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THE MARINE RESOURCES OF SALEM SOUND, 1997

Bradford C. Chase, Jeffrey H. Plouff, and Wayne M. Castonguay

Massachusetts Division of Marine Fisheries
Department of Fisheries, Wildlife and Environmental Law Enforcement
Executive Office of Environmental Affairs
Commonwealth of Massachusetts

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OBJECTIVES

1. Assess the status of marine fishery resources and water quality in Salem Sound. The assessment targeted the following subjects at subtidal and intertidal habitats.

   - Finfish and major decapods.
   - Presence of shellfish, marine macrophytes, and other macroinvertebrates.
   - Basic water and nutrient chemistry (at marine and river stations).
   - Relationships between watershed and point-source pollution inputs to water quality.
   - Existing commercial and recreational fisheries.

2. Compare the results to the 1965 Salem Sound DMF study and other relevant studies.

3. Provide recommendations for protecting the marine resources of Salem Sound.

View of Salem Sound from Beverly Harbor

EXECUTIVE SUMMARY

INTRODUCTION

Natural marine resources were an essential component of the development of the Salem Sound region, and are important today because of their cultural, aesthetic, commercial, and recreational value. We conducted a year-long study of the marine resources of Salem Sound in 1997, focusing on the status of marine fishery resources and water quality. The study also assisted the conservation interests of local and inter-agency groups, provided limited comparisons to DMF studies on marine resources in the 1960s and 1970s, and provided baseline information to assist the review of large regional projects (power plant, dredging and wastewater treatment plant upgrade).

MARINE WATER CHEMISTRY

Salem Sound is a relatively shallow, well-flushed embayment with minor freshwater inputs. These conditions limit stratification, prevent the development of severe dissolved oxygen depressions and appear to reduce the spatial influence of watershed and point source inputs of nutrients. We measured basic water chemistry, fecal coliform and nutrients during 18 sampling trips in 1997. Most nutrient measurements reflected low concentrations and the fluctuations expected due to seasonal phytoplankton dynamics. Sampling in 1997 revealed the following trends:

- All bottom dissolved oxygen measurements exceeded SA criteria (Mass. DEP surface water quality criteria, Table 3.1) for supporting aquatic life (>75% saturation). No SA or SB violations were recorded for the other basic water chemistry parameters measured.
- Measurements of fecal coliform bacteria met water quality criteria for primary recreation at most stations, however, many stations exceeded criteria for shellfish harvest.
- Elevated surface turbidity, ammonium and orthophosphate were detected near the effluent outfall of the region's wastewater treatment plant.
- The warming influence of the Salem Harbor power plant cooling water discharge was detected by finding elevated surface water temperature at intertidal and subtidal sampling stations in Salem Harbor.
- Estimates of total nitrogen (TN) loading from outfall effluent (941 mt/year) were higher than river sources in 1997, however the daily load is relatively small, representing about 1% of available TN in Salem Sound on a given day.

FRESHWATER WATER CHEMISTRY

The freshwater tributaries running into Salem Sound are relatively small, and 1997 discharge was depressed by dry conditions. The average contribution from all stations was less than 100,000 m^3/day. Given the low freshwater discharge and high tidal range, in most cases, freshwater chemistry influences were confined to river and estuarine habitat. Basic water chemistry reflected conditions that were supportive of aquatic life in most cases, and elevated concentrations of nutrients were found at each freshwater station. Sampling in 1997 revealed the following trends:

- Infrequent violations of SB criteria for dissolved oxygen (< 60% saturation) were recorded, and frequent violations of the SB criteria for pH (< 6.0 pH units) were found at Sawmill Brook, Manchester.
- High measurements of fecal coliform bacteria were recorded at river stations, exceeding water quality criteria for primary recreation and contributing to degraded water quality at estuarine habitats.
- Spring nitrate and orthophosphate and summer dissolved organic nitrogen were found at concentrations that raise concerns over potential impacts to aquatic resources.
- Although TN concentrations in rivers were high, TN loading to Salem Sound was relatively small because of low freshwater discharge. The TN load from the five primary tributaries was approximately 60 mt/year in 1997.

SHELLFISH SURVEY

We surveyed 1,187 acres of intertidal habitat in Salem Sound and found that slightly more than half had potential to support soft shell clams, of which, only 19% contained soft shell clams. High densities of soft shell clams were found in several tributaries to the Danvers River, although several clam flats reported as productive in 1965 were not productive in 1997. Overall, the estimate of productive soft shell clam habitat declined by 72% from the amount estimated in 1965. The accuracy of these estimates and potential causes for this decline are not known. In addition to soft shell clams, we observed large populations of blue mussel and European oyster during the survey, and incidental occurrences of quahog, surf clam, razor clam and American oyster.

FISHERIES

Historically, marine fishery resources had a vital role in the development of culture, commerce and the communities of the Salem Sound region. The commercial fishing industry and its relative contribution to local commerce has decreased dramatically since the 19th century, yet a valuable lobster fishery remains as well as modest local fisheries for mackerel, striped bass, sea scallop and sea urchins. Lobster landings for the region exceeded one million pounds first in 1978 and have fluctuated between one and two million pounds since. Lobster landings in 1997 were about 1.2 million pounds with an ex-vessel value of nearly four million dollars. Recreational fisheries became important to the region in the 20th century. Catches of popular groundfish in Salem Sound are dependent on Gulf of Maine stocks of fish that have declined since the 1965 DMF study. The winter flounder fishery alone was widely renowned and supported five rental boat liveries. Catches of winter flounder in the 1990s have declined sharply since the 1960s and 1970s, and catches of the other groundfish in the Sound have also declined. Striped bass were the top target and catch in Salem Sound in 1997 and provided excellent fishing opportunities to many anglers.

SEINE CATCHES AT INTERTIDAL HABITAT

Twenty-three species of fish and six species of decapods were caught during 136 beach seine hauls at six intertidal habitat stations in 1997. Most of the species occurred infrequently and in low numbers. Atlantic silverside, winter flounder and mummichog were the only species to occur in at least 20% of the hauls. Atlantic silverside, Atlantic menhaden, and Atlantic herring were the top three fish in terms of numbers caught. Sand shrimp was the most abundantly and frequently caught decapod (90% of all hauls). Other than sand shrimp, only green crab and hermit crab occurred frequently. Most fish found at these intertidal habitats were juveniles, seasonal migrants, and schooling species valued as forage. The seasonal movements and aggregations of fish and decapods at these stations are probably most influenced by water temperature and young-of-the-year recruitment.

TRAWL CATCHES AT SUBTIDAL HABITAT

Thirty-five species of fish and nine species of decapod crustaceans were caught during 168 boat trawl tows at five subtidal habitat stations in 1997. Winter flounder, skate, and Atlantic cod were the top ranked fish, respectively, in both relative abundance and frequency of occurrence. Sand shrimp dominated the trawl catch of decapods, and rock crab and lobster were the only other decapods to occur in at least a third of the tows. A large majority of the fish catch was juveniles. Peak catches occurred in the summer and fall, and was probably most influenced by warmer water temperature and young-of-the-year recruitment to subtidal habitats. Overall, the catch composition appeared typical for embayments in the Gulf of Maine. The highest fish diversity was associated with the greater structural complexity of benthic habitats found outside Marblehead Harbor (larger sediments) and BeverlyCove (eelgrass), however, the highest relative abundance and species richness for fish was found at the uniform, muddy bottom in Salem Harbor and Haste Channel.

INVERTEBRATES AND MACROPHYTES

We also recorded the presence of macrophytes and small invertebrates that were caught incidentally at intertidal and subtidal habitats. Thirty-four species of macrophytes were recorded at the seine and trawl stations. Red algae was the most diverse group (16 species) and brown algae were dominant in terms of relative abundance. A total of 22 species of Arthropods was identified in all collections, of which tubed amphipods, sand shrimp, mysid shrimp, rock crab, lobster, and the invasive green crab were most common. The European oyster, green fleece (green algae), and several species of colonial Ascidians and tunicates were other invasive species commonly observed.

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LIST OF ACRONYMS

CPUE	catch per unit effort
DEP	Massachusetts Department of Environmental Protection
DIN	dissolved inorganic nitrogen
DMF	Massachusetts Division of Marine Fisheries
DO	dissolved oxygen
DON	dissolved organic nitrogen
EPA	U.S. Environmental Protection Agency
FOC	frequency of occurrence
GIS	Geographic Information System
m^3/s	cubic meter per second (unit for stream flow discharge)
mgd	million gallons per day
mg/L	milligram per liter
MLW	mean low water
MHW	mean high water
MWRA	Massachusetts Water Resource Administration
NCB	North Coastal Basin
NH_4	ammonium
NMFS	National Marine Fisheries Service
NO_2	nitrite
NO_3	nitrate
NPDES	National Pollutant Discharge Elimination System
NSSP	National Shellfish Sanitation Program
NTU	Nephelometric turbidity units
PAH	polyaromatic hydrocarbons
PCB	polychlorinated biphenols
PO4	ortho-phosphate
POC	particulate organic carbon
PON	particulate organic nitrogen
RPD	relative percent difference
SA	class of DEP water quality criteria that is highly supportive of aquatic life
SAV	submerged aquatic vegetation
SB	class of DEP water quality criteria that is supportive of aquatic life
SMAST	School for Marine Sciences and Technology, Univ. of Mass, Dartmouth
SS2000	Salem Sound 2000
SESD	South Essex Sewerage District
TDN	total dissolved nitrogen
TDP	total dissolved phosphorus
TN	total nitrogen
UNH	University of New Hampshire
ug/L	microgram per liter
µM	micromolar
USGS	United States Geological Service
YOY	young-of-the-year

CONVERSION FACTORS

Multiply U.S. Customary Units	By	To Obtain Metric Units
inch (in.)	2.54	centimeters (cm)
foot (ft.)	0.3048	meters (m)
mile (mi)	1.609	kilometers (km)
nautical mile (nmi)	1.852	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
acre (A)	0.004047	square kilometers (km^2)
cubic feet (ft^3)	0.02832	cubic meters (m^3)
Fahrenheit degrees (°F)	0.5556(°F–32)	Celsius degrees (°C)
Gallons (gal)	3.785	liters (L)
Divide U.S. Customary Units	**By**	**To Obtain Metric Units**
nitrogen (mg/l)	0.01401	nitrogen (µM)
phosphorus (mg/l)	0.030974	phosphorus (µM)

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CHAPTER 1. INTRODUCTION

Salem Sound is a prominent embayment on the north shore of Massachusetts (Figure 1.1) with a long history of interaction between human inhabitants and its natural resources. From the period of European colonization through the Industrial Revolution, the population increased greatly and depended on waterways and the harvest of marine resources for commerce. Water-dependent uses contributed to the degradation of habitat and water quality and reductions in fish stocks. In the latter half of the 20th century, the majority of economic activity on the waterfront shifted from commercial to recreational uses. This period has lead to growing interest in improving water quality and restoring marine resources in the region. To support this goal, baseline information on the status of marine resources in Salem Sound is needed.

The marine resources of Salem Sound were first studied in 1965 by the Massachusetts Division of Marine Fisheries (DMF) (Jerome et al. 1967). This study was conducted under the Estuarine Research Program (Chesmore and Peterson 1970) which completed resource inventories in 17 coastal bays and estuaries over a ten-year period. These studies provided useful information for resource management decisions in the following decades. DMF selected Salem Sound in 1996 to serve as a pilot project to evaluate a return to the original study series. Salem Sound was suitable for this purpose due to the proximity of DMF's Cat Cove Marine Laboratory and the strong support from a local conservation coalition, Salem Sound 2000. The study's timing was fortuitous because the regional sewerage district, South Essex Sewerage District (SESD), was upgrading their primary sewage treatment plant to secondary sewage treatment, and an evaluation was initiated for dredging Salem Harbor. This marine resource study provided valuable pre-operational data on Salem Sound conditions for these projects.

This study was designed as a special investigation under the Sportfish Technical Assistance Program and conducted from January-December, 1997. Several components of the 1965 study were not included in the 1997 study. Information on morphometric conditions in Salem Sound and on historical fisheries was well described in the 1965 study and not repeated in this report. We did not conduct a sportfish survey because information was available from another survey source (MRFSS 1999). We enhanced the present study by adding river sampling, nutrient measurements, and increased fisheries sampling frequency during May-October. The present study was conducted in cooperation with Salem Sound 2000, the Massachusetts Department of Environ-mental Protection (DEP), the North Coastal Basin Watershed Team, Massachusetts Audubon Society and Salem State College.

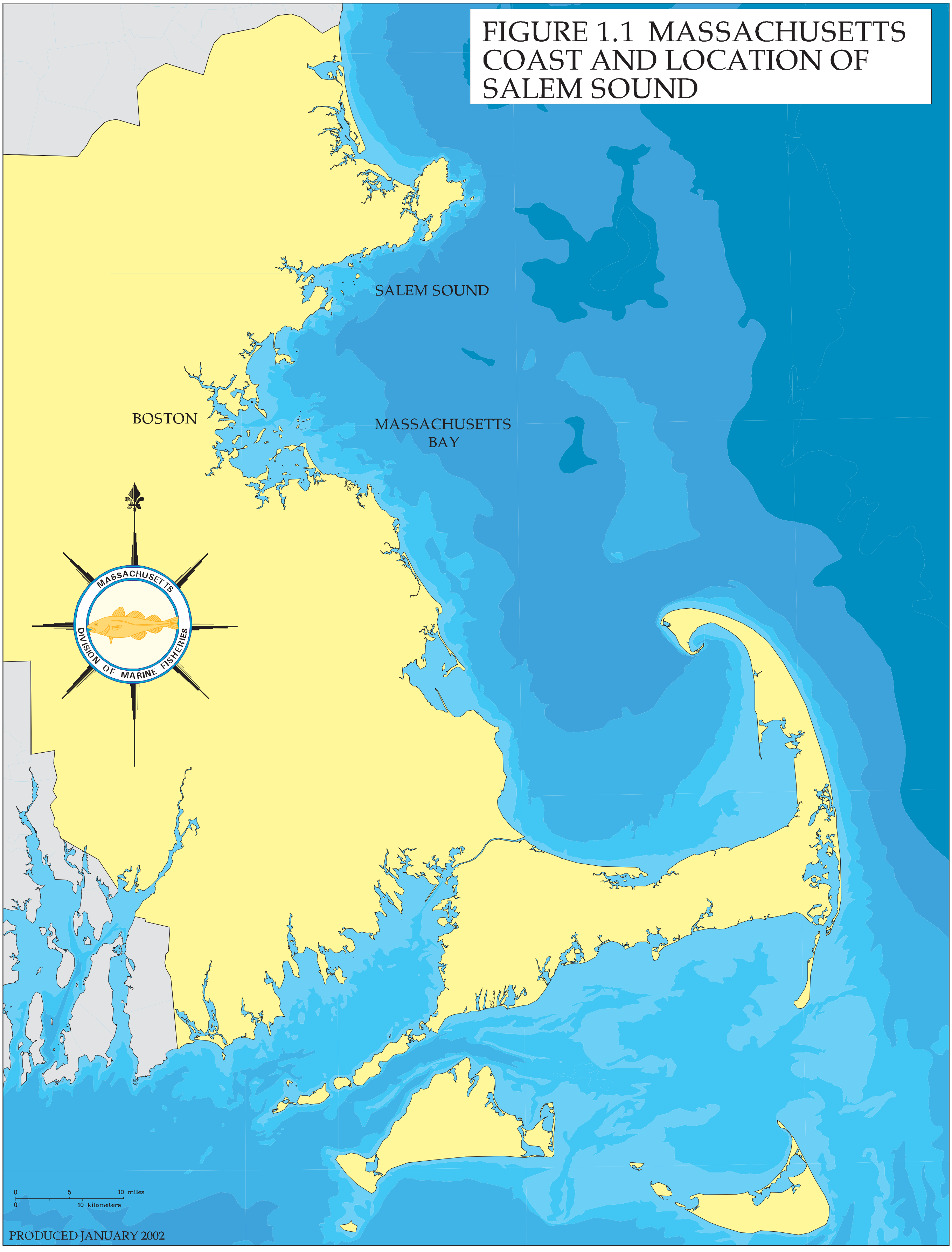
PHYSICAL DESCRIPTION

Salem Sound borders Massachusetts Bay approximately 24 km northeast of Boston Harbor. Salem Sound is a large coastal embayment (36.6 km^2) of moderate depth (mean 9.15 m MHW) (Jerome et al. 1967). Semi-diurnal tides with a mean amplitude of 2.75 m provide substantial flushing of the Sound with water from Massachusetts Bay. The water volume reduction in the Sound from high tide to low tide averages 29%. River flow into Salem Sound is minor relative to the seawater volume and primarily enters through the Danvers River estuary. Tidal activity dominates the water flow in the Danvers River. Approximately 70% of the total water volume is exchanged with each tidal cycle (MDWPC 1985).

Bedrock forms the geological basis of Salem Sound's shoreline, and the effects of glaciation and erosion are more recent, superficial influences. No barrier beaches occur in the Sound, although numerous small, sandy beaches are dispersed between rocky headlands. Salt marshes are not currently a major feature of the Sound. The Danvers River is a glacially carved estuary that probably contained large amounts of salt marsh prior to colonial development. An estimated 182 acres of salt marsh existed in the region in 1965 (Jerome et al. 1967). Currently, the estimate is 65.5 acres (Mass GIS, 1990 data), primarily found in the Danvers River estuary, Forest River and Chubb Creek inside Manchester Bay.

Sea level change has greatly influenced the profile of the shoreline and islands of Salem Sound in recent geological history. Following the Wisconsin glacial retreat, sea level quickly rose (+18 m of present Boston Harbor) then declined (-22 m of present) from about 14,000 to 10,000 years ago (Kaye and Barghoorn 1964). Since this period, sea level has risen slowly, and presently at the rate of 1 m per 1,000 years for the last 3,000 years (Duke Energy 2000). Glacial till, depositional sediments and bedrock are the primary components of subtidal substrates. Bottom sedimentation continues to be influenced by erosion, deposition, and wave and current activity. The geological history and present conditions result in a variety of benthic habitats, from dramatic bedrock out-cropping to fine, silty substrates. Jerome et al. (1967) provides greater detail on the geology and morphology of Salem Sound.

FIGURE 1.1 MASSACHUSETTS COAST AND LOCATION OF SALEM SOUND



CLIMATE

Salem Sound experiences a typical maritime climate for the temperate region of the North Atlantic Ocean. Prevailing westerly winds drive the seasonal climate patterns that bring cold and often stormy weather in the winter, elevated precipitation in spring and warm and calmer weather during summer. The available rainfall and air temperature data indicate that 1997 was a dry year with normal temperatures. Total precipitation (water equivalent of liquid and frozen precipitation) was 35.9 inches in Beverly and 32.7 inches in Marblehead in 1997 (NCDC 1998). Long-term records (since 1872) are available from Boston's Logan Airport, located 25 km from Salem Sound. Boston recorded 30.4 inches of precipitation in 1997, which was 11.1 inches below normal (NCDC 1998). All months from April-October had below normal precipitation, resulting in lower discharges at local rivers. The average annual temper-ature was 48.3 °F at Beverly and 50.8 °F at Marblehead (NCDC 1998). The Boston average was 50.9 °F, which was -0.3 °F below normal. Long-term global records indicate that mean surface air temperature has increased in the 20th century, particularly during the last two decades (EPA 1997). This global trend is consistent with Boston temperature data that recorded eight of the ten warmest years in the 20th century during the latter half of the century and four of these warmest years in the 1990s (NCDC 2001).

Wind direction in Salem Sound prevails from the southwest during the warmer months and tends to originate from the northwest (with greater variation) during the cooler months (Chesmore et al. 1973; CDM 1987). Wind records from Boston indicate that normal conditions occurred in 1997: southwest winds prevailed from May-November and from the northwest during the remaining months (NCDC 2001). Storms are an important natural process that can influence benthic habitats and communities in the Gulf of Maine (Witman 1996). No severe storms occurred (excessive wind, flooding and erosion) in 1997, although record snow fell on April 1st, when over 20 inches of snow was recorded in the Salem Sound region.

SALEM SOUND WATERSHED

The Salem Sound coastal region is included within the drainage system called the North Coastal Basin (Halliwell et al. 1982). The North Coastal Basin includes 435 km^2 in Suffolk and Essex Counties and contains 27 communities (DeCesare et al. 2000). The following six communities border Salem Sound and comprise an area of 171 km^2: Marblehead, Salem, Peabody, Danvers, Beverly, and Manchester. Most of the small freshwater tributaries that reach Salem Sound flow through the subwatershed systems of the Danvers River, Manchester Bay, and Beverly, Salem and Marblehead Harbors. The four largest tributaries in terms of drainage area (Wandle 1984) are the North River (29.8 km^2), Crane River (14.8 km^2), Sawmill Brook (13.0 km^2), and the Porter River (11.4 km^2). All of these larger freshwater inputs except Sawmill Brook flow into the Danvers River estuary. Greater details on characteristics of the North Coastal Basin watershed are available in the North Coastal Basin Assessment (DeCesare et al. 2000)

Human Population. Native Americans existed in the Salem Sound region for thousands of years prior to European contact, although there is little evidence that native populations occurred in Massachusetts Bay 10,000 years before present (Duke Energy 2000). European settlers colonized the Salem Sound region in the early seventeenth century while seeking economic opportunities and freedom from homeland governments. Native American populations declined quickly in response to warfare and disease, and were eventually assimilated into colonial populations. Agricultural and fishery resources were the primary attractants for the settlers, of which cod fishing was the driving force of early commerce and prosperity. The Salem Sound region developed into a center for maritime commerce during the next 150 years. The Salem maritime industry became famous for the entrepreneurial success found in far seas trading. This rich cultural tradition is cherished today and supports a growing tourism industry.

The maritime industry diminished with the emergence of steam-power vessels in the mid-19th century and the increased use of deeper ports elsewhere. However, the regional population continued to grow during the industrial revolution as many manufacturing mills were constructed and increased the need for manpower. A new age of commerce developed around the mills. The population peaked during the early 20th century as the mills prospered, reaching levels slightly higher than found today. The overall population for the six communities has remained stable around 170,000 since 1965 (Figure 1.2). The current population depends on an economy that is a composite of retail, service, manufacturing, and tourism. This present day economy is more diverse than previous eras when mill manufacturing, maritime trading, and the utilization of marine resources were dominant. A chronology of events related to the human development and utilization of natural resources in Salem Sound is listed in Table 1.1.

Land and Water Use. Land use categories for each community in Salem Sound were provided by the Massachusetts GIS Program using 1990 data (Figure 1.3, page 6). Overall, residential development is the major land-use category and total developed land (residential, commercial, industrial and urban) account for nearly 60%

Figure 1.2 Human population in six communities along Salem Sound, 1965-1997. Population data were recorded from the annual reports of the municipalities.

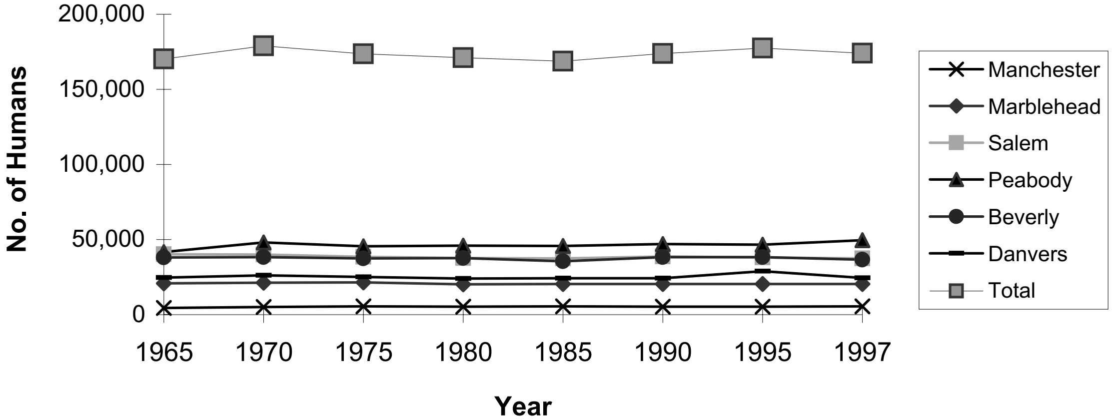
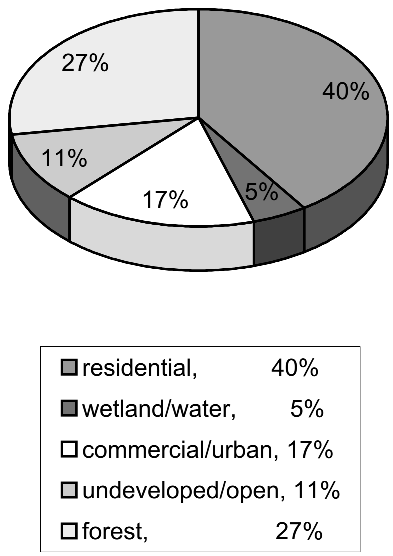


Table 1.1 Chronology of events important to natural resource utilization in Salem Sound. Sources: Jerome et al. (1967), Anderson et al. (1975), PAL (1995), Duke Energy (2000).

Early 1600s	Initial European contact and settlement.
1650-1750	Fisheries harvest is primary industry; maritime commerce development.
1750-1850	Maritime trading peaks; development of tannery industries.
1850-1900	Maritime trading declines; industrial technologies enhance tanning industry.
1905	Haste Outfall pipe for raw sewage discharge is constructed.
1910-1920	Tanning and industrial mills peak with WW I demand; population peak.
1925	South Essex Sewerage District (SESD) established.
1940-1960	Tanning and industrial mills diminish after WW II, but remain important.
1952	Coal burning power plant with sea water cooling constructed at Salem Harbor.
1970	U.S. Congress passes Clean Air Act.
1972	U.S. Congress passes Clean Water Act.
1972	Power plant adds 4th generating unit; circulating water capacity exceeds 600 mgd.
1977	SESD upgrade from raw to primary sewage treatment, discharge at Haste Outfall.
1998	SESD upgrade to secondary sewage treatment, diffuser added to Haste Outfall.

of all land use (Figure 1.4). The coastal areas of Salem Sound south of Manchester are very developed with residential, commercial and industrial properties. A total of 38% of the total acreage is classified as open/ undeveloped or forest. A majority of this is forest away from the coast in Manchester, Beverly and Peabody.

Figure 1.4 Major land-use categories for communities bordering Salem Sound (percent acreage), Mass. GIS 1990 data.



The amount of impervious surfaces near the coast has increased greatly since 1965 due to growing transportation and retail demands. The loss of pervious surfaces can increase the concentration of stormwater pollutants directed to adjacent wetlands. Route 128 is a major highway that runs along most of the communities a few miles from the coast of Salem Sound. The highway actually crosses over the three western tributaries in the Danvers River, where extensive development is found in close proximity to the highway and rivers. The highway was completed in the late 1940s and adjacent lands were steadily developed in the following decades. This corridor now contains several large malls and shopping areas that contribute to a high density of impervious surface near the Danvers River estuary. Municipal water supplies are drawn from the Ipswich River Basin and local reservoirs, except for Marblehead uses Massachusetts Water Resource Authority (MWRA) sources. Sewage disposal for households in the region occurs primarily at two wastewater treatment facilities; the South Essex Sewerage District serves most of the region and a smaller plant serves the town of Manchester.

Waterways. The waterways of Salem Sound are well suited for a wide variety of commercial and recreational activities. The ample depth, numerous anchorages and the surrounding natural resources attracted settlers to this region over 375 years ago, and the importance of the Sound to the local economy has been continuous to the present day. Water uses until recently were weighted heavily towards commerce. The "working waterfront" is still very much a part of the Salem Sound shoreline, although recreational uses have increased in recent decades. In terms of water quality, most of Salem Sound is now classified as SB waters by DEP, which specifies that areas are "designated as habitat for fish, other aquatic wildlife and for primary and secondary contact recreation", and in approved areas are suitable for shellfish harvesting with depuration (MDEP 1996).

Completely describing water-dependent uses in Salem Sound is beyond this study's scope. There are many water uses and shoreline activities that are not well documented by a common source. Each harbor has several marinas, yacht clubs, and other businesses that support commercial and recreational boating. There is also a commercial shipping terminal in Salem Harbor that receives shipments of oil and coal. The coal is used primarily to fuel the Salem Harbor power plant next to the terminal. To illustrate the importance of the boating industry in Salem Sound, a survey was conducted of the Harbormasters of five communities with berthing for commercial and recreational vessels. The Harbormasters of the five communities reported a total number of 5,605 assigned boat moorings and registered slips in 1997 (Table 1.2). Only one other source was found of earlier boat counts for Salem Sound. The SESD Draft Facilities Plan (CDM 1987) included a 1986 telephone survey that tallied 6260 total berths in the area. The higher total in 1986 occurred because of higher counts in Beverly and Marblehead, despite the lack of reporting for Danvers. Both these surveys did not include trailered boats registered in the region. The accuracy of both surveys is uncertain, but it is reasonable to conclude that high densities of boats were found in Salem Sound harbors during 1997 and the number of moorings and slips probably ranged between 5,000 and 7,000 annually during the last 15 years.

MAJOR POLLUTION SOURCES

Currently, the primary sources of pollutants to Salem Sound are two permitted point sources, the SESD wastewater facility and the Salem Harbor power plant, and the non-point sources of stormwater run-off and atmospheric deposition. All these sources contribute a variety of nutrients, trace elements, inorganic and organic compounds and pathogens that at high concentrations can threaten marine resources. Nutrients such as nitrogen and phosphorus act as limiting agents to plant growth, and, therefore, are necessary to all ecosystems. In excess, nutrients can increase primary and secondary production to harmful levels. High plant and algae production can

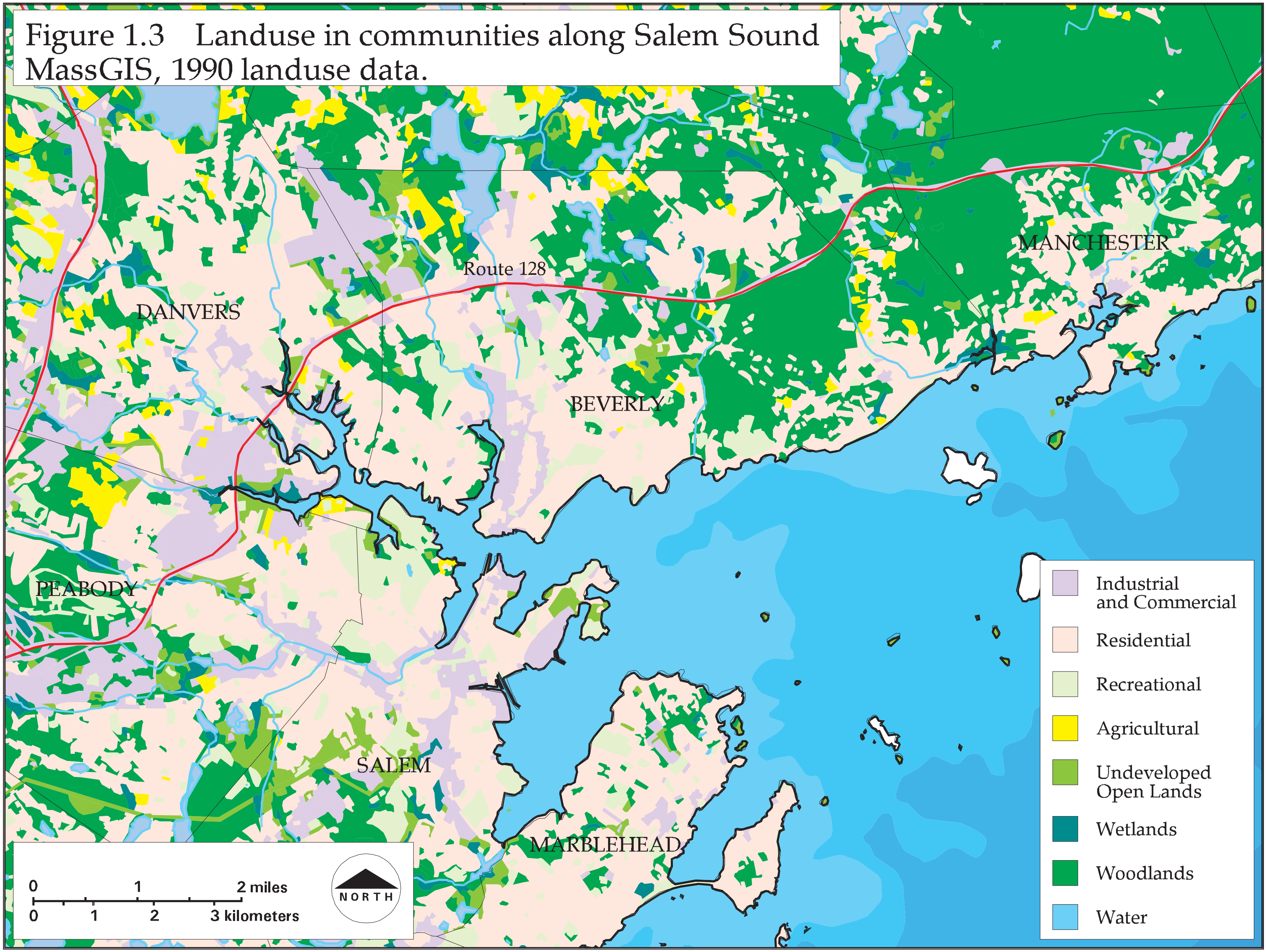


Figure 1.3 Landuse in communities along Salem Sound
MassGIS, 1990 landuse data.

Table 1.2 Boat berths in five communities bordering Salem Sound, 1997. Data were reported by Harbormaster's offices for each community.

	Moorings	Slips	Total Berths
Salem	1000	370	1370
Danvers	110	700	810
Beverly	476	289	765
Marblehead	NA	NA	1990
Manchester	548	122	670
Total			5605

result in increased water column oxygen demand and eventually disrupt natural marine communities. Numerous contaminants originate from metals and compounds used in manufacturing and the burning of fossil fuels. These contaminants can be toxic at high concentrations to marine organisms, especially at early life stages. Pathogens harmful to human health may not threaten marine organisms, but their presence in seafood can limit or prevent the harvest and consumption of valuable species. A common example is the use of fecal coliform bacteria as a pathogen indicator in the management of shellfish harvest.

Historical Point Sources of Pollution. The freshwater streams leading into the Danvers River were a good source of waterpower for colonial manufacturing mills. In particular, leather tanneries became an important local industry during 1750-1850 in response to growing domestic and overseas markets established by maritime trading (PAL 1995). The North River in Peabody became a center for the leather tanning industry, earning the name, "Blubber Hollow", as waste products from mills fouled the river. By 1890, there were 61 leather industry establishments in Peabody alone and the North River was severely degraded by the inputs of industrial waste. Early in the 20th century the number of tanneries declined but productivity remained high with the advent of automation technologies and the market of World War I. Other manufacturing businesses developed along Salem Sound rivers during this time and also used the waterways as conduits for waste disposal.

The tanning industry went into decline following World War II as the industry shifted to cheaper production outside of New England. The remaining tanning mills, metal plating shops and a variety of other businesses continued to freely use the waterways for power, cooling, and waste disposal up until the implementation of the Clean Water Act in the 1970s. As the regulatory effects of the Clean Water Act occurred during the 1980s and 1990s, the water quality of Salem Sound's rivers has improved, but remnants of region's manufacturing era are found in the sediments of local rivers and harbors.

Recent sampling of sediments in Salem Sound's waterways found contaminants that originated from industrial point sources. High levels of chromium, lead and zinc, all by-products of leather tanning processes, were found in North River sediments (Edwards and Kelcey 1989). Sampling in Salem Harbor during the 1980s as part of national study on marine sediments found contaminants related to industrial manufacturing and petroleum constituents from the burning of fossil fuels (NOAA 1988). The concentrations of chromium were ranked highest among all national testing locations; cadmium and lead were ranked second. The study also found relatively high concentrations of mercury, polychlorinated biphenyls (PCBs), and polyaromatic hydrocarbons (PAHs). The reporting of these high concentrations of contaminants resulted in a national reputation for Salem Harbor as a polluted waterbody. Contaminants found in sediments were not evenly distributed, but typically found in depositional zones downstream of former locations of industrial point sources. The biological consequences of the contaminated sediments are not certain, but remain a concern related to activities such as dredging and fishing.

South Essex Sewerage District. The state legislature created SESD in 1925 in order to resolve problems with sewage collection in the region. Soon after, SESD extended an outfall pipe that had delivered raw sewage since 1905 to a discharge near Great Haste Island. This raw discharge continued until the completion of a primary treatment plant in Salem in 1977. The plant's National Pollution Discharge Elimination System (NPDES) permit allowed a design flow of 41 million gallons per day (mgd) and typically discharged 25-30 mgd of effluent at the same outfall through 1997. The origin of this flow is a network of natural water sources that each municipality maintains, of which the Ipswich River and Wenham Lake are two of the largest sources. The plant has since been upgraded (June 1998) to secondary treatment and now discharges from a 660 ft. diffuser pipe attached to the original outfall. Chlorination of the effluent has occurred for decades and dechlorination is planned for effluent treated under the new secondary treatment system. Large amounts of nutrients (primarily nitrogen and phosphorus) enter

Salem Sound through the sewer plant. Concerns exist for contributions of nutrients, pathogens, chlorine, and various contaminants that flow through the sewage collection system.

Salem Harbor Power Plant. The Salem Harbor electricity generating station has operated since 1952, using fossil fuel to generate electricity and contains once-through sea water systems for cooling. A fourth generating unit was added in 1972, bringing the circulating water volume to 607 mgd, and prompting extensive DMF fisheries investigations (Anderson et al. 1975). The power plant is presently permitted (NPDES) to use up to 669 mgd of sea water for cooling and has limitations on the differential between intake and outfall water temperature. Chlorine is authorized as a sea water system biocide. The primary concerns for the power plant impacts on marine resources are thermal effects from discharge water, entrainment mortality on eggs and larvae, and smokestack emissions from fossil fuel combustion. The previous DMF investigation concluded that thermal impacts were minimal, and the entrainment issue was not evaluated. Older power plants, such as in Salem Harbor, that rely on coal for fuel are known to produce high emissions of nitrogen oxide and sulfur dioxide. The actual contribution of nitrogen and sulfur to the marine environment and resulting effects has not been assessed.

Stormwater Pollution. Stormwater runoff is a natural component of the cycling of water between the earth and atmosphere. With undeveloped land, most water infiltrates the pervious surface of the ground and surface runoff is minor. Runoff increases as land is developed and more of the ground surface becomes impervious. Stormwater carries a wide variety of toxic contaminants (trace elements, hydrocarbons, organic compounds, salt) that enter watersheds through residential, commercial and industrial activities (MDEP and MCZM 1997). Runoff can also contain excessive nutrients, sediment and pathogens that can impact human health and natural habitats. In coastal areas, typical drainage patterns deliver runoff to tidal rivers and estuaries. The increase in impervious surfaces carries two major concerns: lost benefits of naturally treated stormwater through soil infiltration and accumulated contaminants are often deposited and concentrated in sensitive aquatic habitats. The watershed adjacent to Salem Sound is highly developed with urban and industrial landscapes found along some tributaries. During the last 50 years, the population has remained fairly stable but impervious surfaces have greatly increased. The construction of Route 128 improved automobile transportation in the area and increased residential and commercial activities away from downtown areas. Large shopping areas were developed along Route 128 in close proximity to tributaries of the Danvers River in the 1970s and 1980s. Currently, concerns over acute impacts from point source pollution are diminishing at a time when uncertainty exists over stormwater impacts in the region. A recent study did provide a glimpse of the problem's magnitude with estimates that 66% of total nitrogen that enters Salem Sound originates from non-point land uses (Menzie-Cura 1996).

Atmospheric Pollution. Concerns are growing over the impact of atmospheric pollution on the health of aquatic resources (Hicks et al. 2000, and Scavia et al. 2002). Atmospheric and stormwater pollution are closely linked because of precipitation's role in delivering pollutants to aquatic habitats. However, specific consideration should be given to atmospheric pollution because significant amounts of deposition occurs directly to waterbodies, uncertain amounts of pollutants are imported from outside the watershed, and remediation requires large-scale, national efforts. Atmospheric pollution is delivered by both wet and dry deposition. Acidic deposition, toxic compounds, trace elements, and non-toxic compounds (nutrients) are components of atmospheric deposition. The U.S. Environmental Protection Agency (EPA) monitors five major pollutants (particulate matter, ozone, sulfur dioxide, carbon monoxide and nitrogen dioxide) in relation to established air quality standards (EPA 1998). The primary source of these pollutants is the combustion of fossil fuels, with major contributions coming from power plant emissions and automobiles. Also a concern for human and natural resource health are atmospheric emissions of toxic pollutants such as lead, mercury and polychlorinated biphenyls, that can accumulate in aquatic food webs (EPA 1997a).

Sulfur dioxide and nitrogen oxides are of particular concern to aquatic resources because of their contributions to acid rain (both) and eutrophication (nitrogen oxides). Monitoring within Massachusetts has shown a general decline in sulfur dioxide concentrations in ambient air during 1988-1997 (EPA 1998). The same monitoring program found stable concentrations of nitrogen dioxide during 1988-1997. Recent studies have shown that atmospheric contributions of nitrogen can be a significant source to coastal waters. For Chesapeake Bay (EPA 1997b) and Buzzards Bay (Howes and Goehringer 1996), estimated nitrogen inputs from atmospheric deposition were 27% and 22% of total loads, respectively. The source and fate of atmospheric pollutants in the Salem Sound region are not certain. Within the watershed, it is expected that the Salem Harbor power plant is a major source of nitrogen and sulfur oxides, and that the residential density and major transportation corridors contribute high automobile emissions.

PREVIOUS MARINE RESOURCES STUDIES

The reports of two previous investigations on the marine resources of Salem Sound are available for comparison to the present study: the 1965 DMF study of the marine resources of Beverly-Salem Harbor (Jerome et al. 1967), and the DMF investigation on the effects of the Salem Harbor power plant on marine resources during 1971-1979 (Chesmore et al. 1972, 1973; Anderson et al. 1974-1979). These documents provide useful information on fish species composition and the general health of the marine environment at the time of the studies. Comparisons of the present study to the previous studies should be made cautiously. None of the studies assessed fish population size. Differences in methods, gears, objectives, environmental effects and the span of time all reduce the utility of comparing changes at the population level. However, the three studies collectively provide a useful portrayal of marine resources in the region and are the best references on fishery resources in Salem Sound during the 20th century.

1965 DMF Study. The 1965 DMF study was the 4th in a series of 17 studies on the marine resources in coastal bays and estuaries of Massachusetts. The present study was modeled after the 1965 study using the primary objective of surveying marine resources throughout one calendar year. The study centered on monthly water chemistry, beach seine and boat trawl sampling at similar stations to those sampled in 1997. The study also included extensive shellfish resource sampling and documentation of the local lobster fishery and sportfishery. Raw data on fish collections are no longer available for this study. References to specific methods, gears, and results will follow in the appropriate chapters.

Salem Harbor Power Plant Investigations, 1971-1979. Investigations related to the Salem Harbor power plant were conducted by DMF under the direction of a multi-agency Technical Advisory Committee and funded by the New England Power Company (Anderson et al. 1975). The study was deemed necessary to assess the effects of existing power generation on marine resources and to evaluate potential impacts from additional fossil-fueled electric generating units. Unlike the 1965 and 1997 studies, these investigations spanned many years and focused on Salem Harbor. The power plant investigations also addressed a wider range of issues, including ichthyoplankton and plankton collections, water intake impingement, thermal discharge profiles, and bioassays. There were similar monthly fish collections to the other studies conducted with seines and trawls, but comparisons are difficult because of changing sampling methods and collection frequencies. Raw data on fish collections are no longer available. The best year for comparisons is 1972 when seine and trawl collections were made with similar methods throughout Salem Sound. Little sampling was conducted outside of Salem Harbor after 1973.

STUDY AREA

The previous DMF study referred to the study area as "Beverly-Salem Harbor", although all stations were within the embayment known as Salem Sound. The 1965 study area boundary was used again in 1997 (Figure 1.5). Sampling stations for the 1997 study were selected to replicate some stations used in 1965, and to provide resource information by habitat type.

Beach Seine Stations. We inspected six beach seine stations used in 1965 during 1996 to confirm suitability for seining and habitat type, and five were selected for use in 1997 (Figure 1.5, and Table 1.3). The Causeway Station, Marblehead, was eliminated because it could only be sampled at higher tide stages and yielded very low catches in 1965. A sixth station was added, Sandy Beach, located on the Danvers River, and along with Obear Park represented tidal river habitats. Both river stations have sloped banks with sand and mud substrate and experience minor salinity depressions due to freshwater inputs. Proctor Point, Tuck Point, and Pioneer Village represented harbor beach habitats. These harbor stations are moderately protected from wave action, and have mostly mud and sand substrate with some cobble and patches of blue mussels *(Mytilus edulis)*. West Beach represented dynamic beach habitat. It is exposed to wave surges and possesses uniform, sandy substrate.

Trawl Stations. We selected six trawl stations with the intention of conducting duplicate tows at specific habitats, while including several of the stations sampled in 1965 (Figure 1.5, and Table 1.3). The Salem Harbor and Haste Channel trawl stations represented harbor channel habitat and have similar depths and homogenous substrate (mud with little structure). The remaining three stations all provided distinct habitats. The Marblehead Harbor trawl station is a broad area that represented outer channel habitat. It is the deepest station with heterogeneous substrate that includes sand, gravel, kelp patches. Trawl tows were conducted outside of the harbor entrance buoys in the open channel where the tow path was dictated by the configuration of lobster gear. Beverly Cove is the shallowest of trawl stations and has mixed macrophyte and sand substrate, dominated by eelgrass. We selected two trawl stations in the Danvers River for duplicate tows because of their close proximity and similar river channel habitat. A narrow channel and high density of moorings prevented duplicate tows in the same river stretch. The Salem Harbor and Haste Channel stations were the same as in 1965 and Marblehead Harbor and upper Danvers River stations border those from the 1965 study.

Figure 1.5 Salem Sound Marine Resource Study study area and sample stations, 1997.

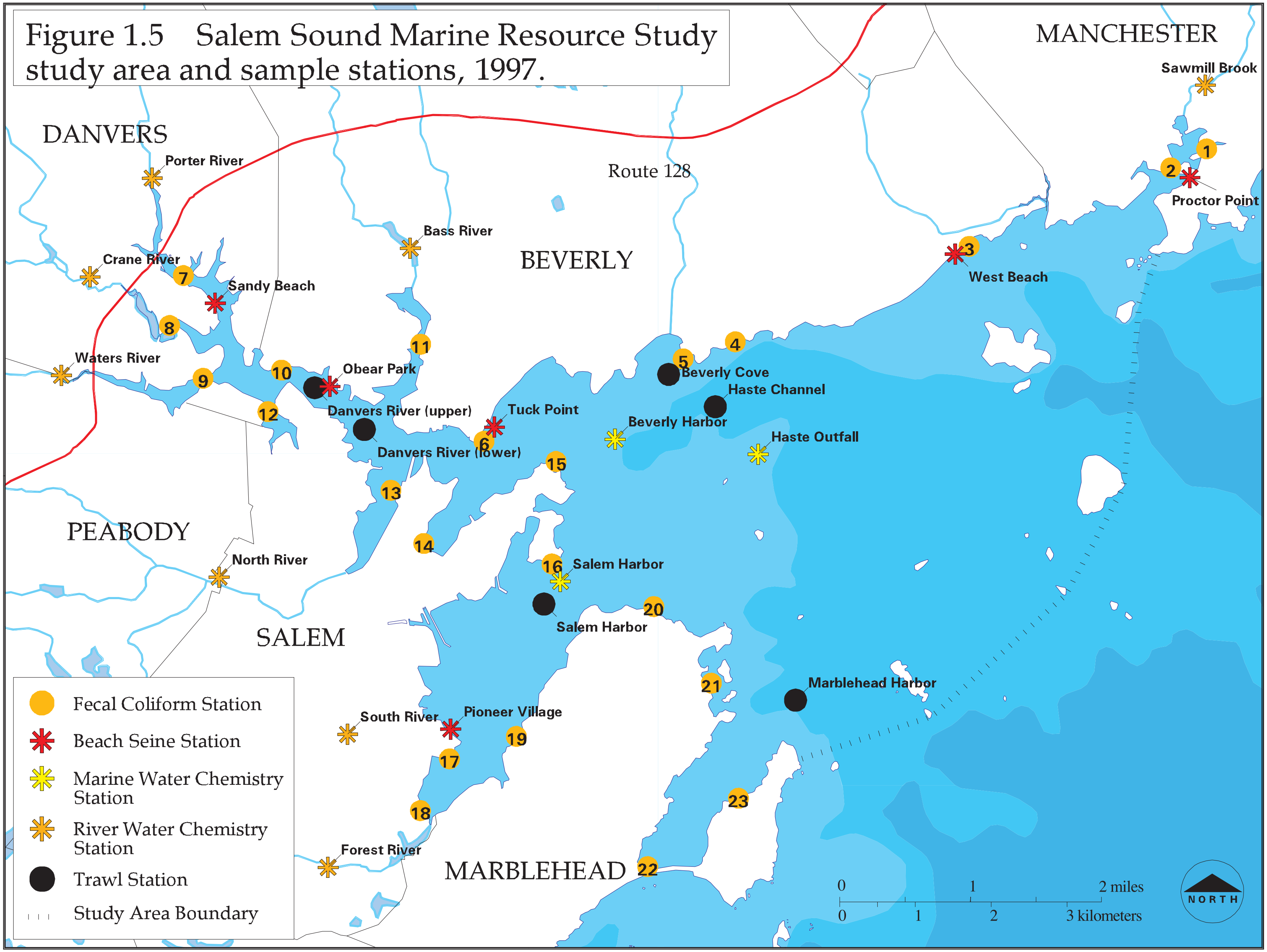


Table 1.3 Salem Sound marine and river sampling stations, 1997. The sampling target was 18 visits for the marine and primary river stations (Porter, North and Crane Rivers), and 12 for seine stations.

Station		Latitude	Longitude	Mean Depth (m)	Station Classification	Sample No. (Fisheries)	Sample No. (Water)
Subtidal- Trawl							
Beverly Cove		42° 32' 47"	70° 51' 03"	3.8	eelgrass	17	17
Danvers River	(upper)	42° 32' 43"	70° 54' 14"	5.5	river channel	18	18
Danvers River	(lower)	42° 32' 26"	70° 53' 47"	4.8	river channel	18	17
Haste Channel		42° 32' 34"	70° 50' 38"	11.2	harbor channel	17	17
Marblehead Harbor		42° 30' 37"	70° 49' 56"	12.7	outer channel	16	16
Salem Harbor		42° 31' 16"	70° 52' 11"	10.2	harbor channel	17	18
Marine- Water Chemistry							
Salem Harbor		42° 31' 25"	70° 52' 02"	8.6	marine	NA	18
Beverly Harbor		42° 32' 25"	70° 51' 30"	6.3	marine	NA	18
Haste Outfall		42° 32' 15"	70° 50' 15"	8.6	marine	NA	18
Intertidal- Seine							
Proctor Point,	Manchester	42° 34' 03.7"	70° 46' 21.3"	0.5-1.0	harbor beach	8	11
West Beach,	Beverly	42° 33' 38.1"	70° 48' 21.0"	0.5-1.0	dynamic beach	12	12
Tuck Point,	Beverly	42° 32' 26.6"	70° 52' 36.9"	0.5-1.0	harbor beach	12	12
Pioneer Village,	Salem	42° 30' 26.6"	70° 53' 01.6"	0.5-1.0	harbor beach	12	12
Obear Park,	Beverly	42° 32' 43.3"	70° 54' 05.4"	0.5-1.0	tidal river	12	12
Sandy Beach,	Danvers	42° 33' 16.7"	70° 55' 06.7"	0.5-1.0	tidal river	12	12
River- Water Chemistry							
Porter River,	Danvers	42° 34' 06.6"	70° 55' 40.2"	0.14	freshwater	NA	18
North River,	Peabody	42° 31' 27.7"	70° 55' 05.6"	0.27	freshwater	NA	18
Crane River,	Danvers	42° 33' 27.5"	70° 56' 14.0"	0.19	freshwater	NA	18
Waters River,	Danvers	42° 32' 48.4"	70° 56' 29.8"	0.19	freshwater	NA	14
Sawmill Brook,	Manchester	42° 34' 40.4"	70° 46' 12.6"	0.17	freshwater	NA	11
Bass River,	Beverly	42° 33' 38.0"	70° 53' 21.5"	-	freshwater	NA	7
Forest River,	Salem	42° 29' 31.9"	70° 54' 08.1"	0.16	freshwater	NA	6
South River,	Salem	42° 30' 24.8"	70° 53' 57.1"	0.11	freshwater	NA	5

Marine Water Chemistry. Basic water chemistry measurements were made during each visit to trawl and seine stations. We selected three additional stations for nutrient and basic water chemistry measurements in the study area. The purpose of these measurements was to characterize water chemistry and nutrient concentrations in Salem Sound relative to the existing SESD outfall and river inputs. The Haste Outfall station was located approximately 100 m from the outfall off Great Haste Island. Beverly Harbor and Salem Harbor nutrient stations were located at approximately 1.5 and 2.5 km from the outfall, respectively.

River Water Chemistry. We selected eight fixed river stations to measure basic water chemistry, nutrients, fecal coliform bacteria, and discharge of major freshwater inputs in Salem Sound. These stations were not sampled during the 1965 study. River stations were selected to be as close as practical to the tidal interface in order to characterize the watershed influence on freshwater chemistry. The presence of landmarks and suitability of streambed for discharge measurements also influenced station selections. The Porter, Crane, and North Rivers were selected for 18 visits in 1997. These three Danvers River tributaries discharge the most freshwater to the Sound and contained existing or former anadromous fish spawning runs. Five small streams were also selected for biweekly sampling during May through October: Bass and Waters rivers are tributaries to the Danvers River, South and Forest rivers flow into Salem Harbor, and Sawmill Brook flows into Manchester Harbor. The river names used are local names for the rivers near their coastal confluence. The names are consistent with DEP stream inventory classification (Halliwell et al. 1982) except for Porter River (DEP – Frost Fish Brook) and Sawmill Brook (DEP – Cat Brook).

Table 1.4 Salem Sound fecal coliform bacteria shore sampling stations, 1997.

Fig. 1.5 (No.)	Sampling Station	DMF Shellfish Area No.
	Manchester Harbor	
1	Masconomo Park	N15.1
2	Manchester YC	N15.1
	Beverly Shore	
3	West Beach	N16.0
4	Mingo Beach	N16.0
5	Lynch Park	N16.0
6	Tuck Point	N17.0
	Danvers River	
7	Porter River	N17.0
8	Crane River	N17.0
9	Waters River	N17.0
10	Fosters Point	N17.0
11	Bass River	N17.0
12	Kernwood River	N17.0
13	North River	N17.0
	Salem Shore	
14	Collins Cove	N17.0
15	Willows Pier	N17.0
16	Winter Island	N18.1
17	Forest River Park	N18.0
18	Forest River	N18.0
	Marblehead Shore	
19	Village Street	N18.0
20	Fluen Point	N19.0
21	Browns Island	N20.0
22	Inner Harbor	N20.0
23	Eastern YC	N20.0

Fecal Coliform Shore Stations. We established 23 shore sampling stations to measure fecal coliform concentrations in addition to sampling at marine and river stations (Figure 1.5, and Table 1.4). These shore stations were not sampled in 1965. Shore stations were selected for their proximity to shellfish beds in the interest of isolating significant sources of fecal contamination.

Shellfish Survey. We surveyed all intertidal area in the study area to evaluate potential shellfish habitat. Soft shell clam populations were targeted and the presence of other species of shellfish were recorded. The same intertidal clam flats surveyed in 1965 were revisited in 1997 and are shown in Figure 4.1. in Chapter 4.

Sampling Schedule. The monthly sampling design used in 1965 was enhanced to provide better coverage of the warmer months when greater biotic activity is expected. Marine and river water chemistry sampling was done on consecutive days during 18 sampling periods. Seining was conducted independent of the 18 sampling periods and remained on the monthly schedule used in 1965. Trawling and river water chemistry sampling trips were conducted monthly for January-April, November and December, and biweekly for May-October. The actual day of sampling was not fixed or randomly selected because boat operations and trawling were highly dependent on weather and tide conditions. During biweekly sampling, sampling periods were separated by the 15th day of the month and by at least two weeks.

Pioneer Village Beach Seine Station

CHAPTER 2. FISHERIES

Marine fishery resources were a major influence on human settlement in the Salem Sound region. The dependence on fisheries for food and commerce shown by early populations has diminished greatly. Currently, local fisheries constitute a small portion of the region's economy. However, the heritage of utilizing fishery resources is firmly imbedded in the culture of Salem Sound communities. Coastal communities continue to hold marine resources in high regard for their economic, recreational and ecological value. Information on fisheries harvest in this region is very limited. Both commercial and recreational fishery data are recorded on wider geographic scales. We did not conduct specific investigations on local fisheries during the 1997 study. We reviewed available DMF commercial catch records and federal recreational survey data in order to summarize the status of local fisheries in 1997.

Lobster fishery boats in Beverly Harbor

COMMERCIAL FISHERIES

Commercial fisheries were vital to the development of commerce and culture in communities of the Salem Sound region. The 1965 report includes a good account of these historical fisheries. The codfishing grounds off Marblehead have been routinely visited for spring and fall harvests for over 350 years. Commercial fisheries were major components of the region's economy during the 1600s until the mid-1800s, when nearshore stocks declined and other industries developed. As an example of the magnitude of the colonial fisheries, in 1732, there were 120 schooners fishing out of Marblehead, employing over 1,000 crew. Although commercial fisheries continue to decline in modern times, several fisheries still provide substantial economic benefits, and are traditional features to Salem Sound.

The lobster fishery was by a large margin the most important and valuable fishery in Salem Sound in 1965, and in 1997. In addition to the lobster fishery, modest fisheries occurred in Salem Sound in 1965 for groundfish with gillnets and for pelagic species (primarily mackerel) with trap nets. The ports of Beverly and Marblehead provided the primary infrastructure to support these inshore fisheries. The trap fisheries continue on a small scale. Gillnetting for groundfish has not been allowed within the Sound since the mid-1980s. The small-scale commercial harvest of striped bass, sea urchins, sea scallops and bait digging for clams and sea worms also continues to generate commercial landings in Salem Sound.

Lobster Fishery. The 1965 report recorded a commercial catch of 292,337 pounds of lobsters by 45 lobstermen. The estimated value of lobster catch in 1965 was about $244,000, the most valuable commercial fishery in the region. The importance of this fishery continues today. For all state waters in Massachusetts, the commercial lobster fishery is the most valuable fishery (Pava et al. 1998). Massachusetts' North Shore has long been a major producer of lobsters, and in 1997, Essex County landed more lobsters than any state county. A total of 134 commercial lobster permits were issued to fishermen in Salem, Danvers, Beverly, Marblehead, and Manchester in 1997, and total harvest recorded for these permits was 1,244,161 pounds (Figure 2.1).

Lobster catch records were summarized for 1963 to 1997(1966 data were missing) (Figure 2.1). Landings rose steadily from 1965, passing the million pound mark in 1978, and peaking at 1.86 million pounds in 1986. Landings have declined since 1986, and catches have ranged between 1.2 and 1.5 million since 1992. The number of permits issued has also declined from a peak of 188 in 1986 to 134 in 1997. Throughout this time series, Beverly and Marblehead have been the ports with the highest landings and the most licensed lobstermen. Landings increased sharply in the 1970s, an era marked by major changes in fishing practices. The numbers of pots set in the fishery and participants increased greatly, the use of 10-20 pot trawls replaced single pots and hydraulic haulers became standard equipment. Improvements to electronic navigation systems assisted the expansion of the fishery outside of Salem Sound into Massachusetts Bay. More fishermen began to fish over a wider spatial and temporal scale as they pursued lobsters during their fall migration out of the Sound.

