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A Technical Characterization of Estuarine and Coastal New Hampshire

New Hampshire Estuaries Project

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A Technical Characterization of

Estuarine and Coastal New Hampshire

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TABLE OF CONTENTS

APPENDICES

EXECUTIVE SUMMARY

This technical characterization report provides a comprehensive compilation of information on key issues related to water quality and natural resources in the estuaries of New Hampshire. The report has identified some significant issues and problems facing these estuaries that will require management attention. Issues common to estuaries across the nation have been addressed to varying extents, depending on their significance in New Hampshire. Much of the trend information is biased by the sporadic interest given to the different resources and water quality issues through the years. Studies have focused to differing extents on the various areas of the coast, providing more information and better documentation where greater scrutiny was given. Problems have been identified in relation to accepted standards where possible to provide the basis for developing a clearer vision for the future of New Hampshire's coastal resources and water quality.

Bacterial contamination of estuarine waters in New Hampshire is widespread. There are no grossly contaminated areas, but every estuarine surface water body is subject to bacterial contamination for some time or during some event each year. The overall issue is that the bacterial contaminants measured are indicators of fecal contamination, and, as such, indicators of the potential presence of pathogenic microorganisms that can cause disease in humans that consume contaminated shellfish or that are exposed through contact with water. The concentrations of the indicator bacteria are generally quite low in many areas and most uses are supported. There has been a clear decreasing trend in bacterial concentrations over the past ten years in most areas of coastal New Hampshire, largely as a result of upgrades in wastewater treatment facilities (WWTFs). However, sources of contaminants persist for all coastal waters, especially during and following runoff events. This contamination occurs at concentrations that commonly require limiting uses of surface waters to protect humans from pathogens.

The issue of bacterial contamination is presently being addressed by determining sources of contaminants associated with stormwater runoff. Good documentation of the presence of elevated bacterial contaminants in stormwater runoff and their impact on water quality in surface waters exist. The actual sources of these bacteria are not known in all areas. Existing evidence suggests that runoff from impervious areas, sewage cross-contamination in urban stormwater systems, WWTFs, ineffective septic systems and possibly waterfowl are the prime suspected sources for runoff-associated contamination.

A major problem caused by bacterial contamination is the closure of shellfish beds. Approximately 63% of estuarine waters in New Hampshire are closed to shellfishing. Recreational shellfishing is a popular activity in the state, and the closures represent not only limitations of activities that have long been treasured but also serve as the early warning system that other problems may also be present in the estuaries. Efforts to open shellfish-growing waters are recognized to be simultaneously beneficial to other living resources and ecosystem functions, and continued efforts to open shellfish beds by improving water quality should benefit the whole estuarine ecosystem.

The public health significance of the elevated concentrations of bacterial indicators is not well understood. It has been documented in many studies in New Hampshire and throughout the world that the bacterial indicators used by state agencies have significant limitations. Difficulties in finding actual sources of bacterial contamination may be related to some of these implicit limitations of the indicators used to assess water quality. The implications and repercussions of detecting indicator bacteria should be supported with verification of the presence or absence of actual pathogens. A potential, emerging problem is the presence of nonfecal-borne bacterial pathogens. These include *Vibrio* sp. and *Aeromonas* sp. that have received recent attention by researchers at UNH. Naturally occurring bacterial pathogens cannot be controlled by traditional elimination of human pollution sources and thus pose a different, more insidious public health problem.

Trace metal and toxic organic contamination is also ubiquitous throughout New Hampshire's coast. There is ample information to provide an assessment of the spatial distribution and identification of trouble spots relative to regional background levels of these contaminants in sediments and biota. Sites with elevated concentrations of contaminants include the sediment depositional areas around the Portsmouth Naval Shipyard on Seavey Island in particular, with other hot spots for specific contaminants at various sites throughout the coast. The most common contaminants present at elevated concentrations are chromium, lead, mercury, copper, zinc and PCBs. Contaminants like DDT (and metabolites) and PAHs are present at concentrations well above background levels, but not at levels that are of concern to humans and other biota, and are well within expectations based on regional distributions of these compounds. The large amount of information on tissue concentrations of toxic compounds in shellfish serves as a useful database for assessing potential health risks for seafood consumption by humans. The most acute documented concern is the relatively high concentrations of PCBs in lobster tissue and tomalley. There are consumption advisories for tomalley from lobsters in the Great Bay Estuary and for bluefish throughout the coast. Concentrations of lead in mussels from around Seavey Island have been high relative to published FDA "Action Levels", while other metals have not exceeded these levels. On a regional scale, metals in mussels from sites in New Hampshire are elevated along with mussels from Massachusetts Bay and are sometimes the highest in the region. Metals of concern include chromium, lead, mercury, cadmium, nickel and zinc. Organic contaminants in mussels have generally been well below action limits. However, mercury, PCB and DDT concentrations in finfish and lobsters from sites in the Great Bay Estuary and the nearby coast are of concern to both humans and wildlife. Other studies have indicated a few instances of relatively minor toxicity effects on marine and estuarine biota. Much of the toxic contaminants present in New Hampshire's estuaries is probably the result of historic sources, such as tanneries, landfills and petroleum processing facilities. This historical contamination is largely stored in the fine-grained sediments dispersed throughout the estuaries. Identified sources that continue to load contaminants to the estuaries include stormwater runoff from impervious surfaces, low concentration in some monitored point source discharges, pesticide application for mosquito control and agricultural purposes, atmospheric deposition of mercury and episodic oil spill events. Other suspected sources include municipal discharges, defense facilities and Superfund sites, stormwater runoff and contaminated groundwater. The less well characterized sources warrant further investigation to determine if already elevated levels of some toxic contaminants are increasing as a result of ongoing sources.

Nutrient loading occurs in all New Hampshire estuaries and their tributaries. Present and historical databases suggest that nutrient concentrations within the main area of Great Bay have not changed significantly over the past twenty years, and in fact, seasonal trends appear to have been maintained in a consistent fashion. No significant systemic eutrophication effects have been observed, with only isolated incidences

1.1

GEOGRAPHICAL AND PHYSICAL SETTINGS

The State of New Hampshire has two important estuaries along its approximately 220 miles of tidal shoreline. The Great Bay Estuary, the largest in New Hampshire, is a drowned river valley that is similar to some of the estuaries found along the Maine coast. The Hampton/Seabrook Estuary is a bar-built estuary situated behind barrier beaches and surrounded by expansive areas of saltmarsh. Though quite different in size, topography of the watershed, geomorphology, hydrodynamics, and ecology, the Great Bay and Hampton Harbor estuaries can have similar geographically-related problems. It is for this reason that these areas are collectively the main foci of the New Hampshire Estuaries Project.

Both estuaries have been studied by several organizations that include the University of New Hampshire, Jackson Estuarine Laboratory (JEL), N.H. Fish and Game Department (NHF&G), NH Department of Environmental Services (NHDES), N.H. Office of State Planning (NHOSP), New Hampshire Department of Health and Human Services (NHDHHS), Normandeau Associates, Inc. and the U.S. Fish and Wildlife Service. Substantial historic databases are available on the physical and chemical properties of these estuaries, including sedimentology, hydrography and nutrient concentrations. There are also extensive inventories of seaweed species, estuarine fish and invertebrates as well as standing crop and distributional data for seagrasses and marsh plants. There are numerous data layers for the area digitized on the state Geographic Information System (GIS), including hydrography, land cover, land use, point sources of pollution, potential nonpoint threats, bathymetry, wetlands and intertidal macroalgae, and several others. Monitoring data as well as other research efforts in Great Bay have been reviewed in a document entitled "The Ecology of the Great Bay Estuary, New Hampshire and Maine: An Estuarine Profile and Bibliography" (Short, 1992). This document summarized the research and management efforts in the Great Bay Estuary as of 1991 and provides references for detailed information. An extensive body of work on the Hampton Harbor Estuary was compiled as part of the Environmental Impact Statement for the construction and operation of the Seabrook nuclear power plant. Monitoring efforts continue today both in the estuary and offshore at the cooling intake and outfall sites. The Hampton Harbor Sanitary Survey (NHDHHS, 1994), a result of the 1993 CORD Shellfish Taskforce's efforts, describes water circulation, bacterial contamination and the effect of storms and tidal conditions in the estuary.

1.1.1 THE GREAT BAY ESTUARY

The Great Bay Estuary is a tidally dominated, complex embayment on the southern New Hampshire-Maine border (Figure 1.2). The estuarine tidal waters cover approximately 17 square miles (10,900 acres), with a 144-mile shoreline of steep wooded banks with rock outcroppings, cobble and shale beaches, and fringing saltmarsh. The estuary extends inland from the mouth of the Piscataqua River between Kittery, Maine, and New Castle, New Hampshire through Little Bay to Great Bay proper, a distance of 25 km or 15 miles (Brown and Arellano 1979). The junction of Little Bay and the Piscataqua River occurs at Dover Point. Little Bay turns sharply at Cedar and Fox Points near the mouth of the Oyster River and ends at Furber Strait near Adams Point. Great Bay begins immediately inland or "upstream" of Furber Strait. With the exception of the eastern shore of the Piscataqua and Salmon Falls rivers which are bordered by southern York County, Maine, the estuary is entirely in Strafford and Rockingham Counties of New Hampshire. New Hampshire municipalities on the shores of the estuary include Portsmouth, Newington, Dover, Rollinsford, Madbury, Durham, Newmarket, Newfields, Exeter, Stratham and Greenland.

FIGURE 1.2

The Great Bay and Hampton/Seabrook Harbor estuaries and surrounding municipality boundaries

S. MIRICK

Great Bay

The largest cities in the watershed include Rochester, Dover, Portsmouth, and Exeter and have estimated populations of 28,726, 26,200, 22,830, and 13,258, respectively (NHOSP, 1997). Data on current and projected population and population density for all towns in Strafford and Rockingham Counties are presented in Appendix A.

Two-thirds of the 930 square mile Piscataqua River drainage basin is located within New Hampshire, with the remainder in southern Maine (Reichard and Celikkol, 1978). Tidal waters from the Atlantic Ocean enter the estuarine system at Portsmouth Harbor, flooding the three major portions of the Estuary; the Piscataqua River, Little Bay and Great Bay. The estuary derives its freshwater inflow from seven major rivers, four of which are gauged by the U.S. Geological Survey (USGS) (the Lamprey, Oyster, Cocheco, and Salmon Falls rivers). The Lamprey, Squamscott and Winnicut rivers flow directly into Great Bay. The Salmon Falls, Cocheco, Bellamy, and Oyster rivers flow into the estuary between Furber Strait and the open coast. River flow varies seasonally, with the greatest volumes occurring as a result of spring runoff. However, the tidal component in the estuary dominates over freshwater influence throughout most of the year. Freshwater input typically represents only 2 percent or less of the tidal prism volume (Reichard and Celikkol, 1978; Brown and Arellano, 1979), but the percentage varies seasonally. Estimates of flow for all rivers (Appendix B) suggest that the average combined freshwater inflow is greater than 1000 cubic feet per second. Approximately 50 percent of the average annual precipitation (42 inches) in the Great Bay Estuary drainage basin enters the estuary as stream flow (NHWSPCC, 1975).

Tidal height ranges from 2.7 m at the mouth of the estuary to 2.0 m at Dover Point, increasing slightly to 2.1 m at the mouth of the Squamscott River. The phase of the tide lags significantly moving up the Great Bay Estuary from the ocean and the slack tides can be as much as 2.5 hours later in the Squamscott River than at the mouth of the estuary. Strong tidal currents and mixing limit vertical stratification during most of the year throughout the estuary. Partial stratification may occur during periods of intense freshwater runoff, particularly at the upper tidal reaches of rivers entering the estuary. The large tidal range during spring tides results in exposure of extensive mudflats along the fringing areas of the Piscataqua River, Little Bay and the tributaries as well as large expanses of exposed tidal flats in the central part of Great Bay. High summer temperatures in these shallow flats can reach 30°C in the summer and -2°C during the coldest part of winter when much of Great Bay can freeze over. Ice scour in winter and early spring can play a major role in both sediment transport and disturbances to submerged aquatic vegetation and benthic fauna.

The observed flushing time for water entering the head of the estuary is 36 tidal cycles (18 days) during high river flow (Brown and Arellano, 1979). Tides cause considerable fluctuations of water clarity, temperature, salinity and current speeds, and have a major impact on bottom substrata. Shallow areas of the estuary are also greatly affected by wind-wave conditions which can influence grain size distributions and sediment transport throughout the estuary. Waves resuspend sediments, increasing turbidity levels well above levels attributed to tidal currents alone (Anderson, 1972). A horizontal gradient of decreasing salinity exists from the mouth of the harbor to the tidal reaches of the tributaries and the upper portions of Great Bay. The range of this gradient (0-30 ppt) depends on tidal cycle, season and rainfall conditions.

The Great Bay Estuary has a variety of different habitats including approximately 1,000 acres of saltmarsh, 52 acres of major oyster beds, 2,575 acres of scattered clam flats, 5,000 acres of subtidal eelgrass, extensive intertidal and subtidal macroalgal cover, mudflats and rocky outcroppings and islands. The subtidal substrate in the lower estuary is primarily rock and cobble, with sand and mud-sand mixture in the intertidal and nearshore subtidal areas. Some hard substrate can be found in channel areas of the upper estuary and tidal rivers, but the dominant substrata are sandy mud and silt. Because of this habitat diversity, Great Bay Estuary supports a wide variety of flora and fauna described in more detail in Chapter 3: Living Resources.

Land cover for the watershed of the Great Bay Estuary, mapped using 1988 and 1990 LANDSAT Thematic Mapper imagery, has been digitized on the state GIS system. Land cover shows the watershed is primarily forested, with smaller percentages of other land cover categories Table 1.1, Appendix C). Most of the urban land is concentrated in the municipalities of Rochester, Dover, Portsmouth, and Exeter.

Land use information for the watershed, developed in the 1980s and early 1990s by Rockingham and Strafford Regional Planning Commissions, has also been mapped and digitized on the state GIS system (Appendix C). Land use surrounding the Great Bay Estuary ranges from urban/industrial near the mouth of the Piscataqua River and in the cities and towns located at the head of tide of each of the tributaries, to rural, residential and undeveloped private and public lands. The Portsmouth Naval Shipyard, a major military base, is located on Seavey Island in Portsmouth Harbor, and the former Pease Air Force Base in Newington and Portsmouth is currently under commercial development as the Pease International Tradeport. A portion of the estuary is part of the National Oceanic and Atmospheric Administration's (NOAA) National Estuarine Research Reserve Program and is managed by NH Fish and Game Department. Just over 1,000 acres of the former Pease Air Force Base are now the Great Bay National Wildlife Refuge, managed by the U.S. Fish and Wildlife Service. Land and shoreline ownership around the Great Bay Estuary and throughout its tidal waters is predominantly private, with some lands protected or in government ownership (Short and Webster, 1992). For lands within 300 feet of the tidal waters of the Great Bay Estuary system, 38% is developed, 18% is permanently protected, 7% is undevelopable and 37% is developable (Rubin and Merriam, 1998). Acquisition of lands for conservation easements is an ongoing process, with both government (U.S. Fish and Wildlife Service, N.H. Fish and Game Department, Great Bay National Estuarine Research Reserve) and private programs operating.

MORRISON

The Hampton/ Seabrook Estuary

1.1.2 HAMPTON/SEABROOK ESTUARY

The Hampton/Seabrook Estuary is a tidally dominated, shallow, bar-built estuary located at the extreme southeast corner of New Hampshire (Figure 1.2). It is located entirely in Rockingham County and is bordered by the towns of Hampton, Hampton Falls and Seabrook. The Estuary is roughly rectangular in shape, has approximately 72 miles of tidal shoreline and has a total area at high tide of approximately 475 acres. The topography of the 47 square mile watershed is relatively flat with approximately 17 percent (5,000 acres) of saltmarsh. Eighty percent of the watershed is in New Hampshire, with the remainder in Massachusetts. There is one harbor entrance through which all tidal waters enter and exit. Tides are semi-diurnal with a mean tidal range of 2.5 meters and spring tidal range of 2.9 meters. During average wind conditions approximately 88 percent of the water in the estuary is exchanged on each tide (PSNH, 1973). The typical substratum is more coarse-grained than that found in the Great Bay Estuary, and more typical of a barrier system. The estuary receives freshwater input from the Taylor River and Hampton Falls River (which converge to form the completely tidal Hampton River) to the north; the Browns River and Mill Creek to the west; and the Blackwater River to the south. Numerous small tidal creeks from the surrounding wetlands also drain into the estuary. River flows vary seasonally with the highest flows occurring in spring due to snowmelt and precipitation. Average annual precipitation is approximately 42 inches. Total mean freshwater discharge has been estimated to be 4.08 cubic ft/sec (NHDHHS, 1994a) and is minimal when compared to the average tidal flow of 22,000 cubic ft/sec. Water depth is relatively shallow, ranging at mean low tide from less than one meter in the tidal creeks and rivers to over six meters at the harbor entrance. Most of the harbor channels have a low tide depth of one to three meters.

During periods of light winds, the tidal flows dominate water circulation. Circulation can change considerably, however, in response to high wind and storms. Strong westerly and northwesterly winds alter tidal flows by forcing surface waters out of the mouth of the estuary, while during northeast storms, surface waters are pushed landward, impeding the seaward flow of ebb tide water (NAI, 1977). The estuary is generally well mixed with little vertical stratification, though some stratification does occur, particularly in the tidal rivers and creeks during high flow periods (NHDHHS, 1994a).

Perhaps the most striking feature of the Hampton/Seabrook Estuary is the large expanse (5,000 acres) of contiguous salt marsh that surrounds the estuary. The estuary is also the most popular location in coastal New Hampshire for recreational harvesting of softshell clams. Mussels, lobsters, and a variety of finfish are also present. Sandy beaches both within and adjacent to the estuary are a major tourist attraction. Some of the last remaining sand dunes in coastal New Hampshire are located in the area. The Seabrook dunes, damaged by a series of coastal storms, were recently restored with sand and American beach grass.

Land cover for the Hampton/ Seabrook Estuary Watershed, mapped using 1988 and 1990 LANDSAT Thematic Mapper imagery, has been digitized on the state GIS system (Table 1.1). Land cover shows the watershed is primarily forested, but not to the extent (on a percentage basis) of the Great Bay Estuary Watershed. A large amount of urban land is concentrated near the estuary in the Town of Hampton (estimated 1996 population of 13,003).

Land use information for the watershed, developed in the 1980s and early 1990s by Rockingham Planning Commissions, has also been digitized on the state GIS system (Appendix C). The Hampton Harbor area is the major summer resort area along the New Hampshire coast. Development bordering the estuary is primarily residential and concentrated in the beach areas on the eastern shore. Of the lands within 300 feet of the tidal waters of the Hampton/Seabrook Estuary, 14% ar edeveloped, 10% are permanentlyt protected, 4% are developable and 71% are deemed undevelopable, primarily because of the large expanse of salt marsh around the estuary.

Commercial development consists mostly of shops, hotels, and restaurants that support the tourist industry. The populations of both Hampton and Seabrook double in the summer to approximately 23,000. Total daily beach population, which includes daily visitors, vacationers at the hotels and motels (~30,000) and permanent and summer residents, can be as high as 100,000. Industrial activity in the watershed includes plastics, shoe and furniture manufacturing and metal fabrication. Most of these industries are small with the largest employing 1,000 people and total industrial employment at approximately 3,000. Seabrook nuclear power station, located on the western shore of the estuary, is a prominent feature.

1.1.3 BEACH AND DUNE SYSTEMS

The New Hampshire coast between the Great Bay and Hampton/Seabrook estuaries has significant areas of beaches and dunes. The beaches are heavily used in the summertime for bathing and surfing, and have experienced severe erosion during several recent storm events. The beaches and the rocky intertidal areas have been maintained to protect private and public properties and to provide conditions at the beaches that allow the economically-important tourist trade to remain viable. The historical extent of the dune areas has been drastically reduced by human development. Some of the remaining dunes, including those in Seabrook, have undergone some restoration.

TABLE 1.1

Watershed land cover for the New Hampshire portions of the Great Bay and Hampton/Seabrook Harbor estuaries.

	GREAT BAY ESTUARY		HAMPTON/SEABROOK ESTUARY	
CATEGORY	Acres	% of Total	Acres	% of Total
Forested	296,070	66	10,094	40
Wetland	44,703	10	5,392	21
Urban	43,944	10	5,800	23
Agriculture	28,418	6	2,039	8
Disturbed	8,494	2	380	2
Cleared	9,240	2	400	2
Water	17,211	4	1,030	4

BIOLOGICAL SETTING

New Hampshire's estuaries are composed of a variety of habitats. They serve as nursery areas for commercially important fish and shellfish species and sustain runs of numerous anadromous species. The primary producers include a diverse community from benthic diatoms to salt marshes and from microscopic phytoplankton to seaweeds and eelgrass. Along with the estuarine aquatic habitats, the surrounding terrestrial and wetlands areas support a variety of birds and mammals.

1.2.1 FISH AND SHELLFISH

Because of the diversity of habitats, New Hampshire's estuaries support an impressive array of living resources. The estuaries sustain runs of anadromous sturgeon, shad, alewives, lampreys, smelt and salmon that spawn in the freshwater portions of the rivers and streams. Freshwater areas of the rivers and streams in Hampton Harbor are directly accessible by anadromous fish, and in all the major rivers in the Great Bays Estuary, which were dammed in the 1800s for hydropower, fish ladders have been built and maintained to allow anadromous species access to freshwater spawning areas. The estuaries also serve as nursery areas for commercially important species such as lobsters, winter flounders, cod, pollack, eels and hake. Both juvenile and adult striped bass can be found in increasing numbers between May and October as they forage on the abundance of baitfish such as silversides and smelt. The remarkable recovery of the east coast stocks of striped bass has been in part due to the availability of summer feeding areas such as Great Bay and Hampton Harbor. Berrys Brook in Rye, a tributary to the lower Piscataqua River, has a rare population of sea run brown trout. Shellfish are also abundant. There are 52 acres of oyster beds, over 2500 acres of scattered clam flats and significant areas with blue mussel beds, razor clams and scallops in Great Bay Estuary and its tributaries (Appendix D). Hampton Harbor supports abundant populations of softshell clams (approximately 2000 bushels) and blue mussels. An inventory of invertebrates and fish species is listed in Appendix E.

S. MIRICK

Snowy Egret

1.2.2 BIRDS AND MAMMALS

A diverse bird population occurs within the estuaries of coastal New Hampshire, with as many as 110 species (excluding upland birds) observed using the estuaries. Coastal New Hampshire is part of the Atlantic flyway and is an important migratory stopover as well as wintering area for waterfowl. Seabirds, wading birds, shore birds, estuarine birds of prey, waterfowl and diving birds are found throughout the estuarine areas.

Seabirds (i.e. cormorants and gulls) are year-round residents of Great Bay. Herring gulls and great black-backed gulls are common within the estuary. The common tern (threatened in N.H.) nests in several areas of Great Bay and Hampton Harbor. Double-crested cormorants are present from April to November. Waterfowl, including black ducks and Canada geese, occur in fall and winter. Goldeneyes, scoters, scaups, buffleheads, mergansers and grebes are also seasonal visitors in Great Bay Estuary. A year-round population of mute swans, now totaling more than 60 birds, nests along the shores of Great Bay Estuary and spends the winter in the open waters of the bay. The great blue heron is the most prominent wading bird, occurring primarily from April to October. Other wading species include snowy egrets, green herons, black-crowned night herons, glossy ibis, greater and lesser yellowlegs, and least sandpipers. Upland sandpipers are a rare species, though there is a nesting population adjacent to the runway at the Pease International Tradeport. Common terrestrial species include the American crow, belted kingfisher, ruffed grouse, and wild turkey.

Several endangered and threatened bird species, including bald eagles, common terns, upland sand pipers, marsh hawks, ospreys and common loons utilize part of Great Bay Estuary's diverse habitat at various times of the year. The estuary supports the largest winter population of bald eagles in New Hampshire. During recent winters up to fifteen eagles have occupied this wintering area simultaneously during early December through March. Ospreys, common loons and pied-billed grebes forage in the bay during migration; one osprey pair nested on the Bay in 1990, and more have nested since.

Mammals common to the Great Bay and Hampton/Seabrook estuaries include otters, minks, and beaver. Muskrats nest and overwinter in many areas of the bays and rivers, and harbor seals are frequently observed in fall, winter and spring.


