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NEW BEDFORD HARBOR
TASK 22
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ACTIVITY 22.3
EXPOSED SPECIES ANALYSIS

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NOTICE

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1.0 INTRODUCTION

The Exposed Species Analysis was conducted as part of the Environmental Exposure Assessment for the New Bedford Harbor risk assessment. The Exposed Species Analyses focuses on a representative subset of species identified in New Bedford Harbor and describes how the range, distribution, and life cycle characteristics of these organisms may influence exposure to contaminants identified in this area. Species profiles for 33 representative species are included in this report.

This report also includes an overview of how the Environmental Exposure Assessment will be organized. Section 2.0 includes an introduction and the first two sections of the Environmental Exposure Assessment. (Subsequent sections to be included in the Environmental Exposure Assessment which are not included in this report will focus on quantifying exposure concentrations at various locations throughout the harbor and summarizing how exposure information will be used to assess risk to aquatic organisms.) Section 2.0 of this report also describes the New Bedford Harbor study area and the physical parameters influencing species distribution, and presents species profiles. Section 3.0 of this report presents a summary of the Exposed Species Analysis.

2.0 ENVIRONMENTAL EXPOSURE ASSESSMENT

The purpose of an exposure assessment is to identify the receptor species at risk of exposure to contaminants and to determine the major pathways through which they may contact contaminants. For an aquatic environment, such as the New Bedford ecosystem, identifying receptors and determining the rates of exposure is difficult due to the dynamic interactions between water, sediment, and aquatic organisms.

The impact of the physical environment as well as species specific factors will be considered in evaluating species exposure to PCBs and heavy metal contamination detected in this area. This exposure assessment will be divided into four sections. The first provides a brief description of the study area and how the physical parameters influence species presence and distribution throughout this area. The second section evaluates a representative subset of the species detected throughout the area to describe contaminant exposure at New Bedford Harbor. The third section, to be included as part of the risk assessment, will identify exposure concentrations at various locations throughout the harbor and relates these to the range and distribution of a representative subset of species to assess exposure. The fourth section will summarize environmental exposure and describe how this information will be used to assess risk.

2.1 PHYSICAL DESCRIPTION OF NEW BEDFORD HARBOR

The New Bedford Harbor area contains approximately six square miles of open water, tidal creeks, salt marshes, and wetlands. The major fresh water inflow to this area is the Acushnet River. The introduction of the fresh water river into the salt water harbor creates a unique ecosystem comprised of salinity, depth, and temperature gradients. This ecosystem provides habitats for a wide variety of aquatic organisms that utilize this area for spawing, foraging, and overwintering. Figure 1 illustrates the study area for the environmental exposure assessment.

The species distribution throughout this study area is governed by the physical and chemical parameters discussed above. Species survival is often limited to a small range in these parameter values and thus species will distribute in areas throughout the estuary/harbor area best suited for their growth and reproduction. Areas of high salinity such as those observed in Buzzards Bay are inhabited by species such as the striped bass which have developed osmoregulatory mechanisms suitable for dealing with such conditions. Low saline tolerent species such as the Mummichog could not survive in Buzzards Bay and therefore are found in the estuarine areas near the freshwater/salt water interface. While the fully developed adult species may be able to tolerate certain physical and chemical parameters, the survival of the egg and juvinile stage of the same organism may

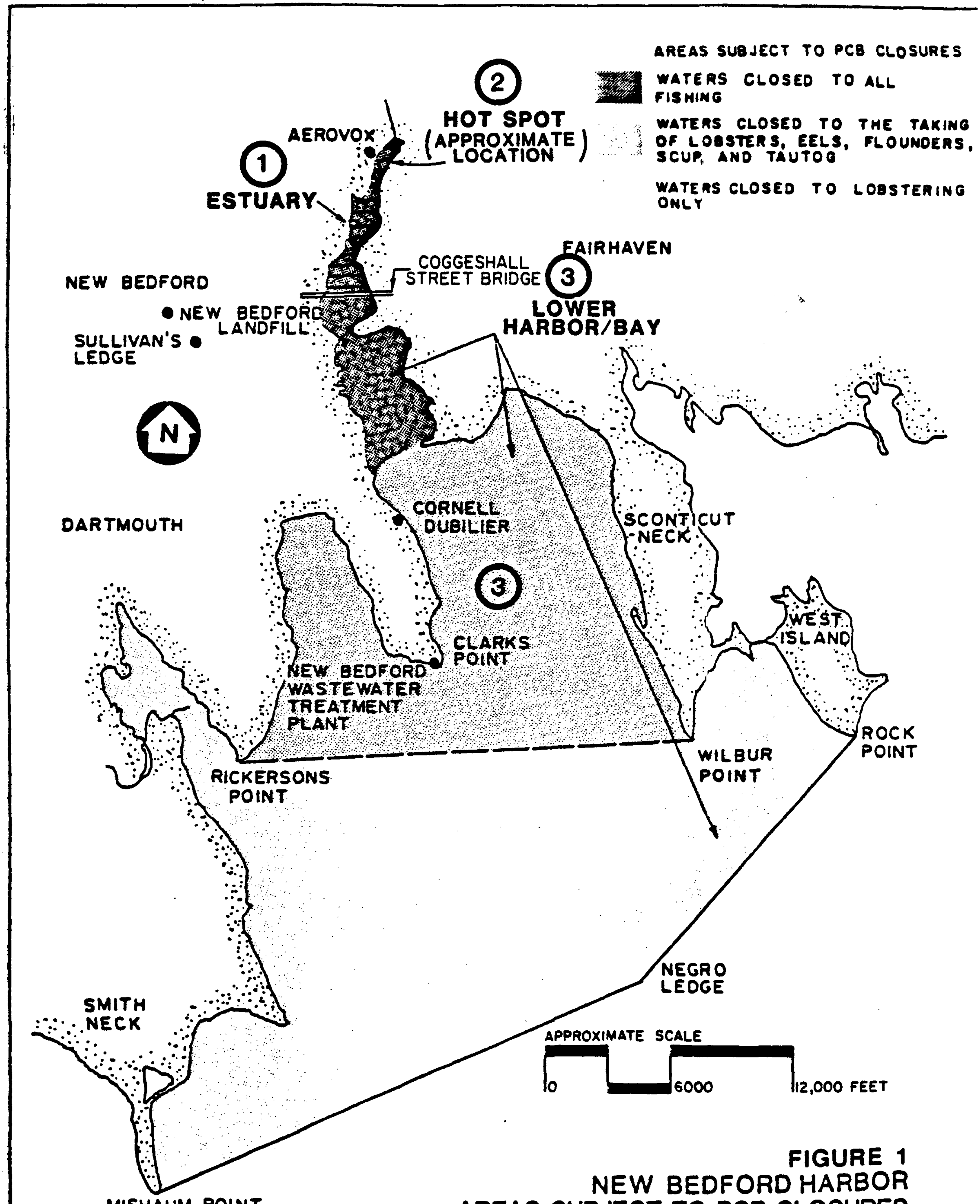

FIGURE 1
NEW BEDFORD HARBOR
AREAS SUBJECT TO PCB CLOSURES

be dependent upon less stressful areas of the environment. Many anadromous fish inhibit Buzzards Bay but come into the estuary to spawn. The eggs hatch and juviniles develop in this area, utilizing the low salinity and high nutrient conditions for optimal growth.

Figures 2 through 4 illustrate the salinity, depth, and temperature gradients observed in the New Bedford Harbor area. These three factors are considered to be the major physical parameters which dictate species distribution and are used to discuss the potential range and distribution of the species inhabiting the New Bedford Harbor area. (These figures will be referred to in the species profiles presented later in this section.)

2.2 EXPOSED SPECIES ANALYSES

The exposed species analyses provide information on how and which species may be exposed to the contaminants in New Bedford Harbor. To determine this information, both the routes of contaminant exposure and the receptor organisms (species) were identified. The following is a brief discussion of this process and the organizational structure used to present this information in the species profiles.

There are three primary routes through which aquatic organisms may become exposed to contaminants:

- o Water column (direct contact with the water column via the gills or epethelial tissue);
- o Sediments (direct contact or ingestion of sediments); and
- o Food Webs (ingestion of forage species).

Organisms in New Bedford Harbor can be exposed by any one or all three of these routes of exposure depending upon the habitat and life cycle stages of the organism. The interrelation of these three routes make it difficult to definitively assess exposure. In terms of species/exposure relationships at New Bedford Harbor, direct contact with dissolved or particulate contaminants in the water column is the primary route of exposure for pelagic fish, bivalves, and plankton. A secondary route of exposure for pelagic fish and bivalves is consumption of contaminated biota. For benthic fish and invertebrates, direct contact and ingestion of contaminated sediments are the primary routes of exposure while direct contact with the water column being the secondary route of exposure. Forage species such as the mummichogs and grass shrimp are food for secondary and tertiary consumers. Ingestion of these species can result in the biomagnification of PCBs and metals. Although the focus of this exposed species analysis will be the primary route of

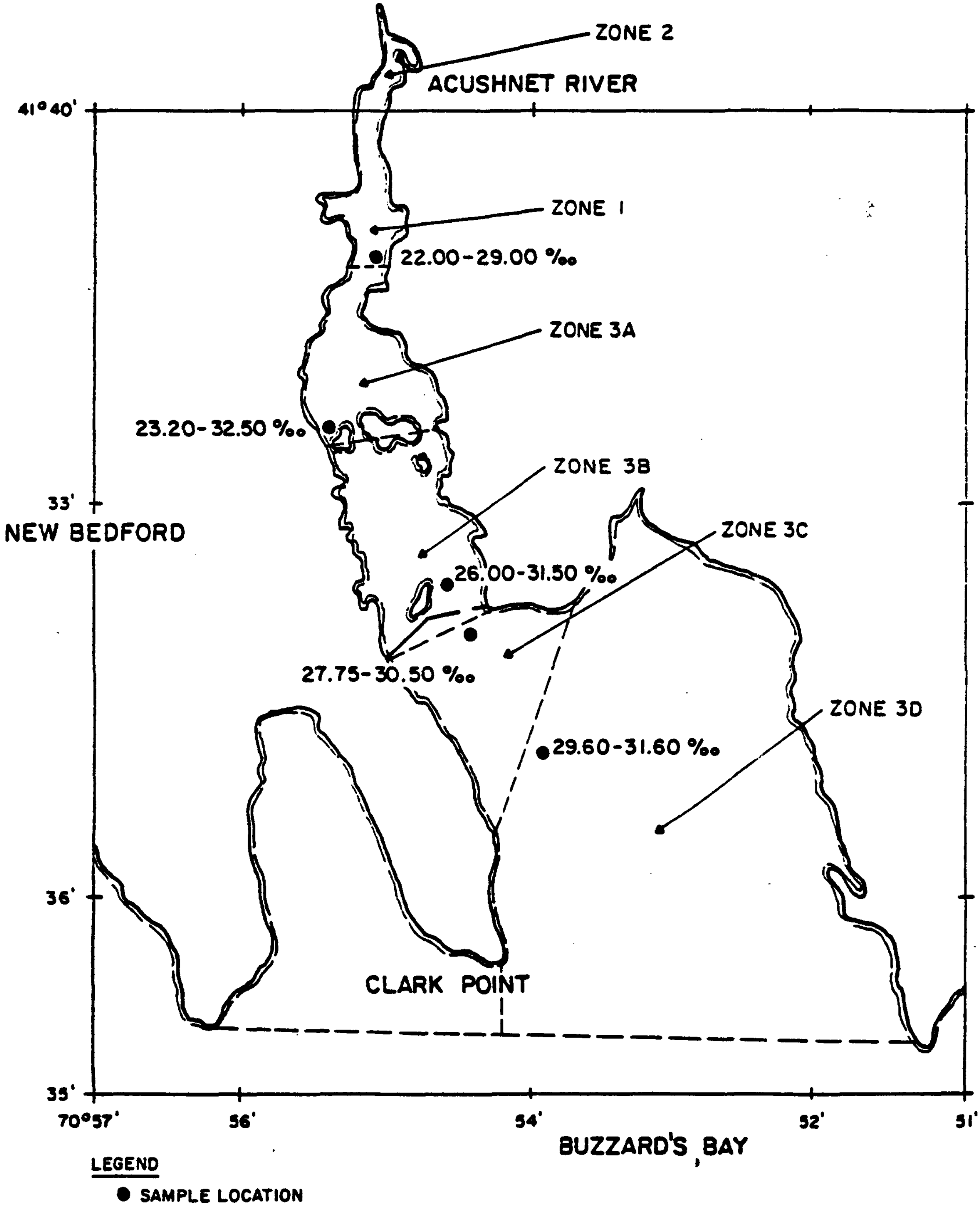

FIGURE 2
SALINITIES FOR ZONES 1-3D
NEW BEDFORD HARBOR

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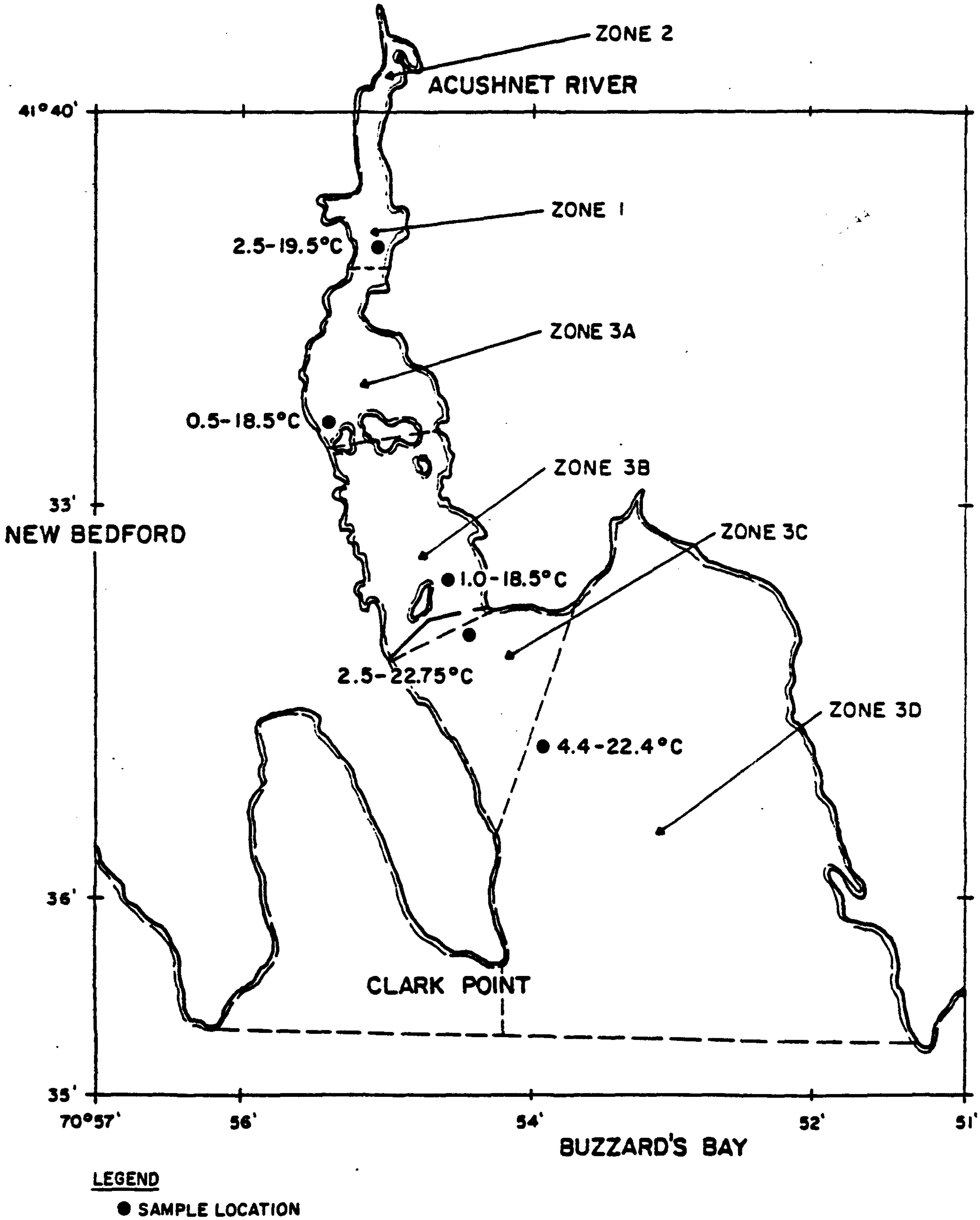

FIGURE 3
TEMPERATURE RANGE IN ZONES 1-3D
NEW BEDFORD HARBOR

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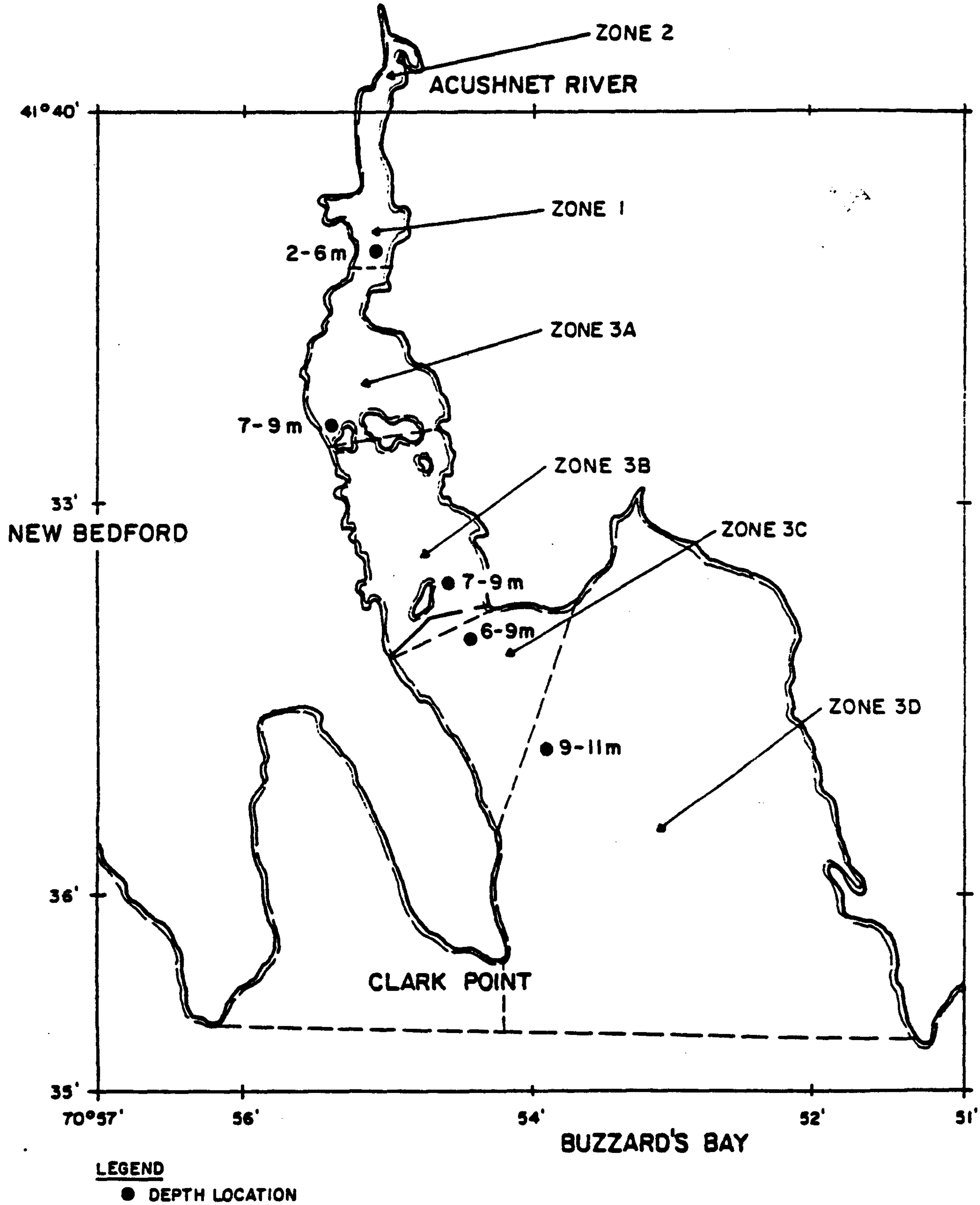

FIGURE 4
WATER DEPTHS IN ZONES 1-3D
NEW BEDFORD HARBOR

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exposure, it will also address the secondary and tertiary routes of exposure to provide an accurate description of exposure to the species in New Bedford Harbor. Primary exposure routes were determined based on the habitat requirements of adult species while the secondary and tertiary exposure routes were determined based on the different life stages of the species.

As indicated, the primary route of contaminant exposure changes over the course of the species life cycle. For example, direct contact with contaminants in the water column is the primary route of exposure for anadromous fish using the estuary for a spawning ground while the eggs released by these adults are highly susceptible to the contaminants in the sediments. Thus, the same species may be exposed by different routes of exposure depending upon its life stage. An exposure assessment for New Bedford Harbor must therefore consider not only which species are exposed but how exposure occurs given the life stage of an organism.

To evaluate contaminant exposure, species profiles were developed for selected organisms which discuss the unique life cycle characteristics of each species and how these dictate species/exposure relationships.

To assess exposure, it is not necessary to complete an exposed species analysis for every species within New Bedford Harbor. Therefore, a representative subset of species (see Table 1) were identified as the focus of this exposure assessment. These species fall into four selected classes of aquatic organisms: finfish, crustaceans, molluscs, and plankton. These species classes were chosen as they provide representative organisms from each trophic level and include species exhibiting both pelagic and benthic habitation. Focusing the exposed species analyses on these organisms will ensure that all routes of contaminant exposure are assessed.

The individual species selected were based upon the review of biological survey data collected by:

- U.S. Army Corps of Engineers (USACE, 1986);
- Camp, Dresser, and McKee (CDM, 1979);
- Woods Hole Oceanographic Institute (WHOI, 1986);
- Clayton (1976); and
- O'Brien (1975).

The following criteria were used in making the final selection of organisms for the exposed species analyses:

- Commonality to New Bedford Harbor;
- Distribution within the study area;
- Food chain importance (producer, primary consumer, secondary consumer, or tertiary consumer);
- Exposure considerations (contact with water, sediment, or ingestion of biota);
- Commercial and recreational utilization;
- Availability of site-specific and non site-specific ecotoxicity data; and
- Availability of biological and ecological information.

A total of 33 organisms were selected for the exposed species analyses (see Table 1). A species profile was developed for each organism describing both the species/exposure relationships and the life cycle characteristics which influence the type of contaminant exposure. A brief discussion of the major topics covered in these profiles includes:

- A description of how exposures to specific heavy metals and PCBs may vary based on the range and distribution of the aquatic organism within New Bedford Harbor;
- A description of how the population characteristics of a specific aquatic organism may enhance or inhibit exposure to heavy metals and PCBs at New Bedford Harbor;
- A description of how the reproductive habits of aquatic organisms will effect exposure to heavy metals and PCBs at New Bedford Harbor;
- A description of how the eggs, larvae, and juvenile stages of aquatic organisms may be exposed to heavy metals and PCBs at New Bedford Harbor;
- A description of how the feeding and predation of aquatic organisms may result in contaminant exposure; and
- An evaluation of the utilization (commercial and recreational) of aquatic organisms and the potential of human exposure to heavy metals and PCBs via the consumption of contaminated biota.