The declining catches in the late 1990s are a cause of concern over the health of the lobster stock. The most recent stock assessment for the Gulf of Maine stock records high fishing mortality rates that result in an overfished classification for the fishery (NEFSC 1996).

Massachusetts DMF has monitored the lobster fishery in the Salem Sound region since 1981 (Estrella and Glenn 1998). Catch rates from sampled traps have fluctuated between 0.4 and 0.9 marketable lobsters per trap per haul since 1981. The catch rate in 1997 (0.42) was the second lowest during the period, yet a few years earlier in 1994 the catch rate (0.90) was the second highest on record for Salem Sound. An ongoing concern is the dependency of the fishery on lobsters harvested the first year after molting to legal size. Each year since 1984, over 90% of the harvest were comprised of these new recruits to the fishery.

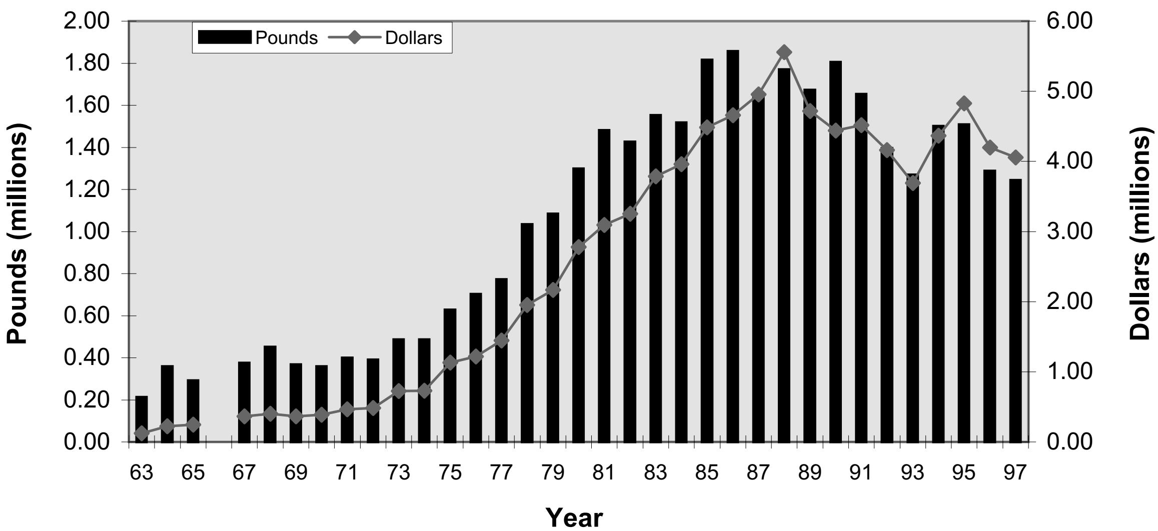
Trap Fishery. Trap nets have been deployed in Massachusetts Bay since the last century for the seasonal targeting of migratory pelagic species. Seven traps operated in 1965, with Atlantic mackerel as the primary target. Approximately 269,000 lbs. of mackerel and 100,000 lbs. of unspecified herring were caught in 1965. Two traps were set in Salem Sound during 1997 at similar locations around the outer islands as fished in 1965. Salem Sound trap records are not available because of confidentiality limitations when few fishermen are involved (Anderson et al. 1998). However, data are available for traps deployed at nearby Cape Ann locations from 1992 to 1997, and probably reflect similar conditions to Salem Sound catches. The Cape Ann fishery primarily targeted mackerel, with average annual catches of about 200,000 pounds. Minor catches of herring (unspecified) and menhaden (<5,000 lbs.) were also recorded.

Communication with a second generation North Shore trap fisherman, Tim Sullivan, provided details of this fishery. Atlantic mackerel remain the primary target, and secondary species such as squid and herring can be important incidental catches. The traps are typically in the water from early May to early June to target mackerel. Striped bass have become a common by-catch of his trap fishery in the 1990s. Regulations require that all striped bass be released, and release mortality is suspected to be low. The 1997 season was poor for mackerel, possibly due to adverse weather conditions during the mackerel run. In contrast, 1998 was a good season with over 100,000 pounds from the one trap.

Striped Bass. Records of commercial landings of striped bass were not available in 1965. Anecdotal observations indicate a robust rod and reel fishery existed during this time. Harvest records since 1986 in the Salem Sound area show increased participation and landings beginning in the mid-1990s. Striped bass are harvested commercially by rod and reel during a brief summer season under an annual quota. The available landings data are reported for catches made by fishermen who list their homeports as Marblehead, Salem, Beverly, Danvers, and Manchester. In 1997, 200 permits from these homeports recorded landings of about 16,000 lbs. worth nearly $25,000. The reported catches may not have exclusively come from Salem Sound or have been sold to Salem Sound ports. Most fish are sold in nearby Gloucester. The available data still show an overall trend of a modest fishery that provides supplementary income to a growing number of participants. The catch records also provide another reflection of increases in the population of striped bass along the East Coast in response to extensive restoration efforts beginning in the 1980s (ASMFC 1998a).

Sea Urchin. A fishery developed for green sea urchins in Salem Sound during the late 1980s in response to Asian market demand for raw urchin roe. Urchins are caught by scuba divers and draggers towing small dredges. The

Figure 2.1 Commercial lobster landings in Salem Sound from 1963-1997. Catch data recorded from DMF commercial permits issued in the ports of Salem, Marblehead, Beverly, Danvers, and Manchester.



fishery is regulated to occur in the fall after the majority of fixed gear in the lobster fishery is moved outside of Salem Sound. The dragger catch provides a majority of landings and peaked during the early 1990s when it was common to observe 10-20 boats working inside of Salem Sound (B. Chase, pers. comm.).

Commercial landing data for Salem Sound are not available because most catches were landed in Gloucester and catch location data are not recorded. The fishery clearly has declined in recent years. During 1997 sampling trips for this study and other field efforts we observed no more than three urchin draggers on a given day. A reduction in the urchin resource is the likely cause of declining catch and effort. Urchin dragging inside Salem Sound is contentious because of conflicts with lobster gear and concerns over habitat damage. Urchin divers believe that dredges negatively impacted the benthic community and over-harvested urchins in the 1990s. No quantitative evidence is available on dredge impacts on habitat in the Sound. The role of sea urchins as keystone consumers in hard bottom benthic communities (Witman 1996) further confounds this topic. Sea urchins can influence habitat structure and species richness through extensive kelp bed grazing.

Other Fisheries. Minor catches of sea scallops and soft shell clams and seaworms for bait were also made within Salem Sound in 1997. Scuba divers harvested scallops typically during the spring and early summer. Most harvesting actually occurs outside of Salem Sound in 50-80 feet of water. Catch records specific to this region were not available for 1997. Reportedly, less than 10 divers made intermittent catches of scallops to supplement their incomes. The commercial digging of seaworms and clams for bait has declined from 1965 when it provided primary incomes for some participants and commercial catch records indicate over 30,000 lbs. of seaworms sold. Local catch records are not available for 1997, but some digging was observed and catches primarily supplied local bait and tackle shops. The bait fishery decline is probably a function of both lower seaworm availability and the reduction in local demand because of the decline in the recreational winter flounder fishery.

RECREATIONAL FISHERIES

The 1965 report described a robust recreational fishery that attracted many anglers to the Salem Sound region. It was called "an excellent sportfishery"…… dependent on winter flounder……which abounds throughout the area through most of the year". Five boat liveries rented skiffs for fishing in the Sound. An estimated 27,800 skiffs were rented in 1965, with winter flounder as the primary target. Anglers also commonly targeted striped bass, mackerel, smelt and cod and haddock. A logbook provided by an avid recreational fishermen (J.P. Boucher, Salem) portrayed fishing conditions from 1963-1968 where there was no need to leave the Sound to catch groundfish, and ample catches of winter flounder, cod and haddock were made within Salem Harbor. Rod and reel catches of large numbers of adult winter flounder (20-80) were made from late spring to early fall with a half-day of effort.

Codfishing off Marblehead

Table 2.1 NMFS Marine Recreational Fisheries Survey results for Salem Sound for May-October, 1997 (N = 190 intercepts).

Species	Primary Target Species (No. of Intercepts)	Total Catch
striped bass	93	233
skate	0	68
Atlantic mackerel	3	23
winter flounder	8	12
bluefish	5	6
Atlantic cod	3	5
white perch	0	3
Atlantic tomcod	0	2
spiny dogfish	0	2
summer flounder	2	0

Three DMF surveys documented the prominence of winter flounder in Massachusetts' recreational fisheries during the 1960s and 1970s (Fitzpatrick and Russell 1961; MDMF 1977; and Anderson et al. 1975). A recreational fishing survey in 1960 found winter flounder was the most sought after species for all of coastal Massachusetts (Fitzpatrick and Russell 1961). A 1975 survey by DMF reached similar conclusions and found winter flounder was the top recreational fish on the North Shore in terms of catch and effort (MDMF 1977). A Salem Harbor study, as part of the power plant investigations, found winter flounder to comprise 70% of the total recreational catch for April to October in 1972 and 65% in 1973 (Anderson et al. 1975).

Recreational fisheries have clearly declined from this era, with the exception of a strong striped bass fishery in the 1990s. The recreational fishery specific to Salem Sound is not well documented and no surveys were conducted for the present study. The Marine Recreational Fisheries Statistical Survey conducted by NMFS covers most of the Massachusetts coast and provided limited data on Salem Sound. This survey conducts dockside interviews (intercepts) of anglers returning from fishing trips. A total of 190 intercepts are available for the municipalities along Salem Sound during May-October 1997 (Pers. Comm. NMFS, Fisheries Statistics and Economics Division) (Table 2.1). Striped bass clearly dominated as a target and catch in Salem Sound's recreational fisheries. Despite the data limitations, the rank of top five targets (striped bass, bluefish, mackerel, cod and winter flounder) was similar for the 1965 fishery, except for the addition of bluefish. The data set also highlights the common presence of skate as bycatch, and minor targeting for winter flounder (<5% of trips).

As much as striped bass are a success story in Salem Sound and elsewhere, the reduction of the winter flounder fishery represents a tremendous loss of economic and recreational opportunities. A single boat livery operated in Salem Sound in 1997 at the Salem Willows fishing pier and continued to rent skiffs for the day. Catch and effort data were not available for this business. Nine bait and tackle shops operated in the Salem Sound region and all were visited several times in 1997 to discuss fishery issues. Bait shop owners unanimously stated that striped bass were keeping shops in business and the twenty year drop in the winter flounder fishery has left a large void in their income and fishing opportunities for the average angler. Efforts have been in place since the mid-1980s to reduce all harvest of winter flounder. A 12 inch minimum size went into effect in 1986, and in 1990 the recreational season was closed for the March and April spawning period and a 10 fish per angler bag limit was enacted. Seasonal restrictions and a ban on night dragging in state waters were implemented in the 1980s to reduce commercial pressure.

In 1997, the bait and tackle shop owners indicated that the attainment of the winter flounder bag limit was a rare event, usually reserved for an angler with much knowledge of the Sound. During over 30 boat sampling trips in Salem Sound in 1997, little fishing effort for winter flounder was observed. We did not observe any angling for winter flounder in Salem Harbor. In contrast, the 1972–1973 sportfish survey conducted 30 weekly trips to Salem Harbor for each year and observed an average of 22 fishermen per weekday in 1972 and 28 per weekday in 1973, with winter flounder as the primary target (Anderson et al. 1975).

In addition to the decline in recreational winter flounder catches, angling has also declined for cod, haddock and smelt since the 1965 study. Cod and haddock are no longer common targets within Salem Sound. Local anglers continue to pursue cod in the spring and fall outside of Salem Sound. Few fishermen now target smelt at any time in the Sound. Fishing for bluefish is a positive change from 1965 to 1997. Catches of bluefish were not recorded in 1965 as few bluefish visited the Gulf of Maine in those years. Present catches are less consistent than that found in the late 1970s and 1980s, but an annual run of bluefish is expected each year and provide an excellent gamefish for anglers. Another change from 1965 is the catch of summer flounder. Incidental catches of this large, predatory flounder have increased in Salem Sound during the late 1990s.

CHAPTER 3. WATER CHEMISTRY

Marine organisms depend on clean water to support metabolic and habitat requirements. Nutrients are essential for marine plant production, but at high concentrations can be toxic to some organisms and result in excessive plant growth and reduced dissolved oxygen in the water column. Our objective was to compare water chemistry in Salem Sound and its tributaries to water quality standards for supporting aquatic life (Table 3.1), and identify associations between water quality and major sources of pollution. The following three types of measurements were made: basic water chemistry, nutrient, and pathogen indicator (fecal coliform bacteria). Most previous measurements of water chemistry in Salem Sound were conducted as part of environmental permit applications, and were short-term with low sampling frequencies. This is the first investigation in Salem Sound to routinely measure water chemistry at both marine and river stations, and relate findings to aquatic communities and sources of pollution.

METHODS

BASIC WATER CHEMISTRY MEASUREMENTS

The following parameters (with accuracy in parentheses) were measured each seine, trawl and river sampling trip using a YSI 6820 multi-parameter water quality monitor: water temperature (± 0.15 °C), depth (± 0.12 m), dissolved oxygen (± 0.2 mg/l), dissolved oxygen saturation (± 2% of air saturation), specific conductivity (± 0.5% of reading plus 0.001 mS/cm), salinity (the greater of ± 1.0% of reading or 0.1 ppt), pH (± 0.2 units), and turbidity (the greater of ± 5% of reading or 2.0 NTU). We calibrated the YSI 6820 using standard methods before each deployment. Hydrolab Surveyor II and YSI 6000 multi-parameter water quality instruments were used as back-ups and calibrated with the same process. Dissolved oxygen (DO) measurements were not made before dawn (period of minimum concentrations) because of the time constraint of sampling 6-8 stations.

Trawl and Marine Stations. We measured surface and bottom water chemistry by positioning the YSI 6820 sonde at approximately 0.5 m from the surface and within one meter from the bottom. We measured light penetration (± 0.5 m) using a 0.25 m standard secchi disc. Tidal stage in hours was recorded relative to the nearest low tide at Boston Harbor (White 1997).

Seine Stations. At each station, a single water chemistry measurement was recorded at a location between the two seine replicates and at about half the haul depth. Only surface measurements were made, with the sonde positioned approximately 0.5 m from the surface. Tidal stage in hours was recorded relative to the nearest low tide at Boston Harbor (White 1997).

River Stations. At each station, a single water chemistry measurement was recorded at a location selected to represent mixed river flow. The sonde was placed on the stream bottom at the same location for each visit. Because some stream locations were close to the zone of tidal influence, sampling at tide stages that influenced freshwater flow was avoided. Tidal stage in hours was recorded relative to the nearest high tide at Boston Harbor (White 1997) corrected by site specific delays. Stream flow discharge was measured with a Teledyne-Gurley 622-AA current meter attached to a wading rod. Discharge transects with uniform streambed dimensions were selected, and three velocity measurements per meter were made at each station.

NUTRIENT MEASUREMENTS

Nutrients were not sampled in 1965, and few measurements have been made in Salem Sound or freshwater tributaries since then. We selected nutrient parameters and the sampling approach from the MWRA Boston Harbor Program, which has conducted extensive nutrient sampling in Boston Harbor and Massachusetts Bay since 1992. The primary focus was to identify influences from anthropogenic nutrient enrichment. The following parameters were measured: nitrite/nitrate, ammonium, ortho-phosphate, total dissolved phoshorus (TDP), total dissolved nitrogen (TDN), silicate, particulate organic nitrogen (PON), particulate organic carbon (POC), and chlorophyll *a*. Ratios of dissolved inorganic nitrogen (DIN, or nitrite/nitrate/ammonium) to silicate and ortho-phosphate were calculated to compare ambient conditions to optimal ratios for phytoplankton growth.

The three largest Danvers River tributaries (Porter, Crane, and North rivers) were sampled during each sampling period. Chlorophyll was sampled only at these three stations, during March-December. The remaining river stations were sampled during May through December. Three Salem Sound marine stations (Salem Harbor, Beverly Harbor and Haste Outfall) were selected to provide baseline nutrient concentrations in relation to watershed inputs and the SESD effluent outfall. Data from a MWRA station in Massachusetts Bay were used for comparison to the three Salem Sound marine stations.

Sampling protocols were adopted from the Estuarine & Coastal Chemistry Laboratory at the University of New Hampshire (UNH) and are outlined in Loder and Boudrow (1997). The UNH laboratory measured all nutrients except PON, POC and chlorophyll a, which were subcontracted to the School for Marine Science and

Table 3.1 Massachusetts Surface Water Quality Standards (MDEP 1996).

Specific criteria are set for classifying waterbodies that relate water quality to the following designated uses: aquatic life, fish consumption, water supply, primary and secondary contact recreation, aesthetics, agricultural and industrial uses, and shellfish harvesting. The harbors and tidal rivers of Salem Sound are designated as Class SB, except for Marblehead Harbor which is Class SA.

The following water quality criteria are used by DEP to assess the status (*support*, *partial support*, or *non-support*) of waterbodies for the designated uses of aquatic life and primary recreation. These parameters were measured at river and marine sampling stations in Salem Sound during 1997. The table values are the minimum to *support* the designated uses.

Parameter	Class	Unit	Note
Dissolved Oxygen	Aquatic Life (SA)	$\geq$ 6.0 mg/l	$\geq$ 75 % saturation
	Aquatic Life (SB)	$\geq$ 5.0 mg/l	$\geq$ 60 % saturation
Temperature	Aquatic Life (Coastal)	$\leq$ 29.4^{o}C	$\leq$ 26.7^{0}C max. daily mean
pH	Aquatic Life (Coastal)	6.5 - 8.5	0.2 max. change from normal range
Turbidity	Aquatic Life (Coastal)	5 NTU	max. change from normal range
	Primary Recreation	$\geq$ 1.2 m	secchi disk depth
Fecal Coliform Bacteria	Primary Recreation	$\leq$ 200/100 ml	geometric mean for $\geq$ 5 samples (<10% of samples >400/ml)

DEFINITIONS

CLASS SA *"These waters are designated as an excellent habitat for fish, other aquatic life and wildlife and for primary and secondary recreation. In approved areas they shall be suitable for shellfish harvesting without depuration. These waters have excellent aesthetic value."*

CLASS SB *"These waters are designated as habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas they shall be suitable for shellfish harvesting with depuration. These waters have consistently good aesthetic value."*

AQUATIC LIFE *"use is supported when suitable habitat is available for sustaining a native, naturally diverse, community of aquatic flora and fauna".*

PRIMARY RECREATION *"use is supported when conditions are suitable for any recreation or other water use in which there is prolonged and intimate contact with the water with a significant risk of ingestion of water".*

Technology (SMAST) at the University of Massachusetts, Dartmouth. The UNH analyses were made with a Lachat QuickChem 8000 autoanalyzer, and SMAST used a Perkin Elmer 2400 Elemental analyzer. The minimum detection limits and analytical precision for parameters are reported in Table A.1.

We collected all river and marine nutrient samples using acid-washed materials (10% hydrochloric acid) and held samples on ice until processed later in the day at the DMF Gloucester laboratory. Once processed, samples were held in a -80°C freezer until transfer to UNH and SMAST laboratories. Quality assurance and control protocols of DEP's 104B(3) program were adopted for the nutrient measurements. Analysis of the Relative Percent Difference (RPD) of duplicates was the primary method for assessing sample precision. Refer to Chase (1999) for further details on sample collection, processing, analysis and quality assurance/control protocols.

Annual TN (total nitrogen) load (mt/yr) was estimated for the five major freshwater inputs to Salem Sound by multiplying monthly TN concentrations by discharge (m^3/s) measurements for each river (Isaac and Cooperman 2000). Discharge and TN values for May-October are biweekly averages. February values were adopted for January when no flow measurements were made. Missing values for Sawmill Brook and Waters River were estimated by applying a ratio (monthly contribution of TN and discharge to annual budget) from the primary stations (average for Crane, Porter, and North rivers) to the mean of May-December measurements for Sawmill Brook and Waters River. The river TN load was compared to SESD's effluent input and marine concentrations to provide insight on the sources of TN to Salem Sound. Daily sewage discharge data were available from SESD, and effluent nitrogen measurements were made 12 to 26 times per month in 1997 (SESD 1998). These data were converted to m^3/s and TN mg/l and compared to river inputs.

FECAL COLIFORM SAMPLING

Surface water samples were collected at marine, river, and shore stations in sterilized polypropylene bottles and maintained at less than 10°C until analyzed. Shore sampling targeted the final three hours of ebb tide. The sampling schedule did not allow for targeting dry or wet weather conditions, although rainfall data (NCDC 1998) assisted in the interpretation of results. Shore stations (23) were all located on intertidal habitats adjacent to shellfish growing areas. Shore samples were analyzed within six hours of collection, and river and marine samples within 24 hours at DMF's Gloucester Laboratory. Samples were collected and processed utilizing the A-1 technique according to standard methods of the National Shellfish Sanitation Program (NSSP) (NSSP 1997). Fecal coliform densities were reported as the most probable number per 100 ml of water. The geometric mean and tenth percentile of fecal coliform results were calculated by station according to NSSP methods (NSSP 1997).

WATER TEMPERATURE MONITORING

Three Ryan Tempmentor thermographs were deployed in Salem Sound to record continuous (every 2 hours) water temperature measurements in 1997. The specified accuracy of ±0.3°C was confirmed with a certified thermometer prior to use. Two locations were selected for monitoring: the Salem Harbor water chemistry station, and Glover Wharf Marina along the Beverly Harbor waterfront. Surface and bottom temperature monitors were set off a floating slip close to the harbor channel at Glover Wharf. The Salem Harbor monitor was attached to a mooring that also served as the water chemistry station mooring. Only bottom temperature was monitored at the Salem Harbor location.

RESULTS

SEINE STATIONS (INTERTIDAL HABITAT)

Monthly water chemistry measurements were made at all seine stations, except Proctor Point, which was not sampled in January because of ice. All measurements of basic water chemistry were within limits that support aquatic life (Tables A.2, A.3 and A.4). Violations of DEP water quality criteria were not found for these parameters. Most parameters did not vary greatly among stations or seasons. Salinity was slightly depressed at the Danvers River stations, and DO and water temperature displayed seasonal trends. The upstream Danvers River station, Sandy Beach, showed the most freshwater influence, with a mean salinity of 29.3 ppt. The annual means of the other stations were closely matched (30.6 to 31.4 ppt). The lowest DO saturation level recorded was 86% and the annual means for all stations were supersaturated. Pioneer Village had the warmest annual mean water temperature (12.0°C). Annual means ranged from 10.4 to 11.6°C at the other stations. Thermal warming from the Salem Harbor power plant discharge of cooling water influenced water temperature at Pioneer Village. This effect was apparent when comparing the mean temperature of the seine stations during the cooler months of November-April when temperature changes are conservative (Table 3.2).

Table 3.2 also compares water chemistry data from 1997 to 1965, when the stations and sampling schedule were nearly identical. Only water temperature, salinity and DO were suitable parameters for comparison between the two studies. Salinity provides a good comparison because of the similar sampling accuracy and consistency of salinity in marine waters. Salinity measurements were similar for the two time periods. Annual means of DO for both periods were similar and reflected high saturation levels in the intertidal zone. Water temperatures were cooler in 1965 than in 1997. The influence of the Salem Harbor power plant on water temperature at Pioneer Village during the cooler months apparently also occurred in 1965, but to a less extent than 1997. Despite the apparent differences in water temperatures between studies and between Pioneer Village and other stations none of these differences were statistically significant (t-test, df = 10 and 22, $P > 0.05$).

MARINE STATIONS

Water chemistry was measured during 18 sampling trips at the trawl and nutrient stations in 1997 (Table 3.3). Some stations were sampled for water chemistry less than eighteen times because of technical problems. The general trends in these data correspond with the major water chemistry characteristics known for Salem Sound: it is a well-flushed embayment with minimal stratification from October to April, minor freshwater influences, and rare violations of SA criteria for bottom water DO (CDM 1978; CDM 1987; CDM 1991; Dallaire and Halterman 1991; and SESD 1998). No comparisons were made to water chemistry data collected during the 1965 trawling trips because only surface water temperature and salinity were recorded in 1965 and few samples were collected (5-11 per station). The following paragraphs summarize major trends for water chemistry parameters that displayed temporal or spatial variation.

Table 3.2 Water temperature, salinity, and dissolved oxygen at beach seine stations in 1965 and 1997. The *Cool Months* (°C) data are mean values from November-April. Monthly samples were collected at each station (N = 12) in 1997, except for Proctor Point (N = 11), where the average January temperature for the other stations was applied to the missing January value.

Station	Water Temperature *Annual Mean (°C)* 1965	Water Temperature *Annual Mean (°C)* 1997	Water Temperature *Cool Months (°C)* 1965	Water Temperature *Cool Months (°C)* 1997	Salinity *Annual Mean (ppt)* 1965	Salinity *Annual Mean (ppt)* 1997	Dissolved Oxygen *Annual Mean (mg/l)* 1965	Dissolved Oxygen *Annual Mean (mg/l)* 1997
Proctor Point	9.7	11.3	3.4	5.0	30.3	30.6	10.0	10.1
West Beach	9.1	10.4	3.9	5.2	31.8	31.3	9.9	10.1
Tuck Point	9.6	10.5	3.8	5.0	31.3	31.2	9.8	9.9
Pioneer Village	9.9	12.0	4.8	7.1	31.3	31.4	10.0	9.9
Obear Park	11.1	10.8	4.2	5.2	28.4	30.6	8.8	9.7
Sandy Beach	-	11.6	-	5.1	-	29.3	-	9.5
All Stations	9.9	11.1	4.0	5.4	30.6	30.7	9.7	9.9

Table 3.3 Salem Sound water chemistry at trawl and nutrient stations: mean values for January-December, 1997.

Parameters		Danvers River (Upper)	Danvers River (Lower)	Beverly Harbor	Beverly Cove	Haste Channel	Haste Outfall	Marblehead Harbor	Salem Harbor
Samples		18	17	18	17	17	18	16	18
Temp. (°C)	*surface*	11.5	11.9	11.0	11.4	11.4	11.0	11.7	12.6
Temp. (°C)	*bottom*	11.3	12.2	9.8	11.3	9.6	9.3	9.3	9.6
Salinity (ppt)	*surface*	31.4	31.3	31.9	31.7	31.8	31.8	32.1	32.1
Salinity (ppt)	*bottom*	31.4	31.7	32.3	32.0	32.1	32.3	32.4	32.3
Sp. Cond. (mS/cm)	*surface*	47.9	48.2	48.7	48.7	49.6	48.4	48.8	48.9
Sp. Cond. (mS/cm)	*bottom*	48.0	48.3	49.2	48.8	48.9	49.2	49.4	49.2
pH	*surface*	7.8	7.8	7.9	7.9	7.9	7.9	7.9	7.9
pH	*bottom*	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9
D.Oxygen (mg/l)	*surface*	9.4	9.2	10.1	9.9	10.0	10.0	10.0	10.1
D.Oxygen (mg/l)	*bottom*	9.2	9.2	10.1	10.0	9.4	9.8	9.5	9.7
D.Oxygen (% sat.)	*surface*	102.4	104.2	109.8	110.5	111.4	109.3	110.5	113.8
D.Oxygen (% sat.)	*bottom*	100.9	102.8	108.1	110.3	100.3	103.2	99.4	102.0
Turbidity (NTU)	*surface*	9.9	5.2	1.2	1.1	0.9	7.8	2.1	3.8
Turbidity (NTU)	*bottom*	3.9	4.9	1.5	2.4	2.0	4.5	2.2	3.9
Secchi disc (m)		3.2	3.6	4.1	-	4.7	3.8	4.7	3.5
Depth (m)		6.0	5.4	6.3	4.3	10.9	8.6	13.1	8.6

Salinity. Salinity measurements were stable and consistent among stations and seasons. Most measurements were in the range of 31-32 ppt. There was minor evidence of stratification during the summer because of thermal warming and reduced mixing. The greatest difference between mean surface and bottom salinity was 0.5 ppt at the Haste Outfall station. This minor difference may result from freshwater in the discharge effluent. Freshwater inputs influenced the depression of salinity at the Danvers River trawl station. The lowest mean salinity for surface water among stations was 31.3 ppt at the lower river station. The highest mean salinity was 32.4 ppt at Marblehead Harbor, the most seaward station.

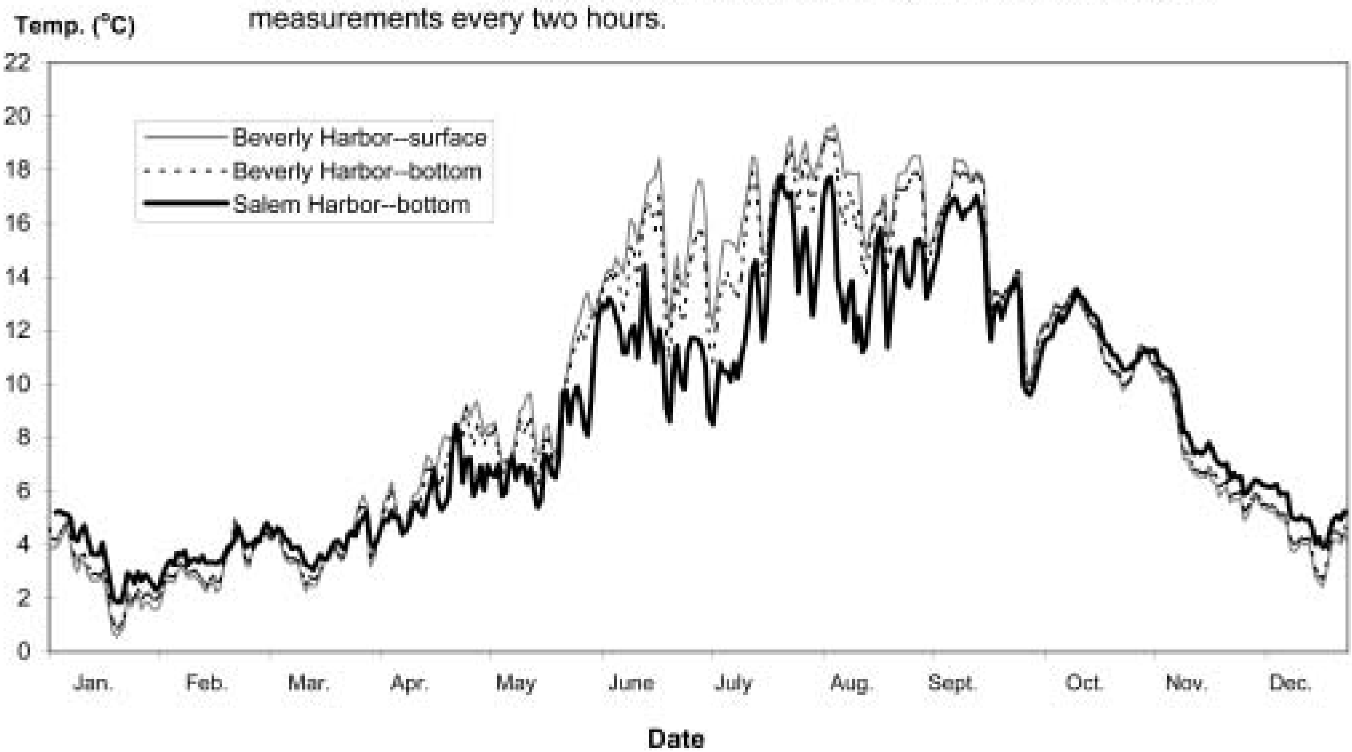
Water Clarity. The measurements of turbidity and secchi disc depth reflected relatively good water clarity at most sample stations. Mean turbidity measurements were low (range of 1-3 NTU) and mean secchi disc depth was at least three meters at each station, and exceeded four meters at three stations. The upper Danvers River station had the lowest water clarity. This is probably related to particle suspension from watershed inputs and estuarine flushing. The highest turbidity outside of the Danvers River occurred at the Haste Outfall station. Visual observations of the outfall plume confirmed that these measurements were elevated by the SESD outfall discharge.

Dissolved Oxygen. All measurements of DO at marine stations in 1997 produced concentrations adequate to support aquatic life. The lowest bottom DO level measured was 75.3% saturation (Upper Danvers River station in August) and only three bottom measurements out of over 130 were less than 80% saturated. The mean surface concentrations of DO at all stations were supersaturated (>100%). The only mean bottom concentration of DO that was not supersaturated occurred at Marblehead Harbor station, the deepest marine station (mean depth of 13.1 m). Evidence of minor seasonal stratification of DO was found at all stations. The difference between surface and bottom DO concentrations was greatest during summer and differences were proportional to station depth.

Table 3.4 Mean monthly water temperature recorded by thermographs at the Salem Harbor marine station and Glover Wharf in Beverly Harbor, 1997.

	Beverly Harbor *Surface*		**Beverly Harbor** *Bottom*		**Salem Harbor** *Bottom*	
	(°C)	(sd)	(°C)	(sd)	(°C)	(sd)
January	2.5	1.15	2.8	1.16	3.5	1.10
February	3.0	0.77	3.2	0.65	3.6	0.46
March	3.8	0.91	3.9	0.77	4.1	0.55
April	6.5	1.71	6.2	1.48	5.6	1.16
May	9.0	1.65	8.4	1.55	7.2	1.29
June	14.9	1.64	14.0	1.51	11.4	1.43
July	16.5	1.83	15.4	2.12	12.8	2.74
August	17.7	1.31	16.9	1.39	14.1	1.76
September	16.1	1.97	15.9	1.85	14.9	1.64
October	11.7	1.20	11.7	1.17	11.7	1.14
November	8.2	2.13	8.4	2.04	8.9	1.79
December	4.4	0.94	4.6	0.91	5.4	0.80
1997 mean	9.5		9.3		8.6	

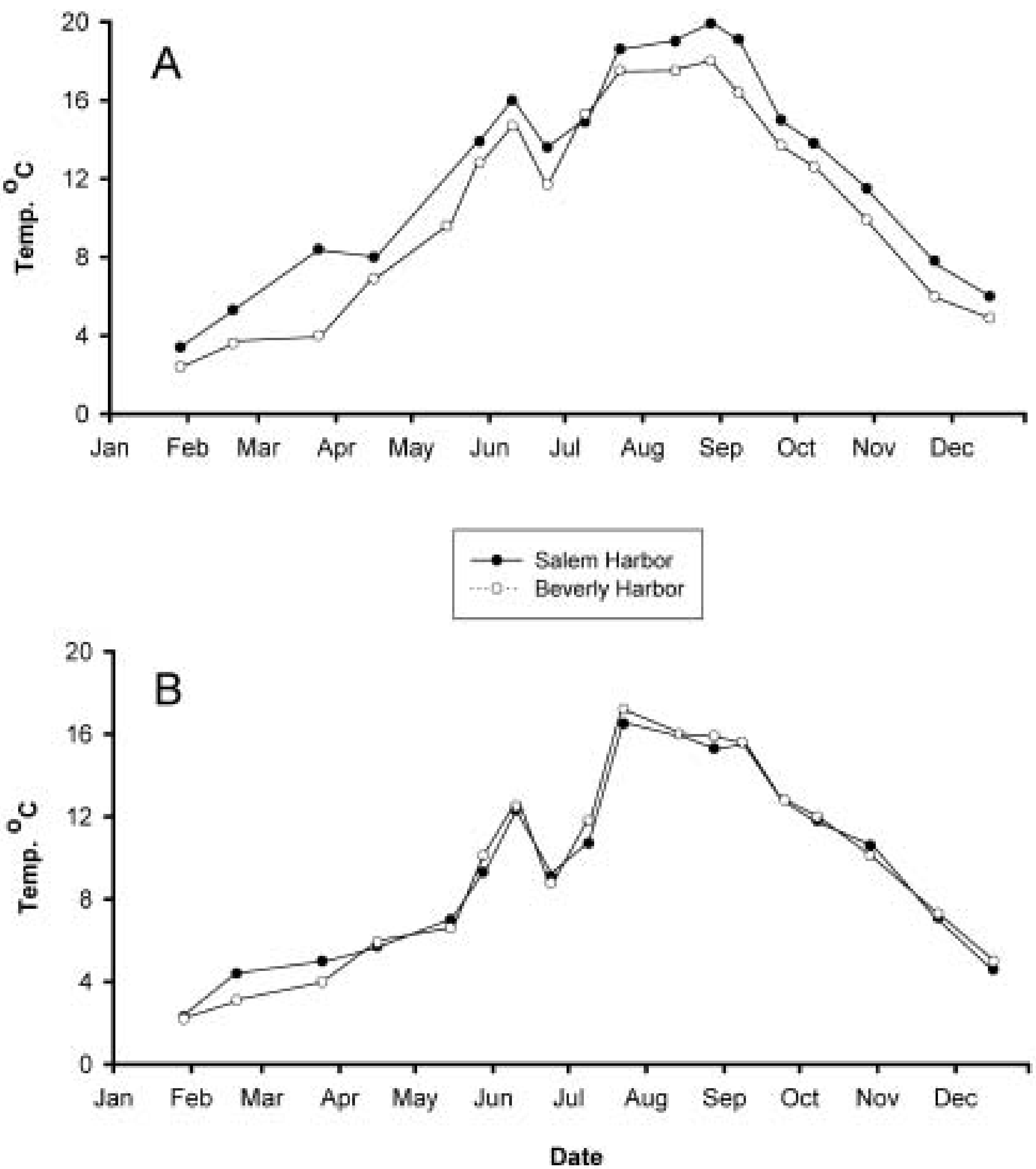
Figure 3.1 Average daily water temperature in Beverly Harbor and Salem Harbor, 1997. Thermographs were deployed to record water temperature measurements every two hours.



Water Temperature. Water temperature was the most dynamic water chemistry parameter measured as it changed in response to seasonal warming and cooling. Water temperatures warmed rapidly in the spring resulting in minor stratification at most stations from May through September. The coolest mean bottom temperature (9.3ºC) occurred at the two deepest stations, Haste Channel and Marblehead Harbor. The warmest mean surface temperature occurred at the Salem Harbor station, located about 0.75 km from the Salem Harbor power plant thermal discharge. This station also had the largest difference between mean surface and bottom temperatures (2.8ºC).

The recordings of the continuous water temperature monitors displayed a substantial amount of daily variation, especially for the warmer months of May-October (Figure 3.1). The surface and bottom temperatures in Beverly Harbor were closely matched from October to April, and then showed a slight differential due to surface warming (Table 3.4). Tidal action in the Danvers River

Figure 3.2 Surface (A) and bottom (B) water temperature (°C) at Salem Harbor and Beverly Harbor stations, 1997.



appeared to be mixing the entire water column in Beverly Harbor with minor stratification in the summer. Salem Harbor bottom temperatures followed a similar trend as in Beverly Harbor, although November to April temperatures were slightly warmer and May-October temperatures were slightly cooler. A comparison of water temperature at Salem Harbor and Beverly Harbor stations (Figures 3.2) illustrate the surface warming in Salem Harbor and lack of evidence of warming lower in the water column.

RIVER STATIONS

The Porter, Crane and North Rivers stations were visited during all 18 sampling periods to measure basic water chemistry. The remaining five river stations were visited from May through December. Boston's Logan Airport records in 1997 indicated that rainfall was more than 11 inches (27%) under the annual average (NCDC 1998), resulting in low flows throughout the North Coastal Basin (Socolow et al 1998). These flow conditions clearly influenced discharge measurements in 1997 and precluded water chemistry measurement in several of the smaller streams during the warm months. Water chemistry at the river stations reflected conditions supportive of aquatic life according to SB criteria. During summer, numerous DO measurements were below SA criteria, but only two fell below SB criteria. Violations of water pH criteria (< 6.5 pH) only occurred at Sawmill Brook. Raw data for river stations are in the Appendix (Tables A.5-A.9) and annual mean data are presented in Table 3.5. The following paragraphs summarize major water chemistry trends at the river stations.

Porter River. Several parameters measured in the Porter River reflected good water quality in comparison to the other river stations. The water temperature remained relatively cool in the warmer months, not exceeding 20°C (Figure 3.3). Dissolved oxygen levels were the highest of all stations (mean = 10.5 mg/l) and only once did DO saturation fall below 80% (Figure 3.4). Turbidity and pH were found in a similar range as most other river stations and were supportive of aquatic life.

Crane River. This station showed signs of a stressed river system. Dissolved oxygen averaged 82% saturation for the year, with five measurements below 75% and one SB violation in August (59%). Water temperature reached 20°C during each visit during June through August. The mean turbidity was the highest among river stations (14.1 NTU). The mean specific conductivity was relatively high, approaching 1.00 mS/cm during the coldest months. Crane River had the second highest mean discharge among river stations (0.173 m^3/s), although similar to the other stations, experienced very low flows during the summer (Figure 3.5).

North River. Most basic water chemistry parameters were at similar levels as the other river stations. Dissolved oxygen averaged 88% saturation for the year and fell slightly below 75% saturation only on three occasions. The turbidity mean of 5.2 NTU was the lowest among river stations. The North River is the largest river in the Salem Sound region and drains a large area of developed watershed in Salem and Peabody. Discharge measurements were the highest at this station, averaging 0.230 m^3/s for the year.

Sawmill Brook. Limited comparisons of the water chemistry at Sawmill Brook and the remaining stations are possible because of lower sampling frequency and low flow conditions. The flow levels at Sawmill Brook were too low for most of September and October to be quantified, but water chemistry measurements were still possible. Sawmill Brook had the lowest pH and DO levels among river stations, and second lowest specific conductivity. More than half of the pH measurements were below SB criteria (6.5 pH). Approximately half of the DO measurements were below SA criteria (75% saturation).

Table 3.5 Salem Sound water chemistry at river stations: mean values for January-December, 1997.

Station	Sample (No.)	Water Temp. (°C)	Salinity (ppt)	Sp. Cond. (mS/cm)	pH	D.O. (mg/l)	D.O. (% sat.)	Turbidity (NTU)	Flow (m^3/sec.)
North River	18	13.2	0.0	0.70	7.2	9.5	88.0	5.2	0.230
Crane River	18	13.2	0.0	0.72	7.2	8.9	82.1	14.1	0.173
Porter River	18	11.5	0.0	0.66	7.1	10.5	94.6	7.7	0.084
Waters River	14	14.4	0.0	0.93	7.2	9.4	91.8	6.2	0.025
Sawmill Brook	13	13.3	0.0	0.28	6.3	8.0	75.2	8.1	0.099
Bass River	7	16.8	0.0	0.26	7.7	10.0	100.8	5.4	0.048
Forest River	6	14.3	0.0	0.55	7.3	9.2	88.2	8.6	0.044
South River	5	12.7	0.0	0.52	7.1	7.8	65.6	5.3	0.051

Figure 3.3 Water temperature (°C) at Salem Sound river stations, 1997.

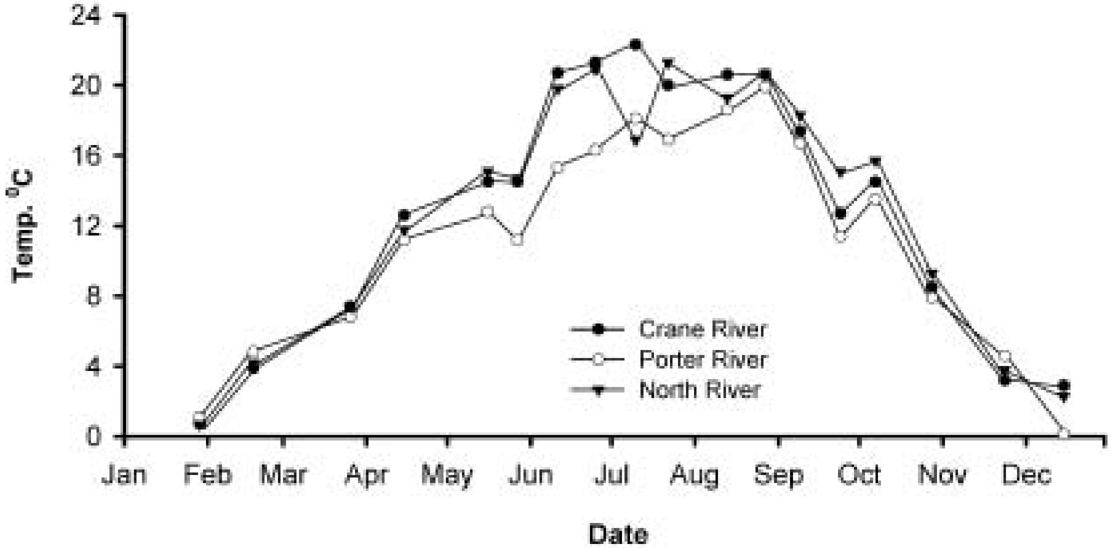
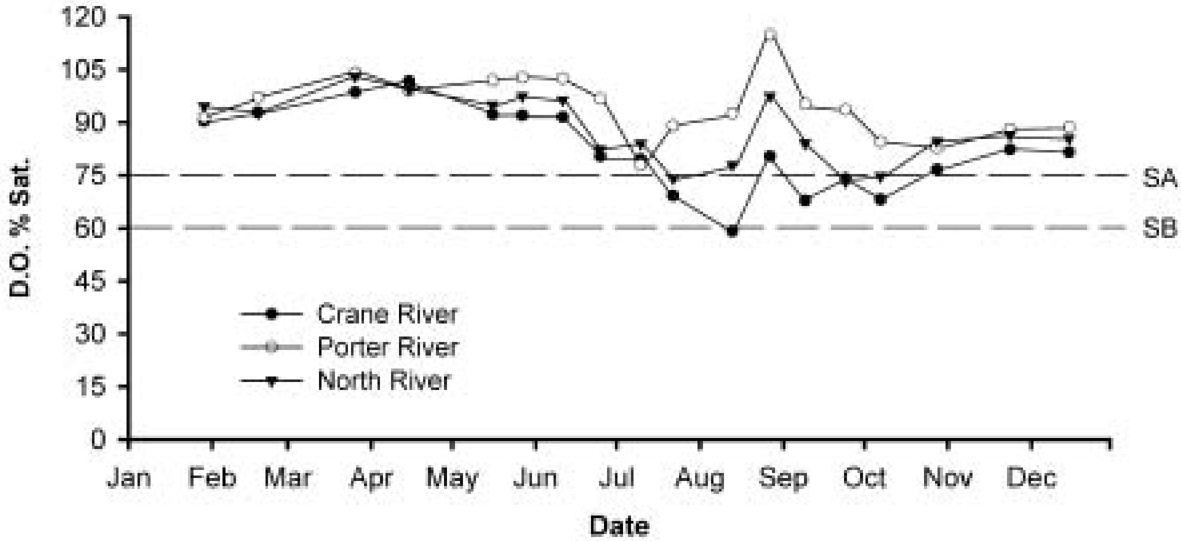


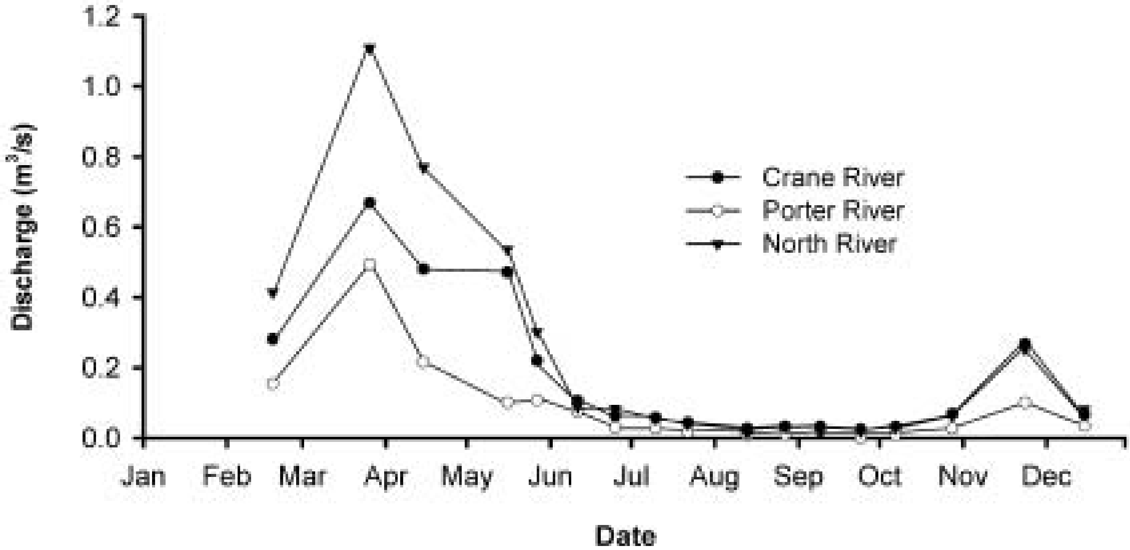
Figure 3.4 Dissolved oxygen (% saturation) at Salem Sound river stations, 1997. SA and SB criteria for supporting aquatic life (MDEP 1996) are indicated.



Waters River. The freshwater portion of Waters River contains two small creeks that cross under Endicott Street. Sampling was conducted just below the downstream confluence of the two creeks. This location was within the zone of tidal influence. Specific conductivity was variable and high on occasion, even though measurements were made close to low tide. Wet weather quickly degraded water quality in this river, although dry weather water quality was relatively good for the parameters measured.

Bass River, Forest River and South River. These stations were sampled infrequently because of low flows, making it difficult to draw conclusions from the measurements. The stations clearly contributed minor amounts of freshwater to Salem Sound during 1997. The freshwater portion of the Bass River flows out of Shoe Pond, which is regulated by the Beverly Municipal Golf Course. Freshwater could be consistently sampled only at the spillway of the Shoe Pond Dam, however, no water spilled over the dam during August, September and October station visits. During this

Figure 3.5 River discharge (m^3/s) at Salem Sound river stations, 1997.



same period, the Forest River was nearly dry and South River was dry and the streambed was overgrown with vegetation. Despite the few measurements, the low specific conductivity (0.26 mS/cm) and high pH (7.7 pH) at the Bass River were notable. The high pH is a concern because ammonia toxicity increases at levels close to 8.0 pH.

FRESHWATER NUTRIENTS

River Stations. The North, Porter and Crane Rivers were measured for nutrients during each sampling period. Summary statistics for these stations and Sawmill Brook and Waters River are provided in Table 3.6. Nutrient data for South River, Bass River, and Forest River are not included because low flow conditions limited sampling to 5-7 periods. Raw nutrient data for all river stations are presented in the Appendix (Table A.10-A.15). Seasonal trends of major nutrient concentrations at the three primary stations were plotted for 1997 (Figures 3.6 and 3.7). High concentrations of silicate, ortho-phosphate, and DIN occurred during the late-winter and spring period of high run-off, as expected because of the correlation between precipitation and watershed nutrient concentrations (Boynton et al. 1995; Ward and Twilley 1986). The overall temporal trend for TN appeared relatively stable because as DIN concentrations declined in early summer, dissolved organic nitrogen (DON) concentrations increased and remained high for the rest of the year. The spring peak in DIN was driven by high nitrate (NO_3), which is consistent with observations in the Chesapeake Bay region (Boynton et al. 1995; Stevenson et al. 1993). Once silicate, phosphate and DIN declined in spring and early summer, they remained low through December. Particulate concentrations (POC and PON) were relatively stable throughout the year, except for the Crane River, which showed much variability. We observed consistently low chlorophyll at most stations, except for variable concentrations in the Crane River.

North River. The highest mean TN among the three primary stations occurred at the North River (157 mM). High values of DON contributed greatly to the relatively high TN. The North River also had the highest mean ammonium (10.35 mM), which was influenced by very high spring concentrations. Other than TN and ammonium, the North River nutrients did not deviate much from the ranges found at the other stations. As the largest freshwater discharge with the highest mean TN, the North River contributed the largest load of TN into Salem Sound among river sources (Table 3.7).

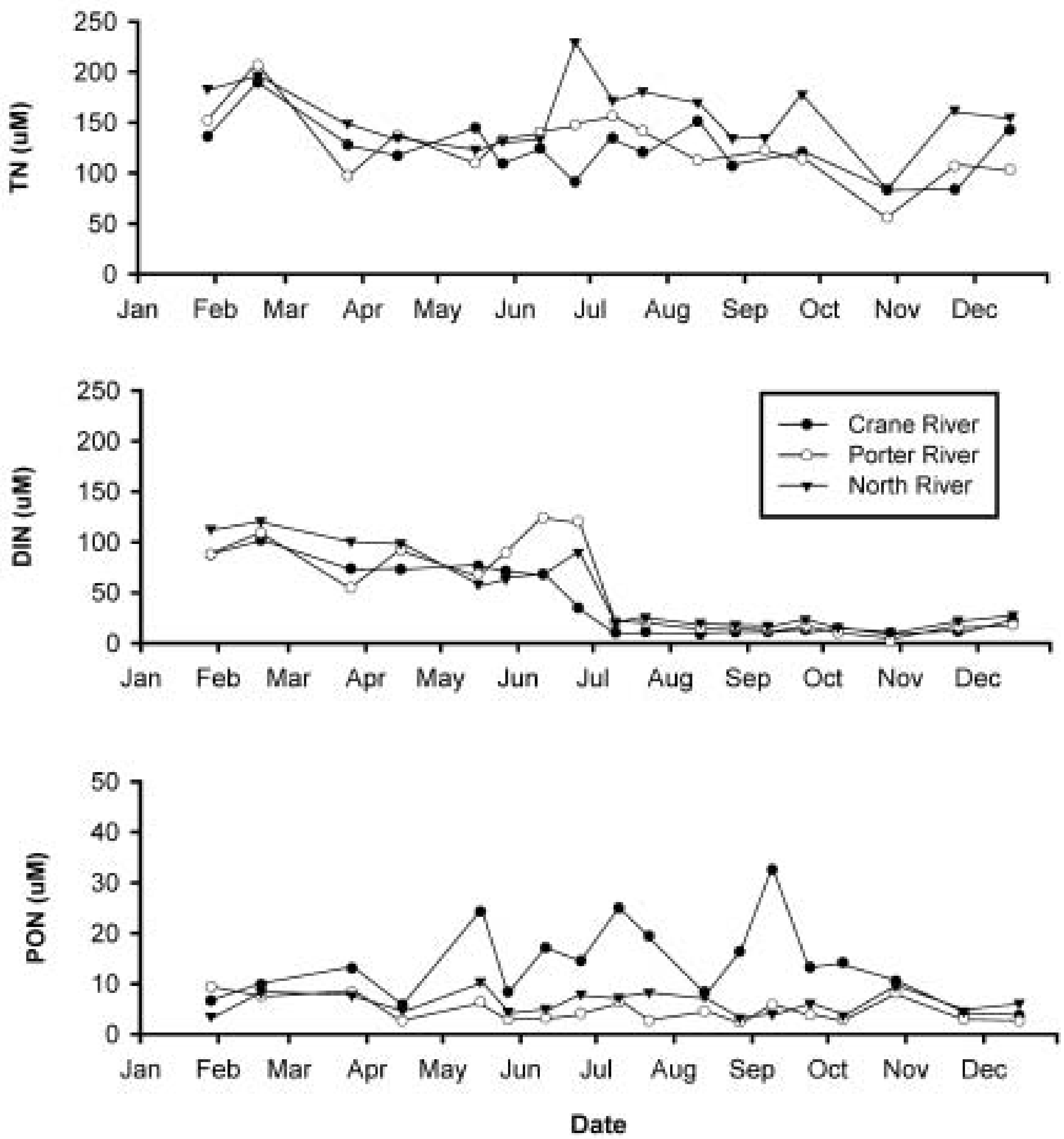
Porter River. The Porter River also showed evidence of nutrient enrichment, although nutrient concentrations were not generally high relative to the other stations. The mean values for Porter River TN and DON were close to those for Crane River, which were the lowest for January-December. The lower TN resulted from relatively low DON, PON, and NH_4. No parameter displayed much deviation from the mean values of other stations and only silicate (77mM) held the highest rank among rivers.

Crane River. Crane River was unique among river stations by having substantially higher mean concentrations of POC, PON and chlorophyll, with wide seasonal variation in those parameters. The mean concentrations of TN and DON were the lowest for January-December. Crane River substrate in the vicinity of the sampling station exhibited the most abundant periphyton growth observed at river stations in 1997. The nutrient concentrations measured in 1997 do not clearly indicate the cause of the periphyton growth, but suggest that dissolved nitrogen may not be a primary source.

Sawmill Brook. Comparisons of Sawmill Brook data to other stations are limited because only 13 sampling visits were made from May-December. Sawmill Brook had the lowest mean TN of the five stations reported in Table 3.6. The absence of early season sampling may depress the TN mean. Sawmill Brook contained fine suspended material that colored the water copper-brown all season long and made sample filtering very difficult. The composition of the material is uncertain: turbidity, POC and PON were not at unusually high levels.

Waters River. This station was successfully sampled during 14 sampling visits from May-December. Despite the absence of early season measurements, the mean TN was the highest among river stations (211 mM). The TN mean was most influenced by the highest mean DON value observed (132 mM). The lack of early season sampling may have suppressed the low ortho-phosphate that is typically elevated by spring watershed contributions. Low discharge in the Waters River barely provided enough

Figure 3.6 Total nitrogen (DIN+DON+PON), dissolved inorganic nitrogen (DIN) and particulate organic nitrogen (PON) at Salem Sound river stations, 1997.



water to sample during the dry summer in 1997. The river did respond quickly to rainfall with stormwater flashes that drained from the high density of impervious surfaces upstream of the sampling station.

Other Stations. Sampling was infrequent at the Bass, Forest and South Rivers because of the dry conditions of 1997, and few conclusions can be drawn from these data (see Table A.15 for raw data). These streams dried out for much of June-October, which prevented consistent sampling. Both Bass River and South River had no flow during most of July-September, with the exception of stormwater pulses.

Nitrogen Loading. The annual TN loading from the five major freshwater inputs to Salem Sound was estimated to be approximately 58 mt for 1997 (Table 3.7). North River had the highest contribution of TN to Salem Sound in 1997, followed by Sawmill Brook, and Crane River. Waters River had high concentrations of TN, but with the lowest mean discharge, contributed only about 5 mt for the year. Considering inputs from the other three stations, small creeks not sampled, and the low precipitation of 1997, the average annual watershed contributions of TN may be higher, in the vicinity of 100 mt/yr. These assumptions do not include direct groundwater and

Figure 3.7 Ortho-phosphate (PO_4), Silicate (SiO_2), and Chlorophyll *a* (Chl.*a*) at Salem Sound river stations, 1997.