GBNERR

Eelgrass

1.2.3 PRIMARY PRODUCERS

Primary producers in the Great Bay and Hampton/Seabrook estuaries include phytoplankton, benthic diatoms, saltmarsh plants, brown, red and green macroalgal species and eelgrass. Phytoplankton support a broad spectrum of planktonic consumers including bivalve, crustacean and fish larvae, as well as the large populations of sessile filter feeding invertebrates. Grazers such as snails, deposit feeding worms and other invertebrates feed on the benthic diatoms that grow on the exposed tidal flats.

Approximately 5,000 acres of eelgrass (*Zostera marina*) occurs in the Great Bay Estuary, though none occurs in Hampton Harbor. Eelgrass supplies the estuarine food web with organic matter, helps to stabilize sediment, and provides habitat for juvenile fish and invertebrates. Following substantial loss of eelgrass cover in the 1980s to an eelgrass wasting disease, eelgrass beds have expanded in the past several years and the populations appear to be in good condition. The importance of eelgrass beds is reflected in state and federal wetland regulatory actions that may require substantial mitigation, as was the case for the expansion of the Port of Portsmouth in 1993.

A total of 219 seaweed species are known from New Hampshire, including the Isles of Shoals (Mathieson and Hehre 1986, Mathieson and Penniman 1991). Of this total, 169 taxa (77.2% of total) are recorded from the Great Bay Estuary, including 45 Chlorophyceae, 46 Phaeophyceae and 78 Rhodophyceae. A variety of seaweed species occur within Great Bay that are absent on the open Atlantic coast north of Cape Cod. These species, which have a disjunct distributional pattern, may represent relict populations that were more widely distributed during a previous time when coastal water temperatures were warmer (Bousfield and Thomas 1975). Alternatively, they may have been introduced from the south. These seaweeds (e.g. *Gracilaria tikvahiae, Bryopsis plumosa, Dasya baillouviana, Chondria tenuissima, Lomentaria clavellosa, Lomentaria orcadensis* and *Polysiphonia subtilissima*) grow and reproduce during the warm summer and are able to tolerate colder winter temperatures (Fralick and Mathieson 1975, Mathieson and Hehre 1986). Several of these seaweed taxa and several invertebrates exhibiting this same pattern also occur in the Great Salt Bay at the head of the Damariscotta River in Maine, an area somewhat similar to Great Bay. The disjunct distributional pattern described for the seaweeds is also found for several marine/estuarine invertebrates (Bousfield and Thomas 1975, Turgeon 1976).

There are approximately 1,000 acres of saltmarsh in the Great Bay Estuary and over 5,000 acres of saltmarsh in the Hampton Harbor Estuary. Though these marshes are dominated by *Spartina alterniflora* and *Spartina patens*, a total of 69 species of plants have been identified in New Hampshire saltmarshes (Short and Mathieson, 1992). In addition to the rare and endangered birds previously mentioned, a number of rare and endangered plants are also found within the Great Bay Estuary. These species include the prolific knotweed (*Polygonum prolificum*), Eastern lilaeopsis (*Lilaeopsis chinensis*), Turks-cap lily (*Lilium superbum*), marsh elder (*Iva frutescens*), stout bulrush (*Scirpus robustus*), exserted knotweed (*Polygonum exsertum*), and the large saltmarsh aster (*Aster tenufolius*). New Hampshire's saltmarshes have received a great deal of attention from resource managers over the past decade concerned about enhancing the functions of these important natural communities.

E. FINNERAN

The Great Bay and Hampton/Seabrook estuaries are extremely important to the local, regional, state, and national economies. From the time of first European settlement, the Great Bay Estuary was a center of commerce for natural resource based industries such as commercial fishing and logging. Virgin forests, bountiful runs of anadromous fish such as salmon, shad, sturgeon and river herring, as well as plentiful shellfish resources were the basis of a rapidly expanding economy. Plentiful timber and tidal water access to the towns gave rise to a large shipbuilding industry during the 1700s. Sailing barges called gundalows carried raw materials and manufactured goods to the towns in the estuary. During the 19th century, shoe and textile manufacturing became important and mills were built in all towns with access to navigable waterways. Increasing populations, lack of sewage treatment, pollution from sawmills and other industries, as well as unwise exploitation of natural resources, led to habitat degradation and declines in important fish and shellfish species. Abatement of pollution sources began in the 1940s and continues today, and the water quality and habitat areas have made a significant recovery.

Today there are varied commercial activities centered on the estuarine systems. Energy production facilities are located on the lower Piscataqua River as well as on the shore of Hampton Harbor. Shipping of lumber, mineral salt, gypsum, scrap metal, and other products occurs from the Port of New Hampshire in Portsmouth. The estuarine systems act as nursery areas for several species of fish that support local and regional fisheries in the Gulf of Maine. Although commercial fishing and shipping are important to the Gulf of Maine regional economy, tourism and recreation have become an increasingly important part of the New Hampshire Seacoast economy. The recreational industries supported by the activities described below are dependent on good water quality and a healthy ecosystem.

1.3.1 RECREATIONAL RESOURCES AND VALUES

Recreational activities in the Great Bay and Hampton/Seabrook estuaries are extensive and diverse, and have become a significant portion of the New Hampshire Seacoast economy. Boating, fishing, swimming, SCUBA diving, and other water sports are important recreational activities. Passive forms of recreation such as birdwatching and sight-seeing are also common.

1.3.1.1 Boating

Boating activities in the estuarine systems include sailing, fishing, water skiing, wind surfing, rowing, kayaking and canoeing. Boater registration records from 1993 indicate a total of almost 3,500 boats registered for tidal waters (note that the registration category is "fresh and tidal water" thus, not all of these boats are in the tidal waters all year). Just over 3,100 (90%) of these boats were in the "private/rental" class, while the remaining 10% were in the "charter/commercial" class (N.H. Dept. of Safety, 1994). During the 1980s, the Great Bay Estuary experienced a dramatic increase in boating activity as evidenced by the number of mooring permits issued by the state. The rate of increase leveled off following the adoption of the Harbor Management Plan.

Most of the approximately 1,400 moorings in N.H. tidal waters are used by pleasure boaters, with the rest of the mooring permits going to commercial boats and to commercial lease holders (marinas). The high demand for moorings is reflected in the length of the mooring waiting list, maintained by the N.H. Port Authority. There are currently almost 550 people waiting for a mooring, with the length of the wait ranging from three to 20 years, depending on the location requested (N.H. Port Authority, 1995).

1.3.1.2 Shellfishing

Shellfishing is also an important recreational activity in the estuaries. The Great Bay Estuary supports a large recreational shellfishery for oysters, clams and mussels. Oysters are the predominant shellfish resource utilized in Great Bay, although Little Harbor supports more concentrated populations of clams. Major oyster beds are located in Great Bay proper, as well as in the Piscataqua, Bellamy, and Oyster rivers, with scattered pockets of oysters also found throughout the estuary (Figure 1.3). The estimated dollar value of oysters in major beds was nearly $1.6 million in 1981 and $3 million in 1994. Approximately 5,000 bushels of oysters, valued at $300,000 are harvested annually by the 1,000 license holders (Manalo et al., 1991). Recreational harvesting of shellfish in the Great Bay Estuary is currently limited to most of Great Bay and Little Bay, with the upper Piscataqua River, and the smaller tidal rivers closed to harvesting due to bacterial pollution (Figure 1.4). The harvesting of softshell and razor clams in Great Bay, though difficult, has become intensified because of the closure of more popular clamming areas such as the flats in Hampton and Little Harbors.

The principal shellfish resource in Hampton Harbor is the soft shell clam, located in five major resource areas (Figure 1.5). These flats had been closed since 1988, but with the conditional reopening of some of the flats in the fall of 1994 and further openings in 1995 and 1998 (Figure 1.6), almost 3,000 clamming licenses were sold in 1994 (up from 239 licenses in 1993). Prior to clam bed closures in 1988, the average number of licenses sold in the State between 1971-1987 was 6,400. The clam flats and mussel beds in Rye, Little and Portsmouth harbors, the lower Piscataqua River, the Back Channel and, in 1998, the open coast (Figure 1.7), remain completely closed to recreational harvesting(Figure 1.8). The contribution of recreational shellfishing to the local and state economy has been estimated to be $3 million per year (Manalo et al., 1992).

1.3.1.3 Fishing

The Great Bay Estuary supports a diverse community of resident, migrant, and anadromous fishes, many of which are pursued by recreational fishermen. The most abundant species include Atlantic silverside, rainbow smelt, killifish, river herring, Atlantic tomcod, white perch, winter and smooth flounders. Year-round residents such as Atlantic silverside, killifish, Atlantic tomcod, winter flounder (juveniles), and smooth flounder are found throughout the estuary. Recreational fishermen pursue striped bass, bluefish, salmon, eels, tomcod, shad, smelt, and flounder. Fishing is not limited to boat access, as cast or bait fishing is

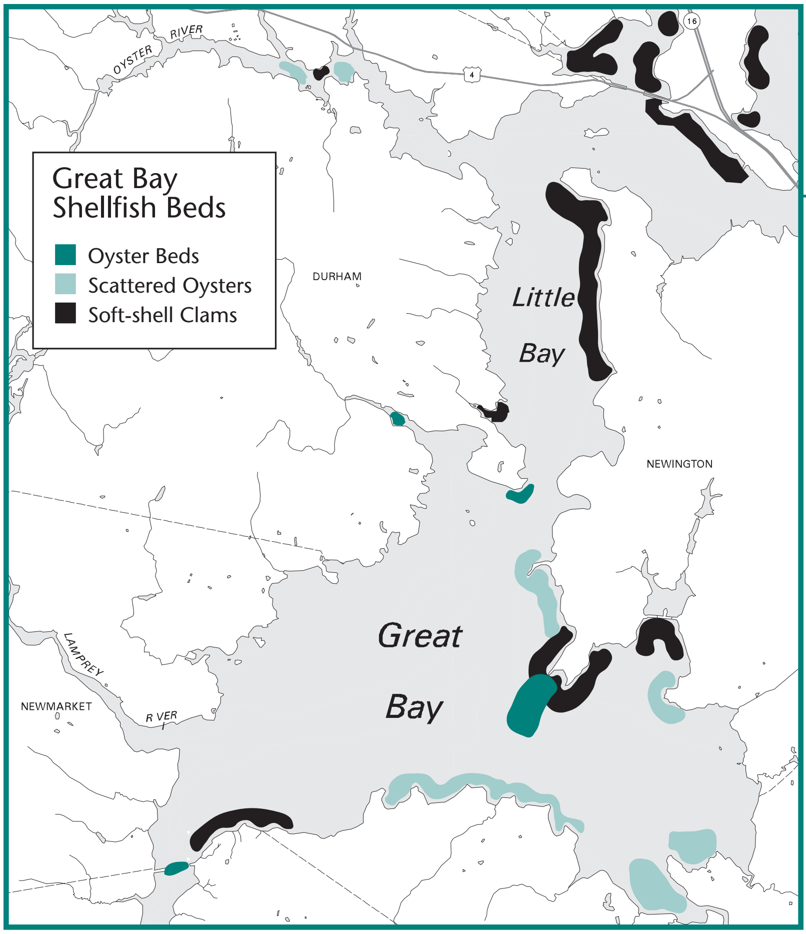


FIGURE 1.3

Shellfish resources in Great Bay, Little Bay, and tributaries.

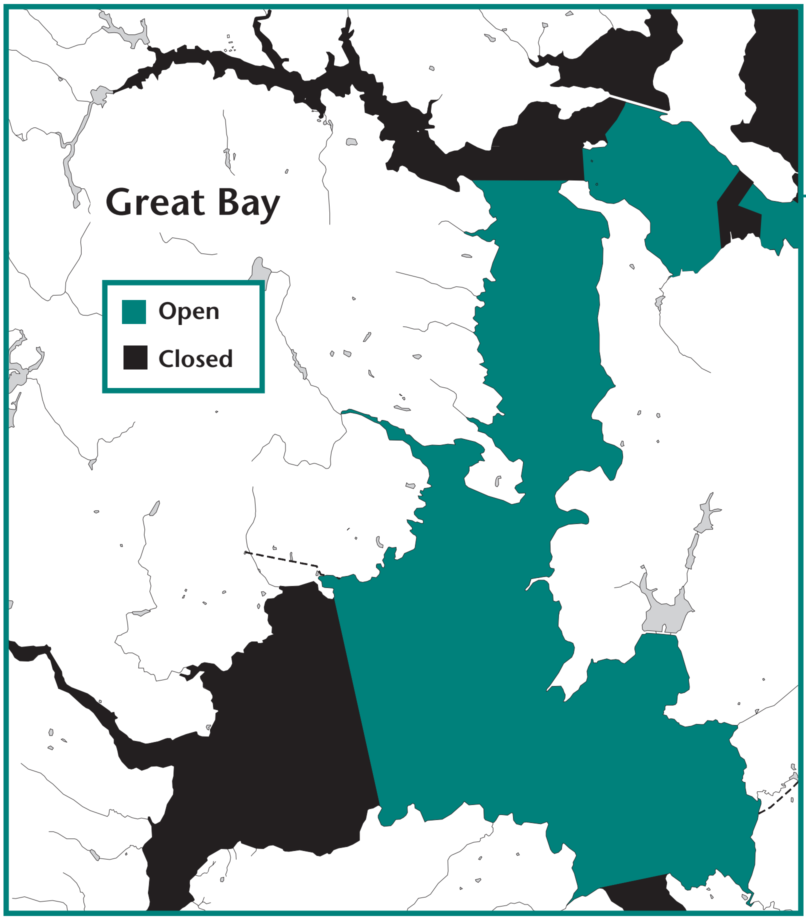


FIGURE 1.4

1998 Shellfish waters classification for the Great Bay Estuary.

FIGURE 1.5

Hampton/Seabrook Harbor clam flats

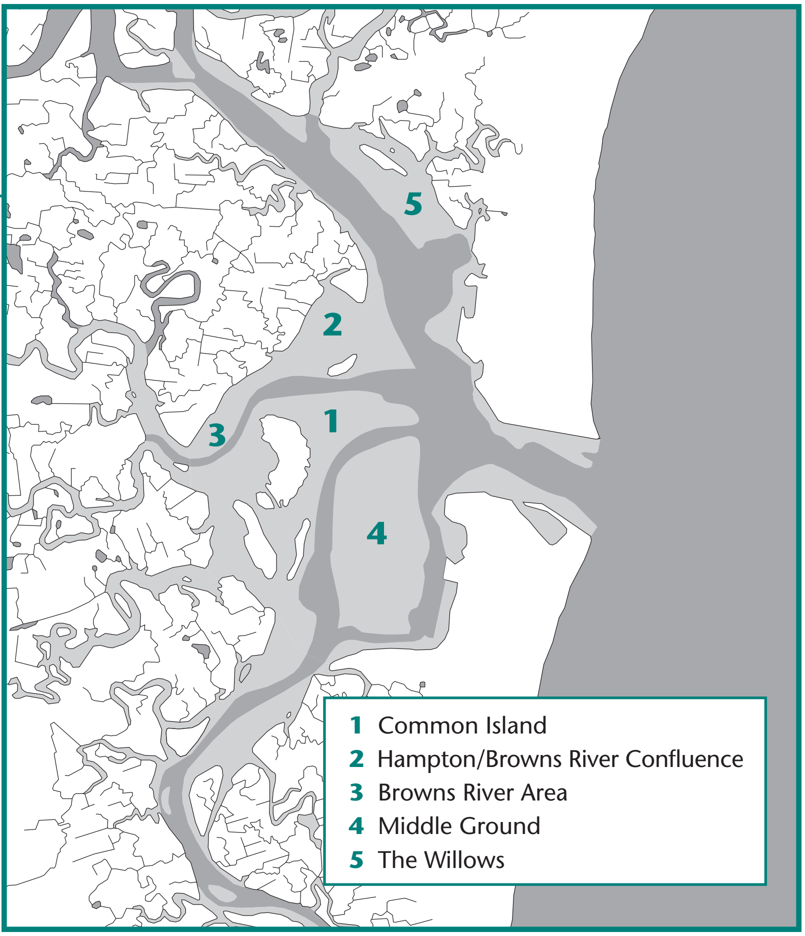
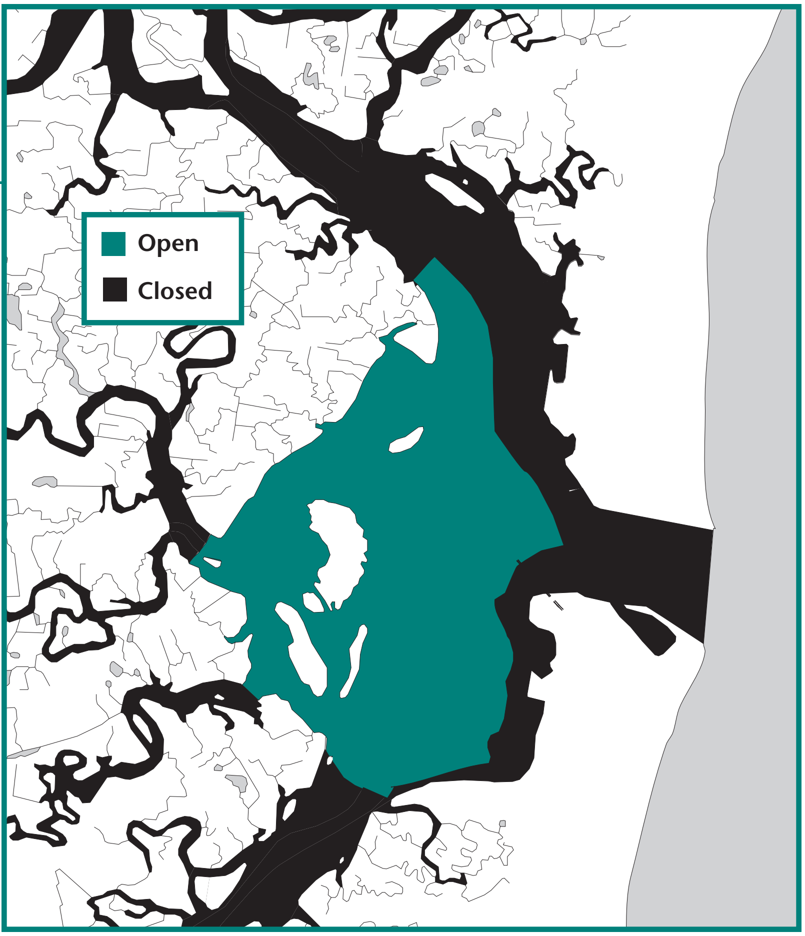


FIGURE 1.6

1998 Shellfish water classification for Hampton/Seabrook Estuary



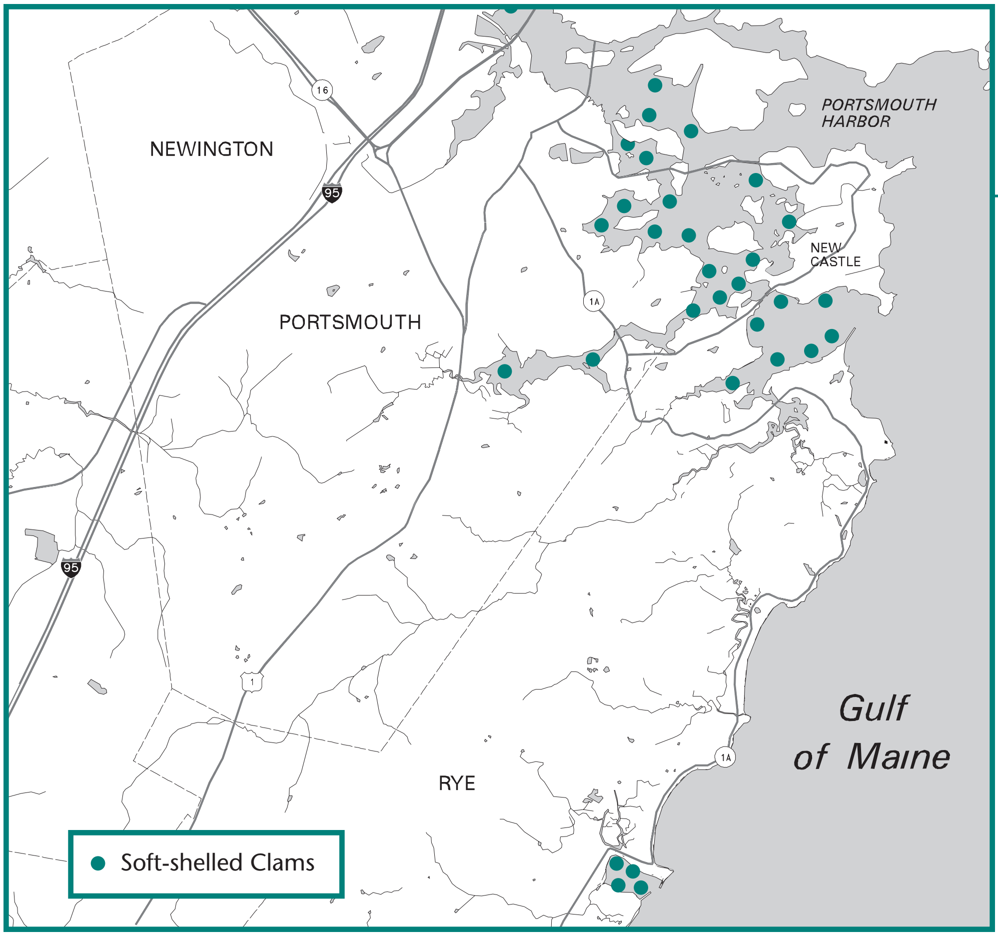


FIGURE 1.7

Shellfish resources in Portsmouth, Rye, and Little Harbors.

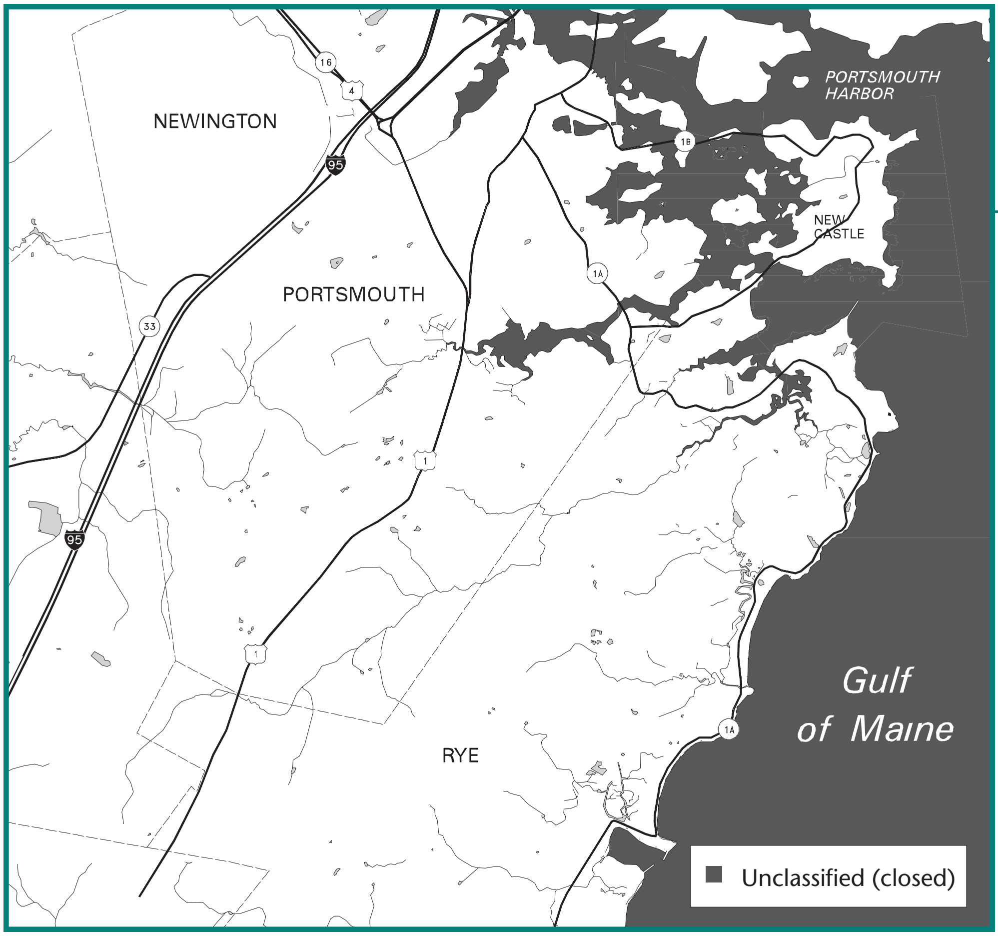


FIGURE 1.8

Shellfish classification for Portsmouth, Rye, and Little Harbors and the northern open coast.

done from the shore in many places and from the bridges crossing the estuary. Several charter boat companies in the Great Bay Estuary take fishermen to pursue striped bass, bluefish, and pollack, while companies operating out of Hampton Harbor carry fishing parties to the offshore waters to pursue cod, bluefish, flounder, mackerel, and other fish. One of the major winter activities in Great and Little Bays is ice fishing for smelt. The smelt fishery in Great Bay occurs primarily in the Greenland Cove, Lamprey River, Squamscott River and Oyster River areas from early January to March. The N.H. Fish and Game Department has pursued stocking and monitoring efforts on selected fish stocks (e.g., shad and Atlantic salmon) in order to enhance recreational fisheries (NHF&G 1989). Another important recreational fishing activity is the trapping of lobsters. Almost 150 recreational lobstermen set traps throughout the Great Bay and Hampton/Seabrook estuaries, with the Portsmouth Harbor area being a popular location.

