustaining aquatic resource functions in the watershed and are the most appropriate compensation for the authorized impacts.

(8) *Credit release schedule.* (i) *General considerations.* Release of credits must be tied to performance based milestones (*e.g.* , construction, planting, establishment of specified plant and animal communities). The credit release schedule should reserve a significant share of the total

credits for release only after full achievement of ecological performance standards. When determining the credit release schedule, factors to be considered may include, but are not limited to: The method of providing compensatory mitigation credits (e.g., restoration), the likelihood of success, the nature and amount of work needed to generate the credits, and the aquatic resource type(s) and function(s) to be provided by the mitigation bank or in-lieu fee project. The district engineer will determine the credit release schedule, including the share to be released only after full achievement of performance standards, after consulting with the IRT. Once released, credits may only be used to satisfy compensatory mitigation requirements of a DA permit if the use of credits for a specific permit has been approved by the district engineer.

(ii) For single-site mitigation banks, the terms of the credit release schedule must be specified in the mitigation banking instrument. The credit release schedule may provide for an initial debiting of a limited number of credits once the instrument is approved and other appropriate milestones are achieved (see paragraph (m) of this section).

(iii) For in-lieu fee projects and umbrella mitigation bank sites, the terms of the credit release schedule must be specified in the approved mitigation plan. When an in-lieu fee project or umbrella mitigation bank site is implemented and is achieving the performance-based milestones specified in the credit release schedule, credits are generated in accordance with the credit release schedule for the approved mitigation plan. If the in-lieu fee project or umbrella mitigation bank site does not achieve those performance-based milestones, the district engineer may modify the credit release schedule, including reducing the number of credits.

(9) *Credit release approval.* Credit releases for mitigation banks and in-lieu fee projects must be approved by the district engineer. In order for credits to be released, the sponsor must submit documentation to the district engineer demonstrating that the appropriate milestones for credit release have been achieved and requesting the release. The district engineer will provide copies of this documentation to the IRT members for review. IRT members must provide any comments to the district engineer within 15 days of receiving this documentation. However, if the district engineer determines that a site visit is necessary, IRT members must provide any comments to the district engineer within 15 days of the site visit. The district engineer must schedule the site visit so that it occurs as soon as it is practicable, but the site visit may be delayed by seasonal considerations that affect the ability of the district engineer and the IRT to assess whether the applicable credit release milestones have been achieved. After full consideration of any comments received, the district engineer will determine whether the milestones have been achieved and the credits can be released. The district engineer shall make a decision within 30 days of the end of that comment period, and notify the sponsor and the IRT.

(10) *Suspension and termination.* If the district engineer determines that the mitigation bank or in-lieu fee program is not meeting performance standards or complying with the terms of the instrument, appropriate action will be taken. Such actions may include, but are not limited to, suspending credit sales, adaptive management, decreasing available credits, utilizing financial assurances, and terminating the instrument.

(p) *Accounting procedures* . (1) For mitigation banks, the instrument must contain a provision requiring the sponsor to establish and maintain a ledger to account for all credit transactions. Each time an approved credit transaction occurs, the sponsor must notify the district engineer.

(2) For in-lieu fee programs, the instrument must contain a provision requiring the sponsor to establish and maintain an annual report ledger in accordance with paragraph (i)(3) of this section, as well as individual ledgers that track the production of released credits for each in-lieu fee project.

(q) *Reporting* . (1) *Ledger account* . The sponsor must compile an annual ledger report showing the beginning and ending balance of available credits and permitted impacts for each resource type, all additions and subtractions of credits, and any other changes in credit availability (e.g., additional credits released, credit sales suspended). The ledger report must be submitted to the district engineer, who will distribute copies to the IRT members. The ledger report is part of the administrative record for the mitigation bank or in-lieu fee program. The district engineer will make the ledger report available to the public upon request.

(2) *Monitoring reports* . The sponsor is responsible for monitoring the mitigation bank site or the in-lieu fee project site in accordance with the approved monitoring requirements to determine the level of success and identify problems requiring remedial action or adaptive management measures. Monitoring must be conducted in accordance with the requirements in §230.96, and at time intervals appropriate for the particular project type and until such time that the district engineer, in consultation with the IRT, has determined that the performance standards have been attained. The instrument must include requirements for periodic monitoring reports to be submitted to the district engineer, who will provide copies to other IRT members.