TABLE 1
SPECIES OF CONCERN FOR NEW BEDFORD HARBOR[a]

WATER COLUMN	SEDIMENTS	FOOD WEBS
Striped Bass (*Morone saxatilis*)	Winter Flounder (*Pseudopleuronectes americanus*)	Atlantic Silverside (*Menidia menidia*)
Bluefish (*Pomatomus saltatrix*)	American Eel (*Anguilla rostrata*)	Mummichug (*Fundulus heteroclitus*)
Blueback Herring (*Alosa aestivalis*)	Scup (*Stenotomus chrysops*)	Blue Crab (*Callinectes sapidus*)
Alewife (*Alosa pseudoharengus*)	Tautog (*Tautoga onitis*)	Green Crab (*Carcinus maenas*)
Atlantic Menhaden (*Brevoortia tyrannus*)	Amphipod (*Ampelisca vadorum*)	Soft-shell Clam (*Mya arenaria*)
Atlantic Mackerel (*Scomber scombrus*)	Tubificid worms (*Tubificoides* sp.)	Quahog (*Mercenaria mercenaria*)
Copepod (*Acartia tonsa*)	Slipper shell (*Crepidula fornicata*)	Grass Shrimp (*Palaemonetas vulgaris*)
Opposum Shrimp (*Neomysis americana*)	Eastern Mud Nasa (*Nassarius obsoletus*)	Clam Worm (*Nereis succinea*)
Diatom (*Rhizosolenia alata*)	American Lobster (*Homarus americanus*)	Mud Worm (*Streblospio benedicti*)
Diatom (*Skeletonema costatum*)		Thread Worm (*Capitella capitata*)
Atlantic Ribbed Mussel (*Modiolus demissus*)		
Blue Mussel (*Mytilus edulis*)		
Atlantic Bay Scallop (*Aequipecten irradians*)		
Eastern Oyster (*Crassostrea virginica*)		

[a]Illustrations for these organisms are in Appendix B.

2.2.1 Water Column Exposure

Many of the fish associated with New Bedford Harbor swim between the surface and deeper water and contribute organic matter by egestion, excretion, and death. The following fish from New Bedford Harbor are representative of this pelagic life style: striped bass (Morone saxatilis), bluefish (Pomatomus saltatrix), blueback herring (Alosa aestivalis), alewife (Alosa pseudoharengus), Atlantic menhaden (Brevoortia tyrannus), and the Atlantic mackerel (Scomber scombrus).

Organisms which are unable to maintain their distribution against the movement of water massess are referred to as "plankton". Included in this group are phytoplankton (plants) and zooplankton (animals). Generally, all plankton are very small and in many cases, microscopic. The following plankton from New Bedford Harbor are representative of this free-floating existence: copepod (Acartia tonsa), opposum shrimp (Neomysis americana), diatom (Rhizosolenia alata), and the diatom (Skeletonema costatum).

Many bivalves are found on hard rock bottoms or semi-hard mud, normally setting on areas already inhabited by other bivalves. These organisms are filter feeders, filtering large quantities of water daily to extract the edible particles. Direct contact to the visceral organs from water-bound contaminants is a primary source of exposure. The following bivalves are representative of this life style: Atlantic ribbed mussel (Modiolus demissus), blue mussel (Mytilus edulis), Atlantic bay scallop (Aequipecten irradians), and the Eastern oyster (Crassostrea virginica). The uptake and retention of PCBs and heavy metals by these fish, plankton, and bivalves is directly from the water column via the gills, epethelial tissues, visceral organs, and the planktonic test (valve or covering). Below is a concise description of three selected organisms and how their life cycle characteristics reflect potential PCB and heavy metal exposure in New Bedford Harbor, the remaining profiles are in Appendix A.

Striped Bass (Morone saxatilis)

Range and distribution

The striped bass, Morone saxatilis, occurs from the St. Lawrence River to the St. John's River in northern Florida to Louisiana (Clayton, 1976). The majority extend from Cape Cod to Cape Hatteras. Except during migrations, adults are located strictly near shore in salt, brackish, and freshwater environments like New Bedford Harbor. In Massachusetts waters striped bass are summer transients, regularly appearing in estuarine and nearby coastal waters in temperatures from 14.0 to 18.0°C and in salinities as low 25.3 parts per thousand (see Figures 2 and 3). Many of these fish are believed to be produced in Chesapeake Bay and regularly migrate northward along the coast. In New Bedford Harbor the striped bass has been found in Zones 1, and 3a-3d in low abundance but is thought to be absent from Zone 2 (Hot Spot) (Bourque, 1986). From November to October a reverse migration occurs, as the bass leave Massachusetts and move to their overwintering grounds. These sites are generally in Delaware and Chesapeake Bays, although some fish overwinter further north off the New Jersey coast and possibly in the Hudson River. Occasionally striped bass overwinter in rivers of southern New England, including Massachusetts (Clayton, 1986). The migratory habits of this species subject it to water-bound contaminants (PCBs and heavy metals) in New Bedford Harbor (see Figure 5).

Population characteristics

Striped bass caught in Massachusetts waters have ranged up to 20 years of age and 127 cm in length. Striped bass live more than 40 years and reach a weight of over 54.4 kg, but specimens heavier than 34 kg are rare. Some female striped bass are sexually mature at age 4, and essentially all are mature by age 6. Males tend to mature earlier than females; most males are sexually mature by age 2 and virtually all by age 3. Fecundity varies with the size of the female: about 14,000 eggs are produced by a 1.4 kg fish, 250,000 by a 2.2 kg fish, and about 5 million by a 22.7 kg fish. Today, as in the past, stocks of striped bass in Massachusetts waters and the Gulf of Maine fluctuate in abundance periodically. The factors controlling this phenomenon are not yet well understood. Striped bass are very sensitive to heavy metals and will not avoid contaminated areas if favorable temperature or oxygen concentrations exist (NOAA, 1985).

Reproduction

Evidence of spawning has not been reported in Massachusetts in recent years. Striped bass are anadromous and spawn during April through June, depending on the water temperature. Spawning may occur between 12 and 23°C although most eggs are

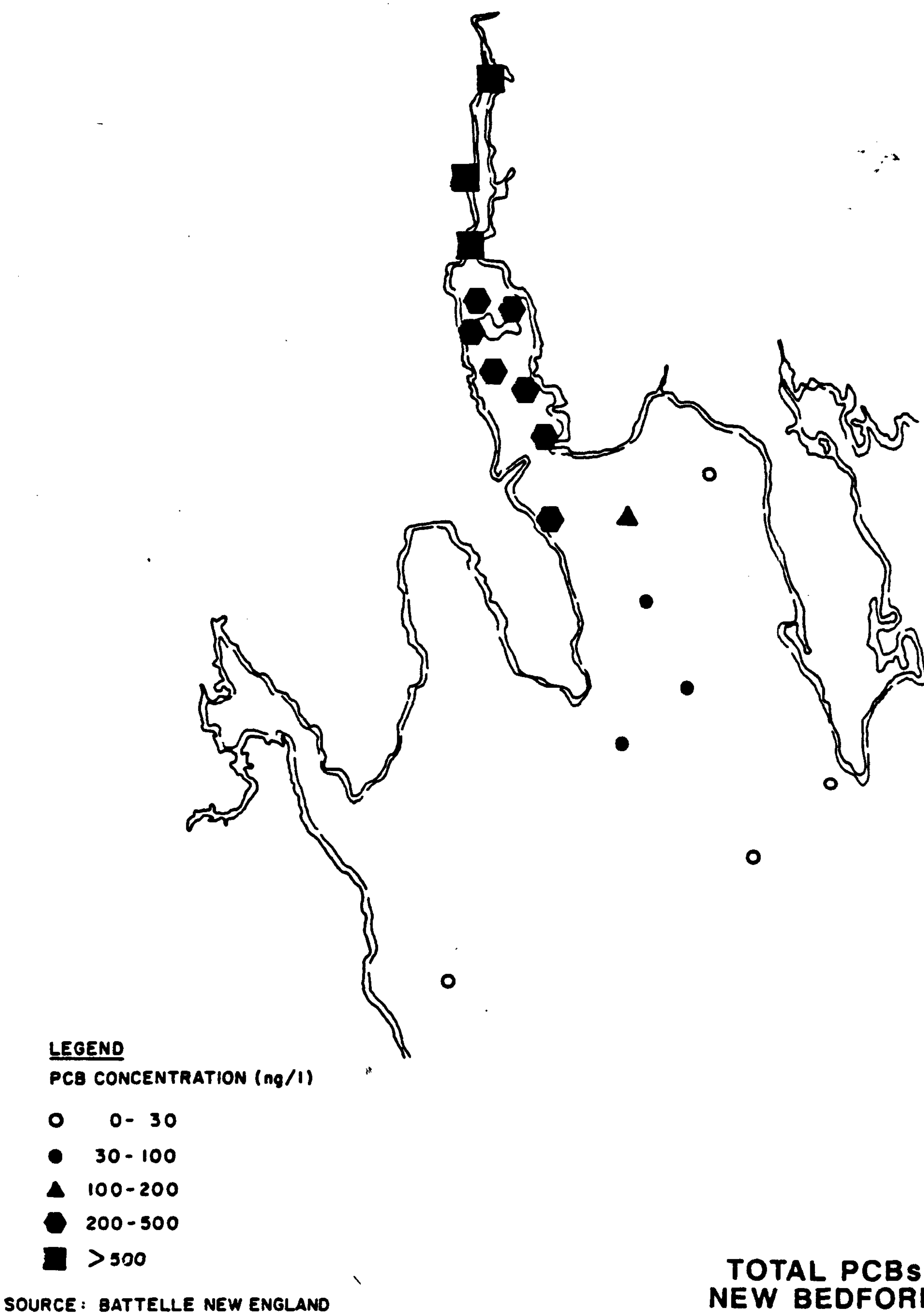

FIGURE 5
TOTAL PCBs IN WATER
NEW BEDFORD HARBOR

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laid at 18°C (Figures 2 through 4). Spawning fish require rapidly flowing, turbulent waters usually near the saltwater-fresh water interface of an estuary. In New Bedford Harbor the hurricane barrier along with PCBs and heavy metals may inhibit this species reaching suitable spawning grounds in Zone 2.

Eggs, Larvae, Juveniles

The eggs of striped bass are nonadhesive, becoming pelagic in fast flowing water but semi-demersal in quiet water. The pelagic and semi-demersal characteristics of striped bass eggs can subject them to PCB and heavy metal exposure by both surface water contact and direct contact with contaminated sediments. Developing eggs may remain in their natal river due to tidal fluctuations or be swept into brackish water before hatching. Eggs hatch in 30 hours at 21-22°C, 48 hours at 18°C, and 70 to 74 hours at 14 to 16°C. The young usually remain in their natal estuarine system until they are about 2 years old, whereupon they begin their migration (Clayton, 1976).

Feeding and Predation

The striped bass is a voracious feeder, consuming both fish and invertebrates in the shore zone and estuaries. In the Gulf of Maine there are reports that they prey primarily on herring, rainbow smelt, sandlance, eels, silver hake, squid, crabs, lobsters, and sea worms all found in New Bedford Harbor. In estuarine waters they may often be associated with mussel beds that produce large numbers of polychaetes. Feeding often occurs in schools during darkness, the period of maximum activity for seaworms. Juveniles feed more extensively on amphipods, shrimp, and small crabs (Clayton, 1976). This top carnivore may be subject to high tissue burdens from the consumption of various prey organisms at New Bedford Harbor.

Utilization

The striped bass is a recreational species in Massachusetts, and is distributed along most of the Massachusetts coastline. In 1972 Massachusetts commercial landings totaled well over 500 MT; most were caught by hook-and-line (Clayton, 1976). However, the abundance of this species has dropped considerably in Massachusetts waters. Landing statistics for New Bedford Harbor indicate that only 5,800 lbs were brought ashore in 1985 (NMFS, 1986), reflecting in part the recently imposed fishing regulations implemented to protect this species, as well as its increasing scarcity. The striped bass is considered by local fisherman to be the most lucritive marine species, and consumption of this organism may be a pathway of exposure to humans at New Bedford Harbor.

Copepod (Acartia Tonsa)

Range and Distribution

Acartia is a marine calanoid with a planktonic lifestyle. These organisms undergo daily depth migrations. These diurnal variations are signaled by changing light intensity; copepods swim toward the surface as it grows darker. The depth at which these animals are found also depends on species, sex, temperature, season, and physiological condition (Kaestner, 1980).

Acartia tonsa dominates the zooplankton biomass in Buzzard's Bay from May to November. However, preliminary evidence suggests that production rates of this copepod are reduced near and around the hurricane barrier (Zones 3b, 3c, and 3d) (Figure 1), at New Bedford Harbor, an area contaminated with heavy metals and PCB's (Capuzzo, 1986). During laboratory experiments using resuspended sediments from the estuary north of the hurricane barrier, reduced survival rates of 50 percent were noted for Acartia. These sediments contain high concentrations of metals and PCBs (Cu - 500 ppm; Zn - 300 ppm; PCBs - 75,000 ppm) (Capuzzo, 1986).

Population Characteristics

This copepod is a floating animal with a long stiff prosome and a short abdomen. Some progress is made with continuous gentle swimming movements (Kaestner, 1980; Wetzel, 1983). Copepods have no special respiratory structures and probably respire directly through the integument (Kaestner, 1980). These characteristics would result in exposure to contaminants through direct contact with the water mass. During laboratory experiments using resuspended New Bedford sediments survivors showed depressed respiration and metabolic rates (Capuzzo, 1986).

Reproduction

Reproduction in calanoid copepods is sexual. The male is attracted to the female using chemical senses. During mating the male attaches a spermatophore near the gonopore of the female. One female can be successively fertilized by several males (Kaestner, 1980). Fertilization can take place immediately, or up to several months after copulation. Eggs are carried in a single sac by the female. The number of eggs produced is directly dependent on food availability (Wetzel, 1983).

Copepods collected in the region beyond the hurricane barrier at New Bedford Harbor were shown to be deficient in lipid reserves at the time of collection (Capuzzo, 1986). It is believed that this contributes to the observed reduction in egg production. Acartia tonsa is susceptible to rapid loss of energy reserves and egg production declines rapidly during brief periods of starvation (Dagg, 1970) or toxicant stress (Capuzzo, 1980). Therefore, reduced production rates at New Bedford Harbor could be the result of poor food quality or contaminant toxicity (Capuzzo, 1986).

Eggs, Larvae, Juvenile

Calanoid eggs are laid several hours to several days after copulation. Acartia creates subitaneous and resting eggs. The resting eggs go through diapause in the sediments, which could result in increased exposure due to direct contact. After hatching, the larvae develop through six nauplier and five copepodid stages. The larvae are free-swimming and progress from one stage to the next by molting (Kaestner, 1980). The timing of these molts can depend on seasonal conditions (Wetzel, 1983). During these molts, the copepod can be more susceptible to contaminant exposure through contact with the water mass. Some of the nauplier larvae have yolks, and therefore do not feed directly from the water mass (Kaestner, 1980).

During the previously mentioned laboratory studies (Capuzzo, 1986) which utilized contaminated sediments from above the hurricane barrier at New Bedford Harbor, a significant reduction in egg viability was noted after 72 hours of exposure and throughout a post-exposure period. It is suggested that reduced viability, which correlates with a reduction in the total lipid content of the eggs is due to a failure of the stressed copepods to accumulate or mobilize enough yolk to support the embryo (Capuzzo, 1986).

Feeding and Predation

Acartia is a predatory copepod (Kaestner, 1980). It does not strain its food from the water, but propels water past the body by flapping four pairs of feeding appendages. The second maxillae captures 'parcels' of water containing food. Particles of food are placed in the mouth by the first maxillae (Wetzel, 1983). Calanoids feed on diatoms, radiolarians, coccolithophorids, tintinnids and small crustaceans (Kaestner, 1980).

Species of fish found in New Bedford Harbor which prey upon copepods are Menidia menidia (Atlantic silverside), and the larval form of the winter flounder, Pseudopleuronectes americanus. The larval flounder feeds upon the nauplier larvae of copepods. In addition, Alosa pseudoharengus (Alewife), larval Brevoortia tyrannus (Atlantic Menhaden), and Alosa aestivalis (Blueback herring) feed on copepods.

Utilization

Although Acartia is not directly utilized by humans, these copepods provide an important food resource for many fisheries. A direct relationship exists in many Massachusetts coastal streams between standing crops of zooplankton and the growth and feeding of young-of-the-year blueback herring (Clayton, 1976). Examples of specific species which prey upon Acartia are given in the previous section. Many of these fish, such as menhaden, herring, alewife and silverside can be important forage species for predatory fish such as Potatomus saltatrix (bluefish), and Morone saxatilis (striped bass).

Diatoms (Skeletonema costatum)

Range and Distribution

Skeletonema costatum is a free-floating chained diatom (Parsons, 1977). It can adapt to ranges in temperature by increasing enzyme levels, allowing a constant rate of photosynthesis at varying temperatures (Wetzel, 1983). Diatoms are abundant in both fresh and marine waters.

At New Bedford Harbor, Skeletonema costatum was observed beyond the hurricane barrier in Zone 3d (Lillick, 1937). This study may indicate the historical distribution of this diatom. A 1972 study by the Massachusetts Water Resources Commission indicates that diatoms were seen sporadically throughout Zones 2, 3a, and 3b.

Population Characteristics

These phytoplankton have siliceous tests (exoskeletons) (Duxbury, 1977). Because of their planktonic lifestyle, exposure to contaminants can occur through direct contact with the body mass. Arochlor 1254 at 10 ug/l has been shown to reduce growth, carbon fixation, and cell division rates in Skeletonema costatum (O'Connors, 1978).

In general, phytoplankton abundance depends on nutrient availability, light mixing, zooplankton grazing and concentrations of man-made contaminants (O'Connors, 1978). PCB exposure has been shown to reduce phytoplankton biomass (O'Connors, 1978). There is a shift to smaller sized taxa within natural estuarine phytoplankton communities. In addition, there is a dose dependent suppression of algae growth. Repeated exposures to PCBs at the 10 ug/l level ultimately caused mortality of phytoplankton (O'Connors, 1978).

Reproduction

Diatoms reproduce vegetatively, generally at night (Wetzel, 1983). New valves are formed inside the cells. Cell division results in 2 unequally sized daughter cells. One is the same size as the parent; one is smaller. As division continues, half the daughters grow smaller to a critical limit. At this point, sexual reproduction is initiated. A fertile protoplasm is released and gametes fuse to form the auxospore stage (Duxbury, 1977).

Eggs, Larvae, Juveniles

The auxospore stage results from sexual reproduction in diatoms. Fertile protoplasm is released, the auxospore begins to form a new test, and eventually reproduces vegetatively (Duxbury, 1977). Because the test (or exoskeleton) is missing during the auxospore stage, it is possible that risk of exposure to PCBs and metals at New Bedford Harbor is greater at this time, due to direct contact with the water mass.

Feeding and Predation

Diatoms are photosynthetic primary producers, which play an important role as a food resource for macrozooplankton (i.e., copepods) and planktivores (i.e., herring). (Parsons et al, 1977). PCB exposure can have wide reaching effects on phytoplankton roles in food webs. As previously mentioned, PCB exposure can result in a shift to smaller phytoplankton taxa. The change from large to small taxa causes variation in the food web which favors gelatinous predators and reduces the harvestable fish biomass (O'Connors, 1978). Neomysis americana (oppossum shrimp) and Acartia tonsa (a copepod) are two of many zooplanktons which prey upon diatoms at New Bedford Harbor.

Utilization

Diatoms, as described under the previous heading, provide an important food resource as primary producers, and can ultimately affect harvestable fish biomass.

Diatomaceous earth, which forms from accumulation on the sea floor of the siliceous tests of diatoms, is used extensively as an abrasive, filler, filtration powder, and in insulation products (Duxbury, 1977).

2.2.2 Sediment Exposure

Many species of benthic fish and invertebrates are found in New Bedford Harbor. This analysis of those species will discern what role their specific life cycle characteristics will play in PCB and heavy metal exposure. The following fish and invertebrates are representative of a benthic life style: Northern lobster (Homarus americanus), winter flounder (Pseudopleuronectes americanus), American eel (Anguilla rostrata), scup (Stenotomus chrysops), tautog (Tautoga onitis), amphipod (Ampelisca vadorum), tubificid worms (Tubificoides sp.), slipper shell (Crepidula fornicata), and the Eastern mud nasa (Nassarius obsoletus). The uptake and retention of PCBs and metals is via direct contact with and ingestion of contaminated sediments, however, direct contact with the water mass will contribute to exposure. Below is a concise description of four selected organisms and how their life cycle characteristics reflect PCB and heavy metal exposure in New Bedford Harbor, the remaining species profiles are in Appendix A.

Winter Flounder (Pseudopleuronectes americanus)

Range and distribution

The winter flounder, Pseudopleuronectes americanus, is found from southern Labrador south to Georgia and is most common off the New England coast (Clayton, 1976). Also called the blackback flounder, it is observed in estuarine waters and salt water as deep as 130 m, but is more common at shallow depths inshore (Clayton, 1976). It has been found in Zones 1, 2, and 3a-3d in New Bedford Harbor (GCA, 1986a). Migratory studies have shown the movement of the winter flounders to be temperature regulated with seasonal dispersal southeastward along the New England coast. However, juvenile flounders remain in the estuaries until their third year (Clayton, 1976). As a result, this may expose juveniles to significant levels of PCBs and metals in New Bedford Harbor via the water column, at an important stage in the development of the individual.

Population characteristics

Fecundity for this species is estimated at 200,000 to 1,500,000 eggs per female, per year, with an average of 600,000. It has recently been demonstrated that less than 40 newly hatched larvae per 100,000 survive their first year. It appears that the physical characteristics of the spawning grounds are important in determining survival rates (Clayton, 1976).

Reproduction

The Acushnet River estuary and New Bedford Harbor provide a spawning ground for the winter flounder from January to May. During the warmer months the adults will move offshore, but are believed to return to the estuary of their origin for spawning (Clayton, 1976). Such migratory behavior has the potential to expose New Bedford Harbor populations to PCBs and metals on an annual basis. Winter flounders spawn on sand or silt-sand bottoms of estuaries. Although spawning has been recorded in depths to 75 m, this is not common (Clayton, 1976). Direct contact with PCBs and metals in sediments during spawning activities may be a deleterious exposure for these organisms.