Studies by N.H. Fish and Game consultants identified substantial sums of monies spent on marine recreational fishing. An estimated 88,000 saltwater anglers spent over $52 million in 1990 on fishing-related activities (approximately $600 per person). The largest expenditures were for food and beverages, automobile fuel, charter/ party boat fees, bait and fishing tackle, and boat fuel. A substantial amount of that total is estimated to come from expenditures in Great Bay estuarine activities.

1.3.1.4 Passive Recreation

There are several types of passive recreation that are common in and around the Great Bay and Hampton/Seabrook estuaries. One of the major attractions of New Hampshire's estuaries, particularly Great Bay, is the beautiful scenery. Several large tour boats bring groups into the Bay to see the fall foliage and to enjoy the water views and largely unspoiled shorelines. Fishermen, sportsmen, and boating enthusiasts frequent the estuary year-round. Though the scenic use of Great Bay is enjoyed primarily by way of boating, a number of public access areas, parks, and nature trails provide sweeping views of the Great Bay Estuary. These areas include:

- Adams Point in Durham
- Cedar Point in Durham
- Hilton Park in Dover
- GBNERR Sandy Point Discovery Center in Stratham
- Chapman's Landing in Stratham
- Prescott Park in Portsmouth
- Bellamy and General Sullivan Bridges in Dover
- Bellamy River Wildlife Management Area in Dover

Numerous state parks exist along the Atlantic coastline from Rye to Hampton, providing swimmers, sunbathers, fishermen, and picnickers with both sandy beaches and rocky shorelines. Several towns around the estuary maintain access and recreation facilities, including Wagon Hill Farm in Durham (Oyster River), Fox Point in Newington (Little Bay), Pierce Island and Prescott Parks in Portsmouth (Piscataqua River), as well as access points in Dover (Cocheco River), Newmarket (Lamprey River), and Exeter (Squamscott River). Historic sites such as Fort Constitution in New Castle, Strawberry Banke in Portsmouth, and Fort McClary and Fort Foster in Maine are also located on the Piscataqua River.

Bird watching by an active seacoast chapter of the Audubon Society, as well as by other groups, is increasing in popularity. A volunteer group now conducts regular surveys of waterfowl, seabirds, songbirds, and raptors for the Great Bay National Estuarine Research Reserve. Great Bay is a favored wintering site for bald eagles, with as many as 15 individual birds having been observed over the course of a winter. Nesting ospreys are also a popular attraction. The opening of the Great Bay National Wildlife Refuge in the fall of 1995 has resulted in increased use of the area for bird watching and enjoyment of nature.

1.3.2 COMMERCIAL RESOURCES AND VALUES

1.3.2.1 Industry and Shipping

Commercial uses of the Great Bay Estuary are primarily concentrated in Portsmouth Harbor and along the New Hampshire side of the Piscataqua River. The Port of New Hampshire in Portsmouth Harbor, a center of deep-water cargo shipping activities including fuel oils, wire cable, cement, scrap metal, salt, gypsum, coal, propane, gasoline, and other products, supports numerous industries located along the lower Piscataqua River. Tonnage for 1992 was just over 4,100,000 tons, with just over half of the total being oil shipments. Additionally, the Portsmouth Naval Shipyard, located on Seavey Island in Portsmouth Harbor, uses the estuary to provide submarine access to repair facilities and for shipping activities.

1.3.2.2 Fishing

Commercial fishing in New Hampshire occurs mainly offshore, and is based in fishing cooperatives in Portsmouth and Seabrook. However, eels, lampreys and baitfish such as silversides, mummichogs and river herring are harvested commercially in the Great Bay Estuary. A substantial commercial lobster fishery exists in the Great Bay Estuary and other coastal waters, with almost 300 lobstermen harvesting nearly 881,300 pounds, valued at approximately $5-6 million each year. Studies conducted for the Fish and Game Department estimate over $1.8 million is expended annually by commercial fishing interests.

Several small charter boats take passengers fishing for striped bass, bluefish, and pollack in the Great and Little bays, while charter boats based in Hampton and Seabrook take passengers offshore to pursue cod, flounder, mackerel, and others.

Four commercial shellfish aquaculture operators in the Great Bay Estuary were active in the 1970s and 1980s. The only shellfish aquaculture business operating today is located in Spinney Creek on the Maine side of the Piscataqua River. However, there has been recent interest in reviving aquaculture in New Hampshire.

1.3.2.3 Tourism and Recreational Industries

Tourism has become a major industry in the New Hampshire Seacoast, and the Seacoast Region is an important area for this industry in the state. Approximately 10 percent of all visitors to New Hampshire come to the Seacoast, exceeded only by the White Mountains and Lakes Regions (Institute for New Hampshire Studies, 1993). The Travel and Tourism industry, which includes businesses such as hotels/motels, marinas and related boating stores, tour boats, retails stores, fishing charter boats, parks and other recreational facilities, and restaurants, supports just over 15 percent of the jobs in the Seacoast, making it the region's second largest industry (Table 1.2). A healthy estuarine system is critical to maintaining this portion of the seacoast economy. In a survey of summer vacationers in 1993, respondents were asked what their "image" of New Hampshire was. The most common responses were "scenic," "clean," and "beautiful" (Institute for New Hampshire Studies, 1993). Closed shellfish beds and other visible signs of pollution, therefore, clearly detract from the estuaries' value to the tourism industry.

TABLE 1.2

Employment in the New Hampshire seacoast economy. Data from Institute for New Hampshire Studies (1993).

Industry	Total Employment (%)
Manufacturing	32.2
Travel and Tourism	15.3
Other Services	15.2
Other Retail	12.1
Government	7.7
Transportation/Public Utilities	7.5
Agriculture/Mining/Construction	7.1
Financial/insurance/Real Estate	2.9

2

PRESENT STATUS AND HISTORICAL TRENDS IN WATER QUALITY

The ability of an estuary to support a variety of unique habitats, diverse assemblages of organisms and a variety of human activities is largely dependent on environmental quality. Waters that can affect estuarine water quality include groundwater, precipitation, wetlands and surface waters, including estuaries, rivers, lakes, streams and ocean waters. Water quality in turn is dependent on the types and amounts of contaminants that enter estuaries as a result of human activities, and the natural processes of an estuary that transform, assimilate and transport contaminants. Both humans and natural ecosystems depend on certain levels of water quality for providing safe drinking water and as habitat for sustained food sources. There are many other human uses of the estuary and its surrounding environment, some of which may contribute to contaminant loading. The following chapter is organized by contaminant category in order to summarize information for each category, to frame issues, to assess the significance of issues and to develop the context to formulate corrective management strategies where necessary. Generally speaking, the primary contaminants of concern for most estuaries, including those in New Hampshire, are:

1. microorganisms from improperly treated sewage, urban stormwater runoff and other nonpoint sources;
2. nutrients from point sources (sewage treatment plants) and nonpoint sources (riverine input, surface runoff, septic systems, atmospheric deposition, etc.);
3. toxic contaminants (trace metals, organics, oil, pesticides, etc.) whose sources may be historic (chromium, pesticides), potential (oil) or current (metals and PAH's from stormwater, industrial and municipal wastewater and atmospheric deposition);
4. sediments of upland watershed or riparian origin that are carried into the estuaries by runoff.

These contaminants are listed in no particular order of priority. This section of the report describes the current status and spatial and temporal trends of these contaminants in coastal New Hampshire, and provide information on documented and suspected sources. Documented and potential impacts to living resources are also discussed. The term 'contaminant" is used most often because the alternative term, 'pollutant', is only used when there are biological effects associated with the presence of chemicals in the environment.

Overflow pipe on North Mill Pond

OVERALL WATER QUALITY AND USE SUPPORT

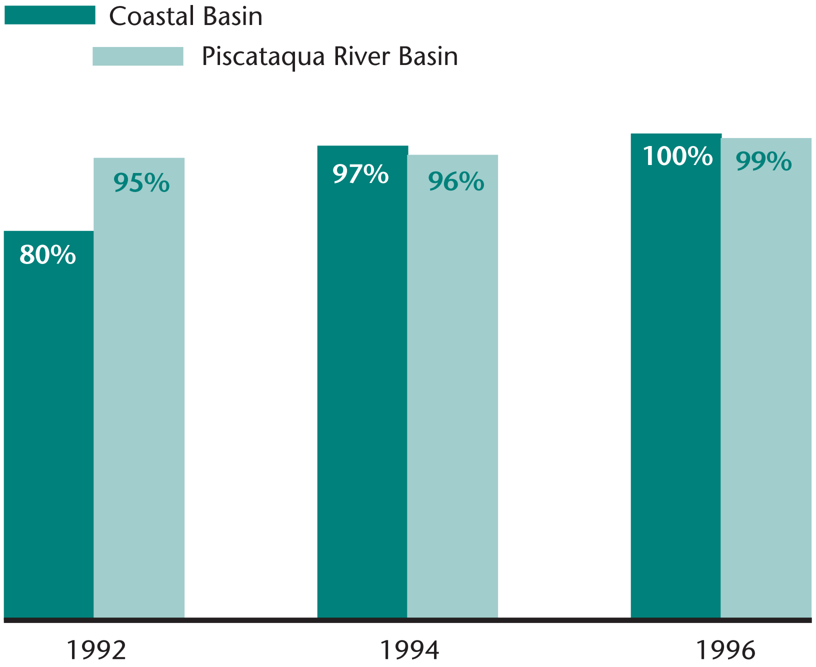
2.1.1 BACKGROUND

The Federal Water Pollution Control Act, as reauthorized by the Water Quality Act of 1987, requires New Hampshire to submit a report that describes the status of ground and surface waters to the US Environmental Protection Agency (USEPA) and Congress every two years. These "305(b)" reports have been published every two years since 1988. Surface waters are assessed according to overall quality and use support, individual use impairments, causes of impairments, trends in water quality, wetlands and public health/aquatic life concerns. More detailed summaries of overall quality/use support and some individual use impairments are summarized in Appendix F for the 1988 through 1996 305(b) reports.

Overall water quality and use support data are separated into freshwater and tidal waters, then by defined areas in the coastal area. The classification for use support provides information on the miles of freshwater streams and rivers in the Coastal and Piscataqua River basins supporting all uses. The tidal waters include the open ocean (Isles of Shoals), coastal shoreline and the estuaries as separate areas. Figures 2.1 and 2.2 summarize the trends in water quality for these waters from 1992 to 1996. Water bodies are classified as either "fully supporting", "partially supporting" or "not supporting" all uses. The definitions for these classification categories are as follows:

- fully supporting: criteria for contaminants or conditions are not exceeded, or are exceeded infrequently for any measurement, and no bans/advisories are in effect;
- partially supporting: criteria for contaminant exceeded at low to medium frequency for any measurements, restricted consumption advisory or ban in effect, or advisory lasting only a short period;
- not supporting: criteria exceeded at medium frequency, advisory periods too long or too frequent, or "no consumption" ban in effect.

FIGURE 2.1 *Percent of classified coastal waters as fully supporting all uses: Freshwater (NHDES, 1996b).*

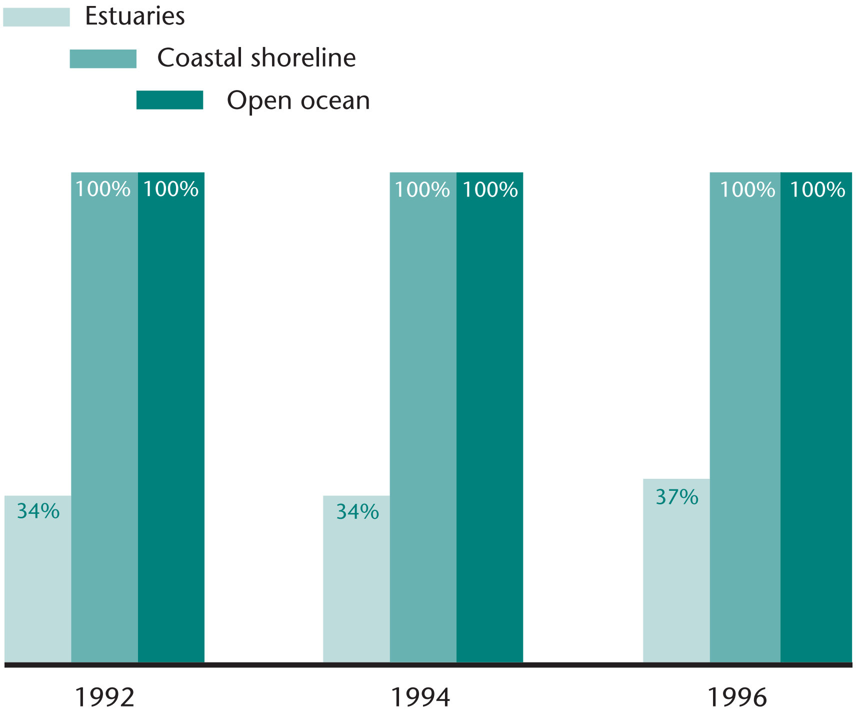


These classification categories are defined in more detail for the different individual use categories, including aquatic life use, drinking water use, recreational use and fish consumption use, based on USEPA guidelines. The aquatic life use category criteria are based on conditions where chlorine, ammonia or other toxicants cause violations based on acute toxicity tests, or conditions relative to dissolved oxygen, pH or temperature exceed criteria limits.

The overall program of assessing water quality and use support has evolved since 1988. In general, less information was available in earlier years for assessing surface waters, and the assessment of some uses was incomplete. More recent data, showing a high degree of support for all uses, are more complete and therefore more accurate relative to a greater range of contaminants. Between the 1990 and the 1992 305(b) reports, the USEPA suggested that New Hampshire and other states use a new database (Waterbody System software; River Reach File-RF3) for defining hydrologic features. The miles for surface waters reported by New Hampshire decreased from 14,544 to 10,841 miles as a result of differences in scale used to trace hydrologic features. In previous years, NHDES only assessed, or made use support decisions, on 1348 miles statewide. The assessed waters tended to be "problem" waters. In 1992 and thereafter, NHDES has used any available information to assess all waters, and area/mileage assessed for all freshwater and estuarine waters thus increased from 1990 to 1992. Other changes in the program resulted from passage of HB 560, amending RSA 485:A, by the legislature in 1991. Thereafter, all existing Class C waters were reclassified and upgraded to Class B, with the goal of attaining "fishable and swimmable" conditions in all surface waters. HB 560 also included adoption of different bacterial indicators for freshwater and tidal waters. Based on EPA recommendations, fecal indicators were changed as *Escherichia coli* was adopted for freshwater and enterococci was adopted for tidal recreational waters. RSA 485:A was also changed to allow for use of any indicator adopted by the National Shellfish Sanitation Program (NSSP) for classification of shellfish growing waters.

Percent of classified coastal waters as fully supporting all uses: Tidal water (NHDES, 1996b).

FIGURE 2.2



Hampton Beach

2.1.2 STATUS AND TRENDS OF OVERALL WATER QUALITY AND USE SUPPORT

There has been a general improvement in water quality in the fresh and tidal surface waters of New Hampshire since 1988 that can be attributed in large part to improvements in sewage treatment facilities. In the Coastal Basin, at least 75% of the rivers and streams have fully supported all uses since 1988, improving to 100% support of all uses in 1996 (Figure 2.1; NHDES, 1996b). The Piscataqua River Basin has had as little as 45% of rivers and streams supporting all uses (NHDES, 1990). In 1996, only 11 of 1001 miles of freshwater rivers and streams in the Piscataqua River Basin were partially or not supporting full use.

For all uses of New Hampshire's open ocean and coastal shoreline areas, only swimming restrictions were impairments from 1992 to 1996. This areas has since had shellfish harvesting closures imposed. From 1992 to 1996, the coastal basin and open ocean waters fully supported all uses (Figure 2.2). Estuaries have had large areas with classifications that reflect impaired use because of restrictions on shellfish harvesting due to the presence of indicators of pathogens (Figure 2.2). Recent efforts to reclassify shellfish waters have resulted in improved use support in 1996. Indicators of pathogens also caused decreased support for swimming in open ocean and coastal shoreline areas from 1988-1992, while estuarine waters have had no restrictions on swimming.

Whole effluent toxicity tests decreased uses of some coastal tributaries in 1992, and the presence of elevated metal concentrations decreased use support in tidal waters in 1994. Metals also impaired use of some freshwater streams in 1996. Aquatic life support was impaired in the Lamprey River in 1994 because of metals (NHDES, 1994). Only 4.4 square miles of estuarine waters supported aquatic life

TABLE 2.1

National Pollutant Discharge Elimination System (NPDES) permitted sites in coastal New Hampshire area for which monitoring data are available in the Permit Compliance System database.

NEW HAMPSHIRE

Wastewater Treatment Plants (WWTP)		Receiving waters
NH0020966	Wallis Sands, Rye	Atlantic Ocean
NH0100196	Newmarket	Lamprey River
NH0100234	Portsmouth	Piscataqua River
NH0100251	Rollinsford	Salmon Falls River
NH0100277	Somersworth	Salmon Falls River
NH0100455	Durham	Oyster River
NH0100609	Rockingham County Complex (prison)	Ice Pond Brook
NH0100625	Hampton	Tide Mill Creek
NH0100668	Rochester	Cocheco River
NH0100676	Milton	Salmon Falls River
NH0100692	Epping	Lamprey River
NH0100854	Farmington	Cocheco River
NH0100871	Exeter	Squamscott River
NH0101028	Star Island Conference Center	Atlantic Ocean
NH0101141	Newington	Piscataqua River
NH0101192	Newfields	Squamscott River
NH0101303	Seabrook	Atlantic Ocean
NH0101311	Dover	Piscataqua River
NHG640006	Swains Lake Village Water District	Swains Lake via wetland
Industry		
NH0000469	Tillotson Healthcare Co., Rochester	Salmon Falls River
NH0001091	KJ Quinn & Co., Inc., Seabrook	Cains Brook
NH0001490	Simplex	Piscataqua River
NH0001503	Bailey Corp.	Hunts Island Creek
NH0020923	Little Bay Lobster	Piscataqua River
NH0022306	Morton International, Seabrook	Cains Brook
NH0022055	EnviroSystems-Hampton	Taylor River
NH0022985	Aquatic Research Organisms	Taylor River
NH0090000	Pease	Piscataqua River
NHG250317	GE Somersworth	Salmon Falls River
Power Plant		
NH0001601	PSNH Newington Station	Piscataqua River
NH0001473	PSNH Schiller Station	Piscataqua River
NH0020338	Seabrook Station	Atlantic Ocean
Water Treatment Plant		
NH0000884	Portsmouth (Madbury)	Johnson Creek
NH0001031	UNH	Oyster River
NHG640007	Newmarket	Lamprey/Piscassic rivers

MAINE

Wastewater Treatment Plants (WWTP)		Receiving waters
ME0101397	Berwick Sewage District	Salmon Falls River
ME0100285	Kittery	Piscataqua River
ME0100820	South Berwick Sewer District	Salmon Falls River
Industry		
ME0000868	Portsmouth Naval Shipyard, Dry docks	Piscataqua River
ME0022861	Pratt & Whitney	Great Works River
ME0022985	Watts Fluidair, Corp., Kittery	Wilson Creek

use in 1996, the other areas only partially supported aquatic life because of elevated levels of PCBs in lobster tomalley (NHDES, 1996b). Overall, none of the estuarine water supported full use because of either PCBs or pathogens. Recreational uses and fish consumption were fully supported in all estuarine waters. The health advisory for lobster tomalley is probably the result of historical PCB contamination, and the re-classification is based on studies conducted in the late 1980s and early 1990s (Isaza et al., 1989; Schwalbe and Juchatz, 1991).

Septic systems, land disposal of solid wastes, stormwater runoff, CSOs and point sources have been the most common suspected sources cited in 305(b) reports for non-support, although the estuarine sources of the PCBs responsible for the lobster consumption advisory are unknown. The presence of pathogens, indicated by the presence of elevated concentrations of fecal indicator bacteria, has been the most common pollutant. Other problem pollutants and conditions have been in-stream toxicity, low dissolved oxygen, ammonia and metals. The trends presented in the two figures reflect to a great extent the evolving program of assessment.

The State of New Hampshire regulates point sources primarily through the National Pollutant Discharge Elimination System (NPDES). Dischargers are required to obtain discharge permits and the discharge has to meet set limits. The permitted dischargers in New Hampshire and Maine are listed in Table 2.1. Sites are categorized as wastewater treatment facilities (WWTFs), industries or power plants. There are 19 WWTFs, ten industries and three power plants permitted dischargers in coastal New Hampshire waters, and three WWTFs and three industry permittees in Maine that discharge into the waters of the Great Bay Estuary.

The NPDES program is a source for a limited range of general contaminant data in point source effluent. Monitored permit data are available from the Permit Compliance System database which is maintained by the USEPA. The NHDES and the USEPA both get reports from permittees and act on violations, should they occur. A review of data for 1996 at all permitted sites in Table 2.1 showed violations of bacterial indicator limits were frequent at some sites and were always met at other sites. Only rare violations of limits for discharges of metals occurred. Various toxicity assays are used on effluent at most facilities other than some power plants. Some facilities had no violations while others had occasional violations of toxicity limits. Two WWTFs in New Hampshire had problems with meeting ammonia discharge limits.

In general, the water quality in coastal New Hampshire has improved. The major factor has been improved sewage treatment facilities capabilities for eliminating microbial contaminants from their discharges. However, both monitoring activities and the contaminants measured have increased during the last ten years, resulting in identification of previously undocumented causes for use limitations. These changes have occurred while loading characteristics, discharge permit requirements and contaminant issues have changed to reflect evolving concerns. There is a continuing need to identify and reduce or eliminate sources of pollutants that are presently responsible for limitations on uses of the state's estuarine and coastal waters.

2.2

STATUS AND TRENDS OF MICROBIAL PATHOGENS AND FECAL INDICATORS

Humans are susceptible to diseases caused by waterborne microorganisms. Some viruses, bacteria and protozoa are human pathogens, and their presence in surface waters and shellfish is a public health threat. Some pathogenic microorganisms are present naturally in estuaries and coastal waters. The ecology of many of these indigenous microorganisms is not well understood, and their presence would be difficult to manage. However, most waterborne pathogens of concern in northern New England are of fecal origin and thus are not natural inhabitants in estuarine waters. These microbes are introduced into coastal waters largely as a result of human activities, and can thus theoretically be controlled. Known anthropogenic sources include inadequately treated wastewater discharges, septic systems, boat discharges, urban and agricultural runoff and sanitary landfills, although significant contamination can also come from waterfowl and other wildlife.

2.2.1 PATHOGENS, BACTERIAL FECAL INDICATORS AND WATER QUALITY STANDARDS

The State of New Hampshire, along with every other jurisdiction that has the need to assess water quality and classify waters, uses bacterial indicators of fecal contamination to assess the sanitary quality of water. The number of potential fecal-borne pathogens, both bacterial and viral, are too numerous and difficult to measure on a routine basis. New Hampshire presently uses fecal coliforms for shellfish growing waters, as recommended by the National Shellfish Sanitation Program (NSSP, 1995). For recreational uses of marine and estuarine waters, enterococci are used, and *Escherichia coli* is used for freshwater recreational uses, both as recommended by the U.S. EPA. The bacterial indicator standards for classifying surface waters in New Hampshire are summarized in Table 2.2. These indicator bacteria have been chosen as the best indices of fecal contamination for the different purposes based on numerous studies. In many studies conducted by UNH/JEL, *Clostridium perfringens* is also included as an indicator of long-term fecal contamination and contamination associated with resuspended sediments. The following is a summary of information on the status and trends of these indicator bacteria, with some limited information on actual bacterial pathogens and viruses. Because of the extensive amount of data for the numerous bacterial indicators that have been used, fecal coliform data will be used for most illustrations of spatial and temporal trends.