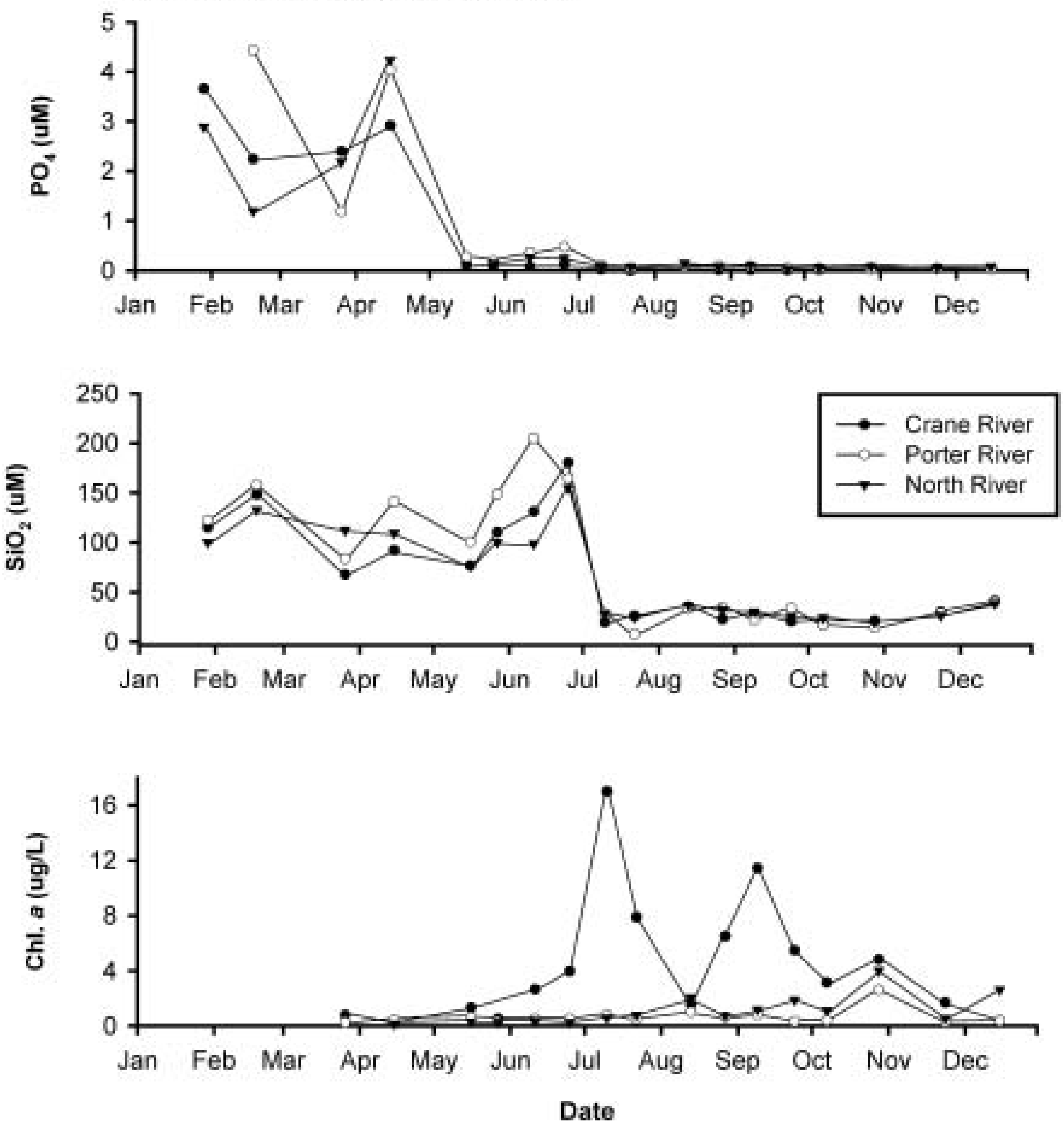


Table 3.6 Mean nutrient concentrations (with standard errors) for Salem Sound river stations, 1997. Nitrate (NO_3) and Nitrite (NO_2) were measured separately each month except May and June.

Station	Visits	TN (uM)	TDN (uM)	DIN (uM)	DON (uM)	PON (uM)	NH_4 (uM)	N+N (uM)	NO_3 (uM)	NO_2 (uM)
Crane River	18	124.05	111.52	39.47	68.70	13.73	6.46	33.01	26.82	0.26
(SE)		6.77	6.83	7.93	7.90	1.84	1.60	6.57	7.42	0.03
North River	18	156.76	150.30	51.26	96.98	6.31	10.35	40.88	35.30	0.60
(SE)		8.13	8.13	9.08	10.08	0.52	2.61	6.84	8.08	0.10
Porter River	18	127.36	122.26	49.73	67.97	4.83	2.65	47.09	33.28	0.23
(SE)		8.26	8.28	10.18	8.95	0.55	0.67	9.62	8.92	0.05
Waters River	14	211.49	208.28	71.87	131.62	2.96	2.58	70.33	35.02	0.19
(SE)		11.29	11.33	16.03	22.47	0.28	0.77	16.05	1.33	0.03
Sawmill Brook	13	115.62	109.89	24.02	81.93	5.73	3.08	20.94	13.98	0.13
(SE)		11.37	11.62	6.27	11.19	1.31	1.43	4.96	2.58	0.03

Station	Visits	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)	TDN:TDP	C/N	Chl. *a* (ug/l)	Phaeo. (ug/l)	Total (ug/l)
Crane River	18	0.86	0.66	65.82	147.26	225.53	11.97	4.34	2.12	6.46
(SE)		0.19	0.29	12.22	16.09	56.47	1.06	1.15	0.44	1.44
North River	18	1.06	0.67	65.17	76.59	222.06	12.23	1.12	0.52	1.65
(SE)		0.21	0.28	10.58	7.30	57.38	0.75	0.28	0.09	0.31
Porter River	18	1.28	0.68	76.77	50.67	134.42	10.44	0.64	0.63	1.28
(SE)		0.30	0.33	15.08	6.78	20.07	0.53	0.14	0.20	0.27
Waters River	14	0.90	0.06	68.69	35.28	357.70	11.79			
(SE)		0.19	0.01	15.13	4.19	64.35	0.63			
Sawmill Brook	13	1.29	0.04	23.00	79.33	104.64	11.57			
(SE)		0.20	0.01	4.01	14.15	15.03	1.63			

Table 3.7 Total nitrogen load budget for major freshwater inputs to Salem Sound, 1997. Monthly loads were calculated using mean TN (mg/L) and discharge (m^3/s) for each river. TN units were converted by: TN mg/L = TN uM x 0.014.

River Station	Drainage Area (km^2)	TN Samples (No.)	TN Mean (mg/L)	Discharge (m^3/s)	TN Load (mt/yr)
Crane River	14.8	16	1.74	0.220	12.34
North River	29.8	17	2.19	0.307	20.95
Porter River	11.4	16	1.76	0.115	6.37
Waters River	NA	11	3.10	0.054	5.33
Sawmill Brook	13.0	13	1.58	0.294	13.23
TN Sum					58.22

Table 3.8 Mean nutrient concentrations (with standard errors) for Salem Sound marine stations, 1997. Nitrate (NO_3) and Nitrite (NO_2) were measured separately each month except May and June.

Station	Visits	TN (uM)	TDN (uM)	DIN (uM)	DON (uM)	PON (uM)	NH_4 (uM)	N+N (uM)	NO_3 (uM)	NO_2 (uM)
Haste- surface	18	54.70	46.63	23.06	23.58	8.07	20.15	2.91	3.35	0.68
(SE)		9.28	9.00	4.98	7.79	0.93	4.62	0.85	0.95	0.39
Haste- bottom	16	19.74	14.87	4.54	10.32	4.87	2.25	2.29	2.51	0.20
(SE)		1.04	1.07	0.75	0.81	0.36	0.39	0.55	0.59	0.03
Salem- surface	18	36.51	30.06	3.94	26.41	6.32	1.84	2.10	2.46	0.18
(SE)		11.87	12.01	1.04	11.48	0.70	0.52	0.59	0.66	0.04
Salem- bottom	16	31.00	22.33	4.36	17.97	8.67	2.23	2.14	2.33	0.20
(SE)		7.94	8.19	0.86	8.12	0.73	0.43	0.60	0.67	0.04
Beverly- surface	18	20.39	15.06	5.04	9.99	5.33	2.45	2.59	2.98	0.19
(SE)		1.19	1.28	0.88	0.68	0.63	0.49	0.63	0.72	0.04
Beverly- bottom	15	20.91	14.46	4.16	10.30	6.45	1.95	2.22	2.49	0.18
(SE)		1.29	1.35	0.85	0.87	0.59	0.40	0.64	0.72	0.04

Station	Visits	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)	TDN/ TDP	POC/ PON	Chl. a (ug/l)	Phaeo. (ug/l)	Total (ug/l)
Haste- surface	18	1.80	1.53	6.48	68.84	29.25	8.32	0.89	0.12	1.01
(SE)		0.35	0.26	1.00	9.78	2.15	0.44	0.21	0.03	0.22
Haste- bottom	16	0.57	0.63	4.52	36.98	28.91	7.76	1.03	0.26	1.29
(SE)		0.07	0.06	0.55	2.47	2.43	0.37	0.22	0.10	0.25
Salem- surface	18	0.48	0.59	4.23	48.82	30.29	7.86	1.24	0.18	1.42
(SE)		0.05	0.11	0.67	5.79	2.20	0.52	0.29	0.04	0.30
Salem- bottom	16	0.56	0.65	4.66	64.73	25.16	7.52	1.62	0.48	2.10
(SE)		0.03	0.07	0.60	5.18	1.25	0.18	0.37	0.13	0.44
Beverly- surface	18	0.62	0.61	4.60	41.34	26.21	7.85	1.09	0.17	1.27
(SE)		0.06	0.06	0.63	5.53	1.69	0.27	0.26	0.05	0.27
Beverly- bottom	15	0.54	0.59	4.38	49.68	28.01	7.93	1.19	0.22	1.41
(SE)		0.06	0.07	0.64	4.02	1.76	0.34	0.26	0.06	0.25

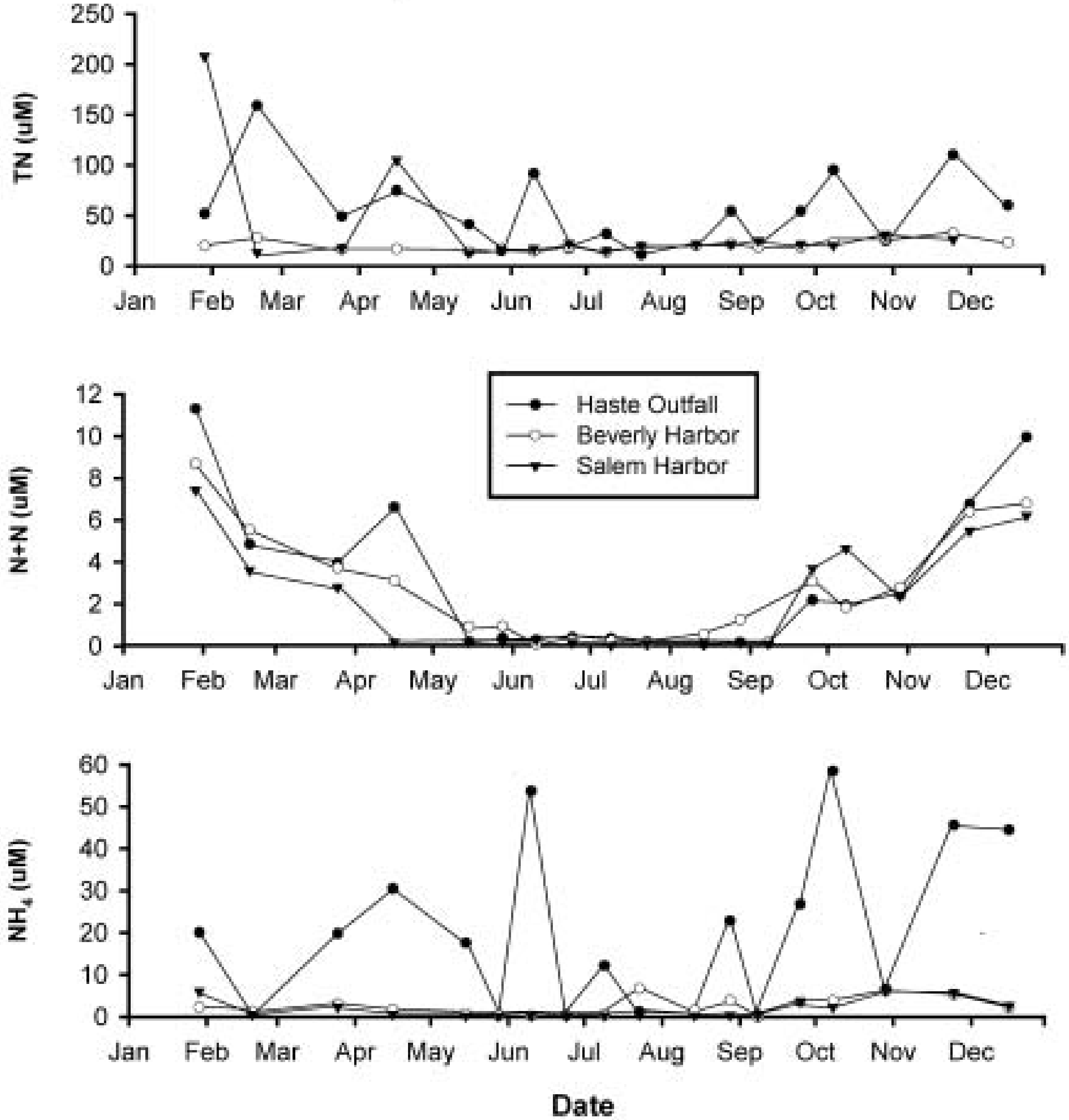
atmospheric inputs to Salem Sound, which can be significant sources of TN (Millham and Howes 1994; Jarrell 1999). It is also important to consider that the sampling frequency conducted may not have captured the relative contribution of dry and wet weather discharges. Sampling in 1997 was inadvertently weighted towards dry weather conditions: 14 of 18 sampling dates coincided with dry weather (<0.5 in. of precipitation during three days, Table A.5).

MARINE NUTRIENTS

All surface and most bottom nutrient measurements were successfully made at the three marine stations for each sampling period. Data on mean concentrations are presented in Table 3.8 and all station measurements are in the Appendix (Tables A.16–A.21). The surface concentrations of major nutrients at the three marine stations are plotted over time to illustrate seasonal trends in 1997 (Figures 3.8 and 3.9). Three major patterns emerge: wide variability of marine nutrients, seasonal response of some nutrients to phytoplankton dynamics, and influence of SESD effluent at the Haste Outfall station.

The high variation in nutrient data can result from the effects of ocean inputs, vertical mixing, stratification, nutrient regeneration, differential rates of phytoplankton uptake, and anthropogenic inputs. Dissolved inorganic nitrogen (ammonium, nitrate, and nitrite) are forms of nitrogen most available to phytoplankton. The data indicate DIN concentrations declined during spring and remained low until fall. An exception to this trend was spikes of DIN at the Haste Outfall station, which were caused by effluent ammonium. Away from the outfall influence, DIN values were low and fairly consistent. Nitrate and ammonium comprised the bulk of DIN at Beverly Harbor and Salem Harbor, with a minor contribution from nitrite.

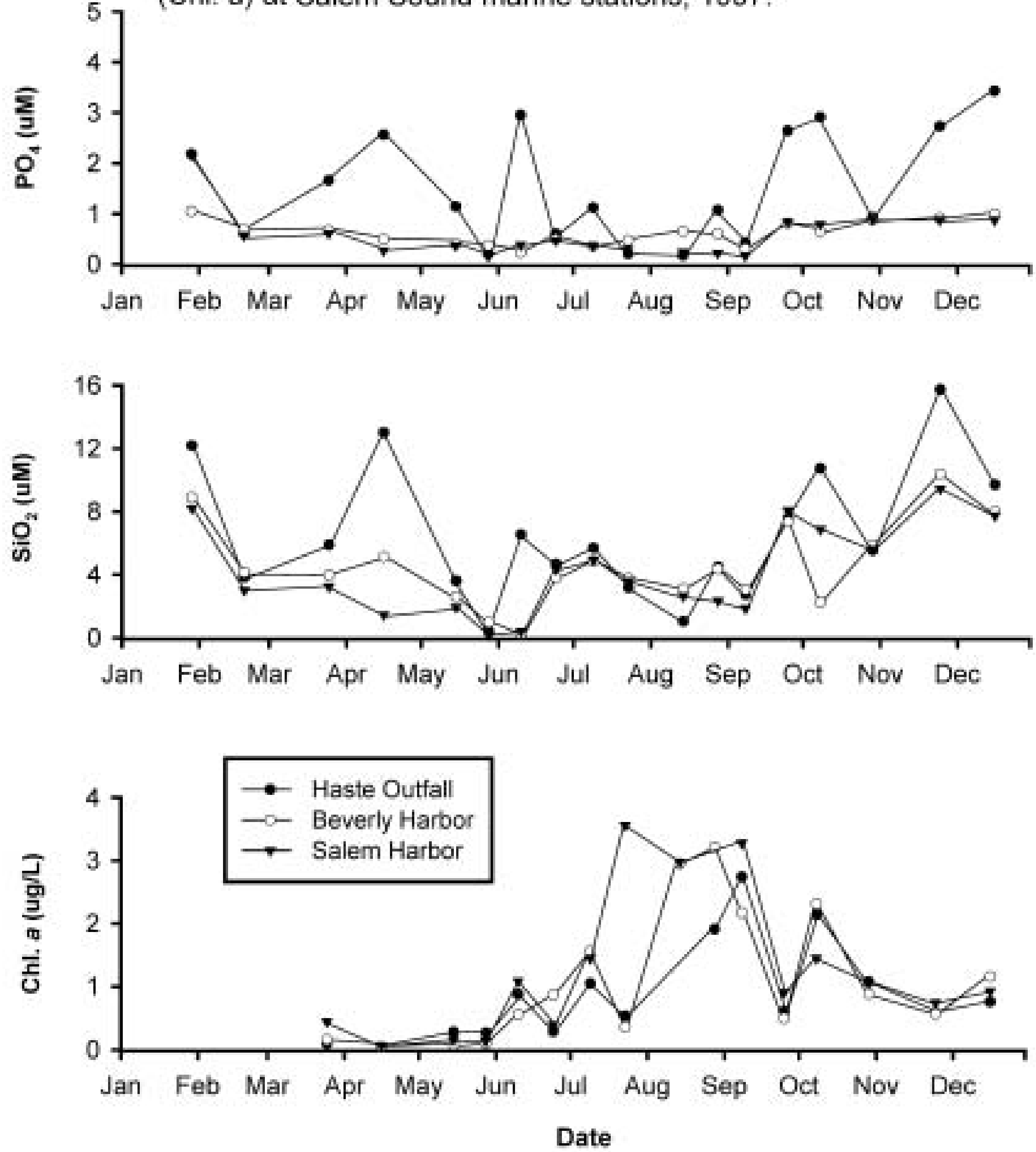
Figure 3.8 Total nitrogen (TN), nitrate plus nitrite ($NO_3 + NO_2$), and ammonium (NH_4) at Salem Sound marine stations, 1997.



Similar to DIN, the depression of ortho-phosphate and silicate in the warm months is also a function of plankton uptake. Chlorophyll is a primary indicator of phytoplankton abundance and the particulates (PON, POC) are secondary indicators. The PON concentrations were variable, with moderately higher values during the warm months. The POC concentrations were less variable with no apparent seasonal trend. The patchiness of plankton may have influenced the variability in particulate concentrations. Chlorophyll a was generally low (mean ~1-2 ug/L) and did not elevate during March-May, as would be expected for spring blooms. Chlorophyll began to increase in June and peaked from July to early September.

Ratios of essential nutrients provide insight on watershed inputs and help identify which nutrients limit phytoplankton growth. Ratios were calculated for $DIN:SiO_4$ and $DIN:PO_4$ at the marine stations (Figures 3.10 and 3.11). Ratios of $DIN:SiO_4$ for both Beverly Harbor and Salem Harbor were approximately 1:1, which are considered typical. The Haste station ratio was 3:1, resulting from elevated ammonium in the outfall effluent. Ratios of $DIN:PO_4$ were generally lower than the optimal 16:1, with the exception of the Haste station which had

Figure 3.9 Ortho-phosphate (PO_4), Silicate (SiO_2), and Chlorophyll *a* (Chl. *a*) at Salem Sound marine stations, 1997.



higher DIN and PO_4 but at a ratio close to the optimum. These ratios imply that excessive DIN was available at the Haste outfall station, however, DIN may have been limiting to phytoplankton growth at the other stations.

Haste Outfall Station. Elevated surface nitrogen and phosphate were expected because the station was located approximately 100 m northwest of the SESD primary effluent outfall. The high variability in ammonium and phosphate can be attributed to the outfall plume at the fixed station. Winds from the south and east pushed the plume across the station towards the Beverly shore. Winds from the north and west usually drove the visible plume away from the station towards the outer Sound. The high spikes in DIN all came from sampling in the plume. A few very low values of DIN occurred when the plume was directed out of the Sound. Outside of phosphate and ammonium, only surface DON showed elevated concentrations relative to other stations. Chlorophyll levels were similar at all three stations. We expected higher chlorophyll levels at the Outfall station, in response to uptake of the available ammonium.

Despite the moderate depth (8.6 m mean), strong stratification of nutrient concentrations occurred at the Outfall station. Bottom nutrient values were consistently

Figure 3.10 DIN vs. SiO_4 ratios for surface measurements at Salem Sound marine stations, 1997. A molar ratio slope of 1:1 is considered optimal for phytoplankton growth.

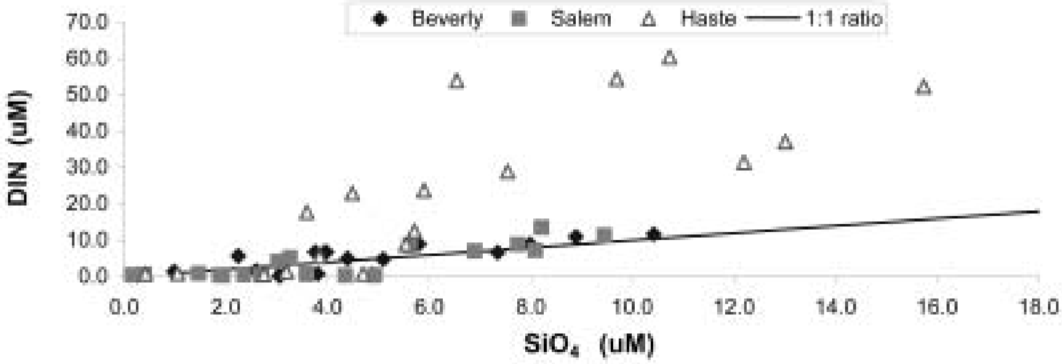
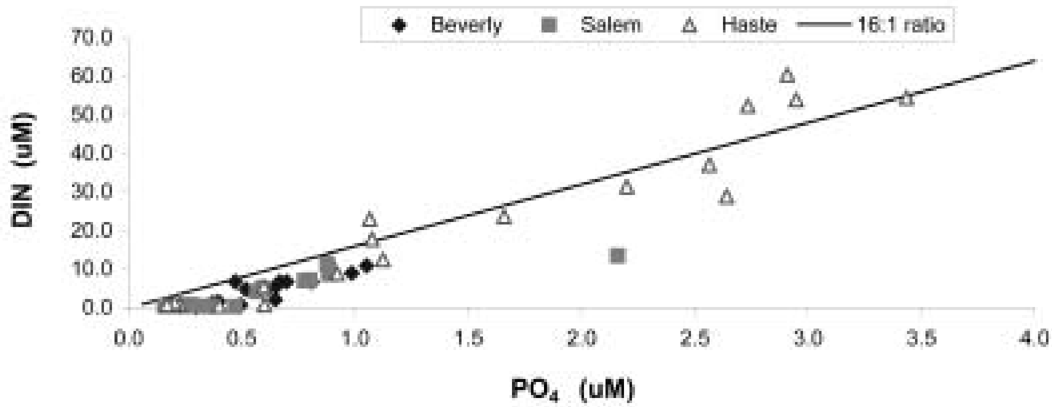


Figure 3.11 DIN vs. PO_4 ratios for surface measurements at Salem Sound marine stations, 1997. A molar ratio slope of 16:1 is considered optimal for phytoplankton growth.



low, and within the range of Salem Harbor and Beverly Harbor. The stratification found with nutrients was not pronounced in the basic water chemistry data, as indicated by the minor depression of surface salinity. The average monthly freshwater flow from SESD outfall ranged between 0.72 m^3/s to 2.11 m^3/s in 1997, with mean of 1.1 m^3/s (SESD 1998). This amount slightly exceeds the mean of 1.0 m^3/s for the major freshwater tributaries to Salem Sound (Table 3.9). Despite this relatively large amount of freshwater, the spatial influence of the outfall plume is apparently transient, limited to the upper water column, and highly dependent on wind and tide conditions.

Beverly Harbor Station. The similarity of surface and bottom measurements indicated that this station was well mixed. The lack of stratification is due to the relatively shallow depth and tidal movements in the harbor and Danvers River. The values for most nutrient parameters were low and stable. Mean TN was 20.4 µM for the surface water and 20.9 µM for bottom water. Dissolved organic nitrogen was the major contributor to TN (mean of ~10 µM).

Salem Harbor Station. Mean bottom TN concentrations were greater than those found at the other marine stations. Both surface (35 µM) and bottom (31 µM) means were influenced by a few early season DON measurements that exceeded 100 µM. The cause of periodic DON enrichment was not apparent, but may be related to high river DON observed in the spring. There was more evidence of stratification than at Beverly Harbor, but it was inconsistent among parameters. Mean bottom measurements for PON (8.7 mM), POC (73 mM), and chlorophyll a (2.1 ug/L) were the highest among marine stations.

Table 3.9 Monthly values for parameters used to estimate nutrient loading in Salem Sound, 1997. All monthly measurements at marine and river stations were averaged. SESD data were converted from monthly mean discharge (MGD) and TKN data in NPDES #MA0100501 reports. TN units were converted by: TN = TKN + (NO_2+NO_3), assuming (NO_2 + NO_3) equals 1.2% of known TKN (GOM 1987).

	Marine TN (mg/l)	*Marine* PO_4 (mg/l)	*SESD* Flow (m^3/s)	*River* Flow (m^3/s)	*SESD* TN (mg/l)	*River* TN (mg/l)	*SESD* TN (mt/month)	*River* TN (mt/month)
January	0.794	0.042	1.26	1.31	27.69	2.43	93.4	8.5
February	0.609	0.020	1.20	1.31	23.83	3.04	69.2	9.6
March	0.634	0.025	1.41	3.56	22.42	1.90	84.7	18.1
April	0.660	0.026	2.11	2.23	17.65	2.00	96.5	11.6
May	0.269	0.012	1.26	1.17	25.89	1.86	87.4	5.8
June	0.373	0.021	0.92	0.29	30.84	2.12	73.5	1.6
July	0.251	0.013	0.80	0.16	32.68	2.41	70.0	1.0
August	0.348	0.017	0.78	0.09	35.28	2.18	73.7	0.5
September	0.331	0.022	0.72	0.08	23.90	2.09	44.6	0.4
October	0.431	0.031	0.76	0.14	35.48	1.60	72.2	0.6
November	0.557	0.040	0.94	1.23	35.81	1.52	87.3	4.8
December	0.365	0.045	1.08	0.31	31.07	1.69	89.0	1.4
Mean	0.468	0.026	1.10	0.99	28.55	2.07		
Sum							941.5	63.9

Nitrogen Loading. The relative contribution of TN to Salem Sound was estimated from nitrogen data collected at the marine and river stations and from SESD effluent monitoring. Monthly mean discharge estimates for SESD's primary treated sewage effluent indicated that freshwater contributions were of a similar magnitude to the rivers in 1997 (Figure 3.12). Despite similar discharges, the TN load from the rivers was far lower than SESD because of much higher nitrogen concentrations in the effluent (Table 3.9). The river load estimate in Table 3.9 differs slightly from Table 3.7 because monthly loads from all river were summed as opposed to using monthly data for individual rivers. The river TN load estimate for 1997 was 64 mt/yr, in comparison to 941 mt/yr from SESD. The 1997 SESD estimate is lower but a similar magnitude to previous estimates of 1,679 mt/yr TKN (TN = TKN + (NO_3 + NO_2)) in 1987 (GOM 1987), and 1,950 mt/yr TN for 1988-1990 (Menzie-Cura 1991).

These watershed inputs of nutrients can be compared to nitrogen and phosphorus residing in the marine waters of Salem Sound. Table 3.9 contains mean TN and PO_4 estimated from all marine stations (surface and bottom data were averaged). Jerome et al. (1967) reported the MHW volume of marine waters in Salem Sound was 332,079,246 m^3 and the MLW volume was 237,297,925 m^3. The mean TN of 0.468 mg/l results in estimates of 155 mt of TN at MHW and 111 mt of TN at MLW. The mean PO_4 of 0.026 mg/l results in 8.6 mt at MHW and 6.2 mt at MLW. Therefore, average daily river loads of TN would

Figure 3.12 Monthly mean discharge from Salem Sound rivers and SESD effluent outfall, 1997.

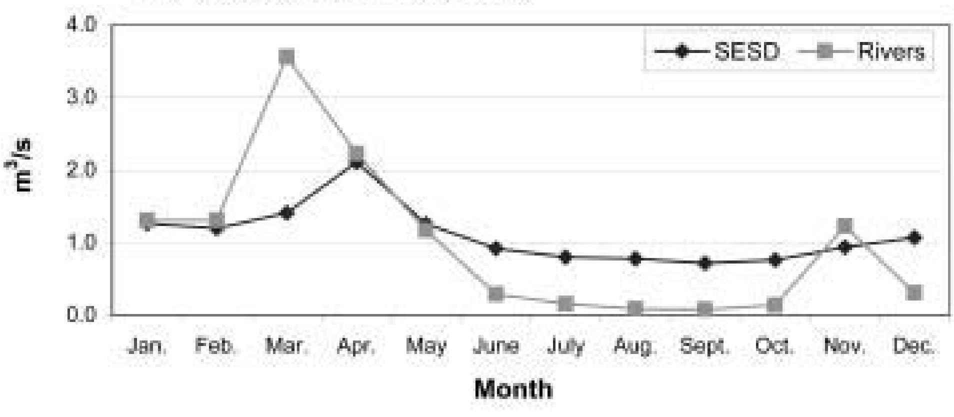
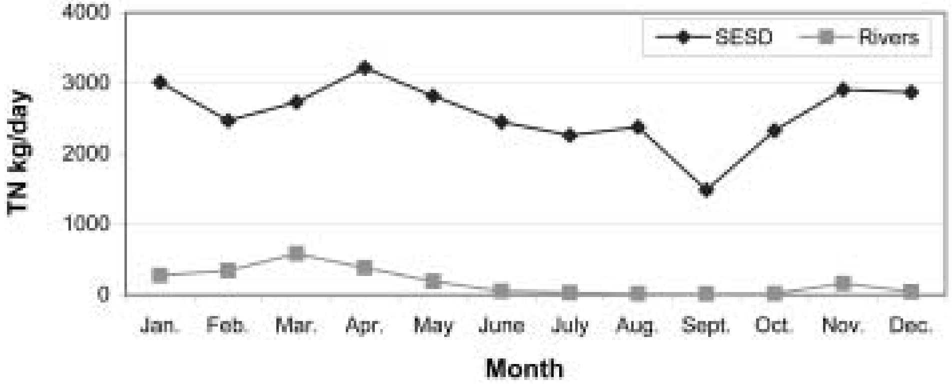


Figure 3.13 Total nitrogen load (TN kg/day) from Salem Sound rivers and SESD effluent outfall, 1997.



be approximately 0.1% of total TN present, and SESD's load represents 1-2%. Using Menzie-Cura (1996) data for TP and 1997 PO_4 field measurements as a proxy for phosphorus, the average daily contribution of watershed phosphorus is roughly 5% from SESD and 1% from the rivers.

This nutrient loading is a rough estimate based on 18 grab samples, and do not account for the cumulative effect of watershed loadings or consider atmospheric and groundwater inputs. River inputs appear to be relatively minor compared to the SESD outfall (Figure 3.13), and daily contributions from both are small compared to resident TN and TP in Salem Sound. The tidal action and bathymetry of Salem Sound apparently allows assimilation of watershed nutrients without evidence of elevated concentrations a few kilometers from the sources. However, impacts to marine resources in the vicinity of high nutrient concentrations (Haste Outfall and upper estuary) are uncertain.

FECAL COLIFORM BACTERIA

Fecal coliform bacteria samples were collected at marine, river and shore stations in 1997 and the results were compared to shellfish and surface water quality criteria. Summary statistics for all stations (Figure 1.5) are presented in Table 3.10. The following paragraphs summarize sampling results by station type and geographic location. We refer to water quality criteria for shellfish growing areas (Table 3.11) only to compare 1997 measurements of fecal coliform to established limits for shell fishing. The region is presently closed (classified prohibited) to shellfishing. A reclassification of shellfish growing areas can occur only after a formal sanitation survey.

River Stations. Because river station samples were freshwater, fecal coliform counts were compared to surface water quality standards for supporting primary recreation (Table 3.1) instead of shellfish criteria. All five stations that were sampled routinely (11 samples) had fecal coliform counts that exceeded the standard for supporting primary recreation (geometric mean of 200 fcc per 100 ml). The North River was most contaminated by fecal coliform bacteria: all samples greatly exceeded the criteria for supporting primary recreation. The remaining three stations were sampled infrequently because of low flow conditions, therefore limiting conclusions on fecal coliform counts.

Manchester Harbor (Shore Stations). Fecal coliform counts within Manchester Harbor were variable and subject to influences from Sawmill Brook. The inner harbor station (Masconomo Park) samples indicated the presence of gross bacterial contamination. The rainfall influence of an early December storm contributed to high counts for the subsequent sample. In the absence of this measurement, this station would have demonstrated moderate contamination. The outer harbor station (Manchester Yacht Club) did show potential to meet restricted criteria with a geometric mean of 16 fcc/100 ml. An evaluation of rainfall records indicates that Sawmill Brook was significantly impacted during stormwater events, however, several high fecal coliform counts were recorded during dry weather.

Beverly Shore (Shore Stations). Fecal coliform counts along the Beverly Shore between the Manchester Harbor and Tuck Point were relatively low. Samples from West Beach, Lynch Park, and Tuck Point showed potential to meet restricted criteria, and Lynch Park showed potential to meet approved criteria with a geometric mean of 9 fcc/100 ml. Mingo Beach station had several high counts likely indicating a local bacteria source. No rainfall effects could be detected at any of these stations. Except for Lynch Park, each station in this area did have some intermittently high counts.

Danvers River Estuary (Shore Stations). Fecal coliform counts in the Danvers River estuary and its tributaries were variable and no stations approached approved criteria for shellfish growing areas. In dry weather, the fecal

Table 3.10 Summary statistics for fecal coliform bacteria measurements at shore, river, and marine stations in Salem Sound, 1997.

Station	Samples (No.)	Min. (fcc/100 ml)	Max. (fcc/100 ml)	Geo. Mean (fcc/100 ml)	> 43 (%)	> 260 (%)
SHORE						
Manchester Harbor						
Masconomo Park	20	3	1587	36	30	20
Manchester YC	20	3	110	16	25	0
Beverly Shore						
West Beach	18	3	347	19	28	11
Mingo Beach	18	3	900	38	50	17
Lynch Park	18	<3	87	9	11	0
Tuck Point	18	3	900	16	22	6
Danvers River						
Porter River	17	7	1587	67	59	12
Crane River	18	12	1587	172	94	28
Waters River	18	3	169	34	50	0
Fosters Point	18	3	347	26	22	6
Bass River	18	19	1587	96	72	17
Kernwood River	18	3	900	52	56	6
North River	18	3	900	118	83	33
Salem Shore						
Collins Cove	15	3	>2400	49	53	20
Willows Pier	18	3	>2400	31	44	11
Winter Island	18	3	110	6	6	0
Forest River Park	18	3	532	49	50	11
Forest River	18	3	347	55	61	11
Marblehead Shore						
Village Street	18	3	1587	11	22	6
Fluen Point	18	3	169	10	28	0
Browns Island	18	3	169	10	17	0
Inner Harbor	18	3	>2400	42	67	11
Eastern YC	18	3	>2400	10	17	6
RIVER						
Sawmill Brook	11	28	>2400	336	100	55
Bass River	5	4	133	15	40	0
Porter River	11	243	>2400	1149	100	91
Crane River	11	7	900	266	100	64
Waters River	11	14	>2400	446	100	73
North River	11	900	>2400	2009	100	100
South River	4	87	>2400	437	100	50
Forest River	3	7	99	21	50	0
MARINE						
Haste Outfall (plume)	3	14	347	82	66	33
Haste Outfall	9	<3	243	15	66	0
Beverly Cove	7	<3	133	4	14	0
Beverly Harbor	9	<3	4	2	0	0
Upper Danvers River	8	<3	97	7	37	0
Lower Danvers River	9	<3	61	10	33	0
Salem Harbor	9	<3	4	2	0	0
Marblehead Harbor	8	<3	>2400	8	12	12

Table 3.11 Water quality criteria for shellfish growing areas (NSSP 1997)

As filter feeders, shellfish obtain their food by filtering large quantities of water. During feeding, shellfish have the potential to ingest and concentrate pollutants present in the water column. The primary pollutants of concern are microorganism's that can cause disease in humans. Because these disease causing bacteria and viruses (pathogens) are generally transmitted to humans through feces, the presence of sewage in shellfish growing areas is of major concern. Since it is impossible to test water for the hundreds of pathogens in fecal waste, public health officials examine water samples for the presence of fecal coliform bacteria. Fecal coliform bacteria live in the intestines of warm-blooded animals and are present in large numbers in feces. Their presence in water samples is used as an indicator of the potential occurrence of pathogens.

Five water quality classifications have been developed based primarily on the concentration and variability of fecal coliform bacteria in shellfish growing areas (NSSP 1997). The classification of a shellfish growing area is determined through a sanitary survey study. These studies evaluate the water quality of the area and also identify and evaluate all actual and potential pollution sources that impact a growing area. Typically more than 30 samples are collected under various conditions in order to classify a shellfish growing area. These classifications are:

Approved: Water samples have a geometric mean of ≤14 fecal coliform colonies (fcc) per 100 ml of water and ≤10% of samples >43 fcc/100 ml. Shellfish harvested from approved areas are considered safe for direct human consumption.

Restricted: Restricted waters are considered moderately contaminated. Water samples have a geometric mean of ≤88 fcc/100 ml and ≤10% of samples >260 fcc/100 ml. Shellfish harvested from restricted areas are not suitable for direct human consumption and must either be relayed to an approved area for a designated period of time or processed in a certified shellfish purification plant prior to consumption.

Conditionally Approved or Conditionally Restricted: The water quality in these areas meets either approved or restricted criteria during a predictable period. These areas are affected by intermittent sources of pollution and the shellfishing area is closed until after the pollution causing event has passed and water quality has returned to its designated classification.

Prohibited: All areas not meeting one of the above criteria, or there is insufficient information to properly classify the area. Shellfish cannot be harvested for any consumptive purpose. Prohibited waters are generally considered grossly contaminated.

Note: Percentile standards can vary according to sampling protocol employed. Consult National Shellfish Sanitation Program for greater detail and updates.

coliform counts were generally low, but overall, the samples reflected the influence of bacterial contamination found at upstream river stations. Samples from Fosters Point, Waters River and Kernwood River stations all showed the potential to meet restricted criteria. The remaining stations within the Danvers River estuary exhibited moderate to gross bacterial contamination. The North River and Crane River stations had the highest geometric means among stations in the Danvers River estuary. Both stations, as well as the Porter River and Bass River displayed high counts during dry and wet weather conditions.

Salem Shore (Shore Stations). The fecal coliform counts at the two stations within Salem Harbor (Forest River Park and Forest River) exceeded the range for restricted criteria by a small margin, and several higher counts were related to rainfall. The two locations away from freshwater inputs had lower counts. Winter Island had the lowest counts of any shore station and showed the potential to meet approved criteria. The Willows Pier station slightly exceeded the range for restricted criteria, with intermittent high counts that probably are influenced by inputs from the Danvers River estuary.

Marblehead Shore (Shore Station). Of the five Marblehead shore stations, only the Inner Harbor station did not show the potential to meet restricted criteria. No apparent relationship between rainfall and elevated counts existed in the Inner Harbor, suggesting a chronic source of pollution. The remaining shore stations between Salem Harbor and Marblehead's outer Harbor appeared to benefit from tidal dilution and lack of freshwater influences.

Marine Stations. Fecal coliform bacteria samples collected at the marine stations out in Salem Sound were relatively low, with the exception of the Haste Outfall station. The Beverly and Salem Harbor stations had very low counts and showed the potential to meet approved criteria, although only nine samples were measured. The high counts observed at the Haste Outfall and other marine stations were intermittent without a clear relationship to rainfall. Information was not available on fecal coliform contributions from boating. The discharge from the SESD outfall negatively affected water quality in the outer Sound. Although fecal coliform counts should have been relatively low from this discharge due to primary treatment, relatively high counts were measured directly at the Haste Outfall station and in the outfall plume. The influence of the outfall effluent and bacterial sources in the estuary does not appear to be causing high counts at the Beverly Harbor or Salem Harbor stations. Tidal range and time of travel appears to limit the influence of the outfall and estuary sources on fecal coliform counts at these stations.

DISCUSSION

We attempted to relate ambient water chemistry in Salem Sound to major sources of pollution and water quality standards for supporting aquatic life. Our findings on water quality were generally positive, however, conclusions should be tempered by data limitations. The dataset represents only 18 samples during one year, and 1997 was a dry year. Fourteen of the 18 sampling periods coincided with dry weather conditions. This is an important consideration because river discharge and nutrient concentrations are associated with watershed runoff. Despite the limitations, these data comprise the most detailed annual baseline collected for Salem Sound to date. Observations of basic water chemistry support the expectation that the Sound is typical of embayments in Massachusetts Bay by nature of a wide tidal range, minor seasonal stratification and adequate water quality for supporting aquatic life under most conditions.

The composition and dynamics of nutrients in Salem Sound are not well understood. Evidence is mounting that watershed contributions of nitrogen and phosphorus to Northeastern estuaries increased dramatically during the 20th century (Roman et al. 2000). The impact of high concentrations and loads of watershed nutrients on the marine environment is uncertain. We know that marine plants depend on nutrients for growth but high concentrations can cause excessive growth and reduce water column DO (eutrophication). Chronic eutrophication can further degrade marine habitats by introducing toxic conditions for some organisms and altering the natural composition of aquatic communities (Bricker and Stevenson 1996). Cultural eutrophication is a major concern for the ecological health of embayments in Massachusetts (Galya et al. 1996; Howes and Goehringer 1996). Sewage disposal, combustion of fossil fuels, and stormwater transport of watershed enrichment are primary anthropogenic sources of nutrients contributing to coastal eutrophication. Nutrient inputs from offshore areas can also represent a large natural source to embayments. The following sections discuss the 1997 water chemistry results in relation to the major influences on water quality in Salem Sound.

RIVER WATER QUALITY

Basic Water Chemistry. Measurements of basic water chemistry at the river stations in 1997 portrayed water quality that was supportive of aquatic life according to DEP's surface water quality standards (DEP 1996). Few violations of SB criteria were identified. Only two DO measurements fell below SB criteria, and Sawmill Brook had frequent pH violations. These results are consistent with the North Coastal Basin (NCB) Assessment conducted by DEP from June, 1997, through March, 1998 (DeCesare et al. 2000). The NCB study adopted the seven river stations sampled by DMF in 1997, resulting in comparable water chemistry data. The Sawmill Brook (Cat Brook), Crane River, Porter River (Frost Fish Brook), North River and Waters River stations were sampled most frequently by DEP (N = 6-9). The two rivers showing the most evidence of stress, Crane River (sp. conductivity, turbidity, temperature, DO) and Sawmill Brook (pH, DO) in the DMF study were identified by DEP for similar concerns.

The NCB assessment classified rivers based on their support of designated uses. The basic water chemistry measurements in rivers sampled by both studies resulted in a *"supports aquatic life"* designation for all except Crane River and Sawmill Brook. Crane River received a *"partially supports aquatic life"* designation because of low DO and high conductivity in tributaries of the river. These conditions were considered an influence of urban run-off. Sawmill Brook received a *"partially supports aquatic life"* designation because of SB violations for water temperature, pH and DO. Sawmill Brook pH was the lowest measured for all streams in the entire NCB watershed. A study of the rainbow smelt *(Osmerus mordax)* spawning habitat in Sawmill Brook during 1990 also found low pH (mean = 6.4) during 24 spring measurements (Chase 1995). The three pH data sources for Sawmill Brook contained measurements below 6.0 pH, which can threaten the survival of deposited smelt eggs. The other rivers with anadromous fish populations in the study (Porter and Crane Rivers) did not display acidic conditions.

Fecal Coliform Bacteria. The fecal coliform statistics for the five rivers sampled routinely in 1997 (North, Porter, Crane, Waters Rivers, and Sawmill Brook) exceeded SB criteria for supporting primary recreation. The North River had the highest geometric mean of 2009 fcc/100 ml. The North River data for 1997 are consistent with fecal coliform sampling by Salem Sound 2000 during 1998 and 1999 at the same station. The Salem Sound 2000 sampling produced a geometric mean of 4250 fcc/100 ml during eight dry weather samples and 871 fcc/100 ml during 17 wet weather samples (Salem Sound2000 2000). This indicates significant sources of fecal coliform bacteria are entering the North River during dry weather, presumably through failed or illicit sewer connections. Beyond concerns for primary recreation, the high bacterial counts create a significant challenge to goals of opening shellfish beds at downstream intertidal locations.

Nutrients. Nutrient measurements made at river stations in 1997 found high concentrations of nitrogen and phosphorus parameters, primarily in association with spring run-off conditions. This relationship between watershed nutrients and precipitation has been demonstrated for the Chesapeake Bay region (Boynton et al. 1995; Stevenson et al. 1993; and Ward and Twilley 1986). Few studies have measured nutrients in tributaries to Salem Sound, and no previous investigations have estimated TN loading into Salem Sound based on freshwater measurements. All major Salem Sound tributaries except Sawmill Brook were sampled by DEP on two dates in July, 1985 (MDWPC 1985). Nitrogen values were in a similar range as 1997, except for the Waters River, which had lower values than all 11 measurements in 1997. The NCB assessment measured ammonia (NH_3), nitrate, and total phosphorus during 1997/1998 at common stations as the DMF study (DeCesare et al. 2000). Of these parameters, only nitrate was also measured by DMF in 1997, although the parameters of ammonium (NH_4) and TDP are comparable.

The NCB assessment concluded that ammonia and TP at Crane River, North River and Porter River was elevated. The high nutrient concentrations in the Porter and Crane Rivers did not alter the designations related to aquatic life for those rivers. The elevated nutrients in the North River contributed, along with poor habitat and aquatic community quality, to a designation of *"non-support for aquatic life"* for the river segment that included the North River station. These conclusions are consistent with the nutrient measurements for this study. North River had the highest mean TN and ammonium of the three primary river stations. Unlike the NCB assessment, the 1997 DMF study found very high TN in the Waters River. The Waters River TN was substantially higher than all other stations, despite reduced spring sampling. The high TN was most influenced by high summer DON, however no explanations were found for the large increase over other stations. Comparisons between the two data sets should be made cautiously. When sampling frequencies are low, precipitation and seasonal changes can bias mean nutrient values. The two sampling efforts did corroborate in terms of revealing river concentrations of nitrogen and phosphorus that are a concern for aquatic life and habitat health.

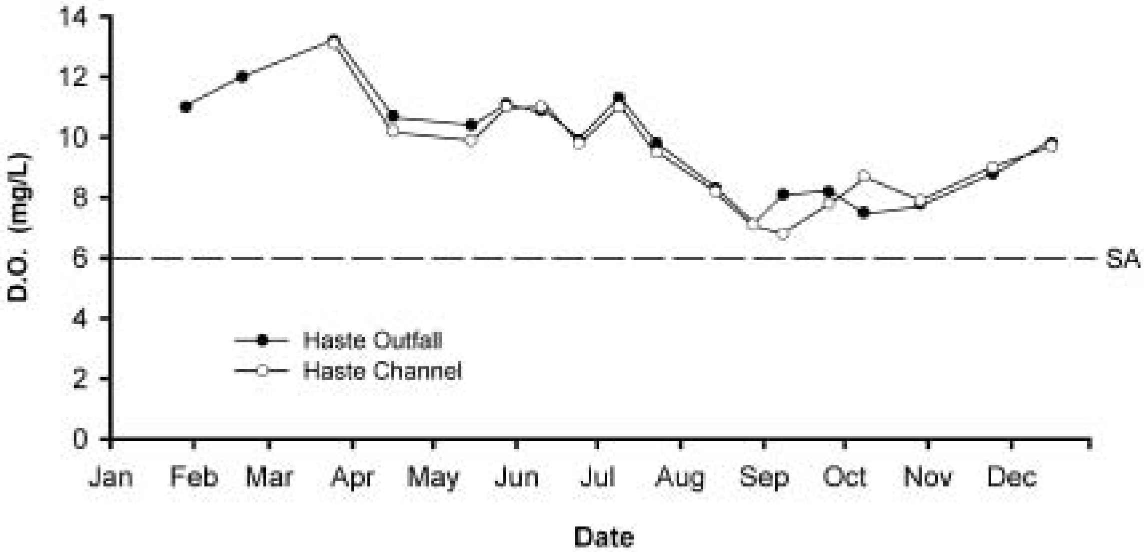
NUTRIENT LOADING

Simple calculations of TN loading from rivers entering Salem Sound and the SESD outfall discharge were made in 1997. Despite high TN concentrations, the river loads were modest (~60 mt/yr) because of low discharge volumes. The SESD outfall discharged a similar volume of freshwater as the rivers in 1997 but much higher TN concentrations resulted in a load estimate of 941 mt/yr. It is not known how well the 1997 river load estimate approximates the actual average annual load for these rivers. The measurements represent a maximum of 18 grab samples during a single, dry year. The episodic effect of storms on watershed flushing can result in a significant portion of annual TN loading to occur over relatively few events (Hicks et al. 2000), and can be underestimated when few grab samples are collected (Jarrell 1999). Long-term flow records are important for accurate nutrient load estimates (Isaac, 1997; Jarrell 1999; Isaac and Cooperman 2000). The 1997 TN load estimate is valuable because it is the first estimate for this region using river measurements and illustrates that the region's major point sources contribute higher loads than watershed river sources.

One previous investigation employed a land use model on nitrogen loading in 44 embayments in Massachusetts Bay, including Salem Sound (Menzie-Cura 1996). Total nitrogen loading was estimated as the sum of contributions from rivers, land use, atmospheric deposition, and point sources. The land use contribution was derived from nitrogen loading coefficients and 1990 GIS land use data. Atmospheric deposition was estimated by applying depositional rates to marine surface waters. Point sources were recorded from NPDES permits for wastewater treatment facilities. The TN load estimated for Salem Sound for all sources was 51 mt/yr. The estimates for the individual TN sources were as follows: point source (21.5%), non-point source (66%), atmospheric (12.5%), river (0%).

The Menzie-Cura (1996) estimate of Salem Sound TN loading appears low when compared to the field estimates for the five Salem Sound tributaries. The 1996 model did not attribute nitrogen loading directly to the rivers, but instead assumed that the modeled value for non-point sources from land-use would represent these contributions. Considering this assumption, the 1997 river

Figure 3.14 Bottom dissolved oxygen at Haste Channel and Haste Outfall stations, 1997. The SA criteria for supporting aquatic life (MDEP 1996) of 6.0 mg/L is indicated.



load estimate was about double the estimate for non-point sources in the 1996 study. The minor role of atmospheric deposition is questionable given the proximity of the Salem Power Plant and transportation corridors. Despite these differences, the magnitude of the loading estimates are similar. Adding the other sources to the 1997 estimate would still not exceed 100 mt/yr, a small amount in relation to contributions from the SESD outfall and emissions from the Salem Power Plant. The Menzie-Cura (1996) study also ranked each embayment in terms of nitrogen sensitivity and risk for eutrophication. Most Salem Sound locations were ranked moderately, although the Danvers River held the highest rank (most sensitive and highest risk) among all Massachusetts Bay locations.

MARINE WATER QUALITY

Basic Water Chemistry. Basic water chemistry parameters at subtidal marine stations and intertidal seine stations consistently displayed water quality that was adequate to support aquatic life. Dissolved oxygen, one of the more critical parameters, was found to exceed SA criteria for all marine measurements. This finding is similar to previous DO sampling in Salem Sound (CDM 1978; CDM 1987; CDM 1991; Dallaire and Halterman 1991; and SESD 1998). None of these studies found bottom DO at subtidal stations to violate SB criteria and SA violations were rare. Little difference was found in the bottom DO at the Haste Channel and Haste Outfall stations (Figure 3.14), providing evidence that the SESD outfall was not affecting bottom oxygen concentrations. Turbidity and secchi disc measurements found favorably water clarity, supporting anecdotal reports from the scuba diving community that water clarity has been improving in Salem Sound in recent years. Reduced water clarity was measured at the Haste Outfall station and was directly related to the effluent plume from the primary sewage treatment plant. Water clarity should improve in this area with the completion of the secondary sewage treatment plant and a multi-port diffuser discharge pipe (1998). The diffuser pipe is expected to disperse and minimize the surface effluent plume.

Water temperature in Salem Harbor was influenced by the thermal discharge from the Salem Harbor power plant. Modest warming of surface water was found at both intertidal and subtidal stations in Salem Harbor relative to other stations in Salem Sound. The influence of the Salem Harbor power plant on Salem Harbor was investigated in the 1970s as part of the permitting process for a fourth power generating unit (Anderson et al. 1975). Thermal plume studies conducted in 1973/1974 used vessel transects and continuous monitoring thermographs at fixed stations. The investigation indicated that the thermal influence of the discharge was limited by tidal flushing. No influence of the thermal plume was evident at a station 2.0 km from the discharge. The maximum vertical penetration of the plume was less than 2 m deep, and the 1°C isotherm of the plume only reached about 15% of the surface area of Salem Harbor at MLW. Observations in 1997 support these finding, although greater range in the harbor was found for the 1°C isotherm. Thermal warming from the power plant was evident at all tide stages at the Pioneer Village seine station (~1.5 km away) and Salem Harbor marine station (~0.75 km away).

Fecal Coliform Bacteria. Monitoring of fecal coliform bacteria as a pathogen indicator has resulted in closed shellfish beds in Salem Sound for many years. As early as 1925, most shellfish flats were closed due to pollution, and during the 1965 study only portions of Salem Harbor were open under a "moderately contaminated" status (Jerome et al. 1967). Extensive improvements to the region's sewage collection and treatment systems in the last two decades may be reducing bacterial pollution. The extent of improvement is uncertain because closed shellfish areas receive little monitoring and the success of point source abatement may be countered with a growing problem of non-point source contributions. Several shore stations in 1997 showed promise towards allowing improved classification of shellfish growing areas. Similar promise was found at marine stations, although sample frequency was not adequate to evaluate existing conditions. A full sanitation survey will be required before management decisions can be made on changing shellfish classifications. Bacterial counts at the Haste Outfall station were variable and at times elevated, reflecting influence from effluent discharge. There was no evidence that effluent bacteria reached the stations in Beverly and Salem harbors where low counts were consistent.

Chlorine. Chlorine compounds have long been used by the major point sources in Salem Sound to reduce bacteria and algal fouling in discharge waters. Concerns have been raised by the fishing industry that chlorine toxicity may be negatively impacting larval shellfish and finfish in Salem Sound. A review of the literature on water chemistry sampling in Salem Sound did not find records of receiving water measurements of chlorine residuals. Measurements of chlorine residuals that result from marine discharges are problematic because of the chemical composition of seawater. No measurements of chlorine residuals were made during the 1997 study. Currently, the use of chlorine in the discharges for SESD and the power plant are regulated under NPDES permits. Future monitoring of discharges and receiving waters may provide more information on potential impacts from chlorine toxicity.

Nutrients. The Beverly Harbor and Salem Harbor marine stations had relatively low nutrient levels that did not indicate influence from the high concentrations measured at river stations and the Haste Outfall station. This finding implies that the tidal range in this shallow embayment aids in assimilating small volume inputs despite high nutrient concentrations. The Haste Outfall station produced high phosphorus and ammonium measurements but little influence was detected a few kilometers from the station. The 1997 nutrient profile at marine stations was consistent to previous nutrient measurements in Salem Sound with minor exceptions. Previous sampling in Salem Sound was conducted for environmental permit applications required for the SESD wastewater treatment facility upgrade from primary to secondary treatment. The first sampling comprised of single measurements during October 1985 (Gardner et al. 1986). This sampling included one station near the Haste Outfall, and at several stations on a course leading out of Salem Sound. The concentrations measured in 1985 did not vary greatly from 1997 samples, with the exception of chlorophyll a, which was high for surface measurements (15-50 ug/L), and highest at the Haste Outfall station. Higher chlorophyll a was also found during 1973 and 1974 Power Plant sampling within Salem Harbor where mean values for spring and fall peaks were in the range of 10-20 ug/L (Anderson et al. 1975).

Nutrient samples were next collected for SESD in 1986 when surface and bottom measurements were made on eight dates from May to October (CDM 1987). Similar stations were visited as the previous study, including the Haste Outfall station. The Haste Outfall station produced high spikes in ammonium (40-80 μM) at the surface, as well as occasional low values (< 0.1 μM). This similarity with 1997 data reflects the influence of the outfall plume orientation. Surface ortho-phosphate (PO_4) at the Haste Outfall was higher (3.8 μM mean) than any station sampled in 1997, and three PO_4 concentrations (5.5-12.4 μM) were very high. This difference may reflect a shift in household use to low phosphorus detergent that occurred in the 1970s and 1980s (Roman et al. 2000). Reference stations outside of Salem Sound had low levels of DIN and phosphate, in a range comparable to surface measurements at the Beverly and Salem harbor stations in 1997. Collectively, the three sets of data for Salem Sound portray a condition of high ammonium and low $NO_2 + NO_3$ in the near-field zone of the SESD outfall and decreased ammonium and increased $NO_2 + NO_3$ away from the outfall. Given the relatively small area influenced by the outfall plume and the minor river inputs, these data point to the offshore waters of Massachusetts Bay as a source of $NO_2 + NO_3$ imported into Salem Sound.

The 1987 SESD Draft Facilities Plan included an evaluation of the 1985-1986 sampling that offered discussion on nutrient and phytoplankton dynamics in relation to the secondary effluent upgrade (GOM 1987). They concluded that ammonium would increase about 30% with secondary discharge, as reductions in organic nitrogen would result in higher ammonium. The report projected that the increase in ammonium should cause an increase in phytoplankton abundance in the vicinity of the outfall, but should not have a significant impact away from the plume (GOM 1987). Future field sampling will be needed to confirm these relationships under conditions of secondary sewage treatment discharge.

MWRA Reference Station. The MWRA has conducted nutrient measurements in Boston Harbor and Massachusetts Bay since 1992 for the purpose of monitoring the environmental effects of large-scale water pollution abatement projects in the region (Galya et al. 1996). This long-term commitment has produced the best record available for nutrient concentrations in Massachusetts Bay. The data series offers a good reference of offshore concentrations to the 1997 Salem Sound data. Comparisons were made with one reference station, MWRA Station NO4, which is located 10 km southwest of Marblehead, seaward of the 40 m depth contour. The sampling schedule used by MWRA was similar to the Salem Sound schedule: 17 sampling periods during the year, and biweekly sampling for most months from March through October. Mean values for surface and bottom nutrients at NO4 for 1995-1997 are summarized in Table A.22 (Cibik et al. 1998).