Eggs, Larvae, Juveniles

Winter flounder eggs are demersal and adhesive, ranging from 0.75 to 0.85 mm in diameter. Eggs can be found from late April to June in most New England estuaries. Direct exposure to contaminated sediments and water is likely in New Bedford Harbor. Incubation of eggs requires 15 to 18 days at a temperature of 2.7 to 3.3°C, and larvae are about 3 to 3.5 mm long at hatching; metamorphosis is complete when fish are 9 mm long. Larvae are abundant in estuaries from March through June (Clayton, 1976). Juvenile flounders generally remain close to the sand or sand-silt bottoms of the estuary, and will not begin migrating until their third year (Clayton, 1976).

Feeding and Predation

Winter flounders feed primarily by day. The adult flounder is limited to smaller invertebrates such as shrimps, amphipods and clams, due to its gape size. Larvae will feed on copepod nauplii, polychaetes and eggs of invertebrates. After metamorphosis, the fish eat mainly crustaceans and polychaetes. During food shortages, the flounder appears to sacrafice egg production in order to maintain body weight (Clayton, 1976). As a result of the winter flounder's feeding habits, this species may bioaccumulate PCBs and metals in New Bedford Harbor, via ingestion of contaminated sediments and prey. The major predator of the winter flounder appears to be the striped killifish (Fundulus majolis), with the small hydromedusa, Sarsia tubulosa, contributing to larvae mortality, however, juveniles will be taken by most piscivores (Clayton, 1976).

Utilization

The winter flounder represents a valuable marine resource; commercial landings in Massachusetts alone were worth 3 million dollars in 1972. Although most winter flounder are caught offshore, inshore fisheries still represent a significant portion of the catch. In 1975, approximately 9 million pounds were landed in New Bedford Harbor, worth 3 million dollars. In 1980, this increased to approximately 14 million pounds, worth 5 million dollars. Landings dropped slightly in 1985 to 10 million pounds, but were worth approximately 11 million dollars (NMFS, 1986).

Although a fishing ban has been placed on winter flounders which extends through Zones 1 to 3, it is possible that fish exposed to PCBs and metals in the upper harbor regions may migrate beyond the area prohibited to fishing. It is, therefore, possible that fish taken from Buzzards Bay and landed in New Bedford Harbor have been exposed to PCBs and metals. This obviously has implications for public health, since the winter flounder is primarily fished for human consumption.

American Eel (*Anguilla rostrata*)

Range and distribution

The American eel, *Anguilla rostrata*, is found from Labrador to the West Indies and is common in New England coastal streams and rivers (Clayton, 1976). In New Bedford Harbor the American eel has been found in Zones 1, 2, and 3a-3c (Bourque, 1986). As eels attain sexual maturity, they migrate in the fall to open sea to spawn. Juveniles return to coastal waters during the late winter or early spring and some travel upstream to freshwater areas. Eels spend most of their adult lives in the same water body; they are chiefly nocturnal and often lie buried in the estuary sediments during the daytime (Clayton, 1976). This behavior has the potential to subject the eel to significant exposures via dermal contact with contaminated sediments in New Bedford Harbor. The activity of the eel decreases as the water temperature declines and they therefore spend most of the winter burrowed in the estuary bed. PCB tissue residues as high as 730 ppm have been found for this species in Zone 2, confirming the significance of the exposure via sediment contact (Kolek, 1981).

Population characteristics

Differential growth exists between sexes; females attain lengths up to 122 cm and males up to 60 cm. Females have been reported to carry between 5 and 10 million eggs (Clayton, 1976).

Reproduction

Spawning occurs in oceanic waters beyond the continental shelf. Little information is available on the specific locations. It is presumed that adults die after spawning (Clayton, 1976).

Eggs, Larvae, Juveniles

Eggs are presumed to be pelagic, gaining their buoyancy from large amounts of lipid (Clayton, 1976). The high concentration of lipids has the potential to expose the embryo to an increased level of PCBs and metals, since these contaminants are highly lipophilic. Larvae are transparent, slender and possess teeth. They range from 65 to 90 mm in length and are pigmented by the time they reach coastal waters. Some of the juveniles ascend rivers and streams, while others remain in estuarine waters (Clayton, 1976). The migratory behavior of juveniles suggests that they frequent the upper estuarine waters of New Bedford Harbor where the PCB and metal concentrations are highest.

Feeding and Predation

American eels are carnivorous, consuming fish, insects, snails and annelids. Feeding occurs primarily at night with little to no activity during the day. In estuarine waters polychaetes, crustaceans and bivalves are generally the most important foods. Young eels are part of the diet of many larger fishes in both freshwater and marine environments, and thus form and important link in the food chain (Clayton, 1976).

Utilization

Small, local commercial and sport fisheries exist for the American eel in tidal waters. There is little demand for this species; larger eels are of commercial value, while smaller eels are used as bait for striped bass. In 1984, landings at New Bedford Harbor were 4,215 lbs. None were landed in 1985 (NMFS, 1986). Portuguese people find eel flesh very enjoyable and may be at risk from consumption of these contaminated organisms (Bourque, 1986).

American Lobster (Homarus americanus)

Range and distribution

The American lobster, Homarus americanus, occurs from Labrador to North Carolina (URI, 1973). In southern New England it is found from the subtidal zone to the continental shelf and has been identified in Zones 3a through 3c in New Bedford Harbor (GCA, 1986a). Although the lobster is termed non-migratory, daily movements may expose each lobster to contact with varying amounts of PCBs. Lobsters will overwinter in inshore waters, moving into shallow water in fall and deeper waters in spring and early summer. Older lobsters tend to be less migratory, suggesting that these individuals will be exposed for the longest period in New Bedford Harbor. The lobster is a bottom dweller that is found on silty sands, and is nocturnal in shallow water. During the daytime it will rest in mud burrows or other suitable shelters (URI, 1973). Burrowing in New Bedford Harbor may resuspend contaminated sediments, thereby increasing the potential for exposure to PCBs and metals in the water column.

Reproduction

Mating takes place after the female has molted. Sperm is held in a seminal receptacle as long as nine months while the eggs are maturing. When mature, eggs are extruded, fertilized and attached to the swimmerets under the abdomen. They remain there for 10 to 12 months until hatched during the summer, in inshore populations like that in New Bedford Harbor. Planktonic larvae drift near the surface for several weeks before becoming demersal. During this time water currents will determine their movement within New Bedford Harbor. Planktonic larvae thus have the potential to be exposed to PCBs and metals via the water column and sediments (URI, 1973).

Juvenile and young adults grow about 14 percent in length and gain 50 percent in weight with each molt. Molting frequency may well be a function of food supply and temperature. It has also been hypothesized that crowding and lack of shelter may also effect the molting cycle (URI, 1973).

Feeding and Predation

Lobsters are carnivores, obtaining only a small part of their food from scavenging. Prey of the lobster includes any fish, mollusks or crustaceans that can be caught and killed by the chelate legs. Feeding has the potential to expose the lobster to PCBs and metals via two routes. The taking of benthic invertebrates from the substrate disturbs the contaminated sediments, which may be ingested during feeding, and the prey itself may have bioconcentrated PCBs and metals, and thus contribute to the dose received by the lobster. In turn the lobster is preyed upon by the tautog, rainbow smelt, American eel, and striped bass (URI, 1973), all of which are found in New Bedford Harbor.

Utilization

The American lobster is the most valuable product of the commercial fishery in the Northwest Atlantic Ocean, and 14.9 percent of the catch in 1968 was taken from Massachusetts. In the New Bedford area, approximately 50 commercial and 100 recreational lobstermen exist. In 1985, 1.6 million pounds were landed at New Bedford Harbor, worth approximately 5.3 million dollars (NMFS, 1986).

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION I

TO: Addressees

FROM: Frank Ciavattieri
New Bedford Project Manager

SUBJ: Draft Report on Exposed Species Analyses

Enclosed is the draft report on Exposed Species Analyses for New Bedford Harbor. The Exposed Species Analyses is part of the exposure assessment element of the environmental risk assessment. The report includes Alliance Technologies, Inc.'s (formerly GCA) Biological Characterizations for finfish, crustaceans, and mollusks, and E.C. Jordan Co.'s characterizations for macrobenthos and plankton.

The purpose of this report is to identify a number of species of aquatic organisms in New Bedford Harbor which can be used to assess the environmental risk associated with the existing and future PCB and metals contamination. A range of species have been identified, including fish and shellfish which are important commercially and recreationally, species sensitive to PCB and metals contamination, and pollutant-tolerant species.

Having completed the analyses, E.C. Jordan is proceeding with identification of PCB and metals concentrations from the New Bedford Harbor data base which the species will be exposed to at various life cycle stages, and analyzing the effects of these exposures to assess risk.

Please review this report and get any comments or questions you may have to either Alan Fowler or myself by August 17, 1987

Addressees: Doug Thompson - EPA
Ed Reiner - EPA
Sally Edwards - EPA
Dave Hansen - EPA Narragansett
Don Phelps - EPA Narragansett
Leroy Folmar - EPA Narragansett
Sharon Christopherson - NOAA
Helen Waldorf - DEQE
Brett Burdick - DEQE
Judy Pederson - MA CZM
Sue Mello - NMFS
Ken Carr - USF&WS
Mark Otis - COE
Russ Belmer - COE

Amphipoda (Ampelisca vadorum)

Range and Distribution

Most species of amphipods live in the ocean between the tide zones and the abyssal depths, and can be either bottom-dwelling or pelagic. Within the tidal zone, densities of amphipods can be very large (Kaestner, 1980). Ampeliscidae exist on both sides of the Atlantic. Many marine species can tolerate brackish water while some are euryhaline (Kaestner, 1980).

Given that many species of amphipods are salinity tolerant and live at intermediate ocean depths ranging from intertidal to more than 600 meters (Kaestner, 1980), the estuary habitat at New Bedford Harbor (Figures 2 and 4) should be conducive to Ampelisca. Results from Army Corps of Engineers sampling identified no Ampelisca vadorum in Zone 1 (the estuary) and Zone 2 (the Hot Spot) (Figure 1), where PCBs and metals (Cd, Cr, Cu, Pb) were in excess of 5,000 ppm (see Figures 6 and 7). A. vadorum was seen in 3 of 9 (Stations 8, 11, and 13, see Figure 8) samples collected between the Coggeshall Street Bridge and the hurricane barrier, and beyond the hurricane barrier in Zone 3c and 3d in 8 of 13 samples, at slightly greater abundances than were seen in Zone 3a and 3b above the hurricane barrier (USACE, 1986).

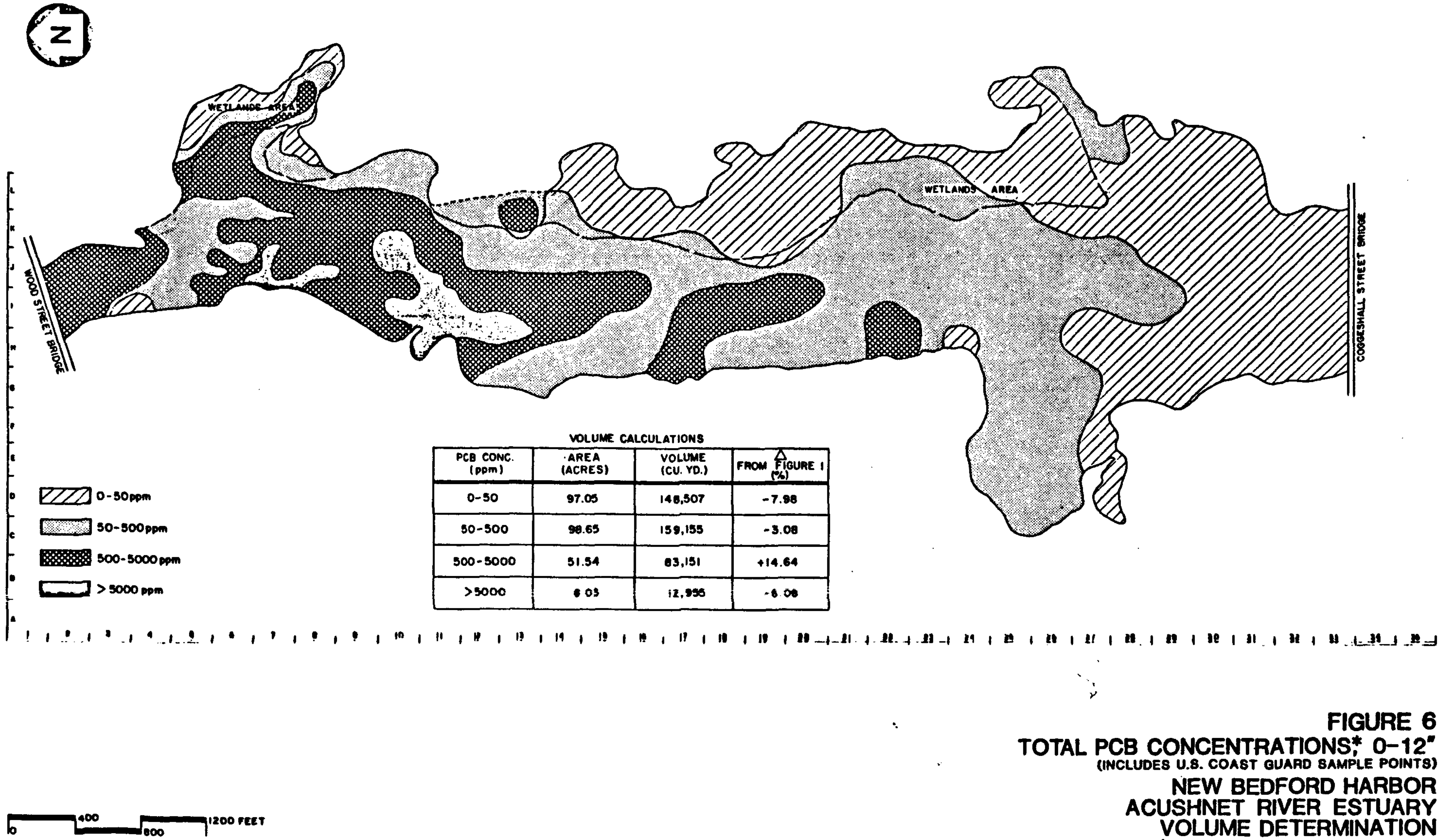
Population Characteristics

Ampelisca is a benthic amphipod which burrows in sediments. After digging itself in, it builds a thin-walled pocket in sand or mud using secretions from its integumental glands. Burrowing is done head first (Kaestner, 1980). Direct contact with contaminated sediments during burrow building may have contributed to the absence of Ampelisca from Zones 1 and 2. Hansen (1986) found sediments from this area to be toxic to the phylogenetically-similar Ampelisca abdita. Preliminary results of a 10-day exposure to sediments from Zones 1 and 2 yielded mortality rates of 92-100 percent (Hanson, 1986).

Thorapods bear the gills of these animals. Respiratory currents are generated through movement of the peropods (Kaestner, 1980). This movement of water across the gills and epethelial tissue will probably enhance exposure to PCBs and metals via direct contact with the water mass.

Reproduction

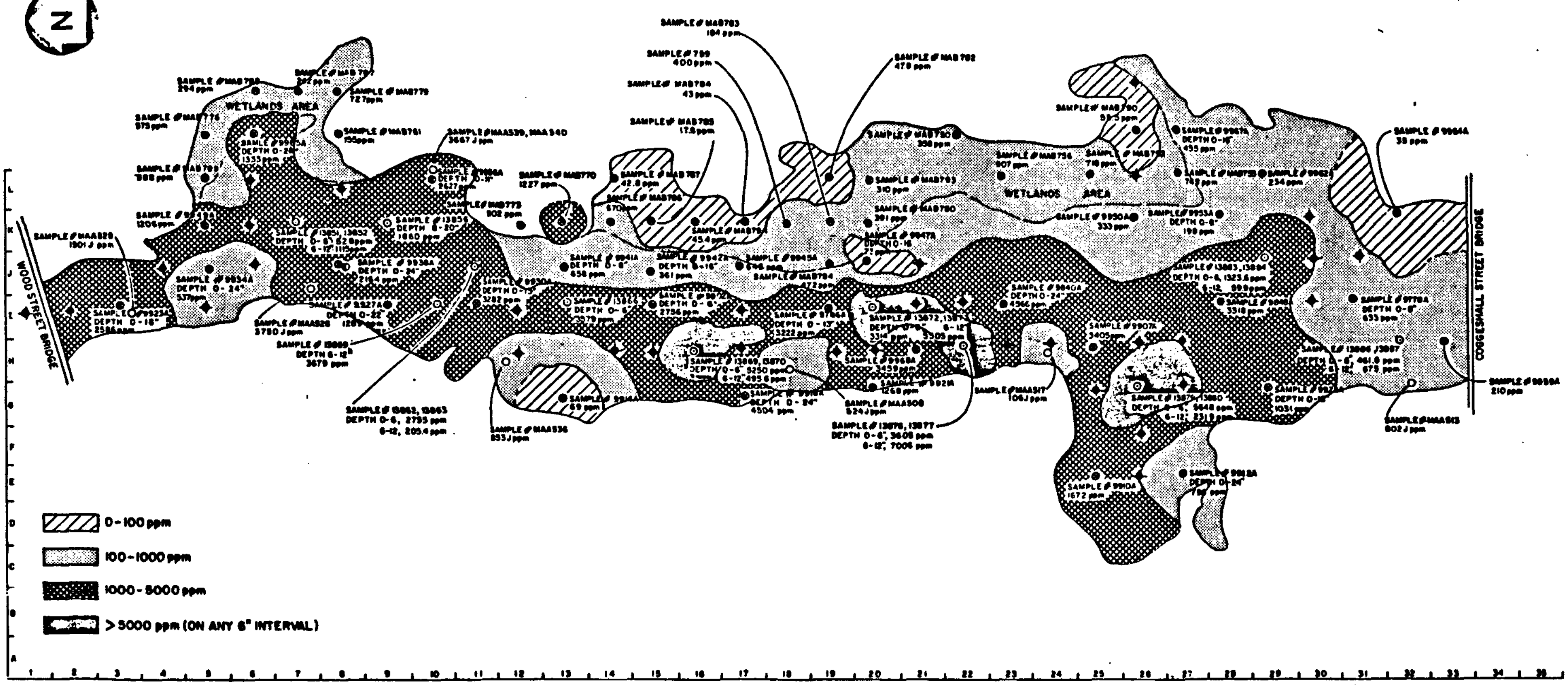
During mating, the male usually rides on the back of the female for several days before the parturial molt. After the female molts, the male turns up the female venter, and bending his abdomen pushes the three anterior folded plepods between the



VOLUME CALCULATIONS

PCB CONC. (ppm)	AREA (ACRES)	VOLUME (CU. YD.)	Δ FROM FIGURE 1 (%)
0-50	97.05	148,507	-7.98
50-500	98.65	159,155	-3.08
500-5000	51.54	83,151	+14.64
>5000	6.03	12,956	-6.06

FIGURE 6
TOTAL PCB CONCENTRATIONS;* 0–12"
(INCLUDES U.S. COAST GUARD SAMPLE POINTS)
NEW BEDFORD HARBOR
ACUSHNET RIVER ESTUARY
VOLUME DETERMINATION
**SUM OF AVAILABLE AROCHLOR DATA*



LEGEND

- ○ BATTELLE HOT SPOT SAMPLING - GROUP 1
- ⊘ USACE SAMPLES - GROUP 2
- ⊙ USACE SAMPLES - GROUP 3
- ◐ BATTELLE SAMPLES - GROUP 3 (ESTIMATED LOCATION)
- ✦ PROPOSED SAMPLE LOCATIONS

0 400 800 1200 FEET

PROPOSED SAMPLE LOCATIONS

E-26
F-26
G-25, G-27
H-12, H-14, H-15, H-17, H-19, H-20, H-23, H-24, H-26
H-27
I-1, I-2, I-5, I-12, I-17, I-21, I-23, I-30
J-4, J-6, J-21, J-30, J-31
K-6, K-30
L-6, L-9, L-26
N-26

FIGURE 7
TOTAL METALS CONCENTRATIONS, 0-12" (Cd,Cu,Cr,Pb)

NEW BEDFORD HARBOR ACUSHNET RIVER ESTUARY VOLUME DETERMINATION*

*TAKEN FROM USACE SPEC. NO. DACW 33

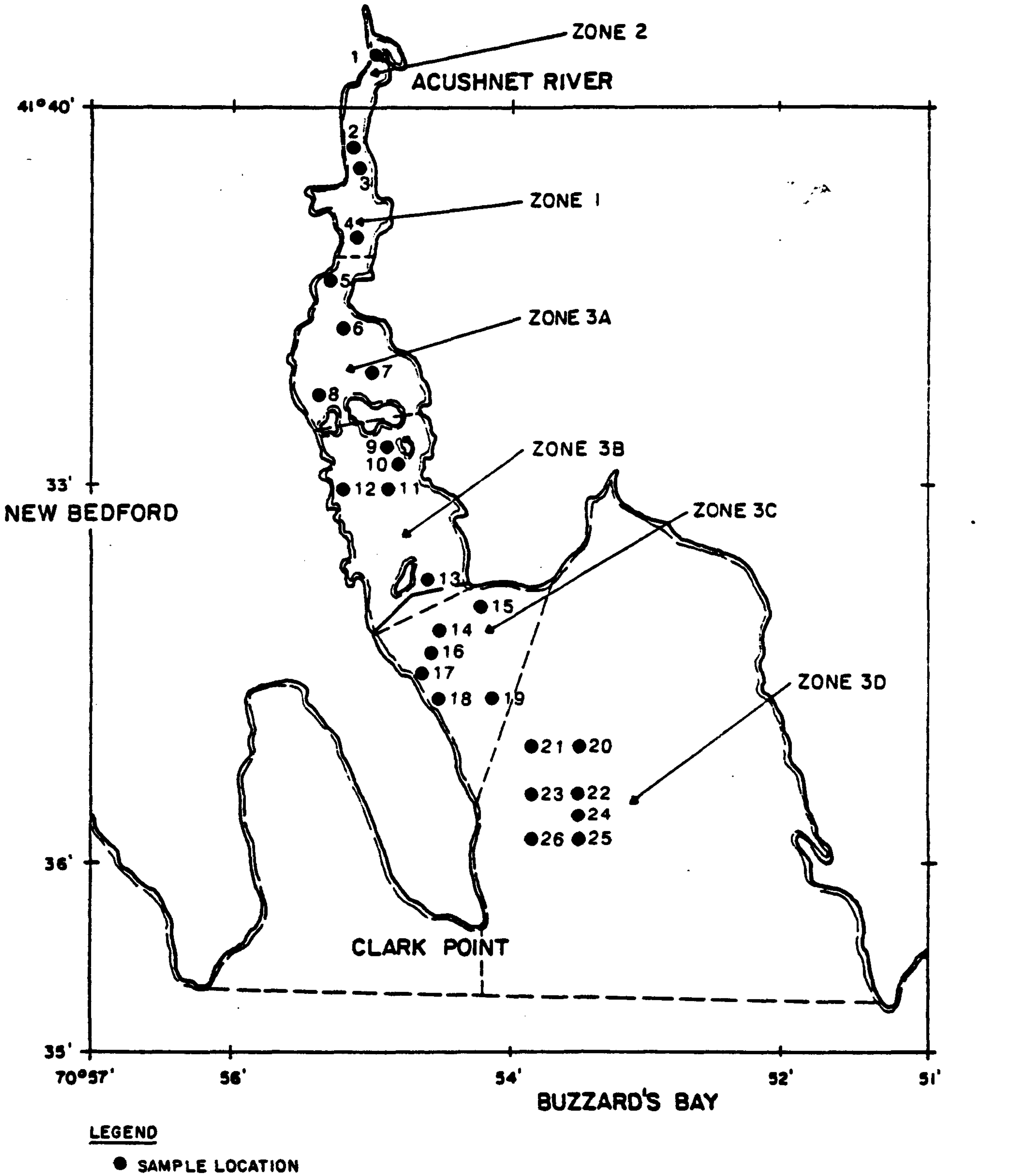


FIGURE 8
BENTHIC SURVEY SAMPLE LOCATIONS IN ZONES 1-3D
NEW BEDFORD HARBOR

4959-22

posterior oostigites of the female marsupium. Fertilization takes place place in the marsupium. There is no nutrient fluid (Kaestner, 1980).