TABLE 2.2

Bacterial indicator standards for surface water classification: freshwater, tidal recreational waters and shellfish-growing waters.

Surface water	Classification	Indicator	Geometric Mean Concentration*	GMC # of samples	Maximum Limit Concentration*	MLC Frequency
Freshwater	Class A	*Escherichia coli*	47	3 in 60 days	153	1 of 3 samples
FW designated beach	Class A	*Escherichia coli*	47	3 in 60 days	88	1 of 3 samples
Freshwater	Class B	*Escherichia coli*	126	3 in 60 days	406	1 of 3 samples
FW designated beach	Class B	*Escherichia coli*	47	3 in 60 days	88	1 of 3 samples
Tidal Recreational		enterococci	35	3 in 60 days	104	1 of 3 samples
Shellfish-growing	Approved	Fecal coliforms	14	30 (most recent)	>43	<10% of samples
	Restricted	Fecal coliforms	14-88	30 (most recent)	>260	<10% of samples
	Prohibited	Fecal coliforms	>88	30 (most recent)		

* Concentrations per 100 ml

2.2.1.1 Spatial Distribution

The spatial distribution of bacterial indicators in coastal New Hampshire has been relatively well documented in most areas. Adequate spatial coverage of sampling is necessary to aid in the identification of contaminant sources and to document the effects of efforts to reduce pollution sources. In general, bacterial contaminants are present at higher concentrations in tributaries in comparison to the main estuarine waters (Great Bay; Hampton Harbor) and the Atlantic Ocean. This is a function of the most important sources of contaminants being present upstream and along the shorelines of the tributaries, the smaller volumes of water in tributaries having less capacity for favorable dilution impacts on contaminant concentrations, and contaminants are subject to physical and biological processes that remove them from water as a function of time, distance and changing environmental conditions during transport through the tributaries to the main water bodies.

Early data on bacterial contamination can be found in Jackson (1944). These data reflected the high concentration loading of untreated sewage into the tributaries to Great Bay Estuary, all of which had average total coliform concentrations of >800 /100 ml, with averages ranging from 803 to 9,020/100 ml. Concentrations were much lower at sites in Great and Little bays, but remained elevated compared to more recent data, ranging from 20 to 144/100 ml and generally in excess of the limit of 70 total coliforms/100 ml for shellfishing. In 1974, the New Hampshire Water Supply and Pollution Control Commission (NHWSPCC) reported median total coliform concentrations ranging from 50/100 ml at an upstream site in the Exeter River to 109,000/100 ml at an upstream site in the Cocheco River in freshwater tributaries (NHWSPCC, 1975). In tidal waters, concentrations were <21/100 ml at Hampton Harbor, the Atlantic coast areas and in the Bellamy River, but ranged up to 307,000/100 ml in the Cocheco River.

State agencies have conducted routine monitoring of coastal waters for over 30 years. Freshwater sites are monitored by NHDES, with NHDES, NHDHHS and NHF&G monitoring tidal waters. Citizen volunteers have also been involved in monitoring microbial water quality in the coastal waters. The Great Bay Watch has monitored fecal coliforms at up to 24 sites in the Great Bay Estuary for over ten years (Reid et al., 2000). UNH and JEL have contributed substantial water quality data as a result of numerous studies throughout coastal New Hampshire.

Great Bay and Upper Little Bay with Squamscott/Exeter and Lamprey Rivers

This area extends from the dams on the two rivers through all of Great Bay and upper Little Bay to Fox Point and the area south of the mouth of the Oyster River (Figure 2.3). The most spatially and temporally intensive database for bacterial contaminants in Great Bay is the NHDHHS shellfish water monitoring program database. The data for 12 of the NHDHHS sampling stations (Figure 2.3) were reviewed and interpreted as part of the 1995 sanitary survey for the approved shellfishing areas in Great and Little bays (NHDHHS, 1995; Jones and Langan, 1995b). Fecal coliform concentrations were low enough to support an approved classification for much of Great Bay, although elevated concentrations near the mouths of the Lamprey, Squamscott, Oyster and Winnicut rivers only supported restricted or prohibited classifications. Major rainfall events had significant negative effects on water quality throughout the area and were noted as a potential condition for classification. The area near the mouths of the Squamscott and Lamprey rivers has recently been subject to more detailed monitoring to better define the boundary between restricted and approved classifications. Dye studies for the Durham and Newmarket wastewater treatment facilities (WWTFs) plus the Great Bay Marina have been conducted, and the results will provide needed data to better define safety zones in areas

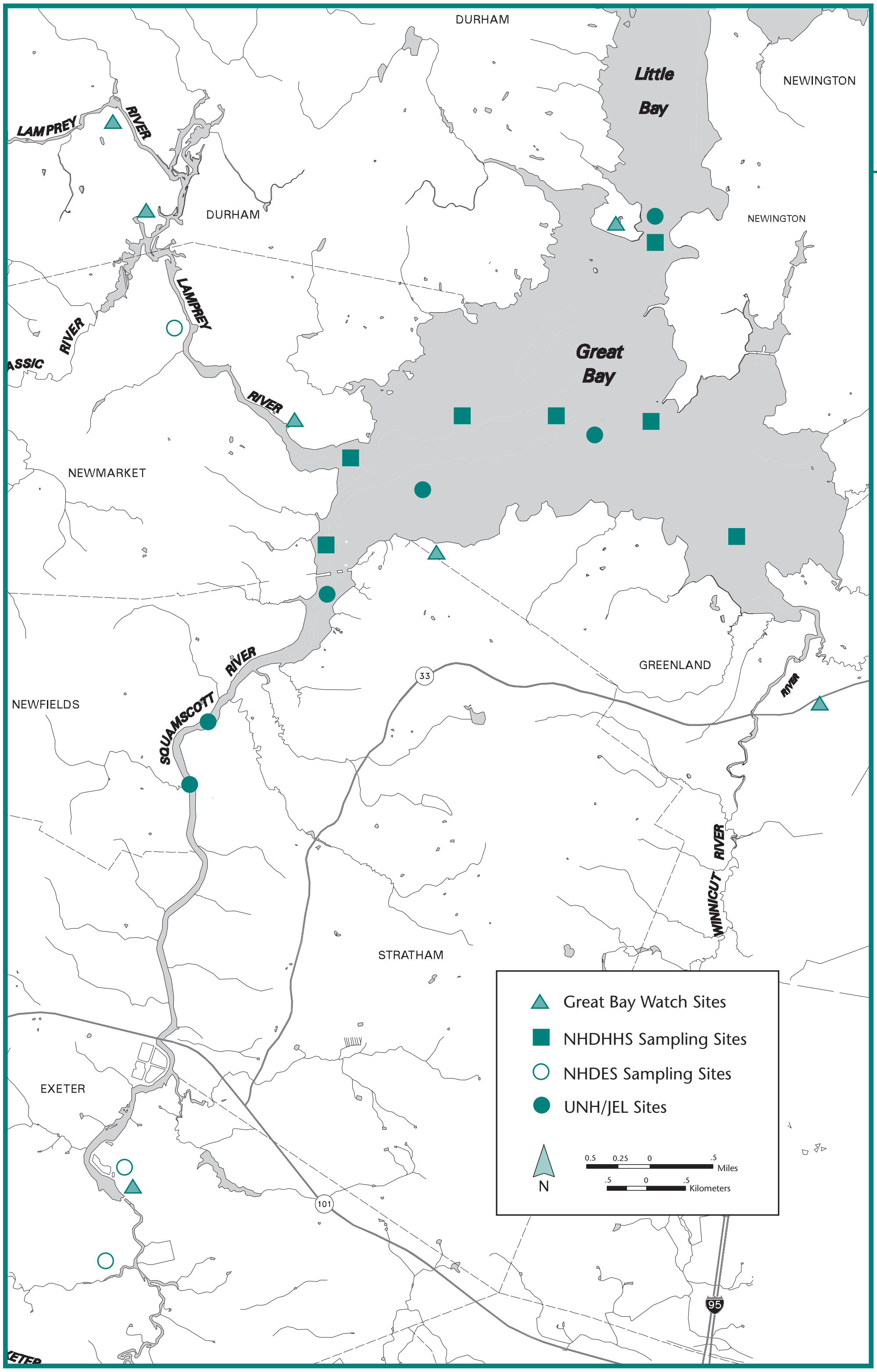


FIGURE 2.3

Great Bay, Upper Little Bay, Squamscott/Exeter River and Lamprey River water quality sampling region.

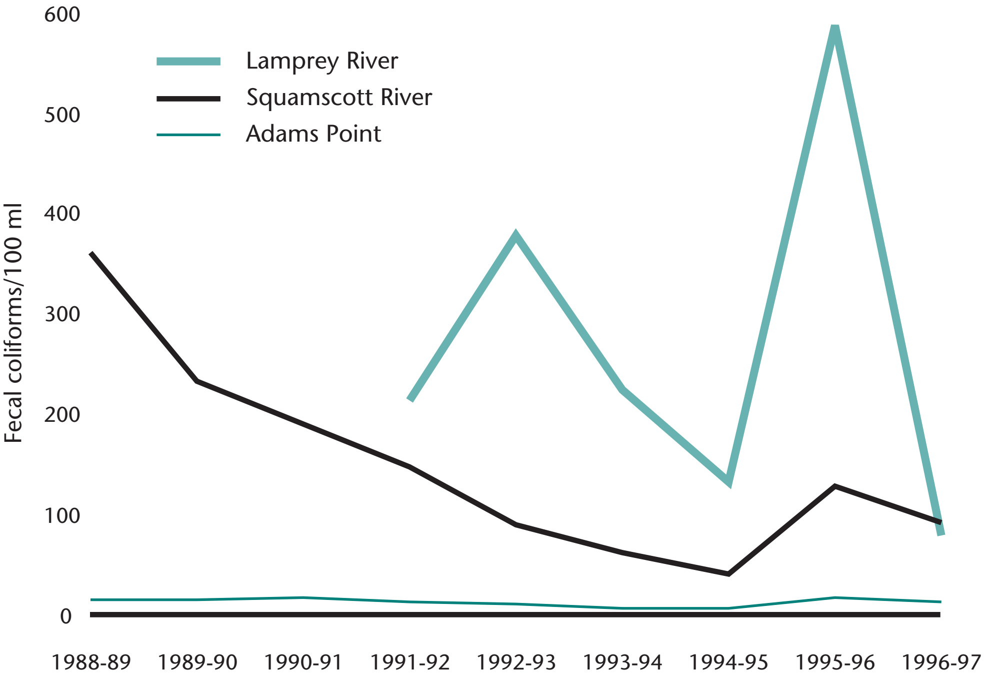
around the mouths of the Lamprey and Oyster rivers and in Little Bay.

The long-term Great Bay National Estuarine Research Reserve (GBNERR) monitoring program has provided an eleven year database for fecal coliforms, enterococci, *E. coli* and *C. perfringens* at Adams Point between Great and Little bays, Chapmans Landing in the Squamscott River and at the Town Landing on the Lamprey River (Langan and Jones, 2000; Langan and Jones, 1997). In 1996-97 as in 1988-97, fecal coliform, *E. coli*, enterococci and *C. perfringens* concentrations were lowest at Adams Point at both high and low tides (Figures 2.4 and 2.5; Appendix G). Most indicators have been present at relatively low concentrations in the Squamscott River at high tide, whereas at low tide contaminant concentrations have been much higher. The large difference in contaminants in the Squamscott River is a result of dilution with less contaminated bay water at high tide. Bacterial indicators in the Lamprey River are present at elevated concentrations at both high and low tides. Similar observations, i.e., elevated bacterial levels in the Lamprey River compared to other areas in Great Bay at both high and low tide, have been reported by the Great Bay Watch (Reid et al., 2000). The Town Landing area appears to be significantly affected by undefined localized conditions that are currently under investigation by state agencies.

The water quality in the tributaries to Great Bay has been assessed as part of numerous other studies. Both the Lamprey and Squamscott rivers were part of a three year project to investigate the effects of storm events on water quality in all tributaries (Figures 2.6 and 2.7) to the Great Bay Estuary (Jones and Langan, 1994a; 1995a; 1996a). An analysis of all three years can be found in Jones and Langan (1996a). The geometric mean fecal coliform (FC) concentrations were relatively low during dry weather over the three year study at the freshwater sites just above the dams on both the Lamprey (9 FC/100 ml) and the Squamscott (31 FC/100 ml) rivers (Figure 2-6). Compared to the freshwater sites, the concentration at the tidal water sites were lower in the Squamscott (23 FC/100 ml) and higher in the Lamprey (48 FC/100 ml) during dry weather. Concentrations increased significantly at all four sites during storm events (Figures 2.6

FIGURE 2.4

Temporal trends for fecal coliforms (colonies/100 ml) at three sites in the Great Bay Estuary at low tide.



and 2.7). During the same years, fecal coliform concentrations in the Squamscott River downstream of the dam in downtown Exeter were generally >50/100 ml (Reid et al., 2000). Fecal coliform concentrations in the Winnicut River have been elevated compared to most other sites in Great Bay at low tide, but are diluted to low concentrations at high tide (Reid et al., 1998). The small tributaries that flow into the Winnicut River and the southeast corner of Great Bay were sampled during 1994-95 (Jones and Langan, 1995b). Despite some elevated concentrations of fecal coliforms, the tributaries appeared to have little impact on water quality in Great Bay.

Both the tidal and freshwater portions of the Squamscott/Exeter River watershed were studied in detail during 1994-95 (Jones and Langan, 1995c). Along the main channel of the Squamscott River, concentrations of fecal coliforms and *E. coli* increased dramatically going upstream from Chapmans Landing to the Exeter WWTF discharge pipe. Bacterial contaminants were present in relatively high concentrations in some of the fifteen small tributaries sampled along the Squamscott River, and analysis of salinities and bacterial contaminants suggested that the tributaries were affecting contaminant concentrations between Chapmans Landing and the upper reaches of the tidal river. However, there was no evidence for significant influence on water quality by any one tributary on the Squamscott River. Samples collected from ten sites in the freshwater Exeter River and tributaries showed higher concentrations in the downstream area near downtown Exeter. In a follow-up study, bacterial concentrations in the freshwater tributaries to the Exeter and Squamscott rivers were found to be elevated above state standards during dry and wet weather, with more severe contamination during wet weather (NHOSP, 1995a). The sites with higher concentrations in the lower portions of the Exeter River close to downtown Exeter were affected by stormwater runoff, and were suspected to be affected by septic systems and agricultural runoff (Becker and Radacsi, 1996).

An earlier study focused on the area from the Exeter River dam to Adams Point during 1989-90 (Jones, 1990). Prior to February, 1990, elevated bacterial concentrations in the Squamscott River were

Temporal trends for geometric means of fecal coliforms (colonies/100 ml) at three sites in the Great Bay Estuary at high tide.

FIGURE 2.5

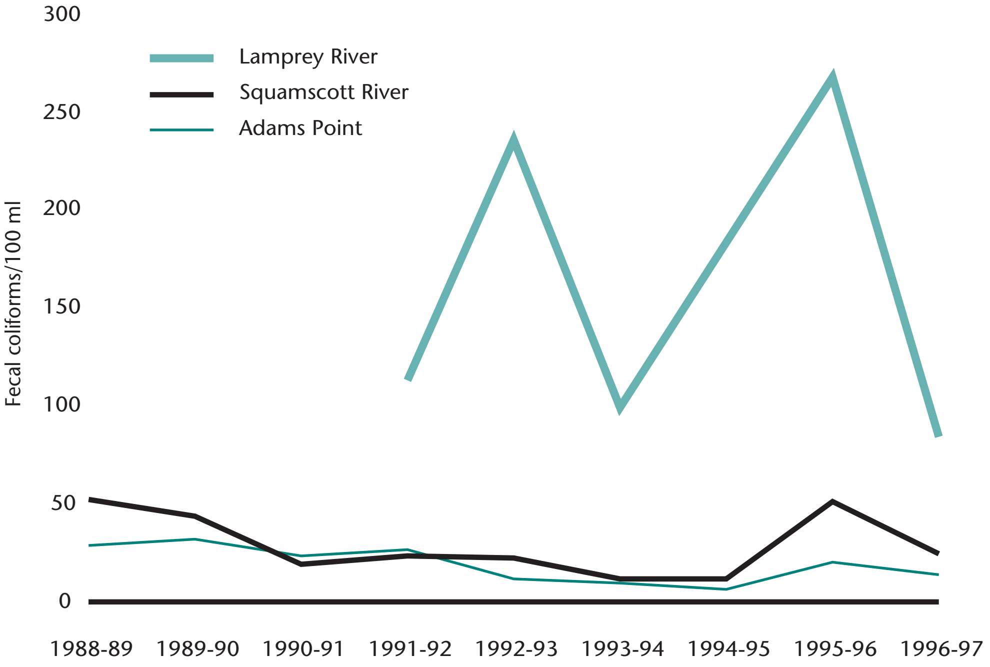


FIGURE 2.6

Geometric mean fecal coliforms (colonies/100 ml) in water collected during dry weather and storm events for three consecutive years in tributaries to the Great Bay Estuary: 1993-96, freshwater.

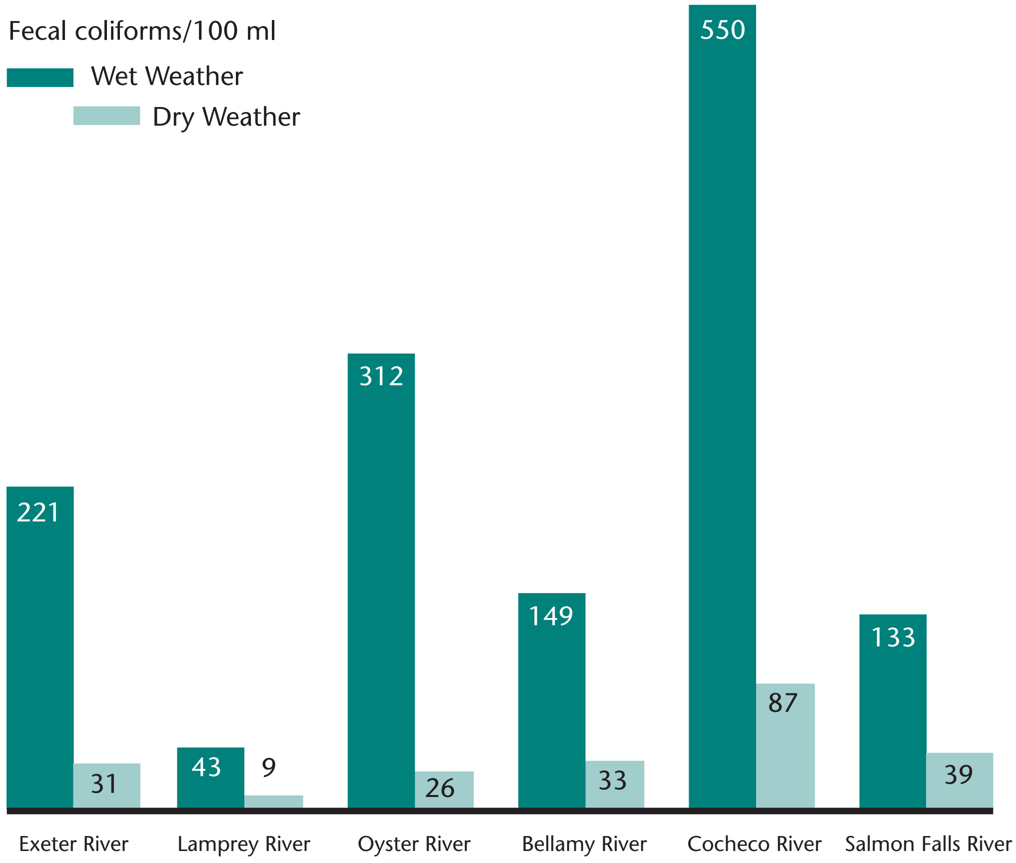
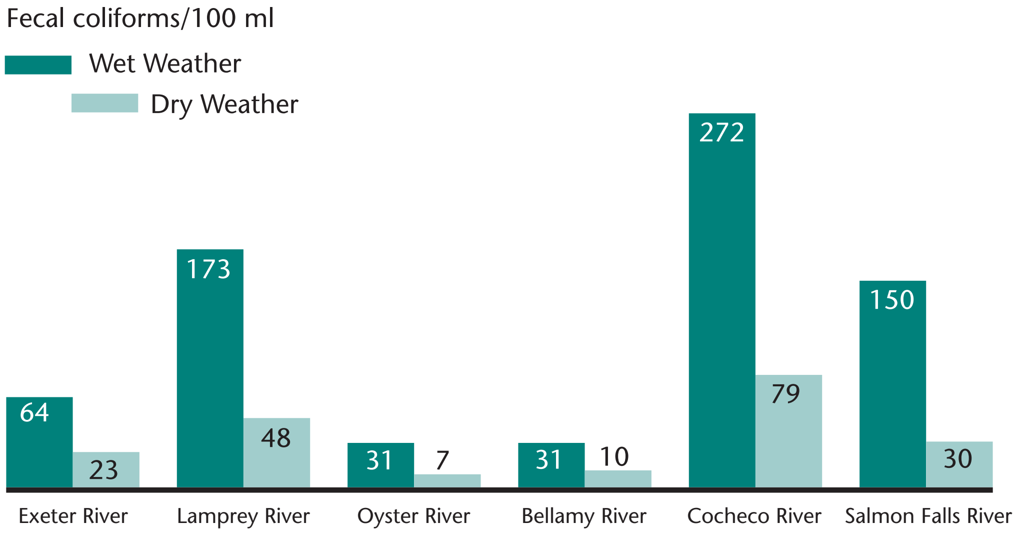


FIGURE 2.7

Geometric mean fecal coliforms (colonies/100 ml) in water collected during dry weather and storm events for three consecutive years in tributaries to the Great Bay Estuary: 1993-96, tidal water.



dominated by discharges from the Exeter WWTF. Water quality in the Squamscott River and Great Bay improved following the upgrading of the facility in early 1990. The concentrations of fecal coliforms, *E. coli* and enterococci discharged from the WWTF were high (105-106/100 ml) prior to the upgrade, and decreased to low levels (< 4/100 ml) thereafter. A comparison of indicators demonstrated the misleading nature of the total coliform assay. The organisms dominating a positive test value of 3000 total coliforms/100 ml in effluent collected after the upgrade when other indicator concentrations were nondetectable were identified as *Hafnia*, *Citrobacter* and *Aeromonas* sp., all common environmental species not associated with feces. These data were used as part of the justification by the state to discontinue use of total coliforms as an indicator of fecal contamination in surface waters.

