RETURN TO SER AR INDEX

From: Johnson, Judith L NAE
To: Ralph Abele
Cc: Mackay, Joseph B NAE; Sneeringer, Paul J NAE
Subject: Additional references
Date: Monday, July 23, 2012 12:26:10 PM
Attachments: Auster1986.pdf
Heinemann1992.pdf
NBreferencesmodWithComments2.docx

Hi Ralph,

Attached are two additional references that I found in my hard copy files that were on your list (please see added comments on NBreferencesmodWithComments2).

The attached references include the following:

Auster, P. J., and L. L. Stewart. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (NorthAtlantic) Sand Lance. U.S. Fish and Wildlife Service Biological Rep. 82 (11.66). U.S. Army Corps of Engineers, TR EL-82-4. 11 pp.
http://www.nwrc.usgs.gov/wdb/pub/species_profiles/82_11-066.pdf

Heinemann, Dennis. 1992. Foraging Ecology of Roseate Terns Breeding on Bird Island, Buzzards Bay, Massachusetts. Unpubl. Report. U.S. Fish and Wildlife Service, Newton Corner, MA. 54 p

Please call me should you have any questions.

Regards,

Judi

Judith L. Johnson
Army Corps of Engineers
Evaluation Branch
696 Virginia Road
Concord, Massachusetts 01742-2751
978-318-8138
FAX 978-318-8560
judith.l.johnson@usace.army.mil

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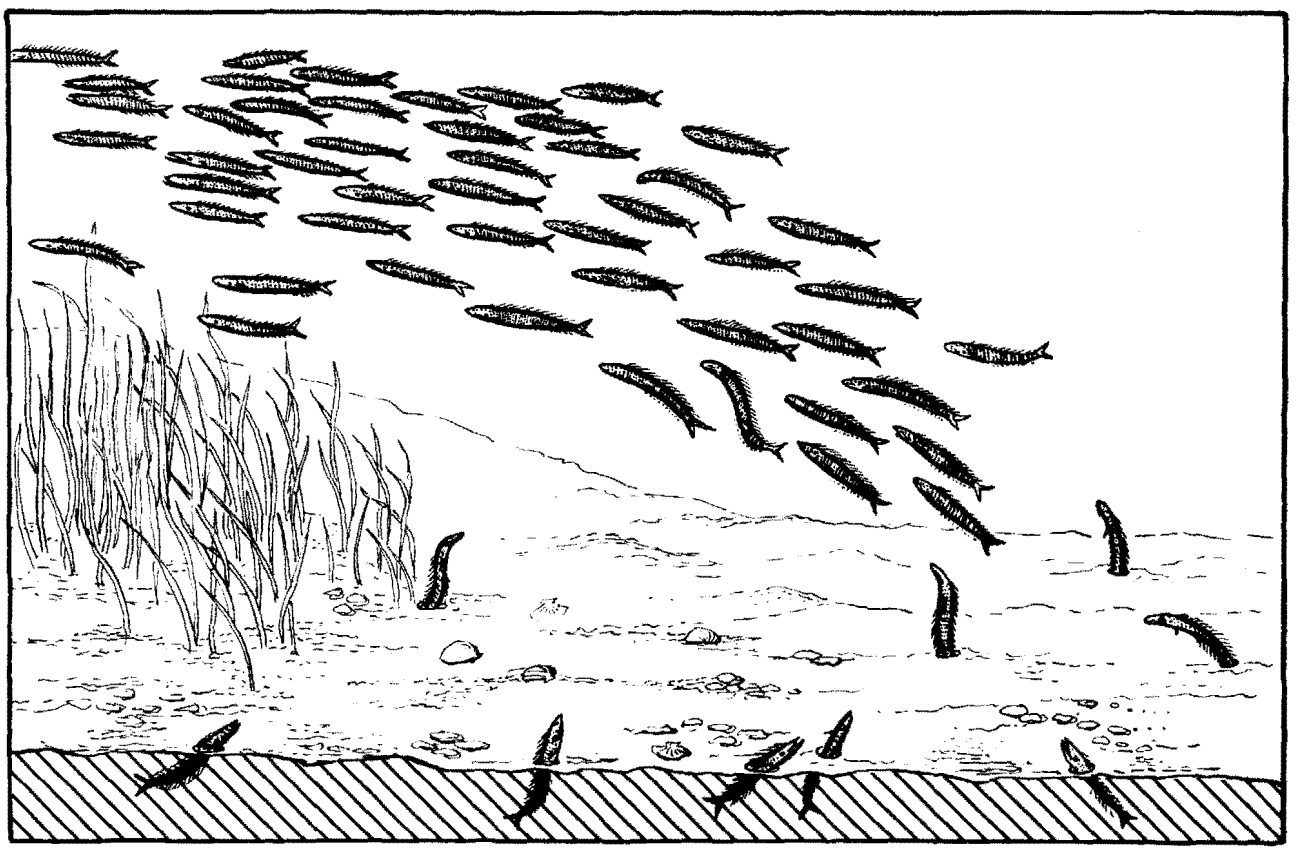
Biological Report 82 (11.66)
June 1986

TR EL-82-4

Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic)

SAND LANCE



Fish and Wildlife Service
U.S. Department of the Interior

Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic)

SAND LANCE

by

Peter J. Auster and Lance L. Stewart
NOAA's National Undersea Research Program
The University of Connecticut at Avery Point
Groton, CT 06340

Project Manager
Carroll Cordes
Project Officer
David Moran
National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, LA 70458

Performed for
Coastal Ecology Group
U.S. Army Corps of Engineers
Waterways Experiment Station
Vicksburg, MS 39180

and

National Coastal Ecosystems Team
Research and Development
Fish and Wildlife Service
U.S. Department of the Interior
Washington, D.C. 20240

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This profile may be cited as follows:

Auster, P. J., and L. L. Stewart. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic)--sand lance. U.S. Fish Wildl. Serv. Biol. Rep. 82 (11.66). U.S. Army Corps of Engineers, TR EL-82-4. 11 pp.

PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to one of the following addresses.

Information Transfer Specialist
National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
NASA-Slidell Computer Complex
1010 Gause Boulevard
Slidell, LA 70458

or

U.S. Army Engineer Waterways Experiment Station
Attention: WESER-C
Post Office Box 631
Vicksburg, MS 39180

CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
kilometers (km)	0.6214	miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
acres	0.4047	hectares
square miles (mi^2)	2.590	square kilometers
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees	0.5556(°F - 32)	Celsius degrees

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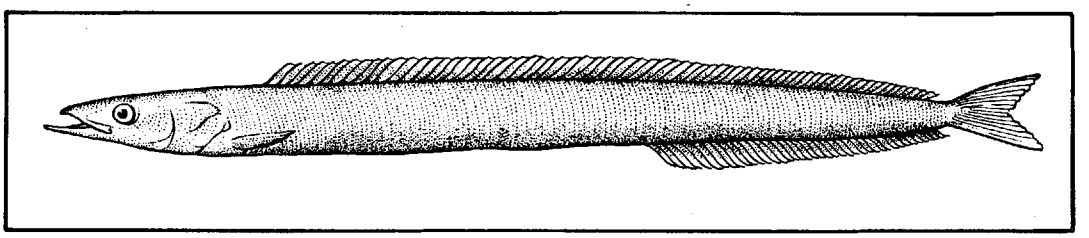

Figure 1. Sand lance.

SAND LANCE

NOMENCLATURE/TAXONOMY/RANGE

Scientific name..... Ammodytes spp.
Preferred common name.....Sand lance (Figure 1)
Other common names..... Sand eel, sand launce, lant, lance, equille, northern sand lance (A. dubius), American sand lance (A. americanus)
Class..... Osteichthyes
Order..... Perciformes
Family..... Ammodytidae

Geographic range: From northern Labrador and Hudson Bay south to Cape Hatteras (Bigelow and Schroeder 1953; Richards et al. 1963; Liem and Scott 1966) and from upper estuaries (Norcross et al. 1961) to the edge of the Continental Shelf (Richards and Kendall 1973)(Figure 2). This genus is most abundant, however, along the inner half of the Continental Shelf and is most commonly associated with sandy substrates (Bigelow and Schroeder 1953; Grosslein and Azarovitz 1982).

MORPHOLOGY/IDENTIFICATION AIDS

Meristic values of sand lance vary greatly with latitude as well as with distance from shore at the same latitude (Backus 1957; Richards et al. 1963; Winters 1970; Scott 1972; Pellegrini 1976). Richards et al. (1963) demonstrated various types of spatial changes in the genus Ammodytes from the northwest Atlantic and distinguished groups with high, intermediate, and low meristic counts. The intermediate group was split, and fish with high to intermediate counts were named A. dubius and those with low to intermediate counts were named A. hexapterus (= A. americanus). The range of meristic characteristics and overlap between species of this genus over a wide geographic area were significant (Table 1). As a result of this variation, sand lance in the North Atlantic area off the coast of the U.S. (Ammodytes spp.) will be covered as a combined group in this profile.

The body of the sand lance is small, elongate, and slender. Body depth is uniform from the opercular region to the beginning of the anal fin. Body depth then begins to taper towards the caudal peduncle. The tail is forked. The anal fin originates under the 29th or 30th dorsal fin ray. The lateral line is straight. The mouth is terminal with lower jaw projecting forward and no teeth (Liem and Scott 1966). Fin ray counts vary as in Table 1.

Color of individual fish is variable. The dorsal surface can be olive, brown, or bluish green. Lower sides are silver with a dull white ventral region. Some individuals have a steel-blue iridescent longitudinal stripe.

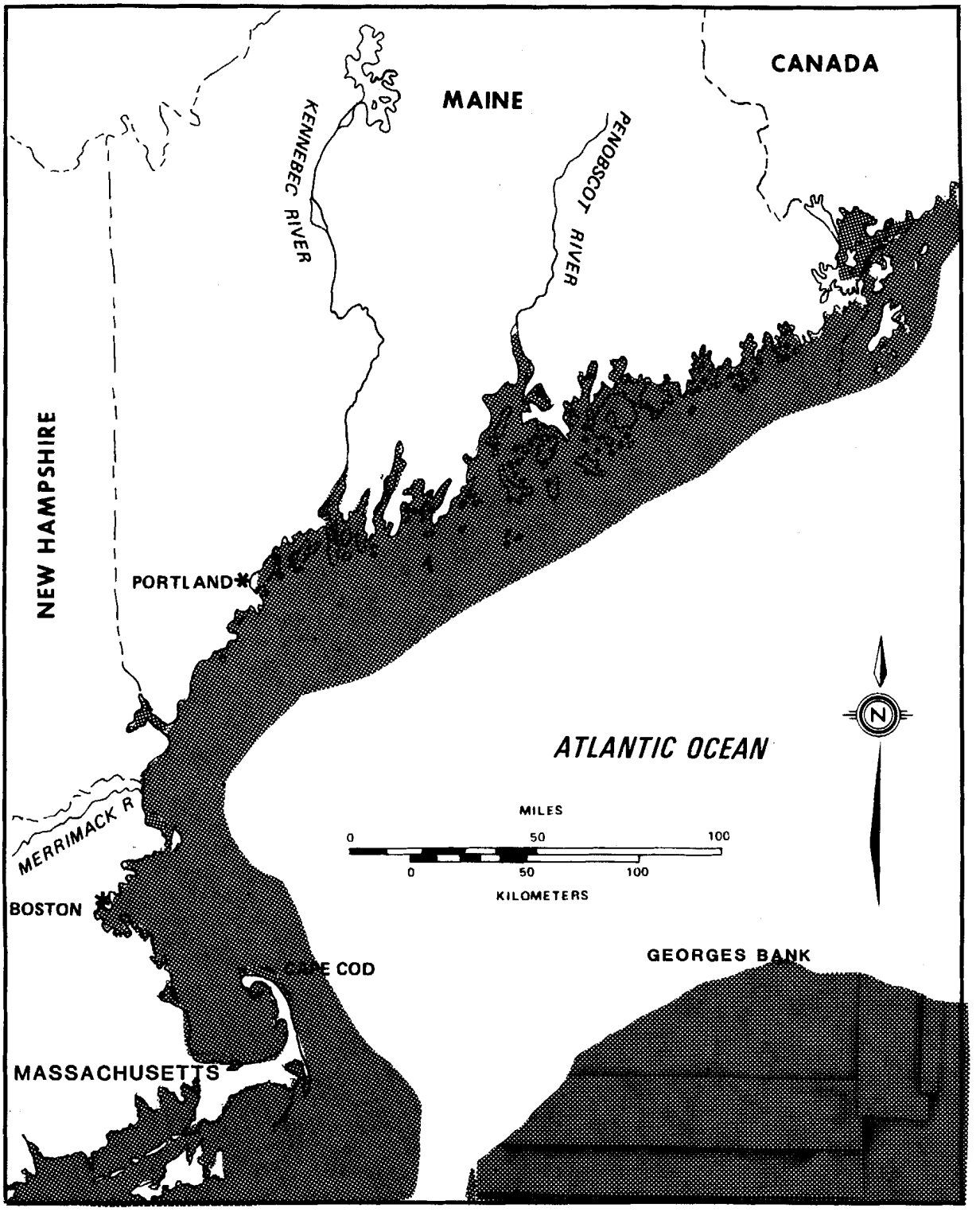

Figure 2. Distribution of sand lances along the North Atlantic coast.

Table 1. Meristic values of Northwest Atlantic species of *Ammodytes* (adapted from Pellegrini 1979).

Species	No. in sample	Vertebrae		Dorsal fin rays		Anal fin rays	
		Range	Mean	Range	Mean	Range	Mean
Ammodytes hexapterus (Richards et al. 1963) East coast of North America	1020	61-73		51-62		23-33	
A. hexapterus (Scott 1972) Newburyport, Massachusetts	73	64-71	68.1	55-61	57.6	27-32	29.4
A. americanus (Backus 1957) Labrador	12	62-69	67.2	56-60	58.5	28-31	29.6
A. americanus adults (Pellegrini 1976)	700	63-73	67.9	52-62	57.4	26-32	29.4
A. americanus juveniles (Pellegrini 1976)	610	64-73	68.0	53-62	57.8	27-33	29.7
A. dubius (Richards et al. 1963) East coast of North America	—	65-78		56-68		27-35	
A. dubius (Leim and Scott 1966) East coast of Canada	—	71-75		62-68		30-35	
A. hexapterus (Winters 1970) Offshore Newfoundland	—	70-78		60-69		30-37	
A. hexapterus (Winters 1970) Inshore Newfoundland	—	63-72		52-60		25-33	

Sand lance eggs, larvae, and postlarvae were described by Norcross et al. (1961), Williams et al. (1964), Richards (1965), and Smigielski et al. (1984), and can be distinguished from those of other species on the basis of morphology.

REASON FOR INCLUSION IN SERIES

Sand lance are widespread along the northeast coast of the U.S. (Sherman et al. 1981; Morse 1982). They are abundant and are an important prey species for many predatory fishes important to commercial and recreational fisheries and are also important prey for marine mammals. Sand lance occur in estuarine, open coastal, and offshore habitats. Contiguous overlapping populations provide linkages between these habitat types and coastal regions.

LIFE HISTORY

Spawning

Sand lance mature during their first or second year (Westin et al. 1979), and males reach maturity several months before females (Scott 1968). Spawning occurs principally from November to March (Bigelow and Schroeder 1953; Norcross et al. 1961). Larval fish survey data indicate that spawning occurs principally inshore although evidence exists of some offshore spawning activity (Richards and Kendall 1973; Sherman et al. 1981; Sherman et al. 1984). Sand lance lay demersal eggs that are deposited on or in sand substrates or on gravel surfaces (Ehrenbaum 1904; Williams et al. 1964). Sand lance larvae are distributed over a wide area of the shelf in winter (Sherman et al. 1984).

Fecundity and Eggs

Westin et al. (1979) showed that sand lance in the Merrimack River exhibited size specific fecundity. The model which describes this relationship is: $f = 0.328\ l^{3.857}$ where f is fecundity (number of eggs) and l is fork length (cm). Estimates of weight loss during spawning of females range from 30% to 45% (Scott 1972; Westin et al. 1979; Smigielski et al. 1984).

Sand lance eggs range in diameter from 0.67 to 1.03 mm and have a single bright yellow oil globule (Williams et al. 1964; Smigielski et al. 1984). Eggs hatch from November to May when water temperatures drop below 9 °C (Wheatland 1956; Norcross et al. 1961; Richards and Kendall 1973). Incubation times of eggs spawned in the laboratory ranged from 30 days at 10 °C to 82 days at 2 °C (Smigielski et al. 1984).

Larvae

Larvae are approximately 3 to 4 mm in length at hatching. After a planktonic stage of 2 to 3 months (Grosslein and Azarovitz 1982), during which they grow to about 35 mm (Scott 1973a), they become semidemersal. Larvae reared in captivity at 7 °C exhibited schooling behavior at a size of 35 to 40 mm 90 days after hatching, and first burrowed into the sand at 133 days after attaining a size of 35 to 40 mm (Smigielski et al. 1984).

Larvae are most abundant off the mouths of major estuaries but are common out to the edge of the Continental Shelf (Norcross et al. 1961; Richards and Kendall 1973). Major concentrations of larvae have consistently occurred in the Georges Bank and the Nantucket Shoals to Long Island, New York, regions since 1976 (Sherman et al. 1981; Morse 1982). Norcross et al. (1961) found that larvae increased in size in samples taken along nearshore to offshore transects, suggesting that the larvae may be able to undertake directed migrations away from the shore.

Richards (1976) reported the occurrence of heterotypic schools of sand lance and herring (Clupea harengus harengus) postlarvae. The ubiquity of this behavior is unknown. Heterotypic schooling has been reported in several diverse species groups (Nursall and Pinsent 1969; Ogden and Erlich 1977; Frank and Leggett 1983; Auster 1984). This behavior is believed to be an adaptive response to predation: increased school size reduces the probability of predation on any individual.

Sand lance larvae feed diurnally. Their diet consists of phytoplankton, invertebrate eggs, and copepod nauplii. As the fish increases in size, phytoplankton such as peridinians decrease in importance and copepod nauplii increase. When larvae become about 21 mm long, their diet consists mostly of adult copepods (Covill 1959).

Juveniles and Adults

Juvenile and adult sand lance have generally been found in schools during the day. Meyer et al. (1979) observed school sizes ranging from about 100 to tens of thousands of fish. We have observed schools of about 20 to 100 individuals along the coast. This observation is consistent with those reported for Hyperoplos lanceolatus and A. tobianus off Europe by Kuhlmann and Karst (1967), who observed school sizes of 30 to 300. In general, school size seems to be smaller in shoaler water, increasing as water depth increases. However, schools may occur at any depth in the water column (Meyer et al. 1979).

The shape of sand lance schools is generally compressed vertically and lengthwise. In shallow water, schools tend to be more compressed vertically and longer than in deeper water (Kuhlmann and Karst 1967; Meyer et al. 1979).

Sand lance are generally found over sandy substrates. Sand is used as a refuge. Individual fish have been observed to burrow into the sand and remain either partly buried (with either anterior or posterior body parts exposed) or totally buried after emerging headfirst and then backing up (Meyer et al. 1979). European sand lance species are reported to school diurnally and seek refuge in sand substrates at night. Schools reform at dawn (Kuhlmann and Karst 1967).

Copepods are the major prey of juvenile and adult sand lance (Reay 1970; Scott 1973b; Meyer et al. 1979). The inclusion of less important prey items such as crustacean larvae (Scott 1973b) and chaetognaths (Meyer et al. 1979) in the sand lance diet probably reflects the utilization of locally abundant prey.

GROWTH CHARACTERISTICS

Reay (1970) reported that 1- to 3-year-old fish dominate sand lance populations but individuals can live to 9 years of age and grow to a total length of 37 cm (Scott 1968). Comparison of length-at-age data suggests that growth rate increases from the New York Bight to the Nova Scotia banks (Grosslein and Azarovitz 1982).

Pellegrini (1976) found that sand lance from the Merrimack River, Massachusetts, had a weight-length relationship described by the model:

$$\log W\ (g) = -2.718 + 3.098\ \log L\ (mm)$$

This model agrees with weight-length relationships found by Scott (1972) for sand lance on the Newfoundland Grand Banks and Emerald Bank.

Growth is fastest during the first year of life and slows with increasing age. The Von Bertalanffy growth model for sand lance from the

Merrimack River, generated from the Ford-Walford relationship, is

$$l_t = 24.08 \quad (1-e^{-0.2508(t+0.5970)}).$$

This model includes both males and females because their growth rates did not differ significantly (Pellegrini 1976).

FISHERY

The use of sand lance in the U.S., limited to occasional use in the baitfish industry, has not been extensive. Annual landings between 1965 and 1973 ranged from 0 to 75 metric tons (Grosslein and Azarovitz 1982). Historically, Bigelow and Schroeder (1953) reported that more than 30 metric tons (67,800 pounds) were landed in 1919 and over 9 metric tons (20,000 pounds) in 1946, from traps in Massachusetts. National Marine Fisheries Service survey data indicate that the sand lance population in the northwest Atlantic increased greatly after 1974 (Grosslein et al. 1980; Sherman et al. 1981). No plans now exist for the management of sand lance in U.S. waters of the northwest Atlantic.

ECOLOGICAL ROLE

Sand lance are a major link between zooplankton production and fishes of commericial importance. They have been found in the stomachs of a wide variety of species, including Atlantic cod, Gadus morhua; haddock, Melanogrammus aeglefinus; silver hake, Merluccius bilinearis; white hake, Urophycis tenuis; yellowtail flounder, Limanda ferruginea; and longhorn sculpin, Myoxocephalus octodecemspinosus (Scott 1968, 1973b; Bowman et al. 1976; Bowman and Langton 1978). They are also important prey of whales and porpoises (Bigelow and Schroeder 1953; Overholtz and Nicolas 1979; Hain et al. 1982). The importance of sand lance as prey of cod increases from south to north (Grosslein and Azarovitz 1982).

Although no specific data exist on diseases of sand lance in the North Atlantic, other studies in the literature suggest that certain trends have been discerned in pollution-related diseases. Sand lance in coastal waters of northeastern United States are associated with surficial sediments through their burrowing behavior. In fishes other than sand lance, fin necrosis has been associated with high coliform counts in coastal waters (Mahoney et al. 1973) and with high concentrations of heavy metals in sediments (Carmody et al. 1973). The frequency of skin tumors in geographically separated populations of flatfishes has been correlated with environmental rather than with genetic factors (Stich et al. 1976). The relationships discerned in these studies may apply to sand lance populations as well.

ENVIRONMENTAL REQUIREMENTS

Temperature

Sand lance occur along the North American coast from 35°N to 69°N. Temperatures within this latitudinal range vary widely. During the time of egg development, bottom water temperatures can be near 0 °C (Richards et al. 1963; Richards and Kendall 1973). Scott (1968) reported that sand lance were taken from the Nova Scotia banks at temperatures ranging from -2 to 11 °C, but they were most abundant between 3 and 6 °C. No records of an upper temperature limit have been published. Reay (1970) reported that A. tobianus along the south coast of England is active at temperatures as high as 18 °C.

Salinity

Tolerance of fluctuations in salinity apparently decreases with increasing age. Sand lance larvae

have been found in waters with salinities less than 1.8 ppt although only a small percentage were taken in samples at salinities less than 30 ppt (Norcross et al. 1961). Richards et al. (1963) reported that sand lance juveniles and adults occur in salinities ranging from 26 to 36 ppt.

Habitat

Sand lance occur throughout the water column over sandy substrates into which they burrow (Bigelow and Schroeder 1953; Reay 1970; Meyer et al. 1979). The sand lance burrows for rest and escape from predators; hence much time may be spent within the substrate, isolated from the water column. Relatively high bottom current velocities must therefore be present to maintain aeration of the interstitial water. The interaction of current velocity with substrate type in keeping interstitial water oxygenated is more critical in defining proper habitat than is the range of substrate particle sizes (Reay 1970).

Other Environmental Factors

European studies have reported on the light-mediated diel cycle of activity in other sand lance species. Direct underwater observations by Kuhlmann and Karst (1967) showed that sand lance (*H. lanceolatus* and *A. tobianus*) are diurnal schoolers, resting in the sand in groups at night. At dawn, schools re-form and begin feeding. In laboratory studies of *A. marinus*, swimming activity was high at light levels of 1000 and 100 lux but was greatly reduced at levels below 10 lux (Winslade 1974). In the same study, it was found that the threshold light intensity for swimming activity in the field was approximately 100 lux, and that buried sand lance may be able to detect light, via the pineal gland, to respond to changes in light intensity.

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P. J. Auster and L. L. Stewart

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Groton, CT 06340

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16. Abstract (Limit: 200 words)

Species profiles are literature summaries on taxonomy, morphology, range, life history, and environmental requirements of coastal finfishes and shellfishes. They are designed to assist in environmental impact assessment. The systematic classification of the sand lances *Ammodytes americanus* and *Ammodytes dubius* is confusing because of overlapping meristic values. In this report, all sand lances in the North Atlantic area off the coast of the United States are treated as a combined group (*Ammodytes* spp.). Sand lances occur in estuarine, open coast, and offshore habitats. They are important prey to many commercially and recreationally valuable fish and marine mammals. Spawning occurs principally inshore between November and March. Larvae are found along the coasts to the edge of the Continental Shelf. Sand lances occur in schools of from tens to tens of thousands of individuals. They are planktivorous predators; copepods are their major prey item. To rest and to take refuge from predators, sand lances burrow into sand substrates. One to three-year-old fish dominate populations. Growth rate probably increases from the New York Bight to the Nova Scotia banks. Exploitation of sand lances off the Northeast coast of the United States is presently only for baitfish.