As with many crustaceans, during reproduction these organisms are vulnerable to predation due to the molting process. More importantly, the shedding of the chitinous outer shell can enhance the effects of exposure to PCBs and metals via direct contact with contaminated sediments and the water mass at New Bedford Harbor (Thursburg, 1986).

Eggs, Larvae, Juvenile

The number and size of eggs increase with the age of the female. In some species, the young leave the marsupium a few days after hatching; in others, the eggs can develop outside the marsupium. Upon hatching, the young resemble adults (Kaestner, 1980).

Temporary residence in the marsupium of the female may offer limited exposure to PCB and metal contaminated sediments and waters, but as with all crustaceans, the growth process (molting) as well as the benthic lifesytle of Ampelisca may later serve to enhance exposure to contaminants at New Bedford Harbor.

Feeding and Predation

Ampelisca sp. are filter feeders. The second maxilla serves as the filter, and produces a current toward the mouth. The animal stirs up material from the bottom with the second antennae and sucks it up with the second maxillae (Kaestner, 1980). Resuspension and ingestion of contaminated sediments during the feeding process of Ampelisca are a primary source of contaminant exposure at New Bedford Harbor for this species.

Ampelisca protects itself from predation by burrowing in bottom sediments. Many species of amphipods are protectively colored (Kaestner, 1980). A number of species found in New Bedford Harbor prey upon amphipods. These include: Anguilla rostrata (American eel), Fundulus heteroclitus (mummichog), Stenotomus chrysops (scup), Tautoga onitis (Tautog) and Psuedopleuronectes americanus (winter flounder). Bioaccumulation of PCBs and metals may be directly attributable to the consumption of Ampelisca by fisheries inhabited in New Bedford Harbor.

Utilization

Ampelisca serves no direct human use resource at New Bedford Harbor, although it is used frequently in laboratory bioassays. Indirectly, Ampelisca does serve as a food resource for many fisheries at New Bedford Harbor and the consequences of its absence from some areas is difficult to assess.

2.2.3 Food Web Exposure

Within the marine environment a major role of many organisms is as a food source (forage) for other fish and invertebrates. These prey organisms (fish and invertebrates) inhabit the estuaries providing an important feeding ground for many other species. The following fish and invertebrates from New Bedford Harbor are important food web organisms: Atlantic silverside (Menidia menidia), mummichog (Fundulus heteroclitus), blue crab (Callinectes sapidus), green crab (Carcinus maenas), soft-shell clam (Mya arenaria), quahog (Mercenaria mercenaria), grass shrimp (Palaemonetes vulgaris), clam worm (Nereis succinea), mud worm (Steblospio benedicti), and the thread worm (Capitella capitata). These organisms contribute to the uptake of PCBs and metals within the food web, and may even be responsible for increasing concentrations of PCBs and metals in organisms related to their trophic status. The individual life cycle characteristics of these organisms is indicative of their PCB exposure, and how they become transmitters via their consumption by other organisms. Below is a description of five selected fish and invertebrates, and how their life history characteristics reflect PCB and metal exposure in New Bedford Harbor. The remaining profiles are in Appendix A.

Atlantic Silverside (Menidia menidia)

Range and distribution

The Atlantic silverside, Menidia menidia, occurs in estuaries from the southern Gulf of St. Lawrence to southern New Jersey (Clayton, 1976). The Atlantic silverside has been found in seven Massachusetts estuaries at 0 to 28.5°C and salinities of 0 to 33.5 parts per thousand (Figures 2 and 3). In New Bedford Harbor the silverside is found in Zones 1, 2, and 3a-3c (Bourque, 1986). The silverside is a common inshore species, that rarely leaves the estuary, it is normally in residence throughout the year although it may move into deeper water during the winter. In the summer it is commonly found in cordgrass, Spartina alterniflora (Clayton, 1976). In Zone 2 (Hot Spot), Menidia is being exposed to the highest concentrations of water and sediment-bound contaminants (see Figures 5, 6, and 7).

Population characteristics

The Atlantic silverside matures at age 1 and is short-lived. The average life-span is only 1 year, by which time it may reach a length of 90 mm. A few fish reach age 2. Specimens collected from the Annisquam River - Gloucester Harbor area in 1966 to 1967 were 15 to 140 mm long. Most adults were 85 to 95 mm long and most juveniles 30 to 40 mm (Clayton, 1976).

Reproduction

The silverside spawns from May to early July in southern New England and later in the Gulf of Maine. They spawn in large schools, depositing eggs on sand among Spartina at high tide (Clayton, 1976). Spawning grounds in New Bedford Harbor would be expected in the upper harbor area close to the freshwater/saltwater interface, where PCB and metal concentrations are highest.

Eggs, Larvae, Juveniles

Eggs are 1.1 to 1.2 mm in diameter and have sticky filaments that attach to the bottom or to vegetation. Hatching occurs in 9 days; the newly hatched larvae measures 5 mm. Growth is rapid, but fry less than 25 mm long are present throughout the summer because of the length of the spawning season. This species, although highly tolerant of low temperatures, appears to require a water temperature of 20°C (Figure 3) to begin spawning (Clayton, 1976).

Feeding and Predation

Adults feed on copepods, shrimp and annelids. They are fed upon by striped bass and other larger estuarine fish-eating species, but are somewhat protected by their choice of a shallow water habitat (Clayton, 1976). The feeding habits of this species and its preference of inshore waters leads to a potentially significant exposure to PCBs and metals in New Bedford Harbor.

Utilization

Silversides are an important estuarine forage resource, but are only rarely used as bait because they are small and soft (Clayton, 1976). The ability of this fish to survive and reproduce in New Bedford Harbor's most highly contaminated areas, may account for high tissue burdens in secondary and tertiary consumers because of biomagnification of PCBs and metals up the food chain.

Quahog (<u>Mercenaria mercenaria</u>)

<u>Range and distribution</u>

The range of the northern hardshell clam <u>Mercenaria mercenaria</u>, extends from the Gulf of St. Lawrence to the Gulf of Mexico and is found mainly in shallow bays, coves and estuaries (URI, 1973). In New Bedford Harbor the quahog has been observed in Zones 1, 2, and 3a-3d (GCA, 1986a). The quahog burrows into the substrate which usually consists of sand or sand-clay. This species is sedentary, remaining in localized areas (URI, 1973). Individuals in the upper harbor area at New Bedford are therefore subject to significant exposures of PCBs and metals (Figures 6 and 7) for long periods of time.

<u>Reproduction and life stages</u>

At approximately 1-year of age and 1 cm in length, almost all members of a quahog population possess mature male gonads. By the end of the second year, approximately half of the population undergo sex reversal, and these clams become sexually mature females. Spawning occurs along their range from late spring to mid-August as water temperatures increase above 20°C. Larvae reared in salinities of 27 parts per thousand and temperatures of 25 to 30°C, in the laboratory set by the end of 7 days, but under natural conditions it is likely that a longer period of time is required (Figures 2 and 3) (URI, 1973). After setting, quahogs burrow into the soft bottom substrate (URI, 1973). This is a major exposure route for this species in New Bedford Harbor and may contribute to resuspension of contaminated sediments. Maximum growth occurs during the summer months and quahogs may attain lengths of 3 1/2 cm after 2 or 3 years (URI, 1973).

<u>Feeding and Predation</u>

Like most clams, the quahog is a filter feeder removing suspended plankton and other food particles from the water (URI, 1973). The quahog may, therefore, bioconcentrate contaminants. Depending on the level of PCBs and metals in the water column, and the degree of sediment suspension; bioconcentration is a potentially significant factor for the quahogs in New Bedford Harbor. Juvenile quahog are the prey of snails, crabs and lobsters, while their shells are still thin. As shells thicken, they provide greater protection and man becomes the major predator (URI, 1973).

<u>Utilization</u>

Approximately 13 million pounds of quahog meat was taken in 1970 between Rhode Island and Virginia. Massachusetts waters yield about 7.0 percent of the total U.S. quahog catch annually (URI, 1973). Although the New Bedford Harbor waters are closed to the taking of shellfish, the illegal poaching of <u>Mercenaria</u> may be a source of contaminated seafood at New Bedford Harbor.

Polychaeta Clam Worm (Nereis succinea)
Mud Worm (Steblospio benedicti)
Thread Worm (Capitella capitata)

Range and Distribution

Generally, Nereis sp. are seen in a variety of locations, including boreal sand flats, sheltered beaches, subtidal sediments, and intertidal flats (Berrill and Berrill, 1981). Nereis succinea occurs in all zones of New Bedford Harbor. In Zone 1 (the estuary), N. succinea was seen in 3 of 3 samples. This worm was also seen in the single sample taken at the Hot Spot or Zone 2 (Station 1). In Zone 3a and 3b, N. succinea was seen in 9 of 9 samples above the hurricane barrier, and beyond the hurricane barrier, it was seen in 9 of 13 samples. Similar abundances were seen throughout the harbor (USACE, 1986).

S. benedicti is a common estuarine species (Berrill and Berrill, 1981). Steblospio benedicti also occurs in all three zones at New Bedford Harbor. In Zone 1, it is seen in 3 of 3 samples, and it is also seen in the Zone 2 (Station 1) sample. S. benedicti was seen in 9 of 9 samples in Zone 3a and 3b above the hurricane barrier. Beyond the hurricane barrier, this polychaete was seen in 6 of 13 samples. Abundances were lower beyond the hurricane barrier than in other harbor zones (USACE, 1986).

C. capitata, like the two previously mentioned species, is often found in estuaries and boreal mud flats (Berrill and Berrill, 1981). Capitella capitata was also seen in all three zones of the harbor with similar abundances of this species found in each zone. This polycheate was seen in 2 of 3 samples from Zone 1, and was seen in the Hot Spot sample (Station 1). It was found in 7 of 9 Zone 3a and 3b samples taken above the hurricane barrier and in 7 of 13 Zone 3c and 3d samples taken beyond the hurricane barrier (USACE, 1986).

The presence of these three species in areas where contamination of PCBs and metals is in excess of 5,000 ppm in the sediments (Figures 6 and 7), may substantiate studies previously completed in New Bedford Harbor calling Capitella, Streblospio, and Nereis sp. "opportunistic species" (pollution tolerant organisms) (CDM, 1983).

Population Characteristics

Polychaetes or marine bristle worms are among the most common animals of the seashore. They are characterized by many bristles on their parapods, and can be burrowing, tube-dwelling or free-swimming (Buchsbaum, 1978).

Nereis sp. spend most of their time burrowing, but can swim while feeding or mating. They can readily leave one burrow to create a new one. Gentle, undulatory movements of the body create a current in the burrow renewing the body for respiration, and bringing chemical stimuli from nearby food organisms. Respiration occurs through extensive networks of capillaries located in the parapods (Buchsbaum, 1978). Capitella capitata are very slender, and hence called "thread worms".

Although these organisms spend much of their time in the sediment, their abundance in the highly contaminated areas of the estuary would imply they are tolerant to PCB and heavy metal contamination at New Bedford Harbor. Moreover, bioconcentration factors for polychaete worms (Arenicola marina and Nereis diversicolor) range from 236 - 800, indicating uptake and retention of Arclors does not occur as readily as with other benthic inverebrates (Palaemonetes 27,000 and Callinectes greater than 230,000) (USEPA, 1980).

Reproduction

In Nereis, external fertilization occurs to adults when the male and female find each other and burst. Since death occurs to adults so soon after fertilization, potential exposure to contaminants via the surface waters is temporary. However, fertilized eggs immediately come into contact with contaminated surface waters. The implication of this exposure is not known, since all three species appear to be abundant throughout the estuary and harbor at this time.

Eggs, Larvae, Juveniles

Fertilized eggs of Nereis sp. develop into a ciliated larvae or trochophore. By the time these eggs hatch, the young have developed beyond the trochopore stage to a juvenile form with three segments and bristles. Only a few primitive forms have "typical trochophore" larvae. The young worm settles to the bottom and takes up a burrowing lifestyle. These worms grown throughout life by adding new segments in a region just in front of the last segment (Buchsbaum, 1978).

Throughout the developmental period of Nereis, from fertilized egg to trochopore, exposure to surface waters is enhanced by this pelagic growth period. Once developed into a young worm, exposure is probably accelerated since sediments at New Bedford Harbor are contaminated with PCBs and heavy metals (Figures 6 and 7).

Feeding and Predation

Nereis sp. have well differentiated heads with prominent sense organs, and an eversible pharynx bearing horny jaws or teeth. These voracious predators prey on other burrowing animals including others of their own species. Nereis forages in the sediments or swims over the surface in search of food (Berrill and Berrill, 1981). When prey is detected, the worm everts its pharynx or proboscis, on the end of which its jaws are located. Nereis seizes its prey, and retracts its proboscis thus drawing the prey into its mouth (Berrill and Berrill, 1981). Occassionally, some Nereis sp. can suspension-feed (Newell, 1979). Nereis sp. are preyed upon by crustaceans, fish, and birds, and are used as bait in fishing (Milne and Milne, 1981).

Streblospio benedicti is known to ingest diatoms, detritus, and mud (Daiber, 1982).

Capitella capitata feeds in much the same manner as earthworms. It eats mud and eliminates all but the digestible organic matter (Berrill and Berrill, 1981). It is also known to ingest diatoms, detritus, and sediments (Diaber, 1982).

All three species of worms must digest and egest large quantities of sediment during the feeding process. This coupled with the fact that they consume other benthic organisms or detrital material can only act to enhance exposure at New Bedford Harbor.

Animals found in New Bedford Harbor which prey on polychaetes include: Anguilla rostrata (American eel), Menidia menidia (Atlantic silverside), Stenotomus chrysops (scup), and Psuedooplueronectes americanus (winter flounder).

Utilization

The polychaetes described above have two important ecosystem functions at New Bedford Harbor. First, they serve as a food resource for economically important species like the winter flounder and the scup. Equally important, it serves as a food resource for the Atlantic silverside, a very important forage species for many of the large predatory fishes at New Bedford Harbor.

Polychaete worms are well known to fisherman and clam-diggers of the New Bedford Harbor area, who call these animals "clam worms" because they commonly occur where clams live. These worms are important to recreational fisherman in the area who use them as bait to catch species like the winter flounder and the bluefish.

3.0 SUMMARY OF EXPOSED SPECIES ANALYSIS

These species profiles provide information relating to a particular species exposure to contaminants in the water or sediment throughout its life stages. As described earlier, exposure via the ingestion of forage species must also be evaluated as this may present a significant route of contaminant exposure. These food chain interactions often result in the bioaccumulation and biomagnification of contaminants throughout the ecosystem. Figure 9 depicts a hypothetical food chain for some of the species identified within New Bedford Harbor. This food chain illustrates how PCBs and metals may biomagnify up trophic levels. The implications of this route of exposure can be illustrated by the lifestyle/exposure relationship involving predatory fish that feed in the estuary. For example, the bluefish may be exposed to low concentrations of contaminants from the water column, but because of biomagnification, this organism may incur potentially toxic levels of contaminants from the consumption of contaminated prey.

These species profiles identify the primary, secondary, and tertiary routes of contaminant exposure for the species in New Bedford Harbor. In addition, these profiles discuss the important exposure routes for the different trophic levels and described the potential for biomagnification of contaminants through food chain interactions. This exposure information, along with the range and distribution information and life cycle characteristics of these species, will be used to evaluate the potential toxicity of the contaminants detected throughout the New Bedford Harbor area.

FIGURE 9
HYPOTHETICAL FOOD CHAIN INTERACTIONS AT NEW BEDFORD HARBOR

Water Column (PRODUCERS)	Water Column (PRIMARY CONSUMERS)	Water Column (SECONDARY CONSUMER)	Water Column (TERTIARY CONSUMER)
	(pelagic)		
Rhizosolenia alata (diatom)	*Acartia tonsa* (copepod)	*Alosa aestivalis* (blueback herring)	
and	or		
Water Column	Sediment/Food Chain	Sediment	*Morone saxatilis* (striped bass)
	(benthic)		
Skeletonema costatum (diatom)	*Mytilus edulis* (blue mussel) and *Nereis succinea* (clam worm)	*Pseudopleuronectes americanus* (winter flounder)	

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APPENDIX A
SPECIES PROFILES

Alewife (Alosa pseudoharengus)

Range and distribution

The alewife, Alosa pseudoharengus, is an anadromous fish of eastern North America found from Nova Scotia to South Carolina (Clayton, 1976). Historically, New Bedford Harbor (Zones 1, 2, and 3a-3d) has been inhabited by this fish (Bourque, 1986). However, anadromous alewife populations have declined sharply. Since colonial times the destruction of spawning areas, the installation of dams, and increased levels of stream pollutants have often been blamed for this decline (Clayton, 1976). Today, alewife runs still occur in a number of places in Massachusetts where coastal stream conditions are suitable, and a small local population is thought to exist in New Bedford Harbor (Bourque, 1986). Direct contact to the gills and epethelial tissue to water-bound PCBs and heavy metals (Figure 5) will be a source of exposure for this organism because of its migratory life-style.

Population characteristics

In the northern part of their range, alewives may return to natal streams as many as three to five times to spawn, whereas in the southern range they spawn only once. Recruitment as adults may occur as early as age 2 in the south and as late as age 5 in the north. Alewives spawning in the Parker River-Plumb Island Sound Estuary in Massachusetts mature at ages 3, 4, and 5 with full recruitment at age 6 (Clayton, 1976). The Parker River Estuary has similar physical and biological characteristics to the Acushnet River Estuary (see Table 2-3). Therefore, predictions on the fisheries of the Acushnet River Estuary can be inferred on the basis of these similarities. Males dominate first-time spawning at age 3 but decline in overall percentage at 4 and 5. There appears to be a higher mortality rate among those that spawned at an early age resulting in older age groups being dominated by alewives that matured at age 4 or 5 (Clayton, 1976). Because these fish may return as many as three to five times to spawn, will account for repeated exposure to water-bound metals and PCBs at New Bedford Harbor.

Reproduction

Spawning migrations begin during early March in the Southern part of the range and late April to early May in New Bedford Harbor (Bourque, 1986). Adult fish migrate from the ocean to the Acushnet River estuary and finally to freshwater to spawn. Water temperature is the dominant environmental factor influencing the rate of alewife migration. When water temperatures are below 118°C, migration does not occur into freshwater (see Table 2). Above this threshold, alewives

TABLE A-1
PHYSICAL CHARACTERISTICS OF NEW BEDFORD HARBOR
AND BUZZARDS BAY, ZONES 1 THROUGH 3

Location	Date	Salinity (0/00)	Temperature (°C)	Sample Depth (m)	Water Depth (m)
Zone 1[a]	11/25/75	23.20	19.5	Surface	2-6
Lat. 41° 39.35'		28.30	12.6	6	2-6
Long. 70° 55.10'		22.00	--	Surface	2-6
		29.10	5.5	4.5	2.6
	03/16/76	25.50	2.5	Surface	2-6
		29.00	5.0	2.9	2-6
Zone 2[a]	09/19/75	32.50	18.5	Surface	7-9
Lat. 41° 38.29'	11/24/75	29.00	10.0	Surface	7-9
Long. 70° 55.09'	01/06/76	23.20	0.5	Surface	7-9
	03/10/76	27.80	2.5	Surface	7-9
		28.75	2.5	5	7-9
	04/27/76	30.60	10.6	Surface	7-9
		30.60	10.0	5	7-9
		29.90	9.9	8.5	7-9
Zone 3[a]	09/19/75	31.50	18.5	Surface	7-9
Lat. 41° 37.65'	11/24/75	28.00	9.7	Surface	7-9
Long. 70° 54.50'	01/05/76	30.05	1.0	Surface	7-9
	03/10/76	26.00	2.7	Surface	7-9
		28.00	2.5	5	7-9
	04/27/76	28.60	10.5	Surface	7-9
		29.90	10.5	5	7-9
		30.10	9.6	8.5	7-9
Zone 4[a]	03/10/76	27.75	2.5	Surface	8-9
Lat. 41° 37.30'		28.40	2.5	5	8-9
Long 70° 54.28'	04/27/76	28.60	10.1	Surface	8-9
		30.10	10.0	5	8-9
		30.50	9.5	9	8-9
	07/06/76	30.90	22.75	9	8-9

(Continued)

TABLE A-1
PHYSICAL CHARACTERISTICS OF NEW BEDFORD HARBOR
AND BUZZARDS BAY, ZONES 1 THROUGH 3
(Continued)

Location	Date	Salinity (0/00)	Temperature (°C)	Sample Depth (m)	Water Depth (m)
Zone 5[b]	07/29/82	30.89	22.4	1	9-11
Lat. 41° 36.8'		30.96	22.0	2	9-11
Long. 70° 53.8'		30.98	22.0	3	9-11
		31.03	21.7	4	9-11
	10/28/82	31.48	12.3	1	9-11
		31.35	12.3	2	9-11
		31.33	12.3	3	9-11
		31.49	12.0	4	9-11
		31.60	11.8	5	9-11
	01/13/83	31.37	4.4	1	9-11
		31.35	4.4	2	9-11
		31.35	4.4	3	9-11
		31.37	4.5	4	9-11
		31.36	4.7	5	9-11
	05/05/83	29.60	12.2	1	9-11
		29.59	12.2	2	9-11
		29.67	12.2	3	9-11
		30.05	11.9	4	9-11
		30.50	11.4	5	9-11

[a] Data file: New Bedford Harbor, Massachusetts. Jeffrey P. Ellis, et al. December 1977, WHOI-77-73.

[b] Hydrographic Study of Buzzards Bay, 1982-1983. Leslie K. Rosenfeld, et al. WHOI-84-5.