Oyster and Bellamy Rivers and Lower Little Bay

This area extends from the freshwater portions of the two rivers through the tidal portions and into Little Bay from Fox Point to the General Sullivan Bridge (Figure 2.8). In the Oyster River, the DES and DHHS database results have been augmented by more detailed UNH studies (Jones and Langan, 1994c; 1993a; Margolin and Jones, 1990) and a recent study by NHCP (NHCP, 1996). NHDHHS data for 12 sampling stations in and around Great and Little bays were reviewed and interpreted as part of the 1995 sanitary survey (NHDHHS, 1995; Jones and Langan, 1995b). Fecal coliform concentrations were low enough to support an

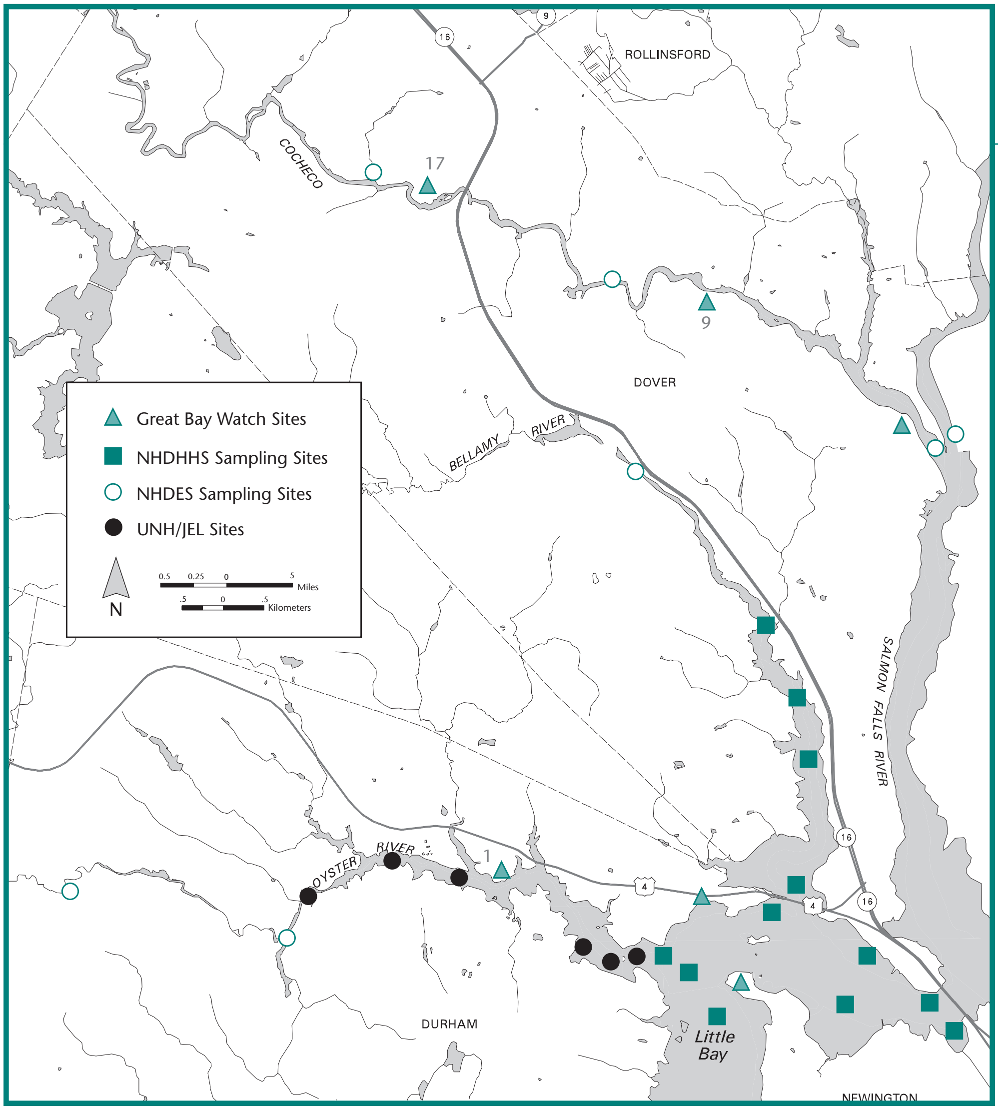


FIGURE 2.8

Oyster River, Bellamy River and Lower Little Bay water quality sampling region.

approved re-classification for the area in Little Bay that was monitored, which included two new sites during 1995-96 near Mathes Cove and Langley Island. Elevated concentrations near the mouth of the Oyster River only supported a restricted classification. Major rainfall events had significant negative effects on water quality and were noted as a potential condition for classification. Dye studies for the Durham WWTF and for the Great Bay Marina, conducted by USEPA in 1996 and 1997 (reports in preparation), will provide needed data to better define safety zones around these sites.

A new sanitary survey focused more intensive monitoring, including four new sites, in lower Little Bay (NHDHHS, 1998). Sanitary survey work was also performed in the Bellamy River and the analysis of fecal coliform data has been published (Jones, 1998a). The shoreline survey and fecal coliform concentrations at five of the six sites were consistent with an approved classification of much of lower Little Bay. Initially, only an area around Broad Cove was classified as approved, as other areas required additional samples. In June, 1998, as part of an amendment written to the original sanitary survey, most of the rest of lower Little Bay was re-classified as approved, except for an area from the mouth of the Oyster River east to Fox Point and areas around the two marinas.

Margolin and Jones (1990) found elevated concentrations of bacterial indicators in the Town Landing area of the Oyster River, especially following rainfall events. Geometric mean fecal coliform concentrations were >14/100 ml at six sites along the length of the river, except the WWTF outfall which had residual chlorine that disinfected the effluent and the river at the pipe. Poliovirus was also detected in 10 of 60 samples at six sites in the Oyster River, suggesting that sewage-borne viral pathogens could be present. There was no relationship between viral detection and concentrations of bacterial indicators.

The Oyster River Nonpoint Source Pollution Assessment project presented a comprehensive assessment of nonpoint source pollution in the Oyster River watershed, with emphasis on the tidal portion of the river and the tributaries that empty directly into the tidal river (Jones and Langan, 1993a). Fecal-borne bacteria levels were elevated in the watershed, and the levels in the tidal area were as high or higher than measurements made in other tidal rivers in the Great Bay Estuary. The geometric mean for fecal coliforms for all tidal sites was 37 FC/100 ml, which is consistent with a restricted or conditionally approved shellfish harvesting classification.

Fecal coliform and enterococci concentrations were highest in the Town Landing area, in Mill Pond and upstream in the tidal tributaries. Extensive sampling in the Beards and Johnson Creek watersheds showed elevated concentrations of bacteria throughout these watersheds. The bacterial contamination was dominated by nonpoint sources suspected to be on-site private sewage disposal systems (OSDs) and associated groundwater flow, urban and agricultural surface runoff, and other as yet undetermined sources. The evidence for these sources was based on elevated bacterial and nutrient contamination in some areas (Deer Meadow and Beards creeks) of the shoreline of the tidal river (suspected source: OSDs), areas within some tributaries where no direct source is apparent (suspected sources: groundwater flow, wildlife), consistent elevated responses to rainfall/runoff, and site-specific sampling around a farm where horses graze in and around a tributary. However, there is also some evidence to suggest that the Durham WWTF and some sewer lines are intermittent sources of significant contamination in water bodies that are crossed by sewer pipes.

The JEL study was continued for a second year, with more emphasis on the Johnson and Beards Creek watersheds (Jones and Langan, 1994c). Fecal coliforms, enterococci and *C. perfringens* concentrations were measured at fifteen sites along the tidal portion of the Oyster River. The highest concentrations were again detected in the upper reaches of the river near the Town Landing, with decreased fecal coliform and enterococci concentrations near the WWTF outfall caused by residual chlorine in the effluent. *C. perfringens* concentrations were highest near the WWTF outfall because their spores are resistant to chlorine disinfection. Elevated concentrations of bacterial indicators were again measured in the two watersheds, and a detailed study of salinity and fecal coliforms suggests that mixing of high concentrations in freshwater with cleaner salt water reduces bacterial concentrations in water beyond dilution effects. Expansion of sample sites into some branch brooks in the Johnson Creek watershed showed high concentrations around some housing developments that depend on septic systems, with one site contaminated by an identifiable residential septic system. In the more urban Beards Creek watershed, houses still on septic systems or leaky sewer lines were probably the sources of bacterial contamination. In fact, a small study at the mouth of Beards Creek gave clear evidence of contamination from a sewer line that crosses the mudflat. The latter and other identified sources of bacterial contaminants have been investigated by NHDES.

In a more recent study, data supported conclusions that the lower portion of the Oyster River watershed around downtown Durham is where most contamination occurs (NHCP, 1996). This study included sampling sites in the upper portions of the watershed and in the College and Pettee Brook areas that were not included in the JEL studies. Septic systems/leaky sewers and urban and agricultural runoff were probably the main sources of bacterial contamination. Sampling at most sites during storm events showed elevated bacterial concentrations, often exceeding 100 *E. coli*/100 ml, and sometimes exceeding 1000/100 ml for some sites.

Samples were collected at sites in the freshwater and tidal areas of the Bellamy and Oyster rivers as part of a three-year study to investigate the effects of storm events in tributaries to the Great Bay Estuary on water quality in the estuary (Jones and Langan, 1996a). The geometric mean concentrations of fecal coliform were relatively low during dry weather over the three year study at freshwater sites in both the Oyster (26/100 m) and the Bellamy (33/100 ml) rivers (Figure 2.6). The concentration in the tidal waters were low in both rivers (<11/100 ml) during dry weather (Figure 2.7). Concentrations increased significantly at all four sites, especially the freshwater sites, during storm events.

Salmon Falls, Cocheco, and (Upper) Piscataqua Rivers

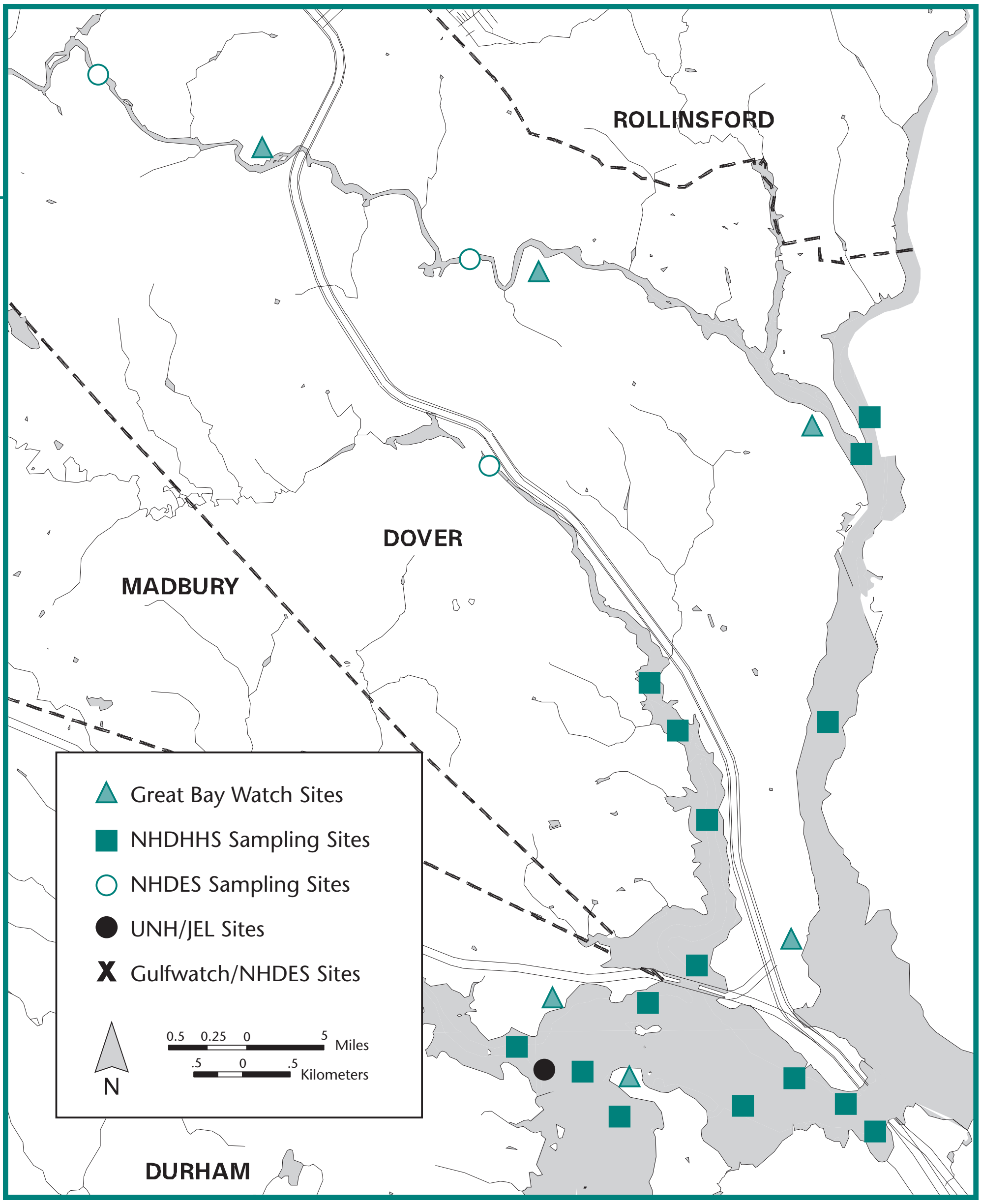
This area includes all estuarine and associated freshwater waters north of where Little Bay and the Piscataqua River meet near Dover Point (Figure 2.9). In the upper Piscataqua, Cocheco and Salmon Falls rivers, the DES and DHHS databases are augmented by some UNH studies, as well as State of Maine and Spinney Creek Shellfish Co. monitoring results (Mitnick and Valleau, 1996; Livingston, 1995). Sites in the freshwater and tidal areas of the Cocheco and Salmon Falls rivers were studied as part of the three-year investigation on storm events in tributaries to the Great Bay Estuary (Jones and Langan, 1996a). The geometric mean fecal coliform concentrations were elevated compared to other tributaries during dry weather over the three year study at freshwater sites in both the Cocheco (87 FC/100 ml) and the Salmon Falls (39 FC/100 ml) rivers (Figure 2.6). The concentration in the tidal waters were low in the Salmon Falls (30 FC/100 ml) and high in the Cocheco (79 FC/100 ml) during dry weather (Figure 2.7). Concentrations increased significantly (all >100 FC/100 ml) at all four sites, especially at the freshwater sites, during storm events. Some attenuation of bacterial concentrations apparently occurs between the upper and lower tidal portions of the Cocheco River, based on samples collected during 1997 (Reid et al., 1998). Even lower concentrations were measured downstream in the Piscataqua River. Lower bacterial concentrations were measured at a more upstream site in the Cocheco River. The high concentrations of bacteria in the downtown and downstream portions of the river suggest that urban areas of Dover are major sources of contaminants to this area of the Estuary, especially during storm events.

More recent studies have focused on contaminants in storm drains in downtown Dover and Exeter (Jones et al., 1999; Jones, 1998). All of the drains had detectable microbial contaminants during dry and wet weather. Levels of contaminants in street runoff were relatively low, suggesting that sources within the stormdrain system, probably illicit connections and leaking sewer pipes, were the major sources of the microbial contaminants. Contaminant concentrations in the Cocheco River were relatively lower during wet and dry weather compared to previous (Jones and Langan, 1996a) data.

Studies that focused on indigenous bacterial pathogens (i.e., vibrios) included assessments of fecal-borne bacteria (Jones et al., 1991a; O'Neill et al., 1990). Relatively high concentrations of fecal coliforms were detected in the Salmon Falls and Piscataqua rivers compared to Portsmouth Harbor during 1989-92. The general trend of higher concentrations of fecal-borne bacteria in tributaries was directly related to incidence of *Vibrio vulnificus* detection, but not for *Vibrio parahaemolyticus*.

FIGURE 2.9

Salmon Falls, Cocheco and upper Piscataqua rivers water quality sampling region.



Portsmouth and Little Harbors and Lower Piscataqua River

This area includes the Piscataqua River south of Dover Point, The Back Channel area and Portsmouth and Little harbors (Figure 2.10). In Portsmouth Harbor, Little Harbor, Back Channel and the lower Piscataqua River, routine NHDHHS and NHDES monitoring provides the most consistent databases, along with some limited UNH/JEL data. The data from the NHDHHS database have been summarized and interpreted relative to shellfish water classification standards in Jones and Langan (1996c), and more recent data are available (Appendix G). Sites in Little Harbor were generally in support of an approved classification, while fecal coliform concentrations were relatively high in Back Channel and tributary sites. Some areas in the Back Channel will probably be within a closed safety zone in the area around the Portsmouth WWTF effluent pipe.

A spatially intensive monitoring program to determine fecal contamination levels in water around Portsmouth Harbor, including some sites on the New Hampshire side, was conducted during 1992-93 (Jones, 1994). The sites were located along the main channel of the Piscataqua River. The geometric means for enterococci in the study area waters were generally consistent with safe recreational use criteria set by Maine and New

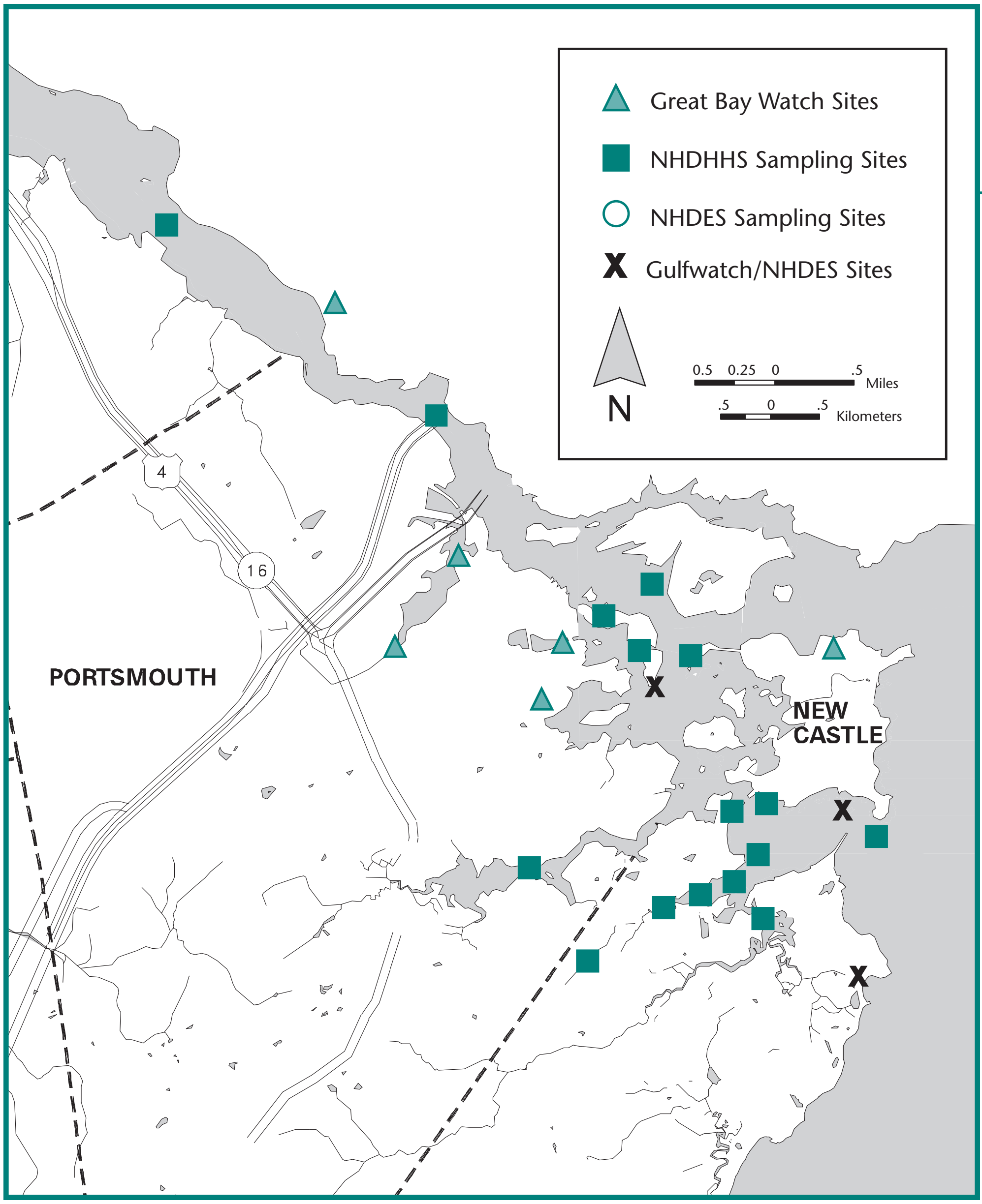


FIGURE 2.10

Portsmouth and Little Harbors and lower Piscataqua River water quality sampling region.

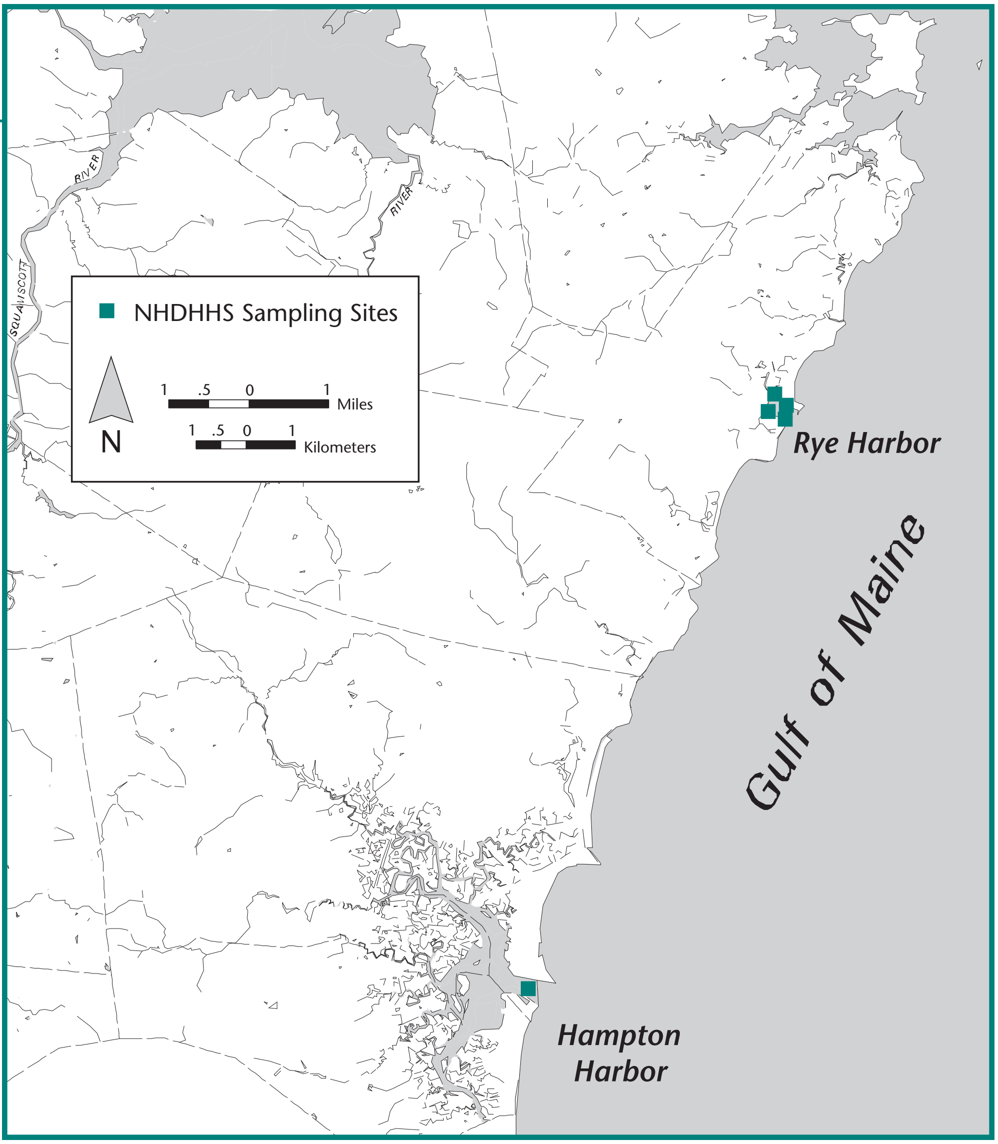
Hampshire (geometric mean <35/100 ml). The geometric means for fecal coliforms were all lower than the limit of 14 fecal coliforms/100 ml for approved shellfish-growing waters, but the frequency of samples greater than 43/100 ml was greater than 10% at the 6 stations. A long-term database (monthly for ten years) for samples from Ft. Constitution in New Castle has shown concentrations of fecal indicator bacteria to be consistently low at the mouth of the river (Dr. S. Jones, unpublished data). Four sites in North and South Mill ponds have been monitored for fecal coliforms saince 1997 by the Great Bay Coast Watch (Reid et al., 2000). Two one-year studies in North Mill Pond included fecal coliform measurements of the pond and storm drains (Jones, 2000; ANMP, 1998).

Rye Harbor and Coastline

This area includes the coastal areas from Little Harbor south to Hampton Harbor (Figure 2.11). In Rye Harbor and the coastline, existing data are mostly from NHDHHS and NHDES monitoring programs. Some of the data from the NHDHHS database have been summarized and interpreted relative to shellfish water classification standards in Jones and Langan (1996c), and more recent data are also available (Appendix G). NHDHHS data for some additional sites in tributaries are not presented, and NHDHHS data are summarized in Appendix G. The geometric mean concentrations of fecal coliforms at all four sites were <14/100 ml. However, the incidence of samples >43/100 ml was in excess of 10% in the

FIGURE 2.11

Coastal New Hampshire, from Little Harbor to the Massachusetts border, water quality sampling region.



last 30 samples at all but an inner harbor site, suggesting non-random contamination events are too frequent in the harbor to allow approved shellfish classification (NSSP, 1995). A boat pumpout facility has recently been put in at the NH Department of Resources and Economic Development (DRED) dock.

Hampton Harbor and Tributaries

This area includes all of the Hampton/Seabrook Estuary and tributaries (Figure 2.12). In Hampton Harbor, routine NHDHHS and NHDES monitoring, in cooperation with NHF&G, has provided long-term databases, while some recent more detailed UNH/JEL studies provide added information (Langan and Jones, 1995 a&b). The NHDHHS data for sites currently used for classifying shellfish waters in Hampton Harbor have been reviewed and interpreted (NHDHHS, 1994a), and more recent data are presented in Appendix G. The geometric mean fecal coliform concentrations for all ten sites were <14/100 ml. However, the incidence of concentrations >43/100 ml exceeds the standard 10% at some sites. Some of the sites with the more frequent incidence of high concentrations are near the mouth of Mill Creek on the west shore, suggesting that contamination from the creek may be influencing water quality in the area. Improved water quality in recent years has resulted in a recent upgrading of the shellfish harvest classification of the large Middle Ground clam flat in Seabrook from restricted to conditionally approved (NHDHHS, in prep.).