17. Document Analysis a. Descriptors

Estuaries	Life cycles	Food chains
Marine fishes	Growth	Temperature
Salinity	Contaminants	Feeding habits

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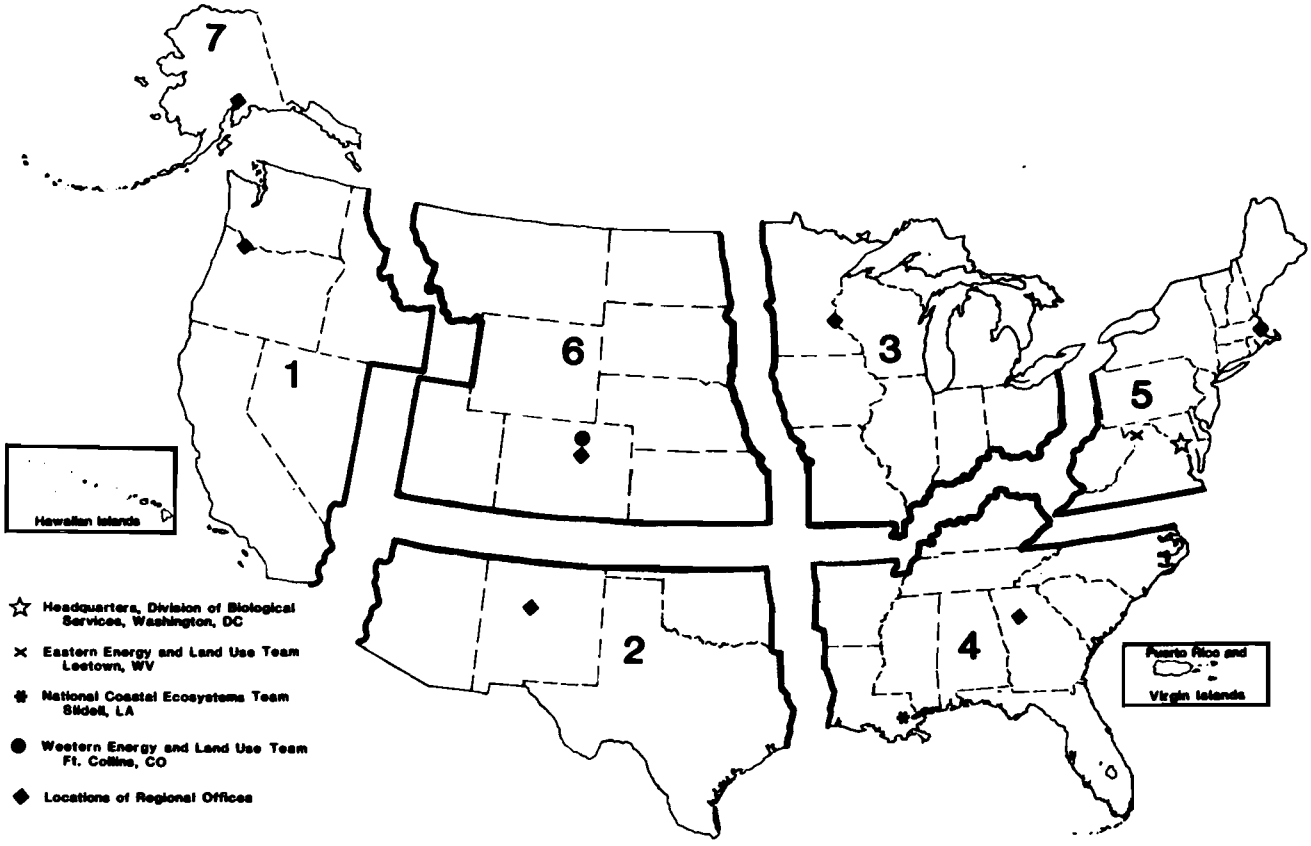

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U.S. Fish and Wildlife Service
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Portland, Oregon 97232

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U.S. Fish and Wildlife Service
P.O. Box 1306
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FORAGING ECOLOGY OF ROSEATE TERNS BREEDING ON BIRD ISLAND, BUZZARDS BAY, MASSACHUSETTS

FINAL REPORT

SUBMITTED TO THE

UNITED STATES FISH AND WILDLIFE SERVICE

NEWTON CORNER, MASSACHUSETTS

by

Dennis Heinemann

Research Ecologist

Manomet Bird Observatory

Manomet, Massachusetts 02345

(508) 224-6521

INTRODUCTION

The Northeast U.S. population of the Roseate Tern (*Sterna dougallii*) has been classified as a federally Endangered species since 1986 (Andrews et al. 1989). This population is currently estimated to be approximately 3200 breeding pairs (Nisbet 1989). Almost half the population breeds on Bird Island (41°40'N, 70°43'W), Buzzards Bay, Massachusetts, and 89-96% of the population has bred in just 4 localities from Long Island to Cape Cod during the last few years (Nisbet 1989). The restricted range, and concentration in so few colonies puts this population of the Roseate Tern in an extremely vulnerable position, and places an inordinate importance on the Bird Island colony. Changes in colony sizes detected in 1990 have further exacerbated this problem (Nisbet pers. comm.). Although Bird Island is not in peril at present (Nisbet pers. comm.), the environmental integrity of this population's foraging grounds is uncertain.

From 1940 to 1970 large amounts of PCB's discharged by industry into the New Bedford sewer system found their way into the Acushnet River Estuary, which empties into Buzzard Bay (Buzzards Bay Project 1987). In addition, Buzzards Bay is connected with Cape Cod Bay through the Cape Cod Canal, and, therefore, may receive water from the highly polluted Boston Harbor. Several studies have found high environmental and biotic levels of PCBs in New Bedford Harbor, the Acushnet River Estuary and Buzzards Bay (e.g. Kolek & Ceurvals 1981, Boehm 1983). PCBs have not been seen as a serious threat to the 1900 pairs of Common Terns (*Sterna hirundo*) breeding on Bird Island (Nisbet & Reynolds 1984). However, near the end of the 1989 breeding season, two Common Terns breeding on Bird Island were found dead, and subsequently discovered to have PCB concentrations of 400 ppm in their brains (concentrations above 300 ppm are lethal; Nisbet pers. comm.). Tissue analyses of 2 Roseate and 3 other Common Terns found dead at or near Bird Island in 1989 did not find similarly high levels of PCBs (Nisbet pers. comm.).

While the threat of PCBs and other toxic pollutants to this population of Roseate Terns cannot be fully evaluated at this time, the threat is clearly present. Data collected this year show that Roseate Terns from Bird Island do not forage in the immediate vicinity of New Bedford Harbor, although they can be found in significant numbers near West Island and Ram Island just 6-9 km away. However, if a project to restore the Roseate Tern to Ram Island (Andrews 1990) is successful, then Roseate Terns may be exposed to significant levels of PCBs on a much more regular basis. Because Roseate Tern populations declined in Northeast North America from 1930 to 1980, because they have become concentrated into a few colonies, and because we have not identified the factors responsible for these changes, it is important that we evaluate potential sources of mortality or reduced fecundity to Roseate Terns as soon as they are recognized (Nisbet 1989). Toxic substances such as PCBs are obtained by terns through their diet, making it necessary to study the diet and foraging areas of this population. Further, Safina et al. (1988) have shown that Roseate Terns in New York suffered reduced productivity in a year of low prey density, suggesting that pollution, habitat alteration, fishing activities or disturbance that reduces prey availability may have serious consequences for the population stability of Roseate Terns.

Preliminary investigations of the diet and foraging ecology of the Bird Island Roseate Terns revealed some critical facts. First, Roseate Terns at Bird Island have a restricted dietary breadth (Nisbet 1981, 1989, pers. comm.). Prior to mid-June over 95% of their diet consists of American sandlance (*Ammodytes americanus*). After mid-June diet breadth increases in most years, and any one of four species may make-up the bulk of their diet. The other species that may be important are all open-water schooling species: Atlantic (*Clupea harengus*), blue-backed (*Alosa aestivalis*) and round herring (*Etrumeus teres*), mackerel (*Scomber scombrus*), and bluefish (*Pomatomus saltatrix*). In addition, surveys conducted prior to 1990 have shown that most of these birds consistently feed in one of two locations while they are breeding (Nisbet unpub. data, Heinemann unpub. data). One location is in the vicinity of Woods Hole and Falmouth, Massachusetts (approximately 16 km from Bird Island),

and the other is near the entrance to the western end of the Cape Cod Canal, Massachusetts (5-11 km from Bird Island); New Bedford Harbor is 17-22 km from Bird Island. Data collected in 1989 on the directions from which Roseate Terns returned to Bird Island, confirmed the findings of the surveys, and suggested that on some days 5-10% of the foragers may return from the direction of New Bedford Harbor (Heinemann unpub. data).

This extreme degree of prey and foraging-site specificity means that these Roseate Terns will be in even greater danger if pollutant levels are found to be high on their foraging grounds or conditions change and bring about an increase in pollutant levels in those areas. Further, the Cape Cod Canal, a major shipping channel, may represent a threat to a critical foraging area for this population in the advent of a spill of toxic materials (e.g. petroleum products), or a change in the policies of the Cape Cod Canal Authority that govern the dredging of the channel leading to the Cape Cod Canal and the shallows near the State Pier at the entrance to the canal, both important areas for foraging Roseate Terns. In early June, 1990, just as eggs were beginning to hatch on Bird Island, the Bermuda Star, a 600' cruise ship, ran aground and leaked 7,500 gallons of oil within 5 km of Bird Island. Luckily the oil did not appear to harm the Roseate Terns (pers. obs.; Nisbet pers. comm.), but had the oil drifted near Bird Island or into the foraging grounds of the Roseate Terns, it could have had devastating effects on the Roseate Tern population. Just a week later a barge carrying over 5 million gallons of oil went aground on rocks even closer to Bird Island. An insignificant amount of oil leaked before the barge was refloated, but, again, the potential for catastrophic damage to the population was very real.

Because of these potential environmental threats to the largest breeding colony of Roseate Terns in North America, research into the foraging ecology Roseate Terns at Bird Island is critical. We need to determine what makes particular foraging areas and prey species important to Roseate Terns. In the advent of changes to those areas or decreases in the availability of prey populations, knowledge of how and why Roseate Terns make their foraging decisions will permit population managers to predict the responses of the population and to make projections about the effects on population dynamics.

Here I provide a final report on research conducted during the 1990 and 1991 nesting seasons under contract to the Endangered Species Office of the U.S. Fish and Wildlife Service, Newton Corners, Massachusetts. Our efforts were directed toward :

1) determining the entire foraging range of the Bird Island Roseate Terns,

2) detecting changes in that distribution during the season and between years,

3) estimating the relative numbers of Roseate Terns using different portions of their foraging grounds, and

4) recording the relative proportions and sizes of different prey species used by Roseate Terns.

SURVEY DESIGN, METHODS AND MATERIALS

Survey of Foraging Grounds

Because previous information indicated that Roseate Terns forage mostly in shallow water near shore, we concentrated our surveys in those areas. We located our survey transects along shorelines and over shoals, and added transects in deeper water whenever

possible to verify our assumption that those areas are unimportant. We tried to place shoreline transects close enough to shore so that we would not miss even single Roseate Terns foraging right along the shore, and yet not so close that we would restrict the amount of water we were able to survey; in some cases ideal transect placement was altered to avoid navigational hazards, such as submerged rocks. Because there are many deep, convoluted harbors and coves in Buzzards Bay, we were unable to survey the entire coastline. In many locations we placed transects across the mouths of harbors and coves, and only investigated them if we observed Roseate Terns flying into or out of them. Previous work by Nisbet (pers. comm.) and Heinemann (unpub. data), had identified the waters at the head of Buzzards Bay, between Stony Point and the Cape Cod Canal, as an extremely important foraging ground. In 1990 other aspects of our research involved counting and observing the Roseate Terns there 1-3 times per week, so set transects were not run through the area in that year. However, in 1991, in order to standardize all of our survey efforts, we surveyed this area in the same manner than we used over the rest of the study area. The study area and names of localities referred to herein are shown in Figures 1-5.

The surveys were not designed to be used to obtain density estimates of foraging Roseate Terns because of the difficulties of implementing line-transect techniques in shoreline surveys made from small boats. Instead we used the surveys to identify foraging grounds, associations with prey species and other predators, and flight lines to and from Bird Island and the foraging grounds.

In 1990, we had planned to run complete surveys every two weeks. However, the discovery that the foraging range was much larger than anticipated, and problems associated with running a new survey (e.g. familiarization with new waters, and several motor break-downs) increased the amount of time required to complete each survey. The first survey was conducted from 5 June to 22 June, and primarily covered the areas that had been know from previous work to be important to Roseate Terns (Figure 6). Because we expanded the area covered and because we had a number of boat problems, the second survey took from 25 June to 24 July to complete (Figure 7). The final survey was run from 25 July to 16 August (Figure 8).

In 1991, we were able to complete more surveys of the study area. The first survey was run from 1 - 14 June (Figure 9), the second from 14 - 21 June (Figure 10), the third from 20 June - 5 July (Figure 11), the fourth from 9 - 24 July (Figure 12), and the last from 25 - 30 July (Figure 13).

Almost all of the transects were run using our 19' Mako with an 85 hp outboard motor. This boat provided a stable platform for survey work, as long as wave heights were below 3'. On two occasions in 1990, in calm weather, we used our 16' Boston Whaler with a 50 hp outboard motor. We used landmarks (e.g. buoys, rocks, towers) and compass headings to follow our transect lines, which were set-out on our charts ahead of time. Our speed varied from 5-25 kts (usually 10-20 kts) depending on the water conditions, proximity to land, and density of terns. Because we were not using the surveys to estimate Roseate Tern density, this variation in speed was not a problem. We used two observers during all surveys. The primary observer, watched for terns continuously, and the other watched while piloting the boat. When terns were spotted we recorded location, numbers, species (Roseate, Common or Least) and activity of the terns; if it was necessary we stopped the boat long enough to obtain accurate estimates. If concentrated feeding activity was going on we attempted to determine the prey species being caught, either with binoculars or by catching predatory fish feeding in the same location and examining their stomach contents. Notes were made about the presence and activity of predatory fish or birds other than terns. Flight directions of commuting birds were recorded. Data on location and number of terns observed were later transferred from field charts to the computer for analysis by CAMRIS (Ford 1989), a Geographical Information System program.

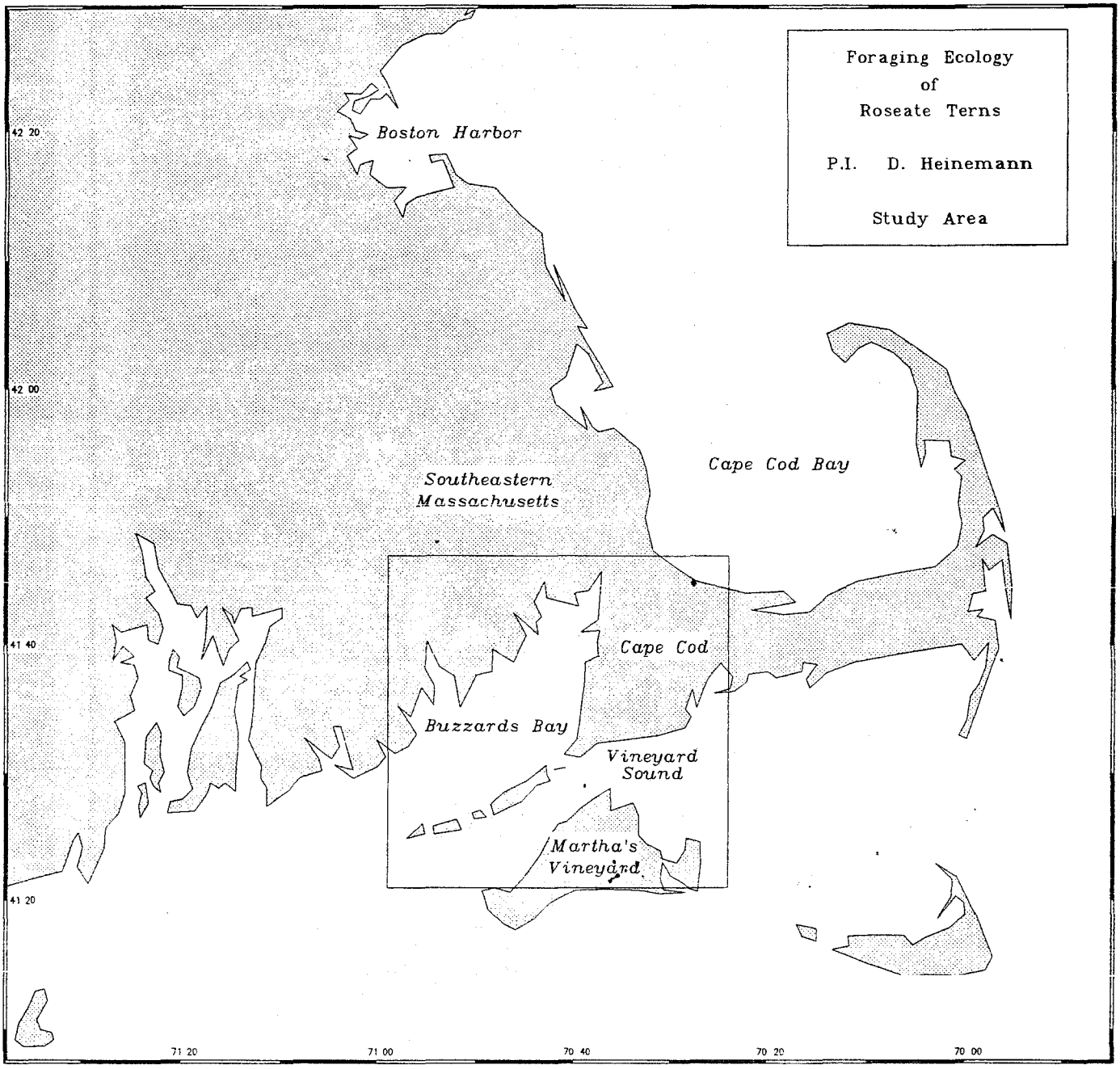

Figure 1. Location of study site in Northeastern United States.

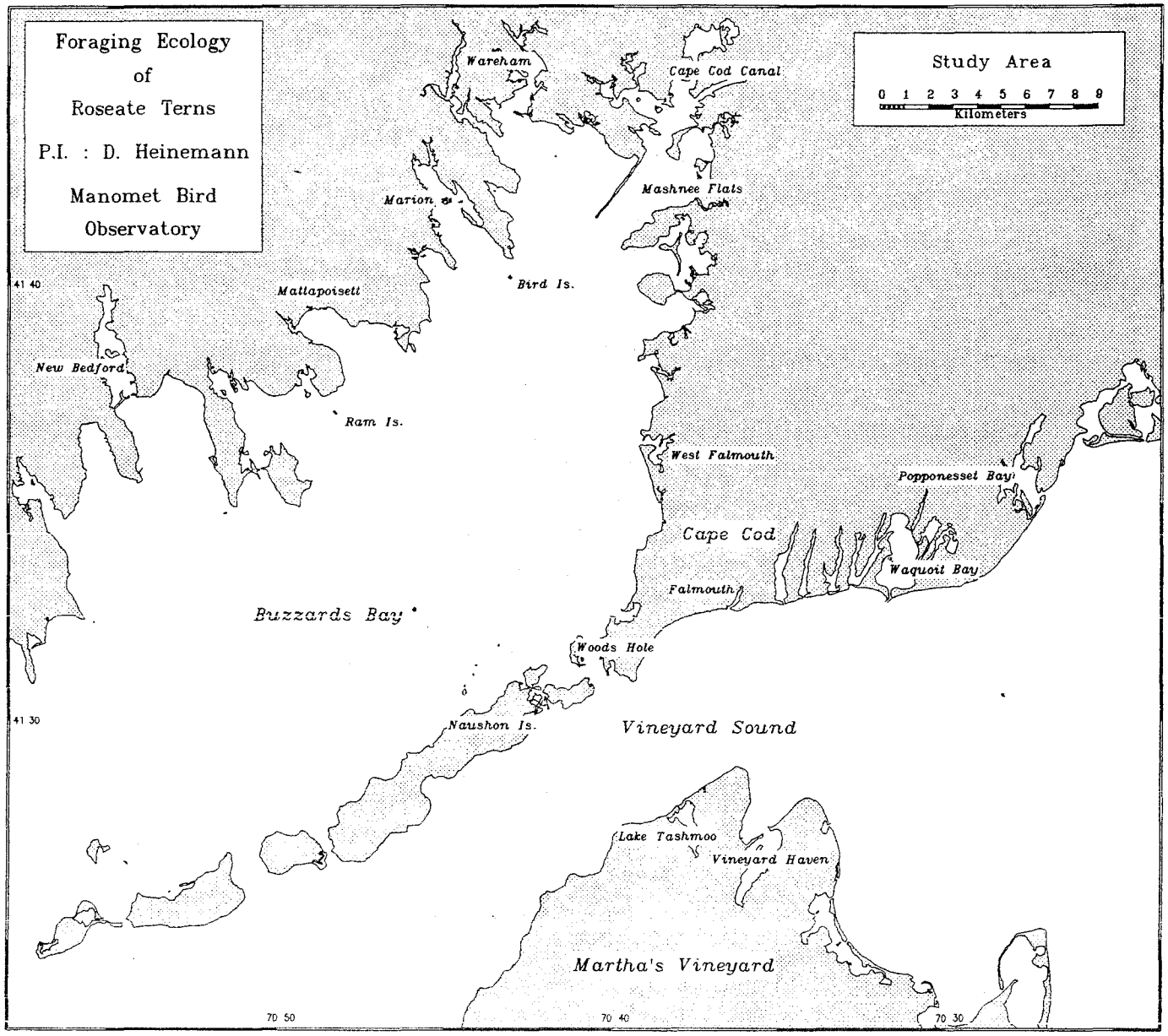

Figure 2. Major localities and reference locations in study area.

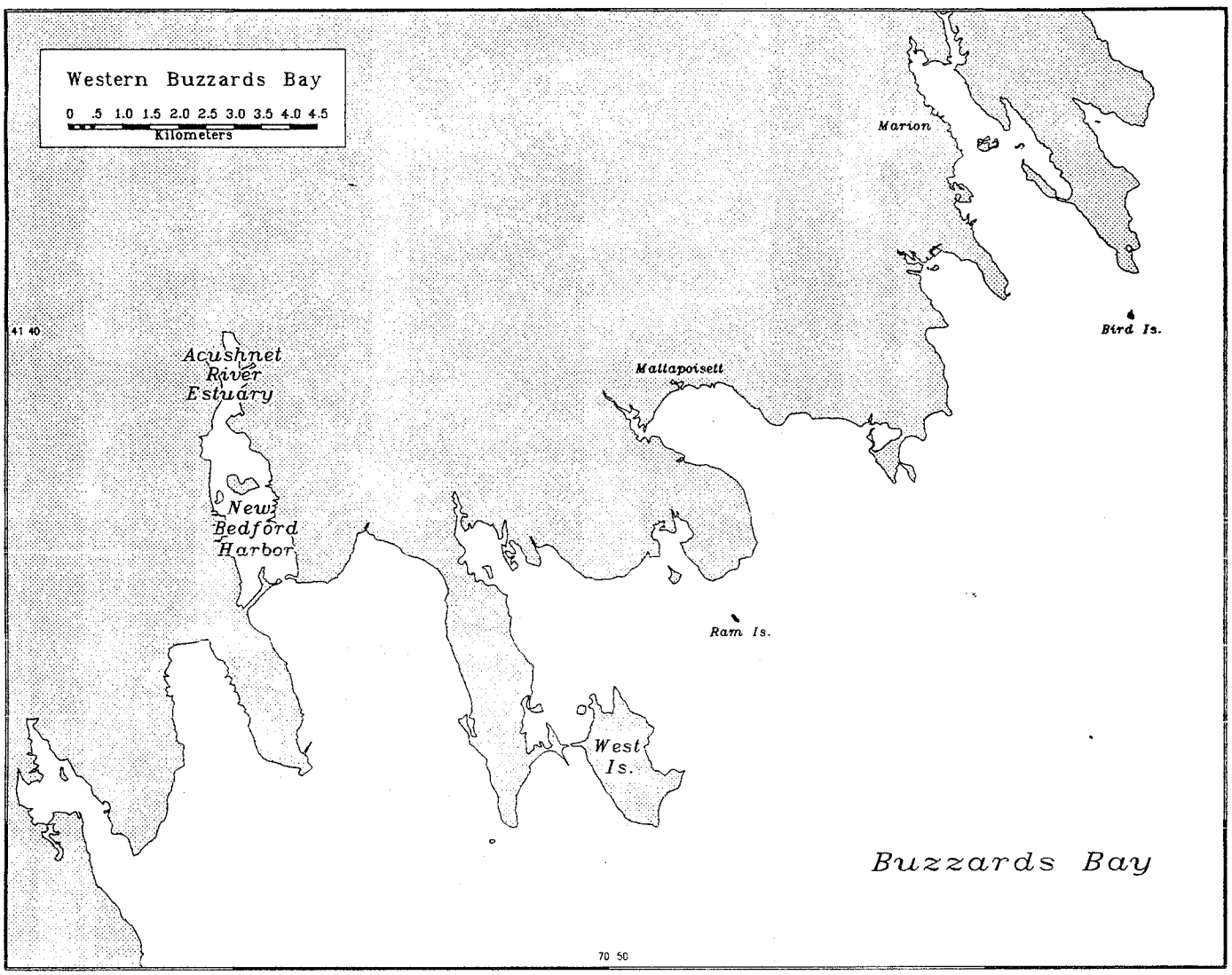

Figure 3. Major localities and reference locations in Western Buzzards Bay.