TABLE A-2
PHYSICAL CHARACTERISTICS OF PARKER RIVER - PLUM ISLAND SOUND ESTUARY

Date	Time	Tidal Stage	Temperature (°F) Water	Air	Salinity (parts per thousand)	pH	Dissolved Oxygen (ppm)	Carbon Dioxide (ppm)	Detergent (ppm)	Transparency (feet)
January 26	10:15 a.m.	High +4 (hrs)	30	34	31.5	8.0	10.0	10.0	0.2	—
February 9	2:00 p.m.	Low +3-1/2	30	35	28.0	8.0	10.0+	10.0	0.2	—
March 25	10:50 a.m.	Low	40	58	24.0	8.0	10.0	10.0	0.1	15+
April 28	1:45 p.m.	High +5	52	58	25.0	8.0	10.0+	5.0	0.1	15+
May 21	2:00 p.m.	Low +4	66	64	24.0	8.0	10.0	10.0	0.1	15+
June 14	12:30 p.m.	High +1	62	52	29.0	8.0	10.0+	10.0	0.1	10
July 17	1:15 p.m.	High __	69	__	31.0	8.0	10.0+	5.0	0.1	15+
August 25	9:00 a.m.	High	66	78	30.0	8.0	10.0+	10.0	0.1	—
September 24	7:35 a.m.	Low +4	70	74	28.0	7.5	10.0	5.0	0.1	—
October 15	12:40 p.m.	Low +3-1/2	56	63	30.0	8.0	10.0+	5.0	0.1	10
November 16	3:00 p.m.	Low +4	46	50	31.0	8.0	10.0+	5.0	0.2	15+
December 16	3:25 p.m.	Low +4	38	40	29.0	8.0	10.0+	5.0	0.2	—

Source: Division of Marine Fisheries, Massachusetts. William C. Jerome, Jr., Arthur P. Chesmore, and Charles O. Anderson, Jr. A study of the Marine Resources of the Parker River - Plum Island Sound Estuary. March 1968.

respond to warming or cooling trends by a corresponding increase or decrease in movement. Daily movement of adults in the freshwater portion of the migration may be characterized by unimodal or bimodal peaks. Movement may occur during day or night. In the Parker River most fish move in the late afternoon; no nighttime activity has been observed. In other studies in Massachusetts and Rhode Island nighttime migration has been documented. Spawning occurs in freshwater ponds at all times of the day, with no discernable periods of increased or decreased intensity. By late June most adults have migrated downstream and returned to sea. In the Parker River, emigration occurs at all hours from sunrise to sunset, but no movement has been observed at night (Clayton, 1976). With bioconcentration factors as high as 270,000 (total PCBs), spawning migrations may account for the uptake and retention of potentially harmful contaminants (U.S. EPA, 1980).

Eggs, Larvae, Juveniles

Eggs of the alewife are broadcast randomly at the spawning site. They are demersal and are somewhat adhesive to vegetation and the substrate, and may be exposed to high concentrations of PCBs and metals in sediments (Figures 6 and 7). The diameter of the egg increases from 0.9 mm (unfertilized) to 0.94 - 1.25 mm after fertilization and water hardening. Hatching time depends on temperature; it occurs in 6 days at 15.6°C and in 3 days at 22.2°C. Optimum hatching (38 percent) occurs at an incubation temperature of 17.8°C (Figures 2 through 4). The larvae are 3.5 to 5.0 mm long at hatching, and are transparent. They remain near the spawning grounds until the late larval stage and then move into deeper water (Clayton, 1976). Young anadromous alewives spend most of their first summer in freshwater ponds where they feed on zooplankton and dipteran larvae (Clayton, 1976). Seaward migration of juveniles into the Acushnet River estuary may begin as early as July and is completed during the fall. The size of migrating juveniles is usually from 55 to 75 mm (fork length), with a mode of 65 mm. Overwintering of juveniles in the ponds has not been observed. Little is known about juveniles after they leave freshwater. They may, however, spend the remaining portion of their first year in the Acushnet River estuary, thus being subjected to PCB and heavy metal exposure, and then migrate to sea after their first year (Clayton, 1976). This seaward migration may account for bioconcentration and biomagnitication of PCBs and heavy metals in New Bedford Harbor.

Feeding and Predation

Alewives in New Bedford Harbor feed on zooplankton as larvae, juveniles, and adults. A high degree of food selectivity has been observed. Copepods, cladocerans, and insect larvae are important items in the diet of all freshwater stages of alewives. Alewives are important forage species. In freshwater, young alewives are preyed upon by largemouth bass, yellow perch, white perch, walleyes, and other piscivores. In the estuaries fish such as bluefish and striped bass are important predators (Clayton, 1976). The tolerance of low salinities and the feeding habits of the alewife result in the potential for high exposure to PCBs and heavy metals in the upper estuary of New Bedford Harbor (Figure 5).

Utilization

New Bedford Harbor has not been a significant port for landings of alewife. In 1984, only 125 lbs were landed (NMFS, 1986). However, alewives are an important forage food of many species of fish, and serve as a source of biomagnification of PCBs and heavy metals for top carnivores at New Bedford Harbor (NOAA, 1985). Local fisherman catch alewife for use as bait to catch more lucritive fisheries like bluefish and striped bass (Bourque, 1986).

Atlantic Menhaden (Brevoortia tyrannus)

Range and distribution

The Atlantic menhaden, Brevoortia tyrannus, is found from Nova Scotia to Palm Beach, Florida (Clayton, 1976). Menhaden are euryhaline, and can occur in estuarine waters at all life stages. In Massachusetts, menhaden have been recorded at a maximum water temperature of 25.7°C and a salinity as low as 29.7 parts per thousand (Figures 2 and 3). In New Bedford Harbor, they are found in Zones 1, 2, and 3a-3d (Bourque, 1986). Tagging studies of the eastern coast indicate that adults migrate northward during the spring and early summer and southward in the fall (Clayton, 1976). It is therefore possible that individuals exposed to water-bound PCBs and heavy metals in New Bedford Harbor may be caught in areas outside the immediate vicinity of the Harbor.

Population characteristics

Some menhaden are sexually mature by their first year, but most by age 2 or 3. Fecundity estimates range from 38,000 to 630,000 for females 203 to 345 mm in fork length. It has been suggested that ova mature continually and are released periodically. The sex ratio at each age remains nearly equal on both an annual and geographical basis. The adult menhaden are mostly 305 to 381 mm long and weigh 300 to 500 g (Clayton, 1976).

Reproduction

Menhaden are believed to spawn in coastal oceanic waters and the larvae enter estuaries and bays where they metamorphose. However, there is evidence that spawning occurs in large bays, like Buzzards Bay. Eggs can be found from mid to late April through June. Estimated larval mortality is 8 to 15 percent daily or 71 to 91 percent mortality over the first 15 days (Clayton, 1976). New Bedford Harbor is a potential spawning ground for this species, resulting in PCB and heavy metal exposure for eggs, larvae and adults, which have been observed in Zones 3b and 3c (Govoni, 1973).

Eggs, Larvae, Juveniles

The eggs of menhaden are pelagic and about 1.5 to 2.0 mm in diameter. Incubation is rapid and larvae are about 4.5 mm long at hatching. The larvae mature into juveniles in the estuaries having made the in shore migration in late winter and early spring. Juveniles will remain in the estuaries for 6 to 8 months before they return to the sea in September and October (Clayton, 1976). Some juveniles will overwinter in the larger estuaries, like New Bedford Harbor. Significant exposure to water-bound PCBs and heavy metals is also possible during this period for susceptible juveniles.

Feeding and Predation

Larvae tend to feed exclusively on copepods, during daylight and early evening. Juveniles shift from an invertebrate diet to diatoms and plant fragments. Filter-feeding begins as the gill rakers become more highly developed and schools of menhaden can exhaust local standing crops of plankton. No other estuarine species eats both zooplankton and phytoplankton during early life in this fashion. The adult menhaden is a voracious feeder and may deplete food sources in upper estuarine areas rapidly. The menhaden is potentially exposed to PCBs and heavy metals in New Bedford Harbor via epithelial tissue and gill contact with contaminated water as well as through the food web. Bluefish and striped bass are important predators to this species.

Utilization

The menhaden is an important commercial resource; U.S. landings in 1975 were 275,000 metric tons. However, New England landings are small and New Bedford Harbor has no records for landings of this species. Local fisherman do catch menhaden for bait to catch other fish, and this species may be a source of high tissue burdens in top carnivores at New Bedford Harbor.

Atlantic Mackerel (*Scomber scombrus*)

Range and distribution

The Atlantic mackerel, *Scomber scombrus*, occurs on the continental shelf on both sides of the Atlantic; in the west it is found from southern Labrador south to Cape Hatteras (Clayton, 1976). The fish winter offshore along the edge of the continental shelf and move shoreward during the spring. Mackerel entering the Gulf of Maine are usually plentiful in the western gulf by early June. Normally, mackerel have left the Gulf of Maine by late September, but they may be replaced by fish moving southward from the Gulf of St. Lawrence. In New Bedford Harbor they have been found in Zone 3d only (Clayton, 1976), and may still be exposed to water-bound PCBs and metals, as well as the consumption of contaminated prey.

Reproduction

It has been concluded that two major spawning areas exist: one off New Jersey to Long Island and another in the Gulf of St. Lawrence. Mackerel spawn from May to early July off Canada and as early as April off Virginia; the most important spawning area extends from the Chesapeake Capes to Massachusetts Bay and the second area is in the Gulf of St. Lawrence. Most mackerel mature at age 2 and spawn by day or night probably near the surface. Fecundity ranges from 546,000 to 1,000,000 (Clayton, 1976).

Eggs, Larvae, Juveniles

The pelagic eggs of the mackerel are 1.01 to 1.28 mm in diameter. Hatching occurs 90 to 102 hours after fertilization at an average incubation temperature of 13.8°C. Eggs are most commonly taken at sea temperatures from 9 to 13°C and are most common in the upper 15 to 25 m of the water column. The larvae are 3 mm long at hatching and grow to 10 mm in about 26 days and to 50 mm in another 40 days, at which time they become juveniles and begin to school (Clayton, 1976). Juveniles may be more susceptible to water-bound contaminants associated with Buzzards Bay (Figure 5) than adults.

Feeding and Predation

Young mackerel eat the larvae of small crustaceans, especially copepods, and fish. Although reproduction occurs in the outer zones in Buzzards Bay, young as well as adult mackerel move into the inner harbor of New Bedford where they can take advantage of the abundance of prey items. Therefore, while not spending extended periods of time in contact with contaminated surface water, they are subject to biomagnification of PCBs and metals through the food web. Their major predators are sharks, bluefish and striped bass; cod eat juvenile mackerel as do squid (Clayton, 1976).

Utilization

The fishery has been a highly variable due to fluctuations in year-class strength. New Bedford Harbor landing statistics indicate that only 13,000 lbs were handled in 1984 and that this species was not landed at all in 1985 (NMFS, 1986). Fisherman familiar with mackeral runs at New Bedford Harbor will line the beaches to catch this species, therefore, consumption of this species may be a source of human exposure (Bourque, 1986).

Bluefish (*Pomatomus saltatrix*)

Range and distribution

The bluefish, *Pomatomus saltatrix*, is a coastal species distributed from Cape Cod to South America. Schools of bluefish migrate northward in spring and summer. Adults and juveniles regularly appear in New Bedford Harbor in Zones 1, 2, and 3a-3d (Bourque, 1986). When water temperatures decline to 12-15°C adults move offshore to wintering grounds, and juveniles move south along the coast (Clayton, 1976).

Population characteristics

The maximum length attained by bluefish is approximately 110 cm. They are sexually mature by their second year. Fecundity is 900,000 mature eggs for a 52.8 cm specimen, and 1.1 million for a 58.4 cm fish (Clayton, 1976).

Reproduction

Two major areas and seasons of spawning occur; one during April and May between southern Florida and North Carolina and another between June and August from cape Hatteras to Cape Cod, including New Bedford Harbor. Spawning occurs primarily offshore, peaking in July at a water temperature of 22°C and salinity of 33 parts per thousand (Figures 2 and 3) (Clayton, 1976).

Eggs, Larvae, Juveniles

The eggs of bluefish are buoyant and measure 0.9 to 1.2 mm in diameter. Fertilized eggs hatch in 46 to 48 hours at 20°C. Larvae are 2.0 to 2.4 mm long at hatching, and feeding begins at a length of approximately 3.0 mm. Larvae inhabit surface waters, most often found at the edge of the continental shelf. Juvenile bluefish (snapper blues), move inshore during the first year (Clayton, 1976). By midsummer, juveniles appear in the Acushnet River estuary and coastal waters (Bourque, 1986). This pelagic lifestyle and the voracious appetite of the adults and juveniles contribute to direct exposure to PCBs and metals via the water column and food web.

Feeding and Predation

Bluefish are voracious feeders, consuming a large variety of fishes and invertebrates throughout the water column. Mackerel, menhaden, herring, alewife, and Atlantic tomcod, all of which are found in New Bedford Harbor are often important food items. Invertebrates commonly include shrimp, lobster, squid, crabs, mysids, and annelid worms which are common to New Bedford Harbor. Juveniles are presumably preyed upon by many predatory fish species (Clayton, 1976). An abundance of young bluefish in the near shore zones of the harbor probably contributes to attracting predaceous species. The extensive feeding of the bluefish, as well as the varied diet makes Pomatomus a prime candidate for the biomagnification of PCBs and metals in New Bedford Harbor.

Utilization

Bluefish are a recreational and commercial species during the warmer months in New Bedford Harbor. Commercially, about 159 metric tons of bluefish were landed in Massachusetts in 1972, primarily by angling and otter trawls. Recent landing statistics for New Bedford Harbor indicate that only 11,970 lbs were brought ashore in 1985 (NMFS, 1986). Anglers throughout the New Bedford Harbor area wait patiently every year for bluefish runs, not only for sport but for consumption of the fish. This species is second only to the striped bass in recreational importance, and may account for exposure to humans of contaminated seafood.

Blueback Herring (Alosa aestivalis)

Range and distribution

The blueback herring, Alosa aestivalis, is a fish of eastern North America that ranges from Nova Scotia to the St. John's River, Florida (Clayton, 1976). In the spring it enters New Bedford Harbor to spawn and can be found in Zones 1, 2, 3a-3d, thus being exposed to varied concentrations of PCBs and heavy metals (Figure 5). In New Bedford Harbor its abundance is low and the blueback herring has shared a common fate with the alewife in coastal streams and estuaries in Massachusetts. Destruction of spawning areas, obstructions in the river (hurricane barrier), and increased levels of river pollutants (e.g., PCBs and metals) may be responsible for decline or loss of spawning stocks (Clayton, 1976).

Population characteristics

Adult blueback herring generally live to age 7. However, fish 8 years of age have been observed in the Georges Bank area. No historical data is available on spawning runs in New Bedford Harbor, but in the Connecticut River at Holyoke Dam, Massachusetts, spawning fish range from 3 to 7 years; age 4 predominated among males and age 5 among females (Clayton, 1976). Although the sex ratio probably approximates 1:1 in the ocean, differential ratios may exist in spawning areas, because of different age of recruitment into the spawning population between the sexes. Fecundity estimates varied between 32,925 for an age 5 specimen and 354,270 for an age 7 fish (Clayton, 1976).

Reproduction

As an anadromous species, the blueback herring enters brackish water in the spring, usually by mid-May in New Bedford Harbor, when water temperatures reach 21 to 24°C (Figure 3) (Clayton, 1976). It is probably the long journey from the harbor entrance to the saltwater/freshwater interface in Zone 1, that is responsible for the greatest exposure (via the water column) to PCBs and heavy metals. The consumption of contaminated crustaceans and zooplankton (preferred prey items) also increases exposure for this species. It has been reported that the blueback will spawn at temperatures as low as 14 and 15°C. Data concerning downstream movement of spent adults are sparse, however it is suggested that a rapid egress by mid-August occurs at the Acushnet River (Clayton, 1976).

Eggs, Larvae, Juveniles

Blueback herring eggs are demersal (benthic), somewhat adhesive, semi-transparent, and yellow. Their average diameter is 1.0 mm. Incubation occurs in 50 hours at water temperatures of 22°C. At hatching the length of the larvae averages 3.5 mm. The young are 30 to 50 mm long within a month. The juvenile fish are fairly common in the Acushnet River estuary throughout the late summer and fall (Bourque, 1986). Young-of-the-year first appear in the estuary by July and remain until October, attaining an average length of 70 mm (Clayton, 1976). It has been suggested that their ability to use both saltwater and freshwater nurseries is highly advantageous for the species because population size does not become so dependent on the nursery potential of only freshwater areas. In the case of New Bedford Harbor this may be more of a liability then an asset. Since Zones 1 and 2 water temperatures are conducive to spawning and incubation, this may cause blueback eggs and juveniles to be in direct contact with the highest level of PCB and heavy metal contaminated sediments and surface waters (Figures 5, 6, and 7).

Feeding and Predation

Juvenile bluebacks frequently eat crustaceans (Cladocera and Anostraca), and it appears that food items remain the same throughout the seasons (Clayton, 1976). Also, in many coastal streams in Massachusetts, a direct relationship exists between standing crops of zooplankton and growth and feeding of young-of-the-year blueback herring. Adult food consists primarily of copepods, pelagic shrimp, fish eggs, and larvae. In the Hampton-Seabrook estuary, New Hampshire, barnacle cyprids, cumaceans, and decapods were important food items in the stomachs of adult herring examined (Clayton, 1976). Bluefish and striped bass in New Bedford Harbor feed heavily on juvenile blueback herring, which may have a significant effect on population levels (Clayton, 1976).

Utilization

Traditionally alewives and blueback herring have been classed together commercially as river herring and therefore processed or used in the same manner. No special fishery or processing now exist in New Bedford for blueback herring, but they are routinely caught commercially with alewives. No statistics exist for blueback herring landed at New Bedford Harbor.

However, bluebacks serve an important link as a food source for top carnivores at New Bedford Harbor. This may also account for high tissue burdens in organisms like the bluefish and striped bass, which in turn may be consumed by local fisherman.

Opossum Shrimp (Neomysis americana)

Range and Distribution

Although most species of opossum shrimp are marine, a few like Neomysis live in brackish waters. Neomysis is benthic by day and pelagic by night, during the day it rests on plants such a Ulva (sea lettuce) and Zostera (eel grass) or on stones (Kaestner, 1980). Neomysis like many other shallow water crustaceans (littoral species) move to deeper water in fall and return in spring or summer (Kaestner, 1980). Neomysis has been observed in New Bedford Harbor beyond the hurricane barrier in Zones 3c and 3d (Figure 1), however the physical characteristics of the inner harbor (Figures 2, 3, and 4) appear to be conducive to this shallow water crustacean (CDM, 1983).

Population Characteristics

Neomysis are swimmers and like fish will group together with other opossum shrimp to form swarms (schools) to avoid predation (Kaestner, 1980). Also Neomysis will filter food (diatoms) while swimming, and both exposure to the water mass (via the gills and epethelial tissue) and the consumption of diatoms may account for exposure to contaminants at New Bedford Harbor. Bioconcentration factors (field data) with PCBs (Aroclor 1254) for the phylogenetically - similar Mysis relicta are 125,000 (Veith, 1975), implying that uptake of PCBs from the water mass is significant for this zooplankton.

Reproduction

Mating in Neomysis is nocturnal and occurs after the female has molted and has a brood pouch (Kaestner, 1980). Because molting and reproduction coincide in Neomysis, exposure to contaminants at New Bedford Harbor may be enhanced since crustaceans (Homarus americanus) have been observed to be more vulnerable to contaminant effects during molting (Thursburg, 1986).

Eggs, Larvae, Juvenile

The number of eggs depends on the size of the mother, which increases between broods (Kaestner, 1980). Neomysis sp., 13-15 mm, carries 10-20 eggs; 17-21 mm long, 25-40 eggs, within its marsupium (Kaestner, 1980). It is thought the marsupium offers protection to developing eggs from deleterious environmental perturbations (Kaestner, 1980). At New Bedford Harbor it may also serve to minimize exposure to PCBs and metals.

Young Neomysis emerge from the marsupium after developing 2-4 weeks, and differ little in appearance from adults (Kaestner, 1980). The life span of Neomysis is 1-15 years, during which most of the time is spent molting and reproducing; however, the number of molts to reach maturity is not known (Kaestner, 1980). Since molting enhances vulnerability by exposing the carapace to contaminants, it would appear that developmental processes in Neomysis may be periods of high exposure to contaminants at New Bedford Harbor.

Feeding and Predation

Neomysis is a filter feeder, removing fine detritus, mollusk larvae, diatoms, and other plankton out of the water while swimming just above the bottom (Kaestner, 1980). Neomysis has also been observed catching live copepods, cladocerans ostracods, amphipods, and small mollusc (Kaestner, 1980). The diversity of food preferences of Neomysis along with swimming activity may account for the high bioconcentration factors observed in similar species (Mysis_relicta: 125,000), (Veith, 1975).

The swarms of Neomysis that have been observed in outer New Bedford Harbor (Buzzards Bay) form an important supply of food for fish, and those species that consume Neomysis and other crustaceans are: Alewife (Alosa pseudoharengus), Blueback Herring (Alosa aestivalis), Bluefish (Pomatomus saltatrix), Scup (Stenotomus chrysops), Tautog (Tautoga onitis), and Winter flounder (Pseudopleuronectes americanus) (Clayton, 1976).

Utilization

Sometimes mysids are used for human food in the form of a paste (Kaestner, 1980); however, at New Bedford Harbor this is not the case. Many fish at New Bedford Harbor that constitute commercial fisheries in that area depend on Neomysis as a food resource, and for this reason, they are an important part of ecosystem function at New Bedford Harbor and Buzzards Bay.

Diatom (Rhizosolenia alata)

Range and Distribution

Rhizosolenia is a chain-forming chlorophyll-bearing phytoplankton whose abundance and distribution at New Bedford Harbor is dependent on physical features of the water, currents, tides, temperature and salinity (Lillick, 1937). Lillick found Rhizosolenia and Guinardia to be the most abundant species sampled in August in Zones 3c and 3d (Figure 1) of New Bedford Harbor. This study indicates the historical significance of these diatoms at New Bedford Harbor. A 1972 study by the Massachusetts Water Resources Commission indicated that diatoms were seen sporadically throughout Zones 2, 3a, and 3b. Abundance of phytoplankton like Rhizosolenia are believed to effect abundance of harvestable marine fish resources (O'Connors, 1978). PCB (tetra-chlorobiphenyl) concentrations in the water in Zones 1 and 2 were as high as 0.5 ppb and 0.2 ppb in Zone 3a (Figure 5). Ecotoxicity data for the phylogenetically similar Rhizosolenia setiger yielded no growth or reduced growth in concentrations as low as 0.1 ppb (Aroclor 1254) (Fisher, 1973). Direct contact with the siliceous outer covering to contaminated surface waters at New Bedford Harbor may be effecting the standing stock (biomass) of Rhizosolenia at New Bedford Harbor.

Population Characteristics

Rhizosolenia is an epipelagic (0-150m) chain-forming diatom usually 20-200m (m=micrometer) in length (microplankton) (Parsons, 1977). This free-floating photosynthetic member of the haloplankton has a thick siliceous test (valve or covering) that houses the protoplasm of the plant (Duxbury, 1977). Standing crops of Rhizosolenia and other diatoms have many limiting factors (light intensity, temperature and nutrients), which may effect abundance of this species. PCB and metal contamination at New Bedford Harbor may also be a limiting factor since O'Connors (1978) observed chlorophyll a inhibition, clumped cytoplasms, misshapen nuclei and chloroplasts with Rhizosolenia fragillisima and Skeletonema costatum at PCB (Aroclor 1254) concentrations ranging from 1-10 ppb (O'Connors, 1978).