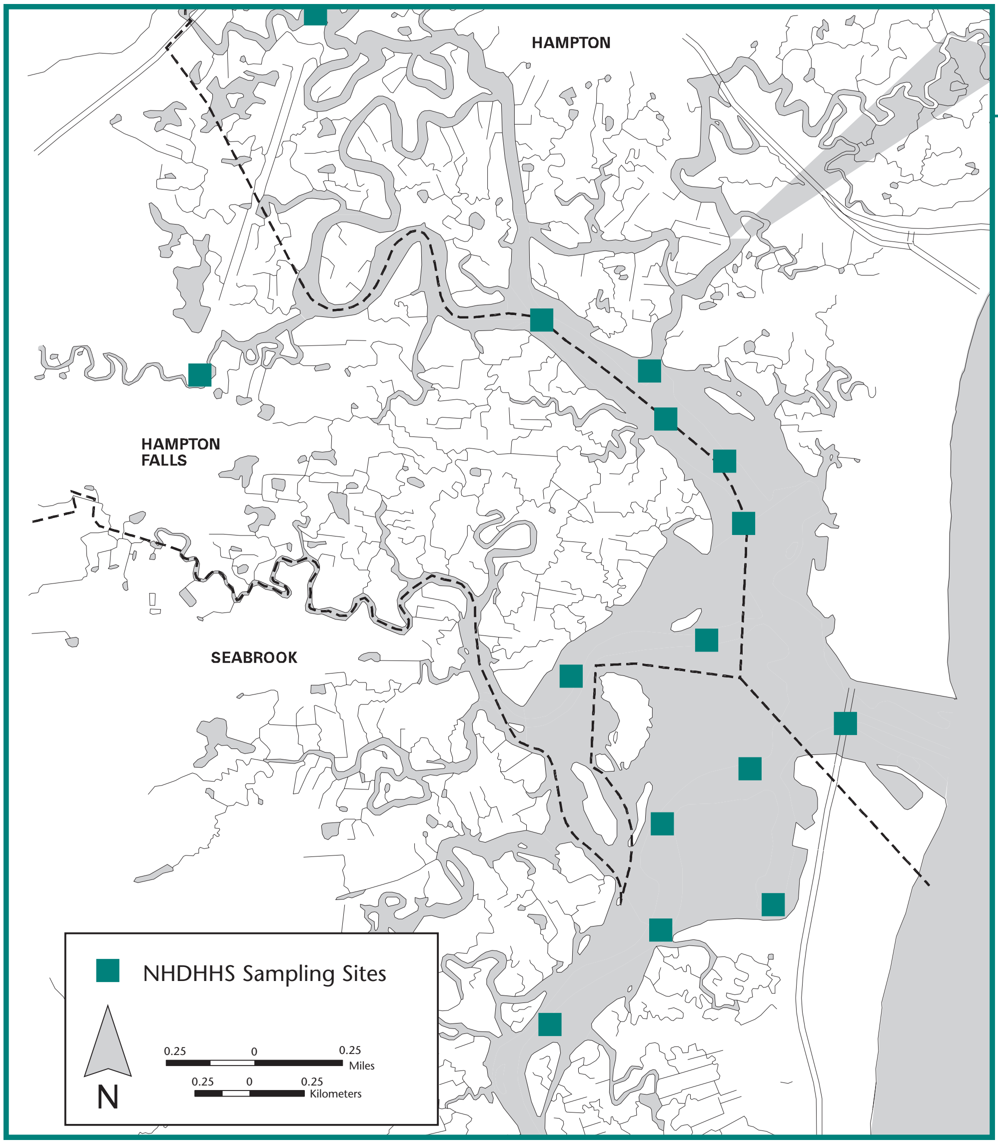


FIGURE 2.12

Hampton Harbor and tributaries water quality sampling region.

Water quality survey on Cocheco River

A two-year study on septic systems in Seabrook included some surface water monitoring, with emphasis on tributaries that border residential areas (Jones et al., 1995; 1996). Samples were collected from 16 sites at low tide in Mill Creek, Farm Brook, some tidal creeks and the harbor. Water from Mill Creek had the highest levels of indicator bacteria (<200 FC/100 ml) during sampling in 1995 and 1996. Concentrations of bacteria detected at all upstream tributary sites were elevated compared to harbor sites. Lower concentrations in the harbor were probably the result of dilution and die-off in the more saline waters, which represents less favorable conditions for bacterial survival. Seven sites, mostly in tributaries, did not meet the New Hampshire swimming water standard of 35 enterococci/100 ml. Based only on the study data, only one site had a mean fecal coliform concentration <14/100 ml. There was no clear relationship between groundwater contamination and surface water quality at any site, although the elevated concentrations of bacteria in streams near high density residential areas suggests septic systems are a likely source of contamination. During 1996-97 when septic systems were being disconnected and sewage was diverted to the new treatment facility, measurements of contaminants in the surface waters of the harbor and tributaries showed little change from previous years (Jones, 1997).

Clearly, there are sources of bacterial contaminants that persist in all areas of coastal New Hampshire and limit uses of estuarine and coastal waters. The concern is the protection of public health in areas that will only experience increased human use in the future. Continued efforts to identify and either eliminate or effectively manage the impacts of fecal contamination sources is an important, on-going issue in coastal New Hampshire. As the next section suggests, water quality in general has improved over the last ten years, but the widespread nature of the problem suggests that much remains unknown about the issue.

2.2.1.2 Temporal Trends

There appear to be some general temporal trends that have occurred in many areas of the Seacoast. Fecal-borne bacterial contaminant concentrations have decreased in all coastal waters since the early 1990s as a result of the extensive improvements to wastewater treatment facilities. Bacterial contaminants are also generally present at higher concentrations at low tide compared to high tide, mostly as a function of mixing of more contaminated freshwater with cleaner tidal water. Bacterial concentrations are often elevated during autumn and winter compared to other seasons in some areas. This observation is probably related both to the amount of runoff associated with rainfall events as a function of seasonal differences in evapotranspiration and infiltration, and to the enhanced survival of bacterial contaminants with colder water temperatures (Jones et al., 1997). The most severe incidences of elevated contamination occur in temporally less predictable conditions, i.e., following rainfall/runoff events and upsets in treatment processes at WWTFs. In addition, >100 year storms such as the one that occurred in October, 1996, tax the capacities of most WWTFs because of infiltration into the sewer systems and overloading of treatment plants. Some areas are more prone to contamination incidences because of proximity to WWTFs, especially those that may lack effective control measures for stormwater runoff and have less capacity for effective wastewater treatment during storm events.

TABLE 2.3

Long-term trends for total coliform concentrations (per 100 ml) in water samples collected from six tributaries to the Great Bay Estuary, 1960, 1975, and 1996.

FRESHWATER SITES AT TIDAL DAMS

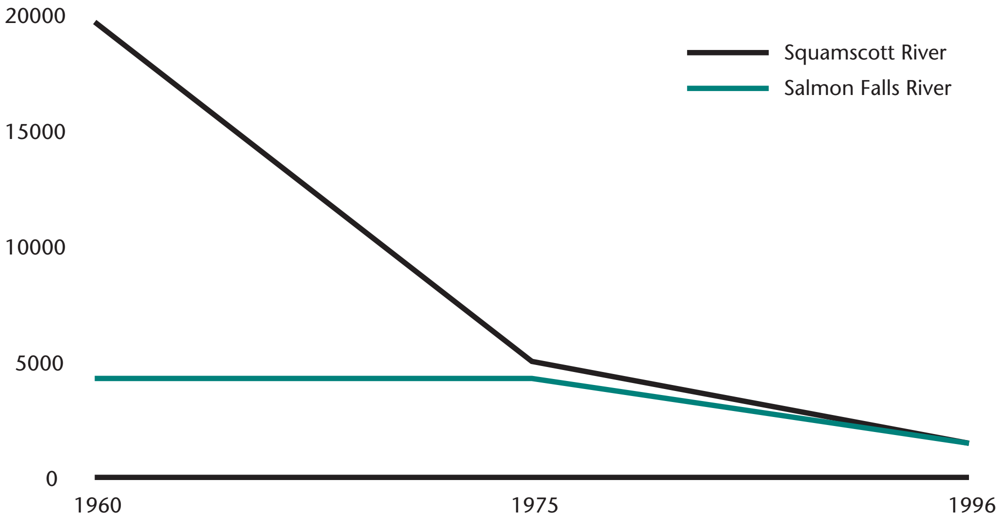
YEAR	Exeter R. 9-EXT	Lamprey R. 5-LMP	Oyster R. 5-OYS	Bellamy R. 5-BLM	Cocheco R. 7-CCH	Salmon Falls R. 5-SFR
1960	19700	524	656	—	16540	4266
1975	5044	1088	3742	4786	133690	4266
1996*	1490	350	1310	1345	1530	1475

*1996 data transformed by multiplying fecal coliform concentrations by 5.

Certain sites in coastal New Hampshire have been sampled for decades and the results can be used for determining temporal trends. Data from three reports (Jones and Langan, 1996a; NHWSPCC, 1975; NHWPC, 1960) are summarized in Table 2.3 to illustrate the dramatic improvements in water quality since 1960. Because the two earlier reports used total coliforms and the third used fecal coliforms, it was assumed that total coliform concentrations were equivalent to five times the fecal coliform concentrations, and the 1996 data were converted to total coliform equivalent data. This conversion is based on the relationship between total and fecal coliform standards for classifying shellfish growing waters (NSSP, 1995). The data show decreases in total coliform concentrations in all six rivers from 1960 to 1996. The decrease was most dramatic in the Cocheco River, which has remained the most contaminated tributary since 1944, but which showed a nearly 100-fold decrease from 1975 to 1996. The higher concentrations in 1975 compared to 1960 may reflect increased loading of wastewater treatment facilities due to the nearly doubling (158,800 to 275,800) of populations in Rockingham and Strafford counties from 1960 to 1980 (NHOSP, 1997a). There was also a dramatic, steady decrease in the Exeter/Squamscott River and a less extensive decrease in the Salmon Falls River (Figure 2.13). The following section summarizes in more detail existing information on the temporal trends of bacterial contamination in the different estuarine and coastal areas of New Hampshire. Where possible, discernable temporal trends are related to

FIGURE 2.13

Total coliforms (colonies/100 ml) in the Exeter/Squamscott and Salmon Falls rivers: 1960-1996.

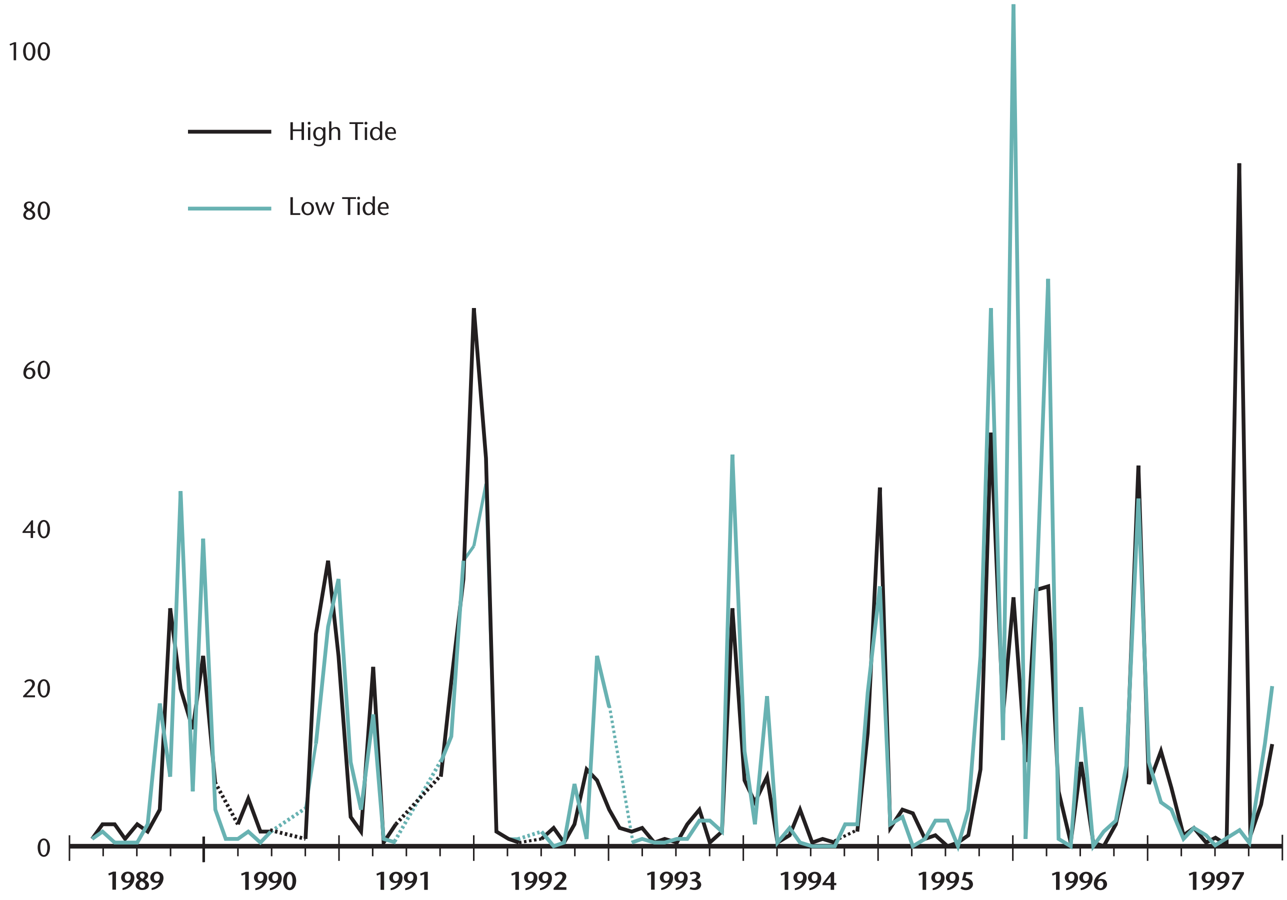


management efforts to reduce pollution.

The overall trend over the nine year period of GBNERR monitoring (Langan and Jones, 1997) has been a general decrease in bacterial contaminants at all sites (Figures 2.4 and 2.5), although concentrations of all indicators were higher during 1995-96 than during previous years. The three-year study of tributaries to Great Bay Estuary also showed some bacterial contaminants were present at significantly higher concentrations during 1995-96 compared to the previous two years in the Lamprey and Squamscott rivers (Jones and Langan, 1996a). The long-term decrease in bacterial concentrations was most dramatic in the Squamscott River, especially after 1990 when the Exeter WWTF was upgraded. Trends for fecal contaminants were less dramatic at other sites like Adams Point, where concentrations have been relatively low (<33 FC/100 ml) since 1988. It also appears that reducing concentrations much below the standard 14 FC/100 ml may be difficult when other areas continue to have higher concentrations. Seasonal trends show contaminants tend to be present in higher concentrations during late autumn and winter, as illustrated in Figure 2.14 for enterococci at Adams Point from 1989-97, which is consistent with runoff conditions and bacterial survival patterns (Jones et al., 1997). As previously mentioned, contamination trends at the Lamprey River do not follow typical patterns, as fecal coliforms are typically highest during the summer, instead of autumn/winter.

Various studies in the Oyster River were conducted from 1992-1997 (Jones and Langan, 1996a; 1994c; 1993a; Reid et al., 1998). The 1992-93 seasonal trends for enterococci showed a clear trend of elevated concentrations in summer, while fecal coliform concentrations

FIGURE 2.14 *Monthly concentrations of enterococci (colonies/100 ml) at high and low tides at Adams Point: 1989-1997.*



exhibited a mixture of trends at all sites (Jones and Langan, 1993a). The next year, seasonal trends for enterococci and fecal coliforms were mixed, while *C. perfringens* showed a clear trend of elevated concentrations during springtime for almost all sites (Jones and Langan, 1994c). In the Johnson Creek watershed, fecal coliform and enterococci concentrations were uniformly at much higher concentrations during summer and, to a lesser extent, autumn, compared to winter and spring. This may be the result of increased regrowth at higher temperatures and reduced flow during warm months. Rainfall events >0.25"/24 h caused elevated concentrations of enterococci at most sites and higher fecal coliforms at sites near the Town Landing. There has been an overall decrease in fecal coliform concentrations near the mouth of Bunker Creek from 1992-97 (Reid et al., 1998). At Mill Pond, fecal coliform and enterococci concentrations were decreasing from 1993 to 1996 during both dry and wet weather (Jones and Langan, 1996a). In the Bellamy River, fecal coliform and enterococci concentrations increased from 1993 to 1996 during both dry and wet weather.

In downtown Dover above the tidal dam, fecal coliform and enterococci concentrations exhibited mixed trends from 1993 to 1996 during both dry and wet weather (Jones and Langan, 1996a). In the tidal portion of the Cocheco River, fecal coliform and enterococci concentrations increased from 1993 to 1996 during both dry and wet weather. The trends for both enterococci and fecal coliforms were mixed for dry and wet weather at the freshwater and tidal sites in the Salmon Falls River.

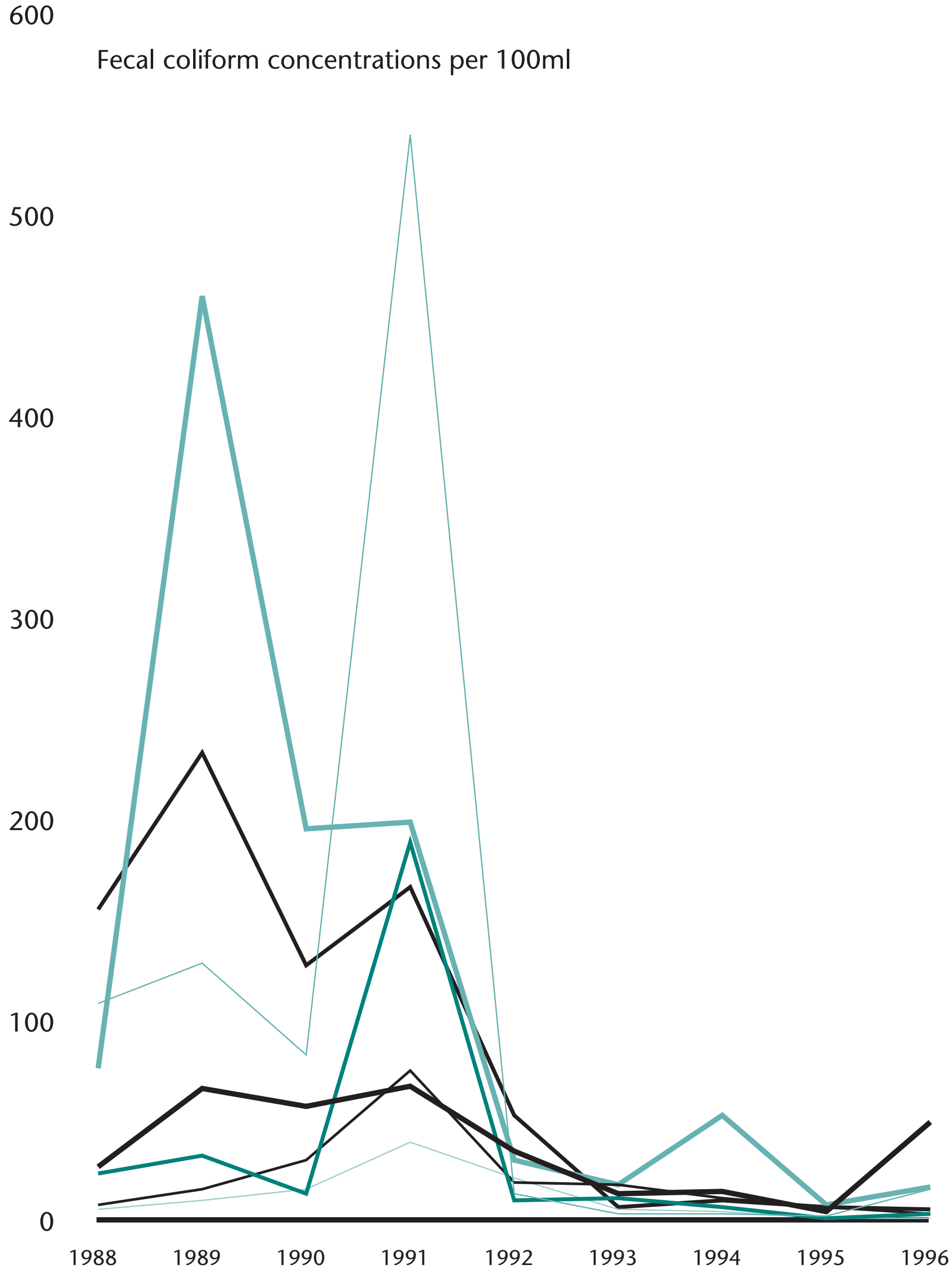
Temporal trends for fecal coliforms showed an overall decrease in concentrations since 1988, especially after 1991, in Portsmouth Harbor, Little Harbor, the Back Channel and the lower Piscataqua River (Figure 2.15). The striking decrease after 1991 was coincident with the construction of advanced wastewater treatment in Portsmouth. Continued detection of fecal coliforms at concentrations >14/100 ml are the result of lingering nonpoint sources and possibly the two CSOs remaining in Portsmouth. The contribution of the CSOs to contaminant loading is not known, although the CSOs discharge a combination of untreated sewage and stormwater during some storm events (NHDES, 1996a).

In Rye Harbor, concentrations of fecal coliforms have decreased at all sites since 1985, especially at the harbor mouth (see Appendix G). Lower concentrations after 1991 could have been the result of connection of some Rye residences to the Hampton WWTF.

The temporal trends for annual geometric mean fecal coliform concentrations in Hampton/Seabrook Harbor showed an overall decrease for all sites from 1988 to 1996. The lowest concentrations for 8 of the 10 sites occurred in 1995. Further improvements in water quality are expected to occur following the completion of connections of all present septic system sites in Seabrook to the new town sewer system. Improvements in the sanitary quality of the Harbor water was not yet apparent in mid-1997 after many of the areas adjacent to tidal waters had been connected (Jones, 1997).

The overall improvement in water quality relative to bacteriological measurements is a reflection of the significant resources expended to improve wastewater treatment facilities in coastal New Hampshire. Population growth continues at a slower pace relative to previous decades. The estimated increase in population in Strafford and Rockingham counties from 1990 to 1996 was 350,000 to 367,900, only a 5% increase (NHOSP, 1997b). Nevertheless, increases in human population, development, impervious surfaces with associated stormwater runoff, and wastewater treatment demands will continue to change the ability of watersheds to handle the additional pollution. A better understanding of the watershed factors that affect transport and fate of microbial contaminants would help frame effective strategies for eliminating or managing pollution sources and transport pathways for these contaminants to estuarine waters.

FIGURE 2.15 *Fecal coliform concentrations at seven sites in Little Harbor, Back Channel and Portsmouth harbor: 1988-1996.*



2.2.2 SOURCES OF FECAL-BORNE BACTERIA

By definition, fecal-borne bacteria are from the small intestines of mammals, and their presence is indicative of the presence of sewage and other fecal material. However, the bacterial indicators cited in this report that are used to assess sewage contamination; total and fecal coliforms, enterococci, *E. coli* and *C. perfringens*, may be found in other animals and are all capable of existing outside of the small intestine and may be found to occur naturally in the environment. Thus, caution is required when interpreting the fecal indicator data in efforts to identify sources of pollution. Ongoing studies by UNH/JEL and NHDES are focused on developing methods (Parveen et al., 1999) to identify specific sources of fecal indicator bacteria.

Prior to the efforts in the late 1980s and early 1990s by New Hampshire to upgrade all WWTFs in the Seacoast, point sources were the major source of bacterial contaminants in the Great Bay Estuary and coast. More recently, the masking effects of point source pollution have been drastically reduced to occasional malfunctions or storm event overloading at WWTFs, and nonpoint source pollution is now the major source of chronic contamination.

A summary of the recent status of sources of bacterial contaminants in shellfish waters was compiled by NHDES (NHDES, 1995). It lists WWTFs, CSOs, and urban stormwater as the major sources of bacteria, and unidentified nonpoint sources as important in some areas. In the following section, the existing information on these and other sources will be described.