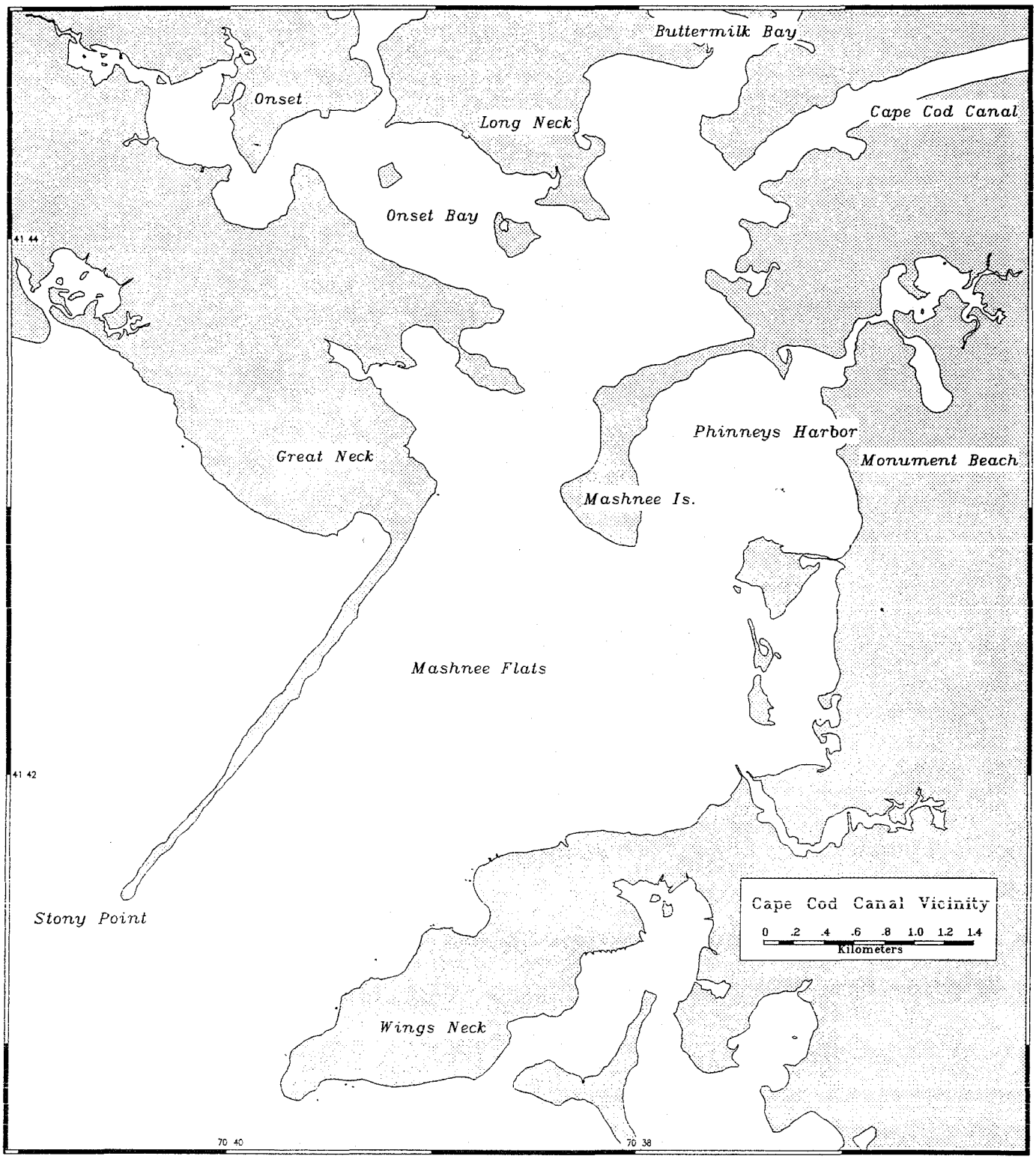

Figure 4. Major localities and reference locations in the vicinity of the Cape Cod Canal.

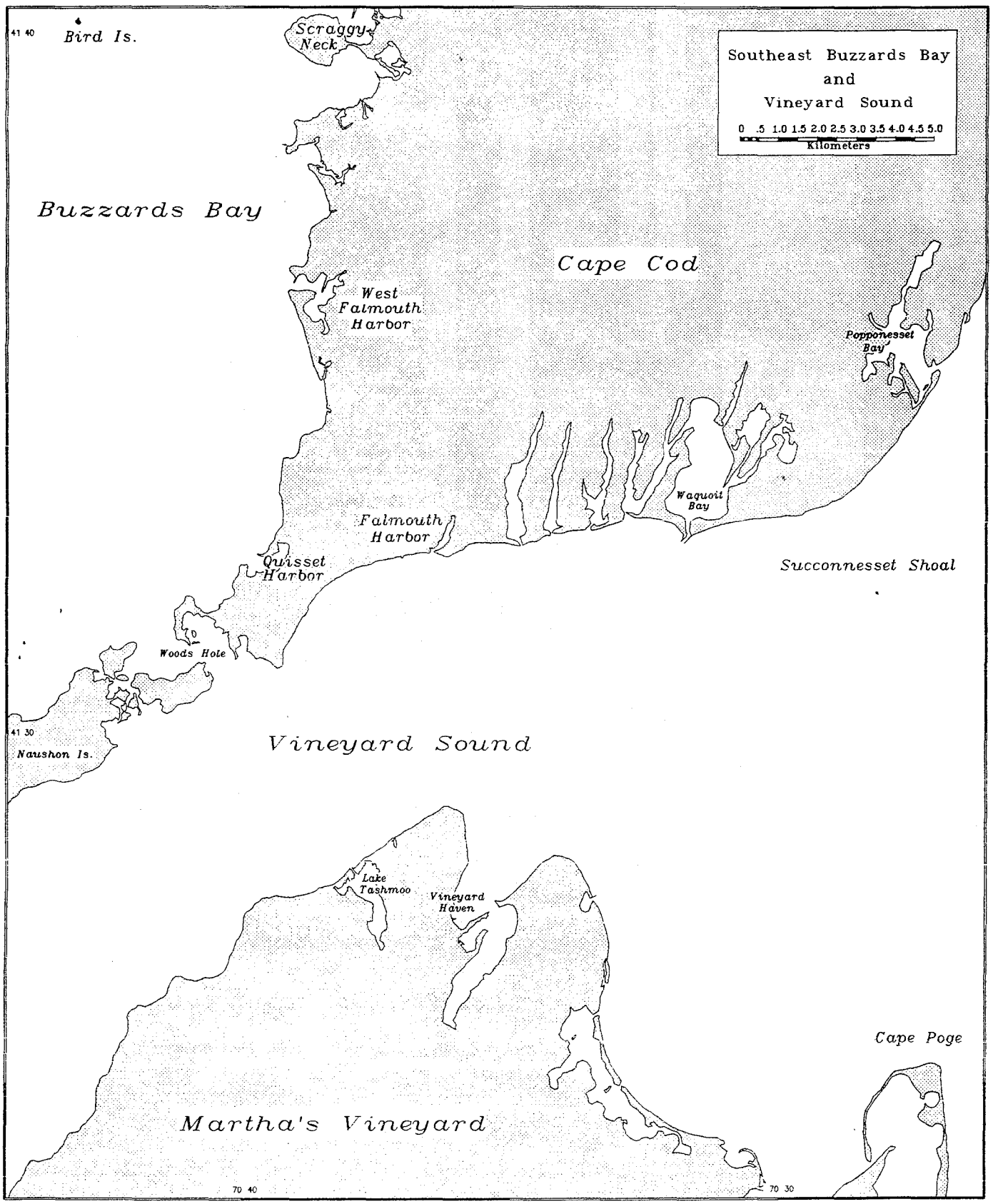

Figure 5. Major localities and reference locations in Eastern Buzzards Bay and Vineyard Sound.

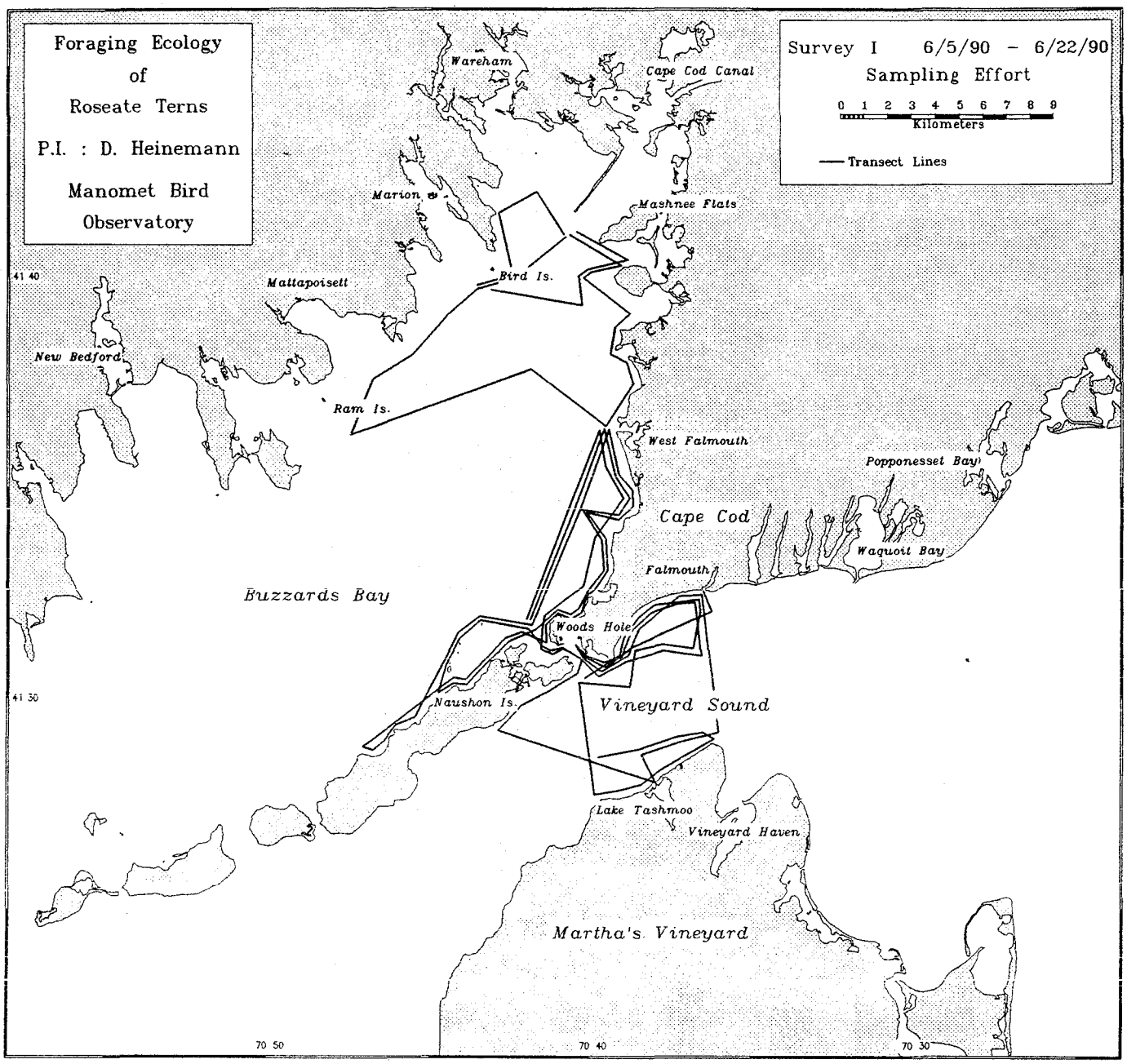

Figure 6. Placement of transect lines during the first survey period in 1990, 5 June to 22 June.

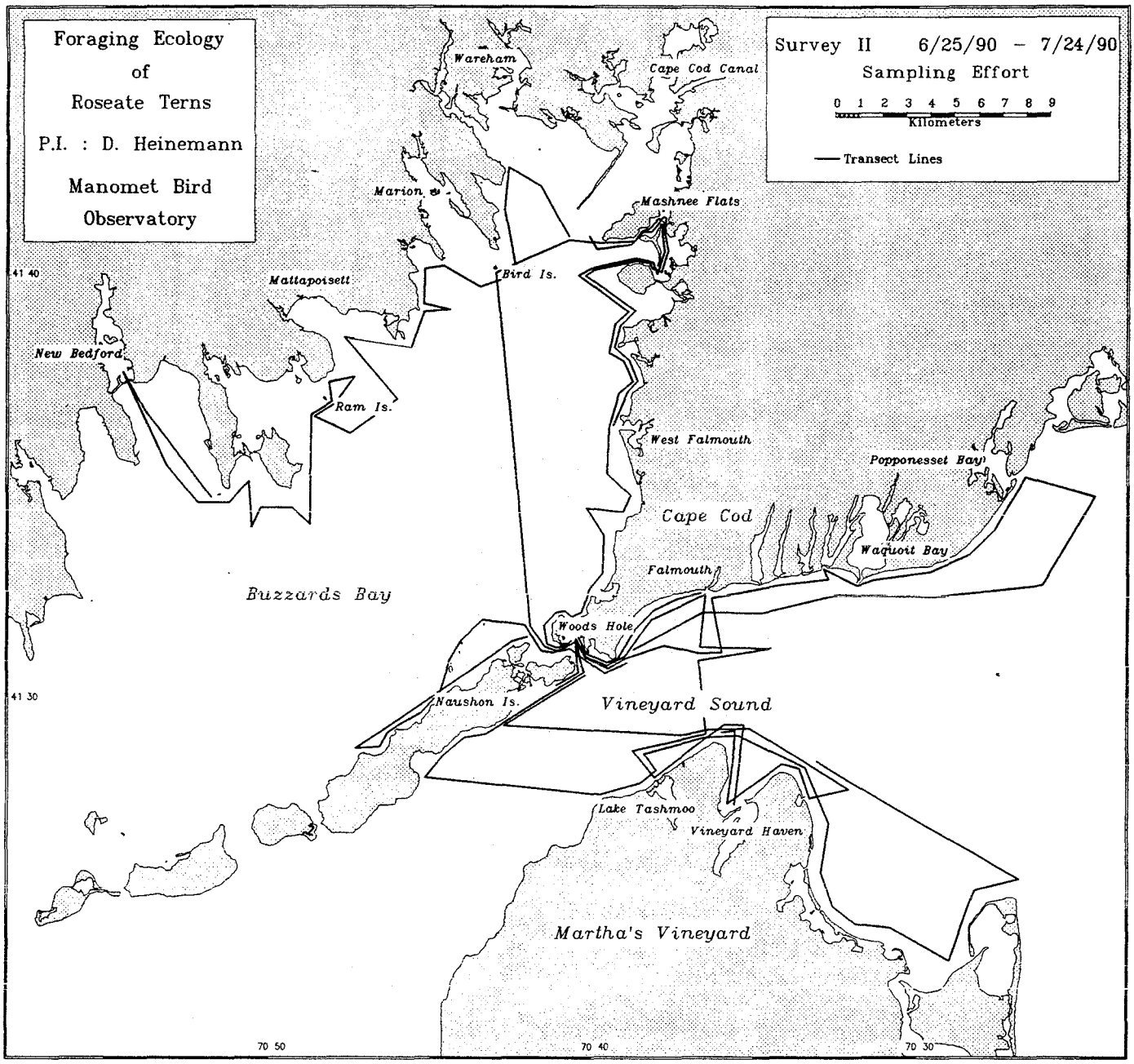

Figure 7. Placement of transect lines during the second survey period in 1990, 25 June to 24 July.

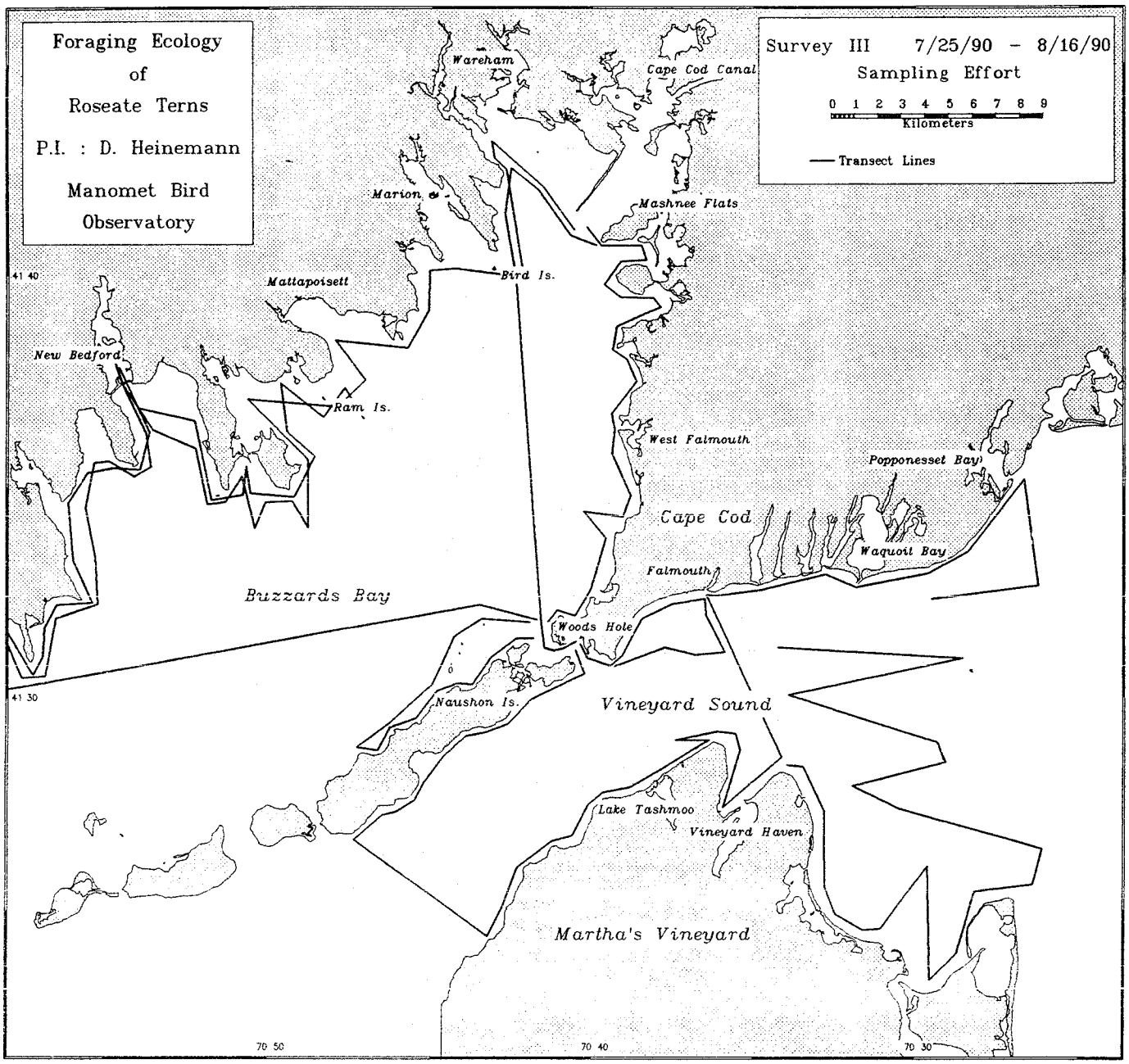

Figure 8. Placement of transect lines during the third survey period in 1990, 25 July to 16 August.

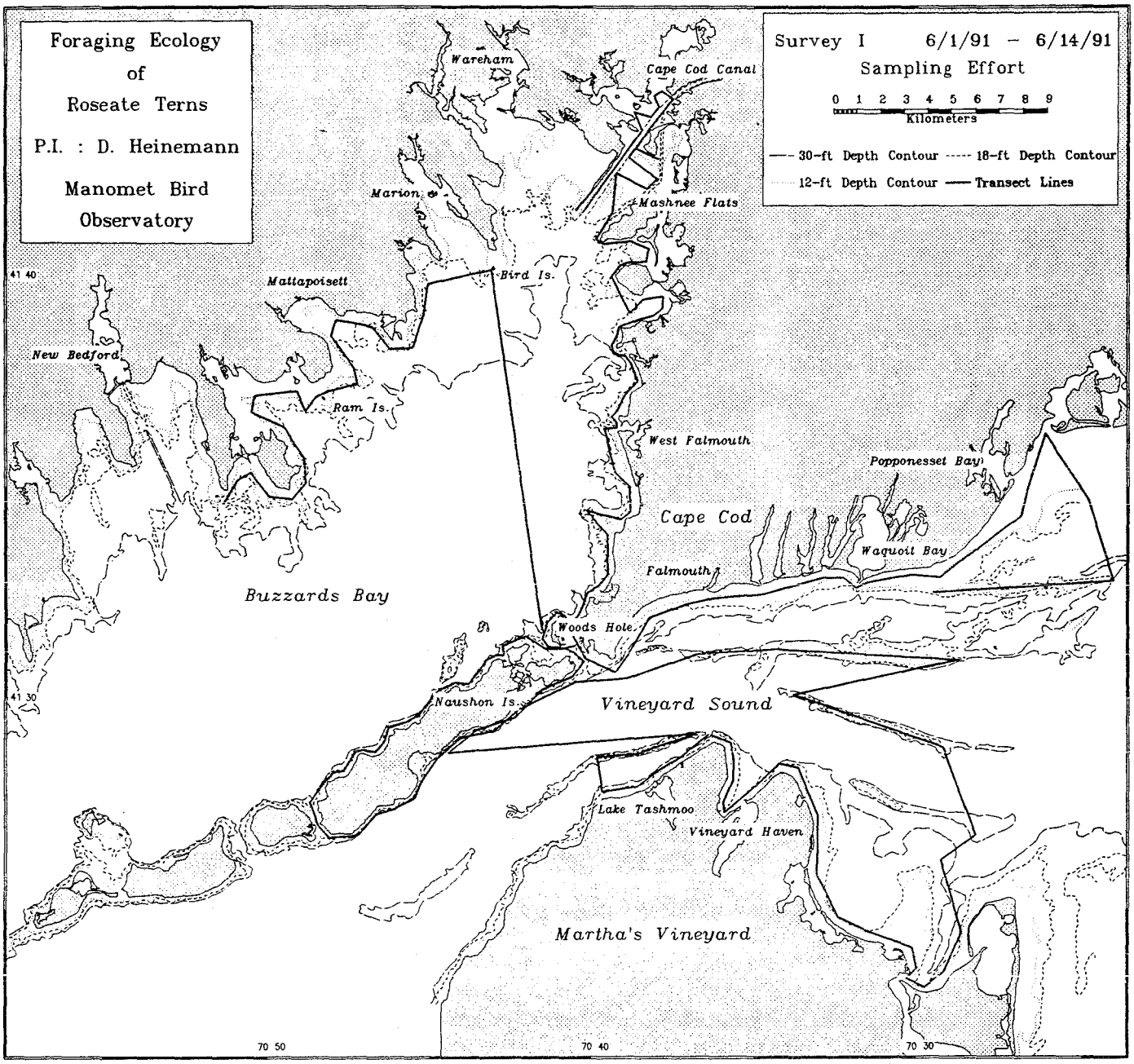

Figure 9. Placement of transect lines during the first survey period in 1991, 1 June to 14 June.

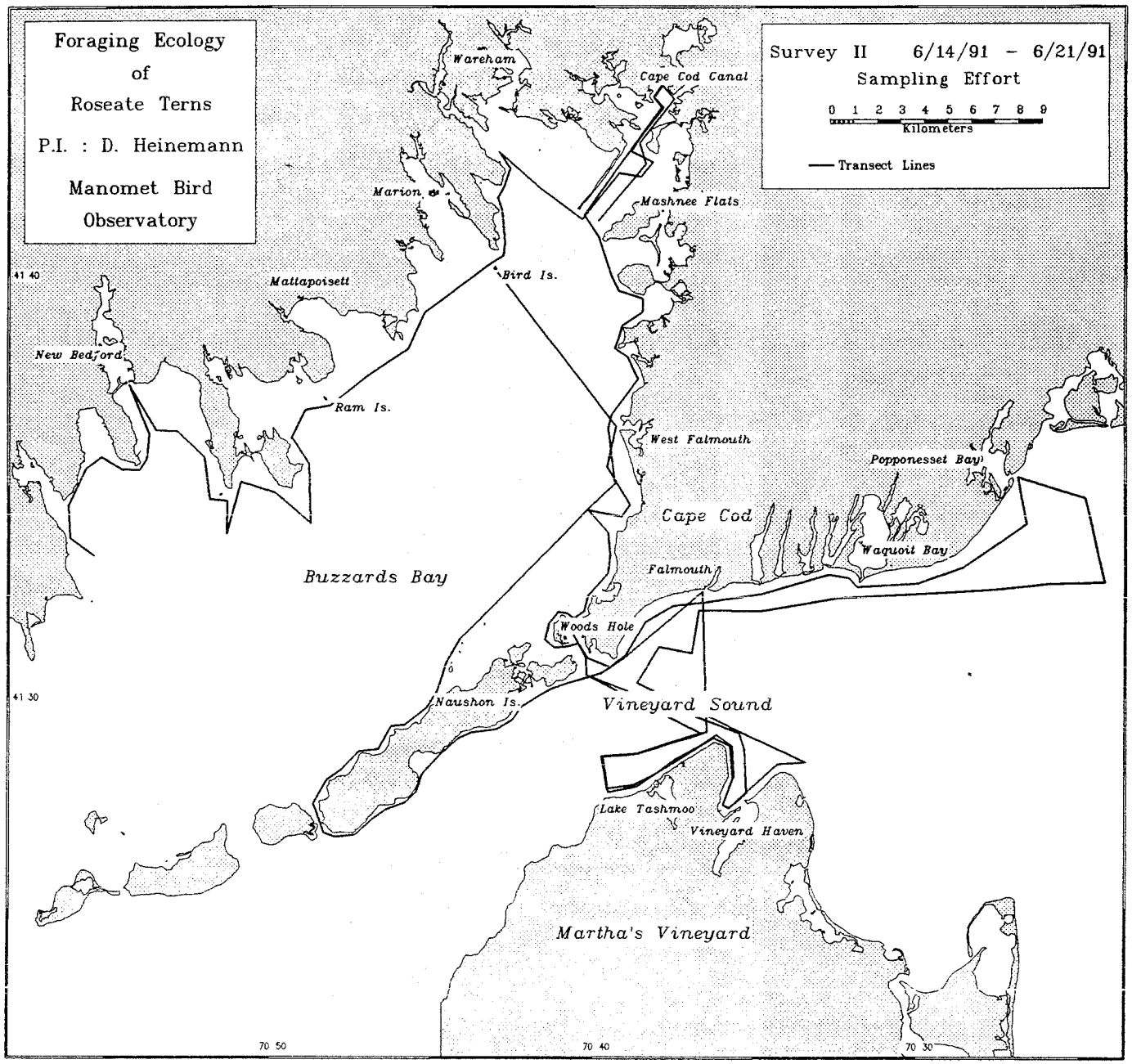

Figure 10. Placement of transect lines during the second survey period in 1991, 14 June to 21 June.