The 1997 Salem Sound data are similar to the MWRA station NO4, with specific differences, particularly at the Haste Outfall station. In general, TN was slightly higher inside Salem Sound due to higher values for PON and DON (Figure 3.15). Other important parameters, silicate, phosphate and chlorophyll a were all in a similar range as the reference station, with slightly higher silicate in the offshore bottom measurements. Plots of offshore nutrient concentration by month show similar trends of high NO_2 + NO_3, phosphate, and silicate in the spring and fall along with minimum levels in the summer: conditions that probably reflect typical plankton removals (Figure 3.16). The offshore bottom concentrations of NO_2 + NO_3 were higher than in Salem Sound, and surface ammonium was higher in Salem Sound. These differences did not result in major differences in DIN among stations except for the higher surface DIN at the Haste Outfall. The higher inorganic nitrogen concentrations at the outfall station did not seem to influence the levels seen elsewhere in the Sound or offshore.

Figure 3.15 Components of total nitrogen (TN) at Salem Sound marine stations and MWRA offshore reference station (#NO4), 1997.

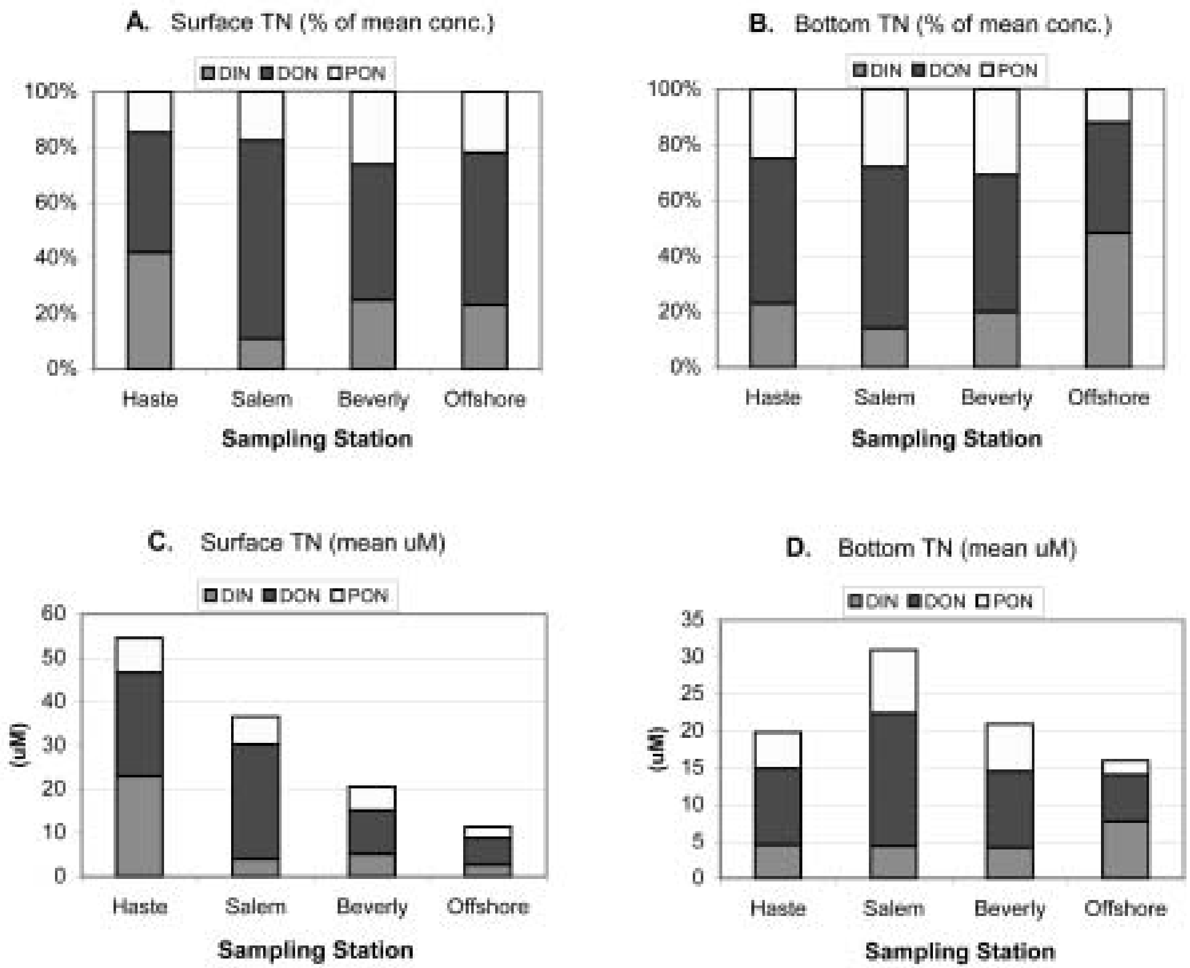
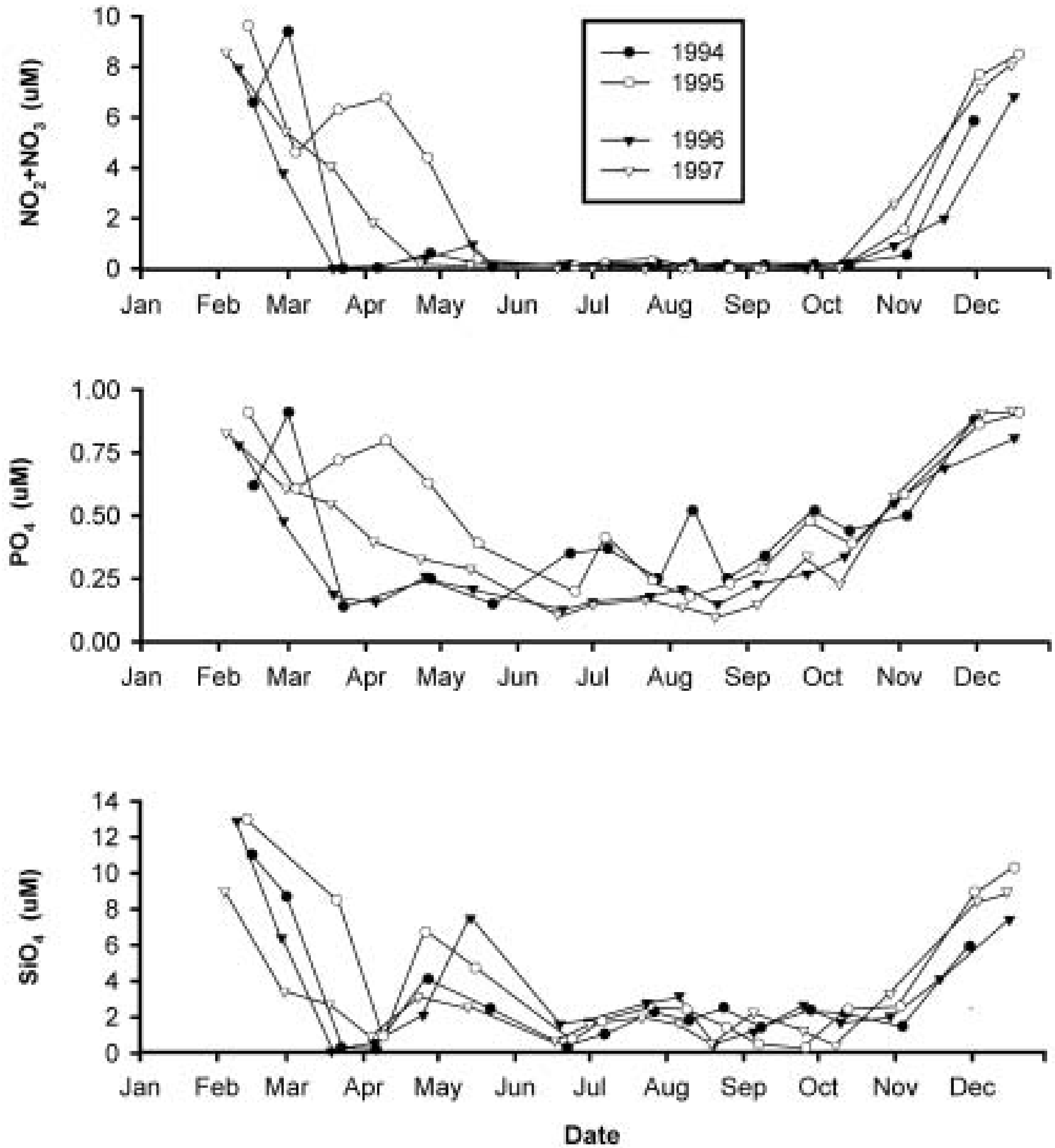


Figure 3.16 Nitrite plus nitrate ($NO_2 + NO_3$), ortho-phosphate (PO_4), and silicate (SiO_2) at MWRA offshore reference station #NO4, 1994-1997.



Sampling at MWRA stations inside Boston Harbor reveals comparable conditions to that found in Salem Sound. The high concentrations and variability in surface ammonium found at the Haste Outfall station were found at several Boston Harbor stations. This condition is likely a function of the MWRA outfall discharge off Deer Island or other land-based sources (Kelly and Turner 1995). The overall TN trend in the harbor is driven by both plankton removal and watershed/effluent discharges, which result in high spring and low summer concentrations. The TN loaded annually by the MWRA primary discharges was estimated to be 8,220 mt prior to the secondary upgrade (Galya et al. 1996). A large portion of this was attributed to ammonium. This large input did not appear to influence the low TN concentrations found at offshore stations during the 1990s. With a TN load close to 1,000 mt/yr, the SESD primary outfall was the second largest municipal point source of TN to Massachusetts Bay in 1997. Since 1997, both facilities have upgraded to secondary treatment.

Nutrient critical values. Critical nutrient values (Table 3.12) can be used to compare Salem Sound data to nutrient criteria for concentrations that can cause negative ecological impacts. These values are useful for comparative purposes, although it should be recognized that relationships between nutrient concentrations and resource conditions are not well established. Some of the strongest relationships have been demonstrated between high nutrients and the poor health of submerged aquatic vegetation in Chesapeake Bay (Stevenson et al. 1993; and Staver et al. 1996). Chlorophyll a is one of the better indicators of phytoplankton/ nutrient dynamics. Chlorophyll a concentrations in Salem Sound were low in 1997 and did not exceed the listed criteria. The nitrogen criteria were met in most cases, except for common violations at the Haste Station. The annual loading criteria pertains to Boston Harbor, but reflects the magnitude of Salem Sound loading relative to the more populated Boston region. The phosphate criteria was exceeded the most, as the mean concentrations for each Salem Sound marine stations exceeded the value considered the limit for submerge aquatic vegetation in Chesapeake Bay.

CONCLUSIONS

Water chemistry sampling in Salem Sound resulted in an overall portrayal of good water quality during 1997. Similar to other embayments in the Gulf of Maine, the high tidal range and shallow depths result in favorable flushing and minimal stratification. Improvements to the region's sewage collection and treatment system since the 1965 study have reduced bacterial and nutrient contributions at the SESD outfall discharge. It is difficult to draw firm conclusions based on one year of sampling, however, several trends indicate that most habitats have adequate water quality and some improvements have occurred.

No concerns were identified from basic water chemistry sampling at intertidal habitats. Tidal flushing reduced the effects of seasonal warming and maintained adequate DO to support aquatic life. Slight warming of water temperature was identified within Salem Harbor at both the subtidal and intertidal stations due to the power plant thermal discharge. Hypoxia (DO < 3.0 mg/L) was not a threat at any station. No SA water quality criteria violations were found for bottom dissolved oxygen.

Table 3.12 Critical nutrient values reported in recent publications.

Parameter	Value (*u* M)	Value (other)	Criteria	Reference
Chlorophyll *a*		>10 ug/l	0 value in Buzzards Bay index	(Costa et al. 1996)
Chlorophyll *a*		>12 ug/l	MWRA warning level for Boston Harbor	(Galya et al. 1996)
Chlorophyll *a*		>15 ug/l	MWRA action level for Boston Harbor	(Galya et al. 1996)
Total pigments		<15 ug/l	Chesapeake Bay SAV	(Stevenson et al. 1993)
DIN	>10	>0.14 ug/l	0 value in Buzzards Bay index	(Costa et al. 1996)
DIN	<10	<0.14 ug/l	Chesapeake Bay SAV	(Stevenson et al. 1993)
NH_4	>15	>0.21 ug/l	non-support, Aquatic Life criteria	(MDEP 1996)
PO_4	< 0.35	<0.01 ug/l	Chesapeake Bay SAV	(Stevenson et al. 1993)
TN load		>12,500 mt/yr.	MWRA warning level for Boston Harbor	(Galya et al. 1996)
		>14,000 mt/yr.	MWRA action level for Boston Harbor	(Galya et al. 1996)

Surface mean DO values were supersaturated at all intertidal and subtidal stations. Water clarity in 1997 showed improvements from previous measurements. The mean secchi disc depth ranged from 3.2 to 4.7 m for the subtidal stations. The lowest water clarity occurred in the Danvers River due to estuarine flushing and reduced clarity was also observed at the Haste Outfall station due to the effluent plume.

River water chemistry measurements created more concern than marine stations. High fecal coliform bacteria counts and low discharge occurred at most river stations. High water temperature, high specific conductivity, and low DO and pH were recorded at specific stations. A combination of these problems resulted in designations of "partially supports of aquatic life" for Crane River and Sawmill Brook (DeCesare et al. 2000). Observations of excessive growths of periphyton were observed at all stations during the warm months, and was most noticeable in the North and Crane Rivers.

Most nutrient concentrations did not exceed critical thresholds for environmental impacts, although specific habitats may be exposed to high concentrations periodically. High TN and PO_4 concentrations at some freshwater stations raise concerns for habitats near the freshwater/saltwater interface. The impact of high DIN from the Haste Outfall on phytoplankton dynamics within Salem Sound is still uncertain. The large flushing capacity of Salem Sound appears to reduce the range of both river and SESD discharge influences, and limit the effect of land-base inputs to nutrient concentrations in the Sound and Massachusetts Bay. This is consistent with findings for Buzzards Bay, another large, well-flushed Massachusetts' embayment (Costa et al. 1996; and Howe and Goehringer 1996). This study did not assess the input of specific contaminants (metal, organic and inorganic toxins from atmospheric, effluent, and stormwater sources), and therefore, potential impacts on water quality and marine resources from these sources are uncertain.

North River, Salem

CHAPTER 4. SHELLFISH SURVEY

Similar to much of coastal Massachusetts, the intertidal mud and sand flats in Salem Sound provide natural habitat for soft shell clams. The harvest of soft shell clams for bait was an important fishery during the 1700s and 1800s when groundfishing was a principal industry in the region (see Jerome et al. 1967, for historical review). By the start of the 20th century, the harvest of soft shell clams had sharply declined in response to low demand for bait and human consumption and declining clam flat productivity (Belding 1909). The use of Salem Sound waterways for sewage disposal created concerns over the consumption of soft shell clams and in 1925 the Massachusetts Division of Fisheries and Game closed most shellfish flats in the region for harvest (Belding 1930). At the time of the 1965 DMF study, there were small areas in Salem and Marblehead still open for restricted harvest. By 1972, all shellfish flats in Salem Sound were closed and have remained closed to the present.

Although the soft shell clam flats of Salem Sound remain closed for consumptive harvest, the populations are valuable as forage for other species and provide for limited bait harvest. The only previous survey of soft shell clams in Salem Sound was conducted during the 1965 DMF study. The objective of the 1965 survey was to estimate the size and potential economic value of soft shell clam populations in this region. We conducted a qualitative survey in 1997 to estimate the amount of productive habitat and population of legal sized soft shell clams. Both surveys are useful in the absence of a quantitative population assessment, although caution should be used when evaluating and comparing single-year qualitative surveys.

METHODS

DMF staff conducted surveys of soft shell clam beds on 22 dates between March and December, 1997, with assistance from trained SS2000 volunteers at the Forest River. The intertidal area throughout Salem Sound was surveyed on foot within two hours of low tide to evaluate its capability to support soft shell clam populations. We classified intertidal habitat as having the potential to support soft shell clams or not, based on the suitability of intertidal substrate. This classification relied on the extensive experience of author, Wayne Castonguay. All potential habitat for soft shell clams was surveyed on foot while visually examining the substrate for clam siphon holes and routinely turning over the substrate with a clam fork. Potential soft shell clam habitat was then classified as productive or non-productive based on the presence/absence of soft shell clams. After locating soft shell clams, we mapped the extent of each clam bed and increased sampling to estimate population density.

Several cubic foot samples of substrate were turned over with a clam fork within each clam bed and examined for legal sized clams (>2 in). We categorized each bed into four qualitative density categories: *None; Low* (< 1 clams/ft^3); *Moderate* (1-5 clams/ft^3); and, *High* (>5 clams/ft^3). All habitat and density data were transferred to maps and digitized into a GIS database. We mapped all intertidal area (based on mean tide level), potential habitat, and density data and calculated the area within each bed. We estimated clam population size by assigning values (clams/ft^2) to each density category (*None* = 0; *Low* = 1; *Moderate* = 2.5; and, *High* = 5) and then multiplying those values by the area for each clam bed sampled. The number of bushels represented by this estimate was calculated by assuming there are 400, 2.5-inch clams per bushel (Belding 1930). In addition to soft shell clams, we recorded observations of other shellfish species known to inhabit Salem Sound.

RESULTS

A total of 1,187 acres of intertidal area was surveyed throughout the Sound (Figure 4.1, page 50-51). Of this, 662 acres (56%) was classified as potential soft shell clam habitat (Table 4.1). However, only 19% of the potential habitat actually supported soft shell clams. Fifty-two acres of the productive habitat (41%) supported low densities, 36 acres (28%) supported moderate densities, and 39 acres (31%) supported high densities of clams. We estimated that the study area contained 38,576 bushels of legal sized clams (>2 inches) in 1997. Survey results by area are as follows:

Manchester Harbor. This area is located between Gales Point and Chubb Creek and consists of 81.48 acres of intertidal habitat. The majority of the intertidal area consisted of rocky areas, exposed ledge, and exposed sandy beach. Of this, 27.58 acres (34%) were potentially suitable soft shell clam habitat and only 4.49 acres (16%) were productive. We estimated that 1,205 bushels of legal-sized clams were present in the area.

Beverly Shore. This area is located between Chubb Creek and Lynch Park on the northern shore of the Sound and contains 153.09 acres of intertidal area. This shoreline is characteristic of a high energy, exposed shoreline and consists primarily of sandy beach with intermittent areas of rock and exposed bedrock. All potentially suitable soft shell clam habitat was located on the eastern side of two coves protected from the prevailing open ocean waves. Only 12.57 (8%) acres of intertidal habitat were classified as potential soft shell clam habitat and of this, 2.68 (21%) were productive. We estimated this area contained 530 bushels of legal sized clams.

Table 4.1 Soft shell clam habitat survey results, Salem Sound, 1997.

Location	Total Intertidal (acres)	Potential Habitat (acres)	Productive Habitat (acres)	Legal Size Soft shell clams (No.)	Bushels (No.)
Manchester Harbor	81.48	27.58	4.49	482,077	1,205
Beverly Shore	153.09	12.57	2.68	202,078	530
Beverly Harbor	123.73	20.91	1.04	59,335	148
Bass River	48.98	46.95	10.1	1,426,422	3,566
Danvers River	113.36	71.48	15.67	1,791,659	4,479
Porter River	56.65	56.27	18.7	2,453,363	6,133
Crane River	39.98	37.43	6.47	690,498	1,726
Waters River	42.01	32.11	21.62	3,287,298	8,218
Kernwood River	31.14	28.6	9.83	1,146,656	2,867
North River	76.33	61.62	12.33	1,403,181	3,508
Collins Cove	72.67	60.12	16.96	1,442,874	3,607
Salem Harbor	229.65	150.55	3.26	538,767	1,347
Forest River	12.72	12.59	3.55	492,453	1,231
Marblehead Shore	63.54	20.76	0.1	4,383	11
Marblehead Harbor	41.25	22.98	0	0	0
Total	1186.58	662.53	126.81	15,421,046	38,576

Beverly Harbor. The Beverly Harbor area is the northerly shoreline between Lynch Park and the Beverly Salem Bridge. Intertidal habitat in the harbor has been reduced by shoreline construction (bulkheads, ect.), and the remaining intertidal area consists primarily of sandy beach. Of 123.73 acres in this area, 20.91 (17%) were classified as potential soft shell clam habitat, of which only 1.04 acres (5%) were productive. We estimated that this area contained 148 bushels of legal sized clams.

Bass River. The Bass River tributary is located between the Beverly Salem Bridge and Kernwood Bridge on the western edge of Beverly Harbor. The intertidal area is highly variable and consists of cobble, sand, firm mud, soft mud and silt. Of the 48.98 acres of intertidal habitat, the vast majority (96%) was classified as potential soft shell clam habitat. Only 10.1 acres (21%) of this were productive; however, a majority of the productive habitat contained high densities of clams, resulting in an estimate of 3,566 bushels of legal sized soft shell clam.

Danvers River. This area contains all coves and shoreline along the Danvers River upstream of the Beverly-Salem Bridge not otherwise subdivided into the tributaries listed below. It consists of 113.36 acres of intertidal land and varies from sand to mud to silt substrate. The majority of this area (63%) was classified as potential soft shell clam habitat but only 15.67 acres supported clam populations. We estimated this area contained 4,479 bushels of legal sized clams.

Porter River. The Porter River contains the second largest amount of intertidal habitat among tributaries of the Danvers River estuary. The substrate varied between sand and firm mud, and nearly all (99%) of the area's 56.65 acres were suitable clam habitat. Of this, 18.70 acres were productive and contained high densities of clams. Due to the high productivity, 6,133 bushels of legal clams was estimated for this area.

Crane River. The Crane River consists of 39.98 acres of intertidal habitat. The majority of the intertidal sediments was soft mud and silt and was relatively unproductive. Of this, 37.43 (93%) acres were potential habitat but only 6.47 (17%) were productive. We estimated that this area contained 1,726 bushels of legal sized soft shell clams.

Waters River. This tributary contained 42.01 acres of intertidal habitat. The substrate varied from mud to silt and 32.11 acres (76%) were classified potential soft shell clam habitat. Of this, 21.62 (67%) acres were productive. Most of the productive habitat contained high densities of clams, resulting in the largest estimate of legal sized clams (8,218 bushels) among study areas.

Kernwood River. This cove contained 31.14 acres, the majority of which consisted of soft mud and silt. Although 28.60 acres (92%) were potential soft shell clam habitat, only 9.83 acres (34%) were productive. We estimated this area contained 2,867 bushels of legal sized clams.

North River. The North River contained the most intertidal habitat (76.33 acres) among tributaries within the Danvers River estuary. The substrate varied from sand to mud to silt and contained 61.62 acres of potential habitat. Of this, only 12.33 acres (20%) supported clam populations. We estimated that this area contained 3,508 bushels of legal size clams.

Collins Cove. This embayment consists of the area between the Beverly-Salem Bridge and the Salem Willows Park. The majority of the cove is intertidal at low water and contains 72.33 acres of intertidal flats. Sediments are primarily soft mud and silt although small portions consist of sand substrate. Over 80% of this area were potential soft shell clam habitat but clams occurred in only 16.96 acres (28%). We estimated that 3,607 bushels of legal size clams were located in this area.

Salem Harbor. Salem Harbor contained the largest amount of intertidal habitat within the study area (229.65 acres). The substrate varied from rock to cobble to mud and silt. Of this, 150.55 acres were classified as potential soft shell clam habitat. However, only 3.25 acres (2%) were productive. We estimated that this area contained 1,347 bushels of legal-size soft shell clams.

Forest River. This small estuary and tributary runs into Salem Harbor at the Marblehead/Salem border. Except for a few small man-made swimming beaches, the majority of the area consists of mud and silt. Of the area's 12.72 acres of intertidal land, 12.59 (99%) were classified as potential soft shell clam habitat. Of this, 3.55 acres (28%) were productive clam habitat. We estimated that this area contained 1,231 bushels of legal sized soft shell clams.

Marblehead Harbor and Shore. This area consists of the area between Salem Harbor and Marblehead Neck. A majority of the shore is exposed to a high-energy ocean environment and consists of a rock, cobble, or bedrock substrate. This area contains 104.79 acres of intertidal habitat, but only 43.74 (42%) were classified as potential soft shell clam habitat. Potential habitat was primarily limited to protected flats near the head of Marblehead Harbor. Of this, only 0.1 acres contained soft shell clams, and an estimated 11 bushels of legal sized clams.

OTHER SHELLFISH SPECIES

Quahog (Mercenaria mercenaria). Quahogs are distributed commonly from the Gulf of Mexico to Cape Cod and occur incidentally in Massachusetts Bay. Small numbers of quahogs were found at several locations during the shellfish survey. Individuals or small concentrations were recorded in Salem Harbor, North River, Kernwood Cove, Waters River, Porter River, Danvers River, and Manchester Harbor. Relatively large concentrations were noted near the mouth of the North River and in the cove at Tuck's Point Park in Marblehead Harbor. Although more quahogs were found than expected for this region, none of the populations seemed large enough to support commercial harvest.

Blue Mussel (Mytilis edulis). Beds of blue mussels were observed along nearly every shore, bar and island throughout Salem Sound; with expansive beds on the south side of Beverly Harbor and near the mouths of the Bass, North, Waters, and Kernwood Rivers. Blue mussels were commonly observed at lower intertidal habitats and subtidally to shallow depths. Although abundant, no fisheries occurred during 1997 on the North Shore, primarily because most beds are closed for shellfish harvest.

European Oyster (Ostrea edulis). Large populations of European oysters were observed in 1997 in Salem Sound. These non-indiginous oysters are a relatively new resident to the Sound, most likely the result of an accidental release from a private mariculture facility in Salem Harbor during the 1980s (Castonguay and Chase 1996). Since that time, the oysters have multiplied rapidly and have colonized numerous locations in the Sound. They are common on hard, stable substrata or structures between the low water line and 30-ft deep, although they have also been observed in muddy areas attached to any available piece of structure or debris. It is not known if the oysters compete with native shellfish species or other benthic organisms. Outside of co-occurrence with blue mussels, we did not observe much overlap in habitat use between the European oyster and native shellfish.

Razor Clam (Ensis directis). Incidental numbers of razor clams were seen at several locations during the survey at sandy or muddy intertidal habitats. The highest densities were observed near the low water line in Kernwood Cove, Collins Cove, North River and Salem Harbor.

Surf Clam (Spisula solidissima). Surf clams typically occupy subtidal habitats and the lowest reaches of intertidal habitat. Therefore, this survey would not likely encounter many surf clams. Observations of individual surf clams and shack indicate that notable populations of surf clams are limited primarily to the subtidal habitat below the exposed beaches on the Beverly Shore.

American Oyster (Crassostrea virginica). We did not expect to find American oysters in the study area, as they have not been reported in recent years. A few live oysters were found in the Manchester Harbor area and shells were found in Collins Cove.

Sea Scallop (Placopectin magellanicus). Sea scallops were not observed during the intertidal shellfish survey, but were caught during subtidal trawls (Chapter 6).

DISCUSSION

We encourage readers to use caution when interpreting the results of this shellfish survey. Simple extrapolations were used to estimate standing crop of legal size soft shell clams from qualitative density classifications. This method does not allow for calculating statistical confidence in clam population estimates. The absence of data on clams less than legal size is another limiting factor. The value of the shellfish survey is found in the extensive spatial coverage of all potential soft shell clam habitat and the contribution of unique information on shellfish resources in this region.

COMPARISON TO 1965 DMF STUDY.

The shellfish survey conducted by DMF in 1965 (Jerome et al. 1965) is the only other survey on soft shell clams throughout Salem Sound. Comparisons to the 1997 survey are limited by differences in survey methods. The 1965 survey did not cover all intertidal areas; instead they covered only clam flats and determined if they were productive or non-productive. Productive flats were then sampled for clam densities and areas were estimated from aerial photographs and contemporary geodetic charts. The 1997 survey covered all potential soft shell clam habitat and digitized data from productive beds to a GIS database using 1990 chart data. It is difficult to compare these two different qualitative methods for estimating shellfish bed area. Consequently, the accuracy of estimates of clam numbers resulting from area extrapolations is uncertain. Therefore, we limit our comparison to outstanding trends and comments on productive habitat.

The 1997 survey estimated that out of a total of 663 acres of potential soft shell clam habitat only 127 acres (19%) were productive or contained soft shell clams. The 1965 survey estimated that 457 acres were productive and did not report a Salem Sound-wide estimate for potential habitat. The difference in amount of productive habitat between the two studies is considerable. The difference could be inflated by different methods for estimating area. Alternatively, the reduction could be even more significant when considering that the 1965 survey did not include areas in the Porter River and Forest River that were unproductive because tidegates greatly limited tidal action. These two areas have been open to tidal action in recent years and accounted for over 20 acres of productive habitat (with high clam densities) in 1997.

Despite the difficulty of comparing survey methods, the discussion can be reduced to a comparison of the presence or absence (productive or not) of soft shell clams at major clam flats. In this regard, the decline in clam flats with clams present is a compelling change between study periods. There are large stretches of intertidal habitat that were productive in 1965 but did not contain soft shell clams in 1997. This is especially apparent in Salem Harbor and tributaries to the Danvers River. There are a number of reasons why this change may have occurred naturally. Shellfish spawning success can fluctuate annually due to climatic influences and physical alterations from storms can cause major changes to the productivity of clam beds. Clam harvest can quickly reduce populations at specific clam flats. The impact of harvest mortality should not be large because nearly all these beds have been closed to consumptive harvest for both study periods. The percentage of potential soft shell clam habitat (19%) with clams present in 1997 appears low for an unharvested area. It does not appear likely that natural fluctuations or harvesting are responsible for the absence of soft shell clams in all cases where potential habitat was found. This raises concerns over the potential of negative impacts resulting from anthropogenic activities in the region.

Both surveys noted observations of other shellfish species. The 1965 found the duck clam (*Macoma balthica*) was a very abundant bivalve in most surveyed flats. The duck clam was commonly observed in 1997. Quahog and European oysters were commonly observed species in 1997 but they were not reported in 1965. The American oyster was observed infrequently in 1997, but was not reported in 1965. It is not certain if these species were absent in 1965 because the survey was designed to target soft shell clams. There is no evidence that the introduced European oyster existed in Salem Sound during the 1960s and 1970s.

REDUCTION OF PRODUCTIVE HABITAT.

The cause for the apparent reduction in productive soft shell clam habitat is unknown. Natural causes have been discussed as a potential source. Fishing mortality in unharvested areas does not appear responsible. Substantial sewage treatment abatement and water quality improvements have occurred since the 1965 study. Environmental fluctuations, acute pollution discharges, and chronic disruptions from watershed alterations may have contributed, but none have been assessed for the region. Acute pollution discharges should be a declining concern with the implementation of the Clean Water Act. Reductions in pervious surfaces and freshwater base flows in the watershed could increase sedimentation impacts in the upper estuary. The authors have observed direct sedimentation impacts to specific flats in Danvers River tributaries during the 1990s, and suspect that some flats have been chronically degraded by sedimentation. Overall, little information is available on the role of watershed alterations on the productivity of Salem Sound clam beds.

OPENING OF SHELLFISH BEDS TO HARVEST.

The shellfish beds of Salem Sound were closed for consumptive harvest for much of the 20^{th} century. Evidence was found in 1997 to indicate specific locations have some promise to reverse this trend (see Chapter 3). However, a large majority of the Sound was still subject to chronic bacterial inputs that would preclude the initiation of sanitary surveys in these areas without a significant amount of pollution remediation occurring. In general, bacterial counts within upper Manchester Harbor, Bass River, Porter River, Crane River, North River, Collins Cove, and Marblehead Harbor are relatively high and will not support shellfishing until significant source remediation occurs. The water quality in the Waters River, Kernwood River, Danvers River, and portions of Salem Harbor showed more potential for an improved classification. Bacterial counts in deeper embayments and the outer Sound were relatively low; however, a majority of these areas were impacted by intermittent pollution sources that would preclude an improved classification. Clam populations in some of these areas were also too low to support a restricted commercial fishery. Because significant administrative, enforcement, and treatment capacity issues are associated with changing growing area classifications, any changes will require extensive evaluations of existing water quality and available clam population.

It should be noted that since this study was conducted, significant pollution remediation has occurred. Salem Sound 2000 has undertaken a large, Sound-wide pollution source assessment project, and have identified chronic sources of bacteria. Large, untreated sanitary sewage discharges were found within Marblehead Harbor, Collins Cove, The South River, North River, Crane River and Bass River. Some of these sources have been remediated. In addition, the SESD plant has been upgraded (1998) to provide secondary treatment, which may improve water quality in the vicinity of the outfall. These ongoing remediation efforts should reduce bacterial contamination in Salem Sound in the next decade.

Sampling softshell clams in Manchester Harbor

Figure 4.1 Soft Shell Clam Survey, Salem Sound, 1997


MANCHESTER
BEVERLY
Manchester Harbor
Beverly Shore
Marblehead Harbor
Division of Marine Fisheries
DIRECTOR PAUL J. DIODATI
MASS GIS
Massachusetts Geographic Information System
Massachusetts Executive Office of Environmental Affairs - 2002
SCALE 1 : 38000
Intertidal Non Habitat
Habitat No Clams
Low Density
Moderate Density
High Density
Produced January, 2002

CHAPTER 5. SEINE SAMPLING OF INTERTIDAL HABITATS

The beach seine net is a traditional sampling gear used to collect fish at intertidal habitats. We selected this gear to document the presence of fish and decapods at specific intertidal locations along Salem Sound. We selected six sampling stations that represented river bank, harbor beach, and dynamic beach habitats. Five of the six stations were sampled during the 1965 study using similar methods.

METHODS

The six seine stations were visited monthly in 1997. Seining trips targeted the middle of each month, with no trips made during the first or last weeks of each month. We avoided sampling at high tide and attempted to conduct all hauls within three hours of low tide (both ebb and flood stages). We used a Wilcox sinking beach seine with the following dimensions: 15.2 m (50 ft) length, 1.2 m (4 ft) depth, and a 1.2 m x 1.8 m (4 x 6 ft) bag. The mesh was 4.8 mm (3/16 in) square delta nylon. Floats were attached every 50 cm on the float line and lead weights were spaced every 25 cm. The 1965 study used a 60 ft haul seine with 4 ft depth and 1/8 in mesh, and also used a 20 ft beach seine. The 50 ft seine with larger mesh was selected for the 1997 study because it was more manageable than the 60 ft seine and was consistent with recent estuarine seining studies in Massachusetts (Deegan et al. 1993; Buschbaum et al. 1997). Nets were attached to hauling posts with 50 cm of line between post and net and a calibrated spread line was attached to each post for measuring seine spread.

A crew of three deployed the seine from shore using a design to cover a 150-300 m^2 rectangular section of substrate. The net was positioned parallel to shore at a depth of about one meter. The distance from the net to shore was measured to the nearest 0.5 m with a measuring tape. The seine was then hauled straight to shore. The width of the hauled area was measured with the spread line to the nearest 0.1 m (typically 12-14 m). The area swept (m^2) was computed by the distance from shore times spread length. One person trailed the net to release hang-ups. The net was hauled on to the beach, and all fish and most decapods were placed in buckets, counted and returned to the water. Total length (TL) measurements were made of all commercially and recreationally important species. Once the catch was sorted, a duplicate haul was made adjacent to the first haul without sweeping over the same substrate. Seine catch data were evaluated in terms of frequency of occurrence, abundance (numbers caught), relative abundance (catch per haul), species richness (number of species) and diversity to identify seasonal and habitat trends in the intertidal fish community. The Shannon-Weaver index was used as measure of fish diversity that accounts for the number and relative abundance of each species (Ludwig and Reynolds 1988).

RESULTS

A total of 136 hauls was made at the six stations in 1997. Duplicate hauls were made each month at five of the six stations. No hauls were made at Proctors Point from January to April because of the presence of ice. Twenty-three species of fish and seven species of arthropods were caught and quantified (Table 5.1). Six of the arthropods were decapod crustaceans. Shrimp of the order *Mysidacea* were caught at each station, often in high densities, but were not quantified because they were too small to be sampled representatively with the 4.8 mm seine mesh.

Three fish species (Atlantic silverside, winter flounder, and mummichog) occurred in at least 20% of all hauls. Atlantic silverside was the most abundant fish in the total catch and occurred most frequently in hauls (46%). Winter flounder was the fourth most abundant fish caught and ranked second in frequency of occurrence (40%). Mummichog was the fifth most abundant fish caught and ranked third in frequency of occurrence (21%). The only other fish species caught in large numbers were Atlantic menhaden and Atlantic herring. Total catches for these two species were derived from a few hauls with many individuals. Sand shrimp dominated the catch composition of decapods, occurring in 90% of hauls. Haul densities of sand shrimp were very high in May and August at some stations, exceeding 10/m^2. Green crab and hermit crab were the only other decapods commonly caught.

Table 5.1 Seine station catch : all hauls combined from January - December, 1997 (N = 136).

Species Name	Scientific Name	Total Catch (No.)	Frequency of Occurrence (No. of Hauls)	Presence by Month (No.)
FISH				
Atlantic silverside	*Menidia menidia*	10256	62	11
winter flounder	*Pleuronectes americanus*	928	55	9
mummichog	*Fundulus heteroclitus*	396	28	7
Atlantic menhaden	*Brevoortia tyrannus*	5753	19	4
grubby	*Myoxocephalus aenaeus*	23	15	6
Atlantic tomcod	*Microgadus tomcod*	29	11	3
threespine stickleback	*Gasterosteus aculeatus*	13	8	6
northern pipefish	*Syngnathus fuscus*	20	8	4
Atlantic herring	*Clupea harengus*	2150	8	3
windowpane	*Scophthalmus aquosus*	7	7	4
rainbow smelt	*Osmerus mordax*	13	4	3
Atlantic cod	*Gadus morhua*	3	3	1
red hake	*Urophycis chuss*	4	3	3
bluefish	*Pomatomus saltatrix*	14	3	2
sand lance	*Ammodytes americanus*	7	2	1
lumpfish	*Cyclopterus lumpus*	3	2	1
bay anchovy	*Anchoa mitchilli*	2	1	1
silver anchovy	*Engraulis eurystole*	1	1	1
fourspine stickleback	*Apeltes quadracus*	1	1	1
striped killifish	*Fundulus majalis*	6	1	1
striped mullet	*Mugil cephalus*	204	1	1
little skate	*Raja erinacea*	1	1	1
northern sea robin	*Prionotus carolinus*	2	1	1
Total fish catch		19836		
ARTHROPOD				
sand shrimp	*Crangon septemspinosa*	71022	123	12
green crab	*Carcinus maenas*	916	75	10
hermit crab	*Pagurus* sp.	915	57	8
rock crab	*Cancer irroratus*	18	8	6
lady crab	*Ovalipes ocellatus*	31	3	1
shore shrimp	*Palaemonetes pugio*	1	1	1
horseshoe crab	*Limulus polyphemus*	1	1	1
Total Arthropod catch		72904		

The highest catch abundance and number of fish species caught per haul occurred during May to November (Table 5.2, Table A.23, and Figure 5.1). The increased occupancy of fish at these intertidal habitats coincided with water temperatures generally 10°C and higher. The lowest catches occurred during December through April when water temperatures were approximately 5°C or less (Figure 5.1). Of the decapods, only the sand shrimp was caught during each month. Among fish, Atlantic silverside showed the widest temporal range (11 of 12 months).

In addition to water temperature, another important influence on the catch composition was the recruitment of young-of-the-year (YOY) fish to intertidal habitats. The seine catches of fish were dominated by juvenile life stages, of which a majority was YOY. Except for Atlantic silverside, mummichog, pipefish, and sticklebacks, few adult fish were caught at the seine stations (two rainbow smelt, one little skate and one windowpane). Atlantic menhaden and Atlantic herring, ranking second and third in seine catch abundance, were all YOY. Most winter flounder were YOY that moved into the intertidal stations during July and occurred in high densities at some stations in July and August (Figure 5.2, A.1)

Table 5.2 Monthly catch at seine stations: total catch for all stations each month. Twelve hauls per month were targeted at the six stations. A total of 136 hauls were made in 1997.

Species Name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Fish	(No.)	(No.)	(No.)	(No.)	(No.)	(No.)	(No.)	(No.)	(No.)	(No.)	(No.)	(No.)	(No.)
Atlantic silverside	38		2	3	124	40	1049	3036	4708	602	390	264	10256
winter flounder				1	12	24	170	597	54	20	45	5	928
mummichog					6	41	26	114	161	5	43		396
Atlantic menhaden								6	5620	105	22		5753
grubby				4	6	4	3		3		3		23
Atlantic tomcod					23	4					2		29
threespine stickleback	1		1	7			1			2	1		13
northern pipefish							4	1	14	1			20
windowpane								2	3	1	1		7
Atlantic herring					390	1758					2		2150
Atlantic cod			3										3
red hake						1			2	1			4
bluefish							12		2				14
rainbow smelt							2			6	5		13
sand lance						7							7
lumpfish							3						3
bay anchovy										2			2
silver anchovy										1			1
fourspine stickleback		1											1
striped killifish							6						6
striped mullet									204				204
little skate									1				1
northern sea robin									2				2
Total fish catch	39	1	6	15	561	1879	1276	3756	10774	746	514	269	19836
Arthropod													
sand shrimp	38	30	309	373	18074	8559	6916	23578	2645	2197	7336	967	71022
green crab			2	2	44	286	190	201	114	50	22	5	916
hermit crab					12	293	300	186	91	16	15	2	915
rock crab				1		4	1		1	10		1	18
lady crab									31				31
shore shrimp										1			1
horseshoe crab							1						1
Total Arthropod catch	38	30	311	376	18130	9142	7408	23965	2882	2274	7373	975	72904

Figure 5.1 Monthly mean number of fish species per seine haul (± 1 SE), and mean monthly water temperature (°C) for all stations.

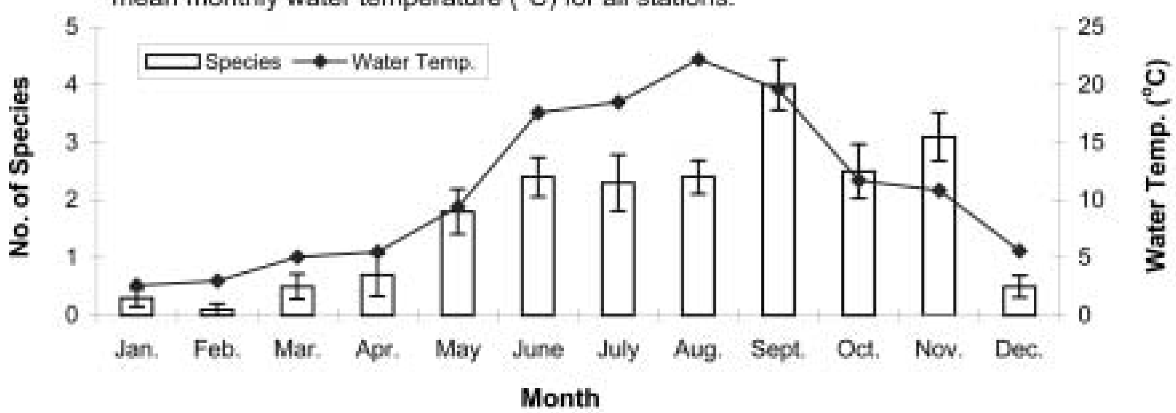


Figure 5.2 Mean catch (± 1 SE) of winter flounder per haul by month for all seine stations (Jan.-April, N=10, May-Dec., N=12).

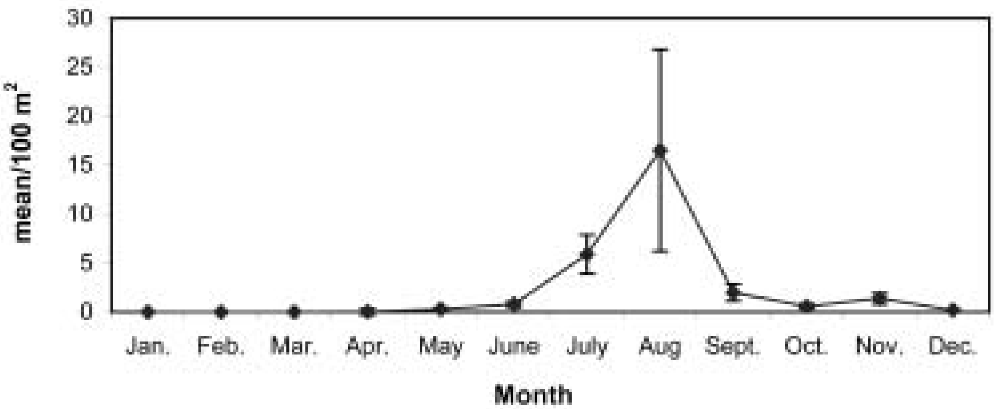


Table 5.3 Fish catch summary for Salem Sound seine stations, 1997. Species rank refers to relative abundance. Diversity was calculated using the Shannon-Weaver index of diversity (H').
H' = -Σ[(proportion of given species in total sample) ln(proportion of given species in total sample)].

Station	Hauls (No.)	Total Fish (No.)	Species (No.)	Catch/Haul (No.)	Diversity (H')	Species Rank (1st)	Species Rank (2nd)	Species Rank (3rd)
Sandy Beach	24	5563	10	232	0.80	silverside	Atl. herring	wint. flounder
Obear Park	24	2321	10	97	0.26	silverside	mummichog	wint. flounder
Tuck Point	24	6724	11	280	0.97	menhaden	Atl. herring	wint. flounder
Pioneer Village	24	2651	7	110	0.37	silverside	menhaden	mummichog
West Beach	24	351	11	15	1.18	silverside	Atl. herring	wint. flounder
Proctor Point	16	2226	15	139	0.90	menhaden	silverside	wint. flounder

No statistical comparisons of seine data were made because of the high variation expected for seine catches from intertidal habitats. The variability in catch data is influenced by gear selectivity, seasonal effects (water temperature and recruitment), tidal effects (water level), and relatively infrequent sampling. The following sections and Table 5.3 summarize catches at each seine station.

Sandy Beach (tidal river habitat). Ten species of fish and four species of decapods were caught at Sandy Beach in 24 hauls (Table A.24). Atlantic silverside (63%), winter flounder (50%), mummichog (46%), sand shrimp (75%), green crab (50%), and hermit crab (38%) were the only species to occur in 20% or more of the hauls. The predominance of these species in the catch composition was typical of most stations. The catches of striped mullet, striped killifish, shore shrimp and horseshoe crab were unique to Sandy Beach. The mean May-November density for silversides was the highest among all seine stations, while the densities of sand shrimp and winter flounder ranked second to Tuck Point.

Obear Park (tidal river habitat). Ten fish species and three species of decapods were caught at Obear Park in 24 hauls (Table A.25). Atlantic silverside (38%), mummichog (33%), winter flounder (25%), sand shrimp (88%), green crab (54%), and hermit crab (33%) were the only species to occur in 20% or more of hauls. All other species occurred infrequently and in low abundance and no species was unique to this station. The species diversity and relative abundance (catch/haul) were the lowest among seine stations. The hauls in May contained high numbers of sand shrimp (11 and $8/m^2$). Despite the proximity to Sandy Beach, the upstream tidal river station, the winter flounder catch was much lower at Obear Park, with a May-November mean density of less than $1/100\ m^2$.

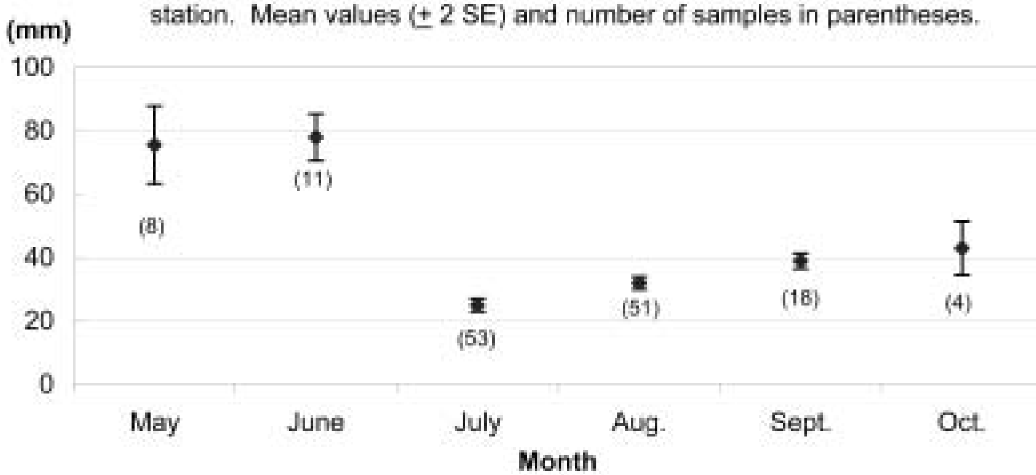
Pioneer Village (harbor beach habitat). Seven species of fish and three species of decapods were caught at Pioneer Village in 24 hauls (Table A.26). Atlantic silverside (58%), winter flounder (38%), mummichog (21%), sand shrimp (96%), green crab (75%), and hermit crab (38%) were the only species to occur in 20% or more of hauls. The least number of fish and decapod species were caught at this station and no species were unique to this station. This was the only station where sand shrimp was not the most abundant species (fish or decapod). Atlantic silverside had the highest May-November density (65/100 m^2) among all species at Pioneer Village. This catch density was most influenced by moderate catches of adult silversides in May and July and large YOY catches during August and September.

Proctor Point (harbor beach habitat). No hauls were possible during January-April because of the presence of ice. Despite fewer seine hauls, 15 fish species and five decapod species were caught in 16 hauls (Table A.27). Atlantic silverside (56%), Atlantic menhaden (38%), grubby (38%), winter flounder (38%), Atlantic tomcod (31%), sand shrimp (94%), green crab (75%), and hermit crab (69%) occurred in 20% or more of hauls. Proctor Point had the highest species richness for fish, especially during the fall when 6-7 species were present each month. The catches of bay anchovy, silver anchovy and lumpfish were unique to Proctor Point. Although more fish species were caught at Proctor Point than at other stations, diversity was ranked only third and abundance for most species were low. The catch of Atlantic tomcod and rainbow smelt was highest among stations, however relative abundance was low (about 1 per seine haul).

West Beach (dynamic beach habitat). Eleven species of fish and five species of decapods were caught at West Beach in 24 hauls (Table A.28). Atlantic silverside (29%), winter flounder (29%), windowpane (21%), sand shrimp (92%), hermit crab (33%), and green crab (25%) were the only species to occur in 20% or more of hauls. The exposure of West Beach to wave action and resulting sandy substrate created a habitat unlike other seine stations, and the species composition reflected this influence. Sand lance, northern sea robin, fourspine stickleback, and little skate were unique to West Beach. More windowpane and lady crab were caught here than at other stations, and mummichog was notably absent. Total fish catch/haul was lowest among the seine stations, however the evenness of catch resulted in the highest species diversity.

Tuck Point (harbor beach habitat). Eleven fish and four decapods were caught at Tuck Point in 24 hauls (Table A.29). Winter flounder (67%), Atlantic silverside (33%), sand shrimp (100%), green crab (58%), and hermit crab (50%) were the only species to occur in 20% or more of the hauls. The mean number of fish species per haul for May-November was the lowest among stations and no unique species were caught at Tuck Point. Despite the low species richness, Tuck Point had the highest catch/haul, and second highest diversity. The mean May-November densities of winter flounder, Atlantic herring, Atlantic menhaden and sand shrimp were the highest among stations. Each of these mean densities were influenced by a few hauls with many individuals. The May hauls contained high densities of sand shrimp (14 and 13/m^2), and one August haul was the largest overall (37/m^2). One haul in August of 384 YOY winter flounder had a major influence on the density and variance of winter flounder catches at Tuck Point. The use of intertidal habitats in Salem Sound by juvenile winter flounder is illustrated by the length data from Tuck Point (Figure 5.3). No winter flounder were caught at Tuck Point during January-March, and a single age-1 flounder was caught in April. All May and June catches of winter flounder were age-1, and all catches from July-October were YOY.

Figure 5.3 Mean length of winter flounder caught at Tuck Point seine station. Mean values (± 2 SE) and number of samples in parentheses.



DISCUSSION

The catch composition at the Salem Sound seine stations was characterized by relatively few species of fish and decapods, with most occurring infrequently. In terms of ecological niche, the fish catch was numerically dominated by schooling, forage species. Based on length-frequency measurements, most of the fish caught were juveniles. A large majority of fish were caught during the warmer water months of May-November (98% by number), and catches peaked in the fall and were influenced by YOY recruitment.

The interpretation of seine catch data and comparisons to previous efforts must be made cautiously because of the effects of infrequent sampling, the transience of species at intertidal habitats, and the changes in gear catchability that can occur with slight changes in seines. The influence of changing tide stage on species presence and density is difficult to quantify and does not effect all species uniformly. Sporadic catches of large numbers of a given species can inflate mean catch densities when sampling only once per month. Examples of this occurred during individual hauls at Tuck Point in August and September when 384 YOY winter flounder (41% of winter flounder catch) and 4,247 YOY Atlantic menhaden (74% of Atlantic menhaden catch) were captured, respectively.

Despite the observed variability, the seine catches of fish and decapods appeared typical of cold-temperate waters in northern estuaries. The numerical dominance of schooling, forage fish was also found during recent intertidal habitat sampling in the Gulf of Maine (Buschbaum and Purintan 1997; and Lazzari et al. 1999) and Cape Cod (Deegan et al. 1993). Mummichog and Atlantic silverside were highly ranked fish among intertidal catches for each of these studies. Sand shrimp is a major faunal component of shallow water habitats from Virginia to the Gulf of Maine. In addition to Salem Sound, sand shrimp was the dominant decapod caught during intertidal sampling in Plum Island Sound, Massachusetts (Buschbaum and Purintan 1997), and at shallow-water stations at a Cape Cod inlet (Heck et al. 1989) and a New Jersey embayment (Sogard and Able 1991). The highest densities of sand shrimp during May-November were found at the three stations associated with the Danvers River (station mean 2-8 shrimp/m^2). Although these densities were relatively high, they were well below the 20-40 shrimp/m^2 found in shallow water habitats in New Jersey during May-September (Sogard and Able 1991). The role of sand shrimp in local energetic pathways was not addressed, but must be important given the high densities.

Comparisons of seine catches specific to Salem Sound are only available from the 1965 DMF estuarine study for Salem Sound (Jerome et al. 1965) and Salem Harbor Power Plant investigations during the 1970s (Chesmore et al. 1972-1974; and Anderson et al. 1975-1979). The following section compares the seine results of these studies.

Table 5.4 Salem Sound seine station catch in 1965; all hauls combined from January-December. Two hauls were made with both 20 ft. and 60 ft. seines during each station visit (N = 71).

Species Name	Scientific Name	Total Catch (No.)	Frequency of Occurrence (No. of visits)	Presence by Month (No.)
mummichog	*Fundulus heteroclitus*	7727	26	8
Atlantic silverside	*Menidia menidia*	1271	15	8
Atlantic herring	*Clupea harengus*	630	3	1
rainbow smelt	*Osmerus mordax*	387	5	5
Atlantic tomcod	*Microgadus tomcod*	251	5	3
fourspine stickleback	*Apeltes quadracus*	75	4	3
ninespine stickleback	*Pungitius pungitius*	47	5	2
threespine stickleback	*Gasterosteus aculeatus*	46	11	6
winter flounder	*Pleuronectes americanus*	19	6	5
striped killifish	*Fundulus majalis*	16	4	2
northern pipefish	*Syngnathus fuscus*	15	6	5
lumpfish	*Cyclopterus lumpus*	5	1	1
red hake	*Urophycis chuss*	3	3	2
cunner	*Tautogolabrus adspersus*	2	1	1
longhorn sculpin	*Myox. octodecemspinosus*	1	1	1
Total fish catch		10495		

Table 5.5 Beach seine catch summary (total number of fish) for three DMF studies in Salem Sound. Pioneer Village, Obear Park, Tuck Point, West Beach and Proctor point are common stations. *Station visits* and *hauls* are estimated for 1972 and *hauls* are estimated for 1965.

Species Name	Scientific Name	1997 (50 ft. net)	1972 (50 ft. net)	1965 (20/60 ft. net)
Stations		*6*	*8*	*6*
Sampling dates		*12*	*14*	*12*
station visits		*68*	*112*	*71*
Hauls		*136*	*224*	*284*
Atlantic silverside	*Menidia menidia*	10256	9771	1271
Atlantic menhaden	*Brevoortia tyrannus*	5753	214	0
Atlantic herring	*Clupea harengus*	2150	1	630
winter flounder	*Pleuronectes americanus*	928	3	19
mummichog	*Fundulus heteroclitus*	396	976	7727
striped mullet	*Mugil cephalus*	204	0	0
Atlantic tomcod	*Microgadus tomcod*	29	0	251
grubby	*Myoxocephalus aenaeus*	23	0	0
northern pipefish	*Syngnathus fuscus*	20	2	15
bluefish	*Pomatomus saltatrix*	14	3	0
rainbow smelt	*Osmerus mordax*	13	2	387
threespine stickleback	*Gasterosteus aculeatus*	13	173	46
sand lance	*Ammodytes americanus*	7	12	0
windowpane	*Scophthalmus aquosus*	7	0	0
striped killifish	*Fundulus majalis*	6	499	16
hake	*Urophycis* sp.	4	0	3
lumpfish	*Cyclopterus lumpus*	3	0	5
Atlantic cod	*Gadus morhua*	3	6	0
northern sea robin	*Prionotus carolinus*	2	0	0
fourspine stickleback	*Apeltes quadracus*	1	0	75
little skate	*Raja erinacea*	1	0	0
bay anchovy	*Anchoa mitchilli*	2	0	0
silver anchovy	*Engraulis eurystole*	1	0	0
ninespine stickleback	*Pungitius pungitius*	0	7	47
cunnner	*Tautogolabrus adspersus*	0	0	2
longhorn sculpin	*Myox. octodecemspinosus*	0	0	1
blueback herring	*Alosa aestivalis*	0	9	0
alewife	*Alosa pseudoharengus*	0	1	0
fourbeard rockling	*Enchelyopus cimbrius*	0	1	0
white mullet	*Mugil curema*	0	1	0

1965 DMF SALEM SOUND STUDY

The 1965 study had very similar spatial and temporal coverage to the 1997 study: six stations were visited monthly and five of those stations were revisited in 1997. The 1965 study used two seines, a 6.1 m (20 ft) beach seine (2.4 m depth and 4.8 mm mesh), and a 18.3 m (60 ft) haul seine (1.2 m depth, 3.2 mm mesh) that was hauled with assistance of a boat. Both nets were hauled twice with each station visit. A total of 71 station visits was made in 1965, compared to 68 in 1997. Data on tide stage, catch per haul, catch by net type, area covered, and catch of decapods are not available. No specific tide stage was targeted for seining. Despite the lack of raw data, it can be assumed that the area covered by all hauls in 1965 exceeded that area covered by duplicate hauls using a 15.2 m net in 1997.

The seine catch in 1965 produced 15 species of fish in contrast to the 22 caught in 1997 (Table 5.4). Mummichog and Atlantic silverside were the only two species that occurred in 20% or more the station visits in 1965. The catches of other species occurred infrequently or in few hauls with large numbers of individuals. Three species were notably absent in one study but present in the other. Ninespine stickleback were caught during five station visits in 1965 but none were caught in 1997. Grubby were caught during 11 station visits and Atlantic menhaden were caught during 13 station visits in 1997, while both were absent in 1965. Differences in winter flounder catches exist between studies. Juvenile winter flounder were a major component of the seine catches in 1997; 928 were caught during 36 station visits, and most were YOY. Only 19 winter flounder were caught during six station visits in 1965, and only three of these individuals were YOY. The increased catch of YOY winter flounder is of interest, but conclusions cannot be drawn from two widely separated datasets. Seine catches for the two studies were similar in several regards. The fish composition at these shoreline habitats was dominated by juveniles of schooling, forage species. Atlantic silverside, mummichog, and Atlantic herring were high ranked species in both studies. This similarity did have the exceptions of the absence of Atlantic menhaden in 1965 and large reduction in mummichog numbers in 1997. Both studies showed a concentration of fish catches during the warm months. The May-November catches comprised 99% of the total seine catch in 1965 and 98% in 1997.