2.2.2.1 Storm-related Runoff

The most common source of bacterial contamination in New Hampshire is runoff resulting from rainfall/snowmelt events in urban and urbanizing areas. This conclusion is based on the elevated concentrations of bacteria detected in all areas following rainfall events and the proximity of urbanized areas to tidal water sampling sites, as reported in almost every recent study. Some reference to stormwater effects in the different areas have already been cited.

The best illustrations of the impact of storm events on surface water quality are some recent projects conducted by JEL. The first is a three-year study on the effects of storm events on water quality in the tributaries of the Great Bay Estuary, as summarized in Jones and Langan (1996a). Statistical analysis of the cumulative 3-year data showed significantly higher bacterial concentrations following storm events at every freshwater and estuarine site (Figure 2.6 and 2.7). The freshwater sampling sites were all located at the tidal dams, all of which are located within urbanized areas of the nearby municipalities of S. Berwick, ME and Dover, Durham, Newmarket and Exeter, NH. More detailed studies of the watersheds around the Exeter (Jones and Langan, 1995c; NHOSP, 1995a) and the Oyster (NHCP, 1996; Jones and Langan, 1993a; 1994c) rivers have confirmed that urban runoff is an obvious source of contamination in these areas. This issue is presently being addressed by support from the NHEP and other ongoing projects. Some municipalities have inventories of stormwater outfalls. Those that have inventories include Greenland and parts of Dover, Rochester and Seabrook. However, the quantity and quality of the information varies, making it difficult to formulate a clear picture of the magnitude of stormwater outfalls as potential pollution sources.

A better understanding of contaminants in stormwater runoff has been recently emerging. NHDES (1997) found significant dry weather contamination in stormwater pipes draining into the Cocheco and Squamscott rivers. A follow-up study included wet and dry weather sampling in the Bellamy and Cocheco rivers (Landry, 1997). Significant contamination was observed in the Cocheco storm drains during dry weather and the Bellamy drains in wet weather. More comprehensive studies by Jones (1998) and Jones et al. (1999) focused on the worst of the drains on the Cocheco River and showed contaminants flowed from the drains continuously during dry and wet weather, in some cases at high concentrations.

Other recent studies on stormwater contamination have been designed to assess the effectiveness of stormwater control measures. Jones and Langan (1996b) focused on ten different stormwater control systems in the NH Seacoast region during 1995-96, including swales, retention ponds, a pond with staggered dikes and an infiltration chamber. First flush (during the first 0.25 inches of rainfall) samples were analyzed for a variety of contaminants, including bacterial indicators. Results showed that wet ponds were more consistently effective at treating diverse contaminants than swales. During summer, bacterial concentrations increased both in influent and effluent water, and all systems were less effective at removal. The results suggest that bacteria may re-grow in the moist, nutrient-rich control systems during dry periods that occur between storms. Elevated concentrations are then discharged with new storm events. This raises the issue of the public health significance of stormwater runoff. It also suggests that some system designs may not be effective in treating bacterial contaminants. A follow-up study (Jones, 1998c) of five systems during dry weather showed evidence of some growth occurring during summertime in some systems and suggested certain conditions may be conducive to growth.

The 1996 New Hampshire Water Quality Report to Congress 305(b) (NHDES, 1996b) reported that 17.3 square miles of coastal estuaries are not fully supporting uses because of pathogen indicators, and that the source of bacteria is unknown. It states that stormwater runoff is a well-documented source of bacteria and nutrients, citing numerous studies (Jones and Langan, 1996a; 1996b; NHCP, 1996; Swift et al., 1996). Stormwater was also cited as a significant source in coastal New Hampshire in another DES report (NHDES, 1995). The 305(b) report also pointed out that rainfall is a condition for closure of Hampton Harbor because of runoff-associated bacteria, as reported in the sanitary survey (NHDHHS, 1994b).

Other studies in New Hampshire have shown degradation of surface water quality from rainfall runoff. The runoff water from seven storm events in two developed areas in Concord had fecal coliform concentrations ranging from 23 to 240,000/100 ml (NHWSPCC, 1979). A more recent study (Comstock, 1997) found *E. coli* concentrations in stormwater runoff consistently exceeded state water quality criteria at both an urban and a residential site. Water quality in Great Bay was reported to be degraded during periods of high rainfall and runoff (NHDHHS, 1992). Several street drainage systems in Hampton and drainage ditches in Seabrook, some of which contained fecal contaminants, were found to drain directly into the marsh and tidal waters of Hampton Harbor (NHDHHS, 1994). NHDES (1997) also reported stormdrain catch basins with high *E. coli* concentrations in Hampton.

The most intensive study on stormwater was conducted by the NH Water Supply and Pollution Control Commission (NHWSPCC) in 1983 as part of the EPA Nationwide Urban Runoff Program (Oakland, 1983). The impacts and methods for control of stormwater were studied in tidal and freshwater portions of the Oyster River watershed in Durham, NH. Water quality in the watershed declined significantly following storm events, especially for total and fecal coliforms. Because Durham maintains a separate stormwater and sanitary sewer system, sources of contaminants during storms were suspected to be from animal feces. Sources for dry weather contamination were not identified. Studies on stormwater runoff control measures showed favorable effects on bacterial contamination with parking lot vacuum cleaning and a river-run impoundment (Mill Pond), but not with a grassed swale. The grassed swale showed significant removal of inorganic nitrogen, but orthophosphate and bacteria concentrations increased. The river-run impoundment, in contrast, showed significant removal of mass loads for bacteria and inorganic nitrogen, with a non-significant increase in orthophosphate, with length of detention time a positive factor.

The major Best Management Practices (BMPs) used to control urban runoff in New Hampshire in 1989 were treatment swales and sedimentation basins (NHDES, 1989a). The report suggested that these control measures are effective for trapping sediments, controlling erosion and removing some heavy metals. However, the report recognized these systems as being ineffective at treating nutrients, bacteria, oil and suspended solids. New rules for stormwater control measures for large developments have been adopted, and a new manual describing acceptable control systems has been published (NHDES, 1996). The effectiveness of each type of system for treating a range of different contaminants is presented, along with advantages, disadvantages and design criteria.

Stormwater runoff is considered to be a serious nonpoint source pollution concern by 68% of polled residents of the Oyster River watershed (Hanratty et al., 1996). Even though 87% said that problem storm drains should be upgraded, they were largely unwilling to pay for corrective actions. NHDES estimated that rehabilitation of coastal collection systems and treatment of stormwater would cost $100-200 million (NHDES, 1995), and that the chances of successful treatment of bacterial contaminants is slim. For ongoing work in the Seacoast, NHDES considers this issue a significant problem, and it is a major focus of the latest NHDES Coastal Basin Nonpoint Source Pollution Assessment and Abatement Plan (NHDES, 1996a). Present efforts by NHDES and UNH/JEL are focused on investigating stormwater systems during dry and wet weather, and following up on problems in tributaries to coastal rivers identified in previous JEL, NHOSP, NHDHHS and NHDES studies.

Unlike previous studies that often conclude that animal feces is the major source of microbial contaminants in stormwater runoff from urban areas, the major source of contaminants in New Hampshire coastal urban runoff appears to be direct sewage contamination from leaking pipes and illicit connections. Thus, even though there may be separate sewage and storm drain systems, their age, design and close proximity below the surface appear to be conducive to cross contamination.

2.2.2.2 Wastewater Treatment Facilities and Combined Sewer Overflows

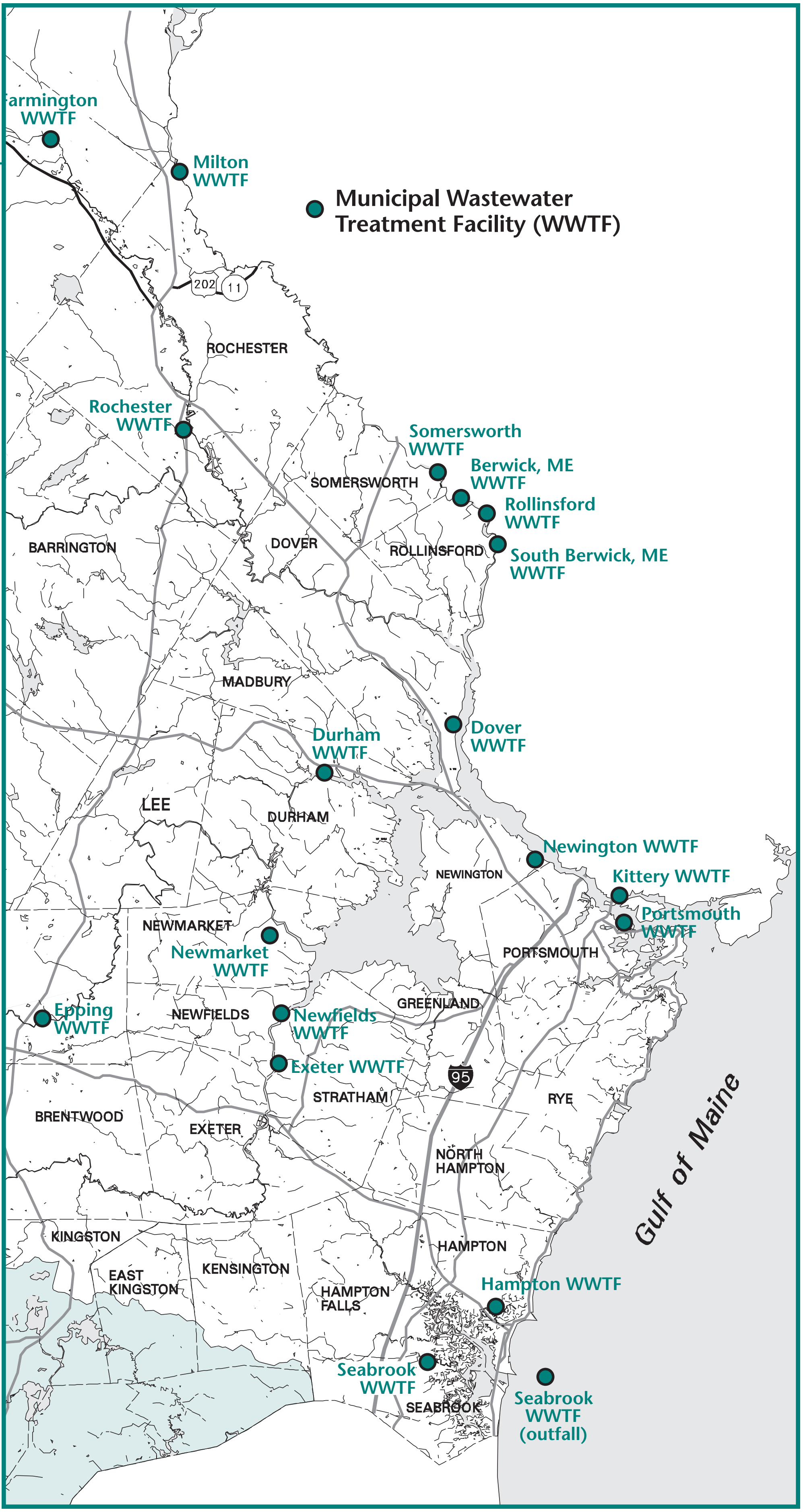
WWTFs are, ideally, capable of reducing microbial contaminant concentrations to meet required criteria in wastewater 100% of the time. However, this does not occur in practice. Changes in waste stream characteristics that modify treatment efficiency, equipment problems, operational changes, human error and acts of God (hurricanes, lightning, storms) all influence the effectiveness of WWTFs. The WWTFs in New Hampshire and their effluent flow ranges are presented in Figure 2.16. NHDES records the number of upsets that facilities report, although documented impacts of upsets in treatment processes on surface water quality are rare (Jones and Langan, 1993a; 1994c). Reporting of upsets has increased in recent years resulting in better characterization of the problem (NHDES, unpublished data). WWTFs report upsets to NHDHHS so shellfish areas can be closed. All coastal WWTFs have a limit of 70 total coliforms/100 ml at discharge pipes, they are required to conduct daily testing and chlorine residuals are required to be low/non-toxic. A few WWTFs still have problems meeting the total coliform discharge limit, and modifications to disinfection systems are being planned for most of these systems.

Some coastal WWTFs and sewer systems have limited capacities for handling stormwater during major storm events. Stormwater can overburden facilities and require bypassing of pump stations. Under these conditions, inadequately treated wastewater is discharged to tidal waters and significant loading of bacteria can occur. This happens several times each year and shellfish beds downstream from the affected facilities have been closed. The ‘100 year’ storm of October, 1996 caused bypasses in all but a few coastal WWTFs. Other stormwater related problems include infiltration of stormwater and high groundwater into sewer pipes. This may result in leakage of pipes. It is suspected to be a problem in all urban areas, and has been documented in Durham (Jones and Langan, 1994c). The problems and the extensive documentation of high levels of contamination in tidal waters following major storm events are the basis for closing the whole coastal area to shellfishing until water quality returns to acceptable levels and shellfish have depurated contaminants. The state has made many improvements in WWTFs throughout the coastal area (Table 2.4), and these efforts continue (NHDES, 1996d).

The two remaining CSOs in Portsmouth are significant sources of bacteria that impact the water quality of

FIGURE 2.16

Municipal wastewater treatment facilities.



Little and Portsmouth harbors. Portsmouth has eliminated eight of ten CSOs, but two remain in South Mill Pond. A concern for the Little Harbor area is that contaminants flushed into South Mill Pond from the CSOs could flow through the Back Channel area into Little Harbor (NHDES, 1995). Elimination of the remaining CSOs would cost an estimated $10 million, as estimated by the city's CSO Facility Plan. Because of the high costs associated with elimination of the CSOs, the City of Portsmouth has filed for a Use Attainability (UAA) Study to reclassify the receiving waters, i.e., South Mill Pond. If they are successful in proving that the costs are essentially prohibitive, then they would not be required to attain the limit of 70 total coliforms per 100 ml in South Mill Pond. In such a case, careful attention to the potential for storm-related contamination to affect any opened shellfish beds in Little Harbor would be necessary. It would also be difficult to open the extensive mudflats in the Back Channel area.

Point source pollution control program activities from 1988-1996: WWTFs and CSOs. **TABLE 2.4**

	Wastewater flow (mgd)				**Date**	
City	**design**	**ave.***	**max.***	**Control measure**	**completed**	**Cost**
Dover	4.4			new 2° treatment facility	1991	$24,300,000
Strafford Co. Facility				cease discharge to Cocheco R.	1992	
Durham	2.5	1.0	4.5	upgrade from 1° to 2° treatment	1981	
				equipment upgrades	1992-93	
				dechlorination	1995	
Exeter	3.0	1.6	6.2	lagoon system built; dechlorination	1990	$5,900,000
				all but one CSO disconnected	1992	$3,400,000
Farmington	0.4			secondary clarifier	1994-95	
Hampton	3.5			sewer project and dechlorination	1993	$4,400,000
Newfields	0.1	0.04	0.2	construction of facility	1983	
Newmarket	0.9	0.6	2.5	upgrade from 1° to 2° treatment	1986	$1,900,000
				dechlorination/dewatering system	1993	
Newington	0.3			upgrade disinfection system	1995	~$350,000
Portsmouth	7.0			new advanced 1° treatment & dechlorination	1992	$15,000,000
				eliminate 10 CSOs	1991	$5,800,000
Rochester	3.9			currently designing new advanced treatment		
Rye				sewers connected to Hampton POTW	1991	$2,400,000
Wallis Sands St. Pk.				UV disinfection; refurbish sand filter	1993	
Seabrook				construction of wastewater treatment facility	1995	
Somersworth	2.4			various improvements; P reduction study		
Star Island				construction of seasonal 2° treatment plant	1994-95	

* in 1994

Ongoing work is focusing on a hydraulics study of the CSOs around South Mill Pond, identification and elimination of illicit connections and dye studies of the WWTF outfall pipe. A safety zone around the outfall pipe will probably extend into the nearby Back Channel.

One CSO remains in Exeter. The CSO is a source of bacteria during storm events when the capacity of the main pump station is exceeded. Under those conditions, sewage can overflow into Clemson Pond, which acts as an emergency holding pond. However, the water that drains from the pond to the Squamscott River is often contaminated (NHOSP, 1995; Jones, 1990).The problem is currently under investigation. Exeter passed a warrant article in 1999 to allocate $1.7 million to address the CSO problem.

As previously stated, the system of wastewater treatment facility pipes that transport sewage from sources to the treatment plant are a potentially significant source. In several coastal New Hampshire municipalities, downtown stormwater drains have high concentrations of fecal contaminants, even during dry weather (NHDES, 1997; NHDES, 1998; Jones, 1998b). This suggests that sewer pipes that cross paths with the storm drains may leak contaminants into the drains. During runoff events, contaminants that accumulate in the drains are washed into the receiving waters. Thus, the system of pipes associated with municipal sewage treatment facilities may be sources of contaminants. The estimated cost for rehabilitating these systems in the coastal urban areas is well in excess of $200 million (NHDES, 1997).

2.2.2.3 Septic Systems

Many shoreline areas adjacent to the shellfish waters of New Hampshire are still served by septic systems. These systems contain high levels of bacteria and nutrients (Jones, 1998d) that can leach into groundwater. An extensive two-year study in Seabrook focused on the potential for existing, operational residential septic systems to contaminate groundwater and adjacent surface waters (Jones et al., 1996; 1995). Little evidence of significant contamination of groundwater downgradient from septic systems could be documented. At one site with a high water table, bacterial contaminants were detected ~9 meters downgradient in the groundwater. Analysis of saturated soil cores showed the presence of high concentrations (>100,000/g soil) of C. perfringens, evidence of long-term and probably cumulative contamination. Other sites also had contaminated soils at downgradient (away from the system in the direction of groundwater flow) areas. The main limitation of any study of subsurface environments is the difficulty of finding contaminant plumes without extensive exploration. The studies concluded that septic systems are indeed potential sources of contamination to tidal waters when systems are located close to the shore, especially in densely populated areas in soils with high water tables and course-grained, excessively-drained soils.

Seabrook has recently connected all residences and businesses to their new sewer system. There are still houses close to tidal waters that remain on septic systems in Hampton and Hampton Falls (NHDHHS, 1994a). The impact of disconnecting the septic systems on water quality was investigated by Jones (1997). No significant improvement in Harbor water quality was observed, possibly because the Mill Creek area had not yet been connected to the WWTF.

Septic systems are numerous around the Little Harbor area in Rye and in some areas in New Castle (Jones and Langan, 1996c). Septic systems are also common around Great and Little bays (Jones and Langan, 1995b), the Squamscott River (Jones and Langan, 1995c) and in the Oyster River watershed (Jones and Langan, 1994c; 1993a). Large areas with houses served by septic systems are also present along the coast and the Piscataqua/Cocheco/Salmon Falls River areas. Thus, septic systems are a widespread, documented potential source of contamination.

2.2.2.4 Agricultural Runoff and Other Nonpoint Sources

On a statewide basis, agriculture has not been a significant nonpoint source problem (NHDES, 1989a). The number of farms in New Hampshire and Strafford County have been declining over the past 25 years. However, horse farms are increasing. Certain activities have been problems on local levels, including manure storage and spreading practices, stable management and milk house waste management. Rockingham County Conservation District has information on contaminant runoff and management strategies for mitigating specific farm sites in the county. UNH/JEL and NHDES conducted studies at a farm in Stratham to determine the effectiveness of constructed wetlands on microbial and nutrient contaminants (Jones and Langan, 1992; 1993b). The construction of a wetland within the drainage swale between the manure storage area and the Squamscott River had no beneficial effects on contaminants during the first year after construction (Jones and Langan, 1993b). Concentrations of fecal indicator bacteria (fecal coliforms, enterococci, E. coli and C. perfringens) were all detected at elevated concentrations (> 105/100 ml) just below the manure pile, and at lower concentrations downstream. A similar trend was observed for nutrients (ammonium, nitrate/nitrite, orthophosphate).

Agricultural use of land within most growing areas have been documented (NHDHHS, 1994a; 1995; Jones and Langan, 1996c). Many of the cited farms are practicing responsible management procedures to prevent animal waste from contaminating bordering water bodies.

There are other potential sources of bacterial contamination near and within New Hampshire's shellfish waters, including storm and parking lot drains, snow dump sites, boats, wildlife and resuspended sediments. A guide for BMPs to control most potential nonpoint sources of pollution is published (NHDES, 1994c) and serves as a useful reference. NHDES has recently been successful in improving and increasing the number of coastal boat pump-out facilities. Further improvements are expected each year. Recent sanitary surveys for some coastal waters include marina assessments (NHDHHS, 1994; 1995; Jones and Langan, 1995b; 1996c).

Animal feces is often mentioned as a probable source of bacterial contamination in stormwater runoff (Jones, 1999; Oakland, 1983). In almost every case, the justification for such conclusions is that no human source could be identified, so the investigators conclude that animal waste must be the source, usually without any direct documentation. Recent studies have shown many previously unsuspected sources of stormwater contamination exist in coastal New Hampshire towns, including stormwater drains, sewer pipes, stormwater treatment systems, etc., including areas where animal feces had been previously suspected (Jones and Langan, 1996b; Jones and Langan, 1993a). More recent studies have shown underground sewage pipes contaminate stormwater drains in urban areas (Landry, 1997; Jones, 1998b). It is likely that human sources of fecal contaminants remain more significant than animal sources in New Hampshire's Seacoast (Jones, 1999). However, the issue of the source of nonpoint source pollution, whether it is of human, animal or other origin, is an extremely important question to address. Not only is it necessary for identifying the source of contamination, but it is essential for determining the public health significance of fecal contamination. A new study by NHDES and UNH/JEL will use new biotechnological methods to differentiate between human and other sources of *E. coli* isolates from New Hampshire coastal waters.

Rye Harbor

2.2.3 MODELING AND DYE STUDIES FOR BACTERIAL FATE AND TRANSPORT

Computer modeling of stormwater runoff impacts to the tidal portion of the Oyster River was conducted as part of a study by Oakland (1983). The goal was to assess impacts relative to state standards for coliform bacteria and dissolved oxygen standards, and assess effectiveness of stormwater control measure implementation. The results of the modeling confirmed observations that coliform standards would be violated routinely during storm events. Violations, even during dry weather, would be most frequent at upstream sites and during ebb tides. Dissolved oxygen standards would be violated much less frequently, only during 28% of storms. The violations would be expected to be short-lived during ebb tides only in the upper reaches of the tidal river. The model found that only Mill Pond, as a river-run impoundment, would have significant impacts on coliform loading, while vacuum cleaning of impervious surfaces could significantly reduce BOD loading.

Numerous dye studies have been conducted to determine potential contamination plumes and contaminant transport from various point sources. Ballestero (1988) reported on a field dye study and calculations for dilution and dispersion using MERGE, a contaminant plume modeling program, for the new Dover wastewater treatment plant outfall diffuser in the Piscataqua River. The purpose of the study was to determine water quality criteria for conservative contaminants in the effluent. The zone of initial dilution was set by the state to be 0.25 miles upstream and downstream from the diffuser. Average dilution at these distances was calculated to be 26,000, with significant dilution occurring as a result of the initial jet aspiration from the diffuser as the effluent entered the river. A modeling study was also conducted for a proposed diffuser for the Newmarket WWTF.

Other dye studies have been conducted to establish safety zones for shellfish harvesting around WWTFs and marinas. A recent dye study was conducted by the US EPA at the Great Bay Marina in Little Bay, but the results have not yet been published. In Hampton Harbor, a dye study was conducted to determine the safety zone downstream from the Hampton WWTF (Fugro-McClelland, 1993).

In Great Bay, the most recent sanitary survey (NHDHHS, 1995) identified the WWTFs in Durham and Newmarket as the plants with the greatest chances of impacting shellfish harvesting. There have been recent dye studies conducted at both sites, but the data are not yet published. An EPA model, CORMIX, was used to model discharges of fecal coliforms from the WWTFs (Langan and Jones, 1995a). At the Newmarket WWTF, the worst case scenario was for a release at mid-falling tide, in which case the plume would reach the mouth of the Lamprey River in 7.2 h with a concentration of 750 fecal coliforms/100 ml. The mouth of the river is an area classified as prohibited for shellfish harvesting. Thus, another model (Brown and Arrelano, 1979) was used to estimate time for the plume to reach the closest approved areas. It was estimated that the total time for the plume released at mid-falling tide to reach restricted waters is 28 h, which is sufficient for closing the area to shellfishing. At the Durham WWTF, the worst case scenario was found to be a release at high tide, in which case the plume would reach the mouth of the Oyster River in 4.2 h with a concentration of 420 fecal coliforms/100 ml. Further transport of bacteria to the Langley Island area could take a total time from a high tide release of 8-12 h.