(3) *Financial assurance and long-term management funding report* . The district engineer may require the sponsor to provide an annual report showing beginning and ending balances, including deposits into and any withdrawals from, the accounts providing funds for financial assurances and long-term management activities. The report should also include information on the amount of required financial assurances and the status of those assurances, including their potential expiration.

(r) *Use of credits* . Except as provided below, all activities authorized by DA permits are eligible, at the discretion of the district engineer, to use mitigation banks or in-lieu fee programs to fulfill compensatory mitigation requirements for DA permits. The district engineer will determine the number and type(s) of credits required to compensate for the authorized impacts. Permit applicants may propose to use a particular mitigation bank or in-lieu fee program to provide the required compensatory mitigation. In such cases, the sponsor must provide the permit applicant with a statement of credit availability. The district engineer must review the permit applicant's compensatory mitigation proposal, and notify the applicant of his determination regarding the acceptability of using that mitigation bank or in-lieu fee program.

(s) *IRT concerns with use of credits* . If, in the view of a member of the IRT, an issued permit or series of issued permits raises concerns about how credits from a particular mitigation bank or in-lieu fee program are being used to satisfy compensatory mitigation requirements (including

concerns about whether credit use is consistent with the terms of the instrument), the IRT member may notify the district engineer in writing of the concern. The district engineer shall promptly consult with the IRT to address the concern. Resolution of the concern is at the discretion of the district engineer, consistent with applicable statutes, regulations, and policies regarding compensatory mitigation requirements for DA permits. Nothing in this section limits the authorities designated to IRT agencies under existing statutes or regulations.

(t) *Site protection* . (1) For mitigation bank sites, real estate instruments, management plans, or other long-term mechanisms used for site protection must be finalized before any credits can be released.

(2) For in-lieu fee project sites, real estate instruments, management plans, or other long-term protection mechanisms used for site protection must be finalized before advance credits can become released credits.

(u) *Long-term management* . (1) The legal mechanisms and the party responsible for the long-term management and the protection of the mitigation bank site must be documented in the instrument or, in the case of umbrella mitigation banking instruments and in-lieu fee programs, the approved mitigation plans. The responsible party should make adequate provisions for the operation, maintenance, and long-term management of the compensatory mitigation project site. The long-term management plan should include a description of long-term management needs and identify the funding mechanism that will be used to meet those needs.

(2) The instrument may contain provisions for the sponsor to transfer long-term management responsibilities to a land stewardship entity, such as a public agency, non-governmental organization, or private land manager.

(3) The instrument or approved mitigation plan must address the financial arrangements and timing of any necessary transfer of long-term management funds to the steward.

(4) Where needed, the acquisition and protection of water rights should be secured and documented in the instrument or, in the case of umbrella mitigation banking instruments and in-lieu fee programs, the approved mitigation site plan.

(v) *Grandfathering of existing instruments* . (1) *Mitigation banking instruments* . All mitigation banking instruments approved on or after July 9, 2008 must meet the requirements of this part. Mitigation banks approved prior to July 9, 2008 may continue to operate under the terms of their existing instruments. However, any modification to such a mitigation banking instrument on or after July 9, 2008, including authorization of additional sites under an umbrella mitigation banking instrument, expansion of an existing site, or addition of a different type of resource credits (e.g., stream credits to a wetland bank) must be consistent with the terms of this part.

(2) *In-lieu fee program instruments* . All in-lieu fee program instruments approved on or after July 9, 2008 must meet the requirements of this part. In-lieu fee programs operating under instruments approved prior to July 9, 2008 may continue to operate under those instruments for two years after the effective date of this rule, after which time they must meet the requirements

of this part, unless the district engineer determines that circumstances warrant an extension of up to three additional years. The district engineer must consult with the IRT before approving such extensions. Any revisions made to the in-lieu-fee program instrument on or after July 9, 2008 must be consistent with the terms of this part. Any approved project for which construction was completed under the terms of a previously approved instrument may continue to operate indefinitely under those terms if the district engineer determines that the project is providing appropriate mitigation substantially consistent with the terms of this part.