Overall, the 1997 seine survey did not reveal any obvious change in the intertidal fish community in Salem Sound. More species of fish and individual fish were caught in 1997; however, the two available seine surveys are not sufficient to make conclusions on changing fish populations. It is worthwhile to note that two stations did produce markedly different catch compositions between studies. Proctor Point seining produced only seven species of fish during 11 station visits in 1965, while 15 species were caught during 8 station visits in 1997. Tuck Point had the highest catch/haul in 1997, with over 6,000 fish caught (11 species). In 1965, Tuck Point produced only 28 fish (8 species), of which only 14 were winter flounder, compared to 526 in 1997. The confounding influence of few large catches of a given species on total catch statistics observed in 1997 also occurred in 1965, as evident from the June hauls at Proctor Point that caught over 6,000 mummichogs (78% of mummichog catch). These large catches reflect the inherent spatial variability of transient aggregations of fish at intertidal habitats.

SALEM HARBOR POWER PLANT INVESTIGATION

The Massachusetts Division of Marine Fisheries was contracted by New England Power Company to conduct investigations from 1971-1979 on the effects of the operation of the coal-powered electric generation station on the marine resources of Salem Harbor (Chesmore et al. 1972-74; Anderson et al. 1975-79). This effort included fish collections using seines, trawls and gillnets. A 15.2 m (50 ft) beach seine (1.2 m depth, and 3.2 mm mesh) was used from 1971 to 1973. In 1971 and 1973, this net was used only at Salem Harbor stations. In 1972, this seine was used at three Salem Harbor locations and five stations in Salem Sound. Among these stations were the six original stations sampled in 1965 and five of the stations sampled in 1997. Duplicate hauls were made during the monthly visits at each station. Biweekly visits were made on a few occasions from April to October. Tide stage was not recorded, but seining at low tide was avoided.

The 1972 catches of the 15.2 m seine are most comparable to the 1965 and 1997 studies because of the similar sized net and the common sampling stations. Raw data are not available for the 15.2 m seine, and catches were reported in quarterly summaries. The 1972 seine survey caught 17 species of fish with the similar dominance of schooling, forage species seen in 1965 and 1997 (Table 5.5). Catch densities of most species were very low. The 1972 data provided several observations that are consistent with results of the 1965 study but are different from those in the 1997 study. Low catches of winter flounder continued as only three individuals were caught the entire year. Grubby was again not present in the 1972 catch. Ninespine sticklebacks also occurred in 1972, whereas none were found in 1997. Four species found in 1972 were not caught in 1965 or 1997, including the anadromous alewife and blueback herring.

In addition, a 36.6 m (120 ft) haul seine (2.4 m depth, 38 mm wing mesh, 19 mm bag mesh) was used during 1971-1974 and 1977-1979. This larger seine was used primarily in Salem Harbor. For most years, monthly station visits were made, and there was some biweekly sampling during the warmer months. The larger net covering both intertidal and subtidal habitat, inconsistent sampling frequency, and incomplete record of catches per haul data diminishes the comparability of these data with later catches using the 15.2 m seine. Despite the different methods used, the 36.6 m seine catch data are valuable because they represent fish composition at these habitats in Salem Harbor during the 1970s. Overall species composition was similar to the other study periods and schooling, forage species continued to dominate the catch at these shoreline habitats. Higher catches of striped killifish occurred in the 1970s than were made during the other sampling periods and few Atlantic menhaden (2) and Atlantic herring (4) were caught. The 36.6 m seine did catch more winter flounder than catches with the 15.2 m seine in 1965 and 1972, and total catches were similar range to 1997.

CONCLUSION

Evaluating seine catch data from the three studies is difficult because of the differences in seine gear, sampling methods, targeted tide stage, and the spurious effect that infrequent large catches of a schooling species can have on abundance ranks. Overall, 35 species of fish are represented in the four data series (including 120 ft. seine). Four of these species occurred in 1997 only: striped mullet, windowpane, northern sea robin, and little skate. The absence of ninespine stickleback and river herring in 1997 is interesting given the observations in earlier studies. After Atlantic silverside, winter flounder was caught most consistently among the seine stations in 1997. The high catches of juvenile winter flounder appear unusual relative to the low catches of juvenile winter flounder in 1965 and 1972 at the intertidal stations. There is not enough information to conclude whether these differences were coincidental or reflect a population or year-class effect.

Overall, most occupants of the intertidal habitats sampled were seasonal migrants and juveniles, and many were schooling, forage species. Seasonal movements and aggregations at these habitats are probably most influenced by water temperature and YOY recruitment. A distinct pattern of habitat use by YOY and age-1 winter flounder emerged from May-November catches in 1997. Spring catches were nearly all age-1 winter flounder, and YOY moved into these stations in July and August. Another example of YOY movements into these habitats was the dramatic appearance of large numbers of YOY Atlantic menhaden in late summer at all stations except West Beach.

No outstanding habitat effects were identified among stations in 1997. The two river bank stations had similar species richness and composition as the two harbor bank stations, although abundance for some species varied. The dynamic beach station differed most from other stations, in that fish abundance was lowest, diversity highest and more unique species were found along the coarser substrate. Otherwise, catches were similar and differences among stations were not obviously linked to identified physical or water chemistry attributes.

Sorting seine catch at Sandy Beach, Danvers River

CHAPTER 6.
TRAWL SAMPLING OF SUBTIDAL HABITATS

We used a bottom-tending shrimp trawl to document the presence of fish and decapods at five subtidal trawl stations in Salem Sound during 1997. Small trawl nets towed from boats have been traditionally used to collect fish from subtidal habitats. We selected a trawl net commonly used for research collections and similar to the trawl used for the 1965 DMF study.

METHODS

We made monthly trawling trips during January-April, November and December, and biweekly trips during May-October, for a total of 18 trips in 1997. Trawling was conducted from a 7 m Steiger Craft boat powered by a 200 HP outboard engine. A Wilcox shrimp trawl net (9.1 m (30 ft) sweep, 8.2 m headrope, 3.8 cm stretched mesh for wings and cod end, and 0.64 cm knotless liner in cod end) was attached to 81 x 41 cm oak doors with steel runners by 1.5 m of rope legs. Trawl lines were set at a 5:1 scope with the length of line dependent on depth.

We conducted five-minute trawls at a target speed of 2.0 nm/hour. Trawl time was recorded by stopwatch and began when trawl doors rested on the bottom and trawl line was secured at the desired length. Boat speed was recorded from a Raytheon NAV298 GPS. Bottom depth was recorded from a Sitex CVS-106 sounder at each minute interval, and average depth was estimated from the five recordings. Trawl start and end locations were recorded from GPS latitude and longitude. A duplicate tow was made along a separate path within trawl stations. Attempts were made to use consistent tow paths for the first and second tow at each station, but minor deviations were common due to lobster gear, wind conditions and boat traffic. Because of boat moorings and a narrow navigation channel, duplicate trawl tows in the Danvers River were made in the middle of the channel at upper river and lower river stations.

After five minutes, the trawl net was quickly retrieved and most invertebrates and all fish were identified, counted and returned to the water. All fish were identified to the species level except for skates (big skate- *Raja ocellata,* and little skate- *Raja erinacea*) which were grouped (*Raja* sp.) due to the difficulty of identifying at sea. Most decapod crustaceans were recorded except for very small species that were not well sampled by the trawl net mesh. Length (total length, mm) was measured for all commercially and recreationally important fish, and carapace length (mm) was measured for lobster and sand shrimp. Unidentified specimens were saved in formalin for later identification at the laboratory.

Trawl catch data were evaluated in terms of frequency of occurrence, species richness (number of species), relative abundance (catch per tow) and diversity to identify seasonal and habitat trends in the fish community of Salem Sound. The Shannon-Weaver index was used as a measure of fish diversity that accounts for the number and relative abundance of each species (Ludwig and Reynolds 1988). The benthic habitat at each trawl station was characterized in terms of sediment composition and macrophyte community. Sediment samples were collected using a Halltech bottom dredge (232 cm^2) during single station visits. Sediment sizes were sorted with Newark standard sieves using a modified Wentworth classification as described in Nielson and Johnson (1983).

RESULTS

TRAWL STATION HABITAT

Sediment measurements at trawl stations in Salem Sound conformed to expectations based on current and depth interactions and previous measurements (CDM 1986). Fine sediments were found in the depositional zones in harbor channels and larger sands were common in the shallow fringes (Beverly Cove) and in the Danvers River (Table 6.1). The largest sediments sampled were found at the deepest station outside of Marblehead Harbor. Individual measurements are provided in the Appendix (Table A.30). Details on macrophyte collections are provided in Chapter 7.

Haste Channel. The substrate consisted primarily of fine sediment (62% fine sand, silt and clay) and appeared as thick, black mud. Haste Channel had the least amount of larger sediments (4% gravel and pebble) among trawl stations. The macrophyte community was sparse at Haste Channel: red kelp (*Laminaria* sp.) and shotgun kelp (*Agarum cribosum*) were the only species found regularly in tows, although the distribution along Haste Channel appeared patchy and many tows had no or little kelp.

Salem Harbor. Salem Harbor's substrate was similar to Haste Channel. Thick black mud and patchy kelp were the primary features of this habitat. More fine sediments were found at Salem Harbor (84% fine sand, silt and clay) than at the other stations. Red kelp dominated the macroalgae community in Salem Harbor. The distribution of kelp was not continuous: many tows had little kelp and others contained large amounts. Spiny sour weed (*Desmarestia aculeata*) occasionally occurred in higher amounts than kelp.

Table 6.1 Mean percent sediment size (SD in italics) at trawl stations in Salem Sound. Sediment measurements were collected with Halltech bottom dredge (232 cm^2) and sorted with Newark sieves. Six samples were collected per station except for eight samples at Marblehead Harbor.

Location	Pebble > 32 mm	Gravel 2-32 mm	Coarse Sand 0.5-2.0 mm	Medium Sand 0.25-0.5 mm	Fine Sand 0.063-0.25 mm	Silt/ Clay < 0.063 mm	Total %
Haste Channel	0	3.9	20.6	13.8	31.9	29.8	100
	0	*4.58*	*23.60*	*9.91*	*18.78*	*12.52*	
Salem Harbor	0.5	9.0	2.3	4.1	56.8	27.3	100
	1.35	*19.33*	*2.17*	*3.18*	*15.60*	*11.24*	
Danvers River (lower)	0.9	12.5	13.6	24.5	37.2	11.4	100
	2.12	*10.57*	*7.71*	*5.06*	*15.55*	*1.44*	
Danvers River (upper)	3.2	4.6	7.2	28.1	49.1	7.8	100
	7.84	*3.42*	*4.73*	*17.11*	*23.39*	*2.98*	
Beverly Cove	0.2	22.0	28.3	27.1	14.2	8.3	100
	0.57	*23.30*	*21.93*	*21.72*	*10.80*	*3.39*	
Marblehead Harbor	8.5	40.5	23.6	10.6	6.5	10.4	100
	8.6	*31.9*	*21.4*	*10.7*	*6.9*	*6.2*	

Marblehead Harbor. The substrate contained the largest material measured among trawl stations. Nearly 50% of the samples consisted of pebble and gravel and only 17% consisted of fine sand, silt and clay. The distribution of pebble and gravel substrate was not uniform. Sediment size diminished with distance from the harbor. Similar to the harbor channel stations, kelp was the primary macroalgae at this location. Shotgun kelp occurred most frequently and red kelp was also common. Sand dollars (*Echinarachnius parma*) and periwinkles (*Littorina* sp.) were commonly found in dredge samples, but were infrequently observed at other stations.

Danvers River. Over 50% of river sediment samples were fine sand, silt and clay. Much of the dredge samples appeared as black mud, although the material was not as fine as that at the harbor channel stations. Medium sand comprised about 25% of the samples, and small patches of coarse sand, gravel and shell deposits were found. Resident macrophytes were not evident along tow paths in the Danvers River. Impressive concentrations of sessile organisms occurred on watershed debris, providing much of the structural integrity of benthic habitat in the Danvers River. Sponges and tunicates attached to debris, branches and derelict lobster pots were caught in nearly all tows. The coarse sediments and populations of sessile filter feeders both reflected the influence of strong tidal flow.

Beverly Cove. Beverly Cove was unique among trawl stations because of the presence of light colored sand and large eelgrass (*Zostera marina*) beds. Nearly 70% of the sampled substrate was coarse, medium and fine sand. There was evidence of gravel patches (22% of samples) in the trawl zone, and minor amounts of silt and clay (8%). The dynamic nature of wave action probably limits silt and clay at this station. Eelgrass was the dominant macrophyte at Beverly Cove, although a greater variety of macroalgae were found compared to the other stations.

TRAWL CATCH: STATIONS COMBINED

One-hundred and sixty eight out of 180 possible trawl tows were completed in 1997. Gear problems reduced the number of successful tows in January and February. Thirty-five species of fish, nine species of decapod crustaceans, and seven species of other invertebrates were caught and quantified (Table 6.2). Five fish species occurred in at least a third of the tows: winter flounder (86%), skate (59%), Atlantic cod (38%), grubby (34%), and cunner (33%). Winter flounder, skate, and Atlantic cod ranked first, second and third, respectively, in both relative abundance and frequency of occurrence. Over a third of the fish species (13) were caught infrequently (1-3 tows). Most fish (82% by number) were caught during the warm months of May-October (Table 6.3). April and November catches were higher than the other cool months due to elevated catches of cod (April) and winter flounder (November). Winter flounder and grubby had the highest monthly frequency of occurrence for fish (11 months). Winter flounder were consistently caught from May-October, occurring in 95% of tows (Table A.31).

Sand shrimp dominated invertebrate catches in frequency of occurrence (92%) and number (87% of all counted invertebrates). Rock crab (88%) and lobster (76%) were the only other decapods to occur in at least a third of the tows. Mysid shrimp were commonly caught, often at high densities, at each station. However, mysids were not quantified because they were too small to be efficiently caught in the trawl. The catch of invertebrates increased during the warm months (Table 6.4), although large numbers of sand shrimp were often caught from

Table 6.2 Trawl station catch in Salem Sound: all tows January-December, 1997 (n = 168).

Species Name	Scientific Name	Total Catch (No.)	Frequency of Occurrence (No. of tows)	Presence by Month (No.)
FISH				
winter flounder	*Pseudopleuronectes americanus*	1070	145	11
skate	*Raja (ocellata and erinacea)*	643	99	9
Atlantic cod	*Gadus morhua*	365	64	8
grubby	*Myoxocephalus aenaeus*	142	57	11
cunner	*Tautogolabrus adspersus*	340	56	9
red hake	*Urophycis chuss*	126	54	8
windowpane	*Scophthalmus aquosus*	154	53	8
rock gunnel	*Pholis gunnellus*	55	30	8
northern pipefish	*Syngnathus fuscus*	92	28	7
lumpfish	*Cyclopterus lumpus*	36	20	6
silver hake	*Merluccius bilinearis*	66	15	4
butterfish	*Peprilus triacanthus*	90	11	4
sea raven	*Hemitripterus americanus*	13	9	7
rainbow smelt	*Osmerus mordax*	25	9	6
white hake	*Urophycis tenuis*	18	8	3
northern sea robin	*Prionotus carolinus*	20	8	2
ocean pout	*Macrozoarces americanus*	7	7	5
shorthorn sculpin	*Myoxocephalus scorpius*	7	6	5
longhorn sculpin	*Myoxocephalus octodecemspinosus*	5	5	4
Atl. silverside	*Menidia menidia*	38	5	3
Atl. herring	*Clupea harengus*	20	4	4
fourspot flounder	*Paralichthys oblongus*	4	3	3
seasnail	*Liparis atlanticus*	5	3	2
summer flounder	*Paralichthys dentatus*	3	2	2
Atl. menhaden	*Brevoortia tyrannus*	3	2	2
Atl. mackerel	*Scomber scombrus*	2	2	2
threespine stickleback	*Gasterosteus aculeatus*	2	2	2
yellowtail flounder	*Limanda ferruginea*	2	2	2
Atl. tomcod	*Microgadus tomcod*	3	2	1
Atl. moonfish	*Selene vomer*	2	2	1
scup	*Stenotomus chrysops*	3	1	1
fourbeard rockling	*Enchelyopus cimbrius*	1	1	1
radiated shanny	*Ulvaria subbifurcata*	1	1	1
striped seasnail	*Liparis gibbus*	1	1	1
Total Fish Catch		3364		
INVERTEBRATE				
sand shrimp	*Crangon septemspinosa*	27940	154	12
rock crab	*Cancer irroratus*	1359	147	12
lobster	*Homarus americanus*	1983	127	9
green sea urchin	*Strongylocentrotus droebachiensis*	157	51	9
green crab	*Carcinus maenas*	390	48	10
hermit crab	*Pagurus* sp.	116	40	9
spider crab	*Libinia emarginata*	50	24	8
red shrimp	*Pandalus montagui*	86	24	6
loligo squid	*Loligo pealei*	54	14	5
european oyster	*Ostrea edulis*	36	6	4
sea scallop	*Placopecten magellanicus*	5	3	3
shrimp (*Eualus* sp.)	*Eualus fabricii*	2	2	2
quahog	*Mercenaria mercenaria*	2	2	2
horseshoe crab	*Limulus polyphemus*	4	1	1
moon snail	*Lunatia heros*	1	1	1
Greenland shrimp	*Lebbeus groenlandicus*	1	1	1
Total Invertebrate Catch		32186		

Table 6.3 Monthly fish catch by number in Salem Sound trawl tows: all stations combined (168 tows).

Species	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
winter flounder		6	7	35	67	86	91	122	144	292	140	80	1070
skate (*Raja* sp.)				3	73	90	155	122	145	53	1	1	643
Atlantic cod		3	38	128	19	9	110	36	22				365
cunner			3		6	12	16	187	57	55	2	2	340
windowpane					9	18	36	17	35	33	5	1	154
grubby	3		13	16	8	15	9	6	2	19	33	18	142
red hake					5	15	44	15	16	26	3	2	126
northern pipefish				4	4	2	2	10	31	39			92
butterfish							2	2	9	77			90
silver hake								28	14	23	1		66
rock gunnel			2	5	24	10	9	3	1		1		55
Atlantic silverside		1								29	8		38
lumpfish				1	2	8	15	7	3				36
rainbow smelt					1		3	3	4	12	2		25
Atlantic herring		6		1			12	1					20
northern sea robin									1	19			20
white hake					6	5	7						18
sea raven					1	2	1	1	3	4		1	13
ocean pout		1	1		2	2	1						7
shorthorn sculpin	1		2	2						1	1		7
longhorn sculpin				1	1	1						2	5
seasnail				4	1								5
fourspot flounder					1	2		1					4
Atlantic tomcod							3						3
summer flounder							1		2				3
Atlantic menhaden									1	2			3
scup										3			3
Atlantic mackerel								1		1			2
Atlantic moonfish									2				2
threespine stickleback				1			1						2
yellowtail flounder		1								1			2
fourbeard rockling						1							1
radiated shanny											1		1
striped seasnail		1											1
Total fish catch	4	19	66	201	230	278	518	562	492	689	198	107	3364

March through December. Rock crab was commonly caught in the cool months, and together with sand shrimp were the only species caught in every month (Table A.32).

Number of Fish Species. Comparisons of the mean number of fish species caught per tow by month and station illustrate seasonal and habitat differences in species richness. The mean number of fish species caught per tow was consistent (approximately five) during the warm months (Figure 6.1). For the remaining months the value was four species or less, with lows of about one species during January and February. More fish species were caught at the harbor channel stations and Beverly Cove (mean of 5.4-5.8 species/tow) than at Marblehead Harbor (mean of 4.3 species/tow) and Danvers River (mean of 3.6 species/tow) stations during the warm months. Harbor channel stations also had the highest overall species richness (Table 6.5).

Numbers of Fish. Comparisons of the mean number of fish caught per tow by month and station illustrate seasonal and habitat differences in fish abundance. Mean fish abundance was lowest during January-March (<10 fish/tow), increased during the spring and summer, followed by an October peak of about 35 fish/tow (Figure 6.2). Comparisons by habitat type show that fish abundance was higher at the harbor channel stations and Beverly Cove than at Marblehead Harbor and Danvers River. Salem Harbor had the highest abundance (37 mean number of fish/tow) of the five stations, more than three times that caught at Marblehead Harbor and Danvers River (Table 6.5).

Table 6.4 Monthly invertebrate catch by number in trawl tows: all stations combined (168 tows).

Species	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
sand shrimp	13	449	1259	4908	4122	1715	997	2217	1045	4958	2651	3606	27940
lobster				7	84	179	114	500	711	311	65	12	1983
rock crab	10	25	20	51	85	102	181	260	347	186	48	44	1359
green crab			4	13	12	38	39	94	79	90	13	8	390
green sea urchin			10		9	27	21	8	2	51	14	15	157
hermit crab		5	8		3	4	26	19	28	19		4	116
red shrimp						12	16	30	6	17		5	86
loligo squid						3	2	6	10	33			54
spider crab				5	3		8	10	12	10	1	1	50
european oyster						2	28	3	3				36
sea scallop					1					3		1	5
horseshoe crab								4					4
shrimp (*Eualus* sp.)						1	1						2
quahog							1		1				2
moon snail					1								1
Greenland shrimp										1			1
Total invert. catch	23	479	1301	4984	4320	2083	1434	3151	2244	5679	2792	3696	32186

TRAWL CATCH: BY STATION

Danvers River (river channel habitat). Sixteen species of fish, six species of decapods, and four species of other invertebrates were caught and quantified from 36 tows in the Danvers River (Table A.33). Winter flounder (83%), skate (50%), grubby (44%), and cunner (44%) were the only fish species to occur in at least a third of the tows. Overall, the Danvers River station had the lowest species richness and diversity and second lowest catch/tow for fish among the trawl stations (Table 6.5). Sand shrimp (94%), rock crab (94%), green crab (89%), and lobster (72%) were the only decapods to occur in at least a third of the tows. Catches of summer flounder, European oyster, horseshoe crab and quahog were unique to the Danvers River.

Winter flounder was the dominant fish, in terms of relative abundance and frequency of occurrence, caught in the Danvers River. More adults were caught in May and June, with the highest catch per tow of five legal size winter flounder (> 305 mm) on June 10th. Catches of YOY winter flounder increased in November and December. Skate egg cases were caught during most tows in the spring and summer, but were not frequently encountered at other stations. Windowpane was a common species at all stations except the Danvers River, where none was caught. The invertebrate composition found in the Danvers River clearly differed from the other stations. In addition to three unique invertebrate species, this was the only station with common catches of sponge and tunicates. Sand shrimp relative abundance was highest at this station, and elevated

Figure 6.1 Monthly mean number of fish species (+/- 2 SE) per tow for all trawl stations during January - December, 1997.

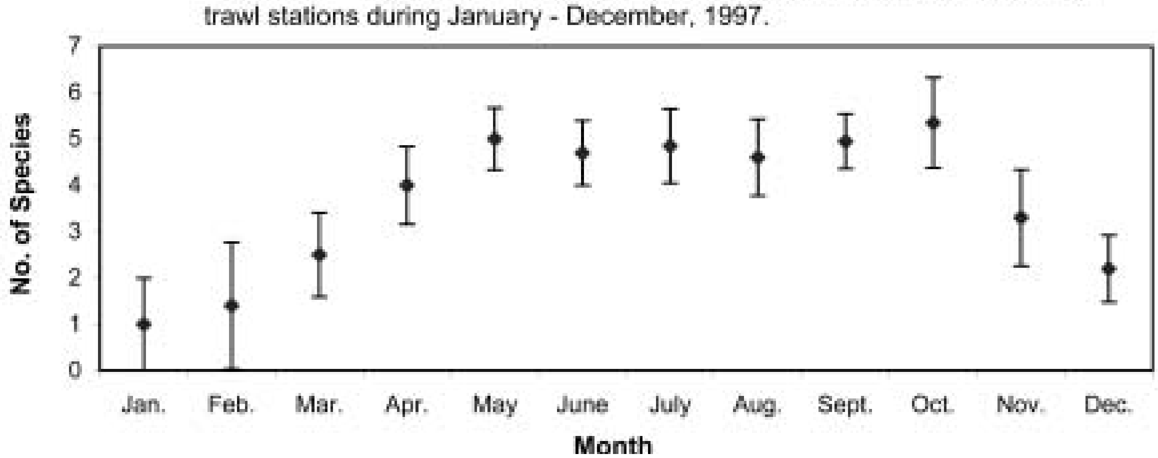
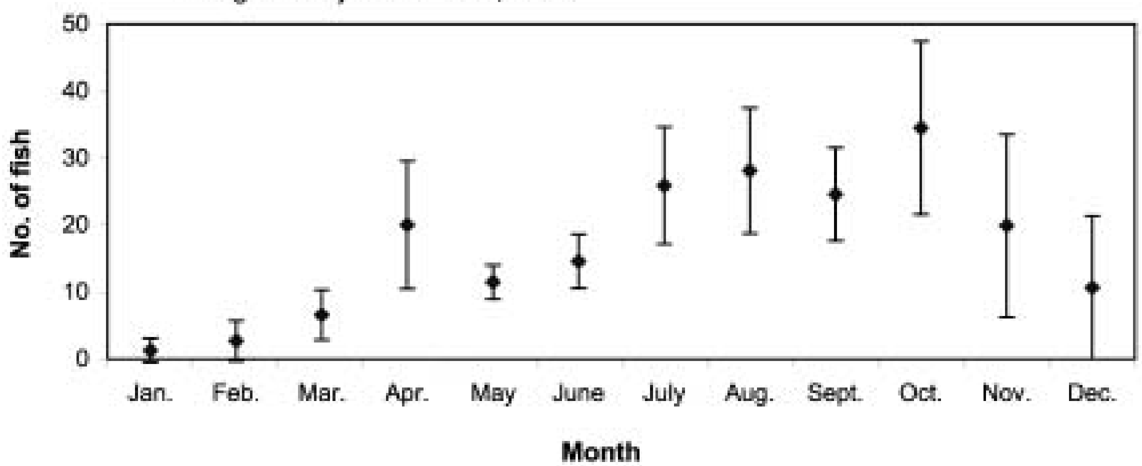


Table 6.5 Fish catch summary for Salem Sound trawl stations, 1997. Species rank refers to relative abundance. Diversity was calculated using the Shannon-Weaver index of diversity.
$H' = -\Sigma$ [(proportion of given species in total sample) ln(proportion of given species in total sample)].

Station	Tows (No.)	Total Fish (No.)	Species (No.)	Catch/Tow (No.)	Diversity (H')	Species Rank (1st)	Species Rank (2nd)	Species Rank (3rd)
Salem Harbor	33	1217	25	36.9	1.98	wint. flounder	skate	Atl. cod
Haste Channel	34	758	20	22.3	1.90	wint. flounder	skate	Atl. cod
Marblehead Harbor	31	311	18	10.0	2.06	wint. flounder	Atl. cod	skate
Beverly Cove	34	656	17	19.3	2.08	cunner	pipefish	wint. flounder
Danvers River	36	422	16	11.7	1.78	wint. flounder	skate	grubby

Figure 6.2 Monthly mean number of fish (+/- 2 SE) per tow for all trawl stations during January - December, 1997.



by large catches in the lower river tows during April and October. This station also produced the highest rank for green crab in both relative abundance and frequency of occurrence (Tables A.34 and A.35).

Beverly Cove (eelgrass habitat). Beverly Cove differed from other stations because of shallow trawl depth, presence of eelgrass and numerous macroalgae species, and had the highest fish diversity. Seventeen species of fish, seven decapods, and two other invertebrates were caught and quantified from 34 tows at Beverly Cove (Table A.36). Six species of fish occurred in at least a third of the tows: winter flounder (79%), skate (56%), cunner (47%), grubby (44%), cod (44%), and red hake (35%). Four decapod species occurred in at least a third of the tows: sand shrimp (97%), rock crab (91%), and lobster (79%), and hermit crab (38%). No species were unique to Beverly Cove.

Winter flounder had the highest frequency of occurrence at this station, but was not dominant due to the high diversity of the remaining catch. The cunner catch/tow was highest among fish at Beverly Cove and highest among stations for this species. Large numbers of 1-2 cm YOY during August elevated total cunner catches. Overall, total numbers of fish peaked during the summer at Beverly Cove, as opposed to the fall peak found at most other stations. The catch/tow for lobster and rock crab were highest among trawl stations. Catches of juvenile lobster and rock crab in the eelgrass beds increased sharply in August and peaked in September. Sand shrimp was second in catch/tow among stations, and the highest densities occurred during April-June. As sand shrimp catches declined in the fall, adult mysid catches increased. As eelgrass biomass diminished sharply in October, fish and decapod catches also declined.

Marblehead Harbor (outer channel habitat). Eighteen species of fish, six species of decapods, and three species of other invertebrates were caught and quantified from 31 tows at Marblehead Harbor (Table A.37). Gear problems in January and February, and tangles with lobster gear limited the number of successful tows to 31. Winter flounder (84%), Atlantic cod (61%), and skate (52%) were the only fish species that occurred in at least a third of the tows. Lobster (87%), sand shrimp (77%), and rock crab (58%) were the only decapods that occurred in at least a third of the tows. Only sea scallop was unique to the Marblehead Harbor station.

Marblehead Harbor station had the lowest fish catch/tow; however, it had the second highest fish diversity, due to higher species evenness and less dominance by common species. Mean bottom temperature was the lowest among trawl stations. The cooler water temperature may have influenced the lower fish abundance and reduced the presence of sand shrimp as a dominant decapod. Fish that prefer cooler water temperatures were ranked high at Marblehead Harbor. The frequency of occurrence for cod was the highest for all stations, and relative abundance for the following species was highest for all stations: sea raven, longhorn sculpin, ocean pout, and sea scallop. Lobster catch/tow and frequency of occurrence was highest among decapods at Marblehead Harbor, and the frequency of occurrence was highest among stations. Winter flounder and skate were commonly caught here, but densities were routinely low, not exceeding 10/tow.

Haste Channel (harbor channel habitat). Twenty species of fish, nine species of decapods and two other species of invertebrates were caught and quantified from 34 tows at Haste Channel (Table A.38). Five species of fish occurred in at least a third of the tows: winter flounder (91%), skate (68%), windowpane (65%), red hake (50%), and Atlantic cod (44%). Four species of decapods occurred in at least a third of the tows: rock crab (97%), sand shrimp (94%), and lobster (71%). Only Greenland shrimp was unique to Haste Channel trawl catches.

Total fish catch and species richness at Haste Channel ranked second to Salem Harbor. Winter flounder, skate and cod were caught in relatively high abundance at Haste Channel, each ranking second to Salem Harbor. The majority of cod were YOY caught in April and July. The relative abundance of windowpane and silver hake was highest among trawl stations. The majority of silver hake were YOY caught in August. Half of the fish species were caught infrequently (1-3 tows). Sand shrimp and lobster were common decapods but did not rank high among stations. The relative abundance of rock crab at Haste Channel was ranked second among all stations, and all but one tow here caught rock crab.

Salem Harbor (harbor channel habitat). Twenty-five species of fish, eight species of decapods and three other species of invertebrates were caught and quantified from 33 tows in Salem Harbor (Table A.39). Five species of fish occurred in at least a third of the tows: winter flounder (94%), skate (70%), windowpane (67%), red hake (45%), and Atlantic cod (33%). Five species of invertebrates occurred in at least a third of the tows: sand shrimp (94%), rock crab (94%), lobster (70%), green sea urchin (58%), and red shrimp (33%). The striped seasnail, radiated shanny, fourbeard rockling, scup, Atlantic moonfish and moon snail were unique to Salem Harbor.

In terms of species richness and relative abundance of fish, Salem Harbor was the most productive trawl station sampled (Table 6.5). Despite high species richness, Salem Harbor ranked only third in fish diversity. This is because most species occurred infrequently and a few species dominated the total catch. Salem Harbor catches of winter flounder, skate and Atlantic cod were highest of all stations. The species composition in Salem Harbor tows were similar to tows from Haste Channel. The ranks of the top five fish in terms of frequency of occurrence are identical at the two stations. From May-October, skate (adults) and winter flounder (juveniles) dominated the fish composition. High winter flounder catches of primarily YOY occurred during October and November (26-56/tow).

RELATIVE ABUNDANCE OF COMMON SPECIES

Catch per tow (number of fish per 5-minute trawl tow) data for the three most commonly caught fish and decapods were used to illustrate seasonal and habitat trends in relative abundance. The following species ranked 1st-3rd for both relative abundance and frequency of occurrence for fish and decapods, respectively: winter flounder, skate, Atlantic cod, sand shrimp, rock crab, and lobster. Catch per tow data for other species were not summarized because catches for many species fluctuated widely and fewer individuals were caught.

Winter Flounder. The relative abundance of winter flounder increased gradually during spring and summer and peaked in the fall at most stations (Figure 6.3). Higher catch rates were found at the harbor channel stations during most months. Salem Harbor had the highest mean catch rate (14/tow) during the warm months and Beverly Cove had the lowest (2/tow). The higher catches in the fall were associated with increasing numbers of YOY flounder aggregating in the harbor channels and the Danvers River. Estimates of relative abundance for all stations combined showed similar seasonal patterns with habitat differences causing substantial variation in the fall (Figure 6.4).

Skate. The occurrence of skate in Salem Sound was mostly limited to the warm months. Only five skates were caught outside of May-October. In addition to the distinct seasonal trend, most skates were caught at the harbor channel stations (Figure 6.5). The highest mean catch rate (12/tow) during the warm months occurred in Salem Harbor and the lowest (2/tow) occurred at the Marblehead Harbor station. Mid-summer peaks in catch

Figure 6.3 Monthly mean winter flounder catch per trawl tow, 1997. Four tows per month were attempted for May-October and two tows per month for the remaining months at each station.

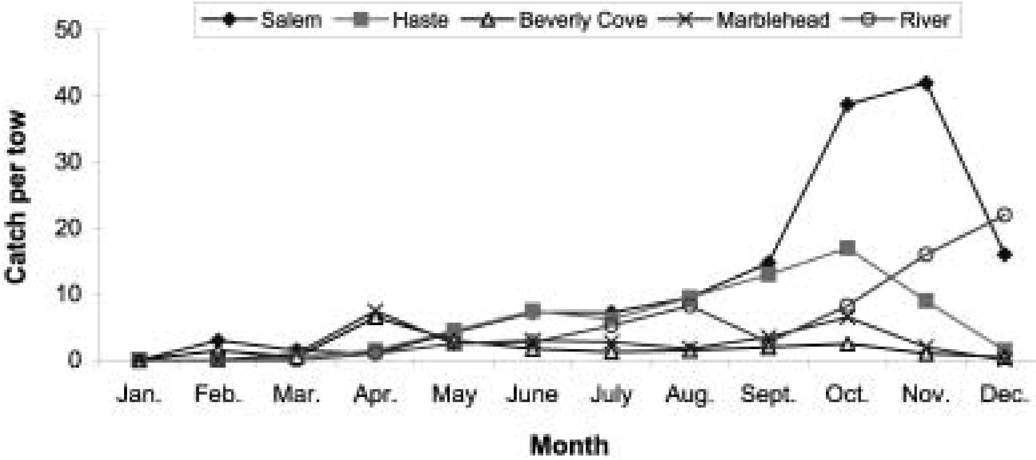
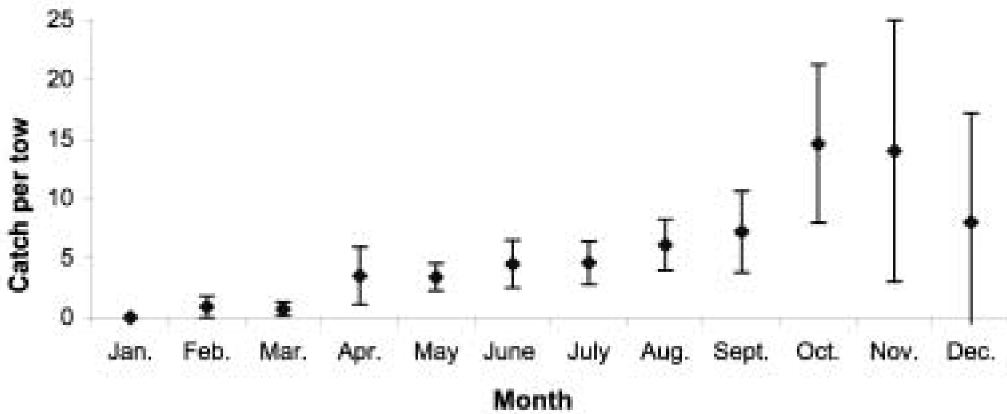


Figure 6.4 Monthly mean trawl catch per tow (+/- 2 SE) for winter flounder at all stations during January-December, 1997.



rates were found at the harbor channel stations and an exodus from these habitats was indicated after the first October trawl sample. The entry and exit of skates in Salem Sound appeared to be influenced by water temperature (Figure 6.6). Figure 6.6 also illustrates the higher catch rates of adult skate than adult winter flounder in 1997.

Atlantic Cod. Mean catch per tow for Atlantic cod was variable during February-September, and no cod were caught during October-January (Figure 6.7). Nearly half of all cod were caught in March and April, and a smaller pulse occurred in July. All cod were YOY that occurred primarily in patchy concentrations at the harbor channel stations. The highest mean catch rate for the year occurred at the Salem Harbor station (5/tow). The lowest mean catch rate occurred in the Danvers River (<1/tow) and none were caught there after May.

Lobster. Lobster were commonly caught from May through November, and few were taken in April and December and none from January-March (Figure 6.8). Mean catch per tow generally increased from May-September at most stations. Large catches of juvenile lobsters were made in August and September at Beverly Cove and Marblehead Harbor, the two most productive stations for lobsters. Relative abundance increased greatly in September at Beverly Cove (mean of 116/tow), suggesting a late summer association with juvenile lobsters and the eelgrass at Beverly Cove. Beverly Cove had the highest mean catch rate (43/tow) during the warm months and Salem Harbor had the lowest (3/tow).

Figure 6.5 Monthly mean skate catch per tow at each trawl station, 1997. Four tows per month were attempted for May-October and two tows per month for the remaining months.

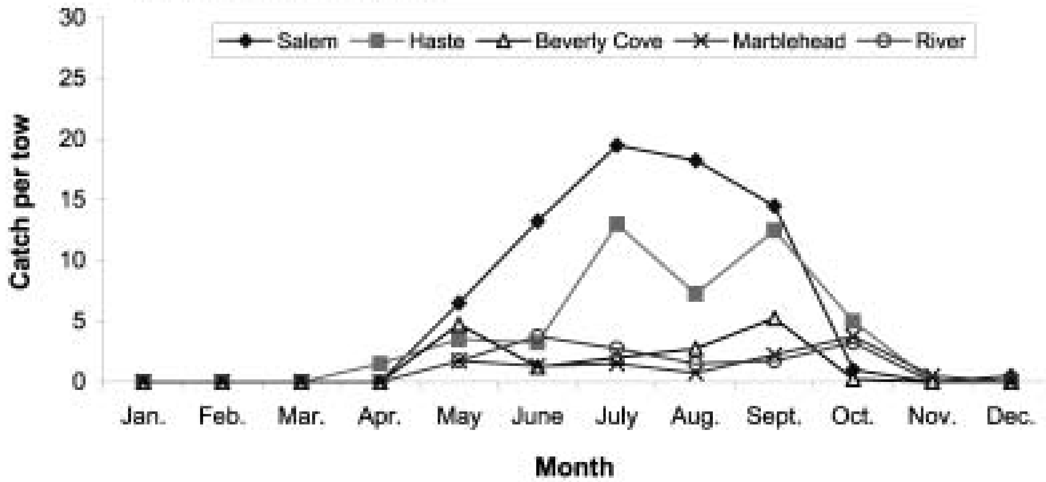
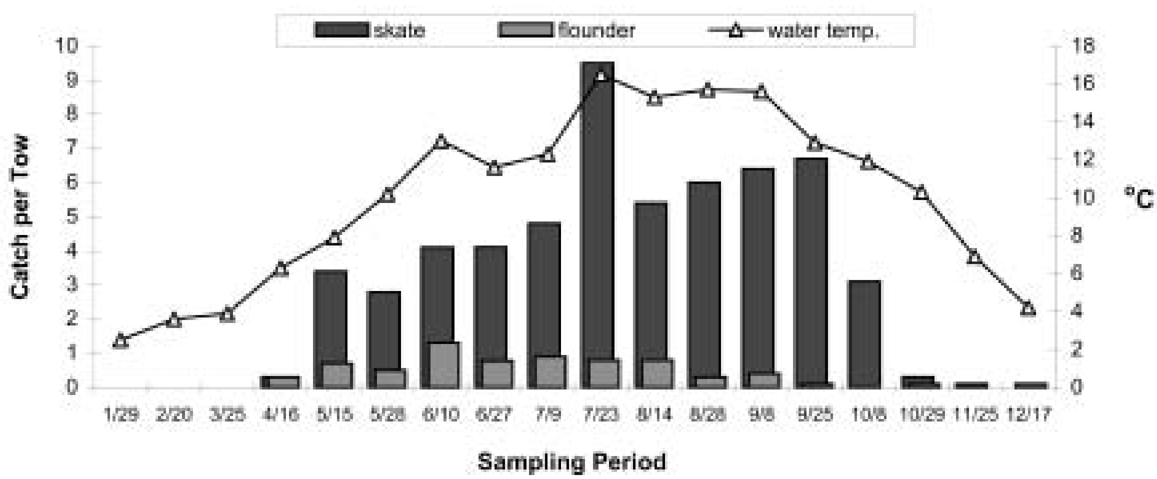


Figure 6.6 Mean catch per trawl tow of adult winter flounder and skate, 1997. All station catch and bottom water tempertures are averaged for each sampling period. Minimum adult size: 350 mm for skate and 305 mm for flounder.



Rock Crab. For most stations, catch rates of rock crab were consistent and not subject to high seasonal variation seen for other species (Figure 6.9). The exception was at Beverly Cove, where a late summer peak was observed, similar to lobster at this station (Figure 6.10). Rock crab was one of the few fish or decapods that showed consistent catches during the cool months. The mean catch rates during May-October for all stations were in a similar range of about 2-6 rock crab/tow except Beverly Cove (24/tow) where large numbers of YOY rock crab were caught in August and September.

Sand Shrimp. Sand shrimp was an abundant decapod at all stations and catch rates were variable; duplicate tow catches commonly differed by hundreds of shrimp and occasionally by thousands. Very few tows had zero catches. The highest catch rates occurred in the Danvers River during the spring and fall (Figure 6.11). Several observed trends in sand shrimp relative abundance may relate to habitat differences. The low catch rates at the Marblehead Harbor station indicated that this cooler, deeper channel does not attract high densities of sand shrimp. Beverly Cove catch rates displayed an April-June peak that may relate to the onset of eelgrass growth. Pooled catches of

Figure 6.7 Monthly mean cod catch per tow at each trawl station, 1997. Four tows per month were attempted for May-October and two tows per month for the remaining months at each station.

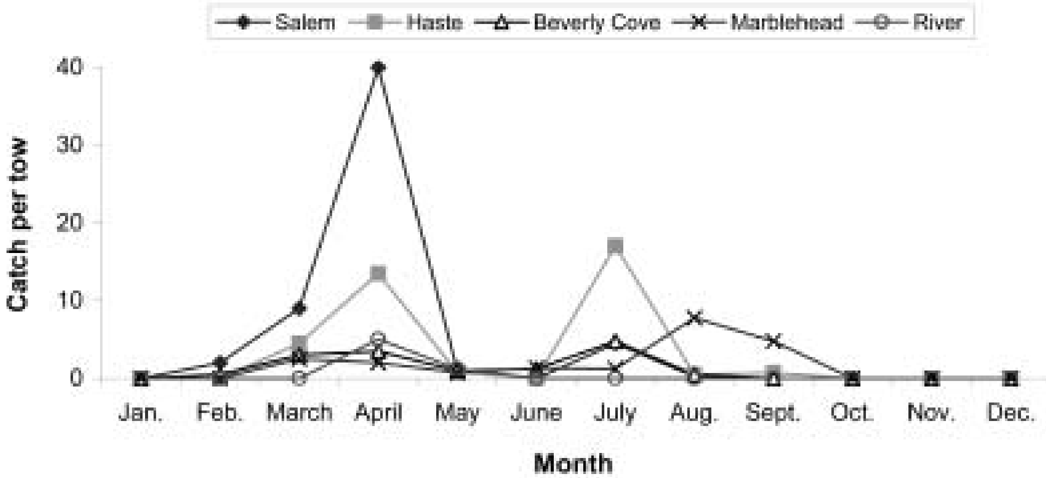
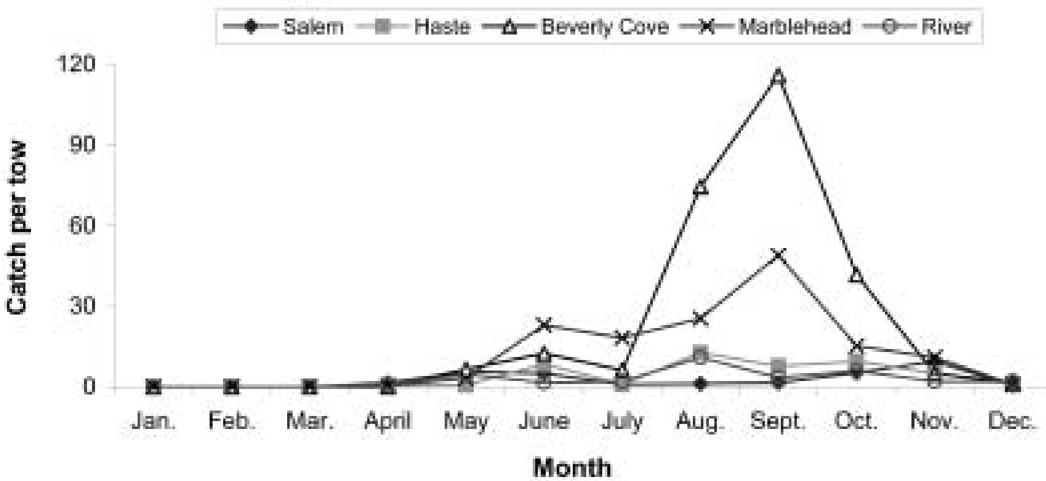


Figure 6.8 Monthly mean lobster catch per tow at each trawl station, 1997. Four tows per month were attempted for May-October and two tows per month for the remaining months.



sand shrimp revealed spring and late fall peaks, coinciding with cool water temperatures (4-10° C) at the subtidal trawl stations (Figure 6.12)

LENGTH DISTRIBUTION OF COMMON SPECIES

Most species were not caught in sufficient numbers to summarize size composition by month or station. Length measurements are summarized below for the three most common fish (winter flounder, cod, skate) and lobster and sand shrimp. Summary statistics for these species are provided in the Appendix (Tables A.40-A.44). Overall, juveniles dominated the catches, with the exception of skate, which were primarily large adults.

Winter Flounder. Winter flounder size distribution varied greatly among stations and months, partially due to the seasonal movements of several age classes. Winter flounder ages were assigned based on known age-length relationships (Witherell et al. 1990). Length frequencies were constructed for the spring, summer and fall to illustrated seasonal age class dynamics in Salem Sound (Figure 6.13). Most winter flounder caught during the

Figure 6.9 Monthly mean trawl catch per tow (+/- 2 SE) for rock crab at all stations during January-December, 1997.

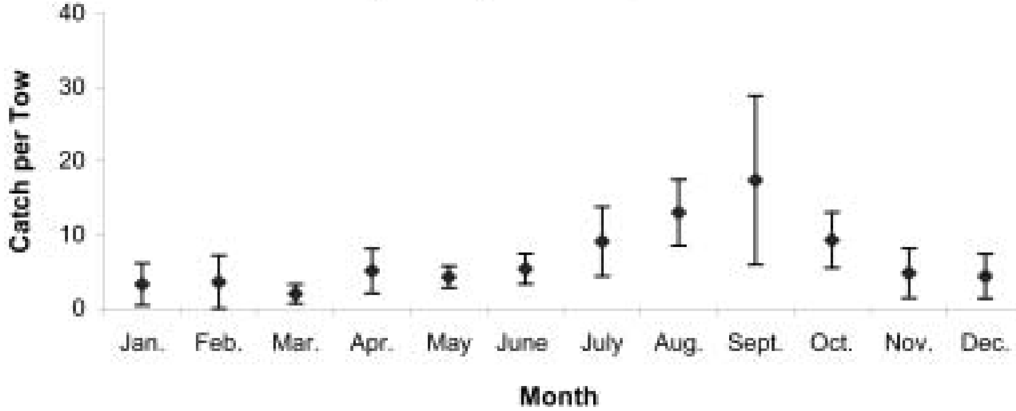
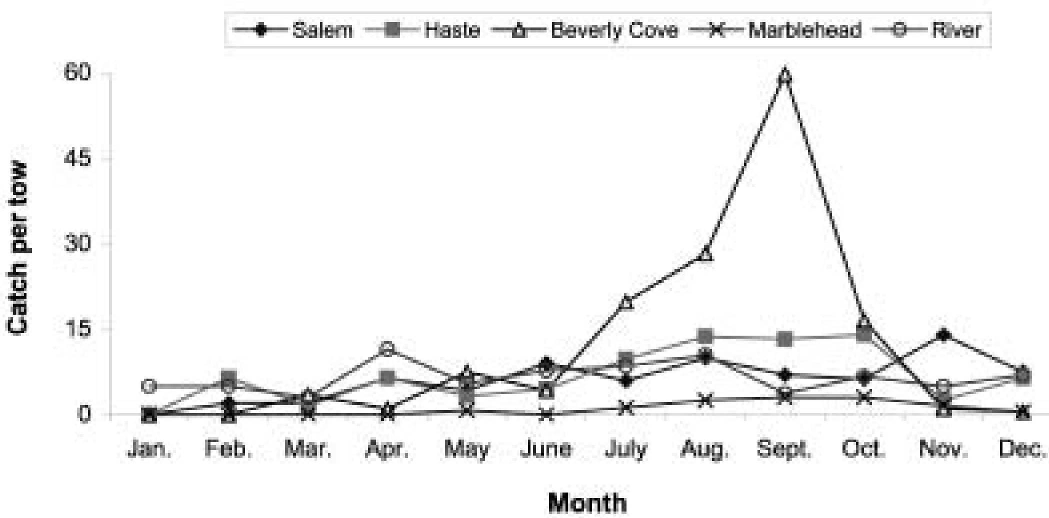


Figure 6.10 Monthly mean rock crab catch per trawl tow, 1997. Four tows per month were attempted for May-October and two tows per month for the remaining months.



spring were age-1, although this period also included the highest catches of legal sized (>305 mm) flounder, and YOY first appear in late June. The summer catches were primarily a mixture of juvenile age classes, as age-1 overlapped with YOY and age-2. Larger flounder left the Sound in the fall, while many juveniles remained. November and December catches were dominated by YOY. Nearly all legal size flounders were caught between April and September with a peak in June. Legal size flounders comprised 16% of winter flounder catches at Marblehead Harbor (highest among stations) and the harbor channel stations had the lowest percentage (≤5%).

Skate. The size compositions of skates were similar among stations during their seasonal occurrence in Salem Sound (Figure 6.14). Most skate were adults ranging in size from 400-550 mm (Figure 6.15). The Danvers River had a largest proportion of adult skates (Table A.42): only three skates <400 mm were caught in the Danvers River. All skates caught were either little skate or big skate. Individuals of both species were identified based on teeth counts, size at maturity and maximum size (Bigelow and Schroeder 1953, and Waring 1984), however, it was not practical to identify all individuals. The common catch of mature males in the size range of 350-450 mm indicated that a majority was little skate.

Figure 6.11 Monthly mean sand shrimp catch per trawl tow, 1997. Four tows per month were attempted for May-October and two tows per month for the remaining months.

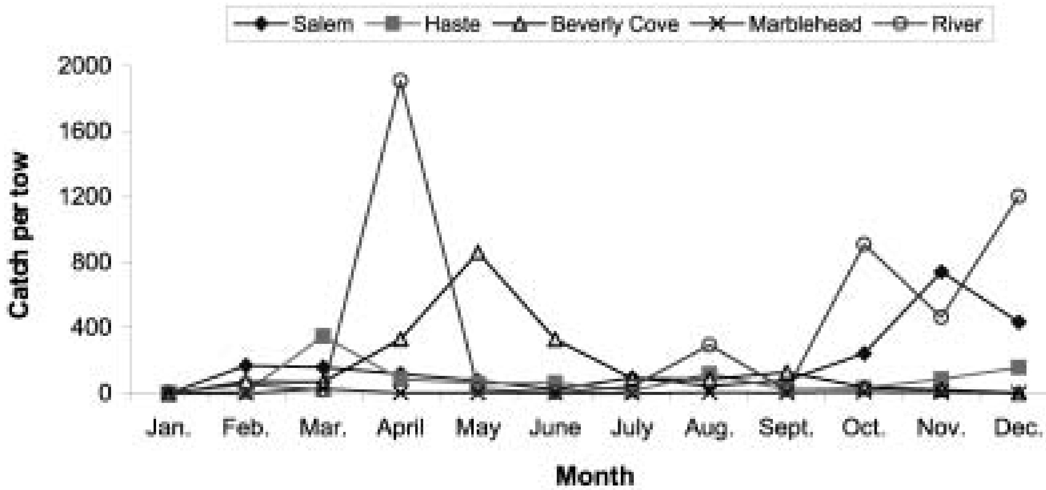
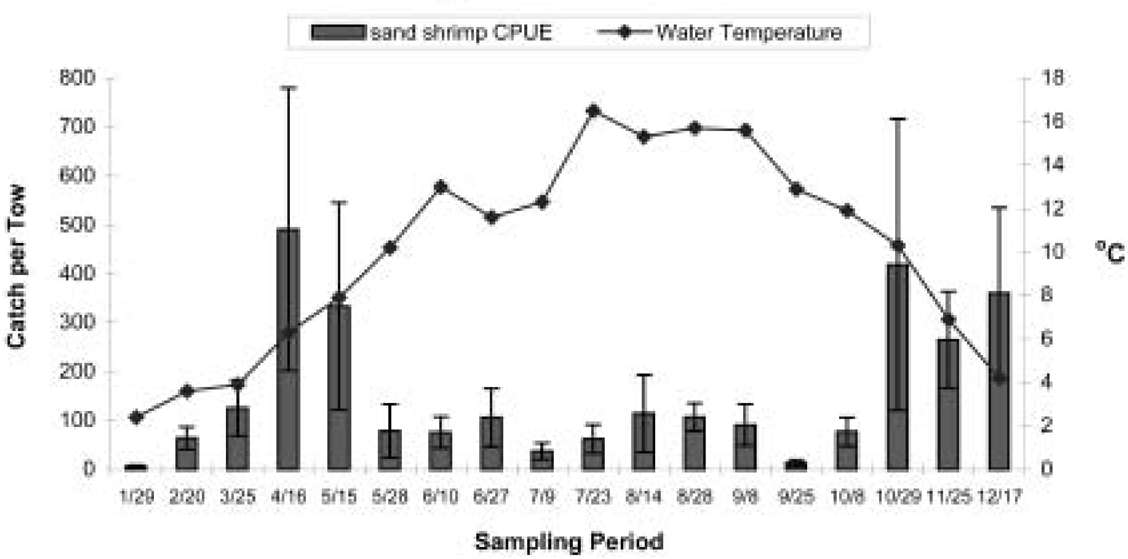


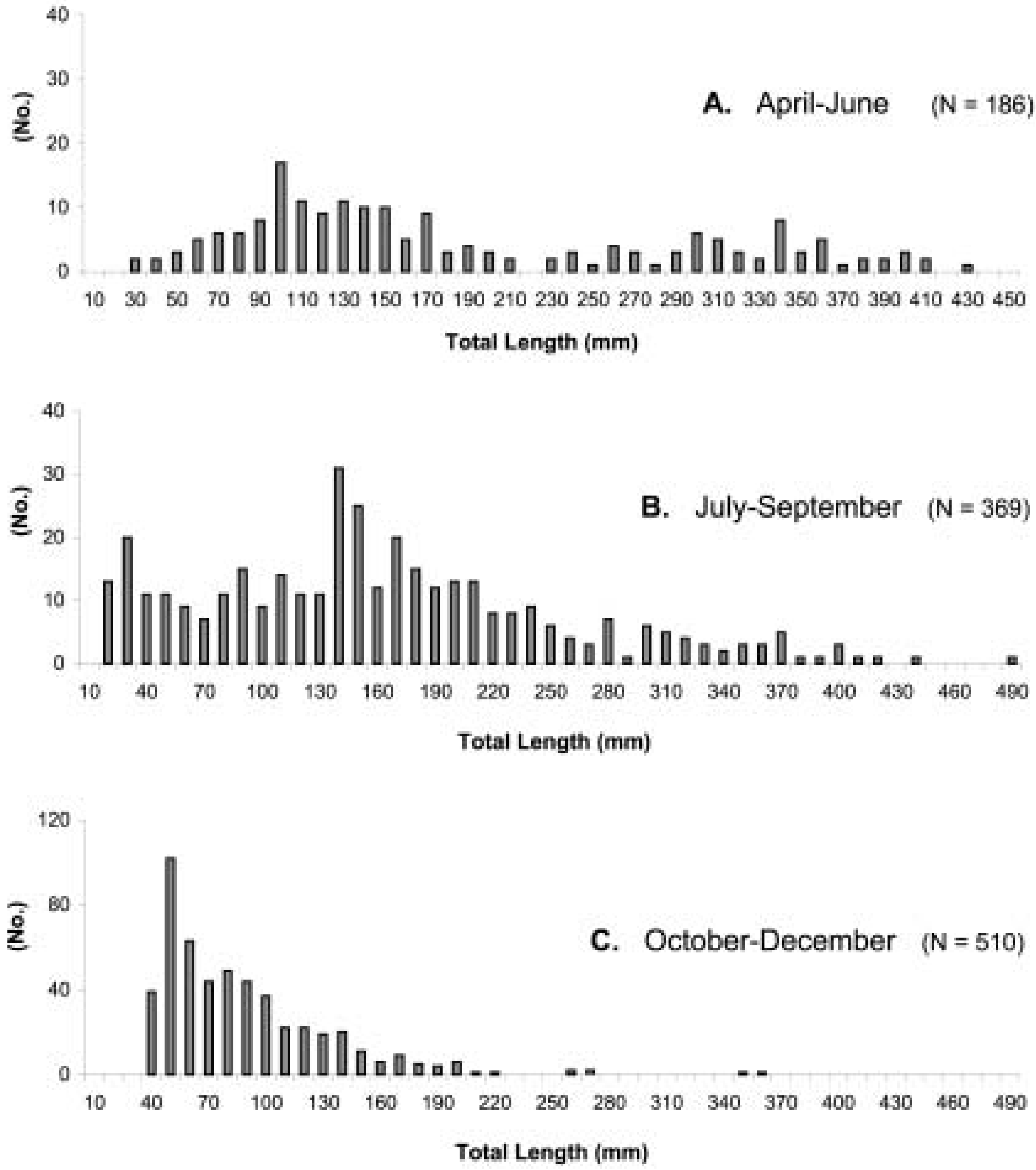
Figure 6.12 Mean sand shrimp catch per tow (+/- 1 SE) and mean bottom water temperature at trawl stations in 1997. Data are means for all stations combined for each sampling period.