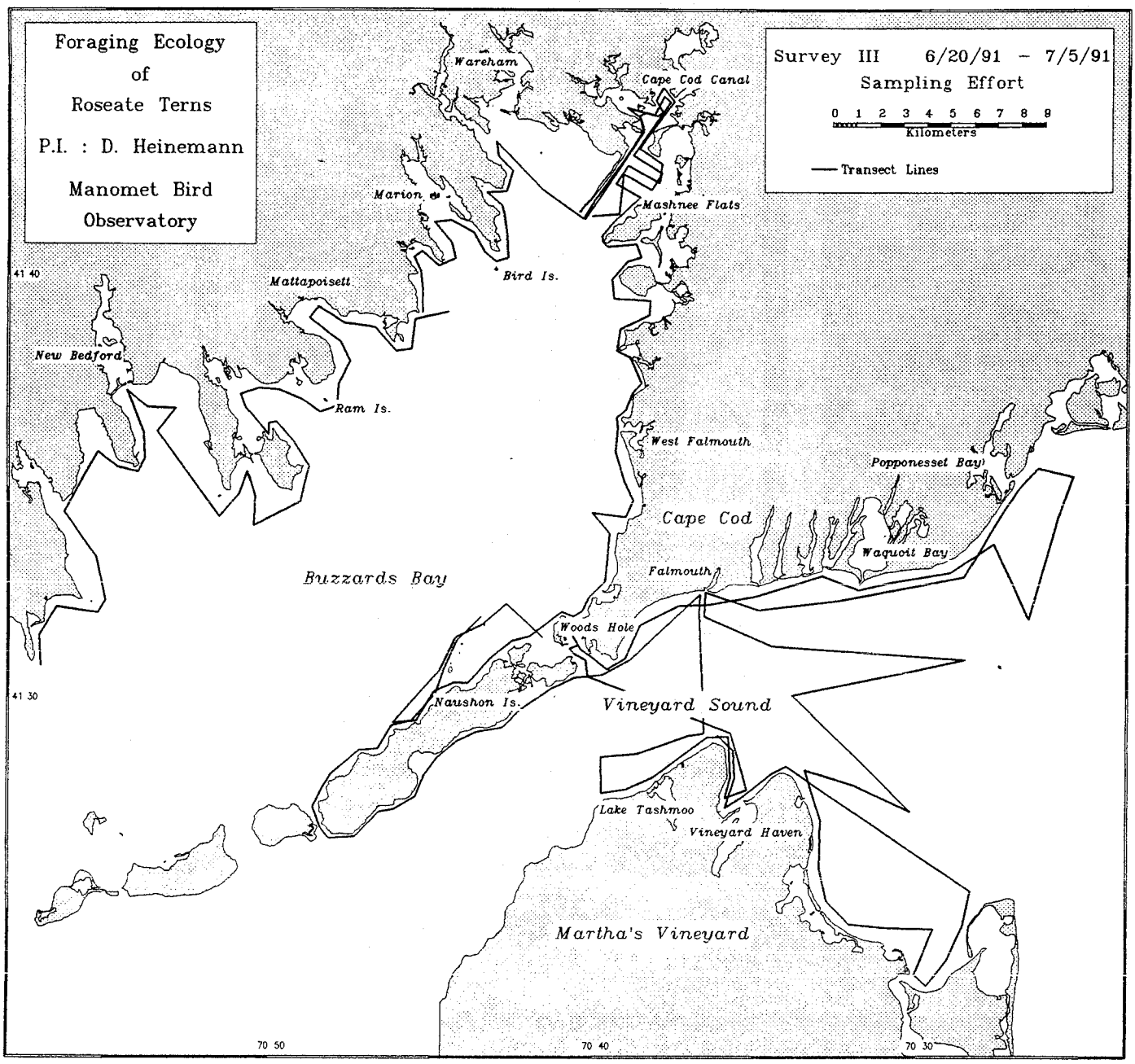

Figure 11. Placement of transect lines during the third survey period in 1991, 20 June to 5 July.

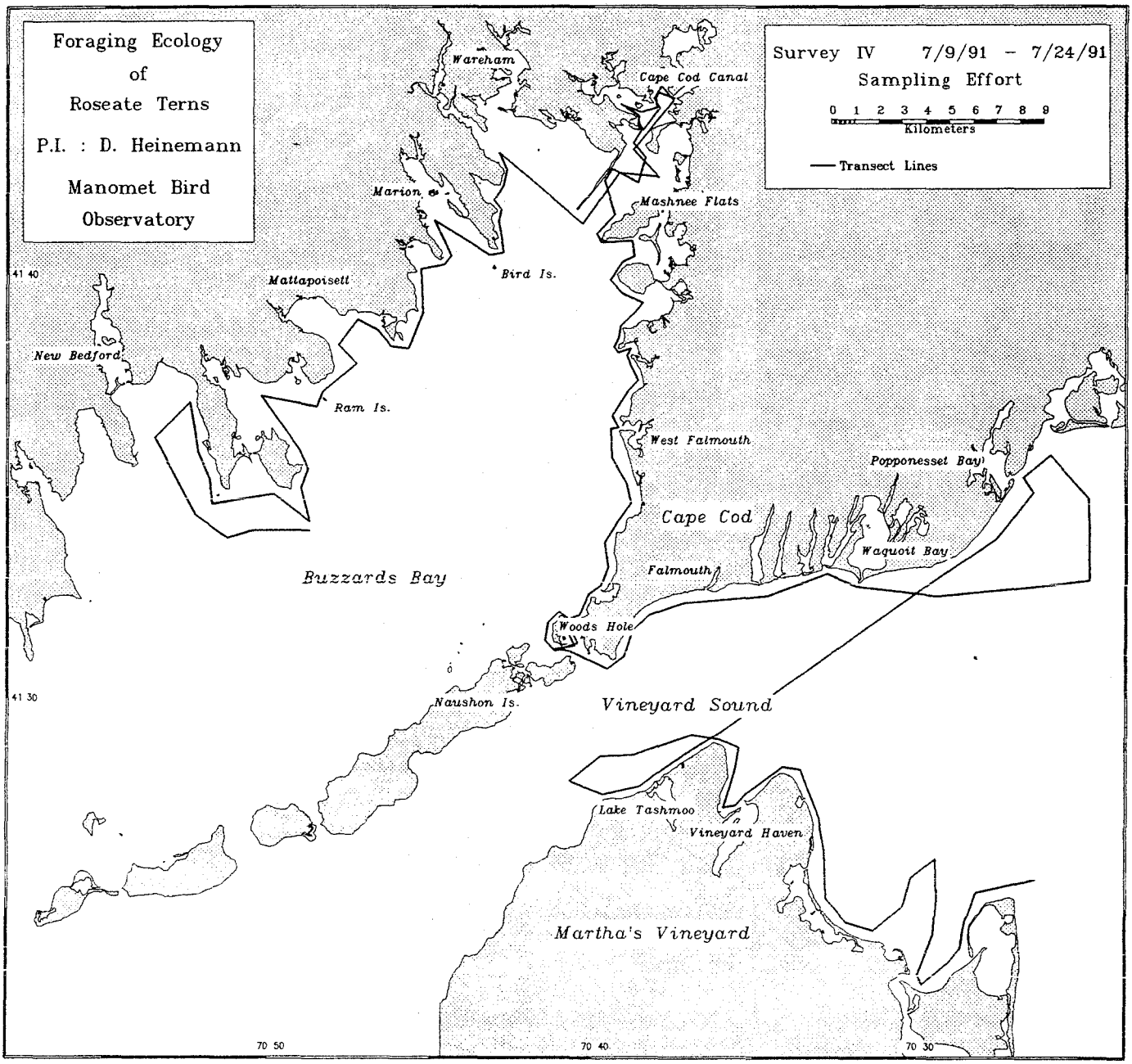

Figure 12. Placement of transect lines during the fourth survey period in 1991, 9 July to 24 July.

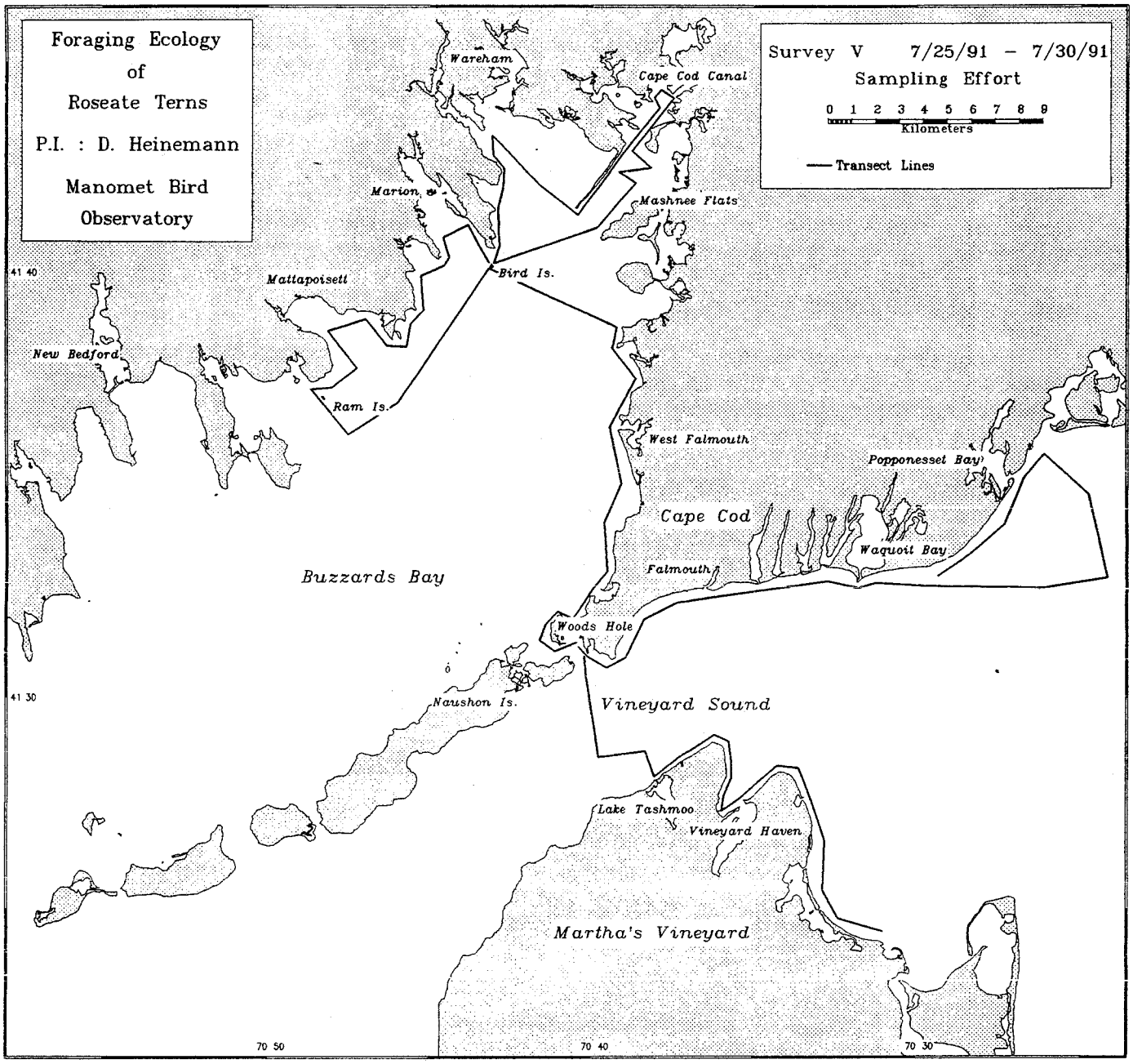

Figure 13. Placement of transect lines during the fifth survey period in 1991, 25 July to 30 July.

Bird Island Sampling Procedures

To assess the relative importance of different foraging areas we used two approaches. First, we used the numbers of Roseate Terns observed foraging in different areas as described above. Second, we recorded the numbers of birds returning to Bird Island from different directions. We established 9 radial sectors around the island of 30-50° each. The 9 sectors were selected so that they faced known or suspected foraging areas, such as Cape Cod Canal, the Woods Hole area, Ram Island and New Bedford Harbor, and West Falmouth (Figure 14). Angles were determined with a hand-held compass and by reference to landmarks on the shoreline. We counted the numbers of Roseate and Common Terns returning with and without fish, for 10-min within each sector. In 1990, we conducted these counts once each on 12 different dates from 8 June to 9 August. In 1991, we often made 2 counts on a single day, with a total of 53 counts being made from 5 June to 1 August.

Our sector-count technique relied on the assumption that the birds foraging in a given sector flew straight back to Bird Island, so that they were counted returning in the same sector. However, our experiences collecting these data, as well as observations made while following commuting birds, suggested that a significant number of the returns occurred in sectors adjacent to those in which the bird was foraging, primarily because of the effects of wind. For that reason, we combined 8 of the sectors into 3 larger sectors for the analysis and display of the data. The three new sectors correspond roughly to the major foraging grounds, N-E: Buzzards Bay north of Bird Island (sectors 'Wareham', 'Mashnee' and 'Pocasset'), SE-S: the east side of Buzzards Bay south of Bird Island and Vineyard Sound (sectors 'W. Falmouth', 'Woods Hole' and 'Open Bay'), and SW-W: the west side of Buzzards Bay south of Bird Island (sectors 'Ram Is.' and 'Bells'); the 'Marion' sector was excluded because very few returns were recorded in that sector. These sectors may be referred to by designations based on their major foraging grounds: Cape Cod Canal vicinity, Woods Hole and Vineyard Sound, and Ram Island.

The diets of the Roseate Terns were determined by visually estimating the type and sizes of prey carried by adults as they circled over the colony looking for their young. These data were recorded with the use of 10x binoculars while we sat at the periphery of the colony where we would not disturb the birds; if we suspected that we were keeping any birds off their nests, we shifted our location after 10-15 min. Prey data were collected in 1990 on 8 dates from 8 June to 3 August, and in 1991 22 samples were obtained on 20 dates from 26 June to 1 August. We classified fish as sandlance, anchovy (*Anchoa hepsetus*), silversides (*Menidia menidia*), herring-type (herring species or bluefish), or unknown. Sandlance because of their distinctive shape were always identifiable, and most of the time anchovy, herring-types and silversides were unambiguously identified. The sizes of fish were estimated by visual comparison to the bill of the birds carrying them, and recorded to the nearest 1/4 bill length. Both members of the team were trained in the identification of the type and size of prey by Ian Nisbet. These data were entered into dBase, and transferred to MBO's VAX computer for analysis by the SAS statistical package.

RESULTS

Foraging Situations

Shoal feeding. Where a very shallow sandbar (less than 3 m) is adjacent to deep water, tidal currents rushing over the bar sweep prey fish (usually sandlance) to the surface, where the plunge-diving Roseate Terns can catch them. The most consistently important 'shoal' feeding ground for this population is over just such a shoal at the center of a shallow area 7.5 km to the northeast of Bird Island, adjacent to the entrance to the Cape Cod Canal, known as Mashnee Flats. The only other important location for this type of feeding is Succonnesset Shoal, which is 4 km east of the mouth of Waquoit Bay in Vineyard Sound.

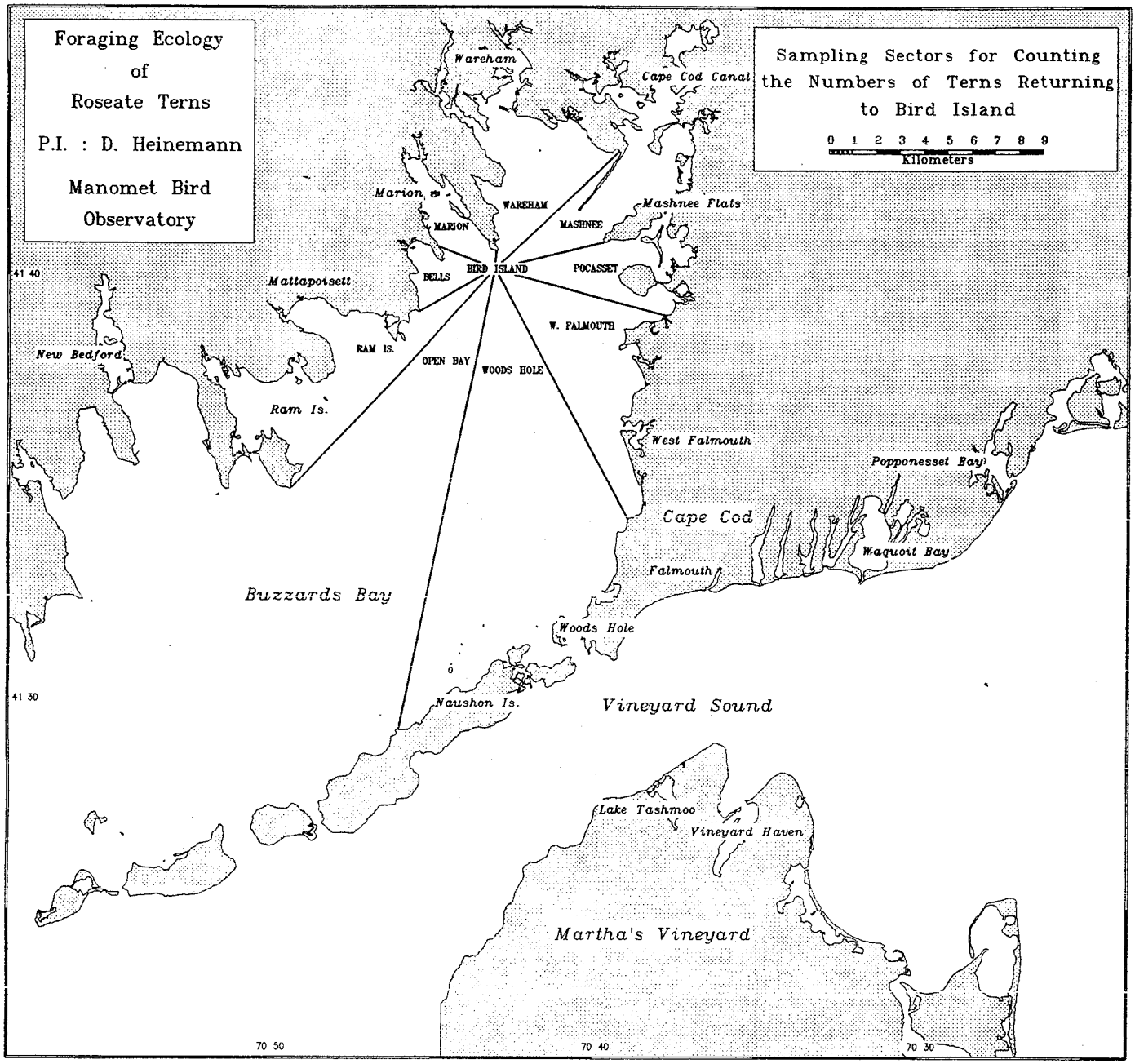

Figure 14. Locations and names of radial sectors around Bird Island used in counting the numbers of Roseate Terns returning to Bird Island from the foraging grounds.

This shoal is from 24 to 33.5 km from Bird Island depending on whether the birds fly on a direct line over the cape or detour through Woods Hole.

Shallows feeding. Closely related to 'shoal' feeding is 'shallows' feeding. When prey move into very shallow water (less than 2 m), they become available to the terns because the water is not deep enough for the fish to stay consistently below the plunge 'reach' of the terns. This type of feeding occurs along beaches throughout their foraging range and at low tide over the tops of several sandy shoals. The most important sites for this type of feeding are the shoal on Mashnee Flats, the entrances to Onset Harbor and Buttermilk Bay between Mashnee Flats and the entrance to the Cape Cod Canal (7.5-10.5 km from Bird Island), adjacent to Ram Island in southwestern Buzzards Bay (9.5 km from Bird Island), and off the mouth of Popponesset Bay on the south side of Cape Cod (24.5-39 km from Bird Island depending on the route taken).

School feeding. Another important source of prey occurs when predatory fish, bluefish, striped bass or bonito, drive schooling fish such as sandlance or herring to the surface. School feeding was seen everywhere within the foraging range of the Roseate Terns from very shallow water to water over 20 m deep. Often this type of feeding occurs at or near shoals because this is where large schools of sandlance are found. This form of foraging has been described and analyzed extensively by Carl Safina (see refs in Safina 1990).

Rip feeding. In previous years, other researchers found that large numbers of Roseate Terns exploited the strong tidal rips that bring prey to the surface near Woods Hole. In 1990, we found that only a small number of Roseate Terns engaged in 'Rip' feeding, and then only at the end of the season, but in 1991 this feeding situation occurred much more often. Predatory fish are often present at these locations. Besides Woods Hole (17.5 km from Bird Island), the entrance to Waquoit Bay (20-29.5 km from Bird Island depending on the route taken), and a rocky shelf beside the Cape Cod Canal channel (9 km from Bird Island) were sites where this type of feeding consistently took place.

Cormorant feeding. Occasionally Roseate Terns take advantage of Double-crested Cormorants, which drive prey to the surface as they feed. This feeding situation occurred most often on Mashnee Flats and along the shore of Martha's Vineyard near Lake Tashmoo.

Colony feeding. At any given time a few Roseate Terns at the colony will be engaged in kleptoparasitizing terns of both species returning to the colony with fish.

We found that very few Common Terns ever joined the Roseate Terns that were 'Shoal', 'Shallows', or 'Cormorant' feeding, but that Common Terns were in the majority in 'School and 'Rip' feeding flocks.

Foraging Distribution and Prey Observations - 1990 Surveys

We did not sample the foraging grounds in the vicinity of the Cape Cod Canal as part of our standard survey, but we did visit this location more than any other. Therefore, we display the observations of feeding terns in that area separately from those made along the regular transect lines that covered the rest of the foraging grounds.

Survey I. During the first survey period (6/5-22) we covered much of the area known at the time to be used by foraging Roseate Terns (Figure 6). As was the case during most of the season, we encountered large numbers of Roseate Terns on Mashnee Flats (Figure 15). Numbers of Roseate Terns on the flats varied from 20 to 160 over our 7 visits during the first survey period. The majority of the Roseate Terns found on Mashnee Flats during the first survey period were engaged in 'Shoal' feeding. When the tide was running the birds fed in a line along the up-current edge of the shoal at the center of the flat, capturing sandlance swept

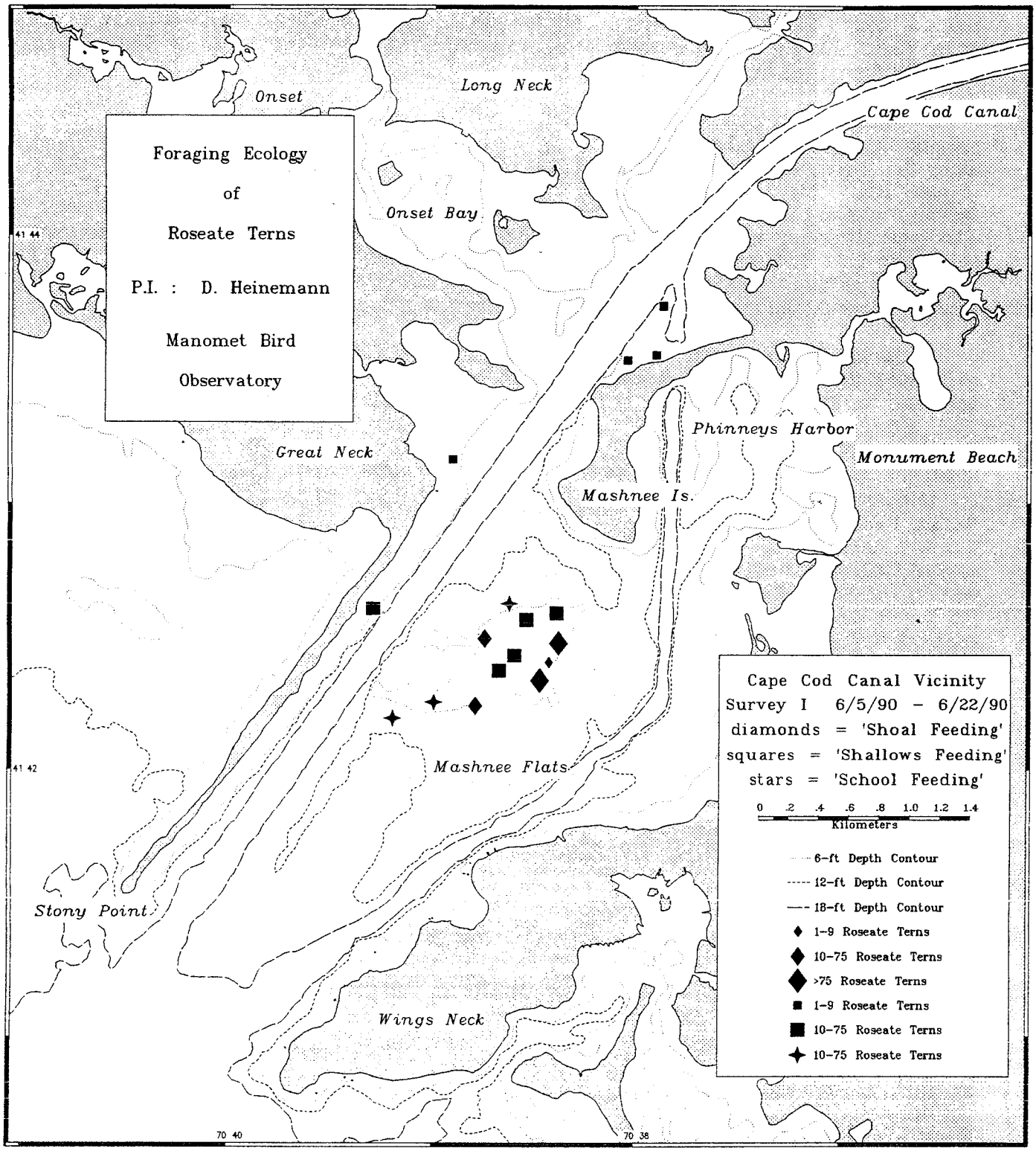

Figure 15. Location of observations of feeding Roseate Terns in the vicinity of the Cape Cod Canal during the first survey period in 1990. Point shape indicates the feeding situation and size is proportional to the number of terns present.

up over the edge. At low tide they spread out all over the shoal to capture sandlance in very shallow water ('Shallows' feeding). Very few flocks were seen off the shallows at the center of the flats. Only a few individuals were seen north of Mashnee Island, and the first was not observed there until 15 June.