Apex Companies, LLC.

184 HIGH STREET
SUITE 502
BOSTON MA 02110
(617) 728-0070

o SEDIMENT SAMPLING LOCATION

oA1 SEDIMENT SAMPLE LOCATION – SIEVE ANALYSIS PERFORMED

DRAWING TITLE:
SOUTH TERMINAL
MARINE
INFRASTRUCTURE PARK
PROPOSED BULKHEAD
EXTENSION
SIEVE ANALYSIS
SAMPLE COLLECTION
LOCATIONS

PLAN SCALE 1"=150'

0 75 150 300
FEET

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-01
Client ID: A1
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	42.8		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	19.1		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	20.6		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	16.9		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.600		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-02
Client ID: A2
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	9.90		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	11.9		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	23.5		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	8.80		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	36.8		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	9.10		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-04
Client ID: B1
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	6.50		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	33.2		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	18.1		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	20.9		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	20.8		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.500		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-05
Client ID: B2
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	1.10		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	11.8		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	11.3		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	27.4		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	46.8		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	1.60		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-08
Client ID: C1
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	3.10		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	5.80		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	6.20		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	21.1		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	62.9		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.900		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-09
Client ID: C2
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	2.70		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	13.8		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	8.70		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	29.7		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	44.2		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.900		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-11
Client ID: D1
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	8.20		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	14.9		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	5.40		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	12.6		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	57.7		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	1.20		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-12
Client ID: D2
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 10:40
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	3.20		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	5.00		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	19.0		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	60.0		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	12.8		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
General Chemistry - Mansfield Lab										
Solids, Total	80.7		%	0.100	--	1	-	08/09/10 10:30	30,2540G	KB

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-15
Client ID: E1
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	18.6		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	9.00		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	4.70		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	25.1		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	41.5		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	1.10		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-16
Client ID: E2
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	7.70		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	20.5		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	9.80		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	28.1		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	33.8		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.100		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-18
Client ID: F1
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	2.60		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	7.00		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	2.90		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	9.40		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	75.8		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	2.30		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-19
Client ID: F2
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	4.70		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	10.6		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	36.6		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	48.0		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.100		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-24
Client ID: G1
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	4.90		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	8.40		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	1.60		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	9.00		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	71.9		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	4.20		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-25
Client ID: G2
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	37.8		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	18.9		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	17.1		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	25.7		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.500		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-27
Client ID: G4
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	8.20		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	10.2		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	32.5		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	48.6		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.500		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-28
Client ID: G5
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	14.5		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	16.3		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	38.7		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	30.1		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.400		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-29
Client ID: G6
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	10.6		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	21.4		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	19.3		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	23.2		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	24.7		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.800		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-30
Client ID: H1
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 11:25
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	0.200		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	1.40		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	0.800		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	11.1		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	82.0		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	4.50		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
General Chemistry - Mansfield Lab										
Solids, Total	74.4		%	0.100	--	1	-	08/09/10 10:30	30,2540G	KB

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-31
Client ID: H2
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	0.700		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	10.3		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	7.60		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	24.4		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	54.5		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	2.50		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-33
Client ID: H4
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	23.1		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	13.1		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	28.7		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	34.9		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.200		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-34
Client ID: H5
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 11:30
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	3.50		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	12.0		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	52.2		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	32.1		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.200		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
General Chemistry - Mansfield Lab										
Solids, Total	83.8		%	0.100	--	1	-	08/09/10 10:30	30,2540G	KB

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-35
Client ID: I1
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	0.800		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	4.30		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	3.80		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	22.3		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	63.2		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	5.60		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-36
Client ID: I2
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	0.600		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	3.30		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	5.00		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	31.7		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	58.4		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	1.00		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-37
Client ID: I3
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	0.200		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	0.500		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	4.90		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	29.0		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	64.5		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.900		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

Project Name: SOUTH TERMINAL
Project Number: 6690

Lab Number: L1012057
Report Date: 08/18/10

SAMPLE RESULTS

Lab ID: L1012057-38
Client ID: I4
Sample Location: NEW BEDFORD, MA
Matrix: Sediment