Atlantic cod. All cod caught in Salem Sound in 1997 were YOY. We grouped all cod lengths because the patchy catches limited comparisons of cod size composition by station (Figure 6.16). The few larger juvenile cod (~100 mm) were YOY caught late in the season. A protracted spawning season was evident by the capture of post-larvae (15-30 mm) in March/April and July. Otherwise, mean cod lengths were very similar (30-50 mm) throughout the period of February to September when the last cod catches were made. Cod larger than 110 mm were not captured, raising the question whether larger cod were present and avoided the shrimp trawl.

Lobster. The majority of lobster was caught from May-November and the average size was fairly consistent among stations and months. Most lobsters were juveniles and only 1% were legal size (>83 mm). The size distribution of lobster was symmetrical about a mode of 50 mm carapace length (Figure 6.17). Mean carapace

Figure 6.13 Length frequency (10 mm intervals) of winter flounder in trawl catch: all stations combined during three month periods of spring (A), summer (B), and fall (C), 1997.



lengths were tightly matched for the five stations (Figure 6.18). Only the Marblehead station lobsters showed separation from the other stations, as they were slightly larger during all months. With the exception of a few cases with small sample sizes, all comparisons of monthly mean carapace length among stations were not significantly different (t-test, $P > 0.05$).

Sand shrimp. Sand shrimp were measured from 12 subsamples of catches at two seine stations (Tuck Point and Sandy Beach) and 23 subsamples of catches from four trawl stations by a Salem State College intern (O'Dochartaigh 1998). The measurements revealed several trends in shrimp size variation among stations throughout the season (Figure 6.19). Monthly mean carapace lengths were largest at Beverly Cove, and smallest at stations within or close to the Danvers River. Gravid females were found in most subsamples measured during April–September, but few were found during October–December. The five highest percentages of gravid shrimp in subsamples occurred at Beverly Cove (25-43% of

Figure 6.14 Mean total length (mm) of skate at trawl stations during May-October, 1997.

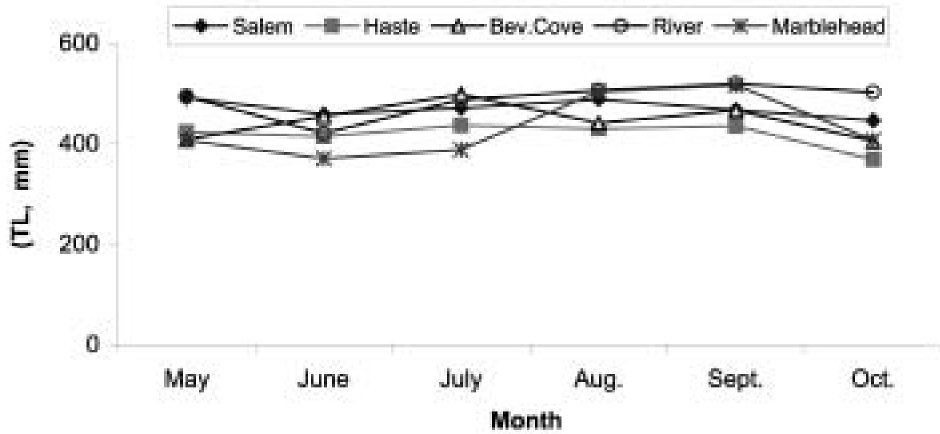


Figure 6.15 Length frequency (20 mm intervals) of skate in trawl catch: all stations combined for May-October, 1997.

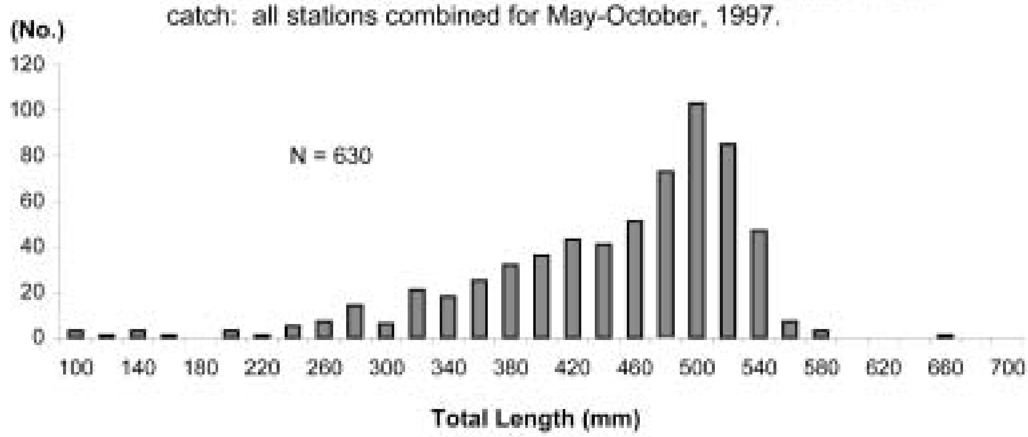


Figure 6.16 Length frequency (5 mm intervals) of Atlantic cod in trawl catch: all stations combined for February-October, 1997.

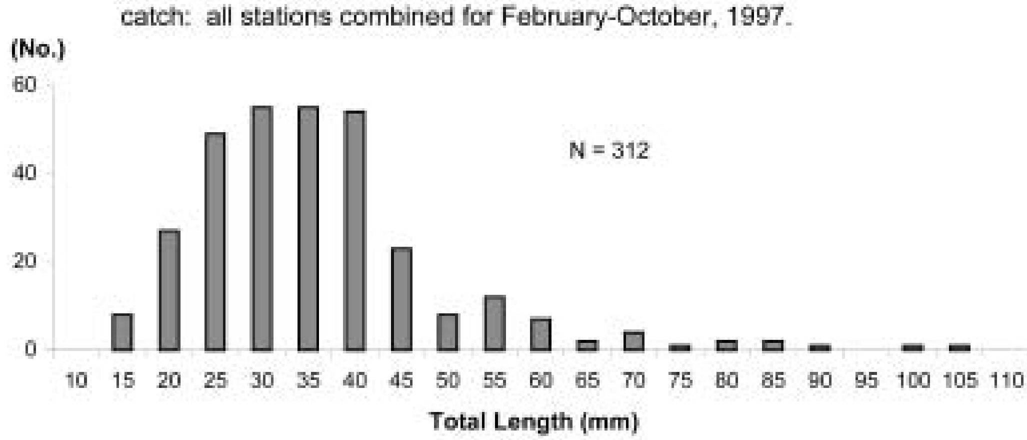


Figure 6.17 Length frequency (2 mm intervals) of lobster in trawl catch: all stations for April-December, 1997.

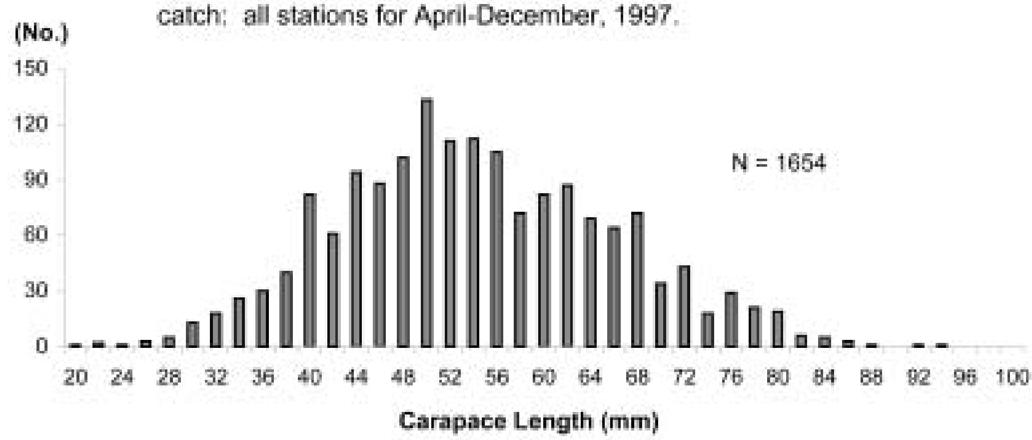


Figure 6.18 Mean carapace length (mm) of lobster at trawl stations during May-November, 1997.

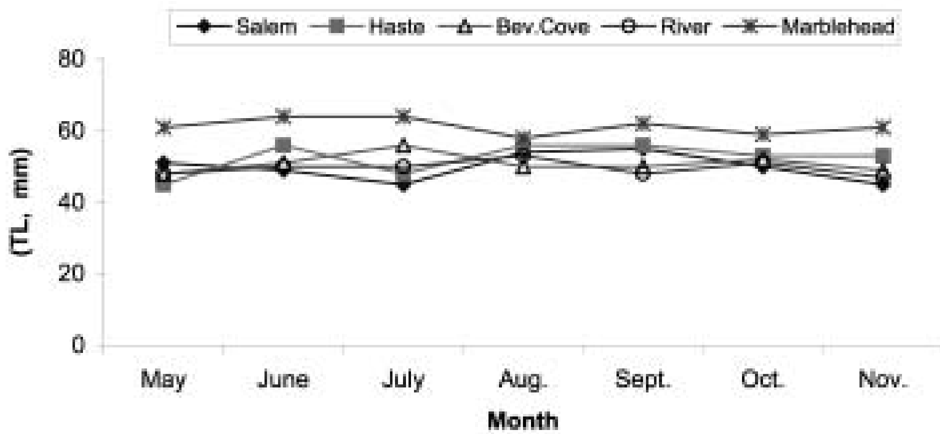


Figure 6.19 Mean carapace length (mm) of sand shrimp taken from seine and trawl station sub-samples, 1997 (O' Dochartaigh 1998).

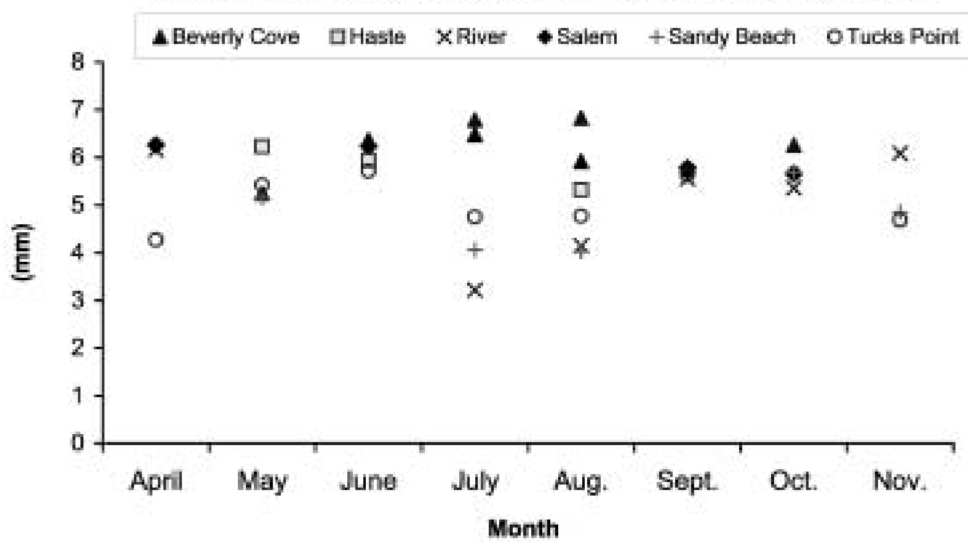


Table 6.6 Length measurements of selected species in trawl catch (TL, mm), 1997.

Species	Station	N	Mean	SD	Range	Month
Atlantic herring	Salem Harbor	12	78	8.08	68-93	July
butterfish	Salem Harbor	51	71	8.51	49-87	Oct.
rainbow smelt	Salem Harbor	22	112	32.75	44-170	July-Oct.
loligo squid	all stations	41	23	6.18	12-40	Sept./Oct.
silver hake	Haste Channel	27	37	4.89	27-50	Aug.
silver hake	Haste Channel	12	62	14.50	48-102	Sept.
silver hake	Salem Harbor	19	98	16.44	67-129	Oct.
red hake	Beverly Cove	37	87	16.91	67-165	July
red hake	Salem/Haste	34	133	56.05	56-239	Sept./Oct.
windowpane	all stations	26	238	57.02	116-320	May/June
windowpane	all stations	38	89	16.63	44-117	Oct./Nov.

subsample). These catch rates indicate an association of large, gravid females with eelgrass habitat during the summer at Beverly Cove.

Other Species. Relatively few length measurements were made for most other species, but, for several species, the data grouped by station or month provides useful information on age composition (Table 6.6). Most of these individuals were YOY or juveniles. All Atlantic herring, butterfish and silver hake, and most rainbow smelt, loligo squid, and red hake caught were YOY. A wider range of sizes was found for windowpane (Table A.45), similar to winter flounder. Mixed sizes were found during May-September, with an increase of YOY evident in August. During June and July, windowpane (mostly 200-300 mm) were caught only at the harbor channel stations. The larger individuals departed the trawl zones in the fall and by October all caught were YOY. The three summer flounder (uncommon in Salem Sound) caught in the Danvers River were large individuals (355, 405, 500 mm).

DISCUSSION

The fish catch composition at the Salem Sound trawl stations was characterized by a large number of fish species, predominance of juveniles and demersal species, and relatively few species that occurred frequently and abundantly. The catch composition of decapods was dominated by three species: sand shrimp, rock crab and lobster. By a considerable margin, winter flounder was the most consistently and commonly caught fish species. Peaks in relative abundance and species diversity came in the summer and fall and appeared to be driven by the recruitment of YOY fish to subtidal habitats. The following section relates our fish and decapod catches to specific subtidal habitats.

SUBTIDAL HABITAT ASSOCIATIONS

Subtidal and intertidal sampling stations were classified in general physical categories prior to sampling in order to contrast species diversity, composition and relative abundance by habitat type. Our interest was to improve our understanding of habitat relationships to the life history of valued fish and crustaceans in Salem Sound. For the intertidal seine stations, major habitat effects among stations were not apparent. More evidence of habitat influence on subtidal fauna was found at the trawl stations.

Harbor Channel Stations. Salem Harbor and Haste Channel had the highest species richness and relative abundance of many common species among trawl stations. The substrate at the harbor channel stations had the highest percentage of fine sediments and provided the least amount of structure. The attraction of the habitat at these stations is not known. Relatively high densities of sand shrimp, mysids, and tubed amphipods at the harbor channel stations suggest the presence of suitable forage. The deeper harbor channels also maintained cooler, more consistent, bottom water than Beverly Cove or the Danvers River. We suspect that the water temperature dynamics and the crustacean forage base were influences on the well-defined migration of skate to the harbor channel habitats during May-October. The Salem Harbor station stood out as having the highest fish abundance, richness and most unique species. It is not possible to determine from our data whether the identified surface warming from heated power plant discharge exerts any influence on subtidal fish and decapod composition and abundance.

The higher fish abundance and richness at harbor channel stations is not consistent with comparisons between vegetated and unvegetated habitats in a Cape Cod inlet (Heck et al. 1989) and Chesapeake Bay (Orth and Heck 1980). More recently, a study of estuarine habitats in New Jersey matched the fauna of trawl catches to habitat type and found a positive association of species richness and diversity to the structural heterogeneity of habitat (Szedlmayer and Able 1996). They identified the physical heterogeneity of habitat as a good predictor of estuarine fish and decapod assemblages. The previous studies also found higher fish diversity at eelgrass and structurally complex habitats. This is consistent with fish catches at Beverly Cove and Marblehead Harbor, however, relative abundance and richness were unexpectedly high at the more homogenous substrate found along the harbor channel stations.

Outer Channel Station. The outer channel habitat at the Marblehead Harbor station was characterized by having greater depth, larger bottom sediments and cooler bottom water temperature than the other trawl stations. Kelp was the primary macrophyte at this station. Species composition of fish did not vary much from the other stations, with the exception of more frequent occurrences for several species that favor cooler water. Relative fish abundance was lowest among stations, however the balanced species composition resulted in the second highest diversity rank. The kelp and gravel bottom was presumably well suited for lobster, as evident by the highest frequency of occurrence rank among stations and the high density of commercial lobster pots.

Danvers River. The river channel habitat in the Danvers River was unusual because of the rich structure provided by a composite of watershed debris, sponges, tunicates, and molluscs. No resident species of macrophytes were identified in the navigation channel used for a trawl path. This benthic structure was not noted in the 1965 study, and was markedly different from all other trawl stations. Catch rates of sand shrimp and green crab in the Danvers River exceeded the other stations. In addition to the green crab, other invasive species, the European oyster and several tunicates were found at high densities. The abundance of these invasive species appears to have increased in the past decade (B. Chase, pers. obs.), however little information is available on ecological interactions between invasive species and natural communities.

Eelgrass Habitat. Interesting associations were identified between the faunal community and specific species and eelgrass beds at the Beverly Cove station. Previous investigations have found vegetated habitats to support higher fish and decapod diversity and abundance than unvegetated habitats (Heck and Orth 1980; Heck et al. 1989; Sogard and Able 1991). Beverly Cove did have the highest species diversity among stations but relative abundance and richness were lower than the less-structured, muddy bottom of the harbor channel stations. A strong seasonal effect was observed at the eelgrass habitat. While the other stations displayed fall peaks of for fish and decapods, the highest catches at the eelgrass habitat coincided with the summer growing season for eelgrass. This relationship has been demonstrated in Chesapeake Bay (Orth and Heck 1980; Heck and Orth, 1980). Sand shrimp, rock crab, mysids, lobster, and cunner all displayed large increases in catch/tow during specific periods of the eelgrass growing season. The catch of juvenile lobster in September was dramatic, averaging over 100 lobster/tow. This association is contrary to Heck et al. (1989) where little evidence was found that eelgrass provided important lobster nursery habitat at a Cape Cod inlet.

Juvenile Nursery Habitat. A common observation for all subtidal trawl stations in Salem Sound was that juveniles dominated the size composition of most fish and decapods. A majority of juveniles were YOY, which recruited to these subtidal habitats in late summer and fall. Two notable exceptions to this trend were the catches of adult skate and juvenile lobster (older than YOY). The selectivity of the shrimp trawl is a potential bias that should be considered when evaluating size composition data. The limited head rope rise and small sweep may have allowed larger individuals to avoid the net. The trawl catches of juveniles does indicate that these habitats are important nursery habitats for several species of fish and decapods.

COMPARISON TO PREVIOUS STUDIES

The interpretation of trawl catch data and comparisons to previous efforts must be made cautiously because differences in sampling design and variation in the efficiency of trawl nets at capturing all species occupying subtidal habitats. The shrimp trawl deployed was a bottom-tending net with sweep of 9.1 m and a maximum head rope rise of 1.8 m. This relatively small net may have been selective towards smaller fish, less able to avoid capture. The net design was also selective for demersal fish and not efficient at catching pelagic species. Therefore, we suspect the catch did not fully portray the pelagic fish community in Salem Sound. Several species of pelagic fish were caught incidentally. Sporadic catches of pelagic fish and observations on the depth sounder of pelagic schools in the water column indicated that pelagics occur more frequently at the trawl stations than found in the trawl catch. Depth sounder observations of pelagic schools were most common at the Salem Harbor station.

Despite the limitations in gear selectivity, we believe the trawling effort provided catches that reflect the composition of resident and migrant fish and decapods expected for subtidal habitats in Salem Sound. The list, dominance, and rank composition for species are typical of cold-temperate waters for embayments in the Gulf of Maine (Bigelow and Schroeder 1953; Jerome et al. 1967; Haedrich and Haedrich 1974; Heck et al. 1989; and Buschbaum and Purintan 1997). The question arises over whether there has been a change in the species composition or in the abundance of important species since the 1965 DMF study on Salem Sound. This important topic is not easily addressed because of the lack of adequate annual baselines to monitor changes. The 1965 DMF study and the Salem Harbor power plant investigations in the 1970s are the only studies available for direct comparison to the 1997 study. In the next two sections, we discuss major findings of the 1965 study and Power Plant investigations and compare them to the 1997 trawl catches.

1965 Salem Sound Study. Comparisons of 1965 and 1997 trawl data are limited because of differences in trawl nets and sampling designs (Table 6.7). Catchability for some species certainly varied between the shrimp trawl used in 1997 and the larger net towed by a 12.2 m dragger in 1965. The shrimp trawls used in 1965 and 1997 were similar in size, but catch comparisons are also limited due to the lack of a liner in the 1965 net and few number of trawl tows in 1965. However, a descriptive comparison of the catch data is useful because the 1965 data still represent a directed trawling effort (36 tows) in Salem Sound with three common stations to the 1997 trawling.

In 1965, 28 species of fish were caught in 36 tows (Table 6.8). Records were not kept on catch of decapods. Similar to 1997, winter flounder was the highest ranked fish in terms of frequency of occurrence in trawl tows (1965 otter trawl - 96%, 1965 shrimp trawl – 83%, and 1997 shrimp trawl – 86%). Other than winter flounder, only Atlantic cod, yellowtail flounder, Atlantic tomcod, and American eel occurred in a third or more of the otter or shrimp tows. Most other species occurred incidentally in only a few tows. Seven species occurred in 1965 trawling that were not found in 1997, while 15 species that were caught in 1997 were not found in 1965. Therefore, 22 species did not co-occur in both sampling periods. This number may appear high but some of absences may be related to sampling design and catchability differences and not reflective of ecological changes. For example, American eel and pollock were caught in 1965 but not in 1997, yet they were observed in 1997 during other components of the study. Environmental influences on fish distribution may account for the presence of warmer water species such as scup, moonfish, summer flounder and northern sea robin in 1997, and their absence in 1965. The differences in shrimp trawl frequency of occurrence for grubby (1965 – 0%, and 1997 – 34%) and ninespine stickleback (1965 – 17%, and 1997 – 0%) appeared unusual. Differences in such catch observations could be related to the use of a cod-end liner in 1997, or coincidental effects of low frequency sampling.

It is tempting to use trawl catch data from the 1965 and 1997 studies as evidence of population changes for important Gulf of Maine groundfish. Winter flounder, yellowtail flounder, Atlantic cod and haddock have declined since the 1965 study (Vaughn 1993; ASMFC 1998b). Winter flounder have clearly declined since 1965 (Figure 6.20), yet were the most common fish caught in both studies. The peak 1965 winter flounder catches were adult fish caught in the spring, while a majority of the catch in 1997 was YOY and age-1 juveniles caught later in the season. Cod were highly ranked in both the 1965 otter trawl and 1997 shrimp trawl catches, but adult cod were common in 1965 whereas only YOY were caught in 1997. Yellowtail flounder were common in 1965 (58% FOC in otter trawl) and uncommon in 1997 (1% FOC in shrimp trawl). Haddock were caught during one tow in 1965 and absent in 1997. However, despite the known Gulf of Maine changes, differences in trawl net sizes and catchability greatly limit the use of Salem Sound data to discuss population changes.

Skate catches between 1965 and 1997 are not similar and may not be biased by differences in net catchability. Over 600 skates were caught at a high frequency of occurrence (59%) in 1997, and most of these were large adults (>40cm). Skates clearly dominated the overall biomass of 1997 fish catches that were otherwise mostly juvenile fish. Only four skates were caught in 36 tows in 1965. The 14.9 m trawl should have easily caught skates of this size if present in large numbers in 1965.

Salem Harbor Power Plant Investigations. Trawl sampling was conducted during DMF's ecological investigation of the impact of the Salem Harbor Power Station on marine resources from 1971-1979. A 14.9 m (sweep) otter trawl net towed by a commercial dragger, and a 9.1 m (sweep) shrimp trawl net towed by a small boat were used to sample fish (Table 6.7). Trawling was not conducted in 1975 or 1976, and annual coverage was not continuous for several other years. Sampling focused on Salem Harbor, but some limited trawling was conducted outside in Salem Sound. Substantial differences exist in sampling designs, trawl nets, and stations between the Power Plant efforts and studies in 1965 and 1997. Sampling methods used in 1972 and the two-year period of April 1977 to March 1979 allow limited comparisons to trawl sampling in 1965 and 1997.

During 1972 and 1977-1979, otter trawl sampling was conducted at the Salem Harbor station and one station in Salem Sound. The shrimp trawl was towed at two stations within Salem Harbor and five stations outside in Salem Sound in 1972. Only the two Salem Harbor stations were sampled in 1977-1979 with the shrimp trawl. A similar sized net for the three otter trawl efforts should have produced similar catchability. The differences in cod-end net liner and sampling designs greatly limit comparisons of the four shrimp trawl sampling records. Replicates and bi-weekly sampling were targeted for the 1977-1979 period, however, deviations from this design were common because of gear problems (primarily lobster pot obstruction).

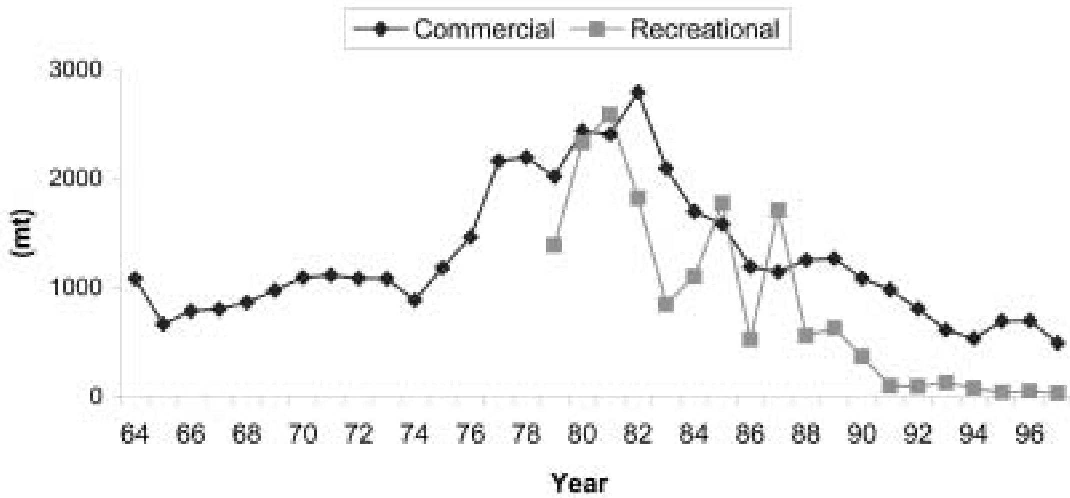
Table 6.7 Trawl net specifications used for Salem Sound marine resource studies. Sampling frequency noted as "monthly*" targeted monthly replicate trawls during the cold months and biweekly replicate trawls during the warm months. Biweekly sampling frequency included intermittent triplicate and weekly sampling.

Year	**Net**	**Boat** (m)	**Sweep** (m)	**Wing Mesh** (cm)	**Cod-end Mesh** (cm)	**Cod-end Liner** (cm)	**Duration of Tow** (min)	**Sampling Frequency**	**Stations** (No.)	**Tows** (No.)
1965	otter	12.2	14.9	12.7	10.2	none	20	monthly	3	24
1972	otter	~12.0	14.9	12.7	10.2	none	20	monthly	2	40
1977-79	otter	~12.0	14.9	12.7	10.2	none	20	biweekly	2	133
1965	shrimp	4.9	9.1	3.8	2.5	none	5	July/Oct.	6	12
1972	shrimp	6.1	9.1	3.8	2.5	0.32	5	monthly	7	104
1977-79	shrimp	6.1	9.1	3.8	2.5	0.32	5	biweekly	2	173
1997	shrimp	7.0	9.1	3.8	3.8	0.64	5	monthly*	5	168

Table 6.8 Number of fish caught and frequency of occurrence (FOC) in 1965 trawl catch. Trawl tows were made with 49 ft otter trawl (24 tows), and 30 ft shrimp trawl (12 tows).

Species	**49 ft. Trawl Catch** (No.)	**49 ft. Trawl FOC** (No.)	**30 ft. Trawl Catch** (No.)	**30 ft. Trawl FOC** (No.)	**Total Fish** (No.)
winter flounder	1724	23	230	10	1954
Atlantic cod	87	18			87
yellowtail flounder	59	14			59
haddock	38	1			38
silver hake	29	3			29
fourspine stickleback			28	2	28
Atlantic tomcod			24	5	24
threespine stickleback			16	2	16
longhorn sculpin	2	2	10	4	12
windowpane	9	3	1	1	10
red hake			10	1	10
ocean pout	9	6			9
American eel			9	4	9
Atlantic silverside			7	1	7
pollock	3	3	3	1	6
rainbow smelt	4	3	2	1	6
northern pipefish			5	2	5
ninespine stickleback			5	2	5
skate (two Raja sp.)	3	3	1	1	4
lumpfish	1	1	3	2	4
sea raven	2	2			2
goosefish	2	2			2
white hake	1	1	1	1	2
blueback herring	1	1			1
spiny dogfish	1	1			1
seasnail	1	1			1
cunner	1	1			1
Total	1977		355		2332

Figure 6.20 Winter flounder commercial and recreational landings (mt) in the Gulf of Maine, 1964-1997 (ASMFC 1998).



Trawling caught 33 fish species in 1972 and 32 fish species in 1977-1979 (Table 6.9). Species totals were similar in 1965 (28) and 1997 (35). Five species were unique to the Power Plant trawling. Eight species were unique to the 1997 study and the 1965 study had one. All unique species occurred incidentally, with the exception of 90 butterfish caught in 11 tows in 1997. Overall, the rank abundance of common fish species caught by the otter trawling is fairly comparable. Winter flounder dominated the otter trawl catch for all periods, with secondary contributions from skate, windowpane, cod and yellowtail flounder. All other species occurred incidentally. The shrimp trawl catch showed a similar rank of common species to that in 1965 and 1997. Winter flounder dominated the catch during each period. Catch rates for Atlantic silversides and stickleback species were much lower in 1997 than the previous three periods, and catches for anadromous fish (smelt, alewife, and blueback herring) were moderately lower. Catch rates for skate were the highest in 1997 despite the use of a larger net during longer tows in 1965, 1972 and 1977-1979.

The Power Plant investigations generated estimates of species richness and diversity specific to Salem Harbor. These data can be compared cautiously to 1997 Salem Harbor data. All annual values (both nets and three Salem Harbor stations) of species richness and diversity in the 1970s are lower than 1997 values. Annual species richness ranged from 9-20 in the 1970s and was 25 in 1997. The annual diversity index (H') ranged from 0.17-1.06 during the 1970s and was 1.98 in 1997. Shrimp trawl catch per tow was typically higher in the 1970s than in 1997. A primary reason for this, and influencing H' as well, were the higher catches of winter flounder, Atlantic silversides and sticklebacks during the shrimp trawling efforts in the 1970s.

The Power Plant investigations found little evidence that the electric generating station was affecting fish populations in Salem Harbor (Anderson et al. 1979). They found no negative trend in catch per tow and the Shannon-Weaver diversity index from 1971 to 1979. The Power Plant study also found a significant association in species rank abundance for Salem Harbor trawl catches between 1971-1974 and 1977-1979 (Anderson et al. 1979). These analyses led to the conclusion that the fish species composition did not change in Salem Harbor. Species rank correlation was not tested between 1997 trawl data and other years because of differences in study designs. Comparisons of fyke and seine net catches at a central Maine estuary during the early 1990s and 1970s found little change in the species composition during the two decades (Lazzari et al. 1999). This appears to be the case for species composition in Salem Sound, and may be typical of embayments in the lower Gulf of Maine. Conspicuous changes in catch rates for some individual species were found; many of these are probably an influence of sampling selectivity, although some may reflect region-wide changes in Gulf of Maine stocks.

Table 6.9 Trawl catch summary for DMF Salem Sound and Salem Harbor power plant studies. Catch per tow numbers are standardized for 9.1 m trawl tows (5 min) and 14.9 m trawl tows (20 min).

Species	**1997** 9.1m Net	**77/78/79** 9.1m Net	**1972** 9.1m Net	**1965** 9.1m Net	**77/78/79** 14.9m Net	**1972** 14.9m Net	**1965** 14.9m Net
(No. of tows)	*(168)*	*(173)*	*(104)*	*(12)*	*(133)*	*(40)*	*(24)*
winter flounder	6.4	8.8	7.5	19.2	24.2	237.0	71.8
skate (*Raja* sp.)	3.8	0.2	0.1	0.1	1.3	1.9	0.1
Atlantic cod	2.2	0.6	0.6		<0.1	3.7	3.6
cunnner	2.0	0.7	0.2		<0.1	0.2	<0.1
windowpane	0.9	0.1	0.1	0.1	0.8	5.6	0.4
grubby	0.8	0.5	0.3				
red hake	0.8	0.4	0.1	0.8	<0.1		
northern pipefish	0.5	1.5	2.9	0.4			
butterfish	0.5						
silver hake	0.4		<0.1		<0.1	0.2	1.2
rock gunnel	0.3	<0.1	<0.1			<0.1	
Atlantic silverside	0.2	4.8	1.9	0.6			
lumpfish	0.2	0.3	<0.1	0.3			<0.1
rainbow smelt	0.1	1.2	0.2	0.2	0.1	0.4	0.2
Atlantic herring	0.1	<0.1			<0.1		
northern sea robin	0.1					<0.1	
white hake	0.1	0.5	0.7	0.1		0.2	<0.1
sea raven	0.1		<0.1		<0.1	0.3	0.1
ocean pout	<0.1	<0.1	<0.1		<0.1	1.2	0.4
shorthorn sculpin	<0.1						
longhorn sculpin	<0.1			0.8		0.3	0.1
seasnail	<0.1		<0.1				<0.1
fourspot flounder	<0.1						
Atlantic menhaden	<0.1	<0.1	<0.1				
Atlantic tomcod	<0.1	3.1	1.8	2.0			
summer flounder	<0.1						
scup	<0.1						
threespine stickleback	<0.1	13.6	5.8	1.3			
yellowtail flounder	<0.1		<0.1		<0.1	10.7	2.5
Atlantic moonfish	<0.1						
Atlantic mackerel	<0.1				<0.1		
radiated shanny	<0.1						
striped seasnail	<0.1					<0.1	
fourbeard rockling	<0.1						
fourspine stickleback		23.3	3.4	2.3			
ninespine stickleback		3.3	1.2	0.4			
American eel		0.4	0.1	0.8			
pollock		0.1		0.3	0.1		0.1
alewife		<0.1	0.1				
mummichog		<0.1	0.1				
striped anchovy		<0.1					
smooth flounder		<0.1					
sand lance			<0.1				
blueback herring			<0.1				<0.1
goosefish						0.1	0.1
striped bass						<0.1	
haddock							1.6
spiny dogfish							<0.1
Total Fish catch/tow	20.0	63.7	27.2	29.6	26.7	261.7	82.4
Number of Species	35	27	29	17	14	18	20

CONCLUSION

Trawl sampling in 1997 provided evidence of a diverse community of demersal fish occupying the subtidal habitats of Salem Sound. Fish species richness was high (35), although the three most common fish (winter flounder, skate and Atlantic cod) comprised over 60% of total fish catches. Decapod crustacean catches displayed lower species richness and diversity, and were dominated by sand shrimp, rock crab and lobster (88% of recorded decapod catch). Few other fish or decapods were caught frequently or abundantly relative to these six species. Overall, the species composition appears typical of that expected for a Gulf of Maine embayment.

A large majority of the fish caught in the shrimp trawl was juveniles. Peak catches of fish in terms of relative abundance, richness, and diversity came in the summer and fall, and appeared most influenced by warmer water temperature and the recruitment of YOY fish to the subtidal habitats. The timing and relative abundance of YOY catches indicate that the stations sampled contained valuable nursery habitat for several commercially and recreationally valuable species. The highest fish diversity was associated with the greater structural complexity found at the Marblehead Harbor (larger sediments) and Beverly Cove (eelgrass) stations. The highest relative abundance for lobster was also found at these stations. Unexpectedly, the highest relative abundance and species richness for fish was found at the uniform, muddy bottom of the harbor channel stations in Salem Harbor and Haste Channel.

Comparisons to previous DMF trawling efforts in Salem Sound reveal no obvious reductions in species diversity or major shifts in the rank of common species over the four data series (1965, 1972, 1977-1979, and 1997). A total of 49 fish species were caught by trawl during the four study periods (including two species of skate). Most of the commonly caught demersal fish held similar ranks among study periods. Winter flounder held a high rank of relative abundance for each trawling effort. Mostly YOY and age-1 winter flounder were caught in 1997, indicating that Salem Sound continues to provide valuable nursery habitat for this species. Comparisons between these studies should be made cautiously because of differences in trawl net selectivity and sampling designs. It is also important to consider that the unusual occurrence or lack of a given species during annual studies may simply be a function of natural annual variation or sampling variability as opposed to ecological changes.

Winter flounder caught trawling in Salem Harbor

CHAPTER 7. OTHER RESOURCES AND COLLECTIONS

The 1997 study focused on water chemistry and marine fisheries resources in Salem Sound. This chapter contains summaries of observations and collections of other marine resources in Salem Sound. The sections include designed collections that accompanied trawl and seine efforts (identification of invertebrates and macrophytes), and discussion on valuable resources that were not specifically sampled (diadromous fish and invasive species). We also included references to independent studies that utilized 1997 field efforts to sample marine resource of local interest (trophic interactions, contaminants, and scuba survey).

INVERTEBRATES

The species composition of invertebrates in Salem Sound is extremely diverse and numerous inconspicuous species are abundant. We endeavored to record the presence of major arthropods in Salem Sound, and all crustaceans of the order Decapoda were quantified and reported in the Seine and Trawl chapters. Some very small arthropods and other invertebrates occurred in trawl and seine catches but could not be accurately quantified because the larger mesh size of the sampling nets. These specimens were saved for later identification. Identification of invertebrates was made using the guides of Smith (1964), Gosner (1978), Meinkoth (1981), and Pollock (1997). Other invertebrate Phyla were also present in Salem Sound but catches were limited because of the fisheries gear used. Observations on the Phyla Porifera, Chordata, Annelida, and Echinodermata were made and summarized below. Observations of the Phylum Mollusca focused on larger bivalves and are reported in the Shellfish Chapter. Other Phyla (Cnidaria, Ctenophora, and Bryozoa) are ecologically important and common to Salem Sound, but are not discussed here because of incompatible collection methods.

Phylum Arthropoda. We identified 22 species of Arthropods in the trawl and seine catch (Table 7.1). Most of these are omnivorous scavengers, and many are important as prey for fish. Eleven species were decapods, the most common order of Crustacea, of which five were frequently caught (sand shrimp, rock crab, lobster, green crab and hermit crab). The lobster is the best known crustacean, as a favored seafood and most economically valuable, living marine resource in Salem Sound. The rock crab and sand shrimp are two other abundant decapods, which were found to be important forage for the striped bass and skate. In addition to the order Decapoda, we identified several species from the orders Mysidacea, Amphipoda, and Isopoda.

Five species of the order Mysidacea were identified. Mysids were common at most trawl and seine stations. Three species were found on occasion at high abundance: *Praunus flexuosus, Mysis mixta, and Mysis stenolepis.* Mysids are small, delicate shrimp not large enough to attract economic interest, but they are vital to local food webs. High densities of small mysids (thousands per trawl tow) were caught in late spring at the Beverly Cove eelgrass station, and larger mysids were caught again in high densities during the September tows.

Four species of the order Amphipoda were identified. The scud (*Gammarus oceanicus*) and skeleton shrimp (*Aeginella longicornis*) were common to the eelgrass station. The tubed amphipod (*Leptocheirus pinguis*) was observed at low frequencies in catches at the Harbor Channel stations, but other observations imply these small amphipods were abundant. For instance, large numbers of tubed amphipods were found in skate stomachs from harbor channel stations. Each bottom grab sample of sediments at the harbor channel stations (N = 12) contained from a few to several dozen tubed amphipods. The Salem Harbor Power Station investigations also noted the abundance of tubed amphipods when benthic sampling in the 1970s recorded tubed amphipods as the numerically dominant Arthropod (Chesmore et al. 1973).

The observations of arthropods in Salem Sound during 1997 indicated that sand shrimp, mysid shrimp, and tubed amphipods were numerically abundant and vital components of local food webs. Lobster, rock crab, green crab and hermit crab were larger Arthropods, also abundant and important to trophic interactions. The eelgrass habitat of Beverly Cove had the highest densities and greatest diversity of Arthropods among seine and trawl stations. More mysids, skeleton shrimp, scuds, baltic isopods, lobster and rock crab were observed at Beverly Cove than at the other trawl stations, and sand shrimp ranked second among stations.

Phylum Annelida. The sampling design did not attempt to quantify the presence of marine worms (Class Polychaeta) because of their small size and burrowing habits. The polychaetes most commonly observed during sampling were sea worms of the *Nereis* genus. Sea worms burrow in mud but also actively swim and were routinely caught at most seine and trawl stations. Sea worms (most often *Nereis virens*) were found in the striped bass stomachs, and were an important component of the skate's diet. The only other polychaete identified was the sea mouse (*Aphrodite hastata*) which occurred in one skate stomach.

Table 7.1 Arthropod species in Salem Sound seine and trawl catch, 1997. Decapods and horseshoe crab were quantified. Other crustaceans were too small to be efficiently caught and quantified by seine (0.5 cm square mesh) and trawl (0.64 cm codend liner) nets.

Species	Common Name	Seine Catch	Trawl Catch	Notes
CLASS: MEROSTOMATA				
Limulus polyphemus	horseshoe crab	1	4	all from Danvers River
CLASS: CRUSTACEA				
Order: Decapoda				
Crangon septemspinosa	sand shrimp	71022	27940	most abundant decapod
Cancer irroratus	rock crab	18	1359	
Homarus americanus	lobster	0	1983	highest commercial value
Carcinus maenas	green crab	916	390	nonindigenous species
Pagurus sp.	hermit crab	915	116	
Libinia emarginata	spider crab	0	50	
Pandalus montagui	Montague's shrimp	0	86	
Eualus fabricii	-	0	2	
Lebbeus groenlandicus	Greenland shrimp	0	1	
Ovalipes ocellatus	lady crab	31	0	September only
Palaemonetes pugio	shore shrimp	1	0	
Order: Mysidacea				
Mysis mixta	oppossum shrimp	yes	yes	common and abundant
Mysis stenolepis	-	yes	yes	common and abundant
Praunus flexuosus	bent mysid	yes	yes	common and abundant
Neomysis americana	-	no	yes	common
Heteromysis formosa	red oppossum shrimp	yes	no	common
Order: Amphipoda				
Aeginella longicomis	skeleton shrimp	yes	yes	common
Gammarus oceanicus	scud	yes	yes	common
Hyperia galba	big-eyed amphipod	yes	no	only 2 caught
Leptocheirus pinguis	tubed amphipod	no	yes	few caught by nets
Order: Isopoda				
Idotea baltica	Baltic isopod	yes	yes	common

Phylum Echinodermata. Echinoderms were not well characterized during this study but deserve mention because of the common occurrence of sea urchins and starfish. The green sea urchin (*Strongylocentrotus droebachiensis*) was found at each trawl station and is one of a few species that support a directed commercial fishery within Salem Sound (Chapter 2). Sea urchins are known to target kelp as food and can limit kelp bed growth. Starfish are of ecological interest because they are major predators on bivalves in Salem Sound, especially on the abundant blue mussel. Several starfish species (primarily Asteriid) were abundant at most trawl stations and were easily observed from piers along the Sound. The only other Echinoderm identified was the sand dollar (*Echinarachnius parma*), which was caught occasionally in trawl tows.

Phylum Porifera. Sponges were noted in trawl catches while recording data on marine vegetation (Table 7.2). Several species of sponges were frequently found attached to debris in trawl catches at the Danvers River station. Small bunches of finger sponge (*Halicona oculata*), red beard sponge (*Microciona proliferai*), and boring sponge (*Cliona* sp.) appeared to be common structural components to the benthic habitat in the Danvers River. The "crumb of bread sponge" (*Halichondria panicea*) was also common in the river and several large colonies weighing 1-2 kg were caught. In contrast, sponges were not common at the other four trawl stations. Fig sponge (*Suberites ficus*) was caught twice each at the two Harbor Channel stations, and the bright orange palmate sponge (*Isodictya* sp.) was observed once in a Salem Harbor tow.

Table 7.2 Sessile sponges and tunicates collected at Salem Sound trawl stations in 1997.

Species	Common Name	Station	Notes
Phylum: PORIFERA			
Halicona oculata	finger sponge	Danvers River	common
Cliona sp.	boring sponge	Danvers River	common
Microciona proliferai	red beard sponge	Danvers River	common
Halichondria panicea	crumb of bread sponge	Danvers River	common
Suberites ficus	fig sponge	Salem Harbor/Haste Channel	four observations
Isodictya sp.	palmate sponge	Salem Harbor/Haste Channel	one observation
Phylum: CHORDATA **Class:** Ascidiacea			
Botryluss schlosseri	golden star tunicate	all trawl stations	most common in river
Styela clava	club tunicate	most trawl stations	most common in river
Botrylloides sp.	orange sheath tunicate	all trawl stations	most common in river
Didemnum sp.	white crust tunicate	all trawl stations	most common in river
Molgula sp.	sea squirt	most trawl stations	most common in river

Phylum Chordata, Class Ascidiacea. Ascidians, commonly known as tunicates or sea squirts, are filter feeders found as sessile colonies or individuals. We identified at least five species of ascidians (Table 7.2), and found them very common at the Danvers River trawl station. The following encrusting tunicates were also common at Beverly Cove and occasionally at other trawl stations: white crust (*Didemnum* sp.), Golden star tunicate (*Botryllus schlosseri*), and orange sheath tunicate (*Botrylloides* sp.). The lobed shaped sea squirt (*Molgula* sp.) and club tunicate (*Styela clava*) commonly occurred in Danvers River and occasionally at the other trawl stations. Of these encrusting tunicates, only the sea squirt is native to the Gulf of Maine (next section). The 1965 study and the Salem Harbor Power Plant investigation did not document the presence of these Ascidians in the 1960s and 1970s, although the studies did not target sessile organisms.

Phylum Chordata, Class Thaliacea. Salps are planktonic chordates that can occur solitarily or attached in chains. They are typically oceanic drifters, but occasionally appear in great numbers in coastal waters. The salp, *Thalia democratica,* appeared in Salem Sound and throughout the North Shore in the fall of 1997 in very high densities. Although often present in offshore waters south of Cape Cod, the occurrence of this salp in Massachusetts Bay was novel to many who are familiar with the waterfront and local newspapers ran stories in 1997 on the oddity.

INVASIVE SPECIES

Invasive species (also called nonindigenous species) are species introduced to ecosystems outside of their native geographic range as a result of human activities (Nico and Fuller 1999). Concern is rising over these introductions because invasive species can compete with indigenous species for food and habitat and import diseases. In the long-term, the potential exists to alter native food webs and unique marine communities. In recent decades, numerous benthic invertebrates have invaded New England coastal waters, and several are currently found as dominant species in subtidal habitats (Whitlatch and Osman 1999; and Sebens 1999). We did not catch any fish species in 1997 that could be classified as invasive, but we did record two invasive invertebrates (green crab and European oyster) and one macrophyte (green fleece) in the trawl catches and made observations of invasive tunicates while trawling and seining.

Green crabs were introduced to New England coastal waters over 100 years ago and have long been known for causing negative predatory affects on valuable populations of blue mussels and soft shell clams (Ropes 1968). Green crab was commonly caught at most trawl and seine stations at a variety of habitats and depths (0-10 m). It was also observed in the diet of skate and striped bass. The relative abundance of catches, range of habitat and trophic contributions all indicate that the green crab is firmly established as an important macroinvertebrate in Salem Sound. The European oyster's presence in Salem Sound is more recent. The bivalve is suspected to have escaped a Salem Harbor marine culture facility in the 1980s (Castonguay and Chase 1996). The European oyster population expanded greatly within Salem Sound in the 1990s and soon was observed in lower densities north (Cape Ann) and south (Boston Harbor) of Salem Sound (B. Chase, pers. obs.). Dense concentrations of the European oyster were observed in 1997 at subtidal habitats in Salem Harbor, Danvers Rivers, and Manchester Bay. The effect of this recent invasion on native marine communities is not known. Field observations made after the 1997 study indicate that the rapid increase in population size has peaked and may have declined in some areas. Green fleece (*Codium fragile*) was found in trawl and seine catches at a low frequency. Green fleece was introduced to New England in the late 1950s from Europe or the Pacific Ocean (Gosner 1978) and is very common south of Cape Cod.

Three colonial ascidians (golden star, orange sheath, and white crust tunicates) and the club tunicate were commonly observed at most subtidal trawl stations. These sessile, filter-feeders were abundant and a distinct structural component of benthic habitats, particularly in the Danvers River. The invasive colonial ascidians have become common to New England coastal waters in the last 20 years and some species (*Botrylloides* sp.) have severely impacted indigenous assemblages (Sebens 1999). Observations in Salem Sound during the 1990s imply that the four invasive ascidians, especially the brightly colored encrusted tunicates, have increased spatially and in abundance (B. Chase, pers. obs.).

A very recent introduction to New England waters, the Japanese shore crab, (*Hemigraspus sanguineus*) was not observed in Salem Sound in 1997. The crab prefers shallow, rocky intertidal habitats, similar to several seine stations that were routinely sampled in 1997. The Japanese shore crab was released from ballast water in New Jersey around 1987 and has since moved north to New England. In 1999, the Japanese shore crab was caught while seining at the Pioneer Village seine station with a local school class (B. Chase, pers. obs.). We have since heard of increasing observations of Japanese shore crabs in Salem Sound.

MARINE MACROPHYTES

Marine macrophytes, commonly known as seaweed, are important to the ecology of Salem Sound because they provide habitat and food for many species of marine fauna and through photosynthesis contribute oxygen to the aquatic environment. The 1965 DMF study recorded species of macroalgae collected at each shoreline seine station and referenced observations made at trawl stations. We recorded the presence of macrophytes at shoreline locations in a similar manner to the 1965 study and enhanced the detail of trawl observations to contribute to a description of subtidal habitats.

Macrophyte presence in trawl catches during 1997 was categorized by the following qualitative ranks based on relative abundance (volume): *dominant* (>50% of seaweed in tow), *secondary* (10-49% of seaweed in tow, and *incidental* (<10% of seaweed in tow). A fourth category, *detrital,* was used for algae that was not resident to the station where it was collected. Species were identified using microscopic analysis and guides by Gosner (1978), Martinez (1994), and Taylor and Villalard (1985). Shoreline collection at seine stations were conducted in 1997 by Salem State College interns (Reynolds 1998) and summarized below.

A total of 34 species of seaweed was identified from the seine and trawl collections in 1997 (Table 7.3). The most diverse phylum was the red algae (*Rhodophyta*) with 16 species identified, followed by brown algae (*Phaeophyta*) with 10 species, green algae (*Chlorophyta*) with 6 species, and only eelgrass (*Zostera marina*) represented the seed-bearing vascular plants (*Spermatophyta*). Only six species ranked higher than incidental (Table 7.4): eelgrass, kelp (*Laminaria* sp.), shotgun kelp (*Agarum cribosum*), soft sour weed (*Desmarestia viridis*), spiny sour weed (*Desmarestia aculeata*), and one green algae species (*Rhizoclonium tortuosum*). We noted rapid growth of most species of seaweed in June and July and a sharp reduction in relative abundance by the end of September. Mostly dead or dying detrital seaweed was observed by late October. Eelgrass, kelps, and sour weeds were the predominant seaweeds found in the trawl catches in Salem Sound. This sampling design concentrated on trawl zones and did not adequately characterize species found within or near the intertidal zone, such as rockweeds (*Fucus* sp.) and sea lettuce (*Ulva lactuca*), which are found commonly along the Salem Sound coastline.

Brown algae had the highest relative abundance among macrophyte phyla in Salem Sound. Kelp species (*Laminaria agardii* and *Laminaria saccharina*) were most common at the deeper stations. Shotgun kelp (or sea colander) was common at deeper stations and most abundant at Marblehead Harbor station (deepest station). The most diversity and abundance of seaweed was found at Beverly Cove. Eelgrass was the dominant plant at this station (74% of tows), although five other species were ranked dominant during at least one tow. The sour weeds were abundant during early summer, especially the spiny sour weed that at times accounted for a large majority of the trawl catch weight. A dramatic increase of *Rhizoclonium tortuosum* occurred at Beverly Cove in late July, but was not seen after August.

Red algae displayed high species diversity but were not found abundantly. Red algae only occurred incidentally and many were mixed with the eelgrass and sour weed at Beverly Cove. Irish moss (*Chondrus crispus*) was found most frequently among the red algae, but only incidental amounts in six tows. No evidence of resident macrophytes was found at the Danvers River trawl station during 36 tows. All observations of seaweed at the river stations were of detrital algae, primarily rockweed and sea lettuce. Sponges, tunicates, and watershed detritus provided the structural diversity of benthic habitats at the Danvers River trawl zones.

Table 7.3 Marine macrophytes collected in Salem Sound, 1997. Presence is noted by an asterisk

Species	Common Name	Trawl 1997	Seine 1997	Seine 1965
Phylum: CHLOROPHYTA (Green Algae)				
Chaetomorpha linum		*		
Ulva lactuca	sea lettuce	*	*	*
Ulothrix flacca		*		
Rhizoclonium tortuosum		*		
Codium fragile	green fleece	*	*	
Enteromorpha intestinalis			*	*
Protomonostroma undulatum			*	
Phylum: PHAEOPHYTA (Brown Algae)				
Desmarestia viridis	soft sour weed	*	*	
Desmarestia aculeata	spiny sour weed	*	*	
Laminaria sp.	kelp	*	*	*
Agarum cribosum	shotgun kelp	*	*	*
Ascophyllum nodosum	rock weed		*	*
Fucus spiralis	rock weed		*	
Fucus vesiculosus	rock weed		*	*
Fucus disticlus edentatus	rock weed		*	
Petalonia fuscia			*	
Petalonia zosterifolia			*	
Chorda filum	devil's shoe lace			*
Phylum: RHODOPHYTA (Red Algae)				
Bonnemaisonia hamifera		*		
Chondrus crispus	irish moss	*	*	*
Antithaminion cruciatune		*		
Callithamnion corymbosum		*		
Phymatolithon laevigatum	pink crust	*		
Hildenbrandia rubra		*		
Polyides rotundus		*		
Dasya baillouviana		*		
Ceramium rubrum		*		
Rhodymenia palmata	dulse	*		*
Palmaria palmata		*		
Porphyra miniata		*		
Porphyr linearis			*	
Porphyr umbilicalis			*	*
Callophyllis cristata			*	
Polysiphonia lanosa			*	*
Phycodrys rubens				*
Phylum: SPERMATOPHYTA (seed plants)				
Zostera marina	eelgrass	*	*	

Comparisons to Previous Studies. The 1965 DMF study reported only 13 species of seaweed, in contrast to 34 species reported in this study. Thirty-six species were reported for both studies combined, of which 23 were only found in 1997. It is not certain if this large increase in reported species represents actual changes in species composition within Salem Sound. Both collection methods were simple in approach and opportunistic. The 1997 collections were conducted at a higher frequency than in 1965, and probably better represents actual species composition. Interestingly, no references were made in 1965 to the ecologically important eelgrass or sour weeds that were abundant in 1997.

Table 7.4 Macrophyte rank at Salem Sound trawl stations in 1997. Species were qualitatively ranked during each trawl as *dominant, secondary, incidental or detrital*. Only the listed species received the ranks of dominant (D) or secondary (S). Table values are the percentage of observations at given ranks.

	Beverly Cove (N = 34)		Haste Channel (N = 34)		Marblehead H. (N = 29)		Salem Harbor (N = 33)		Danvers River (N = 34)	
Species	**D**	**S**	**D**	**S**	**D**	**S**	**D**	**S**	**D**	**S**
Zostera marina	74%,	15%	0	0	0	0	0	0	0	0
Laminaria sp.	6%,	3%	47%,	18%	38%,	38%	55%,	6%	0	0
Agarum cribosum	3%,	0	41%,	12%	76%,	7%	6%,	9%	0	0
Desmarestia viridis	6%,	9%	0	0	0	0	0	0	0	0
Desmarestia aculeata	15%,	15%	0	0	3%,	0	6%,	12%	0	0
Rhizoclonium tortuosum	6%,	9%	0	0	0	0	0	0	0	0

The Salem Harbor Power Plant investigation recorded seaweed species and monitored eelgrass beds in the early 1970s within Salem Harbor. A 1973 list of marine plants contains 17 species (Chesmore et al. 1973). Sour weeds were again noticeably absent on the list. The list does include eelgrass, and observations were recorded of eelgrass at four locations in Salem Harbor: Cat Cove, off Pickering Point, off Folgers Point, and off Derby Wharf. Subsequent monitoring in the late-1970s found that the Cat Cove and Pickering Point eelgrass beds were healthy and expanding.

The present study did not sample eelgrass habitat outside of Beverly Cove, although observations made during sampling trips indicated that the Cat Cove and Pickering Point beds were present and may have expanded. Observations were also made of large beds of eelgrass off Naugus Head, in Manchester Channel, and in the Danvers River near its confluence with Bass River. An eelgrass survey was conducted by DEP in 1997 in Salem Sound, as part of a statewide monitoring program (Charles Costello, DEP, pers. comm.). The use of aerial and boat observations found numerous eelgrass beds (Figure 7.1), including one of the largest eelgrass meadows in the state north of Cape Cod off the Beverly Shore.

We did not target salt marsh species of vascular plants in the present study, although Reynolds (1998) did record the presence of cordgrasses (*Spartina* sp.) and common reed (*Phragmites australis*) near intertidal stations. The 1965 study did record the presence of salt marsh species, and produced a list of plants similar to Reynolds (1998) except that there was no mention of the common reed in 1965.

DIADROMOUS FISH

Diadromous fish are valued for supporting popular sportfisheries, the attraction they provide during spring spawning migrations, and as a vital component of local food webs. Although know to occur in local sport and bait fisheries, little documentation exists for the anadromous rainbow smelt (*Osmerus mordax*), blueback herring (*Alosa aestivalis*) and alewife (*Alosa pseudoharengus*) (both called river herring), and the catadromous American eel (*Anguilla rostrata*) in Salem Sound. The three DMF fisheries studies in Salem Sound recorded sparse catches of the four species, and minor spawning runs of alewife were reported earlier in the 20th century in the North River (Belding 1921) and Crane River (Reback and DeCarlo 1972). Smelt spawning habitat was monitored in the region by DMF during 1988-1991 and documented in the Porter River (Chase 1993) and Chubb Creek, Bennett Brook and Sawmill Brook of Manchester Bay (Chase 1995). No smelt spawning was found in the Forest River (Chase and Roderick 1994), or North River and Crane River (Chase 1993). Specific collections on diadromous fish were not made in 1997. We discuss their status here because of the apparent declining trend in the populations of these valuable species.

Only one diadromous species, rainbow smelt, was caught during the 1997 study. Sparse catches of smelt occurred during seine and trawl sampling, and these were primarily YOY caught from July to November. Twenty-three of the 25 trawl caught smelt came from Salem Harbor and 11 of 13 seine caught smelt came from Proctor Point. No smelt were caught at the Danvers River (near Porter River spawning habitat) and Beverly Cove (eelgrass habitat) stations. The absence of American eel in 1997 catches is probably more reflective of the sampling stations and methods than presence of eels. Juvenile eels were observed at several freshwater sampling stations in 1997. The 1965 and power plant studies caught low numbers of all four diadromous species, except for no catch of alewife and 384 smelt (1 day at Obear Park) in 1965 and one haul of nearly 900 blueback herring caught at Salem Harbor in 1973 during the power plant study.