Reproduction

Reproduction with Rhizosolenia is vegetative; that is, the diatom forms new valves inside its cell, which then splits apart into two daughter cells (Duxbury, 1977). One daughter cell remains the same size as the parent cell, but the other is smaller. On each division, therefore, the size of half the diatom daughter cells becomes smaller and smaller until a limiting size is reached and the diatom forms an auxospore stage

(Duxbury, 1977). It may be during the budding (division) process in which Rhizosolenia is most susceptible to the PCB and metals contamination at New Bedford Harbor since the thick siliceous valves of the organism are not fully developed.

Eggs, Larvae, Juveniles

In the auxospore stage sexual differentiation of the daughter cells take place, and the fertile protoplasm is released from its casing to enlarge to adult size (Duxbury, 1977). At this point Rhizosolenia will begin to form a new frustule (siliceous covering), and begin the process of vegetative production again (Duxbury, 1977). In Rhizosolenia siliceous spindles and protoplasm threads are produced that link individual cells together into chain (Duxbury, 1977). The chain lengthens as each member cell undergoes binary fission to produce linked daughter cells until mechanical action fractures the chain or an auxospore is formed (Duxbury, 1977). At this point in development the potential of direct exposure to the water mass is probably enhanced.

Feeding and Preparation

Rhizosolenia is an organism that synthesizes its own organic substances from inorganic substances (Parsons, 1977). Nutrients, temperature, and light intensity are all limiting factors in the growth requirements of this microscopic plant (Parsons, 1977).

Rhizosolenia along with many other microphytoplankton serve as the primary link in New Bedford Harbor/Buzzards Bay food chain. Predators of Rhizosolenia include the filter feeding Neomysis americana and the raptorial feeding Acartia tonsa (Parsons, 1977).

Utilization

Although Rhizosolenia serves no direct human use resource at New Bedford Harbor, several investigators have observed that "harvestable" marine fish resources are believed to result from an abundance of phytoplankton at the base of relatively short food chains (Parsons, 1977).

Common Blue Mussel (Mytilus edulis)/Atlantic Ribbed Mussel (Modiolus demissus)

Range and distribution

The common blue mussel, Mytilus edulis, and the Atlantic ribbed mussel, Modiolus demissus, are common from Nova Scotia to Florida (URI, 1973). Large beds of these mussels exist in Zone 1 and 3a-3c in New Bedford Harbor (Bourque, 1986). Blue mussel beds are found from the low tide mark to depths of several meters. Subtidal beds are known in Narragansett Bay, Long Island Sound, and in the muddy bottoms of Cape Cod Bay, as well as New Bedford Harbor (URI, 1973). Below the low tide mark the mussels are larger and their meats are proportionately heavier. Mytilus edulis is well suited to cold northern waters, as it is able to tolerate freezing. It can survive at $-10^{o}C$ as compared to Mercenaria mercenaria which succumbs at $-6^{o}C$ (URI, 1973).

The ribbed mussel is found embedded in mudsand flats at the low-tide mark and prefers brackish water. Their shell is thin and yellowish brown, with numerous strong radiating ribs. This bivalve is eurythermal and able to withstand temperatures from $-22^{o}C$ to $36-40^{o}C$ (Tucker, 1968).

Population characteristics

Wherever there is solid substratum, and the salinity does not fall too low, the blue mussel is likely to be abundant. Near the mouths of many estuaries there are extensive areas dominated by Mytilus, which at first site appears to be attached to the surface of the mud. Closer inspection generally show that the tough byssus threads, which are secreted by a gland in the foot, penetrate through the surface layers and are attached to a stone (WRI, 1973). The ionic concentration of the blood of Mytilus edulis, follows that of the external medium down to a salinity of 10 parts per thousand, below this salinity there appears to be some active osmotic regulation, but the mussel cannot survive permanently in salinities below 4 parts per thousand (URI, 1973).

Ribbed mussels are about 4 inches long when they are fully mature, and although sedentary, ribbed mussels are not permanently anchored by the byssal threads (URI, 1973). The adaption of the ribbed mussel to varying salinities is accomplished by regulation of its internal volume. This volume response, however, is unidirectional. While the mussel responds to a low salinity by extruding solute, a high salinity causes it to shrink passively. The ability of the ribbed mussel to withstand perturbations in salinity and temperature have contributed to its success in estuaries such as New Bedford Habor (URI, 1973). It has been observed at New Bedford Harbor that the ribbed mussel is thriving in many tidal marsh areas where it is exposed to air more than water (GCA, 1986b). In these areas the mussel are consuming more oxygen aerially than aquatically. It is proposed that "air-gaping" coupled with the physiological adaptations of extensive tolerance to dehydration and a very high enzyme thermostability makes this possible (URI, 1973). Both the ribbed mussels and blue mussels are being exposed to water-bound contaminants at New Bedford Harbor (Figure 5).

Reproduction

At spawning time the eggs and sperm of the blue mussel are shed freely into the surrounding water, and may be so numerous as to give a milky appearance to wide areas. The fertilized eggs give rise to veliger larvae which become planktonic and spend several weeks drifting in the Harbor (Morton, 1979).

The ribbed mussel is capable of spawning 12 million eggs, all of which can develop into larvae. During this stage the larvae find new settling sites, and gain access to a rich food supply of phytoplankton (URI, 1973). The pelagic characteristics of mussel eggs and the demersal characteristics of the veliger larvae give rise to PCB and metal exposure from contaminated surface waters and sediments (Figures 6 and 7) at New Bedford Harbor.

Eggs, Larvae, Juveniles

The blue mussel and ribbed mussel have planktonic larvae with a long larval life of up to 2 or 3 months, before finding a settling site (URI, 1973). Both mussels will settle in great numbers under optimal conditions, and the stock of benthic adults is thus subject to great fluctuations according to seasonal conditions such as temperature, salinity, and food supply (URI, 1973). This extended exposure in the water column can be deleterious to juvenile mussels which may prove to be more sensitive than adults to PCB and metal exposure.

Feeding and Predation

The feeding mechanism of the blue mussel resembles that of many other lamellibranchs (bivalves) in that it relies upon the separation of small particles of detritus and plankton from a current of water that flows through the gills (Morton, 1979). This process is called filter feeding.

Ribbed mussels are also filter feeders, filtering water to extract edible particles. In the ribbed mussel the gills have assumed a major function in feeding. The hairlike cilia create currents of water that come in through the tubelike inhalent siphon and pass over the gills. Tiny food particles, such as planktonic algae and protozoa, adhere to a mucous film that passes slowly, in tiny strands, along the ciliated food gutters to the mussels mouth (URI, 1973). This process of filtration is continuous and allows for exposure to PCBs and metals through direct contact with contaminated water, food, and sediments.

Tautog, scup, and winter flounder eat mussels and clams, and in addition to man can effect population levels of the mussel. There have been instances of the commensal or pea crabs being found in the ribbed mussel and the blue mussel, however, whether or not the relationship is harmful to the mussels is unknown (URI, 1973).

Utilization

In 1985, only 934 lbs of sea mussels were landed at New Bedford Harbor. This species is larger than the blue or ribbed mussel and is generally found in deeper waters. Historically, this port has not handled large quantities of mussels. Mussels do serve as important function as a food source for many economically valuable fisheries at New Bedford Harbor. These mussels do bioconcentrate heavy metals (Pb/BCF = 2,570, Cu/BCF = 90, and Cd/BCF = 306) and may be a source of tissue burdens of metals in secondary and tertiary consumers at New Bedford Harbor (U.S. EPA, 1984a, U.S. EPA, 1984b, and U.S. EPA, 1985).

Eastern Oyster (Crassostrea virginica)

Range and distribution

The Eastern oyster, Crassostrea virginica, occurs from Canada to the Gulf of Mexico (URI, 1973) and is in low abundances in Zones 3a, 3b, and 3c at New Bedford Harbor (GCA, 1986b). Oysters are generally found on hard rock bottoms or semi-hard mud, normally setting on areas already inhabited by other oysters. Shifting sand and soft mud are unsuitable substrates (URI, 1973). Crassostrea virginica is euryhaline, and it can survive salinities from 3 to almost 40 parts per thousand as an adult (Figure 2). The temperature range is from $1^{o}C$ to $30^{o}C$ for its entire distribution (Figure 3). Oysters are able to withstand very high temperatures when lying closed and exposed on mud flats (URI, 1973). Overfishing, pollution, and the oyster drill, Urosalplinx cenaria are all factors contributing to the decrease in oyster populations at New Bedford Harbor (URI, 1973).

Population characteristics

Oysters reach marketable size in approximately 4 to 5 years. Natural deaths are caused by crowding, silting over and by the overgrowth of other organisms. Crepidula, the slipper shell, barnacles, jingle shells and other spat attach to the oyster shell and compete for food. Silting and sedimintation are other causes of death (URI, 1973). Bioconcentration factors appear to be high for PCBs (Aroclor 1254) and metals (Cu) 8,100 and 28,200, respectively. However, little data exist on the affinity of oysters to bioaccumulate contaminants and the subsequent effects.

Reproduction

The Eastern oyster is oviparous and is not usually hermaphroditic. There are seasonal changes in gonad development, with early gametogenesis occurring in the fall and being completed in the spring. Gonads ripen at temperatures between 12 to $18^{o}C$, but some require higher temperatures. Oysters are induced to spawn by cumulative temperature effects. Spawning can be retarded by low temperatures (URI, 1973).

Eggs, Larvae, Juveniles

After fertilization a motile trocophore larvae develops. This stage progresses to the veliger stage which is a free swimming form. Just before metamorphosis the organism develops into a pediveliger stage which is characterized by a foot and eyespots. The pediveliger uses its foot to test the substrate before final setting. The trocophore and veliger larvae are subject to direct exposure to PCBs and metals via contaminated surface waters the subsequent pediveliger stage can potentially be exposed to contaminated sediments.

Feeding and Predation

Oysters, like clams and mussels, are filter feeders, filtering water to extract edible particles (URI, 1973). This allows for extended periods of direct exposure to PCB and metal contaminated surface waters. Oysters feed on phytoplankton, such as *Isochrysis* and *Monochrysis*. They feed most effectively on particles in the 3 to 4 m (m=micrometer) range. Limited food intake delays gonad development. The importance of predators depends on the area of concern. Carnivorous gastropods, such as the oyster drill *Urosalpinx cinerea*, which is in high abundance in New Bedford Harbor, are very destructive to oyster populations (URI, 1973).

Utilization

Based on landing statistics for New Bedford Harbor, this species does not support a significant fishery in the area (NMFS, 1986). However, local residents have been blamed for overfishing the Eastern oyster, and this bivalve is thought to be second only to the soft-shell clam (*Mya arenaria*) in terms of popularity with local clam diggers (URI, 1973). Therefore, *Crassostrea* may be a source of contaminated seafood for residents of New Bedford Harbor.

Atlantic Bay Scallop (Aequipecten irradians)

Range and distribution

The Atlantic bay scallop (Aequipecten irradians) is a subtidal bivalve found mostly in the shallow waters of estuaries and often associated with areas supporting eel grass, Zostera marina (URI, 1973). However, the extensive mortality rate of eel grass in New Bedford Harbor, resulting from disease may adversely affect the scallop populations (URI, 1973). Aequipecten irradians extends from Cape Cod to New Jersey and is commercially harvested along the mid-Atlantic Bight and in the shallow bays of Massachusetts (URI, 1973). In New Bedford Harbor the bay scallop has been found in Zone 3b (GCA, 1986a). The scallop populations vary greatly on an annual basis. A population which supports a fishery one year may be completely absent the next. Possible causes for this instability are predation and the scallop's sensitivity to pollution (URI, 1973). The scarcity of this species in New Bedford Harbor is a possible reflection of overfishing and PCB and metal contamination. The sensitivity of this species has been confirmed in the laboratory with 100 percent mortality being observed at 5 ug/l of copper after 119 days of exposure (U.S. EPA, 1985).

Reproduction

Reproduction is coordinated to environmental changes in temperature and food supply. Aequipecten irradians fails to reach reproductive maturity and spawn at temperatures of 10 to 15°C, but completes the cycle at 20 to 35°C (Figure 3). Spawning normally occurs in early summer, but may occur in fall for southern populations. The planktonic larvae set in about 10 days, and although brief, the planktonic larvae may be exposed to direct contact with PCBs in the surface water. By the end of one year, the adults are approximately 5 to 7 cm in shell length (URI, 1973).

Feeding and Predation

The Atlantic bay scallop is a filter feeder. Much of the food taken by the scallop seems to be suspended benthic material. The process by which the scallop feeds may account for extended periods of PCB and metal exposure to the visceral organs. The major predators of this species are starfish, crabs, and snails (URI, 1973).

Utilization

In 1968, 210,000 pounds of bay scallops were taken from Massachusetts waters. Massachusetts supports one of the larger commercial fisheries for this species, however, recent scallop landings in New Bedford Harbor have primarily been comprised of the sea scallop (Placopecten megallanicus). In 1985, total landings for sea scallops amounted to 9 million pounds, worth approximately 43 million dollars (NMFS, 1986).

Scup (Stenotomus chrysops)

Range and Distribution

The scup, Stenotomus chrysops occurs regularly from North Carolina to Cape Cod (Clayton, 1976). Adults school in groups of similar size and are caught in depths of 2 to 37 m, over smooth or rocky bottoms. The scup is found in Massachusetts waters in the summer and early fall, migrating southward for the winter (Clayton, 1986). In New Bedford Harbor, the scup is found in Zones 3a through 3d (Bourque, 1986). Temporary residence in New Bedford Harbor may account for exposure via water-bound contaminants and direct contact and ingestion of PCBs and metals in sediments.

Population characteristics

Most adults are less than 35 cm long and the sex ratio appears to be 1:1 on the basis of commercial catches studied. Both males and females are mature by their second year (Clayton, 1976).

Reproduction

Little documentation exists on the reproductive habits of the scup. Inshore movements of scup during the spring probably represent spawning migrations. For southern New England stocks, June is the month of peak reproductive activity (Clayton, 1976). These inshore movements may subject eggs and juveniles to water-bound PCBs and metals.

Eggs, Larvae, Juveniles

The eggs of scup are buoyant, and are 0.83 to 1.15 mm in diameter. Eggs are present in Zone 3c of the Acushnet River estuary from May through June in water temperatures of 8.5 to 23.7°C (see Table 2) (Govoni, 1973). Incubation takes about 40 hours at 22°C (Clayton, 1976).

Larvae are about 2 mm at hatching. They become demersal at lengths of 15 to 30 mm. Juveniles are common in shallower and more saline portions of bays and estuaries (Clayton, 1976). Dermal contact and ingestion of PCB and metal contaminated sediments are primary exposure routes for the scup in New Bedford Harbor.

Feeding and Predation

Adults are primarily benthic feeders, consuming small crustaceans, annelid worms, mollusks, squid, hydroids, sand dollars and occasionally young fish. Adults do not feed during spawning. Adults fall prey to cod, bluefish and weakfish

(Clayton, 1976). Consumption of benthic invertebrates that live in potentially contaminated sediments, may account for tissue burdens of PCBs and metals for this organism.

Utilization

In 1972 over 227 metric tons, worth over $250,000 were landed in Massachusetts. Fluctuations of scup in the southern New England fishery are possibly caused by the varying abundances of successive year classes (Clayton, 1976). In 1985, 40,000 lbs were landed at New Bedford Harbor, worth approximately 22 thousand dollars.

Tautog (Tautoga onitis)

Range and distribution

The tautog or blackfish, Tautoga onitis, is a North American coastal fish ranging from Nova Scotia to North Carolina. The tautog represents a prominent member of inshore benthic communities (Clayton, 1976). This species has been found in Zones 3a through 3d in New Bedford Harbor (Bourque, 1986). Tautogs will enter estuarine waters, but not freshwater. The tautog will migrate onshore in spring and offshore in autumn. While inhabiting estuaries and inshore waters in New Bedford Harbor from May to October, adult populations appear to be localized (Clayton, 1976). Populations which inhabit the upper zones in New Bedford Harbor, during the summer, are thus exposed to high concentrations of PCBs and metals for 5 to 6 months. Some young tautoga remain inshore and overwinter in a torpid condition, which increases the duration of exposure.

Population characteristics

The tautog is relatively long lived and slow growing. The male grows faster than the female in length, but not in weight. Fish become sexually mature by the second or third year, and the number of eggs produced by a female increases as a function of weight (Clayton, 1976). Eggs of the tautog have been observed in Zone 3c of the New Bedford Harbor (Govoni, 1973).

Reproduction

Spawning can occur in Massachusetts from May through August; the peak occurs at water temperatures of 17 to 20°C (Figure 3). Spawning occurs primarily in weedy, inshore areas. In Narragansett Bay, peak spawning was found to occur between 13 and 14°C, and it is estimated that the duration of spawning activity for each fish may exceed 2 weeks (Clayton, 1976).

Eggs, Larvae, Juveniles

The eggs of tautog are buoyant and are about 0.9 to 1.0 mm in diameter. Hatching occurs in 42 to 45 hours at 20 to 22C. Larvae are about 2.2 mm at hatching. Larvae are most frequently collected near the bottom of the esturary bed, at the mouth of the river, since inshore areas are often heavily vegetated. Tautog larvae can be collected from June to August at water temperatures of 20.0 to 23.5°C. Juveniles occupy the typical adult habitat, where salinities are above 22 parts per thousand, preferring vegetated areas. Juveniles will overwinter in the estuary (Clayton, 1976). Tautog of age 0 (young-of-the-year) and 1 have been collected in Narragansett Bay and New Bedford

Harbor at depths of 9 to 15 m (Govoni, 1973). Direct contact to water-bound contaminants may be a source of exposure for the buoyant tautog eggs.

Feeding and Predation

Adults feed commonly on intertidal organisms, including blue mussels, barnacles, and crabs. Their diet also includes clam worms, scallops, amphipods, shrimp, isopods, sand dollars and small lobsters. Tautog have been observed to compete with cunner for mussels during May and June, when it is the major food for both species (Clayton, 1976). This benthic feeder has the potential to bioaccumulate significant amounts of PCBs and metals, since it consumes large quantities of benthic invertebrates.

Utilization

The tautog represents an important resource for Massachusetts as a sport fish, as it moves inshore during the spring. Tautog are not generally plentiful enough to be of any commercial value. In 1985, only 1,440 lbs were landed at New Bedford Harbor (NMFS, 1986). However, local fisherman catch and consume tautog in the spring months, and this may be a source of exposure to PCBs and metals for humans via the consumption of contaminated seafood.

Tubificid Worms (_Tubificoides sp._)

Range and Distribution

Oligochaetes can be found in a number of marine or brackish water enviornments. Within the littoral zone, they can exist in damp sand or mud, under stones and rocks lying on the sand, and in or near sources of fresh water on the beach. They are also found in sediments of the sublittoral zone (Cook and Brinkhurst, 1973). Oligochaetes are generally most dense at depths of 2 to 4 cm sediments (Wetzel, 1983).

At New Bedford Harbor, Oligochaetes are found in all zones in varying abundances. These organisms were seen in 3 of 3 samples in Zone 1, the estuary. They were also found in the Hot Spot samples (Zone 2). In Zones 3a and 3b, Oligochaetes were seen in 9 of 9 samples collected between the Coggeshall Street Bridge and the hurricane barrier, and in 4 of 13 samples taken outside the hurricane barrier (USACE, 1986).

PCB and metal concentrations in excess of 5,000 ppm in the estuary and hot spot (Figures 4 and 5) do not appear high enough to exhibit any noticeable toxic effect to these "early colonist" species. Studies have shown that in polluted water bodies tubificid worms are usually the most abundant species (Wetzel, 1983).

Population characteristics

Some oligochaetes are free-burrowing, while others are meiobenthic, living within the interstices of the strata (Cook and Brinkhurst, 1973). They are normally found with their heads down in the mud with the tail protruding. The waving activity of the tail increases with decreased environmental oxygen content. This activity aerates water toward the head (Wetzel, 1983). These worms are often found in very polluted areas where organic concentrations are high and oxygen content is low (Wetzel, 1983). "Changes in abundance of certain species may yield good supporting evidence of the nature and source of pollution materials" (Wetzel, 1983). Oligocheates range from less than 1 mm to around 40 cm in length, and are sometimes found with maximum lengths of over 200 cm (Wetzel, 1983). The fact that this species is pollution tolerant and in such high abundance throughout Zones 1 (estuary) and 2 (hot spot) of New Bedford Harbor is not surprising given the present conditions of this area.

Reproduction

Oligochaetes are hermaphroditic, with sex cells located in special organs in certain segments (Buchsbaum, 1976). Sexually mature oligochaetes possess an anteriorly located thickened region in the body wall which is glandular and produces a cocoon into which eggs are laid (Wetzel, 1983). Sexual reproduction is more common in poor environmental conditions while asexual reproduction predominates under favorable environmental conditions. Breeding is somewhat continuous, but intensifies in late winter and spring (Wetzel, 1983). As with many benthic invertebrates associated with New Bedford Harbor, the ability of this species to reproduce sexually or asexually coupled with its tolerance to contaminated environments may explain the presence of this species in this highly contaminated area (Figures 6 and 7).

Eggs, Larvae, Juveniles

Each segment of the oligochaete, except for the first and a few terminal segments, bears four bundles of setae (needle-like chitinous structure of the integument). Sexually mature Oligochaeta posses an anteriorly located thickened region in the body wall which is glandular and produces a cocoon at oviposition (a structure at the anterior end of the abdomen for laying eggs). Based on limited data, it is estimated that 1 to 4 years is required for oligocheates to reach maturation (Wetzel, 1983). Development is direct, with no larval stage (Wetzel, 1983).

Feeding and Predation

Free-burrowing species feed indiscriminantly on bottom sediments, while meiobenthic oligocheates consume very small organic particles or browse off surfaces of larger particles. Survival requires the availability of suitable substrata and the ability to compete with other bottom-feeders (Wetzel, 1983). The absence of less tolerant species in Zones 1 and 2 at New Bedford Harbor may account for the high productivity of this species in these areas of the estuary.

The density and distribution of the meiobenthos species correlates with the levels of organics (i.e., are controlled by food supply). These animals are attracted to detritus and feed on organisms scraped from decaying substrate (Daiber, 1982). What, if any, deleterious effect this feeding style has on this species is difficult to assess, since it appears to have a much higher tolerance level than other benthic invertebrates associated with New Bedford Harbor.

Animals which prey on worms at New Bedford Harbor include Menidia menidia (Atlantic Silverside) and Stenotomus chrysops (scup). It is important to note that Stenotomus has not been observed in Zones 1 or 2, and Menidia was detected only in small schools throughout Zones 1 and 2 (GCA, 1986). The possible absence of one predator, and the presence of another in low density may also account for the ecological success of this species in New Bedford Harbor.