South of Mashnee Flats, appreciable numbers of foraging Roseate Terns were found only on the east side of Buzzards Bay along the West Falmouth shore, and in Vineyard Sound along the Woods Hole - Falmouth shore and on the northwestern shore of Martha's Vineyard (Figure 16). Most Roseate Terns found along the West Falmouth shore were 'Shallows' feeding, with the largest numbers occurring from West Falmouth Harbor to Quissett Harbor. This type of feeding was also seen during the first survey period along the Martha's Vineyard shore near Lake Tashmoo. The remainder of foraging flocks occurred over prey driven to the surface by predatory fish ('School' feeding), with the most of the concentrations occurring in Vineyard Sound, although the two largest flocks were found just north of Quissett Harbor.

Survey II. During the second survey period (6/25-7/24) we expanded the area covered to include the west side of Buzzards Bay to New Bedford Harbor, and Vineyard Sound northeast to Popponesset Bay and southeast to the eastern end (Cape Poge) of Martha's Vineyard (Figure 7). Our 12 visits to the Mashnee Flat area recorded even larger numbers of Roseate Terns (70-300) than during the first survey period. The birds occurred in more locations (Figure 17), and were found feeding in a wider array of situations. As in the previous survey period, Roseate Terns, often in large numbers, could always be found 'Shoal' feeding along the southern and eastern edges of the shallows at the center of the flats when the tide was running. Unlike the first survey period, we found Roseate Terns following Double-crested Cormorants on several occasions. On many days we observed large mixed flocks of terns (Common and Roseate) 'School' feeding at the southern end of the flat, between Wings Neck and the Stony Point Dike. This was not observed during the first survey period, apparently because the bluefish did not move in numbers that far up into Buzzards Bay until July. Another change from the first survey period, was the appearance of numbers of Roseate Terns north of Mashnee Island. On 6 July we estimated from shore that there were over 200 Roseate Terns feeding north of Mashnee Island. Importantly, on more than one occasion we found Roseate Terns 'Shallows' feeding over a small sand flat just to the east of Long Neck at the entrance to Buttermilk Bay, a feeding site that was quite important in 1991 (see below).

Unlike the previous survey we found large flocks of terns near Ram Island, small numbers along the shore between Mashnee Flats and West Falmouth Harbor, and virtually no Roseate Terns on the east side of Buzzards Bay south of West Falmouth Harbor (Figure 18). The flocks found on the west side of Buzzards Bay were all 'School' feeding, while most of those on the east side were engaged in 'Shallows' feeding along the beach. Again, feeding Roseate Terns occurred along the shore between Woods Hole and Falmouth, and along northern-most shore of Martha's Vineyard. Whereas 'School' feeding had been the rule during the first survey period in these areas, 'Shallows' and 'Cormorant' feeding were the most common modes during the second survey period. In addition, we found large numbers of Roseate Terns feeding at the entrance to Waquoit and Popponesset Bays, and over Succonnesset Shoal to the east of Waquoit Bay. Succonnesset Shoal appeared to have been a site where large numbers of Roseate Terns consistently engaged in 'Shoal' feeding, much like the shoal at Mashnee Flats. Those at Popponesset were feeding over a very large shallow sand flat, but, because of the presence of a dredged channel at the edge of the shoal we were unsure if these birds were 'Shoal' or 'Shallows' feeding or both. The birds at the entrance to Waquoit Bay were also consistently present during this period, due to the consistent presence of schools of bluefish and striped bass. No birds were found east of Vineyard Haven on Martha's Vineyard.

Survey III. During the final survey we achieved our most extensive and complete survey (Figure 8). Many fewer Roseate Terns were found on Mashnee Flats or near the Cape Cod Canal (Figure 19); 10-30 Roseate Terns on 3 visits. These few birds foraged in a wide

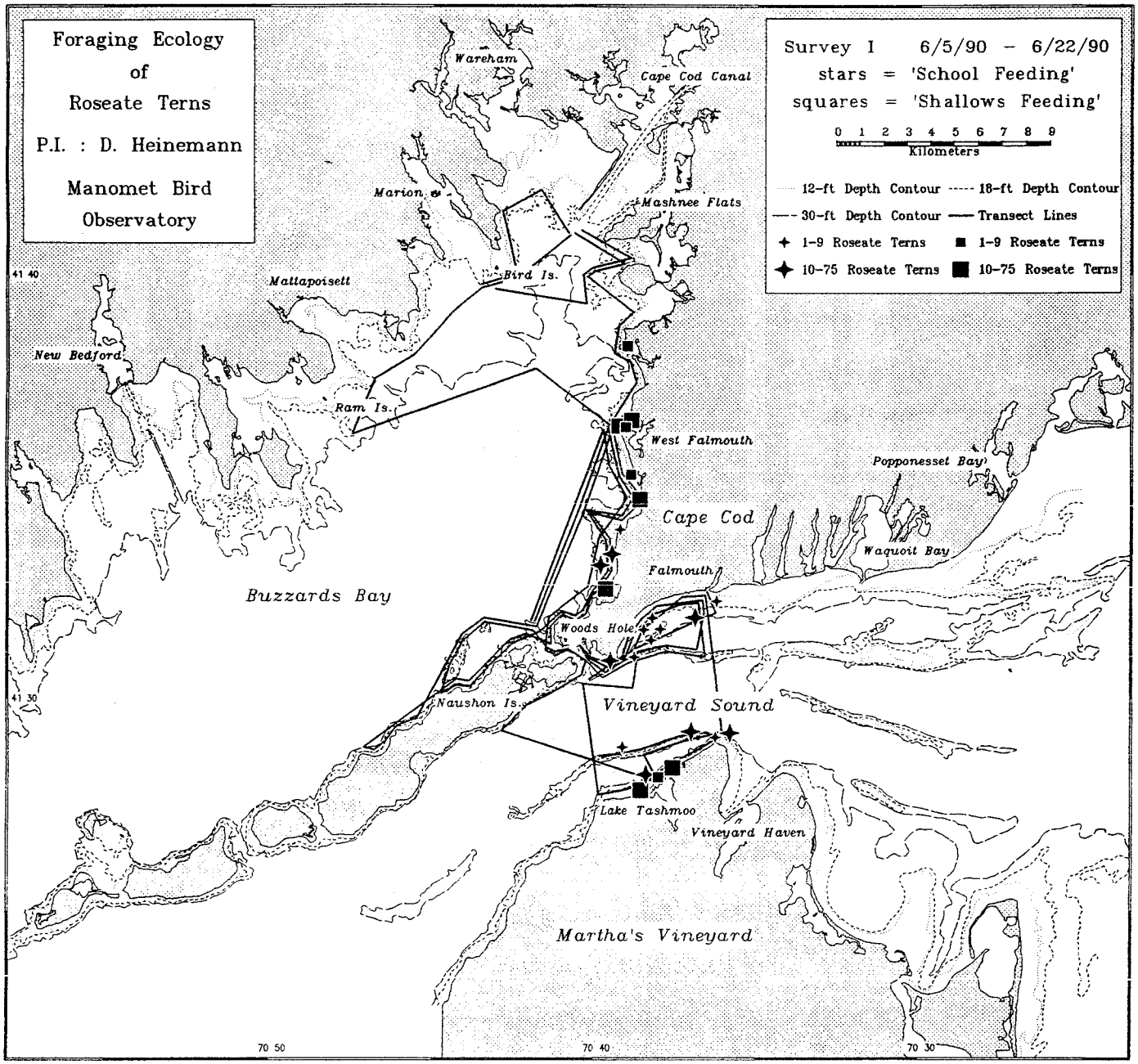

Figure 16. Location of observations of feeding Roseate Terns, excluding the Cape Cod Canal vicinity (see Figure 15), during the first survey period in 1990. Point shape indicates the feeding situation, and point size is proportional to the number of terns present.

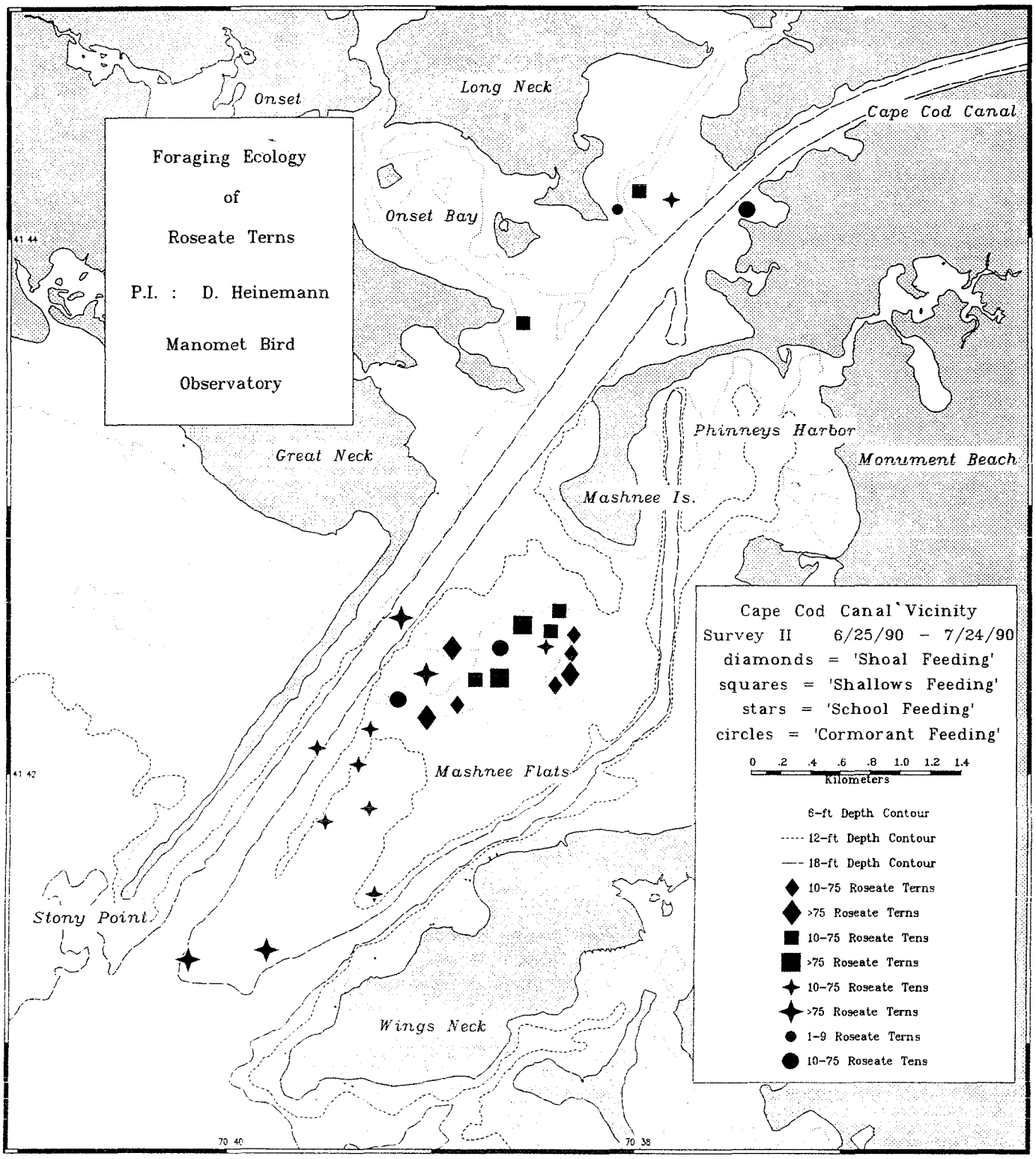

Figure 17. Location of observations of feeding Roseate Terns in the Cape Cod Canal vicinity during the second survey period in 1990.

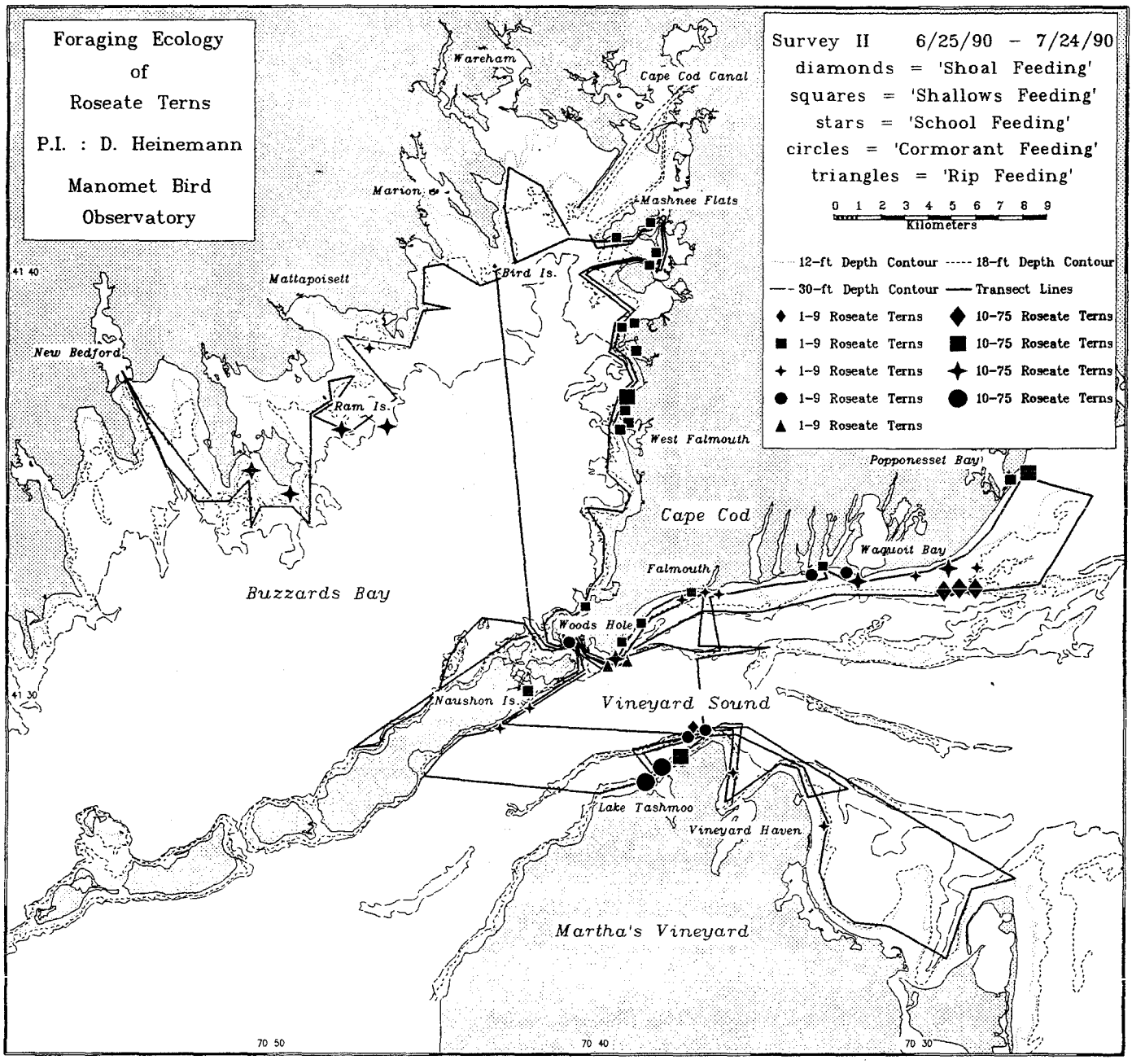

Figure 18. Location of observations of feeding Roseate Terns, excluding the Cape Cod Canal vicinity, during the second survey in 1990.

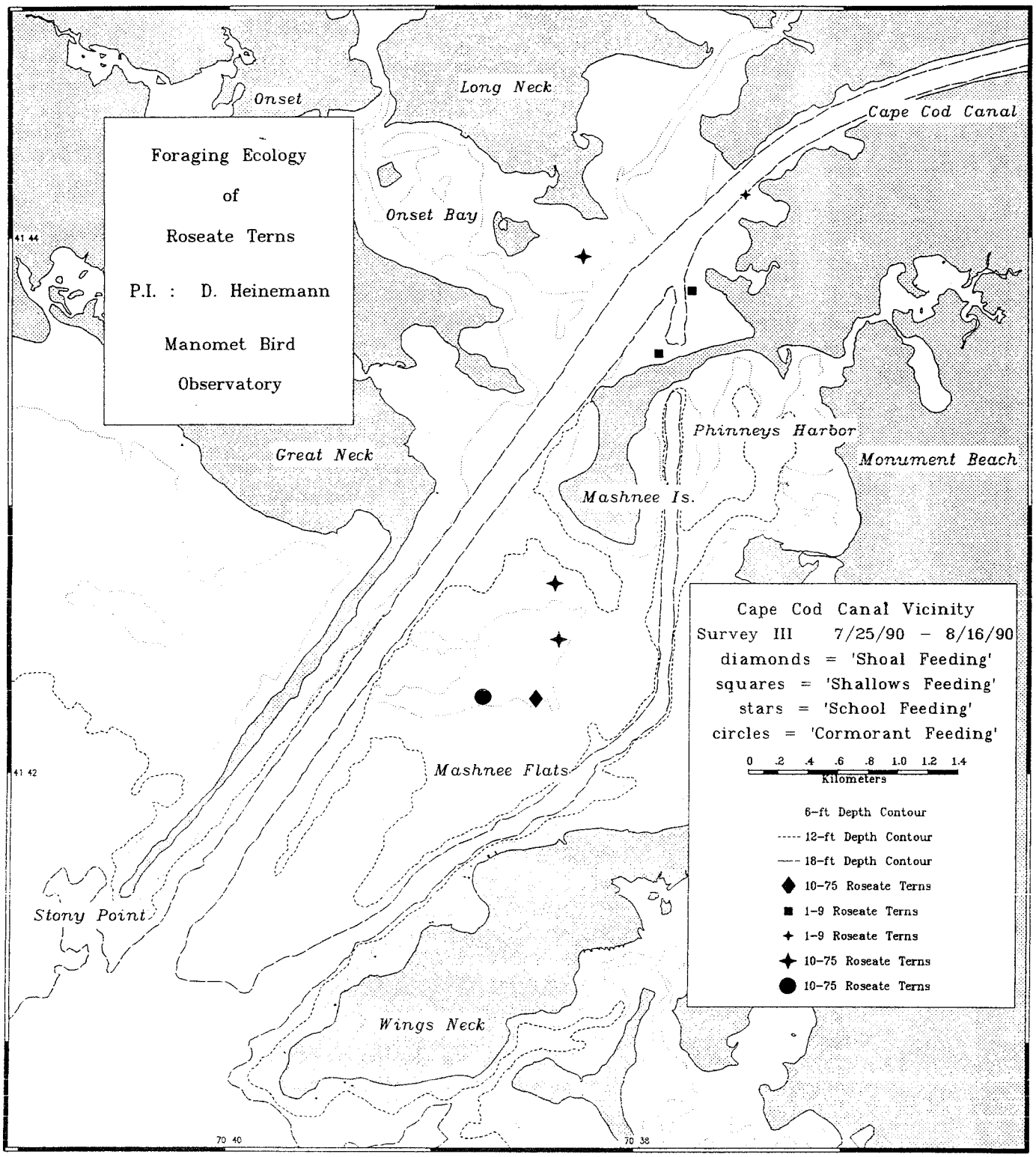

Figure 19. Location of observations of feeding Roseate Terns in the Cape Cod Canal vicinity during the third survey period in 1990.

variety of situations as had been the case in the second survey period. During this survey period birds continued to feed in the Ram Island vicinity, and feeding flocks were found very close to Bird Island (Figure 20). The majority, but not all, of these birds relied on 'Shallows' feeding. Continuing the changes seen earlier, virtually no birds were seen feeding along the eastern shore of Buzzards Bay or along the Woods Hole - Falmouth shore, and Waquoit Bay and Succonnesset Shoal were visited by large numbers of birds. The feeding situations in the latter locations remained the same. For the first time 'Rip' feeding by appreciable numbers of birds was observed in Woods Hole, and substantial numbers of Roseate Terns exploited prey in Vineyard Haven. As in the previous period, Martha's Vineyard east of Vineyard Haven continued to be unexploited.

Overview. The numbers described above and shown on the figures cannot easily be compared among different areas or surveys because sampling effort was not constant. The observations do show where important foraging areas were, when they were occupied and which types of feeding took place. With all Cape Cod Canal observations combined on one map (Figure 21), we can see the extreme importance of Mashnee Flats and especially the shallow shoal at its center. Also, several sizable feeding flocks were seen north of Mashnee Island. Over the rest of the foraging range (Figure 22) we see that other important areas are the west side of Buzzards Bay from West Island to Ram Island, the east side of the bay from Scraggy Neck to Quissett Harbor, Woods Hole, the north shore of Vineyard Sound from Woods Hole to Falmouth Harbor, around Waquoit Bay, on and near Succonessett Shoal, around Popponesset Bay, and on Martha's Vineyard from Vineyard Haven to Lake Tashmoo.

To permit comparison of observed numbers among areas or survey periods, I identified nine regions (Figure 23) that, by visual inspection of the data, appear to differ in the way in which they were used by Roseate Terns (i.e. in terms of the numbers, timing or feeding strategies used); areas with very few observations were excluded. I calculated the total number Roseate Terns seen in each region on each complete pass through the region, and then averaged the totals for each region and survey; many surveys had only one pass through a given region so the single total was used in such cases.

These abundance estimates show that the Cape Cod Canal vicinity (Region 3) was the most important single foraging area during the first three weeks of June (Survey I; Figure 24). During the last week of June and the first three weeks of July (Survey II), the West-Ram Island (Region 1), the Cape Cod Canal (Region 3) and the Waquoit-Popponesset Bays (Region 8) areas were all very important. During the end of July and the first half of August when most of the terns are moving out of the area toward the east, the largest abundances were seen in Vineyard Sound in Regions 8 and 9.

Prey Observations. We were unable to identify the prey being taken by enough feeding flocks to be able to accurately describe the distributions of prey availability or changes in the distributions over the season. With one exception, all prey captured by Roseate Terns 'Shoal' feeding on Mashnee Flats were sandlance. Further, we were able to identify the prey being taken in 5 'Shoal' and 'Shallows' feeding flocks at locations other than Mashnee Flats. In every case, the birds were catching sandlance. Of the 9 'School' feeding flocks for which we identified prey, 5 were taking sandlance, 2 silversides, 2 anchovy and 2 herring-types.

Foraging Distribution and Prey Observations - 1991 Surveys

Survey I. The first survey was conducted from 1-14 June and covered all the foraging range except for the eastern shore of Buzzards Bay between Bird Island and Stony Point (Figure 9), an area where few feeding Roseate Terns have been seen in either year. Feeding Roseate Terns were found throughout their foraging range with the exception of Martha's Vineyard during this period (Figure 25), an significant change from 1990. The usual mix of feeding tactics and large number of birds was observed in the Cape Cod Canal vicinity. As is

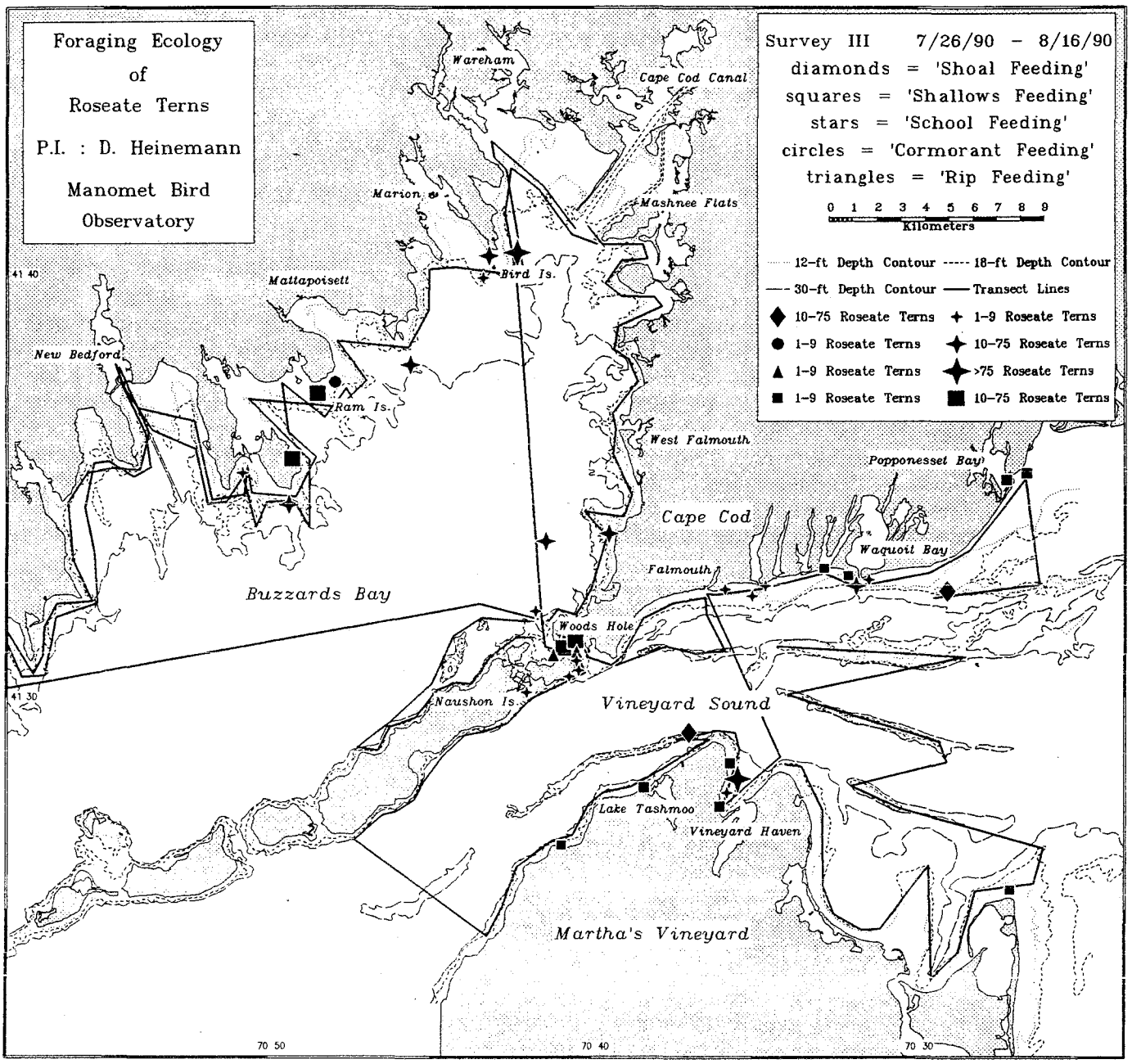

Figure 20. Location of observations of feeding Roseate Terns, excluding the Cape Cod Canal vicinity, during the third survey in 1990.