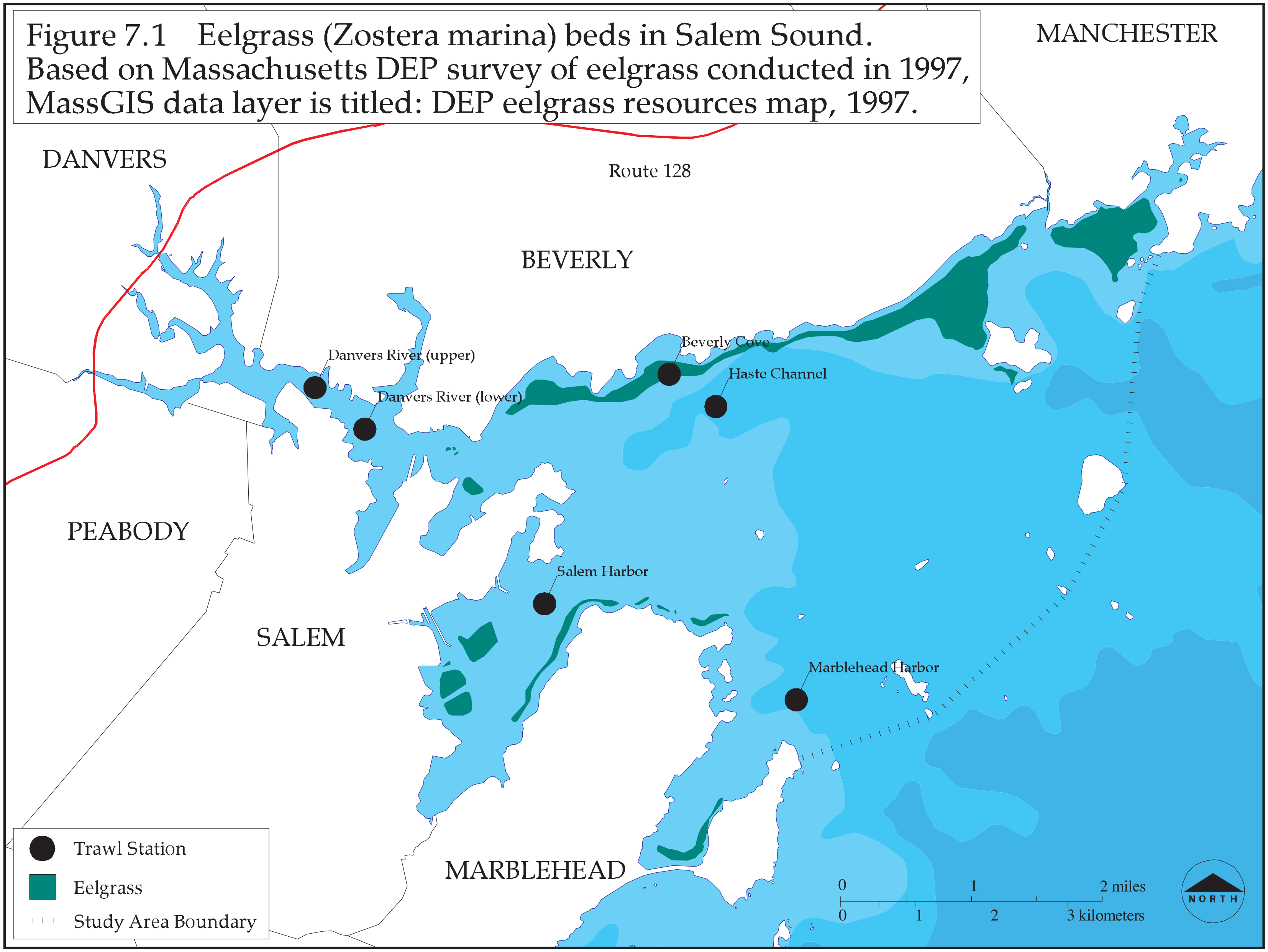


Figure 7.1 Eelgrass (Zostera marina) beds in Salem Sound. Based on Massachusetts DEP survey of eelgrass conducted in 1997, MassGIS data layer is titled: DEP eelgrass resources map, 1997.

We suspect catches from the three studies do not adequately reflect the decline in smelt and river herring populations during recent decades. In 1965, a viable fall and winter fishery existed for smelt in Salem, Beverly and Manchester harbors and modest river herring populations spawned in Danvers River tributaries. River herring runs were reported as severely degraded from passage obstructions and pollution discharges early in the 20th century (Belding 1921). It is not known if the infrequent observations since the 1960s represent remnants from degraded runs in the Danvers River or colonizing river herring from outside of Salem Sound. The DMF smelt monitoring and 1997 observations indicate that smelt spawning habitat is degraded from stormwater inputs of sediments and nutrients which foster excessive periphyton growth. Collectively, the fish catch data, smelt monitoring and anecdotes from local fisheries indicate smelt and river herring populations have declined during the last two decades. As of 1997, smelt and river herring runs have diminished to a very low level of detection.

CONTAMINANTS

Contaminant concentrations in the edible tissues of certain marine fish and shellfish have been monitored by DMF since the mid-1980s to establish baseline data for human health considerations. Samples were collected in Salem Sound during this period of winter flounder, lobster and soft-shell clams. Additional samples of these species and striped bass were collected in 1997. Polychlorinated biphenyls (PCBs) and six trace metals (chromium, cadmium, copper, lead, zinc, and mercury) are analyzed because of potential health risks associated with the consumption of marine organisms that bioaccumulate these contaminants. Once a common by-product of industrial processes, PCB manufacturing is now banned, although a variety of disposal methods have dispersed PCBs in coastal areas where they enter food webs. Trace metals are naturally occurring, but can be found in high concentrations, particularly in sediments near industrial disposal locations. Mercury and PCBs carry U.S. Food and Drug Administration tolerance levels of 2.00 ppm or less for human consumption. There are no tolerance levels for the remaining trace metals because the acute and chronic impacts are presently uncertain.

During 1984-1989, PCBs were found in winter flounder, lobster and soft-shell clams sampled from Salem Sound (Schwartz et al. 1991). The PCB values were significantly lower than comparable samples from Boston Harbor and 98% were below the FDA tolerance level. Trace metals analysis during 1986-1991 for the same species in Salem Sound found primarily low or moderate concentrations (Schwartz et al. 1993). Most cadmium and lead values in winter flounder were below detection limits, and zinc and mercury were significantly lower than Boston Harbor samples. Concentrations in lobsters were also low to moderate except for chromium, which was significantly greater than Boston Harbor values. In contrast to winter flounder and lobster, relatively high concentrations of chromium, cadmium and lead were found in Salem Sound soft shell clams. High cadmium and lead values resulted from samples collected at the "Lead Mills", a former lead mill that operated on the Forest River from 1826 to 1920 (Essex Institute 1971). Both these metals are expected in deposits from lead manufacturing. The high chromium in both lobster and soft shell clams is most likely related to discharges from the leather tanning industry that once flourished in the region.

Sixty-six striped bass were collected from coastal Massachusetts in 1997 and analyzed for PCBs (Schwartz et al. 1998). Included in this sample were 14 striped bass from the Salem Sound region. All striped bass were at least 28 inches, the minimum size for recreational catches. Both the coastal and Salem Sound mean concentration of PCBs was less than 0.30 ppm, and no individual samples exceeded the 2.00 ppm U.S. FDA tolerance level for human consumption and interstate commerce.

No significant annual trends in the concentrations of PCBs and trace metals were found in Salem Sound during 1986-1990. For several parameters there was the appearance of modest reductions during this period. Recent monitoring may confirm the expectation that the levels of these contaminants in the edible tissue of Salem Sound fish and shellfish have stabilized, and some may be declining during the last 20 years. It is important to emphasize the contaminant data address relatively few types of contaminants in only three species. Numerous other toxic pollutants (other metals and inorganic compounds, hydrocarbons) are found in Salem Sound sediments (NOAA 1988; and Edwards and Kelcey 1989). The effect of these other contaminants on marine resources has not been assessed and remains a concern.

TROPHIC INTERACTIONS

The stomach contents of two large predators were collected during the 1997 study for DMF diet studies. Skate (Raja erinacea and Raja ocellata) were collected from trawl catches at all stations during May-October. Striped bass were collected by gillnet and angling during monthly trips from May-October, and represent a subset of samples for a multi-year DMF study on striped bass diet. Diet data for both species will be reported in other documents by DMF. We summarize the results here to provide insight on trophic linkages during the study period.

Table 7.5 Striped bass stomach contents from Salem Sound samples collected during 1997. A total of 120 stomachs was collected, of which 49 contained prey (722 g total prey wt.).

Prey	Percent Occurrence	Percent of Total Wt.
rock crab	36.7	40.3
sand shrimp	24.5	3.2
green crab	16.3	8.7
unidentified fish	16.3	1.7
lobster	12.2	36.4
butterfish	6.1	0.8
unidentified amphipoda	6.1	1.1
unidentified decapoda	4.1	1.1
unidentified polychaete	4.1	0.2
rainbow smelt	4.1	5.3
Atlantic silverside	4.1	1.3
winter flounder	2.0	0.1
baltic isopod	2.0	0.0

Table 7.6 Skate (*Raja* sp.) stomach contents from Salem Sound samples collected during 1997 trawling. A total of 429 stomachs was collected, of which 373 contained prey (1813 g total prey wt).

Prey	Percent Occurrence	Percent of Total Wt.
sand shrimp	50.9	14.5
tubed amphipod	49.6	22.9
sea worm (*Nereis* sp.)	46.9	25.2
rock crab	35.7	18.5
unidentified mollusc	8.0	2.5
unidentified fish	6.7	4.2
scud	4.0	0.3
hermit crab	3.8	1.0
green crab	3.8	2.0
mysid shrimp	2.7	0.3
lobster	2.1	5.5
razor clam	1.9	0.3
unidentified decapod	1.6	0.3
winter flounder	1.3	0.2
hake (*Urophycis* sp.)	0.5	0.3
sea mouse	0.3	0.2
squid	0.3	1.8
red shrimp	0.3	0.1
baltic isopod	0.3	0.0

Striped Bass. The stomach contents of 120 striped bass were sampled from Salem Sound during 1997. Most samples were empty or contained bait, and only 49 stomachs contained natural prey (Table 7.5). Despite the few samples, several observations may reflect actual conditions in Salem Sound. The rocky habitat common on the North Shore provides good habitat for numerous decapod crustaceans. Decapods comprised a large majority of stomach contents (90% by weight). Rock crab and lobster alone accounted for 76% by weight of all prey items. All but one occurrence of rock crab and lobster prey in striped bass stomachs were found in samples collected at the rocky islands in outer Salem Sound. The data support an earlier account on the importance of decapods in the diet of striped bass in the Gulf of Maine (Bigelow and Schroeder 1953). The low occurrence of fish in prey composition may be biased by the small sample size.

Skate. A total of 429 skate stomachs was collected from trawl catches, of which 373 stomachs contained prey contents (Table 7.6). Contents from these samples were dominated by four species of invertebrates. Sand shrimp, tubed amphipod, sea worm (Nereis sp.), and rock crab were found at a high frequency of occurrence and accounted for 81% of all prey weight. Bivalve molluscs ranked fifth in terms of frequency of occurrence (10%), but only accounted for 3% of total prey weight. Most samples listed as unidentified mollusc were the siphons of either razor clams or soft shell clams. All fish prey combined accounted for only 5% of total prey weight. These results do not support the concern that the current high abundance of skate is impacting important finfish through predation on juveniles. For species of commercial and recreational importance, only lobster and winter flounder were found, but at very low frequencies (1-2%). The five winter flounder identified were all YOY. The diet composition reflects bottom-grazing feeding behavior and does not indicate the consistent ability of skate to prey on juvenile finfish.

Comparison of skate diet among trawl stations revealed several associations of prey composition to habitat type (Tables A.45-A.49). The tubed amphipod was the top prey by weight at Salem Harbor and Haste Channel, but it accounted for less than 1% of prey weight at Danvers River and Marblehead Harbor. The species composition at the Danvers River also differed from the Harbor Channel stations by having a lower contribution from crustaceans and more molluscs. The frequency of occurrence for sand shrimp in the diet was highest at Beverly Cove and Danvers River, which is consistent with trawl catch data. Comparisons between striped bass and skate diet are limited due to the sparse number of striped bass samples. The two prey lists do offer some similarities that reflect the value of invertebrate species in local trophic linkages. Crustaceans made up a majority of the prey

Bluefish and striped bass caught in Salem Sound

species composition and fish contributed less than 10% to the total prey weight for both predators. Species of commercial or recreational importance did not make a large contribution to these diet data, with the exception of lobster as striped bass prey.

GILLNET SAMPLING

Gillnets were set on six dates during May-October to supplement striped bass collections for the DMF diet study. A single 85 m floating nylon net (3.4 m depth and 9 cm mesh) was set during the early morning for 4-6 hours near Misery Island. The May and October sets did not catch any fish. The remaining four sets caught 28 striped bass (size range 45-72 cm), two cunner (36-39 cm), one bluefish (55 cm), and one tautog (*Tautoga onitis*) (43 cm). Overnight sets would have certainly caught more fish, but we did not want to catch excessive numbers of striped bass. This sampling documents the presence in Salem Sound of striped bass and tautog in 1997, two species not caught by trawl or seine collections.

SALEM SOUND 2000 SCUBA SURVEY

A scuba survey of benthic fauna and habitat in Salem Sound was conducted from June 1997 through May 1998 by a network of volunteer divers. The survey was organized by Salem Sound 2000 and designed to include DMF trawl and seine stations. Six 100 m transect stations and four invertebrate quadrat stations were selected for monthly sampling (Buchsbaum 1998). The Marblehead Harbor and Beverly Cove transects were at DMF trawl stations, and two quadrat stations, Forest River (Pioneer Village) and Tuck Point were in close proximity to DMF seine stations.

Overall, the most commonly observed fish species were cunner, winter flounder, and sculpin (*Myoxocephalus* sp.). Beyond those three species, only pollock and skate were identified commonly and all other fish were observed incidentally. The most commonly observed decapods were hermit crab, rock crab, lobster and sand shrimp. All decapods observed by the scuba survey were also caught during trawling. The difference in relative ranks of common species between the trawl and scuba methods may reflect upon species behavior which can influence the chance of trawl capture or observation while diving, more so than relative abundance. For example, the scuba survey recorded two pelagic fish not captured during trawling (pollock and striped bass) and the cryptic lobster held a lower rank in the scuba survey. The scuba survey found several periods of increased species activity that coincided with the trawl catch data. Peak observations of small cunner and winter flounder at Beverly Cove matched expected recruitment events in the early fall. The seasonal peak for lobster was also similar to trawl data, occurring from August-October with a September peak. The scuba survey found the invasive bivalve, European oyster, at three transect stations and three quadrat stations.

CHAPTER 8. STATE OF THE SOUND

Our sampling in 1997 provided us with enough information to conclude that Salem Sound is in an adequate state of health to support aquatic life and most recreational uses. This was most evident for marine habitats that benefit from the flushing effects that result from high tidal amplitude and shallow depth. These conditions and minor freshwater inputs limit stratification and the influence of pollutants from a highly developed watershed. Water quality at river and marine stations generally met Massachusetts Surface Water Quality Criteria. Forty-five species of fish and 22 crustaceans were captured during all collections. The species composition found was typical for an embayment in the Gulf of Maine. We make these conclusions recognizing that comparisons to previous studies are limited by the span of time and different methods, and that some parameters and resources were not assessed. The following is a list of general findings and remaining concerns for resource manager to consider as we begin the 21st century.

POSITIVE

- No SA violations of bottom water quality and little indication of marine eutrophication.
- The fish community of subtidal and intertidal habitats appeared diverse and similar in composition to previous studies.
- Salem Sound continues to act as a nursery for important fish species including winter flounder, and Atlantic cod.
- The lobster fishery is the Salem Sound's top commercial fishery, and continues to support a multi-million dollar industry.
- The striped bass fishery is the Salem Sound's top recreational fishery, attracting thousands of anglers and supporting a supplemental commercial fishery.

NEGATIVE

- Non-point watershed sources of nutrient, sediment and bacterial pollution raise concerns for specific freshwater and upper estuary habitats.
- Major point sources in region cause elevated bacteria, turbidity and nutrients (wastewater treatment plant) and water temperature (power plant) that could impact near-field habitats.
- All shellfish beds remain closed because of fecal coliform bacteria concentrations.
- Estimated productive shellfish habitat declined from 1965 to 1997.
- Invasive species (primarily European oysters, green crab, and sessile tunicates) were a common feature of benthic habitats at several stations.
- Reductions in the populations of important groundfish species in the Gulf of Maine have negatively affected recreational and commercial fisheries in Salem Sound.

REMAINING CONCERNS (NOT ASSESSED)

- Effect of power plant entrainment on phytoplankton, fish and invertebrate eggs and larvae.
- Effect of nitrogen and phosphorus inputs from sewage effluent and stormwater on organisms at the base of the food chain.
- Effect of toxic contaminants (other metals, hydrocarbons, inorganic and organic compounds not assessed) on aquatic organisms.
- Status of salt marsh in Salem Sound: losses, alterations, and flow restrictions.
- Status of freshwater withdrawals for municipal consumption and impact on aquatic resources.
- Atmospheric contributions of pollutants from power plant and other sources of fossil fuel combustion.

RECOMMENDATIONS

Non-Point Source Impacts. Evidence of upper estuary and freshwater habitat impacts from stormwater pollution were found in 1997. It is likely that valuable, yet inconspicuous, natural resources at these habitats are chronically threatened by stormwater inputs. We recommend that municipalities in the region implement state and federal measures to reduce stormwater impacts. Beyond the existing stormwater regulatory framework, we urge municipalities to proactively manage roadway, drainage, wastewater delivery and water withdrawal projects to reduce the amounts of nutrients, sediments, bacteria and toxic materials that enter these sensitive habitats.

Watershed Investigations. Future efforts to monitor the health of marine habitats and to correct problems associated with point and non-point source inputs will require a more inter-disciplinary approach to meet these complex challenges. We recommend using emerging technologies in the collection of physical data in the field and GIS mapping to better characterize habitat conditions and integrate biotic collections to physical habitat data. This approach will allow more detailed assessment of watershed impacts and the characterization of important habitats not evaluated in 1997 (ex. salt marsh, benthic substrates, and rocky intertidal).

Wastewater Treatment Plant Outfall. The discharge and destination of the various pollutants found in the wastewater treatment plant outfall effluent should be better quantified and the effects on local species and habitats should be evaluated. Far-field influences were not identified during the present study. However, near-field concerns were raised over the impact of high nutrients, bacteria and contaminants on phytoplankton and benthic habitats.

Salem Harbor Power Plant. The impact of entrainment mortality on phytoplankton and fish and invertebrate eggs and larvae should be assessed. Given the high withdrawal rates allowed (669 mgd) and high temperature exposure, large numbers of planktonic organisms do not survive entrainment and population impacts could be significant. The warming of Salem Harbor from the cooling water discharge at the power plant should also be documented in detail and an interagency review of potential impacts to aquatic organisms should be conducted.

Nutrient/Resource Relationships. High concentrations of nutrients were found at river stations and at the Haste Outfall station. The relationship between high nutrients and surrounding marine resources are poorly understood. It is recommended that investigations be conducted that link nitrogen and phosphorus concentrations to responses of biological indicator organisms. Algal biomass may be a good indicator, using phytoplankton, benthic algae, and macrophytes, at both marine and river stations.

Freshwater Nutrient Reduction. The need to reduce the concentrations of nitrogen and phosphorus in coastal streams is apparent. Inter-jurisdictional efforts are underway to reduce inputs from atmospheric sources and watershed growth, however progress will be slow and measured by decades. Local communities can address smaller scale nutrient sources on a shorter time horizon with relatively inexpensive techniques. It is recommended that local authorities assist in this effort by promoting best management practices for stormwater remediation, riparian buffers, reduced use of domestic fertilizers and the remediation of illicit wastewater discharges.

Sunset in Salem Harbor

Crane River, Danvers

FUTURE ESTUARINE STUDIES.

The experience and data collected in Salem Sound during 1997 should be used to assist an evaluation of future sampling efforts in estuaries and embayments in Massachusetts. It will be vital to select standard methodologies that can be consistently applied. Future studies should include:

Biological Indicator Species. Specific organisms (benthic invertebrate, demersal fish, benthic macrophyte) should be selected for standardized monitoring of population status. Such species should be accessible to quantitative collections, non-migratory, and sensitive to habitat or water quality alterations.

Integration of Physical and Biotic Measures with Water Quality Criteria. Limited water quality criteria exist to link parameters to aquatic resource health. We recommend working with DEP to develop specific criteria that better relate water quality to physical habitat and biotic measurements.

Fisheries Sampling. Sampling of fish at subtidal and intertidal habitats in a similar manner as past studies should be part of future efforts. Careful consideration should be made to define sampling targets and selecting seine and trawl nets that will be adopted as standards for estuarine monitoring. Consideration should also be made to sample pelagic species with gillnets or pelagic trawls.

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APPENDIX

Table A.1 Relative Percent Difference (RPD) summary for nutrient replicates and minimum detection limits (MDL) of nutrient parameters sampled in Salem Sound, 1997. Refer to Chase (1999) for further details on quality control/assurance.

Marine Samples

Parameter	MDL	Analytical Precision	Replicates	RPD Mean	RPD Range	Data Status
	(uM)	*(uM)*	*(No.)*	*(%)*	*(%)*	
TDN	0.01	0.02	17	12.2	1.5 - 46	accept means; 7 > 10%
ammonium	0.03	0.03	17	25.1	1.0 - 124	accept means; 8 > 10%
N+N	0.01	0.03	17	23.3	0.0 - 125	accept means; 9 > 10%
DON	*	*	16	16.9	1.5 - 61	accept means; 8 > 10%
TDP	0.02	0.01	15	10.3	0.0 - 32	accept means; 5 > 10%
Ortho-P	0.02	0.01	17	22.8	2.5 - 114	accept means; 8 > 10%
Silicate	0.03	0.03	18	5.5	0.5 - 20	accept means; 2 > 10%
	(ug/l)	*(%)*	*(No.)*	*(%)*	*(%)*	
PON	10.0	1	15	14.4	0.0 - 41	accept means; 7 > 10%
POC	10.0	1	15	3.3	0.4 - 12	accept means; 2 > 10%
Chl a	1.0	1	10	24.4	0.0 - 91	accept means; high RPDs
Phaeo.	1.0	1	10	76.5	2.3 - 200	accept means; high RPDs
Tot. Chl.	1.0	1	10	22.0	1.6 - 108	accept means; high RPDs

Freshwater Samples

Parameter	MDL	Analytical Precision	Replicates	RPD Mean	RPD Range	Data Status
	(uM)	*(uM)*	*(No.)*	*(%)*	*(%)*	
TDN	0.01	0.02	15	11.9	0.7 - 57	accept means; 7 > 10%
ammonium	0.03	0.03	18	16.4	0.0 - 89	accept means; 6> 10%
N+N	0.01	0.03	17	3.7	0.0 - 18	accept means; 2 > 10%
DON	*	*	15	49.0	0.9 - 151	accept means; high RPDs
TDP	0.02	0.01	12	46.9	3.8 - 145	accept means; high RPDs
Ortho-P	0.02	0.01	18	49.1	0.0 - 200	accept means; high RPDs
Silicate	0.03	0.03	18	19.3	0.2 - 113	accept means; 5 > 10%
	(ug/l)	*(%)*	*(No.)*	*(%)*	*(%)*	
PON	10.0	1	18	9.6	0.9 - 31	accept means; 6 > 10%
POC	10.0	1	18	3.5	0.1 - 8	accept means; 0 > 10%
Chl a	1.0	1	11	27.0	3.2 - 139	accept means; high RPDs
Phaeo.	1.0	1	11	23.4	0.0 - 69	accept means; high RPDs
Tot. Chl.	1.0	1	11	21.3	0.5 - 114	accept means; 3 > 10%

* DON was not measured: derived from subtracting DIN from TDN.

APPENDIX

Table A.2 Beach seine station water chemistry, 1997 (Tuck Point and Pioneer Village).

Station	Date	Time	Tide Stage (min. +/- Low)	Air Temp. (°C)	Water Temp. (°C)	Salinity (ppt)	Sp. Cond. (mS/cm)	pH	D.O. (mg/l)	D.O. (% Sat.)	Turbidity (NTU)
Tuck Point	1/15/1997	11:40	95	1.5	2.5	29.0					
Tuck Point	2/12/1997	9:40	56	1.5	2.6	28.0		7.9	11.1	103.3	2.4
Tuck Point	3/19/1997	12:40	-94	3.5	4.3	33.5	52.06	8.0	11.9	113.9	4.7
Tuck Point	4/11/1997	8:55	-2	3.0	4.5	33.3	51.26	7.8	11.4	108.0	-0.9
Tuck Point	5/19/1997	15:30	-32	10.0	7.9	31.7	48.23		10.3	105.3	9.0
Tuck Point	6/13/1997	12:00	-3	20.5	16.9	31.0	46.75	8.0	10.4	127.6	6.6
Tuck Point	7/14/1997	16:15	197	25.0	15.9	32.0	48.23	7.9	11.1	134.4	4.9
Tuck Point	8/12/1997	15:30	191	22.5	23.0	31.5	47.60	8.0	7.7		
Tuck Point	9/12/1997	18:25	284	22.5	20.5	31.4	47.32	7.9	8.2	108.3	3.8
Tuck Point	10/23/1997	14:28	171	8.0	12.2	31.6	48.50	8.0	8.8	100.4	4.5
Tuck Point	11/10/1997	14:43	102	10.5	10.4	30.5	47.10	7.7	8.5	92.3	4.4
Tuck Point	12/9/1997	12:10	-33	4.0	5.6	31.0	48.38	7.8	9.8	95.8	1.5
Mean				11.0	10.5	31.2	48.5	7.9	9.9	108.9	4.1
Pioneer Village	1/15/1997	10:45	40	3.0	4.5	28.0					
Pioneer Village	2/12/1997	11:20	156	4.5	5.5	29.0		8.0	11.1	111.3	2.2
Pioneer Village	3/19/1997	13:45	-29	2.0	7.0	33.4	50.94	8.0	12.8	129.6	
Pioneer Village	4/11/1997	6:55	-122	0.0	5.5	34.5	52.85	7.7	11.0	108.1	0.9
Pioneer Village	5/19/1997	18:45	163	9.5	8.6	32.3	49.08		10.4	107.7	2.1
Pioneer Village	6/13/1997	13:45	102	20.5	19.7	31.3	47.18	8.0	10.8	139.5	5.5
Pioneer Village	7/14/1997	9:40	-198	28.0	18.8	31.9	48.02	7.9	9.4	119.7	4.1
Pioneer Village	8/12/1997	9:20	-179	19.5	20.1	31.9	48.12	7.9	7.7		
Pioneer Village	9/12/1997	13:10	-31	22.0	21.2	31.6	47.64	7.8	7.5	100.5	12.7
Pioneer Village	10/23/1997	11:07	-30	8.0	12.5	31.7	48.62	7.9	8.5	97.5	3.4
Pioneer Village	11/10/1997	12:55	-6	10.5	12.8	29.9	46.12	7.9	9.5	108.7	7.0
Pioneer Village	12/9/1997	11:00	-93	3.0	7.5	30.9	48.06	7.9	10.4	106.2	2.8
Mean				10.9	12.0	31.4	48.66	7.9	9.9	112.9	4.5

APPENDIX

Table A.3 Beach seine station water chemistry, 1997 (Obear Park and Sandy Beach).

Station	Date	Time	Tide Stage (min. +/- Low)	Air Temp. (^oC)	Water Temp. (^oC)	Salinity (ppt)	Sp. Cond. (mS/cm)	pH	D.O. (mg/l)	D.O. (% Sat.)	Turbidity (NTU)
Obear Park	1/15/1997	12:35	135	1.5	2.0	28.0					
Obear Park	2/12/1997	12:15	196	2.5	2.7	28.0		7.9	11.0	104.0	1.9
Obear Park	3/19/1997	15:40	71	3.0	4.4	31.9	49.22	7.9	12.3	115.5	1.8
Obear Park	4/11/1997	12:05	172	7.0	6.7	31.6	48.23	7.8	11.7	115.9	4.7
Obear Park	5/19/1997	17:15	58	10.5	10.1	30.9	46.91		9.9	104.8	5.9
Obear Park	6/13/1997	15:40	202	20.0	17.2	30.8	46.47	7.9			5.9
Obear Park	7/14/1997	17:25	252	24.0	17.6	32.0	48.23	7.9	10.3	128.9	7.1
Obear Park	8/12/1997	14:05	91	21.0	24.1	31.6	47.70	7.9	8.1		
Obear Park	9/12/1997	11:25	-151	23.5	18.9	31.3	47.21	7.8	7.1	91.0	2.4
Obear Park	10/23/1997	8:32	-200	4.0	10.8	31.3	48.14	7.8	7.9	86.8	1.6
Obear Park	11/10/1997	10:28	-168	10.0	10.1	28.7	44.62	7.6	8.7	92.7	4.0
Obear Park	12/9/1997	10:16	-162	2.0	5.1	30.8	48.24	7.8	9.6	92.5	0.5
Mean			10.8		10.8	30.6	47.5	7.8	9.7	103.6	3.6
Sandy Beach	1/15/1997	13:30	175	3.0	2.0	28.0					
Sandy Beach	2/12/1997	13:10	236	3.0	2.4	27.0		7.9	11.4	105.1	4.4
Sandy Beach	3/19/1997	17:15	151	2.0	5.0	30.1	46.30	7.9	12.1	114.5	2.0
Sandy Beach	4/11/1997	12:30	183	8.5	6.9	28.0	42.83	7.7	11.5	111.5	2.0
Sandy Beach	5/19/1997	20:00	208	9.5	11.7	28.0	42.49		9.3	101.2	27.0
Sandy Beach	6/13/1997	16:40	247	20.5	19.7	30.4	45.83	7.8			8.9
Sandy Beach	7/14/1997	11:35	-113	28.0	22.8	31.5	47.44	7.9	9.1	125.0	18.6
Sandy Beach	8/12/1997	11:45	-64	20.0	24.4	31.1	46.96	7.9	8.7		
Sandy Beach	9/12/1997	10:15	-236	23.5	19.0	30.7	46.23	7.7	6.5	82.7	16.2
Sandy Beach	10/23/1997	9:35	-152	4.5	10.3	31.2	48.11	7.8	7.9	86.4	
Sandy Beach	11/10/1997	11:42	-109	10.5	10.4	26.3	41.17	7.6	8.7	92.3	15.8
Sandy Beach	12/9/1997	9:27	-226	-1.0	4.1	29.6	46.71	7.7	9.8	91.4	1.5
Mean				11.0	11.6	29.3	45.41	7.8	9.5	101.1	10.7

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Table A.4 Beach seine station water chemistry, 1997 (Proctor Point and West Beach).

Station	Date	Time	Tide Stage (min. +/- Low)	Air Temp. (°C)	Water Temp. (°C)	Salinity (ppt)	Sp. Cond. (mS/cm)	pH	D.O. (mg/l)	D.O. (% Sat.)	Turbidity (NTU)
Proctor Point	2/12/1997	7:15	-89	-2.0	2.0	26.0		8.0			3.0
Proctor Point	3/19/1997	10:40	-214	2.5	4.8	33.4	51.24	7.8	12.2	117.8	0.2
Proctor Point	4/11/1997	10:44	107	4.0	4.7	30.8	47.43	7.7	11.7	110.2	1.5
Proctor Point	5/19/1997	12:30	-212	12.0	9.7	30.5	46.23		10.3	108.6	2.4
Proctor Point	6/13/1997	9:00	-183	20.5	15.8	31.5	47.42	8.0	10.7	129.1	54.1
Proctor Point	7/14/1997	13:30	32	29.0	20.3	31.9	47.95	8.0	10.7	140.1	12.5
Proctor Point	8/12/1997	17:50	331	23.0	20.8	31.6	47.81	8.1	9.6		
Proctor Point	9/12/1997	16:45	184	26.0	18.6	31.5	47.47	7.9	7.5	95.9	3.2
Proctor Point	10/23/1997	16:00	263	8.5	11.9	31.5	48.39	8.0	9.0	101.3	10.6
Proctor Point	11/10/1997	16:38	217	9.0	10.6	27.8	43.29	7.8	9.0	96.9	10.9
Proctor Point	12/9/1997	15:15	153	3.5	5.3	29.7	46.62	7.9	10.0	96.2	1.7
Mean				12.4	11.3	30.6	47.39	7.9	10.1	110.7	10.0
West Beach	1/15/1997	8:45	-80	-2.0	2.0	26.0					
West Beach	2/12/1997	8:40	-4	0.5	2.8	28.0		7.8	11.0	104.0	13.0
West Beach	3/19/1997	11:40	-154	2.0	4.8	34.0	52.18	7.9	11.4	110.1	1.5
West Beach	4/11/1997	10:05	108	5.5	4.7	35.0	53.67	7.7	11.1	107.7	-2.0
West Beach	5/19/1997	14:00	-122	12.0	8.4	31.9	48.48		10.7	110.8	1.7
West Beach	6/13/1997	10:15	-108	22.0	16.1	31.1	46.88	8.0	11.0	132.6	2.2
West Beach	7/14/1997	14:30	92	25.0	15.8	32.0	48.24	8.0	12.1	146.5	1.3
West Beach	8/12/1997	16:30	251	19.5	20.9	32.2	48.54	8.0	8.3		
West Beach	9/12/1997	15:10	89	23.0	19.5	31.0	46.65	7.9	8.2	106.1	1.9
West Beach	10/23/1997	13:07	90	10.5	12.4	31.5	48.33	8.0	8.8	100.3	3.7
West Beach	11/10/1997	15:39	158	10.0	10.8	31.3	48.27	7.8	9.1	99.5	14.8
West Beach	12/9/1997	14:03	-80	5.0	6.0	31.3	48.82	7.9	9.8	97.3	0.5
Mean				11.1	10.4	31.3	49.01	7.9	10.1	111.5	3.9

APPENDIX

Table A.5 Crane River station water chemistry, 1997.

Location	Date	Time	Tide Stage (min. +/- low)	Rainfall (in.)	Air Temp. (°C)	Water Temp.(°C)	Salinity (ppt)	Sp. Cond (mS/cm)	pH	D.O. (mg/l)	D.O. (% sat.)	Turbidity (NTU)	Flow (m^3/s)	Depth (ave. m)
Crane River	1/29/1997	7:35	-135	0.32	-7.0	0.7	0.0	0.94	6.9	13.0	90.4			
Crane River	2/18/1997	16:40	53	0.08	4.0	3.9	0.0	1.00	7.1	12.2	92.8	12.4	0.282	0.29
Crane River	3/26/1997	11:15	224	0.35	8.5	7.4	0.0	0.50	7.2	11.8	98.6	49.8	0.669	0.23
Crane River	4/15/1997	17:05	209	0.86	10.0	12.6	0.0	0.74	7.1	10.9	101.7		0.481	0.25
Crane River	5/16/1997	12:10	-150	0.56	13.0	14.5	0.0	0.58	7.1	9.4	92.3	21.3	0.471	0.24
Crane River	5/27/1997	10:10	-40	0.25	15.5	14.5	0.0	0.66	7.3	9.4	92.0	9.7	0.220	0.17
Crane River	6/11/1997	10:27	-58	0	28.0	20.7	0.0	0.75	7.5	8.2	91.5	14.9	0.106	0.19
Crane River	6/25/1997	9:53	-39	0	22.0	21.3	0.0	0.74	7.6	7.1	80.4	11.4	0.064	0.17
Crane River	7/10/1997	9:47	-62	0.16	18.0	22.3	0.0	0.68	7.5	6.9	79.5	12.7	0.058	0.16
Crane River	7/22/1997	9:53	83	0.21	21.5	20.0	0.0	0.72	7.2	6.3	69.2	10.5	0.044	0.16
Crane River	8/13/1997	10:20	-233	0.35	20.5	20.6	0.0	0.76	6.8	5.4	59.1		0.027	0.13
Crane River	8/27/1997	10:45	-229	0	23.5	20.6	0.0	0.60		7.2	80.4		0.033	0.14
Crane River	9/9/1997	9:45	-127	0	17.5	17.4	0.0	0.65		6.4	67.8		0.033	0.15
Crane River	9/24/1997	10:25	-162	0	11.0	12.7	0.0	0.64	7.1	7.8	74.0	8.0	0.025	0.13
Crane River	10/7/1997	8:20	-134	0.20	14.0	14.5	0.0	0.64	7.1	6.9	68.1	10.2	0.032	0.15
Crane River	10/28/1997	11:25	-285	0.65	7.0	8.5	0.0	0.51	6.9	9.0	76.6	11.1	0.069	0.18
Crane River	11/24/1997	10:35	-200	0.71	3.0	3.2	0.0	0.90	6.8	11.0	82.3	6.6	0.268	0.26
Crane River	12/16/1997	14:25	-324	0	6.5	2.9	0.0	0.86	7.2	11.0	81.5	5.0	0.067	0.18
Mean				0.26	13.1	13.2	0.0	0.72	7.2	8.9	82.1	14.1	0.173	0.19

Note: Rainfall data are the total precipitation in Marblehead for 3 days, including 2 days prior to sampling and the day of sampling (NCDC 1998).

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Table A.6 North River station water chemistry, 1997.

Location	Date	Time	Tide Stage (min. +/- low)	Rainfall (in.)	Air Temp. (°C)	Water Temp.(°C)	Salinity (ppt)	Sp. Cond. (mS/cm)	pH	D.O. (mg/l)	D.O. (% sat.)	Turbidity (NTU)	Flow (m^3/s)	Depth (ave. m)
North River	1/29/1997	8:10	-100	0.32	-7.0	0.7	0.0	1.12	7.0	13.6	94.6			
North River	2/18/1997	17:30	103	0.08	4.0	4.2	0.0	1.09	7.1	12.0	92.7	12.6	0.415	0.47
North River	3/26/1997	10:00	149	0.35	9.5	7.4	0.0	0.59	7.3	12.4	103.0	9.9	1.109	0.58
North River	4/15/1997	18:15	279	0.86	9.0	11.8	0.0	0.65	7.0	10.8	99.4		0.770	0.52
North River	5/16/1997	13:30	-70	0.56	17.0	15.1	0.0	0.55	7.1	9.5	95.0	4.4	0.537	0.41
North River	5/27/1997	11:20	30	0.25	14.0	14.7	0.0	0.58	7.3	9.9	97.5	4.3	0.302	0.38
North River	6/11/1997	13:02	97	0	26.5	19.8	0.0	0.74	7.4	8.8	96.4	2.2	0.088	0.33
North River	6/25/1997	11:10	38	0	23.5	20.9	0.0	0.73	7.3	7.4	82.4	3.2	0.084	0.12
North River	7/10/1997	11:00	11	0.16	19.0	16.9	0.0	0.64	7.2	8.1	84.0	8.3	0.057	0.10
North River	7/22/1997	11:40	190	0.21	21.5	21.3	0.0	0.64	7.2	6.6	74.1	5.9	0.040	0.10
North River	8/13/1997	10:50	-203	0.35	20.0	19.3	0.0	0.80	6.9	7.3	77.9		0.014	0.14
North River	8/27/1997	11:20	-194	0	26.5	20.7	0.0	0.65		8.7	97.5		0.030	0.16
North River	9/9/1997	12:35	43	0	19.1	18.3	0.0	0.59		7.9	84.1		0.021	0.16
North River	9/24/1997	12:30	-37	0	13.0	15.1	0.0	0.60	7.3	7.4	73.3	2.4	0.020	0.15
North River	10/7/1997	10:50	16	0.20	20.0	15.7	0.0	0.59	7.2	7.4	74.7	2.2	0.030	0.16
North River	10/28/1997	12:00	-250	0.65	8.5	9.3	0.0	0.44	6.9	9.7	84.7	6.0	0.064	0.35
North River	11/24/1997	11:10	-165	0.71	3.0	3.8	0.0	0.80	6.9	11.4	86.4	4.2	0.253	0.41
North River	12/16/1997	15:15	-274	0	3.5	2.3	0.0	0.75	7.3	11.7	85.5	2.4	0.082	0.10
Mean				0.26	13.9	13.2	0.0	0.70	7.2	9.5	88.0	5.2	0.230	0.27

Note: Rainfall data are the total precipitation in Marblehead for 3 days, including 2 days prior to sampling and the day of sampling (NCDC 1998).

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Table A.7 Porter River station water chemistry, 1997.

Location	Date	Time	Tide Stage (min. +/- low)	Rainfall (in.)	Air Temp. (°C)	Water Temp.(°C)	Salinity (ppt)	Sp. Cond. (mS/cm)	pH	D.O. (mg/l)	D.O. (% sat.)	Turbidity (NTU)	Flow (m^3/s)	Depth (ave. m)
Porter River	1/29/1997	7:10	-160	0.32	-7.0	1.1	0.0	0.45	6.8	13.0	91.4			
Porter River	2/18/1997	16:05	18	0.08	4.0	4.8	0.0	1.09	7.1	12.4	97.1	28.1	0.154	0.17
Porter River	3/26/1997	11:45	254	0.35	9.0	6.8	0.0	0.32	7.1	12.7	104.0	23.7	0.494	0.33
Porter River	4/15/1997	17:30	234	0.86	10.0	11.2	0.0	0.48	7.0	11.0	99.0		0.216	0.18
Porter River	5/16/1997	11:20	-200	0.56	11.5	12.8	0.0	0.32	6.7	10.8	101.9	6.0	0.101	0.09
Porter River	5/27/1997	9:25	-85	0.25	11.5	11.2	0.0	0.49	7.3	11.3	102.7	2.4	0.108	0.12
Porter River	6/11/1997	9:25	-120	0	26.5	15.3	0.0	0.84	7.4	10.3	102.5	6.4	0.075	0.12
Porter River	6/25/1997	9:15	-77	0	21.0	16.3	0.3	1.58	7.2	9.4	96.7	6.5	0.030	0.10
Porter River	7/10/1997	8:40	-129	0.16	16.5	18.1	0.0	0.42	7.2	7.4	77.9	8.4	0.028	0.11
Porter River	7/22/1997	9:10	40	0.21	20.0	16.9	0.4	1.69	7.2	8.6	89.0	4.1	0.017	0.11
Porter River	8/13/1997	13:35	-38	0.35	18.5	18.6	0.0	0.59	7.0	8.8	92.6		0.009	0.09
Porter River	8/27/1997	14:20	-14	0	27.0	19.9	0.0	0.76		10.4	114.8		0.010	0.10
Porter River	9/9/1997	11:00	-52	0	19.0	16.7	0.0	0.33		9.2	95.2		0.021	0.12
Porter River	9/24/1997	11:15	-112	0	11.0	11.4	0.0	0.57	7.0	10.2	93.6	4.3	0.001	0.10
Porter River	10/7/1997	9:15	-79	0.20	15.5	13.5	0.0	0.44	7.2	8.8	84.4	4.0	0.009	0.10
Porter River	10/28/1997	16:00	-10	0.65	6.5	7.9	0.0	0.36	7.2	9.8	82.7	2.6	0.028	0.14
Porter River	11/24/1997	14:30	-35	0.71	3.0	4.6	0.0	0.56	6.8	11.3	88.0	2.0	0.101	0.21
Porter River	12/16/1997	8:00	47	0	-4.0	0.1	0.0	0.53	6.8	12.9	88.6	2.1	0.034	0.14
Mean				0.26	12.2	11.5	0.0	0.66	7.1	10.5	94.6	7.7	0.084	0.14

Note: Rainfall data are the total precipitation in Marblehead for 3 days, including 2 days prior to sampling and the day of sampling (NCDC 1998).

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Table A.8 Sawmill Brook and Waters River station water chemistry, 1997.

Location	Date	Time	Tide Stage (min. +/- low)	Air Temp. (°C)	Water Temp.(°C)	Salinity (ppt)	Sp. Cond. (mS/cm)	pH	D.O. (mg/l)	D.O. (% sat.)	Turbidity (NTU)	Flow (m^3/s)	Depth (ave. m)
Sawmill Brook	5/27/1997	16:00	310	14.0	16.2	0.0	0.23	6.2	9.5	96.7	6.3	0.233	0.23
Sawmill Brook	6/11/1997	8:40	-135	26.5	16.4	0.0	0.27	6.3	8.4	85.8	8.4	0.050	0.12
Sawmill Brook	6/25/1997	14:55	293	22.5	19.1	0.0	0.22	6.4	7.5	81.1	15.4	0.045	0.14
Sawmill Brook	7/10/1997	15:00	289	20.0	18.1	0.0	0.27	6.5	6.9	73.2	11.5	0.026	0.15
Sawmill Brook	7/22/1997	14:30	-348	22.0	17.3	0.0	0.27	6.7	7.3	76.0	6.8	0.011	0.10
Sawmill Brook	8/13/1997	9:30	-263	19.0	16.0	0.0	0.30	5.7	7.1	71.2		0.004	0.10
Sawmill Brook	8/27/1997	9:45	-259	21.0	16.6	0.0	0.29		6.9	71.2		0.006	0.16
Sawmill Brook	9/9/1997	9:00	-142	17.0	15.1	0.0	0.25		6.5	64.8		0.004	0.14
Sawmill Brook	9/24/1997	9:40	-177	10.5	11.1	0.0	0.30	6.5	6.9	62.8	7.1		
Sawmill Brook	10/7/1997	13:30	206	21.0	14.7	0.0	0.35	7.1	6.6	65.4	4.9		
Sawmill Brook	10/28/1997	10:15	-325	7.0	7.5	0.0	0.34	6.2	7.6	63.7	11.5	0.012	0.13
Sawmill Brook	11/24/1997	9:15	-250	4.0	3.1	0.0	0.31	5.2	11.1	82.7	7.0	0.584	0.41
Sawmill Brook	12/16/1997	16:40	-159	1.0	1.1	0.0	0.29	6.1	11.7	82.4	2.1	0.113	0.19
Mean				15.8	13.3	0.0	0.28	6.3	8.0	75.2	8.1	0.099	0.17
Waters River	5/16/1997	13:00	-100	17.0	14.5	0.0	0.60	7.0	10.0	98.6	15.7	0.061	0.13
Waters River	5/27/1997	10:35	-15	14.5	14.1	0.0	0.87	7.4	10.7	104.3	5.2	0.066	0.18
Waters River	6/11/1997	11:50	25	28.0	16.4	0.0	0.75	7.6	11.6	119.0	5.6	0.025	0.14
Waters River	6/25/1997	10:15	-17	23.5	16.3	0.3	1.44	7.2	9.4	96.4	6.1	0.015	0.10
Waters River	7/10/1997	10:20	-29	18.5	16.9	0.0	0.64	7.2	8.1	84.0	8.3	0.020	0.16
Waters River	7/22/1997	10:45	135	21.5	17.2	0.3	1.45	7.0	8.1	84.6	7.1	0.022	0.17
Waters River	8/13/1997	14:10	-3	19.0	16.3	0.0	0.73	6.8	8.3	83.4		0.026	0.20
Waters River	8/27/1997	13:45	-49	27.0	17.6	0.0	0.78		10.0	105.2		0.025	0.23
Waters River	9/9/1997	11:55	3	19.5	16.4	0.0	0.67		9.2	93.8		0.019	0.23
Waters River	9/24/1997	11:50	-77	13.0	14.7	0.0	0.88	7.3	9.5	93.7	1.9	0.013	0.24
Waters River	10/7/1997	10:15	-19	19.0	14.8	0.0	0.81	7.3	9.0	89.4	2.9	0.009	0.23
Waters River	10/28/1997	16:30	20	7.0	11.1	0.0	1.22	7.2	8.6	78.0	2.5	0.013	0.26
Waters River	11/24/1997	14:00	5	2.0	8.6	0.0	1.08	7.0	8.7	74.6	5.2	0.019	0.18
Waters River	12/16/1997	9:00	107	-4.5	6.4	0.0	1.03	7.1	9.8	79.9	7.7	0.010	0.24
Mean				16.1	14.4	0.0	0.93	7.2	9.4	91.8	6.2	0.025	0.19

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Table A.9 Bass River, Forest River and South River station water chemistry, 1997.

Location	Date	Time	Tide Stage (min. +/- low)	Air Temp. (°C)	Water Temp.(°C)	Salinity (ppt)	Sp. Cond. (mS/cm)	pH	D.O. (mg/l)	D.O. (% sat.)	Turbidity (NTU)	Flow (m^3/s)	Depth (ave. m)
Bass River	5/16/1997	16:10	n/a	16.0	16.7	0.0	0.21	7.6	10.1	103.7	6.2	0.077	0.14
Bass River	5/27/1997	15:10	n/a	15.0	17.5	0.0	0.21	8.1	10.5	109.5	4.2	0.058	0.03
Bass River	6/11/1997	15:40	n/a	30.0	24.6	0.0	0.23	7.7	9.1	109.4	8.4	0.001	
Bass River	6/25/1997	14:20	n/a	22.0	24.4	0.0	0.23	7.8	8.5	101.4	5.1	0.001	
Bass River	7/10/1997	14:00	n/a	22.5	26.5	0.0	0.24	8.0	7.7	95.6	3.9	0.001	
Bass River	11/24/1997	10:00	n/a	5.0	4.1	0.0	0.31	6.8	11.5	88.4	4.9	0.164	0.05
Bass River	12/16/1997	13:40	n/a	7.0	3.9	0.0	0.38	7.8	12.8	97.9	5.2	0.035	0.02
Mean				16.8	16.8	0.0	0.26	7.7	10.0	100.8	5.4	0.048	0.06
Forest River	5/16/1997	14:50	10	16.0	16.9	0.0	0.45	7.3	8.9	91.9	3.6	0.074	0.19
Forest River	5/27/1997	12:30	100	15.0	17.5	0.0	0.45	7.5	9.3	97.5	8.2	0.068	0.17
Forest River	6/11/1997	14:15	170	29.5	24.6	0.0	0.57	7.5	7.3	88.3	23.2	0.018	0.16
Forest River	6/25/1997	12:31	119	23.0	21.6	0.0	0.49	7.5	7.8	88.2	12.6	0.005	0.11
Forest River	11/24/1997	13:05	-50	3.0	3.8	0.0	0.60	7.0	10.5	79.5	2.3	0.073	0.22
Forest River	12/16/1997	10:15	182	-0.5	1.6	0.0	0.73	7.1	11.6	83.5	1.7	0.024	0.13
Mean				14.3	14.3	0.0	0.55	7.3	9.2	88.2	8.6	0.044	0.16
South River	5/27/1997	14:08	n/a	15.0	21.2	0.0	0.43				4.1		
South River	6/11/1997	14:55	n/a	31.5	26.2	0.0	0.52	7.3	4.0	49.3	6.1	0.004	0.03
South River	10/28/1997	14:05	n/a	8.0	9.4	0.0	0.49	7.3	7.8	68.3	10.1	0.061	0.14
South River	11/24/1997	12:15	n/a	4.0	3.4	0.0	0.56	6.7	9.5	71.7	3.7	0.113	0.16
South River	12/16/1997	11:20	n/a	2.0	3.4	0.0	0.59	6.9	9.7	73.2	2.4	0.024	0.11
Mean				12.1	12.7	0.0	0.52	7.1	7.8	65.6	5.3	0.051	0.11

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Table A10. Nutrient concentrations at the Crane River water chemistry station, January-December 1997.

Date	Sample Period	TN (uM)	TDN (uM)	DIN (uM)	N+N (uM)	NH_4 (uM)	DON (uM)	PON (uM)	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)	Chl. *a* (ug/l)
01/29	1	136.20	129.56	87.62	65.77	21.85	41.94	6.64		3.66	115.24	112.3	
02/18	2	189.53	179.64	101.86	81.75	20.12	77.77	9.89	0.51	2.24	148.45	249.3	
03/26	3	127.89	114.81	73.69	58.95	14.74	41.13	13.08		2.40	67.56	242.4	0.79
04/15	4	117.21	111.40	73.02	68.77	4.25	38.38	5.81	0.69	2.92	92.17	63.8	0.29
05/16	5	144.84	120.58	76.42	65.30	11.12	44.17	24.26	0.44	0.11	76.77	241.3	1.33
05/27	6	109.49	101.16	71.36	60.27	11.08	29.80	8.33	1.09	0.11	110.32	89.3	0.53
06/11	7	124.29	107.15	68.14	61.44	6.70	39.01	17.14	0.56	0.07	131.21	191.1	2.64
06/25	8	91.16	76.62	34.86	28.04	6.82	41.76	14.54	0.09	0.13	180.37	147.3	3.97
07/10	9	134.56	109.59	10.15	9.05	1.11	99.44	24.97	1.24	0.03	19.55	233.8	17.00
07/22	10	120.65	101.20	11.13	9.58	1.55	90.07	19.45	2.77	0.00	25.95	171.0	7.89
08/13	11	151.18	142.75	8.77	7.34	1.42	133.98	8.43	1.57	0.09	35.41	85.3	1.57
08/27	12	107.04	90.69	10.82	10.19	0.63	79.88	16.35	0.80	0.02	22.83	149.1	6.51
09/09	13			10.95	9.11	1.84		32.61		0.02	27.15	218.0	11.44
09/24	14	120.71	107.48	13.28	12.14	1.14	94.06	13.23	1.25	0.01	20.73	117.3	5.49
10/07	15			14.59	13.49	1.10		14.18		0.02	18.42	127.6	3.14
10/28	16	83.39	72.83	10.07	9.51	0.56	62.76	10.56	0.40	0.05	21.29	102.7	4.82
11/24	17	83.79	79.75	11.47	8.80	2.67	68.28	4.04	0.34	0.04	30.05	56.4	1.70
12/16	18	142.82	139.11	22.30	14.65	7.65	116.81	3.71	0.36	0.03	41.36	52.7	0.37
Mean		124.05	111.52	39.47	33.01	6.46	68.70	13.73	0.86	0.66	65.82	147.26	4.34
SE		6.77	6.83	7.93	6.57	1.60	7.90	1.84	0.19	0.29	12.22	16.09	1.15

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Table A.11 Nutrient concentrations at the North River water chemistry station, January-December 1997.

Date	Sample Period	TN (uM)	TDN (uM)	DIN (uM)	N+N (uM)	NH_4 (uM)	DON (uM)	PON (uM)	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)	Chl. *a* (ug/l)
01/29	1	184.00	180.42	113.42	73.93	39.49	67.00	3.58	0.23	2.89	100.17	72.1	
02/18	2	196.95	188.61	121.10	87.56	33.54	67.52	8.34	0.91	1.20	133.12	138.9	
03/26	3	149.74	141.97	100.98	81.37	19.00	41.00	7.77		2.19	112.50	124.9	
04/15	4	135.90	131.06	99.23	84.27	14.96	31.83	4.84		4.24	109.77	47.0	0.14
05/16	5	123.84	113.32	58.71	43.68	15.03	54.61	10.52	0.22	0.12	76.53	115.7	0.29
05/27	6	132.28	127.71	63.69	50.17	13.52	64.02	4.57	0.59	0.15	100.14	63.4	0.24
06/11	7	134.40	129.27	68.90	61.45	7.45	60.37	5.13	0.81	0.26	98.84	62.1	0.38
06/25	8	230.21	222.18	90.34	78.46	11.88	131.84	8.03	0.35	0.25	154.96	93.1	0.26
07/10	9	172.52	165.22	21.16	18.53	2.63	144.07	7.30	1.55	0.10	28.14	72.6	0.58
07/22	10	181.38	173.05	26.11	22.03	4.08	146.94	8.33	1.10	0.07	24.98	108.3	0.79
08/13	11	170.29	162.78	20.57	18.13	2.44	142.21	7.51	3.38	0.15	36.88	73.2	2.05
08/27	12	135.22	131.95	18.56	16.95	1.62	113.46	3.27	1.56	0.08	32.14	34.4	0.74
09/09	13	135.62	131.54	17.76	15.90	1.87	113.77	4.08	1.73	0.11	30.22	41.3	1.20
09/24	14	178.48	172.30	23.88	18.69	5.20	148.42	6.18	1.38	0.04	25.65	50.9	1.89
10/07	15			16.10	14.08	2.02		3.77		0.06	24.34	33.1	1.13
10/28	16	85.33	75.75	11.03	10.41	0.62	64.71	9.58	0.68	0.08	19.50	91.3	4.02
11/24	17	162.95	158.30	22.86	19.37	3.50	135.45	4.65	0.77	0.06	26.60	69.7	0.53
12/16	18	155.87	149.70	28.27	20.77	7.50	121.43	6.17	0.63	0.08	38.56	86.6	2.62
Mean		156.76	150.30	51.26	40.88	10.35	96.98	6.31	1.06	0.67	65.17	76.59	1.12
SE		8.13	8.13	9.08	6.84	2.61	10.08	0.52	0.21	0.28	10.58	7.30	0.28

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Table A.12 Nutrient concentrations at the Porter River water chemistry station, January-December 1997.

Date	Sample Period	TN (uM)	TDN (uM)	DIN (uM)	N+N (uM)	NH_4 (uM)	DON (uM)	PON (uM)	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)	Chl. *a* (ug/l)
01/29	1	152.30	142.92	88.25	81.85	6.40	54.67	9.38			122.46	75.6	
02/18	2	206.69	199.13	109.08	103.30	5.77	90.05	7.56	1.05	4.43	157.66	121.2	
03/26	3	97.28	88.97	54.75	49.75	5.00	34.22	8.31		1.19	83.52	109.0	0.25
04/15	4	136.88	134.22	92.10	89.83	2.27	42.12	2.66		4.03	140.94	33.1	0.41
05/16	5	109.80	103.42	68.56	62.24	6.32	34.86	6.38	0.40	0.27	100.56	66.7	0.61
05/27	6	133.19	130.24	89.28	84.30	5.09	40.85	2.95	1.09	0.18	148.78	29.5	0.34
06/11	7	140.44	137.22	124.04	120.15	3.89	13.19	3.22	0.96	0.36	205.02	36.9	0.50
06/25	8	147.75	143.59	120.36	111.83	8.53	23.24	4.16	0.85	0.47	164.29	52.9	0.50
07/10	9	156.40	150.09	20.78	19.40	1.38	129.31	6.31	1.60	0.10	27.87	64.2	0.77
07/22	10	141.68	138.96	20.52	19.53	0.99	118.44	2.72	4.64	0.04	7.67	28.9	0.48
08/13	11	112.83	108.29	14.74	14.51	0.23	93.55	4.54	1.35	0.09	33.27	43.8	1.01
08/27	12			16.40	16.20	0.20		2.46		0.08	34.18	28.2	0.63
09/09	13	122.16	116.35	13.65	13.23	0.42	102.71	5.81	1.39	0.08	22.23	47.9	0.82
09/24	14	113.90	110.08	16.36	16.06	0.30	93.72	3.82	1.53	0.04	33.62	25.3	0.32
10/07	15			10.25	10.07	0.17		2.90		0.04	16.88	24.0	0.39
10/28	16	56.14	47.98	1.93	1.92	0.01	46.06	8.16	0.92	0.03	14.23	67.5	2.60
11/24	17	106.90	103.92	15.95	15.69	0.26	87.98	2.98	0.51	0.04	28.80	30.2	0.28
12/16	18	103.36	100.71	18.08	17.68	0.40	82.63	2.65	0.40	0.03	39.79	27.1	0.36
Mean		127.36	122.26	49.73	47.09	2.65	67.97	4.83	1.28	0.68	76.77	50.67	0.64
SE		8.26	8.28	10.18	9.62	0.67	8.95	0.55	0.30	0.33	15.08	6.78	0.14

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Table A.13 Nutrient concentrations at the Waters River water chemistry station, May-December 1997.