Date Collected: 08/06/10 00:00
Date Received: 08/06/10
Field Prep: Not Specified

Parameter	Result	Qualifier	Units	RL	MDL	Dilution Factor	Date Prepared	Date Analyzed	Analytical Method	Analyst
Grain Size Analysis - Mansfield Lab										
% Cobbles	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Gravel	ND		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Gravel	27.4		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Coarse Sand	16.0		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Medium Sand	28.4		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Fine Sand	27.7		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE
% Total Fines	0.500		%	0.100	NA	1	-	08/06/10 00:00	12,D422	SE

APPENDIX 28

August 23, 2010

Mr.Roland Letendre
Owner
Hathaway Mills LLC
84 Gifford Street
New Bedford MA, 02740

Mr. Matthew Morrissey
Executive Director
New Bedford Redevelopment Authority
1213 Purchase Street
New Bedford MA 02740

Dear Mr. Morrissey:

I write to state at I am aware of the City and the Commonwealth's plans to establish an intermodal facility in the south terminal area of New Bedford. As a real estate owner in the immediate area, and one who is operating an existing business, I support and endorse the efforts to create such a facility. As we discussed, I anticipate working out a temporary access easement across a portion of my property bordering Gifford Street.

Do not hesitate to call me with any questions.

Sincerely,

Roland Letendre

Roland Letendre

August 23, 2010

Mr. Matthew A. Morrissey
Executive Director
New Bedford Redevelopment Authority
1213 Purchase Street
New Bedford, MA 02740

Dear Mr. Morrissey:

I am writing to state that at I am aware of the City of New Bedford and the Commonwealth's plans to establish an intermodal facility in the south terminal area of New Bedford. As a real estate owner in the immediate area, and one who is operating an existing business, I support and endorse the efforts to create such a facility.

Do not hesitate to call me with any questions.

Sincerely,

Robert K.Gardner III
President

Mr. Robert K.Gardner III
Bayline inc. Boatyard and Transport / DMD Development
109 Gifford Street / 4 Silva Street
New Bedford, MA 02744
508-994-2944

NEW BEDFORD HARBOR DEVELOPMENT COMMISSION

August 26, 2010

Curt Spalding
Regional Administrator for New England
US Environmental Protection Agency
5 Post Office Square
Mail Code: ORA01-4
Boston, MA 02109

Dear Mr. Spalding,

This letter is enclosed herein to express our full support of the South Terminal Marine Park project that will enable New Bedford to emerge as a leading hub for import /export trade and provide a state of the art port facility for the emerging offshore energy industry.

An important component of the existing proposal includes the use of the Gifford Street Boat Ramp to stage wind blade equipment. The Harbor Development Commission, as the governing entity for the Harbor, and manager of this city owned property agrees to make the acreage available at this site for this specific purpose, a total of 1 acre. To accommodate commercial haulers that currently use the boat ramp, a 36 foot wide accessway will be delineated apart from the staged wind blades. Use of the facility will be made via appointment with the Harbor Development Commission.

Recreational boaters will be directed to the City's boat ramps at East Rodney French Blvd. and West Rodney Blvd, boat ramps within minutes of Gifford Street. East and Rodney French Blvd. Boat Ramps are currently being rehabilitated and will be in superior condition to meet the use requirements of the recreational boating community. These ramps will also support the demands of commercial haulers.

It is important to note that the Gifford Street Boat Ramp is an underutilized facility in much need of repair. Given the low use of the facility and its inferior condition, we do not anticipate any problems with the temporary use of the site for staging wind blades. Engineering and permitting for the repair work is underway. We will proceed with construction after the temporary use of staging wind blades is no longer required.

I am happy to answer any questions and can be reached at (508) 961-3000. Thank you for your consideration of the South Terminal Marine Park Project that promises to bring thousands of jobs to our region as well as restore the environmental health of the Harbor through the removal of contaminated sediments.

Sincerely,

Kristin Decas
Executive Director

106 Co-Op Wharf P.O. Box 50899 New Bedford, MA 02745 Tel: 508-961-3000 Fax: 508-979-1517