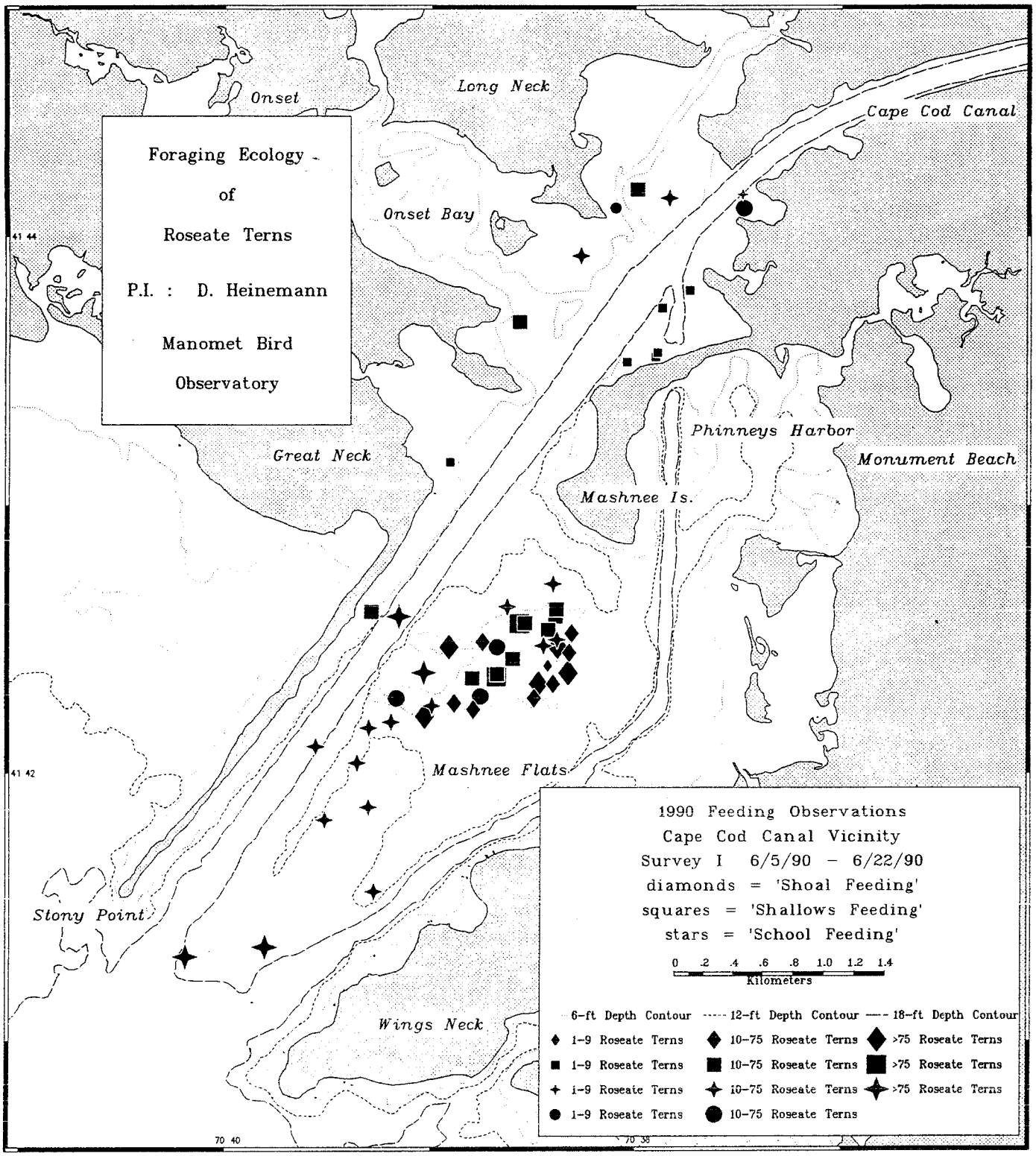

Figure 21. Location of all observations of feeding Roseate Terns in the Cape Cod Canal vicinity during 1990. Point shape indicates the feeding situation, and point size is proportional to the number of terns present.

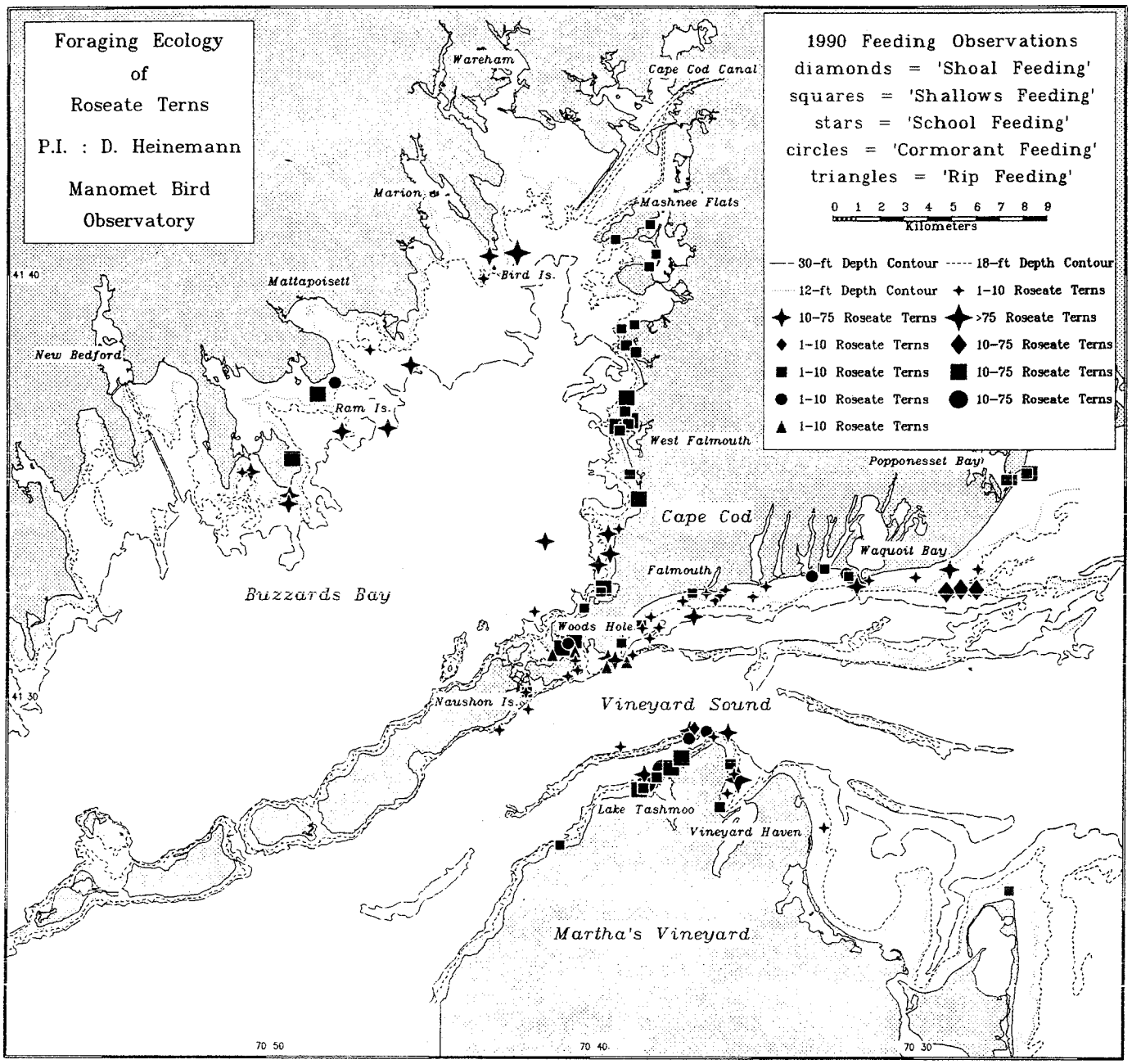

Figure 22. Location of all observations of feeding Roseate Terns in 1990, excluding the Cape Cod Canal vicinity. Point shape indicates the feeding situation, and point size is proportional to the number of terns present.

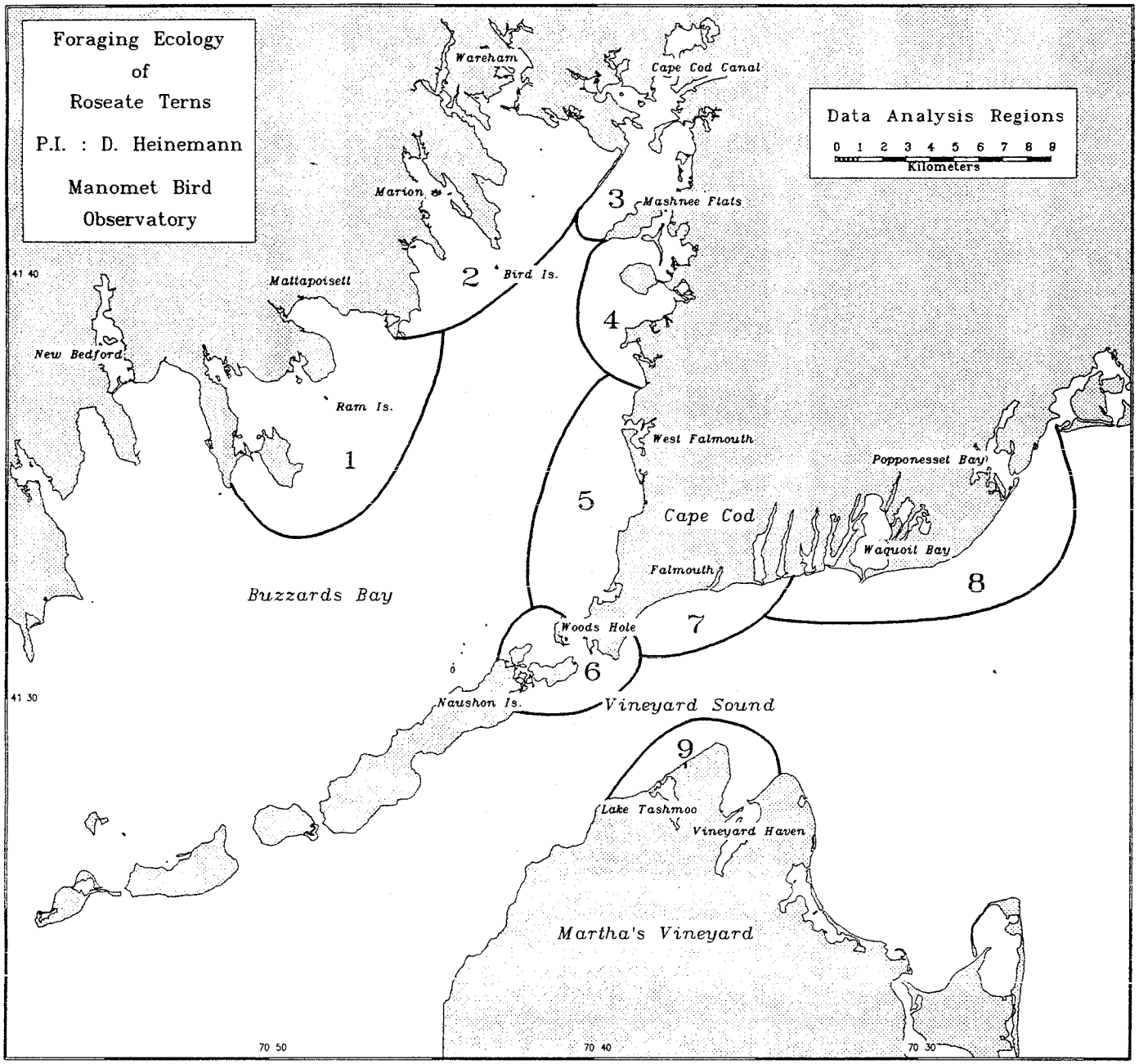

Figure 23. Location of Regions used to pool feeding observations for analysis.

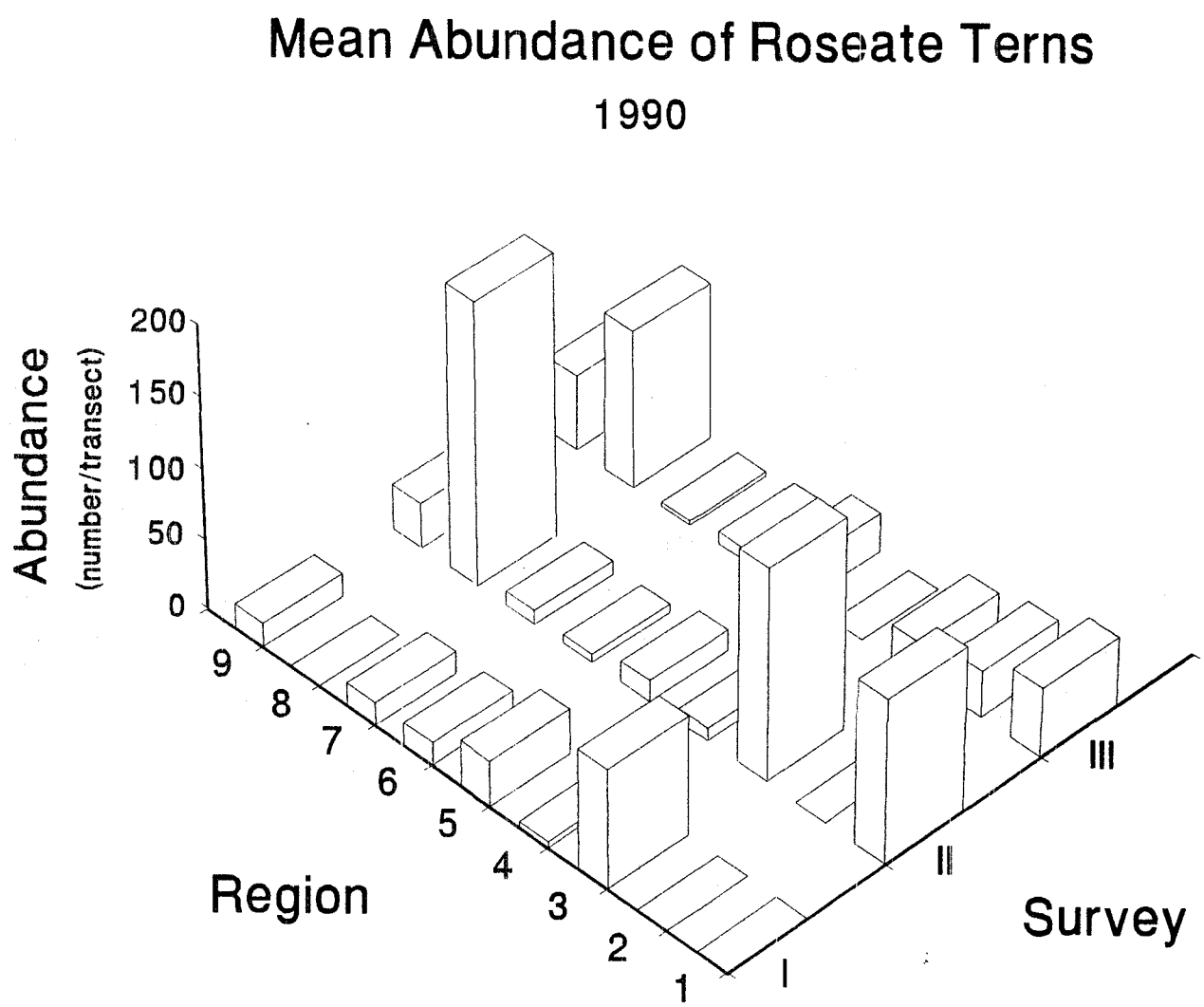

Figure 24. Mean abundances of Roseate Terns by Region and Survey in 1990.

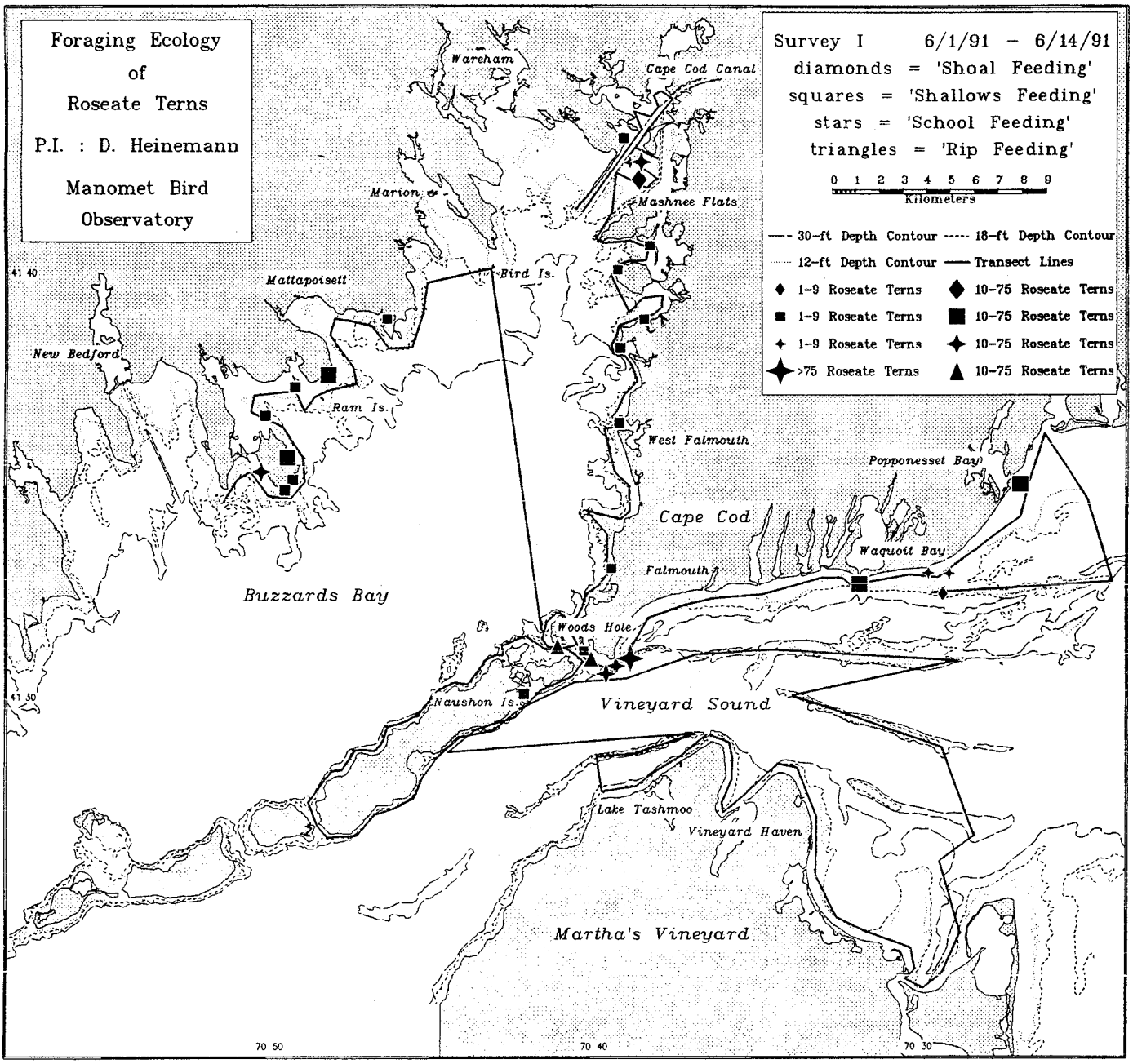

Figure 25. Location of observations of feeding Roseate Terns during the first survey in 1991.

1990, no birds were found north of Mashnee Island during this early period. Around Buzzards Bay, 'Shallows' feeding was common along the beaches, with the largest numbers occurring adjacent to Ram Island and around West Island, an area where no Roseate Terns were seen in 1990 during the first half of June. Unlike most of 1990, large numbers of Roseate Terns made use of Woods Hole, where 'Rip', 'School' and 'Shallows' feeding were all common. Again, the entrances to Waquoit and Popponesset Bays were important sites for 'Shallows' feeding Roseate Terns.

Survey II. The second survey period ran from 14-21 June and covered the entire foraging range (Figure 10). Important changes occurred between this and the previous period. Unlike the first two weeks of June, no feeding Roseate Terns were found on the west side of Buzzards Bay or on the northern side of Vineyard sound (Figure 26). Furthermore, several flocks of Roseate Terns were found on Martha's Vineyard. The distribution of flocks on the east side of Buzzards Bay, including Woods Hole showed little change. The numbers of Roseate Terns using the Cape Cod Canal area increased, and, much earlier than in 1990, large numbers of individuals were found feeding north of Mashnee Island.

Survey III. The third survey, which began on 20 June and was completed on 5 July, covered the entire foraging range (Figure 11). During this period, the vast majority of birds were recorded in the vicinity of the Cape Cod Canal (Figure 27). Large numbers of feeding Roseate Terns were found on Mashnee Flats and at the mouths of Onset and Buttermilk Bays. Unlike any other time, a few small flocks were seen just west of Bird Island, and one large flock occurred in deep water just east of Bird Island. Two flocks were found at West Island, but none around Ram Island. The only other birds found south and east of the island were at Waquoit and Popponesset Bays. These changes from the previous periods and 1990 appeared to be due to an earlier influx of warm water and large numbers of bluefish into upper Buzzards Bay.

Survey IV. The fourth survey was conducted from 9-24 July and covered the entire foraging range except for Naushon Island (Figure 12). During this period, the vast majority of birds were recorded in the vicinity of the Cape Cod Canal (Figure 28). Again feeding flocks were found over most of the foraging range, but large numbers occurred only in the Cape Cod Canal area and at Ram Island.

Survey V. The last survey of 1991, 25-30 July, was somewhat abbreviated because it did not extend past Ram Island on the west side of Buzzards Bay and did not cover Naushon Island (Figure 13). Not surprisingly we found fewer birds than earlier in the season, because most young had fledged and left the area by this time. The overall distribution of birds during this period (Figure 29) was very much like that seen during the previous survey.

Overview. The Cape Cod Canal Vicinity was the single most important foraging ground for the Bird Island Roseate Terns. Within that area, Mashnee Flats was consistently important as in other years, and 'Shallows' feeding by large flocks was observed several times north of Mashnee Island (Figure 30). Of special interest were feeding flocks seen consistently over a small shoal just west of the entrance to the canal at the opening to Buttermilk Bay and several flocks scattered about the outer part of Onset Bay. Considering the entire study area (Figure 31) we see that besides the Cape Cod Canal area, West and Ram islands, the eastern shore of Buzzards Bay north of Woods Hole, Woods Hole itself, the south shore of Cape Cod from just east of Falmouth Harbor to Popponesset Bay, and Martha's Vineyard from Lake Tashmoo to Vineyard Haven were very important.

Comparisons of mean numbers within surveys and regions shows the extreme importance of the Cape Cod Canal area (Region 3; Figure 23) relative to other regions (Figure 32). The importance of the Cape Cod Canal Region increased steadily during the first half of the season and didn't decrease until the very end of July when most young had fledged. The West-Ram Island area (Region 1) was moderately important during two surveys. We suspect

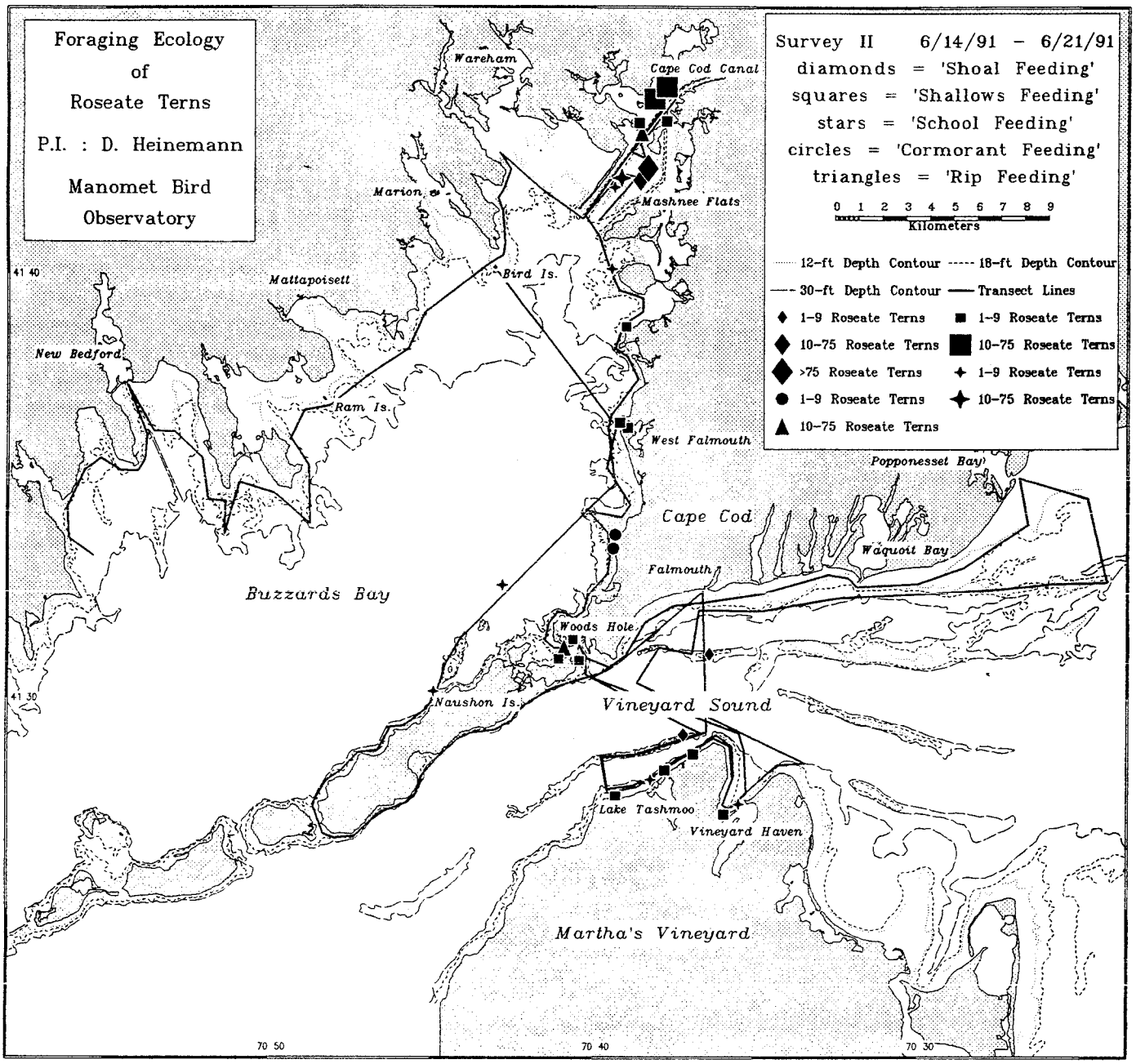

Figure 26. Location of observations of feeding Roseate Terns during the second survey in 1991.