Date	Sample Period	TN (uM)	TDN (uM)	DIN (uM)	N+N (uM)	NH_4 (uM)	DON (uM)	PON (uM)	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)
05/16	5	199.29	194.72	140.54	134.76	5.78	54.18	4.57	0.36	0.16	137.79	62.2
05/27	6	202.10	200.26	172.55	166.97	5.59	27.71	1.84	0.29	0.13	178.95	23.2
06/11	7	231.97	229.11	130.35	128.33	2.02	98.76	2.86	1.62	0.07	157.97	31.9
06/25	8	173.13	169.84	197.56	202.54	10.39	19.71	3.29	0.58	0.11	137.67	45.0
07/10	9	243.16	238.47	37.61	34.73	2.88	200.88	4.69	1.37	0.06	27.08	37.5
07/22	10	244.32	240.59	38.65	35.29	2.53	201.94	3.73	1.96	0.03	16.45	47.6
08/13	11	240.60	237.59	38.06	35.95	2.11	199.53	3.01	1.17	0.06	38.30	39.0
08/27	12	235.00	233.38	38.11	37.46	0.65	195.27	1.62	1.50	0.05	40.60	20.6
09/09	13			38.34	37.80	0.53		2.11		0.03	40.53	17.8
09/24	14			39.65	38.55	1.10		1.59		0.02	39.56	17.7
10/07	15			37.50	37.01	0.49		2.50		0.04	38.07	18.6
10/28	16	250.15	247.61	35.87	35.55	0.32	211.74	2.51	0.50	0.01	36.18	28.1
11/24	17	144.72	142.02	24.82	23.73	1.10	117.20	2.70	0.29	0.03	30.32	40.0
12/16	18	161.91	157.46	36.52	35.94	0.58	120.94	4.45	0.25	0.03	42.21	64.7
Mean		211.49	208.28	71.87	70.33	2.58	131.62	2.96	0.90	0.06	68.69	35.28
SE		11.29	11.33	16.03	16.05	0.77	22.47	0.28	0.19	0.01	15.13	4.19

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Table A.14 Nutrient concentrations at the Sawmill Brook water chemistry station, May-December 1997.

Date	**Sample Period**	**TN** (uM)	**TDN** (uM)	**DIN** (uM)	**N+N** (uM)	**NH_4** (uM)	**DON** (uM)	**PON** (uM)	**TDP** (uM)	**PO_4** (uM)	**SiO_4** (uM)	**POC** (uM)
05/27	6	85.70	80.01	25.32	18.75	6.57	54.69	5.69	2.07	0.08	11.54	116.2
06/11	7	108.23	98.47	48.81	40.48	8.34	49.65	9.76	1.47	0.06	45.19	171.6
06/25	8	131.47	124.39	81.46	65.14	16.32	42.93	7.08	0.80	0.02	41.91	118.6
07/10	9	169.14	159.54	21.90	20.75	1.15	137.64	9.60	1.75	0.02	11.49	100.5
07/22	10	157.58	157.22					0.36	0.91		13.97	32.7
08/13	11	156.03	155.67	23.43	22.74	0.69	132.24	0.36	2.95	0.04	39.43	31.1
08/27	12	137.59	134.06	19.62	18.90	0.72	114.44	3.53	0.98	0.03	33.50	54.7
09/09	13	142.68	139.78	21.34	20.69	0.65	118.44	2.90	0.74	0.02	28.96	39.6
09/24	14	133.73	129.12	17.90	17.25	0.65	111.22	4.61	1.84	0.02	27.86	50.5
10/07	15	99.12	93.78	12.86	12.41	0.45	80.93	5.34	1.51	0.03	22.26	48.3
10/28	16	95.10	77.06	8.80	8.68	0.12	68.26	18.04	0.95	0.09	18.03	172.7
11/24	17	45.76	41.55	3.36	2.82	0.54	38.19	4.21	0.23	0.01	1.86	56.0
12/16	18	40.92	37.97	3.38	2.62	0.76	34.58	2.95	0.61	0.01	3.00	38.8
Mean		115.62	109.89	24.02	20.94	3.08	81.93	5.73	1.29	0.04	23.00	79.33
SE		11.37	11.62	6.27	4.96	1.43	11.19	1.31	0.20	0.01	4.01	14.15

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Table A.15 Nutrient concentrations at the Bass River, Forest River and South River water chemistry stations, May-December 1997.

Station	Date	Sample Period	TN (uM)	TDN (uM)	DIN (uM)	N+N (uM)	NH_4 (uM)	DON (uM)	PON (uM)	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)
BR	05/16	5	69.76	56.22	15.36	11.60	3.76	40.86	13.54	0.09	0.06	0.00	125.8
BR	05/27	6	63.17	42.02	4.86	3.09	1.77	37.16	21.15	0.90	0.04	6.64	169.2
BR	06/11	7	71.02	63.67	4.86	1.40	3.46	58.81	7.35	0.90	0.11	9.02	68.7
BR	06/25	8	57.46	49.69	7.82	2.72	5.10	41.88	7.77	0.18	0.06	22.80	82.3
BR	07/10	9	65.81	55.35	1.55	1.21	0.34	53.80	10.46	0.57	0.01	5.01	138.2
BR	11/24	17	100.50	58.88	4.30	4.30	0.00	54.57	41.62	0.54	0.02	14.27	307.6
BR	12/16	18	81.18	52.83	5.31	5.31	0.00	47.52	28.35	0.45	0.03	21.38	196.9
Mean			72.70	54.10	6.30	4.23	2.06	47.80	18.61	0.52	0.05	11.30	155.53
FR	05/16	5	61.32	55.81	5.63	1.29	4.34	50.18	5.51	0.26	0.06	32.05	67.2
FR	05/27	6	61.92	54.67	6.24	1.16	5.08	48.43	7.25	0.54	0.10	33.41	101.2
FR	06/11	7	125.41	93.95	12.05	7.67	4.38	81.90	31.46	0.89	0.17	57.86	498.9
FR	06/25	8	91.31	66.94	23.41	17.30	6.11	43.52	24.37	0.59	0.21	165.25	380.3
FR	11/24	17	50.91	46.15	1.65	1.07	0.57	44.51	4.79	0.51	0.02	27.19	48.6
FR	12/16	18	32.43	28.52	0.99	0.76	0.23	27.53	3.91	0.30	0.03	28.25	40.1
Mean			70.55	57.67	8.33	4.87	3.45	49.34	12.88	0.51	0.10	57.34	189.38
SR	05/27	6	84.45	70.13	22.26	7.73	14.53	47.87	14.32	0.44	0.13	80.35	177.6
SR	06/11	7	98.08	85.40	12.20	0.89	11.31	73.20	12.68	2.32	0.24	114.09	129.8
SR	10/28	16	77.86	59.88	4.61	2.32	2.29	55.27	17.98	1.02	0.06	34.96	162.3
SR	11/24	17	77.30	74.05	9.97	8.82	1.15	64.08	3.25	0.38	0.05	29.52	33.9
SR	12/16	18	88.16	82.82	12.82	9.34	3.47	70.00	5.34	0.52	0.04	39.96	71.9
Mean			85.17	74.46	12.37	5.82	6.55	62.08	10.71	0.94	0.10	59.78	115.10

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Table A.16 Surface nutrient concentrations at the Beverly Harbor water chemistry station, January-December 1997.

Date	Sample Period	TN (uM)	TDN (uM)	DIN (uM)	N+N (uM)	NH_4 (uM)	DON (uM)	PON (uM)	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)	Chl *a* (ug/l)
01/29	1	20.01	18.41	10.97	8.70	2.27	7.44	1.60	0.92	1.05	8.89	17.2	
02/19	2	28.16	15.63	6.84	5.53	1.31	8.16	12.53	0.51	0.68	4.15	118.7	
03/25	3	16.87	14.87	6.82	3.73	3.09	8.05	2.00	0.67	0.67	3.98	15.5	0.16
04/16	4	17.14	13.20	4.81	3.12	1.69	8.40	3.94	0.50	0.49	5.13	35.4	0.05
05/15	5	14.47	9.73	1.67	0.93	0.73	8.06	4.74	0.34	0.40	2.60	37.0	0.08
05/28	6	17.09	9.47	1.40	0.94	0.46	8.07	7.62		0.37	0.98	45.3	0.10
06/10	7	14.70	10.05	0.34	0.10	0.24	9.70	4.65	0.21	0.23	0.25	38.8	0.56
06/24	8	18.21	13.32	0.82	0.30	0.52	12.50	4.89	0.56	0.50	3.81	31.7	0.87
07/09	9	13.98	7.95	0.73	0.26	0.47	7.21	6.03	0.42	0.36	4.87	40.8	1.56
07/23	10	19.40	15.28	6.80	0.10	6.70	8.47	4.12	0.50	0.47	3.76	32.0	0.36
08/14	11	20.15	12.11	2.13	0.54	1.59	9.98	8.04	0.60	0.65	3.12	60.0	2.95
08/28	12	22.21	15.45	5.13	1.24	3.90	10.32	6.76	0.60	0.60	4.37	47.6	3.21
09/08	13	18.84	11.30	0.18	0.20	0.00	11.12	7.54	0.35	0.30	3.06	52.8	2.17
09/25	14	18.64	15.13	6.73	3.07	3.66	8.39	3.51	0.73	0.81	7.35	26.6	0.50
10/08	15	23.46	15.97	5.68	1.85	3.83	10.29	7.49	0.62	0.65	2.24	62.3	2.31
10/29	16	27.21	24.25	8.95	2.79	6.16	15.29	2.96	0.89	0.88	5.84	26.3	0.89
11/25	17	32.68	29.90	11.71	6.41	5.31	18.20	2.78	1.09	0.91	10.39	20.3	0.57
12/17	18	23.79	19.10	9.02	6.81	2.21	10.08	4.69	1.08	0.99	7.99	35.8	1.16
Mean		20.39	15.06	5.04	2.59	2.45	9.99	5.33	0.62	0.61	4.60	41.34	1.09
SE		1.19	1.28	0.88	0.63	0.49	0.68	0.63	0.06	0.06	0.63	5.53	0.26

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Table A.17 Bottom nutrient concentrations at the Beverly Harbor water chemistry station, January-December 1997.

Date	Sample Period	TN (uM)	TDN (uM)	DIN (uM)	N+N (uM)	NH_4 (uM)	DON (uM)	PON (uM)	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)	Chl a (ug/l)
01/29	1												
02/19	2	20.33	16.03	6.99	5.55	1.44	9.05	4.30	0.59	0.64	4.77	49.1	
03/25	3	17.31	15.14	6.31	3.62	2.69	8.82	2.17	0.62	0.69	4.00	22.3	0.13
04/16	4												0.15
05/15	5												
05/28	6	15.47	7.69	0.67	0.38	0.29	7.02	7.78	0.18	0.25	0.26	51.1	0.09
06/10	7	14.88	7.48	0.43	0.17	0.26	7.06	7.40	0.24	0.26	0.40	56.8	1.20
06/24	8	29.09	19.90	1.47	0.79	0.68	18.43	9.19	0.68	0.60	3.74	72.3	0.50
07/09	9	16.20	9.79	0.62	0.19	0.42	9.17	6.41	0.47	0.35	4.14	45.5	1.04
07/23	10	14.65	9.49	1.69	0.14	1.55	7.80	5.16	0.39	0.31	3.68	41.1	1.47
08/14	11	25.71	15.70	2.50	0.46	2.03	13.20	10.01	0.45	0.53	3.93	72.6	3.44
08/28	12	24.60	16.71	5.44	0.90	4.54	11.27	7.89	0.55	0.63	6.45	66.4	1.01
09/08	13	18.72	9.97	1.71	0.33	1.38	8.26	8.75	0.42	0.26	3.49	57.1	2.66
09/25	14	18.82	12.67	5.02	3.01	2.01	7.65	6.15	0.60	0.73	6.53	45.6	0.77
10/08	15	19.62	11.20	2.53	1.31	1.21	8.67	8.42	0.47	0.57	1.70	64.6	2.67
10/29	16	28.78	24.36	8.58	2.76	5.82	15.78	4.42	0.86	0.89	5.88	37.5	0.82
11/25	17	26.09	21.03	8.21	5.72	2.49	12.82	5.06	0.57	0.92	8.97	37.9	0.82
12/17	18	23.43	19.75	10.29	7.93	2.35	9.46	3.68	1.05	1.24	7.70	25.3	1.01
Mean		20.91	14.46	4.16	2.22	1.95	10.30	6.45	0.54	0.59	4.38	49.68	1.19
SE		1.29	1.35	0.85	0.64	0.40	0.87	0.59	0.06	0.07	0.64	4.02	0.26

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Table A.18 Surface nutrient concentrations at the Haste Outfall water chemistry station, January-December 1997.

Date	Sample Period	TN (uM)	TDN (uM)	DIN (uM)	N+N (uM)	NH_4 (uM)	DON (uM)	PON (uM)	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)	Chl *a* (ug/l)
01/29	1	52.08	47.73	31.39	11.31	20.07	16.35	4.35	2.09	2.18	12.18	48.2	
02/19	2	159.08	155.80	5.58	4.85	0.73	150.22	3.28	5.30	0.60	3.85	24.3	
03/25	3	49.22	44.11	23.75	3.95	19.79	20.37	5.11	1.64	1.66	5.90	52.2	0.10
04/16	4	74.97	65.48	37.14	6.63	30.51	28.33	9.49	2.69	2.56	13.01	82.1	0.05
05/15	5	41.45	32.76	17.81	0.20	17.62	14.95	8.69	1.00	1.14	3.61	81.7	0.28
05/28	6	15.18	8.73	0.76	0.38	0.38	7.98	6.45	0.16	0.20	0.42	40.8	0.27
06/10	7	91.75	78.46	53.99	0.29	53.70	24.48	13.29	2.84	2.95	6.54	182.3	0.88
06/24	8	17.64	13.57	0.77	0.41	0.37	12.80	4.07	0.56	0.60	4.68	27.1	0.29
07/09	9	32.14	25.06	12.56	0.37	12.20	12.49	7.08	1.07	1.12	5.71	53.0	1.05
07/23	10	11.44	7.94	1.42	0.20	1.22	6.52	3.50	0.23	0.20	3.19	22.0	0.54
08/14	11	20.27	11.50	0.91	0.11	0.80	10.59	8.77	0.30	0.17	1.05	70.4	
08/28	12	54.48	39.65	23.02	0.16	22.86	16.64	14.83	1.38	1.07	4.50	101.1	1.91
09/08	13	18.86	12.40	0.62	0.14	0.48	11.78	6.46	0.32	0.42	2.75	45.9	2.74
09/25	14	54.51	43.94	28.98	2.19	26.80	14.96	10.57	2.38	2.64	7.55	85.5	0.61
10/08	15	95.46	80.78	60.48	1.95	58.53	20.31	14.68	2.78	2.91	10.73	130.4	2.14
10/29	16	25.21	21.29	8.99	2.43	6.56	12.30	3.92	0.81	0.92	5.55	29.9	1.08
11/25	17	110.44	96.61	52.41	6.78	45.63	44.20	13.83	4.30	2.73	15.74	103.2	0.59
12/17	18	60.47	53.57	54.46	9.97	44.49	-0.90	6.90	2.59	3.43	9.70	59.1	0.76
Mean		54.70	46.63	23.06	2.91	20.15	23.58	8.07	1.80	1.53	6.48	68.84	0.89
SE		9.28	9.00	4.98	0.85	4.62	7.79	0.93	0.34	0.26	1.00	9.78	0.21

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Table A.19 Bottom nutrient concentrations at the Haste Outfall water chemistry station, January-December 1997.

Date	Sample Period	TN (uM)	TDN (uM)	DIN (uM)	N+N (uM)	NH_4 (uM)	DON (uM)	PON (uM)	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)	Chl *a* (ug/l)
01/29	1												
02/19	2	19.41	15.31	7.17	5.61	1.56	8.14	4.10	0.62	0.74	4.54	41.3	
03/25	3	21.44	19.10	6.18	3.28	2.90	12.92	2.34	0.70	0.71	3.12	18.9	0.17
04/16	4	19.01	13.44	3.61	1.88	1.74	9.83	5.57	0.54	0.60	3.10	48.1	0.11
05/15	5												
05/28	6	16.72	8.89	0.86	0.31	0.55	8.03	7.83	0.19	0.27	0.30	48.7	0.19
06/10	7	12.75	8.92	1.28	0.25	1.03	7.64	3.83	0.26	0.39	0.99	43.2	1.11
06/24	8	23.68	18.26	1.71	0.99	0.72	16.55	5.42	0.67	0.65	3.53	50.5	0.79
07/09	9	22.90	16.01	2.97	0.26	2.71	13.05	6.89	1.41	0.46	4.27	44.6	1.03
07/23	10	14.41	9.56	0.85	0.24	0.61	8.72	4.85	0.42	0.39	4.14	34.7	0.93
08/14	11	23.12	18.82	2.71	1.19	1.52	16.11	4.30	0.59	0.59	5.44	33.1	3.67
08/28	12	15.59	11.80	2.53	0.57	1.96	9.26	3.79	0.39	0.48	3.80	29.0	0.97
09/08	13	15.35	10.18	3.24	0.49	2.75	6.95	5.17	0.43	0.39	5.51	32.9	1.22
09/25	14	21.16	14.34	5.67	2.53	3.14	8.67	6.82	0.67	0.70	6.04	40.2	0.84
10/08	15	17.94	13.42	7.72	3.94	3.78	5.70	4.52	0.76	0.87	4.70	35.9	1.65
10/29	16	28.93	23.39	9.44	2.65	6.79	13.95	5.54	0.49	0.97	6.33	44.6	1.25
11/25	17	21.04	17.94	8.99	6.34	2.66	8.95	3.10	0.49	1.08	9.13	20.6	0.65
12/17	18	22.29	18.47	7.77	6.17	1.60	10.70	3.82	0.56	0.85	7.40	25.3	0.88
Mean		19.73	14.87	4.54	2.29	2.25	10.32	4.87	0.57	0.63	4.52	36.98	1.03
SE		1.04	1.07	0.75	0.55	0.39	0.81	0.36	0.07	0.06	0.55	2.47	0.22

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Table A.20 Surface nutrient concentrations at the Salem Harbor water chemistry station, January-December 1997.

Date	Sample Period	TN (uM)	TDN (uM)	DIN (uM)	N+N (uM)	NH_4 (uM)	DON (uM)	PON (uM)	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)	Chl *a* (ug/l)
01/29	1	208.08	202.18	13.53	7.44	6.09	188.65	5.90		2.16	8.22	90.6	
02/19	2	13.89	10.75	4.24	3.62	0.61	6.51	3.14	0.37	0.57	3.03	23.7	
03/25	3	17.96	15.79	5.19	2.81	2.39	10.60	2.17	0.67	0.61	3.25	16.1	0.45
04/16	4	105.17	102.07	0.84	0.19	0.65	101.23	3.10		0.27	1.46	34.1	0.06
05/15	5	13.09	8.34	0.39	0.17	0.22	7.94	4.75	0.23	0.37	1.94	42.1	0.16
05/28	6	16.79	8.67	0.44	0.19	0.24	8.24	8.12	0.20	0.16	0.16	62.9	0.14
06/10	7	17.60	10.50	0.60	0.29	0.31	9.89	7.10	0.41	0.38	0.41	46.5	1.09
06/24	8	22.41	15.88	0.35	0.16	0.20	15.53	6.53	0.55	0.47	4.36	45.8	0.40
07/09	9	15.67	8.73	0.33	0.03	0.30	8.40	6.94	0.43	0.36	4.94	44.7	1.45
07/23	10	20.17	10.29	0.56	0.10	0.47	9.73	9.88	0.45	0.30	3.60	65.3	3.56
08/14	11	22.39	12.43	0.39	0.08	0.31	12.04	9.96	0.40	0.24	2.66	84.8	2.98
08/28	12	21.70	9.32	0.57	0.17	0.39	8.76	12.38	0.31	0.22	2.36	100.5	
09/08	13	25.16	14.01	0.48	0.11	0.36	13.53	11.15	0.27	0.17	1.88	66.6	3.28
09/25	14	21.98	16.99	7.23	3.69	3.54	9.77	4.99	0.56	0.84	8.08	37.2	0.91
10/08	15	20.64	14.49	6.97	4.65	2.33	7.52	6.15	0.68	0.79	6.89	38.6	1.45
10/29	16	31.66	27.60	8.67	2.38	6.28	18.93	4.06	0.79	0.89	5.63	25.7	1.06
11/25	17	26.25	23.01	11.33	5.49	5.83	11.68	3.24	0.93	0.88	9.46	22.7	0.75
12/17	18			8.87	6.22	2.65		4.27		0.88	7.75	30.9	0.93
Mean		36.51	30.06	3.94	2.10	1.84	26.41	6.32	0.48	0.59	4.23	48.82	1.24
SE		11.87	12.01	1.04	0.59	0.52	11.48	0.70	0.05	0.11	0.67	5.79	0.29

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Table A.21 Bottom nutrient concentrations at the Salem Harbor water chemistry station, January-December 1997.

Date	Sample Period	TN (uM)	TDN (uM)	DIN (uM)	N+N (uM)	NH_4 (uM)	DON (uM)	PON (uM)	TDP (uM)	PO_4 (uM)	SiO_4 (uM)	POC (uM)	Chl *a* (ug/l)
01/29	1												
02/19	2	19.92	13.99	5.65	4.63	1.02	8.35	5.93	0.50	0.70	3.10	42.3	
03/25	3	149.03	144.39	5.41	2.84	2.57	138.99	4.64		0.60	3.24	40.9	0.18
04/16	4	19.50	10.37	0.76	0.23	0.52	9.62	9.13	0.43	0.31	1.89	71.6	0.07
05/15	5												
05/28	6	22.74	10.25	0.81	0.25	0.56	9.45	12.49	0.37	0.37	0.43	82.7	2.02
06/10	7	25.74	13.32	1.31	0.28	1.03	12.02	12.42	0.44	0.39	1.16	87.2	1.98
06/24	8	31.13	22.43	1.44	0.81	0.63	20.99	8.70	0.63	0.60	4.11	60.6	0.33
07/09	9	14.91	8.21	0.76	0.14	0.63	7.45	6.70	0.46	0.47	4.45	52.3	1.26
07/23	10	18.95	9.76	0.83	0.17	0.66	8.93	9.19	0.48	0.37	4.23	57.4	5.51
08/14	11	24.13	12.71	3.24	0.35	2.89	9.47	11.42	0.57	0.56	5.70	87.4	2.18
08/28	12	24.06	14.45	6.06	0.93	5.14	8.38	9.61	0.69	0.68	6.71	79.4	
09/08	13	28.90	15.37	3.63	0.67	2.96	11.74	13.53	0.69	0.61	7.10	95.5	2.55
09/25	14	22.55	13.43	5.51	3.65	1.86	7.92	9.12	0.66	0.81	6.98	74.5	0.64
10/08	15	19.91	13.51	4.46	2.63	1.83	9.06	6.40	0.60	0.61	3.29	44.9	2.26
10/29	16	30.54	20.93	8.55	2.47	6.08	12.38	9.61	0.71	0.94	6.00	83.0	1.16
11/25	17	22.03	18.56	10.19	6.32	3.87	8.37	3.47	0.70	1.13	8.63	24.9	0.73
12/17	18	22.00	15.60	11.20	7.82	3.38	4.40	6.40	0.53	1.23	7.59	51.0	1.74
Mean		31.00	22.33	4.36	2.14	2.23	17.97	8.67	0.56	0.65	4.66	64.73	1.62
SE		7.94	8.19	0.86	0.60	0.43	8.12	0.73	0.03	0.07	0.60	5.18	0.37

APPENDIX

Table A.22 Summary statistics for nutrient concentrations at MWRA offshore station #NO4 during 1995-1997. Mean values and standard error (SE) are reported for 17 sampling periods each year. Station is located 10 km southwest of Marblehead.

		TN (uM)	TDN (uM)	DIN (uM)	PON (uM)	NH_4 (uM)	N+N (uM)	PO_4 (uM)	TDP (uM)	POC (uM)	SiO_4 (uM)	Chl *a* (ug/l)
1997	surface	11.33	8.84	2.61	2.49	0.35	2.56	0.40	0.44	18.41	3.13	0.69
	(SE)	0.66	0.64	0.81	0.32	0.08	0.84	0.07	0.06	2.27	0.70	0.14
1997	bottom	15.93	14.24	7.69	1.91	0.90	6.79	0.84	0.84	14.43	7.46	0.48
	(SE)	0.68	0.62	0.53	0.32	0.23	0.59	0.04	0.05	2.55	0.71	0.14
1996	surface	14.87	10.82	1.74	3.27	0.34	1.49	0.34	0.48	24.11	3.46	1.19
	(SE)	1.16	0.90	0.60	0.40	0.06	0.63	0.06	0.07	2.66	0.81	0.29
1996	bottom	13.59	14.11	6.73	1.17	1.11	5.63	0.79	0.85	10.71	7.70	0.66
	(SE)	1.77	0.92	0.50	0.16	0.21	0.64	0.04	0.05	1.81	0.81	0.44
1995	surface	16.43	13.78	3.49	2.82	0.51	3.16	0.52	0.62	20.47	4.79	1.12
	(SE)	2.14	2.16	0.87	0.33	0.09	0.90	0.06	0.05	2.22	1.02	0.41
1995	bottom			8.39		1.28	7.11	0.95			9.81	0.24
	(SE)			0.34		0.29	0.52	0.03			0.73	0.05

Note: surface measurements are taken within 5 m of the surface and bottom are within 5 m of the bottom.

APPENDIX

Table A.23 Monthly catch at seine stations in 1997: frequency of occurrence by number of hauls each month. A total of 136 hauls were made at the six stations.

Species Name	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
(No. of hauls)	*(10)*	*(10)*	*(10)*	*(10)*	*(12)*	*(12)*	*(12)*	*(12)*	*(12)*	*(12)*	*(12)*	*(12)*
FISH												
Atlantic silverside	2		1	2	5	4	4	8	12	10	11	3
winter flounder				1	4	8	10	8	7	6	8	3
mummichog					2	3	3	6	7	2	5	
Atlantic menhaden								4	7	5	3	
grubby				2	3	3	1		3		3	
Atlantic tomcod					7	3					1	
threespine stickleback	1		1	3			1			1	1	
northern pipefish							3	1	3	1		
windowpane								2	3	1	1	
Atlantic herring					1	5				2		
Atlantic cod			3									
red hake						1			1	1		
bluefish							1		2			
rainbow smelt							1			1	2	
sand lance						2						
lumpfish							2					
bay anchovy										2		
silver anchovy										1		
fourspine stickleback		1										
striped killifish							1					
striped mullet									1			
little skate									1			
northern sea robin									1			
ARTHROPOD												
sand shrimp	8	5	8	9	12	12	12	12	11	12	11	11
green crab			1	1	9	12	11	11	12	9	5	4
hermit crab					4	11	11	9	8	7	5	2
rock crab				1		2	1		1	2		1
lady crab									3			
horseshoe crab							1					
shore shrimp									1			

APPENDIX

Table A.24 Sandy Beach seine catch: duplicate hauls made each month January - December, 1997 (N = 24).

Species	Total Catch (No.)	Frequency of Occurrence (No. of Hauls)	Presence by Month (No.)	May-Nov. Mean Density (No./100 m^2)
Fish				
Atlantic silverside	4438	15	9	120.1
winter flounder	264	12	7	7.4
mummichog	238	11	6	7.3
Atlantic menhaden	6	3	2	0.2
bluefish	13	2	2	0.3
Atlantic tomcod	2	2	1	0.1
threespine stickleback	2	2	2	0.0
Atlantic herring	390	1	1	11.5
striped mullet	204	1	1	5.9
striped killifish	6	1	1	0.2
Total fish catch	5563			
Arthropod				
sand shrimp	17877	18	10	527.3
green crab	196	12	6	5.8
hermit crab	179	9	6	5.4
shore shrimp	1	1	1	0.0
horseshoe crab	1	1	1	0.0
Total Arthropod catch	18254			

Table A.25 Obear Park seine catch: duplicate hauls made each month January-December, 1997 (N = 24).

Species	Total Catch (No.)	Frequency of Occurrence (No. of Hauls)	Presence by Month (No.)	May-Nov. Mean Density (No./100 m^2)
Fish				
Atlantic silverside	2201	9	5	67.4
mummichog	80	8	6	2.4
winter flounder	20	6	5	0.6
Atlantic menhaden	7	3	3	0.2
grubby	6	3	2	0.2
threespine stickleback	2	2	2	0.0
rainbow smelt	2	1	1	0.1
Atlantic tomcod	1	1	1	0.0
Atlantic cod	1	1	1	0.0
Atlantic herring	1	1	1	0.0
Total fish catch	2321			
Decapod				
sand shrimp	8866	21	11	244.9
green crab	250	13	7	7.4
hermit crab	108	8	4	3.3
Total Decapod catch	9224			

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Table A.26 Pioneer Village seine catch: duplicate hauls made each month January-December, 1997 (N = 24).

Species	Total Catch (No.)	Frequency of Occurrence (No. of Hauls)	Presence by Month (No.)	May-Nov. Mean Density (No./100 m^2)
Fish				
Atlantic silverside	2449	14	9	64.9
winter flounder	40	9	7	1.1
mummichog	61	5	3	1.8
Atlantic menhaden	95	4	2	2.6
northern pipefish	3	2	2	0.1
grubby	2	2	2	0.1
Atlantic cod	1	1	1	0.0
Total fish catch	2651			
Decapod				
sand shrimp	1757	23	12	48.0
green crab	251	18	10	7.2
hermit crab	145	9	5	4.7
Total Decapod catch	2153			

Table A.27 Proctor Point seine catch: duplicate hauls made each month May-December, 1997 (N = 16).

Species	Total Catch (No.)	Frequency of Occurrence (No. of Hauls)	Presence by month (No.)	May-Nov. Mean Density (No./100 m^2)
Fish				
Atlantic silverside	718	9	6	25.9
Atlantic menhaden	1396	6	4	47.1
grubby	9	6	4	0.4
winter flounder	45	5	4	1.7
Atlantic tomcod	17	5	3	0.6
mummichog	15	3	2	0.7
rainbow smelt	11	3	2	0.4
northern pipefish	3	2	1	0.1
threespine stickleback	3	2	2	0.1
lumpfish	3	2	1	0.1
bay anchovy	2	1	1	0.1
silver anchovy	1	1	1	0.0
Atlantic herring	1	1	1	0.0
red hake	1	1	1	0.0
windowpane	1	1	1	0.0
Total fish catch	2226			
Decapod				
sand shrimp	2427	15	8	76.8
green crab	85	12	7	3.1
hermit crab	194	11	7	7.8
lady crab	2	1	1	0.1
rock crab	1	1	1	0.0
Total Decapod catch	2709			

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Table A.28 West Beach seine catch: duplicate hauls made each month January-December, 1997 (N = 24).

Species	Total Catch (No.)	Frequency of Occurrence (No. of Hauls)	Presence by Month (No.)	May-Nov. Mean Density (No./100 m^2)
Fish				
Atlantic silverside	232	7	5	2.7
winter flounder	33	7	4	0.8
windowpane	5	5	4	0.1
northern pipefish	14	4	3	0.3
Atlantic herring	50	3	2	1.1
sand lance	7	2	1	0.2
Atlantic tomcod	3	2	2	0.1
red hake	3	2	2	0.1
northern sea robin	2	1	1	0.0
fourspine stickleback	1	1	1	0.0
little skate	1	1	1	0.0
Total fish catch	351			
Decapod				
sand shrimp	1497	22	11	30.3
hermit crab	19	8	6	0.4
green crab	17	6	4	0.4
rock crab	12	4	3	0.3
lady crab	29	2	1	0.6
Total Decapod catch	1574			

Table A.29 Tuck Point seine catch: duplicate hauls made each month January-December, 1997 (N = 24).

Species	Total Catch (No.)	Frequency of Occurrence (No. of Hauls)	Presence by Month (No.)	May-Nov. Mean Density (No./100 m^2)
Fish				
winter flounder	526	16	9	12.0
Atlantic silverside	218	8	6	5.5
grubby	6	4	3	0.1
Atlantic menhaden	4249	3	2	139.9
Atlantic herring	1708	2	1	43.3
threespine stickleback	6	2	1	0.0
Atlantic tomcod	6	1	1	0.1
mummichog	2	1	1	0.0
bluefish	1	1	1	0.0
Atlantic cod	1	1	1	0.0
windowpane	1	1	1	0.0
Total fish catch	6724			
Decapod				
sand shrimp	38598	24	12	866.1
green crab	117	14	7	3.0
hermit crab	270	12	8	6.7
rock crab	5	3	2	0.1
Total Decapod catch	38990			

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Table A.30 Sediment measurements at trawl stations in Salem Sound, 1997. Collected with Halltech bottom dredge (232 cm^2) and sorted with Newark standard sieves.

Location	Sample	Pebble > 32 mm	Gravel 2-32 mm	Coarse Sand 0.5-2.0 mm	Medium Sand 0.25-0.5 mm	Fine Sand 0.063-0.25 mm	Silt/ Clay < 0.063 mm	Total %
Haste Channel	HC1	0	0.0	2.9	5.1	51.7	40.3	100
Haste Channel	HC2	0	11.2	63.3	8.8	7.8	8.9	100
Haste Channel	HC3	0	0.2	3.0	4.1	56.1	36.6	100
Haste Channel	HC4	0	0.2	9.9	30.3	31.9	27.7	100
Haste Channel	HC5	0	4.9	11.9	17.7	23.6	41.9	100
Haste Channel	HC6	0	6.7	32.8	16.8	20.2	23.5	100
	Mean	0	3.9	20.6	13.8	31.9	29.8	100
Salem Harbor	SH1	0	2.3	5.1	8.0	48	36.6	100
Salem Harbor	SH2	0	1.7	5.0	8.2	52.2	32.9	100
Salem Harbor	SH3	0	1.0	1.3	2.7	58.5	36.5	100
Salem Harbor	SH4	0	0.4	0.6	3.1	65.1	30.8	100
Salem Harbor	SH5	3.3	48.4	1.0	1.9	35.8	9.6	100
Salem Harbor	SH6	0	0.1	0.6	0.8	81.4	17.1	100
	Mean	0.5	9.0	2.3	4.1	56.8	27.3	100
Lower River	LR1	0	25.0	18.0	21.2	23.9	11.9	100
Lower River	LR2	5.2	24.3	17.7	17.7	24.2	10.9	100
Lower River	LR3	0	15.4	23.8	24.2	23.0	13.6	100
Lower River	LR4	0	1.6	4.1	23.4	58.9	12.0	100
Lower River	LR5	0	4.6	12.5	28.7	43.3	10.9	100
Lower River	LR6	0	3.9	5.5	31.7	49.6	9.3	100
	Mean	0.9	12.5	13.6	24.5	37.2	11.4	100
Beverly Cove	BC1	0	50.8	40.2	0.5	0.8	7.7	100
Beverly Cove	BC2	1.4	0	3.7	54.8	31.4	8.7	100
Beverly Cove	BC3	0	6.4	66.0	13.0	10.7	3.9	100
Beverly Cove	BC4	0	4.9	21.3	45.4	21.2	7.2	100
Beverly Cove	BC5	0	51.2	15.9	11.4	13.7	7.8	100
Beverly Cove	BC6	0	18.6	22.4	37.3	7.4	14.3	100
	Mean	0.2	22.0	28.3	27.1	14.2	8.3	100
Upper River	UR1	19.2	11.1	15.6	35.5	14.1	4.5	100
Upper River	UR2	0	2.6	5.3	41.6	43.5	7.0	100
Upper River	UR3	0	4.5	4.2	40.9	43.9	6.5	100
Upper River	UR4	0	1.3	10.1	38.2	42.1	8.3	100
Upper River	UR5	0	3.5	3.6	8.5	77.5	6.9	100
Upper River	UR6	0	4.6	4.5	4.1	73.5	13.3	100
	Mean	3.2	4.6	7.2	28.1	49.1	7.8	100
Marblehead	MH1	27.4	67.3	0.9	0.7	0.7	3.0	100
Marblehead	MH2	6.7	76.8	3.7	4.1	3.0	5.7	100
Marblehead	MH3	0	45.9	30.0	5.7	5.8	12.6	100
Marblehead	MH4	13.3	61.2	13.7	4.3	1.7	5.8	100
Marblehead	MH5	5.8	62.8	6.7	8.4	7.9	8.4	100
Marblehead	MH6	7.3	0.5	56.5	12.8	1.0	21.9	100
Marblehead	MH7	3.6	4.5	51.4	14.2	10.2	16.1	100
Marblehead	MH8	3.6	5.3	25.8	34.7	21.3	9.3	100
	Mean	8.5	40.5	23.6	10.6	6.5	10.4	100

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Table A.31 Monthly fish catch by frequency of occurrence in Salem Sound trawl tows, all stations combined in 1997 (N = 168).

Species Name	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
winter flounder		3	5	9	20	18	18	18	19	20	8	7	145
skate				1	19	16	15	17	18	11	1	1	99
Atlantic cod		2	7	10	13	5	13	9	5				64
grubby	2		6	7	6	6	3	4	2	6	9	6	57
cunner			2		4	9	6	10	11	12	1	1	56
red hake					5	7	11	9	6	11	3	2	54
windowpane					7	8	7	6	11	9	4	1	53
rock gunnel			2	4	11	6	4	1	1		1		30
northern pipefish				3	3	1	2	4	6	9			28
lumpfish				1	1	5	6	5	2				20
silver hake								2	5	7	1		15
butterfish							1	1	5	4			11
sea raven					1	2	1	1	1	2		1	9
rainbow smelt					1		1	2	2	1	2		9
white hake					3	2	3						8
northern sea robin									1	7			8
ocean pout		1	1		2	2	1						7
shorthorn sculpin	1		2	1						1	1		6
longhorn sculpin				1	1	1						2	5
Atlantic silverside		1								3	1		5
Atlantic herring		1		1			1	1					4
fourspot flounder					1	1		1					3
seasnail				2	1								3
summer flounder							1		1				2
Atlantic menhaden									1	1			2
Atlantic mackerel								1		1			2
threespine stickleback				1			1						2
yellowtail flounder		1								1			2
Atlantic tomcod							2						2
Atlantic moonfish									2				2
scup										1			1
fourbeard rockling						1							1
radiated shanny											1		1
striped seasnail		1											1

Table A.32 Monthly invertebrate catch by frequency of occurrence in Salem Sound trawl tows, all stations combined in 1997 (N = 168).

Species	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
sand shrimp	2	7	10	10	20	18	16	18	16	18	10	9	154
rock crab	2	4	7	8	18	16	20	18	17	19	10	8	147
lobster				5	18	15	15	19	19	19	10	7	127
green sea urchin			3		6	9	10	6	2	8	4	3	51
green crab			2	4	5	6	6	4	5	8	5	3	48
hermit crab		2	1		2	2	8	5	11	8		1	40
spider crab				5	2		5	3	5	2	1	1	24
red shrimp						5	4	7	3	4		1	24
loligo squid						2	1	3	4	4			14
european oyster						1	3	1	1				6
sea scallop					1					1		1	3
shrimp (*Eualus sp.*)						1	1						2
quahog							1		1				2
horseshoe crab								1					1
moon snail					1								1
Greenland shrimp										1			1

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Table A.33 Danvers River trawl station catch: 36 tows (5-minute) conducted during 18 visits from January-December, 1997. Refer to Table 6.2 for species latin names.

Species	**Total Catch** (No.)	**Frequency of Occurrence** (No. of tows)	**Catch per Tow** (No.)	**Presence by Month** (No.)
Fish				
winter flounder	197	30	5.5	9
skate	59	18	1.6	6
grubby	44	16	1.2	9
cunner	34	16	0.9	8
northern pipefish	11	8	0.3	6
Atlantic silverside	37	4	1.0	3
Atlantic cod	15	4	0.4	2
northern sea robin	6	3	0.2	2
red hake	5	3	0.1	2
shorthorn sculpin	4	3	0.1	3
summer flounder	3	2	0.1	2
lumpfish	2	2	0.1	2
white hake	2	2	0.1	2
rock gunnel	1	1	0.0	1
menhaden	1	1	0.0	1
threespine stickleback	1	1	0.0	1
Total fish catch	422		11.7	
Invertebrate				
sand shrimp	12557	34	348.8	12
rock crab	244	34	6.8	12
green crab	348	32	9.7	10
lobster	125	26	3.5	9
hermit crab	49	11	1.4	6
spider crab	25	7	0.7	4
european oyster	36	6	1.0	4
loligo squid	6	4	0.2	4
green sea urchin	4	3	0.1	3
quahog	2	2	0.1	2
horseshoe crab	4	1	0.1	1
Total invertebrate catch	13400		372.2	

Table A.34 Lower Danvers River trawl station catch: 18 tows (5-minute) conducted during 18 visits from January-December, 1997. Refer to Table 6.2 for species latin names.

Species	Total Catch (No.)	Frequency of Occurrence (No. of tows)	Catch per Tow (No.)	Presence by Month (No.)
Fish				
winter flounder	70	15	3.9	9
skate	32	9	1.8	6
grubby	11	7	0.6	6
cunner	5	5	0.3	4
northern pipefish	4	4	0.2	4
red hake	5	3	0.3	2
Atlantic cod	5	2	0.3	2
shorthorn sculpin	2	1	0.1	1
Atlantic silverside	2	1	0.1	1
Northern sea robin	2	1	0.1	1
rock gunnel	1	1	0.1	1
lumpfish	1	1	0.1	1
white hake	1	1	0.1	1
summer flounder	1	1	0.1	1
Total fish catch	142		7.9	
Invertebrate				
rock crab	138	18	7.7	12
sand shrimp	7946	16	441.4	12
green crab	165	16	9.2	10
lobster	52	12	2.9	8
hermit crab	33	6	1.8	5
spider crab	3	2	0.2	2
green sea urchin	2	2	0.1	2
european oyster	1	1	0.1	1
Total invertebrate catch	8340		463.3	

Table A.35 Upper Danvers River trawl station catch: 18 tows (5-minute) conducted during 18 visits from January-December, 1997. Refer to Table 6.2 for species latin names.

Species	**Total Catch** (No.)	**Frequency of Occurrence** (No. of tows)	**Catch per Tow** (No.)	**Presence by Month** (No.)
Fish				
winter flounder	127	15	7.1	9
cunner	29	11	1.6	8
grubby	33	9	1.8	8
skate	27	9	1.5	6
northern pipefish	7	4	0.4	4
Atlantic silverside	35	3	1.9	3
Atlantic cod	10	2	0.6	2
shorthorn sculpin	2	2	0.1	2
Northern sea robin	4	2	0.2	2
summer flounder	2	1	0.1	1
white hake	1	1	0.1	1
lumpfish	1	1	0.1	1
menhaden	1	1	0.1	1
threespine stickleback	1	1	0.1	1
Total fish catch	280		15.6	
Invertebrate				
sand shrimp	4611	18	256.2	12
rock crab	106	16	5.9	12
green crab	183	16	10.2	10
lobster	73	14	4.1	9
european oyster	35	5	1.9	4
spider crab	22	5	1.2	4
hermit crab	16	5	0.9	3
loligo squid	6	4	0.3	4
quahog	2	2	0.1	2
horseshoe crab	4	1	0.2	2
green sea urchin	2	1	0.1	1
Total invertebrate catch	5060		281.1	

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Table A.36 Beverly Cove trawl station catch: 34 tows (5-minute) conducted during 17 visits from February-December, 1997. Refer to Table 6.2 for species latin names.

Species	**Total Catch** (No.)	**Frequency of Occurrence** (No. of tows)	**Catch per Tow** (No.)	**Presence by Month** (No.)
Fish				
winter flounder	68	27	2.0	11
skate	65	19	1.9	6
cunner	240	16	7.1	6
grubby	44	15	1.3	8
Atlantic cod	44	15	1.3	7
red hake	51	12	1.5	6
northern pipefish	71	11	2.1	4
rock gunnel	31	11	0.9	5
lumpfish	16	7	0.5	4
windowpane	7	6	0.2	4
white hake	11	4	0.3	2
Atlantic tomcod	3	2	0.1	1
butterfish	1	1	0.0	1
Atlantic mackerel	1	1	0.0	1
shorthorn sculpin	1	1	0.0	1
yellowtail flounder	1	1	0.0	1
threespine stickleback	1	1	0.0	1
Total fish catch	656		19.3	
Invertebrate				
sand shrimp	7152	33	210.4	11
rock crab	556	31	16.4	10
lobster	1043	27	30.7	8
hermit crab	42	13	1.2	6
green sea urchin	22	8	0.6	6
green crab	4	3	0.1	3
spider crab	3	3	0.1	3
loligo squid	8	2	0.2	2
red shrimp	2	1	0.1	1
Total invertebrate catch	8832		259.8	

Table A.37 Marblehead Harbor trawl station catch: 31 tows (5-minute) conducted during 16 visits from March-December, 1997. Refer to Table 6.2 for species latin names.

Species	Total Catch (No.)	Frequency of Occurrence (No. of tows)	Catch per Tow (No.)	Presence by Month (No.)
Fish				
winter flounder	98	26	3.2	9
Atlantic cod	71	19	2.3	7
skate	45	16	1.5	7
cunner	22	10	0.7	5
grubby	21	10	0.7	8
sea raven	12	8	0.4	7
rock gunnel	8	7	0.3	5
red hake	7	7	0.2	4
longhorn sculpin	4	4	0.1	3
lumpfish	5	3	0.2	2
windowpane	4	3	0.1	3
ocean pout	3	3	0.1	3
silver hake	3	2	0.1	2
northern pipefish	2	2	0.1	2
shorthorn sculpin	2	2	0.1	2
butterfish	2	1	0.1	1
seasnail	1	1	0.0	1
yellowtail flounder	1	1	0.0	1
Total fish catch	311		10.0	
Invertebrate				
lobster	539	27	17.4	9
sand shrimp	192	24	6.2	10
rock crab	46	18	1.5	7
green sea urchin	49	9	1.6	6
spider crab	14	7	0.5	5
red shrimp	25	5	0.8	2
hermit crab	7	4	0.2	2
sea scallop	5	3	0.2	3
loligo squid	4	1	0.1	1
Total invertebrate catch	881		28.4	

Table A.38 Haste Channel trawl station catch: 34 tows (5-minute) conducted during 17 visits from February-December, 1997. Refer to Table 6.2 for species latin names.

Species	Total Catch (No.)	Frequency of Occurrence (No. of tows)	Catch per Tow (No.)	Presence by Month (No.)
Fish				
winter flounder	256	31	7.5	10
skate	181	23	5.3	7
windowpane	73	22	2.1	6
red hake	28	17	0.8	8
Atlantic cod	112	15	3.3	6
silver hake	44	9	1.3	4
grubby	8	7	0.2	6
cunner	19	6	0.6	3
rock gunnel	7	6	0.2	6
lumpfish	9	4	0.3	3
ocean pout	3	3	0.1	2
seasnail	4	2	0.1	2
northern pipefish	3	2	0.1	1
rainbow smelt	2	2	0.1	2
white hake	3	1	0.1	1
northern sea robin	2	1	0.1	1
fourspot flounder	1	1	0.0	1
sea raven	1	1	0.0	1
Atlantic mackerel	1	1	0.0	1
longhorn sculpin	1	1	0.0	1
Total fish catch	758		22.3	
Invertebrate				
rock crab	281	33	8.3	11
sand shrimp	2662	32	78.3	11
lobster	174	24	5.1	9
green sea urchin	33	12	1.0	6
red shrimp	37	7	1.1	5
hermit crab	9	5	0.3	5
green crab	4	3	0.1	3
spider crab	4	3	0.1	2
loligo squid	30	3	0.9	2
Greenland shrimp	1	1	0.0	1
shrimp (*Eualus sp.*)	1	1	0.0	1
Total invertebrate catch	3236		95.2	

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Table A.39 Salem Harbor trawl station catch: 33 tows (5-minute) conducted during 17 visits from February-December, 1997. Refer to Table 6.2 for species latin names.

Species	Total Catch (No.)	Frequency of Occurrence (No. of tows)	Catch per Tow (No.)	Presence by Month (No.)
Fish				
winter flounder	451	31	13.7	11
skate	293	23	8.9	7
windowpane	70	22	2.1	8
red hake	35	15	1.1	8
Atlantic cod	123	11	3.7	6
butterfish	87	9	2.6	3
grubby	25	9	0.8	7
cunner	25	8	0.8	6
rainbow smelt	23	7	0.7	5
rock gunnel	8	5	0.2	3
northern pipefish	5	5	0.2	4
Atlantic herring	20	4	0.6	4
silver hake	19	4	0.6	1
northern sea robin	12	4	0.4	1
lumpfish	4	4	0.1	3
fourspot flounder	3	2	0.1	2
Atlantic moonfish	2	2	0.1	1
scup	3	1	0.1	1
menhaden	2	1	0.1	1
white hake	2	1	0.1	1
radiated shanny	1	1	0.0	1
fourbeard rockling	1	1	0.0	1
striped seasnail	1	1	0.0	1
ocean pout	1	1	0.0	1
Atlantic silverside	1	1	0.0	1
Total fish catch	1217		36.9	
Invertebrate				
sand shrimp	5377	31	162.9	11
rock crab	232	31	7.0	11
lobster	102	23	3.1	9
green sea urchin	49	19	1.5	8
red shrimp	23	11	0.7	6
green crab	34	10	1.0	7
hermit crab	9	7	0.3	4
loligo squid	6	4	0.2	4
spider crab	4	4	0.1	3
shrimp (*Eualus sp.*)	1	1	0.0	1
moon snail	1	1	0.0	1
Total invertebrate catch	5838		176.9	

APPENDIX

Table A.40 Summary statistics for winter flounder lengths (TL, mm) from five trawl stations, 1997.

SALEM HARBOR

	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
N	2	16	29	40	38	59	154	84	32
Mean	180	239	149	115	155	178	100	50	48
SE	110.5	27.04	16.84	20.06	13.49	7.31	2.84	1.34	1.96
Min.	69	94	24	11	17	43	36	31	37
Max.	290	405	380	497	391	302	264	97	85

HASTE CHANNEL

	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
N	2	18	30	27	38	52	67	18	3
Mean	109	173	160	161	112	146	116	74	67
SE	12.00	26.26	13.96	23.37	12.09	6.02	5.60	5.61	24.50
Min.	97	31	83	13	16	60	46	51	42
Max.	121	400	345	411	295	234	343	142	116

BEVERLY COVE

	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
N	13	12	7	5	5	8	10	2	1
Mean	101	128	230	121	157	142	97	52	355
SE	19.21	16.85	40.71	65.19	42.87	37.00	22.30	3.00	
Min.	47	57	73	20	48	32	43	49	
Max.	300	257	335	379	303	321	267	55	

DANVERS RIVER

	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
N	2	10	11	21	33	11	33	32	44
Mean	207	231	301	168	198	148	69	60	47
SE	153.0	43.84	29.73	25.10	17.11	32.59	5.14	2.72	1.23
Min.	54	60	94	28	39	35	34	36	35
Max.	360	421	385	350	437	368	165	94	78

MARBLEHEAD HARBOR

	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
N	**15**	10	9	11	7	14	26	4	0
Mean	**151**	203	263	169	263	191	146	127	
SE	**21.91**	26.87	29.73	29.32	38.22	25.68	9.47	10.82	
Min.	**60**	118	98	75	89	39	57	95	
Max.	**333**	364	348	337	351	332	251	141	

APPENDIX

Table A.41 Summary statistics for skate lengths (TL, mm) from five trawl stations, 1997.

SALEM HARBOR

	May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*
N	25	53	78	73	56	4
Mean	492	459	472	489	468	447
SE	10.14	9.33	6.97	6.66	9.82	78.78
Min.	392	276	275	291	295	211
Max.	584	550	562	568	662	532

HASTE CHANNEL

	May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*
N	14	13	52	29	50	20
Mean	424	415	437	430	436	369
SE	18.33	24.35	10.01	17.70	14.63	25.10
Min.	325	290	256	142	130	200
Max.	552	540	585	555	575	556

BEVERLY COVE

	May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*
	18	4	8	8	21	1
Mean	409	455	499	442	467	406
SE	19.47	26.78	14.35	19.59	12.91	
Min.	279	405	414	339	350	
Max.	566	523	544	503	555	

DANVERS RIVER

	May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*
N	7	15	11	6	7	12
Mean	495	421	488	507	520	503
SE	20.34	41.90	14.66	6.58	5.91	7.15
Min.	423	109	410	479	495	448
Max.	554	557	594	526	535	540

MARBLEHEAD HARBOR

	May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*
N	7	4	6	3	9	15
Mean	407	371	389	504	517	408
SE	39.35	22.14	39.61	25.89	14.31	37.67
Min.	275	320	278	465	445	149
Max.	510	412	524	553	567	550

APPENDIX

Table A.42 Summary statistics for lobster carapace lengths (TL, mm) from trawl stations, 1997.

SALEM HARBOR

	May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*
N	23	25	4	5	9	21	19
Mean	51	49	45	54	55	50	45
SE	2.23	2.50	3.54	5.55	5.51	2.47	3.49
Min.	32	27	39	41	36	35	27
Max.	71	78	55	67	92	67	76

HASTE CHANNEL

	May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*
N	3	34	4	51	31	38	10
Mean	45	56	48	56	56	53	53
SE	2.74	1.94	7.82	1.56	2.30	1.72	2.54
Min.	41	34	29	33	28	32	39
Max.	50	78	63	83	77	72	65

BEVERLY COVE

	May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*
N	26	50	34	193	212	184	10
Mean	48	51	56	50	50	52	49
SE	2.32	1.21	2.03	0.76	0.67	0.72	3.58
Min.	23	32	32	25	26	31	39
Max.	69	67	87	81	82	84	74

DANVERS RIVER

	May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*
N	19	6	9	44	14	19	4
Mean	48	50	50	53	48	51	47
SE	2.45	8.60	4.44	1.43	3.62	3.01	3.75
Min.	30	22	28	37	11	31	37
Max.	68	78	72	79	69	71	55

MARBLEHEAD HARBOR

	May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*
N	13	69	73	102	194	62	22
Mean	61	64	64	58	62	59	61
SE	3.39	1.31	1.29	0.97	0.79	1.30	1.75
Min.	35	42	35	36	36	35	44
Max.	77	88	86	80	95	87	79

APPENDIX

Table A.43 Summary statistics for Atlantic cod lengths (TL, mm), all trawl stations combined, 1997. None were caught during January, and October-December.

	Feb.	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*
N	3	28	124	19	9	81	34	16
Mean	33	31	40	54	53	30	38	54
SE	0.67	0.82	0.58	2.93	4.21	1.67	2.03	5.54
Min.	32	26	25	38	41	16	24	28
Max.	34	45	62	75	83	106	74	93

Table A.44 Summary statistics for windowpane flounder lengths (TL, mm), all trawl stations combined, 1997. None were caught prior to May.

	May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*
N	9	17	36	17	35	33	5
Mean	260	226	258	119	209	88	94
SE	14.59	14.69	9.31	21.72	14.46	2.52	12.98
Min.	168	116	24	22	51	46	44
Max.	320	320	342	284	312	117	114

APPENDIX

Table A.45 Skate (*Raja sp*.) stomach contents collected at Salem Harbor trawl station in 1997 (N = 192, of which 169 contained prey).

Prey	Number of Occurrences	Percent Occurrence	Prey Weight (g)	Percent of Total Wt.
tubed amphipod	118	69.8	298.88	36.1
sea worm (*Nereis sp*.)	103	60.9	263.24	31.8
sand shrimp	71	42.0	70.92	8.6
rock crab	36	21.3	84.85	10.3
unidentified mollusc	11	6.5	9.84	1.2
scud	8	4.7	2.61	0.3
green crab	7	4.1	12.88	1.6
unidentified fish	5	3.0	25.77	3.1
hermit crab	5	3.0	3.28	0.4
mysid shrimp	3	1.8	0.80	0.1
lobster	3	1.8	50.64	6.1
hake (*Urophycis sp*.)	1	0.6	2.47	0.3
winter flounder	1	0.6	0.95	0.1
sum			827.13	

Table A.46 Skate (*Raja sp*.) stomach contents collected at Marblehead Harbor trawl station in 1997 (N = 34, of which 24 contain prey).

Prey	Number of Occurrences	Percent Occurrence	Prey Weight (g)	Percent of Total Wt.
rock crab	14	58.3	71.78	57.3
sea worm (*Nereis sp*.)	10	41.7	24.89	19.9
unidentified fish	4	16.7	16.14	12.9
sand shrimp	4	16.7	4.20	3.4
unidentified decapod	2	8.3	1.62	1.3
hake (*Urophycis sp*.)	1	4.2	2.98	2.4
lobster	1	4.2	2.14	1.7
tubed amphipod	1	4.2	0.21	0.2
unidentified mollusc	1	4.2	1.25	1.0
sum			125.21	

APPENDIX

Table A.47 Skate (*Raja sp.*) stomach contents collected at Haste Channel trawl station in 1997 (N = 100, of which 89 contained prey).

Prey	Number of Occurrences	Percent Occurrence	Prey Weight (g)	Percent of Total Wt.
tubed amphipod	55	61.8	96.25	29.1
sand shrimp	55	61.8	60.49	18.3
rock crab	45	50.6	66.20	20.0
sea worm (*Nereis sp.*)	23	25.8	60.10	18.2
unidentified fish	8	9.0	14.89	4.5
scud	6	6.7	2.06	0.6
mysid shrimp	3	3.4	2.47	0.7
unidentified decapod	3	3.4	3.62	1.1
unidentified mollusc	2	2.2	1.04	0.3
green crab	2	2.2	2.19	0.7
hermit crab	2	2.2	1.49	0.5
lobster	2	2.2	13.44	4.1
razor clam	2	2.2	3.02	0.9
winter flounder	2	2.2	0.60	0.2
sea mouse	1	1.1	2.77	0.8
sum			330.63	

Table A.48 Skate (*Raja sp.*) stomach contents collected at Danvers River trawl station in 1997 (N = 45, of which 39 contained prey).

Prey	Number of Occurrences	Percent Occurrence	Prey Weight (g)	Percent of Total Wt.
sand shrimp	22	56.4	55.24	20.9
sea worm (*Nereis sp.*)	22	56.4	54.25	20.5
rock crab	11	28.2	58.15	22.0
unidentified mollusc	12	30.8	29.89	11.3
hermit crab	4	10.3	7.61	2.9
razor clam	4	10.3	2.70	1.0
unidentified fish	4	10.3	9.61	3.6
tubed amphipod	2	5.1	2.27	0.9
green crab	2	5.1	6.59	2.5
squid	1	2.6	32.17	12.2
lobster	1	2.6	5.09	1.9
winter flounder	1	2.6	0.88	0.3
sum			264.45	

APPENDIX

Table A.49 Skate (*Raja sp* .) stomach contents collected at Beverly Cove trawl station in 1997 (N = 58, of which 52 contained prey).

Prey	Number of Occurrences	Percent Occurrence	Prey Weight (g)	Percent of Total Wt.
sand shrimp	37	71.2	71.13	26.8
rock crab	27	51.9	55.09	20.8
sea worm (*Nereis sp* .)	16	30.8	53.50	20.2
tubed amphipod	9	17.3	16.64	6.3
green crab	3	5.8	14.08	5.3
hermit crab	3	5.8	6.18	2.3
mysid shrimp	4	7.7	2.60	1.0
unidentified fish	4	7.7	10.27	3.9
unidentified mollusc	4	7.7	2.40	0.9
unidentified decapod	1	1.9	1.05	0.4
scud	1	1.9	0.34	0.1
lobster	1	1.9	28.50	10.7
razor clam	1	1.9	0.30	0.1
winter flounder	1	1.9	0.63	0.2
red shrimp	1	1.9	2.22	0.8
baltic isopod	1	1.9	0.32	0.1
sum	265.25			

APPENDIX

Figure A.1 Length frequency of winter flounder caught in 1997 seine catch, all stations combined: April, May, June (A); July, August, September (B); October, November, December (C).