Utilization

Many scientists believe oligochaetes are an important benthic invertebrate for indicating water bodies that may have experienced cultural eutrophication or other contaminant input (Welch, 1980). Moreover, it is thought that species other than *Stenotomus* and *Menidia* prey on oligochaetes. This may be true in Zones 3a-3d where a more diverse group of fisheries is known to exist (Bourque, 1986).

Atlantic Slipper Shell (Crepidula fornicata)

Range and Distribution

The slipper shell, Crepidula fornicata is a shallow-water snail found in Zone 1 (Stations 3 and 4) (Figure 8) and in Zone 3a-3d, both above and below the hurricane barrier (USACE, 1986). It was found at high frequency, occurring at 22 out of 26 sampling stations. It did not occur at the hot spot sampling location, Station 1. The relative abundance of Crepidula fornicata was found to increase dramatically overall (by as much as three orders of magnitude) below the Pope's Island Bridge (Sampling Stations 9 through 26) (USACE, 1986).

Concentrations of PCBs in the sediments in the area of sample Stations 3 and 4 range from 0-500 ppm (Figure 6) and 100-5,000 ppm for metals (Figure 7). Although little data exist on the toxicity of PCBs and metals to Crepidula the absence of this prolific species from the hot spot may be attributable to contaminant levels. (PCBs and metals) in sediments in excess of 5,000 ppm (Figures 6 and 7).

Population characteristics

Slipper shells tend to take up permanent residence wherever the coastal sea water contains high abundance of plankton. This may be any solid surface, including shells of horseshoe crabs, in the doorway of a snail, or atop another slipper shell (Milne and Milne, 1972). Young slipper shells are fairly mobile, but two-year old adults remain effixed in one place for life (Abbott, 1968). Therefore, it appears that once the adult stage has been reached, direct contact with contaminated sediments would not be a significant route of exposure. It's the mobile period (first two years) of this species that may be a period when direct contact with the water mass and contaminated sediments could be significant at New Bedford Harbor. The slipper shell grows to approximately 4 cm in length (Berrill and Berrill, 1981).

Reproduction

Slipper shells are often found in stacks or clumps of up to 40 individuals (Milne and Milne, 1972), with larger, older individuals on the bottom, and smaller, younger individuals on top. In such a stack, the bottom slipper shells are female, the middle individuals are in hermaphroditic transition stage, and the top ones are male (Berrill and Berrill, 1981). As long as the larger female snails at the bottom are present (giving off certain hormones), the top snails remain male. Removal or death of females results in a gradual sex change in some of the males. Sperm is no longer produced, and the penis is gradually absorbed; eventually, an oviduct is formed and the gonads produce eggs (Abbott, 1968).

In New England waters, Crepidula do not develop broods until the temperature exceeds 10°C (Figure 3) inferring that New Bedford Harbor is conducive to the reproduction of this species (Goagland, 1979). Although brooding of eggs is common in Crepidula fornicata, the expulsion of broods under conditions of stress, such as those elicited by contaminants, could provide elaborated exposure to PCBs and metals via direct contact to the water mass at New Bedford Harbor.

Eggs, Larvae, and Juveniles

The female slipper shell lays a gelatinous egg mass which she roofs over to form a capsule, giving the eggs protection. A single female spawns about 10 times annually, depositing 50 to 100 capsules containing 70 to 100 eggs. The female broods the capsules until the free-swimming veligar (larvae) hatch (Abbott, 1968). As mentioned above, young slipper shells are fairly mobile; once they attach themselves to a substrate, the adult slipper shell remains in place for life. It is during the free-swimming veliger (larvae) stage that Crepidula may be exposed to PCBs and metals via the water mass, in search of a suitable settling site.

Feeding and Predation

As adult slipper shells cannot move, they have evolved into a suspension feeder (Berrill and Berrill, 1981). The slipper shell spreads a thin film of mucous over its foot and waits for particles of nourishment to become embedded in it. At approximately 4 minute intervals, the mollusc twists its head to the side and sucks up the loaded mucus. It swallows small particles immediately and stores larger ones in a pouch at the front of its mouth. Seemingly, these may then be eaten during periods when it must clamp its shell tightly closed (Milne and Milne, 1972). The consumption and assimilation of this particle laden mucous may account for the greatest exposure for Crepidula via the ingestion of PCB and metal laden sediments (Figures 6 and 7).

Preditors of the slipper shell in New Bedford Harbor probably include the American eel (Anguilla rostrata) and the tautog (Tautoga onitis).

Utilization

Crepidula does not appear to serve any tangible human-use resource, and although it serves as a food resource for some species at New Bedford Harbor, the success of this species is thought to be attributable to its lack of preference by many fish and larger invertebrates at New Bedford Harbor. The slipper shells presence in highly contaminated areas suggest, like Tubificoides, that Crepidula may be more tolerant to PCBs and metals than other invertebrates, however, very little ecotoxicological data exists to support this assumption.

Eastern Mud Nassa (Nassarius Obsoletus)

The mud snail, Nassarius obsoletus (=Ilyanassa obsoleta) is an intertidal snail generally found in dense concentrations in muddy, intertidal flats in quiet bays and in the bottom of drainage ditches within tidal marshes of the North American east coast (Daiber, 1982). In New Bedford Harbor, it was found in Zone 1 (sample locations 2, 3, and 4) and in Zone 2 (sample location 1) (Figure 8). It was not found in Zone 3a and 3b (sample locations 5 through 13), and was found at only one location in Buzzards' Bay (sample location 18). Therefore, this snail appears to exist primarily in the upper harbor. A close relative, Nassarius trivittatus, was found only in Zone 3a and 3b (USACE, 1986). As the adult snail is generally found in intertidal mud flats, direct contact with contaminated sediments is likely. More importantly, areas of highest abundance appear to be those areas of highest contamination (Figures 6 and 7). This abundance throughout New Bedford Harbor's most contaminated area is not surprising since Nassarius like its freshwater counterpart Physa sp., is a pollution tolerant species (Penak, 1978).

Population Characteristics

The eastern mud nassa averages about 2 cm in length (Abbott, 1968). Mud snails are gregarious and can live out of water for four or five days (Abbott, 1968). The warm water (Figure 3) and intertidal areas of Zone 1 and 2 of New Bedford Harbor clearly offer optimum habitat for this eurythermal and euryhaline (Figures 2 and 3) species.

Reproduction

In Nassarius the female employs her foot, which develops a ventral pedal gland, to mould the unfinished horny egg capsule that emerges from the capsule gland. In male mud snails, the foot develops a muscular penis attached below the right tentacle (Morton, 1979). In Nassarius fertilization is always internal, and this may serve a two-fold purpose for this species at New Bedford Harbor: (1) internal fertilization offers a higher birth rate and survival rate; and (2) there is less exposure to contaminated sediments when eggs and sperm are not randomly displaced on the substrate.

Eggs, Larvae, and Juveniles

Mud snail egg capsules are laid in rows on algae, shells, or stones, or rarely on the underside of moon-snail (naticidae) sand collars (Abbott, 1968). These attached capsules, which average approximately 2.7 mm in height, have been found to contain between 40 and 150 eggs each, usually about 100 eggs per capsule (Daiber, 1982). After hatching, the veligers (larvae) swim freely in search of a substrate suitable for adult life. In laboratory experiments, the presence of a suitable substrate greatly enhanced the rate of settlement of Nassarius obsoletus larvae, while in the absence of such a substrate metamorphosis could be delayed as long as 20 days (Newell, 1979). A few days after metamorphosis begins, the shell darkens and the adult form becomes evident (Daiber, 1982).

It is during the free-swimming larvae stage that this species is most vulnurable to exposure via the water mass to PCBs and metals at New Bedford Harbor.

Once settled to begin adult life, the calcareous shell of this species probably offers some protection from exposure to contaminated sediment and water at New Bedford Harbor. Bioconcentration factors for the phylogenetically-similar Physa sp. for whole body are 56,900, indicated that uptake of PCBs, in particular, is expected at New Bedford Harbor (U.S. EPA, 1980).

Feeding and Predation

Nassa mud snails are among the most active and responsible marine scavengers. They possess the ability to detect the chemical decomposition of dead flesh. Flavors are drawn through the snails siphon and passed over the osphradium (a taste organ located on the roof of the mantle cavity). Within a few seconds, the snail is activated to head directly toward the source of the decomposition flavor (Abbott, 1968). Nassa mud snails scavange sunny mud flats, eating decaying crabs, fish, and invertebrates exposed at low tide. Some species of nassa feed upon the egg massess of polychaete worms by sucking them up through their probosces (Abbott, 1968). Because of its active scavenging habits, the eastern mud nassa may consume organisms which have bioconcentrated elevated concentrations of PCBs or metals, as well as contact contaminated sediments.

It is thought that few predators exist for the mud snail; however, on occasion, the American eel which has been observed in Zone 1 and 2, will eat Nassarius (GCA, 1986).

Utilization

Nassarius offers little in the way of human-use resource, and it appears that very few predatory fish, excluding Anguilla rostrata consume this species. However, the ability of this species to sense dead and decaying matter, may be an important ecological function for this species, in the process of recycling of nutrients in the Acushnet River estuary.

Mummichog (Fundulus heteroclitus)

Range and distribution

The mummichog, Fundulus heteroclitus, occurs from the Gulf of St. Lawrence to Texas in estuaries and brackish tidal pools (Clayton, 1976). It is found in Zones 3b and 3c in New Bedford Harbor (Bourque, 1986). The mummichog is typically located in sheltered tidal areas and salt marsh channels and ditches, and probably is never more than 100 m from shore (Clayton, 1976).

Population characteristics

The mummichog's maximum size is 13 to 15 cm, and it is thought to spawn in the second year of life. No difference in sex ratios have been observed. The mortality rate for first year fish has been estimated as high as 99.5 percent. For age one and older individuals, mortality ranged from 51 to 57 percent/year (Clayton, 1976).

Reproduction

Spawning occurs between June and August in New England waters. Eggs are demersal, dropping to the substrate after being extruded. Mummichogs also lay eggs in empty shells of the Atlantic ribbed mussel, Modiolus demissus, which is common in New Bedford Harbor. This behavior is believed to protect the eggs from predation (Clayton, 1976). Since the eggs of the mummichog are demersal they may be exposed to PCBs and metals in New Bedford via direct contact with contaminated sediments.

Eggs, Larvae and Juveniles

Pale yellow eggs, 2 mm in diameters are produced that adhere to the substrate. Eggs hatch in 9 to 18 days, depending on temperature, and are extremely hardy since they are often subject to periods of desiccation. Larvae are 7 mm long at hatching and fins are fully developed by 11 mm (Clayton, 1976).

Feeding and Predation

Small mummichogs grow rapidly on a diet of harpacticoid copecods, amphipods, benthic diatoms and plant detritus. Diet may be influenced by tide level, time of day, and season. Mummichogs are preyed upon by larger predatory fishes and birds near to the shore. The mummichog is an important link in the food web of many estuaries. In New Bedford Harbor it appears to represent a link between the smaller invertebrates and both benthic and pelagic piscivores (Clayton, 1976).

Utilization

This species is often used by experimental embryologists and physiologists for such studies as pituitary gland research and ectotoxicity testing (Clayton, 1976). The mummichog is not only an important component in biomagnification of PCBs and metals in the aquatic environment, but also serves as a transfer of contaminants between the aquatic and terrestrial environment, via the consumption by avian species.

Soft-Shell Clam (Mya arenaria)

Range and distribution

The soft-shell clam, Mya arenaria, is distributed along the east coast of North America south to Cape Hatteras. This species may penetrate the upper estuarine regions since it has a good tolerance for low salinities (URI, 1973). It is found in New Bedford Harbor in Zones 1, 2, and 3a-3c (USACE, 1986). The soft-shell clam can survive in salinities of 4 parts per thousand and withstand a change of 18 parts per thousand in a few minutes (Figure 2) (URI, 1973). Adult Mya arenaria are found buried in fine sand or sand-mud as much as 2 feet below the estuary bed (URI, 1973).

Reproduction and life stages

The soft-shell clam reaches sexual maturity at one year of age and when approximately 2 cm long. Spawning begins when water temperatures rise to between 10 and 15°C (Table 3). In New England, the principal spawning occurs from June to mid-August. Larvae normally spend a 2-week pelagic period in the plankton before settling. The larvae attach to sand grains or other objects with byssal threads until they are approximately 7 mm long. Adults then burrow deep into the soft substrate (URI, 1973). The soft-shell clam thus has the potential to be exposed to PCBs and metals in New Bedford Harbor via both the water column, in the larval stage, and the sediments in the juvenile and adult stages.

Feeding and Predation

The soft-shell clam is a filter feeder and studies have shown its growth rate to be directly dependent on the concentration of flagellates in the plankton (URI, 1973). This is likely to be true for many estuaries, because Mya arenaria are found in the upper reach of an estuary where flagellates are often more numerous than diatoms in the plankton. The rate of feeding of this species decreases with decreasing salinity (URI, 1973). The green crab, Carcinus maenas is the major predator of the soft-shell clam, and is abundant in New Bedford Harbor. This voracious feeder can dramatically reduce population numbers. Other predators include moon snails, oyster drills, conchs and benthic fish (URI, 1973). The predator-prey relationship of the green crab and soft-shell clam is of particular importance in New Bedford Harbor, since it allows calms from Zones 1 and 2 to contribute potentially high levels of PCBs and metals to the food web. Species that do not pentetrate the estuarine waters as far as Zones 1 and 2 may experience the effects of biomagnification via consumption of the green crab which unlike the non-migratory clam moves into the coastal zones of the harbor.

Utilization

The soft-shell clam is the fourth most economically important mollusk in New England, harvested primarily for human consumption (URI, 1973). At New Bedford Harbor, this organism may play a significant role in the biomagnification of PCBs and metals in the food chain, and may contribute high tissue burdens to top carnivores at New Bedford Harbor.

Blue Crab (Callinectes sapidus)

Range and distribution

The blue crab, Callinectes sapidus, has a range from Nova Scotia to the Gulf Coast (URI, 1973). It is basically a bottom dwelling species and is found in shallow waters in estuaries and bays. In New Bedford Harbor it has been found in Zones 1 and 3a-3c (GCA, 1986a). The blue crab can osmoregulate over a wide range of salinities, although the male can osmoregulate better at low salinities than the female. This explains why males may remain in brackish water throughout the year, showing limited movement, while females migrate into more saline water, having mated in estuarine waters (URI, 1973). Tagging studies have indicated that most crabs, both male and female, do not migrate between estuaries (URI, 1973). It is, therefore, likely that populations in New Bedford Harbor have been exposed to PCBs and metals for some time. This is supported by relatively high tissue concentrations that have been detected in C. sapidus (Kolek, 1981).

Population characteristics

The blue crab can grow to approximately 20 cm in width, and adult size is reached in about 1-1/2 years (URI, 1973). Males reach maturity in 18 to 19 molts and then continue to grow and molt. Females reach maturity in 18 to 20 molts, but growth and molting then ceases. The total number of eggs laid by one individual is 700,000 to 2 million (URI, 1973).

Reproduction and life stages

Blue crabs mate from May to October. Females are receptive after molting. The peak mating occurs in August and September (Kaestner, 1980). The male carries the female until she molts; sperm is then introducted into the seminal receptacles. Females will only mate once a year, but males may mate with more than one female (Kaestner, 1980). Mating occurs in the less saline waters of estuaries and is followed by a migration of females to waters of higher salinity. Most females will spawn twice, once in spring and again in late summer or early fall. The females fasten the fertilized eggs to their pleopods. Hatching occurs in 15 days at 26°C and larvae require salinities of 20.1 to 31.1 parts per thousand to survive (Figures 2 and 3). There are normally seven zoeal stages before hatching into the megalopa. The megalopa molts into a crab after 6 to 20 days. Young crabs migrate into estuarine waters in August (Kaestner, 1980).

Feeding and Predation

The blue crab is bottom dwelling and omnivorous. Important predators of the larvae blue crab are jellyfish, combjellies, and fish. Young crabs are preyed on by benthic fishes such as the windowpane, tautog, winter floundeer and the american eel. Some pelagic fish may also take blue crab, these include the striped bass, bluefish, mackerel and spiny dogfish (URI, 1973). The diversity of both the prey and predators of the blue crab allow bioaccumulation and biomagnification through the food web. Since the majority of these species are found in New Bedford Harbor, the blue crab represents an important link in the biomagnification of PCBs and metals in this ecosystem.

Utilization

The Atlantic blue crab supports the largest crab fishery in the United States. However, large fluctuations in abundance are characteristic of this species. This is apparently due to variable survival rates in the first year of life which are probably related to environmental conditions. It appears that little can be done to stabilize blue crab populations; crab stocks should be managed regionally to protect against environmental degradation (URI, 1973). Total crab landings for New Bedford Harbor in 1985 were 5.1 million pounds, worth approximately 2.2 million dollars (NMFS, 1986).

Green Crab/Shore Crab (Carcinus maenas)

Range and distribution

The green crab, Carcinus maenas, is in high abundance in Zones 1 and 3a-3c in New Bedford Harbor (GCA, 1986b). This estuarine crab has the ability to live in both sea water and fresh water. This species inhabits a wide range of habitats from open rocky shores to sheltered mud flats and salt marsh pools. It is most numerous where shelter is available, and large numbers of small specimens may be found under stones in the middle reaches of estuaries (URI, 1973).

Population characteristics

The green crab exhibits rhythmic patterns of locomotory activity with peaks of activity coinciding with high tide and with darkness. This crab also moves up and down the shore. The larger specimens move further than the smaller specimens, and show some seasonal variation in this movement. In summer many of the crabs move up the shore with the advancing tide and remain on the shore when the tide ebbs, provided that there is sufficient shelter on the shore. However, in winter a much higher proportion of the population moves down again with the tide. During the coldest months the crabs show no signs of moving upshore with the tide. There is also evidence that estuarine individuals move seaward during the cold weather, and that females carrying eggs tend to remain at the seaward ends of estuaries until the larvae hatch (URI, 1973). These organisms are constantly in direct contact with sediment-bound PCBs and metals at New Bedford Harbor (Figures 6 and 7).

Reproduction

Females with eggs attached to the abdominal pleopods are found throughout the year at New Bedford Harbor, but are most abundant in February and March (GCA, 1986b).

Eggs, Larvae, Juveniles

The larvae which hatch from the eggs are zoea. Such larvae are most abundant in the plankton in the spring and early summer. The number of zoeal stages is probably about seven, followed by metamorphosis into a megalopa, which resembles a small crab with a thin extended abdomen. The megalopa can both swim and walk. The megalopa metamorphose into small crabs and their life span is 3 to 4 years (URI, 1973). The zooplankton stage is conducive to direct contact to PCBs and metals through the water column, and having become adults direct contact occurs via contaminated sediments in and around the intertidal zone (URI, 1973).

Feeding and Predation

The green crab appears to be a generalized scavenger, eating anything that it finds or catches. This wide range of feeding habits is coupled with an ability to osmoregulate at salinities lower than the blood concentration, so that the crab is well adapted to live in estuaries (URI, 1973). Bluefish, striped bass, scup, mackerel, and tautog, eat large quantities of green crabs and other crabs at New Bedford, and effect the green crab population significantly (URI, 1973).

Utilization

Green crabs have minor economic importance as bait for sport fishing in coastal areas, and are routinely used in New Bedford by local fishermen (Bourque, 1986). However, this crab serves an important role as a food resource for other fish and invertebrates and may contribute greatly to the biomagnification of PCBs and metals at New Bedford Harbor.

Grass Shrimp (Palaemonetes vulgaris)

Range and distribution

The grass shrimp, Palaemonetas vulgaris, is an intertidal shrimp found in moderate abundance in Zones 3b and 3c in New Bedford Harbor (GCA, 1986b). Burrowing into the substrate protects this crustacean from predators. Palaemonetas, by fanning itself with the pleopods and with beats of the abdomen throws sand up; settling into the depression it lets itself be covered by the slowly settling sandgrains. This technique though a unique way to avoid predation, makes exposure to contaminated sediment very likely (Kaestner, 1980). Although the grass shrimp was not observed in Zones 1 or 2, it is a common littoral brackish shrimp, and able to withstand a wide range of salinities.

Population characteristics

Grass shrimp average about 3.7 cm in length, rarely exceeding 6 cm. They are active swimmers in shallow brackish water, at times colorless and completely transparent. Fecundity estimates vary between 100 to 450 eggs for an adult shrimp (Kaestner, 1980). Bioconcentration factors as high as 27,000 (Aroclor 1254) would imply that this species is a likely candidate for the uptake and retention of PCBs at New Bedford Harbor.

Eggs, Larvae, Juveniles

For the grass shrimp the rate of development, the time between molts, and the number of molts depend on nutrition. Thus, larvae of similar size and development may be of different ages and may have passed through a different number of molts (Kaestner, 1980). It has been hypothesized that vulnerability to contaminants like PCBs and metals is greatest during the molt process, when the shrimp tissue is soft and porous. In well-fed animals, pereopods 3 to 5 (swimming and walking appendages) appear after two molts, at this point the juvenile resembles an adult (Kaestner, 1980).

Feeding and Predation

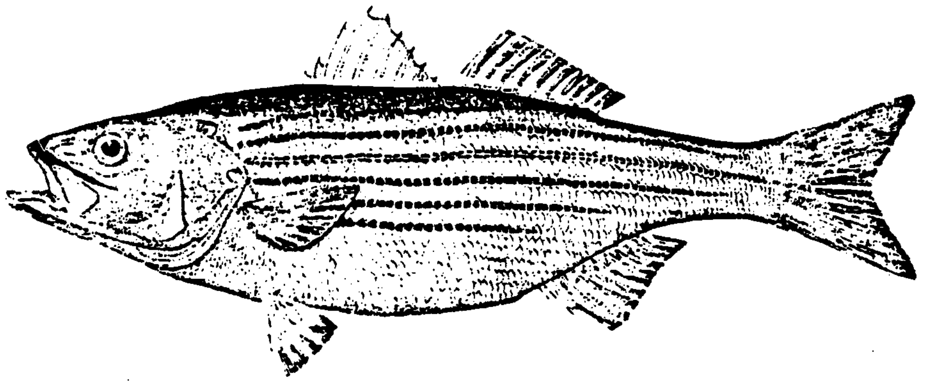
The grass shrimp is not specialized in its feeding and takes whatever it can find. As an omnivore it often takes plant parts, but the preferred food item for grass shrimp is Neomysis vulgaris (Opossum Shrimp) (Kaestner, 1980).

The grass shrimp is an essential food source in New Bedford Harbor, and the main predators of this small shrimp are: striped bass, bluefish, scup, tautog, and the Atlantic mackerel.