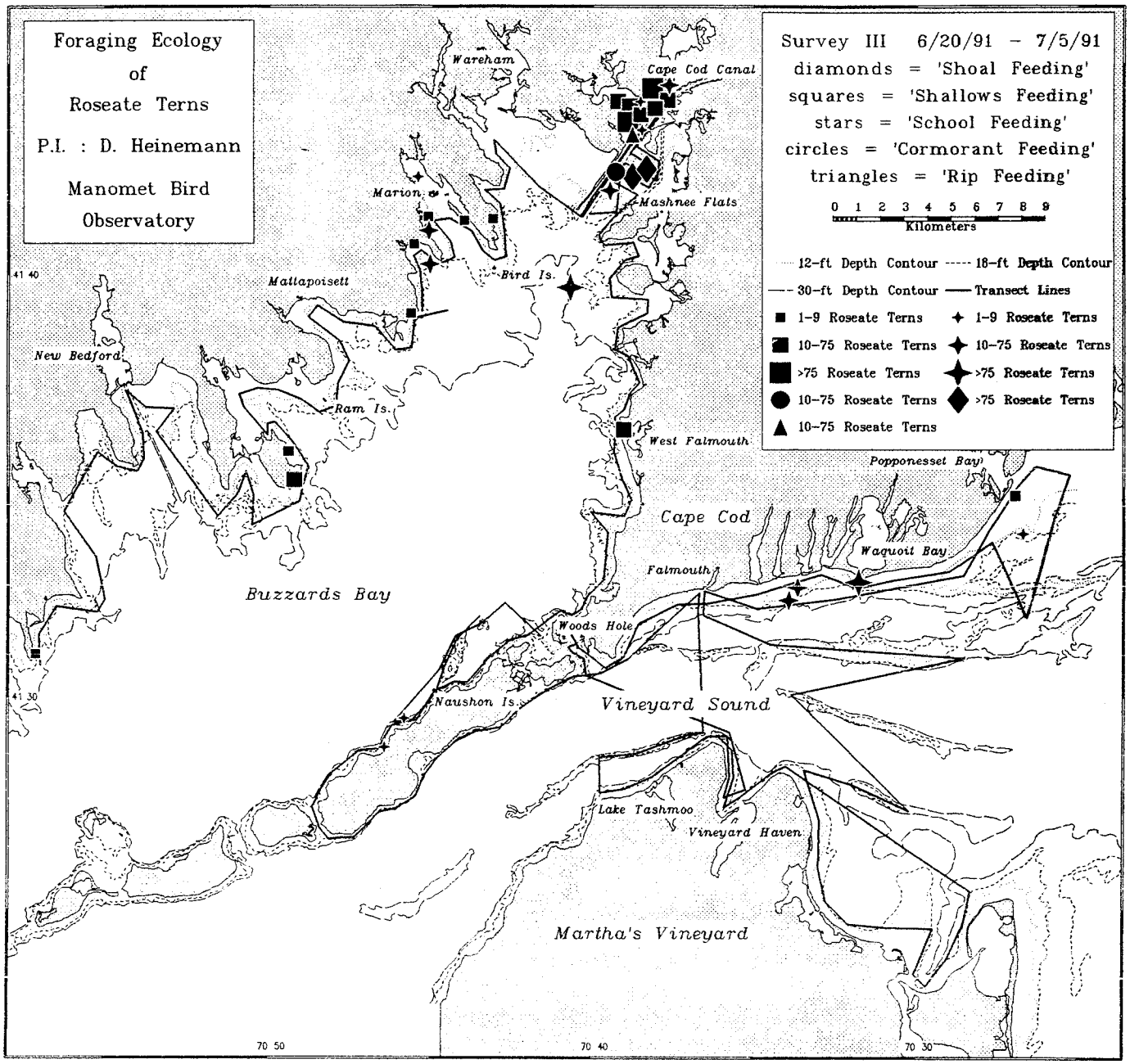

Figure 27. Location of observations of feeding Roseate Terns during the third survey in 1991.

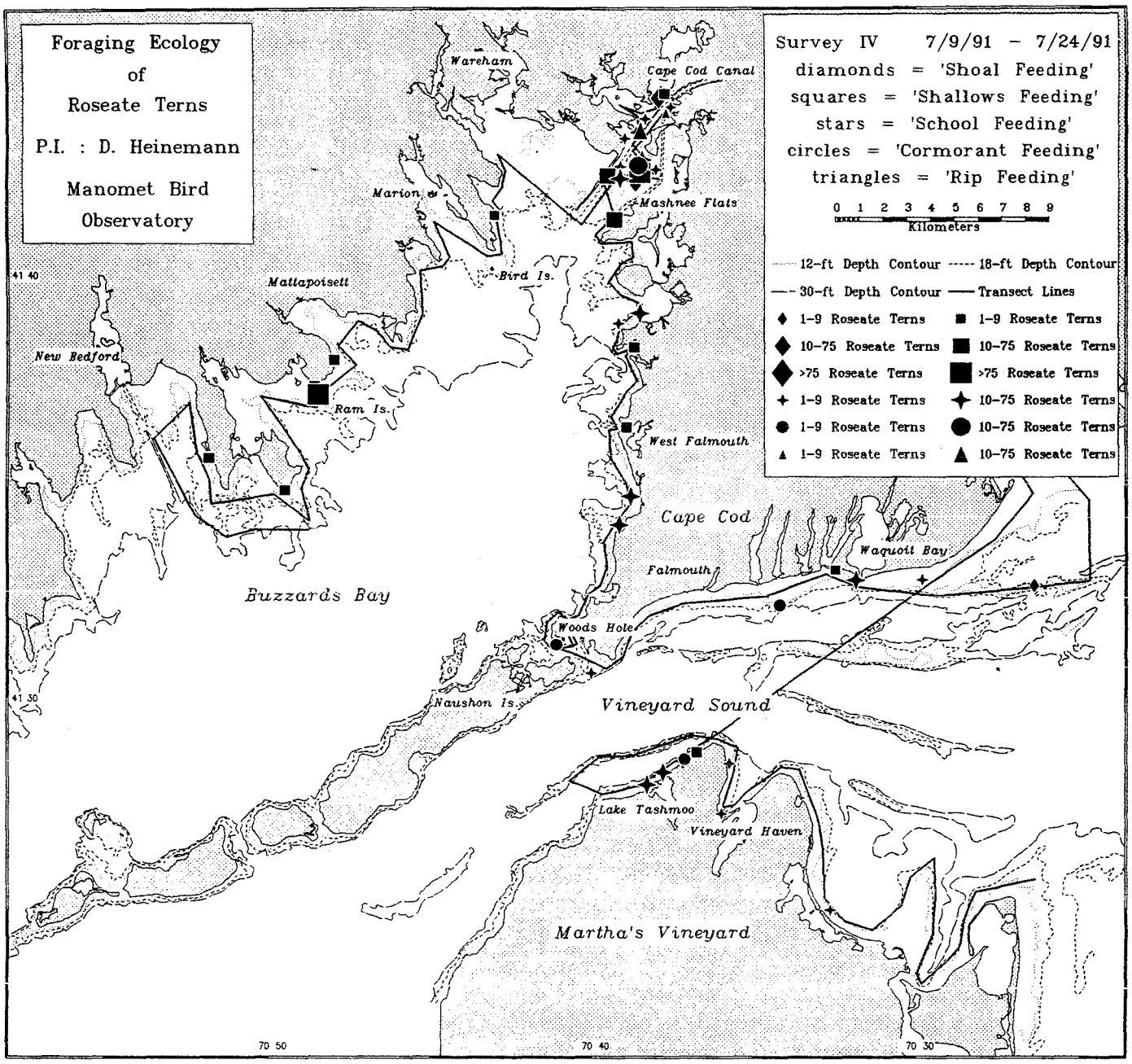

Figure 28. Location of observations of feeding Roseate Terns during the fourth survey in 1991.

that it was more consistently important, but our surveys didn't sample the area during the right part of the tidal cycle every time. There were consistently a significant number of Roseate Terns foraging in the Waquoit-Popponesset Bay area (Region 8). We had virtually no observations of feeding birds along the Vineyard Sound shore from Woods Hole to Falmouth (Region 7) despite the fact that large numbers of terns commute through the area and several flocks were observed there in 1990. The Woods Hole area (Region 6) had appeared to be important most of the season, but the mean numbers were up only at the beginning and end of the season.

Prey Observations. We recorded the prey being taken at 7 flocks that were 'Shallows' or 'Shoal' feeding. In every case the sandlance were being caught, and in one flock herring-types were taken. Of 13 'School' flocks where we were able to identify the prey, 12 were feeding on sandlance, 4 on herring-types, and one each on anchovy and silversides.

Bird Island Sampling

Numbers Returning. The total number of Roseate Terns returning to the island varied during each season. In 1990, low return rates of 7-12 birds/min occurred early and late in the season, before chicks were present and after most chicks had fledged, respectively (Figure 33). Peak numbers of 15-23/min occurred from the third week of June through the second week in July. In 1991, return rates were similar to those recorded in 1990, although the means were somewhat lower (5-6/min). As in 1990, return rate began to increase steadily in the third week of June when the first chicks were hatching. Unlike 1990, the return rate did not plateau in 1991, but increased steadily from the third week of June into the third week of July. In addition to the peak occurring over two weeks later in 1991, the mean was considerably higher (30.7/min), although the lowest counts during the peak period were similar to the single highest count (23/min) obtained in 1990. In 1991, the return rate declined precipitously in the last two weeks of July to level at the end of July that was similar to that observed in 1990.

As indicated by the return counts, the numbers of Roseate Terns using the Cape Cod Canal area in 1990 reached a plateau from the third week of June to the first week of July, and then declined over the remainder of the season (Figure 34). Early and late season rates varied from 1.3-2.3/min, while the mid-season rates ranged from 4.2-8.3/min. In 1991, numbers were moderately high (means: 3.2-4.3; range: 2.2-5.7), by 1990 standards, during the first three weeks of June. Thereafter, they increased steadily through the second week in July, and then declined rapidly. The return rates reached in mid-July (means: 10.5-13.3; range: 8.3-17.6) were considerably higher than any rates achieved in 1990. This pattern was similar to that seen on the foraging grounds.

The numbers of Roseate Terns returning to Bird Island from the direction of West Falmouth - Woods Hole - Vineyard Sound sectors (Woods Hole sectors for short) followed a very similar pattern in both years (Figure 35). Return rates increased gradually during June and reached a peak during the first week of July, declining slowly thereafter.

The patterns of return rates for the Ram Island sectors were also similar in the two years, showing a gradual increase during June and the first half of July (Figure 36). The only major difference occurred in the second half of July. In 1990, the return rates from this sector was quite low (0.9-2.0/min), whereas in 1991, the rate increased during July to a peak of 5.9/min (range: 1.8-13.4/min) in the third week and then dropped off to a mean of 2.3 (range: 0.8-3.4) at the end of the month. This peak in numbers in late July was also recorded on the foraging grounds.

The relative magnitude of the return rates from the three major forgaging grounds can be compared by expressing the rates as a percent of the total rate for the island. In 1990, except for an unusally high value in the first week of June, the contribution of the Woods Hole

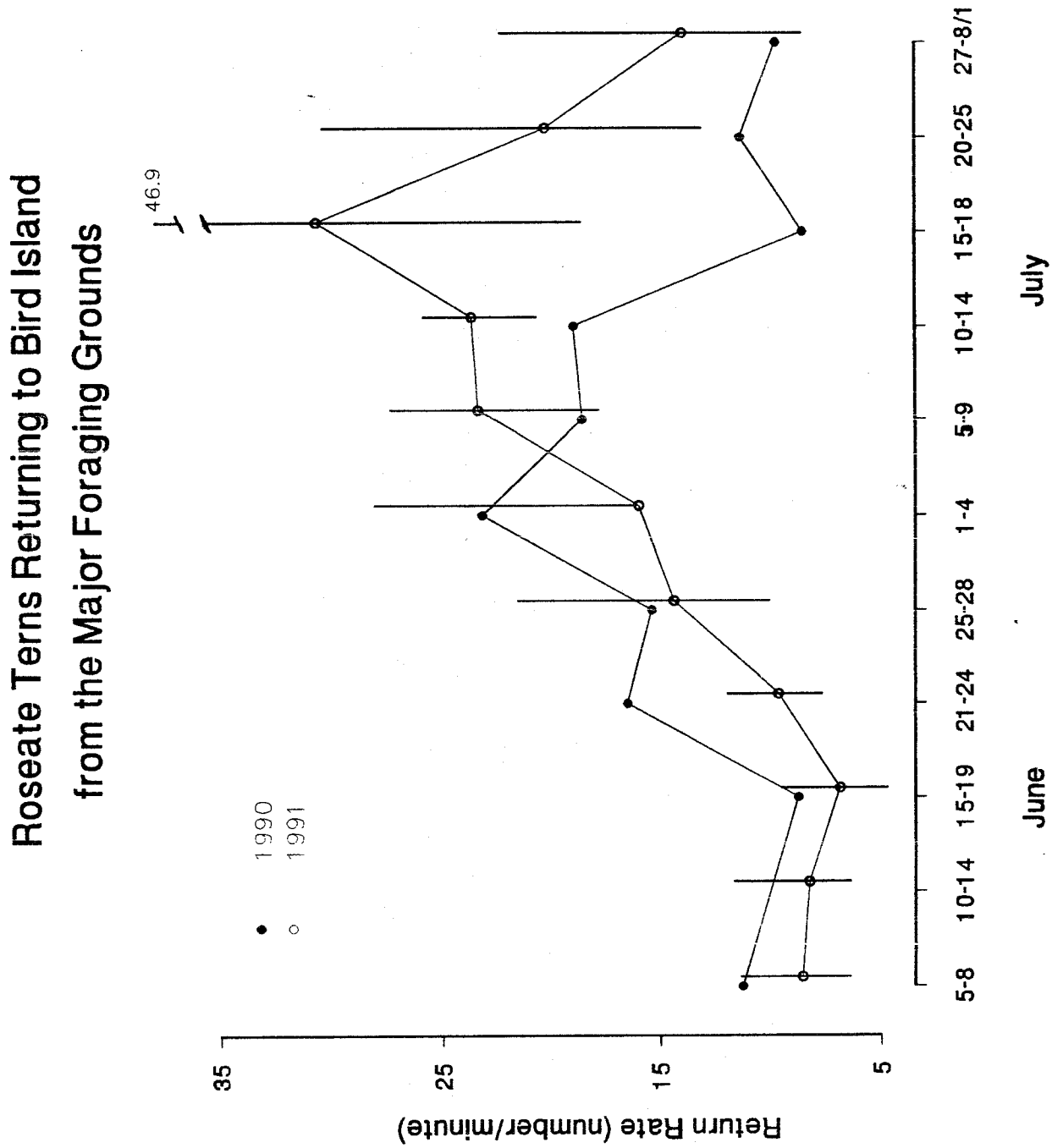

Figure 33. Mean rate of returning Roseate Terns to Bird Island from all sectors, except Marion, during 1990 and 1991. Solid points indicate the single estimate obtained in the specified period during 1990. Open circles indicate the mean of all samples taken in the given period in 1991, and vertical bars show the range of values obtained.

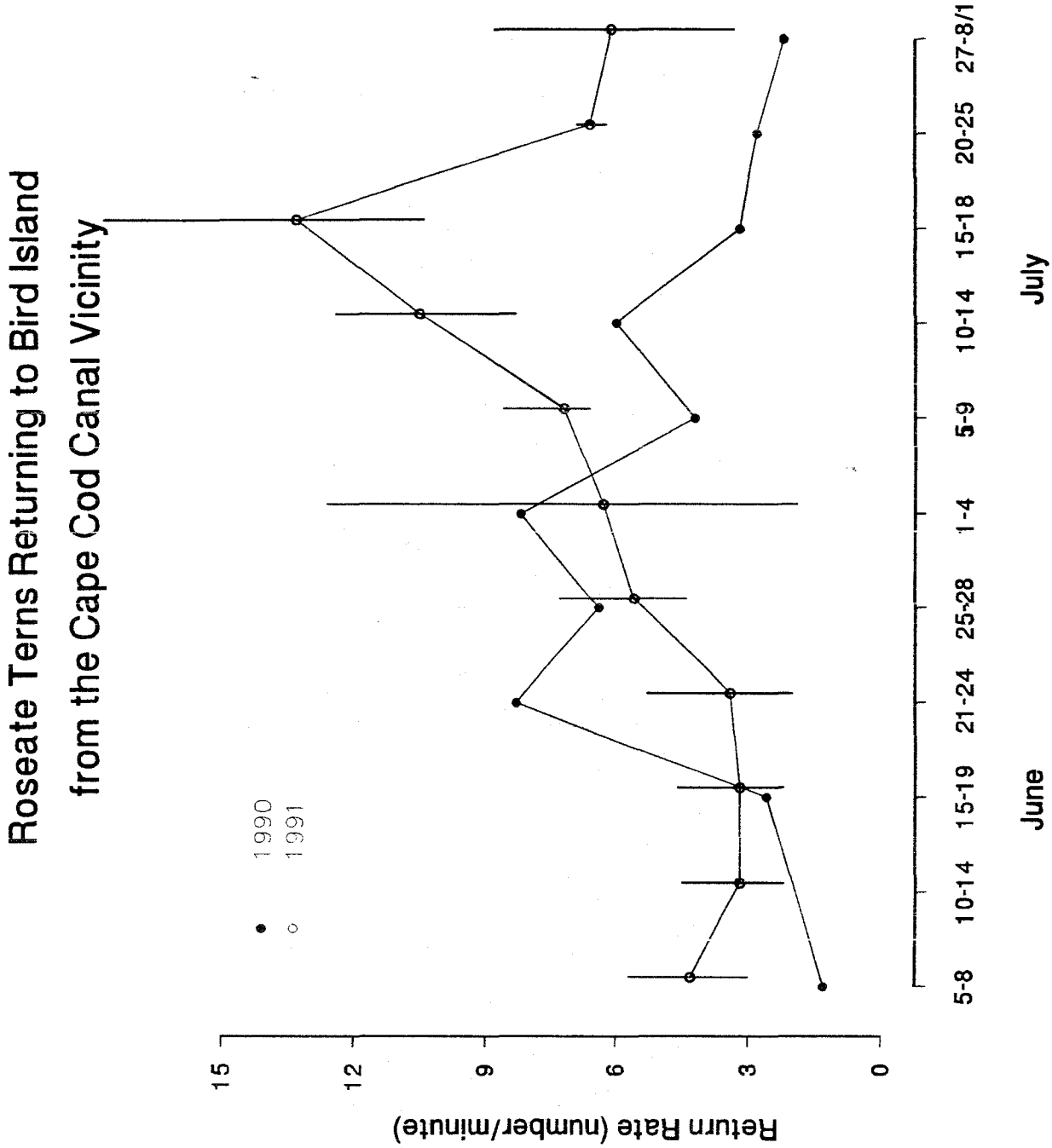

Figure 34. Mean rate of returning Roseate Terns to Bird Island from the Cape Cod Canal area during 1990 and 1991. Points (solid) for 1990 indicate the single estimate obtained in the specified period. For 1991, open circles indicate the mean of all sample taken in the given period, and vertical bars the range of values.

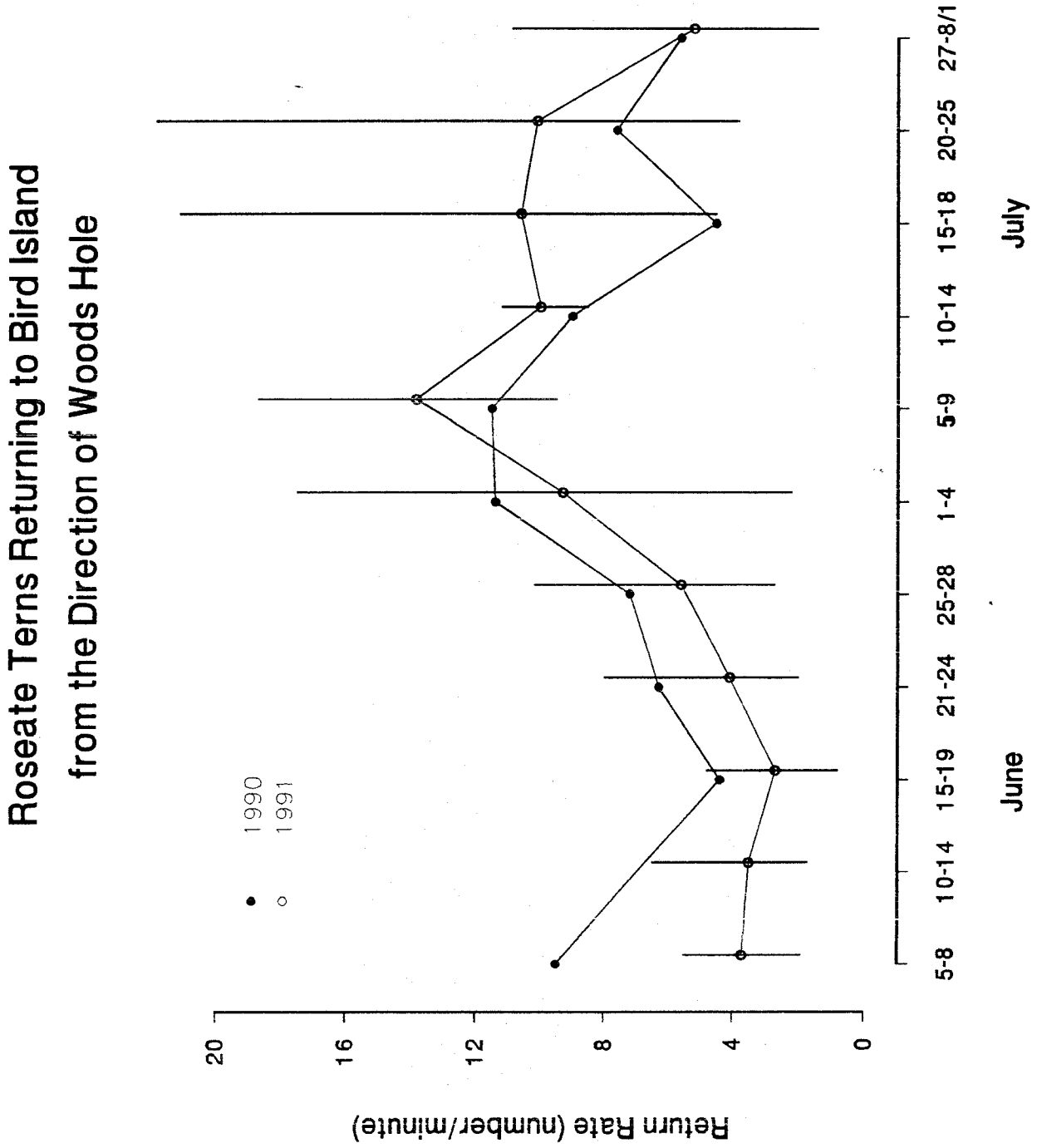

Figure 35. Mean rate of returning Roseate Terns to Bird Island from the Woods Hole - Vineyard Sound direction during 1990 and 1991. Solid circles indicate the single estimate obtained during the specified period in 1990. Open circles and vertical lines show the mean and range of values obtained in the given period in 1991.

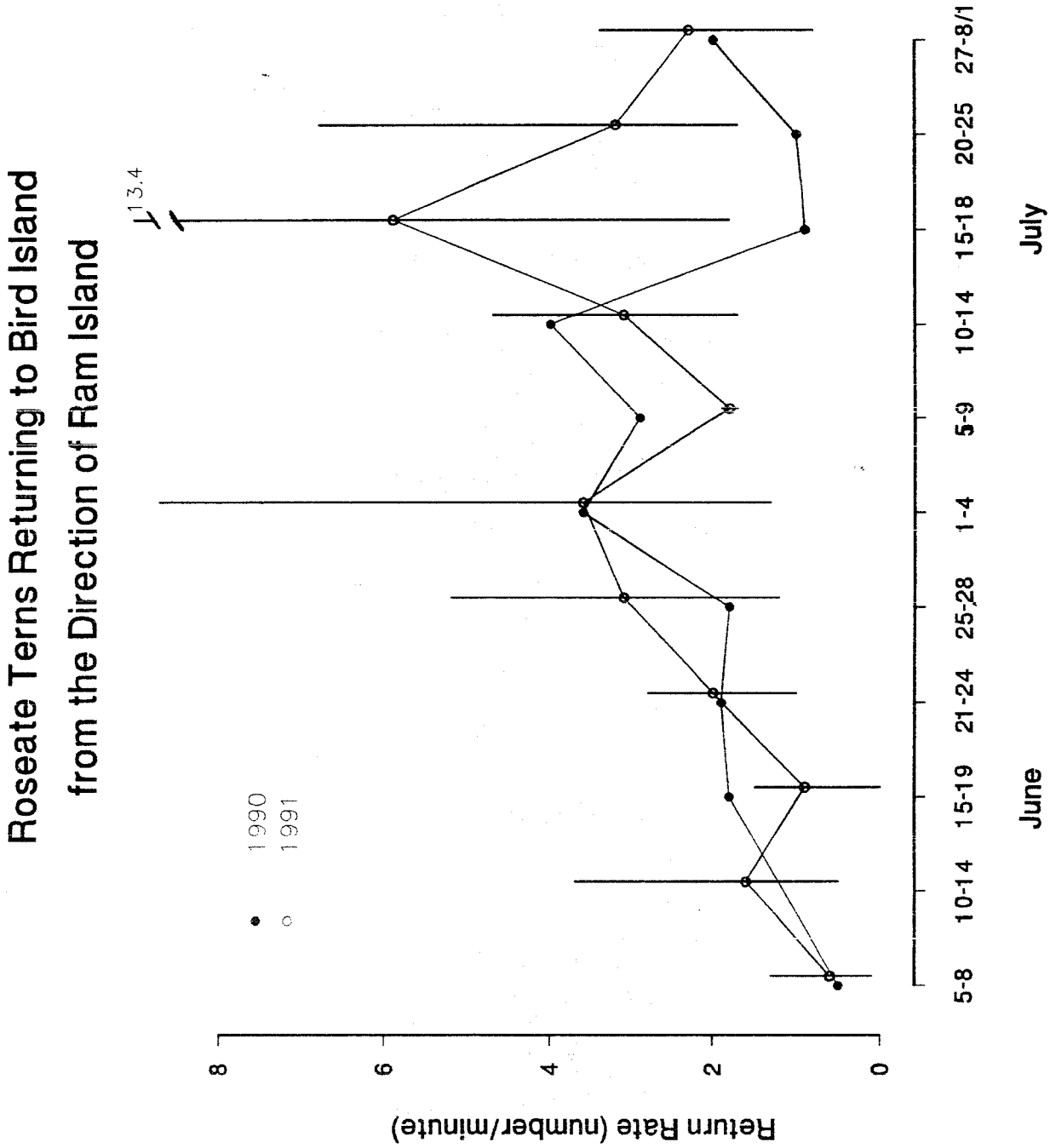

Figure 36. Mean rate of returning Roseate Terns to Bird Island from the Ram - West Island area. Solid circles indicate the single estimate obtained during the specified period in 1990. Open circles and vertical lines show the mean and range of values obtained from all samples taken in the given period in 1991.

sectors was very consistent averaging 51% with a range of 38-67% (Figure 37). On the other hand, the relative contribution of the Cape Cod Canal sectors showed a major peak of 50% at the beginning of the fourth week of June, and a minor peak of 37% at the begining of the third week of July. Over the whole season the Cape Cod Canal sectors accounted for 31% of all the returns to the island (range: 12-50%). The Ram Island sectors were always less important than the others (mean: 14%; range: 4-21%).

The pattern was rather different in 1991, with none of the major foraging grounds showing significant increases or decreases in their relative importance over the season. The difference in the relative contributions of the Woods Hole sectors and Cape Cod Canal sectors decreased from 20% in 1990 (31% versus 51%) to 11% in 1991 (34% versus 43%). Although the peak number of birds coming from the direction of Ram Island was up considerably in 1991, the relative contribution increased only 2%, and the range of values was virtually the same (7-21%).

Prey Items. In 1990, the numbers of prey brought back to Bird Island were overwhelmingly dominated by sandlance (60-100%; Figure 38). It was only in the last 10 days of July that appreciable numbers of any other species were brought back to the island, and those were mostly herring-types, silversides, and anchovies. During 1991, sandlance dominated in every sample, approximately ranging from 50-80% of the total, but significant numbers of other species occurred every time. Of the other species, herring-types were the most important in late June and early July, while silversides were the most important in late July.

Lengths of anchovies were somewhat larger in 1991 (mean=60.6 mm, s.d.=8.68 mm, n=60) than in 1990 (mean=55.0, s.d.=9.30, n=30). The sizes of herring-types were virtually the same in 1990 (mean=61.8, s.d.=13.0, n=24) and 1991 (mean=60.9, s.d.=13.6, n=156). Sandlance showed a similar pattern of little difference between years (1990: mean=59.7, s.d.=15.6, n=281; 1991: mean=60.7, s.d.=10.9, n=985). Silversides showed a marked decrease in size from 1990 (mean=67.9, s.d.=11.7, n=36) to 1991 (mean=55.4, s.d.=12.4, n=152). Mackerel were not seen in 1990; in 1991 they averaged 58.7 mm in length (s.d.=11.7, n=71).

In 1991, we obtained enough observations of prey at the island to examine the effect of time of season on the length of prey brought to the island. Of course we do not know if changes in mean prey length reflect changes in the availability of different size classes of fish, or changes in the prey selected by the terns. The lengths of sandlance increased steadily by 24% from a mean of 55 to 68 mm during the season (Figure 39). While herring-types appeared to show a large increase in size in mid-July, those estimates were based on only 7 fish. Silversides showed a 16% increase in mean length from 58 to 67 mm during the first 3 weeks of July, and then declined to just 50 mm at the end of July; the low mean at the end of June was based on just 3 fish.

DISCUSSION

Prior to this study, it had been determined that the Bird Island population of Roseate Terns was almost entirely dependent on sandlance during the early part of the nesting season (May and early June; Nisbet 1989, Andrews et al. 1989). In this study, all of the fish we observed being brought to the island during two short sampling periods in 1990 on 8 and 15 June were sandlance. In only 1 of 6 samples taken in June in either year was the proportion of diet items that were sandlance less than 80%. Further, we established that sandlance was the most important prey species over the entire season, making up 71% items in the diets of the Roseate Terns at Bird Island during 1990, and 69% in 1991. As in other years (Nisbet

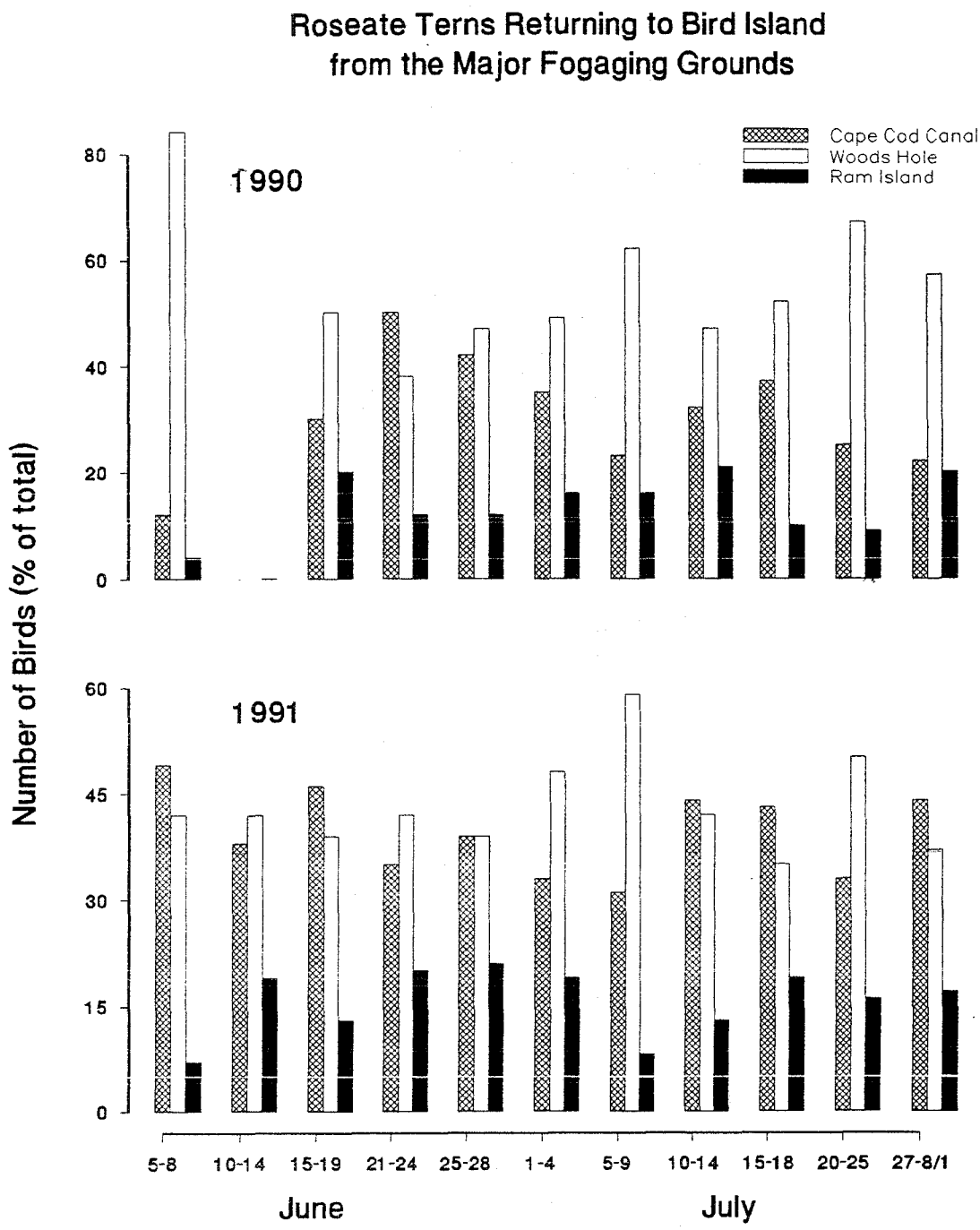

Figure 37. Number of Roseate Terns returning to Bird Island from the three major foraging grounds (Cape Cod Canal area, western Buzzard Bay, Woods Hole and Vineyard Sound, and the Ram - west Island area) during 1990 and 1991. Heights of bars indicated the proportion of the total number of birds returning to Bird Island in the specified period that were coming from foraging ground indicated by the bar's fill pattern.

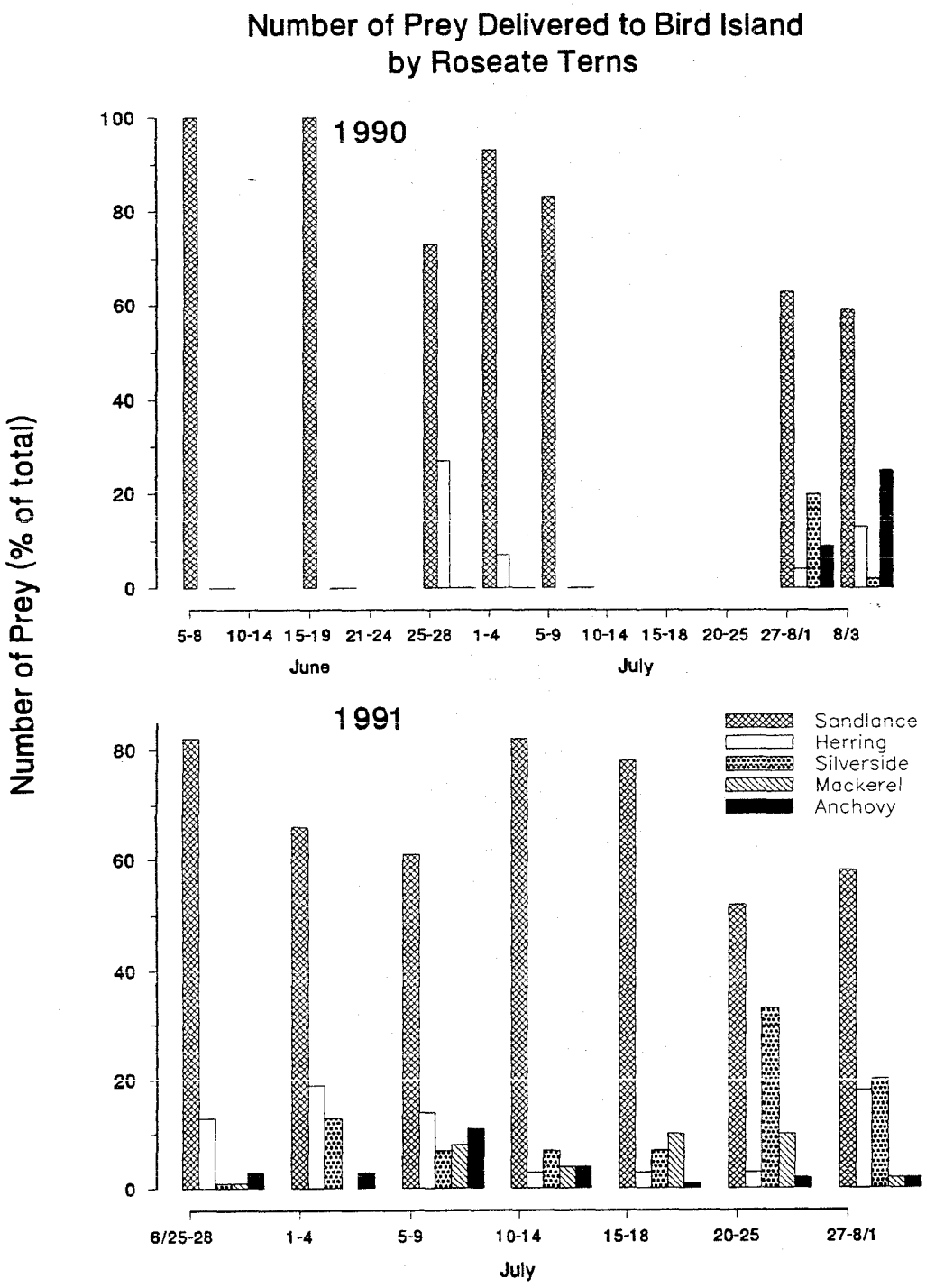

Figure 38. Number of prey items of different types brought back to Bird Island by Roseate Terns during 1990 and 1991. Bar heights indicate the proportion of all prey identified within the given period that were the type indicated by the bar shading pattern.

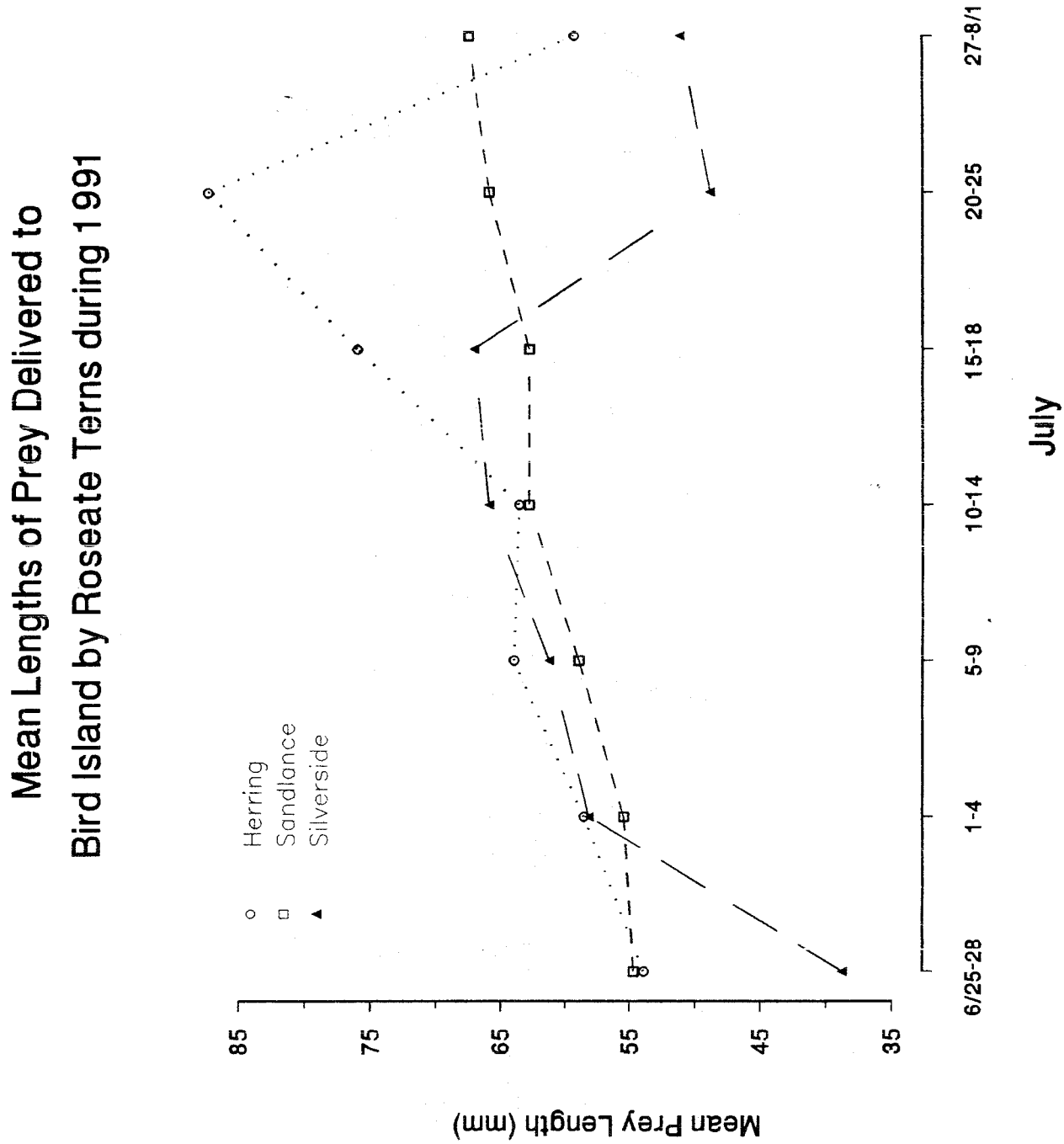

Figure 39. Mean lengths of the three main prey types brought back to Bird Island by Roseate Terns in 1991 as a function of date.

1989, Andrews et al. 1989), a small number of additional species made up the remainder of the diets of the Roseate Terns from late-June on. In 1990 we recorded three other prey types, herring-types (8%), silversides (10%) and anchovy (6%) as important components of the diet, on four, one and two sampling dates respectively. In 1991, the diet breadth was much greater with herring-types making up 11% of the diet, silversides 11%, anchovy 4%, and mackerel 5%, with most types occurring in significant numbers on more than one sampling date.

Our surveys of the foraging grounds suggested that, especially early in the season and more so in 1990 than 1991, most of the sandlance were obtained at sandy shoals such as the one at Mashnee Flats. Thus, the strong dependence on a single prey species is closely tied to almost equally strong dependence on a few particular feeding sites. The shoal at Mashnee Flats, and other feeding sites nearby, constitute the single most important foraging ground for the population. This finding highlights the necessity of determining, 1) what makes that area and other similar shoals (e.g. Succonnesset) important feeding sites, 2) how environmental factors such as water temperature and tidal flux affect prey availability at those sites, and 3) how shipping and dredging practices in the area may affect the site. Several other shoals or shallows that were used consistently in both years were at, or very close, to dredged channel or bay entrances (Onset Bay, Buttermilk Bay, W. Falmouth Harbor, Quissett Harbor, Lake Tashmoo, Waquoit Bay, and Popponesset Bay). In addition, the extensive shallows between Ram Island and the mainland were found to be an important feeding site in 1991 on more than one occassion, which has important implications for the Roseate Tern restoration project that is being conducted there.

During the chick-rearing period, feeding over predatory fish may be equally important to the population as 'Shoal' or 'Shallows' feeding. Safina (1990) has shown that Roseate Tern do better than Common Terns when bluefish are not present, and that when bluefish are present the prey capture rate by Roseate Terns decreases as bluefish activity increases. Nonetheless, bluefish may be critical agents responsible for making prey available to Roseate Terns, thus making Roseate Tern population dynamics partially dependent on the presence and activity of bluefish. Therefore, the fishing pressure on bluefish, and the fisheries management policies covering this species may have consequences for the recovery of the Roseate Tern in the Northeast U.S.

A comparison of the types of feeding flocks that were observed in the two years as a function of location and timing provides support for the claim that predator fish can affect the reproductive dynamics of the Roseate Terns. It appears that 1990 was a typical year with respect to the breeding phenology (I.C.T. Nisbet pers. comm.). In 1990, the first observation of a feeding flock in upper Buzzards Bay (Regions 2-4; Figure 23) with predatory fish confirmed as being present occurred on 21 June. From 5-28 June only 1 of 19 flocks (5.3%; 1 of 9 survey dates) observed in upper Buzzards Bay were feeding over predatory fish, however, 12 of the 19 flocks (63.2%) observed in the rest of Buzzards Bay (Regions 1, 5 and 6) or in Vineyard Sound (Regions 7-9) were 'School' flocks. Begining on 30 June predatory fish were observed in conjunction with Roseate Tern feeding flocks on 12 of 14 survey dates. During the remainder of the season (6/30 to 8/15) the proportion of flocks that were 'School' flocks in upper Buzzards Bay was 59.4% (19 of 32), and 52.8% (28 of 53) in the rest of the foraging range.

In 1991, predatory fish were present in upper Buzzards Bay on our first survey conducted there on 8 June, and on the other two survey dates in June. In June, 44.4% (8 of 18) of the flocks in upper Buzzards Bay were 'School' flocks, and in July the proportion was slightly higher, 54.6% (24 of 44). The corresponding proportions for the rest of the study area were 42.9% and 51.5%, indicating that there was virtually no difference in the importance of predatory fish in the two areas over the season. The earlier movement of predatory fish, mainly bluefish, into upper Buzzards Bay in 1991 may have been due an earlier influx of warm water into the area (pers. obs.), and appears to have been responsible for the increase in importance of the Cape Cod Canal area as a foraging ground.

Breeding phenology was unusual in 1991 (I.C.T. Nisbet pers. comm.). The onset of egg laying was delayed by 10-14 days due to the presence of a Peregrine Falcon at the island at the begining of the season. Nonetheless, all egg laying was completed by the end of June, whereas, in a normal year, inexperienced breeders would be laying all during July. In addition, the experience breeders completed the egg laying period at the normal time, indicating that they had made up the time lost because of the falcon. The presence of bluefish relatively close to the island during all of June may have meant that the availability of prey fish was greater, which would have allowed the terns to produce eggs much more quickly than normally. We suspect that inexperienced breeders are constrained from breeding as early or with as much success as experienced breeders by their relative lack of knowledge of foraging tactics and strategies and of the foraging grounds. It may take several years to learn how to efficiently exploit the variety of feeding situations used by these terns, and to anticipate the availability of prey at different locations and times in the tidal cycle. 'School' feeding may the easiest situation to exploit for young terns because highly developed searching skills are not needed and the prey can be picked off the surface rather than having to be caught with deep plunge dives. If this is the case, then the greater availability of relatively easy to find and catch prey may have had the greatest benefit to inexperience breeders, allowing them complete egg laying early in the season and to achieve a much higher than normal reproductive success.

The Woods Hole vicinity, where the birds exploited the strong tide rips, had been identified in other years as important foraging ground for Roseate Terns (Nisbet 1989). However, in 1990 this area was not used at all until August and then only by a handful of birds. In 1991, the use of this area increased, but it still was not consistently important throughout the season. Further, prior to 1990 there had not been any indication that the Roseate Terns foraged any further from Bird Island than the Woods Hole area (16-20 km). In this study we consistently found large numbers of Roseate Terns foraging in Vineyard Sound all along the Cape Cod shore from Woods Hole to Popponesset Bay and on Martha's Vineyard from Lake Tashmoo to Vineyard Haven. Roseate Terns were regularly flying 20-30 km from Bird Island to forage in Vineyard sound. Incidental observations (S. Hecker and B. Hamilton pers. comm.; pers. obs.) suggested that some, but not all, of these birds may have reduced their flight distances by flying over part of Cape Cod between Woods Hole and Falmouth. These changes represent a major shift in the foraging distribution, or in our knowledge, of the Bird Island Roseate Terns, that presumably reflect changes in the distributions of their prey. Longer flight distances and times mean greater energy expenditures for the terns using these areas, but we saw no evidence that they were bringing back substantially larger prey than were being brought back from closer foraging grounds. This suggests that a shift in the foraging distribution such as the one just described may affect the food delivery rate to chicks. Prey limitation has been shown to reduce the breeding success of Roseate Terns in New York (Safina et al. 1988), thus making it critical to determine the factors responsible for such shifts in prey distribution or availability.

RECOMMENDATIONS FOR CONTINUED RESEARCH

Based on this research and a consideration of the threats to the population of Roseate Terns on Bird Island, I suggest that the following research problems be given priority. These suggestions are in line with the Roseate Tern Recovery Plan (Andrews et al. 1989).

1) Bird Island Roseate Terns show a high degree of prey and feeding site specificity. Research should continue to: a) characterize these aspects of the feeding behavior, b) determine the year-to-year variation in feeding behavior, and c) determine the affect that the environment (e.g. tides, prey availability, competitor density) has on that variation. Because we found large changes in the foraging distribution of Roseate Terns from earlier

studies and differences from 1990 to 1991 that may have had important affects on breeding performance, a multi-year study of foraging behavior and its relationship to distribution and reproduction is critical.

2) Particular habitat features appear to be critical to the successful feeding of Roseate Terns. More study is required to determine how and why shoals are important, and how stable as feeding grounds they are over time. We need to know what the critical features are that determine why one shoal is an important feeding ground and a nearby shoal is not used at all, or a shoal is important in one year but not another. One of the most important goals of the Recovery Plan is to, "evaluate the suitability of existing and potential nesting habitat to support an expanding population" (Andrews et al. 1989, 1.2, p. 36). Research that established the characteristics of critical habitat would make the selection of suitable sites for new colonies a much less problematic process.

3) In addition to the importance of shoals and feeding sites, we know that bluefish are key factors in increasing prey availability to Roseate Terns, and that they may be a key factor in increasing reproductive output of the colony. I recommend that information be found and/or studies be initiated that would document the status and interactions among bluefish and the prey species used by Roseate Terns.

4) The studies recommended above are all related to trying to understand how the abiotic and biotic environment of the Bird Island Roseate Terns affects their foraging behavior, foraging decisions and, ultimately, foraging success. However, as recognized in the Recovery Plan, the effect management of Roseate Terns requires that we understand the relationship between this information and reproductive success. Therefore, I recommend that any foraging research be coupled to research on the reproductive biology of the terns. To achieve this it will be necessary to replicate studies at several colonies, a difficult task, or, alternatively, to focus critical aspects of the research on marked individuals.

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Comment [JLJ16]: Forwarded this document July 19, 2012 entitled CapeWind-BO-21November2008_withCovLttr

Comment [JLJ17]: Forwarded this document July 19, 2012 entitled RoseateTernRecoveryPlan1stUpdate1998

Comment [JLJ18]: Not cited in the body of the report and can be deleted.