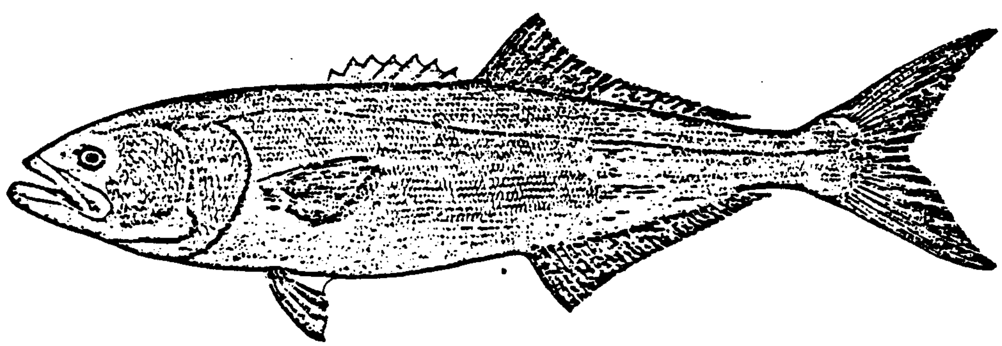
Utilization

The grass shrimp is an important estuarine forage resource, and is used as bait by some fishermen. It has no commercial value, because of its small size (URI, 1973). The grass shrimp serves as a primary link in the biomagnification of PCBs and metals in higher trophic level organisms at New Bedford Harbor.

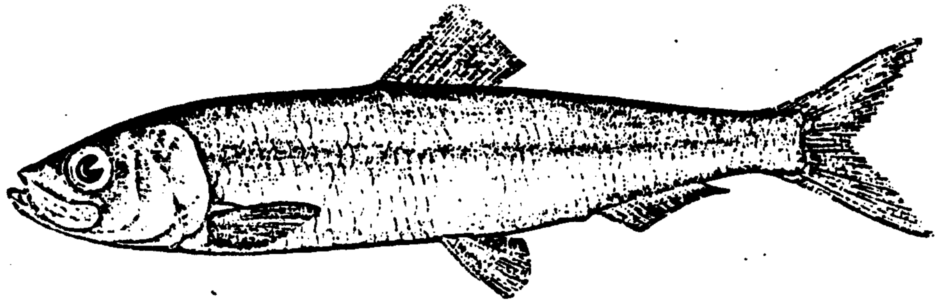
APPENDIX B
SPECIES OF CONCERN FOR NEW BEDFORD HARBOR



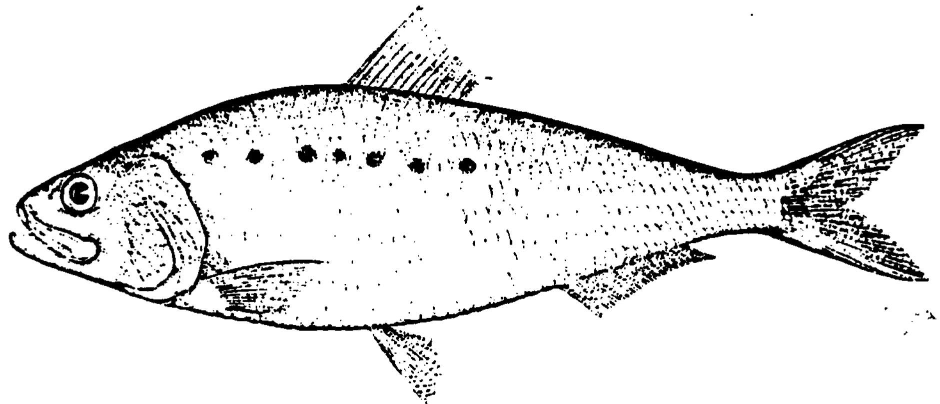
Striped Bass (*Morone saxatalis*)



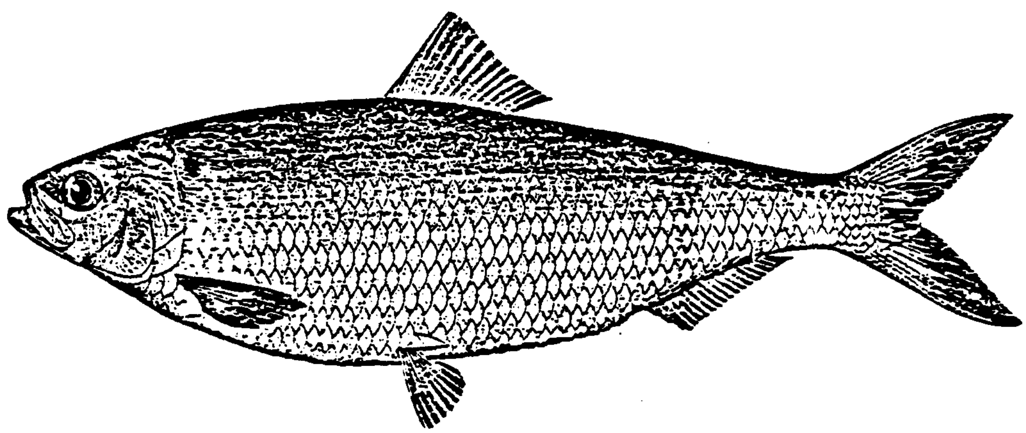
Bluefish (*Pomatomus saltatrix*)



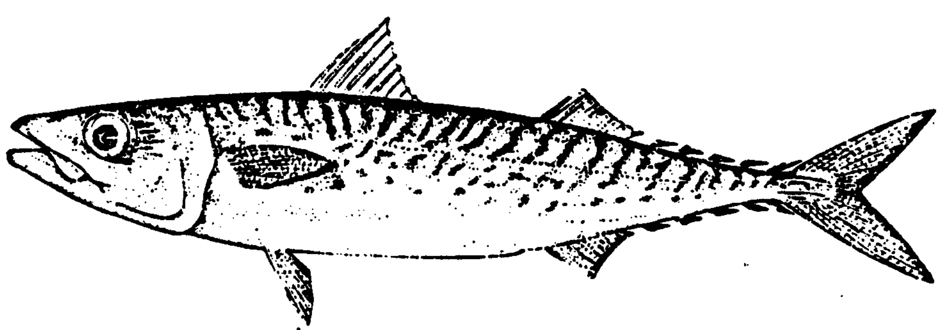
Blueback Herring (*Alosa aestivalis*)



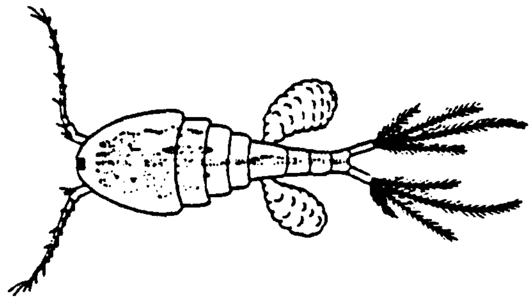
Alewife (Alosa pseudoharengus)



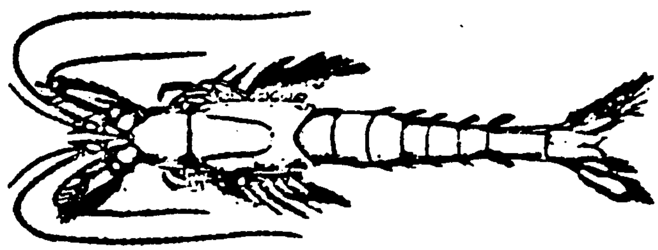
Atlantic Menhaden (Brevoortia tyrannus)



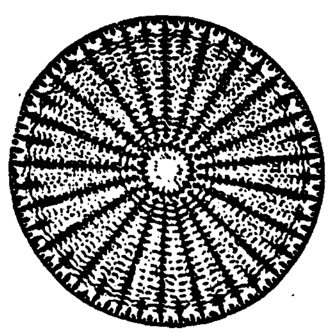
Atlantic Mackerel (Scomber scombrus)



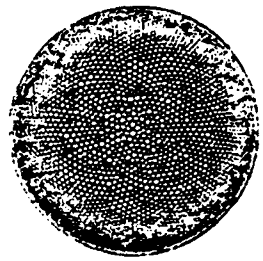
Copepod (Acartia tonsa)



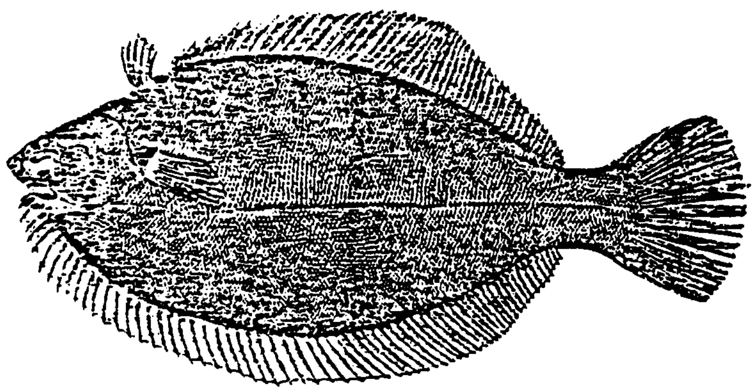
Opposum Shrimp (Neomysis americana)



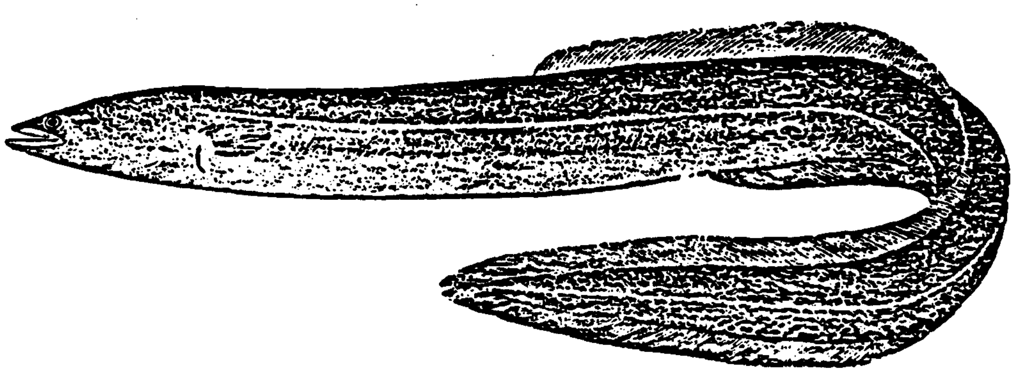
Diatom (Rhizosolenia Alata)



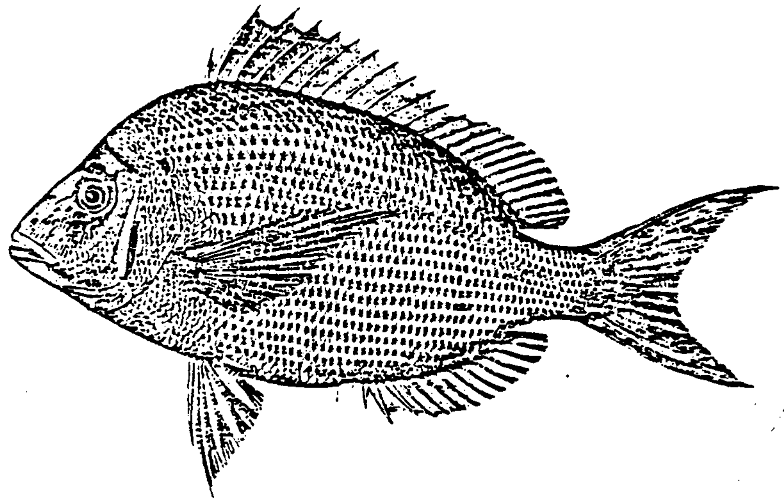
Diatom (Skeletonema costatum)



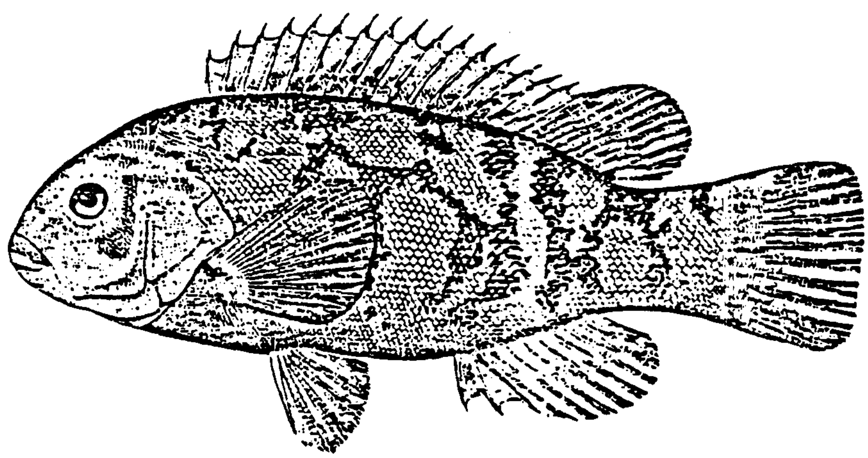
Winter Flounder (Pseudopleuronectes americanus)



American Eel (Anguilla rostrata)



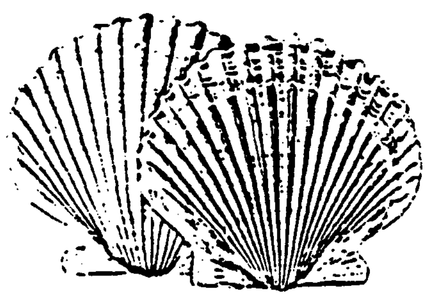
Scup (Stenotomus chrysops)



Tautog (Tautoga onitis)

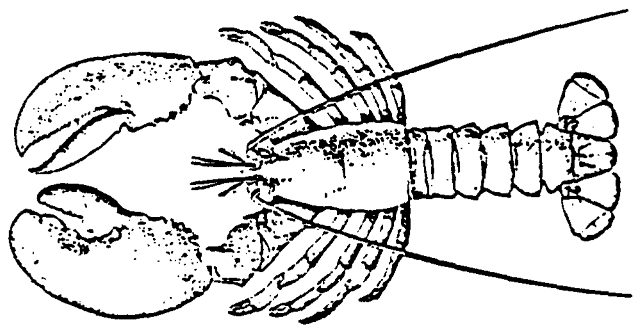
Atlantic Ribbed Mussel (Modiolus demissus)

Blue Mussel (*Mytilus edulis*)

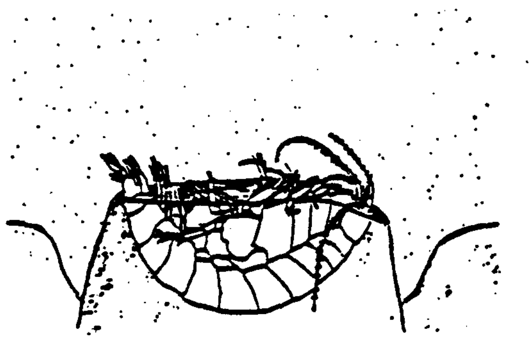


Atlantic Bay Scallop (*Aequipecten irradians*)

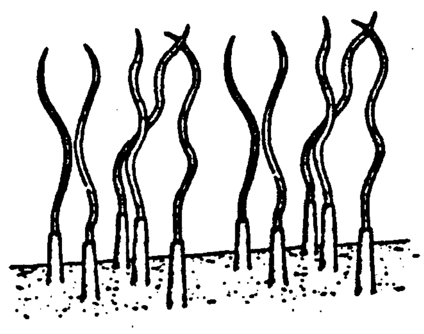
Eastern Oyster (*Crassostrea virginica*)



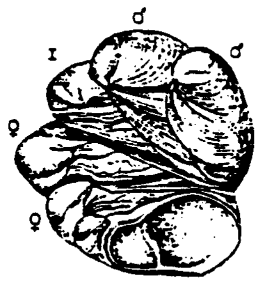
American Lobster (Homarus americanus)



Amphipod (Ampelisca vadarum)

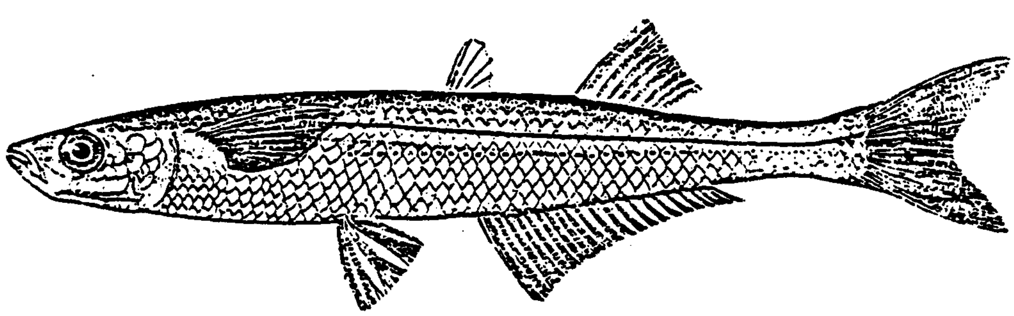


Tubificid worms (Tubificoides sp.)

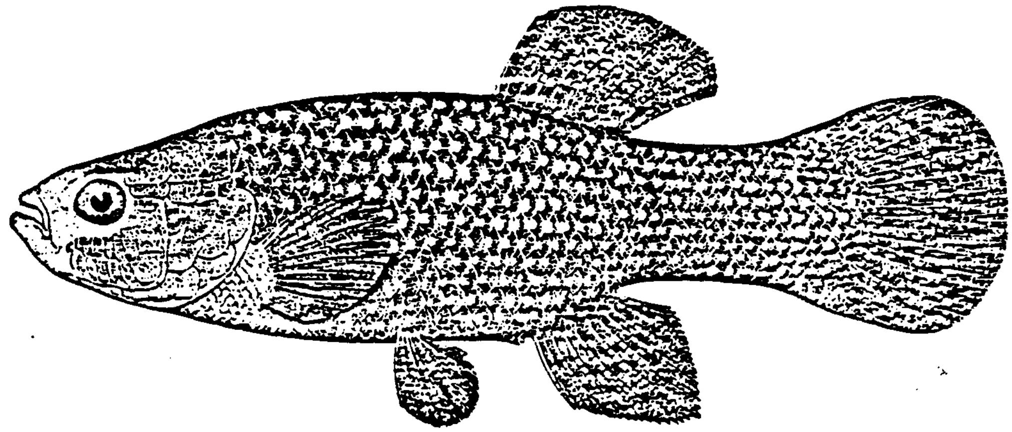


Slipper shell (Crepidula fornicata)

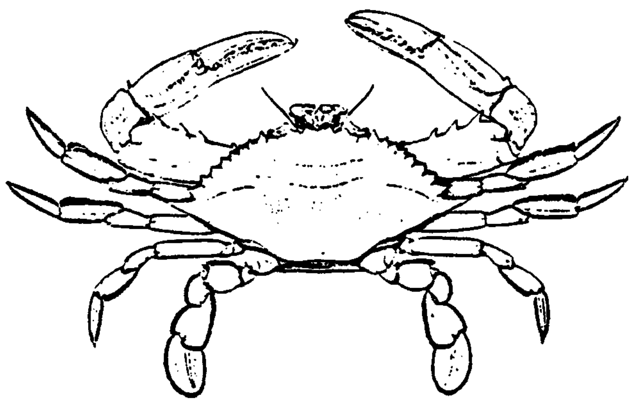
Eastern Mud Nasa (Nassarius obsoletus)



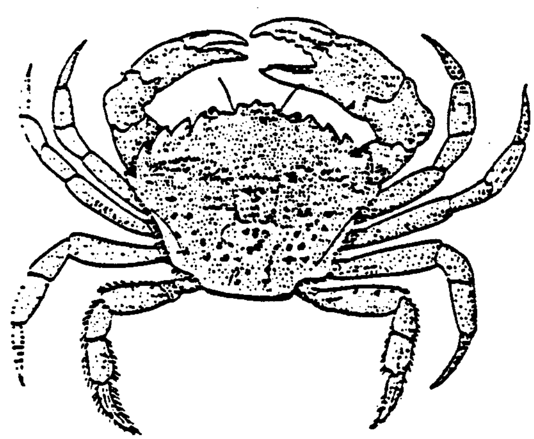
Atlantic Silverside (Menidia menidia)



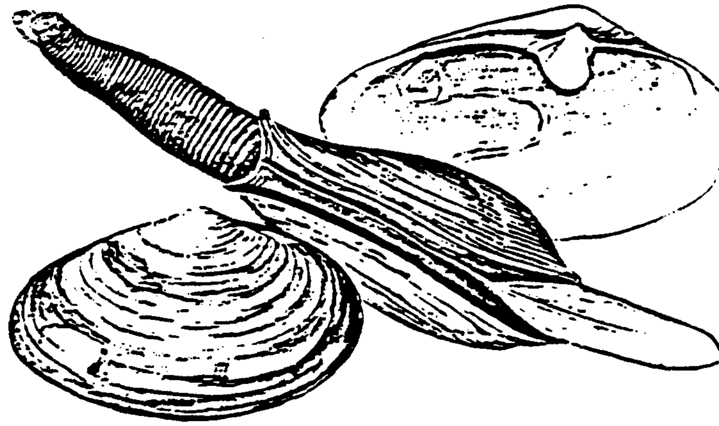
Mummichug (Fundulus heteroclitus)



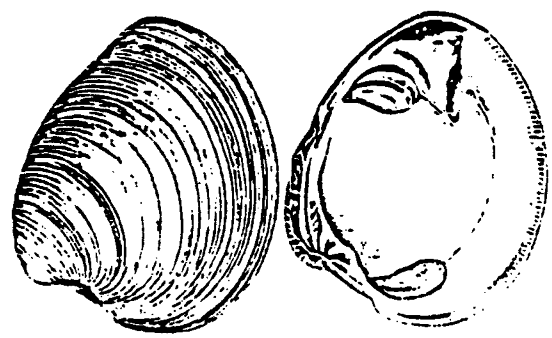
Blue Crab (Callinectes sapidus)



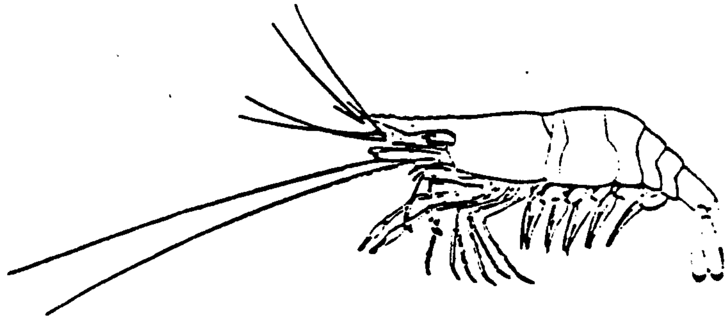
Green Crab (Carcinus maenas)



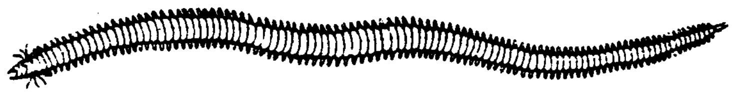
Soft-shell Clam (<u>Mya arenaria</u>)



Quahog (<u>Mercenaria mercenary</u>)



Grass Shrimp (<u>Palaemonetas vulgar</u>)



Clam Worm (Nereis succinea)

Mud Worm (Streblospio benedicti)

Thread Worm (Capitella capitata)