In Hampton Harbor, CORMIX was used to model transport and survival of bacteria discharged from boats moored in Seabrook Harbor during fall-spring when the clam flats in the Harbor are open for harvesting (Langan and Jones, 1995b). Model simulations were run for both a slug release and a slow, continuous release of bacteria over a six hour time period from the vessels. The concentrations of bacteria in the plume at the edge of the adjacent clamflat for both types of releases were 13 and 0.02 fecal coliform/100 ml, respectively, which are both below the regulatory limit of 14 fecal coliforms/100 ml. The conclusion of the study was that the boats present during colder months do not pose a risk of significant contamination to adjacent clamflats. However, because boating activity increases significantly during warm months (mid-May to mid-September) it is recommended that clamflats remain closed during these times. This study did not address the Hampton Marina, which typically has many more boats than Seabrook Harbor.

Current direction and velocity measurements have been used to help predict bacterial transport and impact to shellfishing areas in Hampton Harbor (Langan and Jones, 1995b) and Little Harbor (Jones and Langan, 1996c). In Little Harbor, transport of bacteria discharged from boats at the Wentworth Marina and in the nearby mooring area to shellfishing areas were modeled using estimated discharges and current velocities and directions. Using a variety of scenarios, the modeling effort found it likely that water with fecal coliform concentrations exceeding 14/100 ml could reach clamflats under worst case conditions. Jones and Langan (1996c) recommended that shellfishing be allowed only during colder months when boat traffic and usage is negligible.

2.2.4 IMPACTS OF FECAL-BORNE BACTERIA ON SHELLFISHING

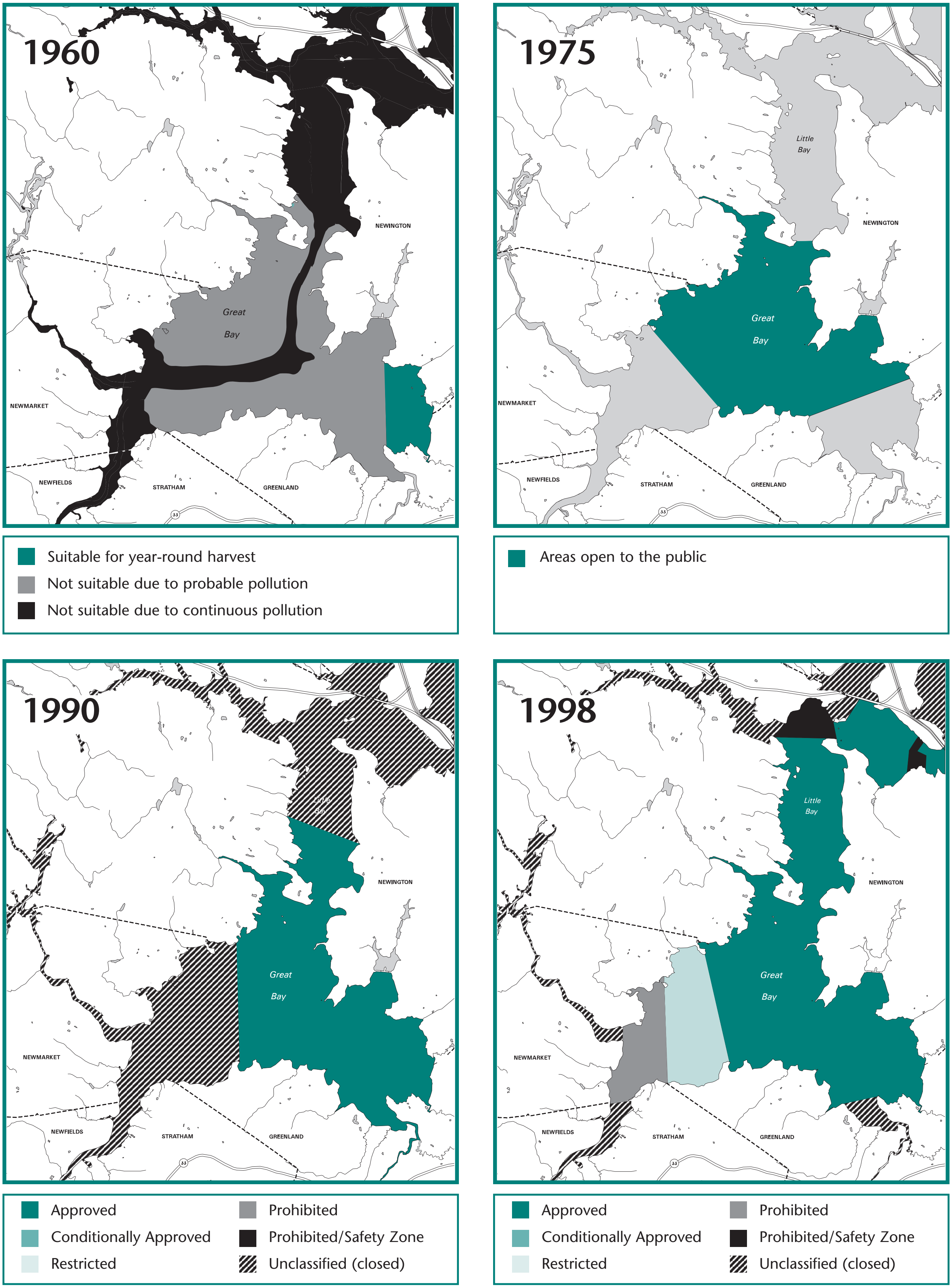
New Hampshire has abundant and valuable shellfish resources. Many citizens have enjoyed the recreational harvest of clams, oysters and mussels over the years in Great and Little bays, Hampton Harbor, Rye Harbor and Little Harbor. However, during the past few decades, all or portions of these areas have been closed for shellfishing because of unacceptable concentrations of bacterial contaminants. Much effort has been dedicated to determining which areas are safe for shellfish harvesting and how to open other areas.

2.2.4.1 Historic Sanitary Assessments of Shellfish-growing Waters

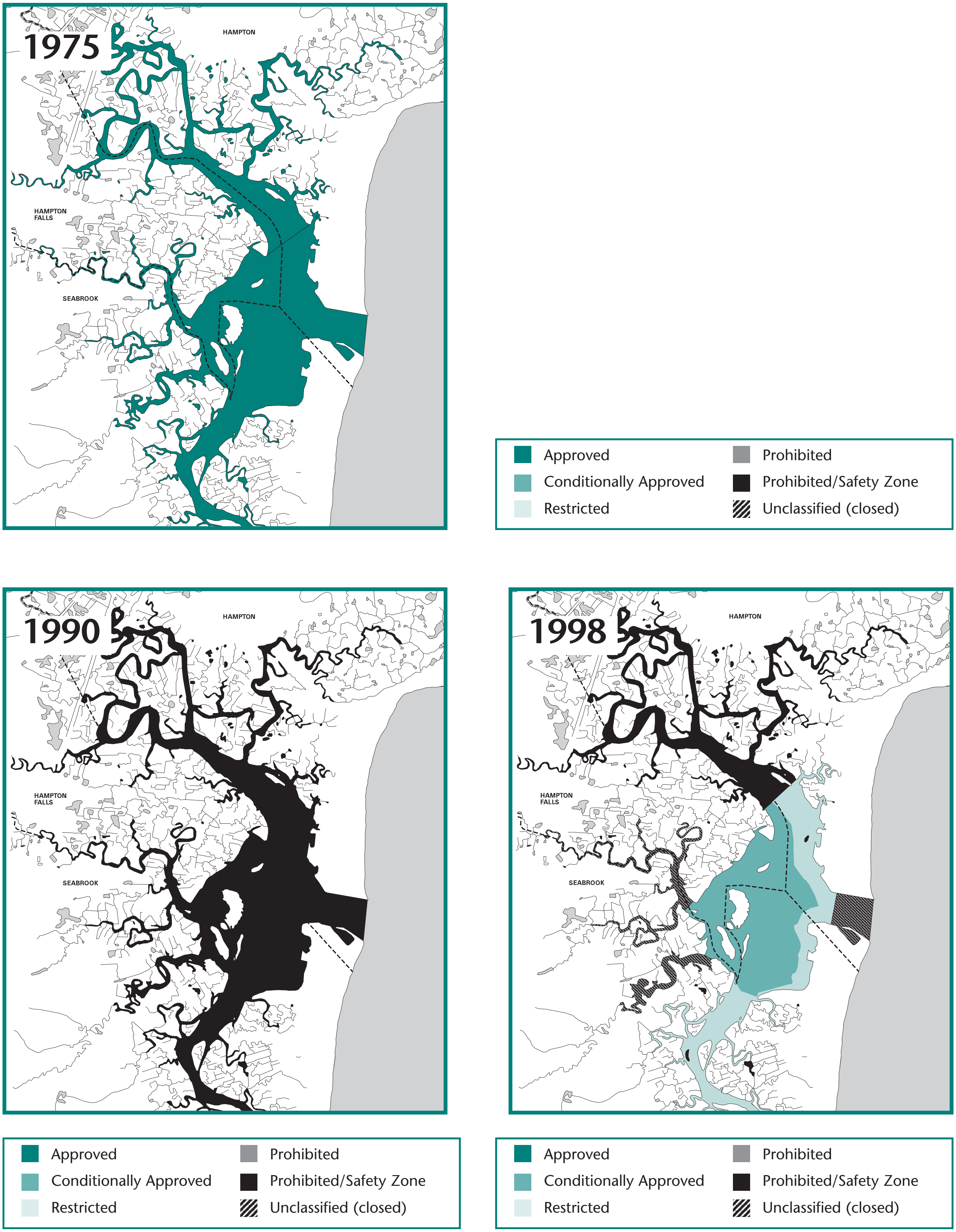
Bacterial contamination of the shellfish growing waters of New Hampshire has been a challenging, continuous problem. New Hampshire has assessed the sanitary conditions of tidal water bodies since 1957 (NHWPC, 1960). Early data on bacterial contamination Jackson (1944) reflected the high loading of untreated sewage into the tributaries to Great Bay Estuary: every tributary had average total coliform concentrations of >800 /100 ml. Total coliform concentrations were much lower at sites in Great and Little bays, although still elevated compared to more recent data and in excess of the limit of 70 total coliforms/100 ml for shellfishing.

Early routine state assessments of the sanitary quality of tidal waters began in 1957 (NHWPC, 1960). The 1960 report included a map delineating suitability of water quality for shellfishing in the Piscataqua River/Great Bay Estuary (Figure 2.17). Only a small portion of eastern Great Bay (Greenland Bay) near the shore between Fabyan and Pierce points was classified as suitable for year-round harvest of shellfish for direct marketing. The rest of the estuary was considered unsuitable for year-round harvesting because of the continuous presence of pollution by raw sewage, except for much of the central area of Great Bay and the outer deeper areas of Portsmouth Harbor. The classification was based on only a few samples (one sample/site in some cases). By 1975, New Hampshire published shellfish waters classification maps based on a median 70 total coliform/100 ml limit for Class A tidal waters (Figures 2.17 and 2.18; NHWSPCC, 1975). Areas where median total coliform concentrations were <70/100 ml included eastern Great Bay between Nannie Island and Birch Pt. beyond the mouth of the Winnicut River, two areas near the western shoreline around the Footman and Vols Islands, the lower tidal portions of the Oyster and Bellamy rivers, Little Harbor and southern portions of the Back Channel, outer Portsmouth Harbor, the northern half of Hampton Harbor and

FIGURE 2.17 *Great Bay Estuary shellfish waters classification trends from 1960 to 1998.*



Hampton Harbor Estuary shellfish waters classification trends from 1975 to 1998. **FIGURE 2.18**



lower portions of some tributaries, Rye Harbor and the whole of New Hampshire's Atlantic coast. Point sources, especially the WWTFs, were the major sources of contamination, and upgrades and construction were slated to occur within a few years of the reports for all areas not currently treating waste with the best available technology.

Contaminated shellfish waters became an even more important issue for the public and their legislative representatives after the NHDHHS closure of Hampton and Little harbors in March, 1989 (NHDES, 1989a). A Shellfish Committee was formed in March, 1988, and ensuing efforts focused on identifying sources of contaminants and eliminating them where possible. A report was written by the agency personnel on the committee in 1989 entitled "Interagency Report on the Shellfish Waters of New Hampshire" to outline what steps were needed to reopen shellfish beds. The report included a few, high priority recommendations/actions:

- prioritize the elimination of sources of bacterial contaminants and conduct a cost/benefit analysis relating remediation costs to the value of shellfish harvest activities;
- increase the effectiveness and efficiency of existing WWTF wastewater disinfection systems;
- communities should survey shorelines and eliminate nonpoint sources of pollution;
- identify sources of pollution where obvious point sources are present;
- prioritize state and federal funding to support WWTF construction and nonpoint programs in coastal communities.

The State began to make progress on each of the key recommendations soon after the 1989 Interagency Shellfish (Flanders, 1989) report was published. By 1991, improvements had been made to Dover, Exeter, Newmarket, Hampton and Portsmouth WWTFs (NHF&G, 1991). Some failed septic systems were identified and abated in Seabrook, Rye eliminated its coastal discharge of raw sewage by building a sewer line to Hampton and all but two CSOs were eliminated in Portsmouth. Shoreline surveys were conducted in Great Bay and the Bellamy River by state agencies (see below), while sources of contamination in the Bellamy River were identified and abated. Some remote residential areas in Hampton were connected into the town sewer system. For all growing areas (Great/Little Bay; Little Harbor; Hampton Harbor; Rye Harbor), specific water quality problem areas were identified, described and prioritized. Concurrent with these efforts were a number of water quality monitoring programs run by state agencies and UNH. The shellfish program continued monitoring waters to support classifications, NHDES continued monitoring some upstream areas as part of their ambient water quality monitoring program, and UNH/JEL initiated monitoring in Great Bay as part of the GBNERR program. However, the 1991 report (NHF&G, 1991) recognized the need for more extensive water quality monitoring in key areas to document improvements in water quality and to support reclassification of areas. The improvements in WWTFs and elimination of major point sources of contamination also provided conditions conducive to assessing NPS pollution.

The shellfish growing waters of Great Bay were the focus of shoreline/sanitary surveys in 1988-91: the Bellamy River (NHDES, 1991) and Great Bay (NHDHHS, 1992). The Bellamy River survey found an unpermitted pipe discharging bacterial contaminants near the Sawyer's Mill apartments in Dover near the tidal dam. No evidence of failed septic systems or other nonpoint sources of contamination was detected, and further studies were recommended. In the Great Bay sanitary survey, water samples collected along the northwest shoreline of Great Bay were all elevated (330-3,300 total coliforms/100 ml) above the total coliform limit of 70/100 ml (NHDPHS, 1992). The dominant source of contamination was considered to be WWTFs discharging into nearby tributaries.

Indigenous estuarine bacterial pathogens like vibrios have been a significant public health concern in the southern areas of the US. In New Hampshire, there has been no documented evidence of food poisoning or wound infections in the local communities associated with the incidence of any *Vibrio* sp., except for an incident of *V. parahaemolyticus* gastroenteritis resulting from consumption of oysters taken from Great Bay waters that occurred in June, 1992 (Dr. R. Rubin, personal communication).

2.2.4.2 Present Conditions

A recent sanitary survey in Great Bay was conducted (NHDPHS, 1995; Jones and Langan, 1995b). The approved area was expanded northward in Little Bay from the cable crossing (Figure 1-6) based on monitoring at NHDHHS stations (Figure 2-3). The northern boundary for the approved area now extends from Fox Point (43°07'10" N. Latitude, 70°51'35" W. Longitude) to the western shore of Little Bay at Durham Point (43°07'14" N. Latitude, 70°52'10" W. Longitude). A new sanitary survey and related studies have focused more intensive monitoring in lower Little Bay and the Bellamy River (NHDHHS, 1998; Jones, 1998a). The shoreline survey and fecal coliform concentrations at five of the six sites were consistent with an approved classification of much of lower Little Bay. Initially, only an area around Broad Cove was classified as approved, as other areas required additional samples. In 1998, most of the rest of lower Little Bay was re-classified as approved, except for an area from the mouth of the Oyster River east to Fox Point, and areas around the two marinas. In Great Bay, a restricted area has been established in the southwestern corner of Great Bay toward the mouths of the Lamprey and Squamscott rivers. The classification of eastern Great Bay has been clarified and is almost all approved, except Greenland Bay south of a line extending from Pierce Point west to the Greenland shoreline.

Little Harbor was the focus of a preliminary sanitary survey in 1995-96 (Jones and Langan, 1996c). Water quality was found to meet approved classification standards in Little Harbor, and no significant sources of pollution were documented. The Wentworth Marina was considered to be a significant potential source of bacterial contaminants. A pumpout facility replaced in 1997 using Clean Vessel Act support and private funds. Even though it has pump-out facilities that are extensively used, such large marinas are regarded as potentially significant sources of contamination relative to classifying shellfish areas. The statewide closure of shellfishing during warm months, June through early September (November for Hampton Harbor), coincides with the timing of the greatest use of the marina, mid-May through mid-September. The absence of boaters at the marina during colder months resulted in little impact of the marina on water quality (Jones and Langan, 1996c), and would probably not be a concern if the area was opened during cold months for shellfishing.

In the rest of the Little Harbor area, the Witch and Seavey Creek area has some problems with water quality and further studies are needed to identify sources. The Back Channel area should also remain closed because of the CSOs in Portsmouth and other recently identified sources.

A sanitary survey was conducted in Hampton Harbor during 1993-94 to support reclassification of the closed shellfish waters (NHDHHS, 1994). The study involved intensive water quality monitoring, experiments designed to test a variety of conditions and consideration of all potential and known pollution sources. The effort resulted in reclassification of portions of Hampton Harbor to “conditionally approved”, limited by rainfall events and closed during warm months (June-October) because of the increased summer population. The classification was based on sampling at NHDHHS sites (Figure 2.12). Elevated concentrations of fecal coliforms at a few sites in the harbor near the mouth of Mill Creek and near River St. and Cross Beach Rd. were investigated further in 1995 (Langan and Jones, 1995a & b). The study and a newer study (Jones, 1997) suggested that elevated bacterial concentrations may originate from Mill Creek or possibly from resuspended sediments; no clearly defined sources were found. Improved water quality in recent years has resulted in a recent upgrading of the shellfish harvest classification of the large Middle Ground clam flat in Seabrook from restricted to conditionally approved (NHDHHS,1998). Clamming can occur from November to May except after rain events of ≥0.1 inches of rain in 24 hours. In addition, the rainfall condition of approved classification has been modified to be seasonal, with less restrictive conditions (0.25" rain per 24 h) in effect for all areas during December through March. It is hoped that complete disconnection of all septic systems in the area will result in improved water quality so even more clam flats can be opened.

2.2.5 MICROBIAL CONTAMINATION Impacts on Swimming and Other Recreational Uses

There have been no reported incidences of water-borne disease in New Hampshire at least since 1992 (NHDES, 1994a; 1996b). Microbial contaminants would be a concern at bathing beaches if swimmers ingested water and became ill. Bacterial indicator standards are based on USEPA studies of disease incidence in association with swimming. Thus, the enterococci standard for tidal recreational waters was developed to protect humans from fecal-borne pathogens. The data from the NHDES 305(b) reports showed swimming was only restricted at open ocean sites in 1991-1994 and at a coastal shoreline site from 1988 to 1990.

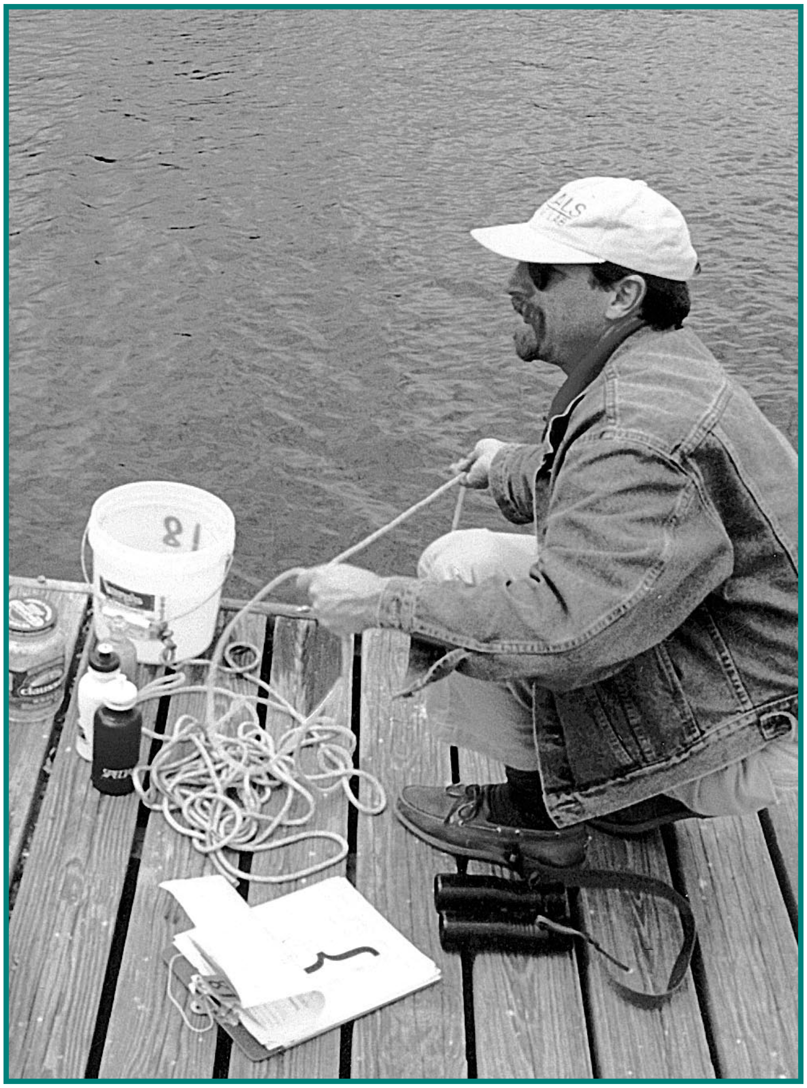
Some temporary closures of beaches in New Hampshire occur during warm months when beaches become overcrowded. The heavy population of swimmers can cause concentrations of fecal-borne bacteria to be present at levels that exceed standards, and time is needed for the water to become clean again prior to re-opening beaches.

2.2.6 FECAL-BORNE PATHOGENS Historical Studies on Indicators and Pathogens

Historically, there has been a great deal of research in Great Bay conducted by researchers at the Jackson Estuarine Laboratory and the Department of Microbiology at the University of New Hampshire on the various aspects of microbial pathogens. The estuary has served as a useful site to conduct these studies, as sewage discharges have contaminated shellfish-growing areas for a long time (NHWPC, 1960; NHWSPCC, 1975; 1981). Slanetz et al. (1964) found good correlations between membrane filtration and multiple tube fermentation tests for coliforms in shellfish and water, and showed that not all positive fecal coliform tubes contained *Escherichia coli.* Fecal streptococci and fecal coliforms were useful indicators of fecal pathogen contamination, as *Salmonella* sp., and on two occasions, Coxsackie viruses were detected in shellfish and waters from areas having high levels of fecal indicator bacteria (Slanetz et al., 1968). However, *Salmonella* sp. (Slanetz et al., 1968) and enteric viruses (Metcalf et al., 1973; Metcalf, 1975) were also detected in samples of water and oysters from areas that met the coliform standard for approved shellfish-growing waters. One general conclusion of the historical studies was that enteric viruses and *Salmonella* sp. had a greater ability to survive than indicator bacteria in estuarine environments, and that these pathogens were often associated with irregular introductions, or pulses, of contamination into the estuary. The findings provided early evidence that contributed to growing doubts about the adequacy of using total coliforms for classifying approved shellfish waters, especially with low indicator levels. The occurrence of the specific pathogens *Salmonella* sp. and enteric viruses was never correlated with any reported incidence of disease caused by these microorganisms in surrounding communities.

The sources and fate of microbial contaminants in Great Bay were the subject of further studies. Metcalf and Stiles (1968) found that enteric viruses were discharged from sewage effluent pipes and disseminated throughout the estuary. The viruses were rapidly taken up by oysters and retained for months within shellfish, especially during cold winter months. Introduction of chlorination as treatment of sewage by a municipal facility caused dramatic decreases in coliform, *Salmonella*, and enteric virus levels, although the pathogens could still be detected in treated effluent on occasion. Slanetz et al. (1972) found rapid die-off of indicator bacteria in oxidation ponds at three wastewater treatment facilities in the estuarine system, especially when three to four ponds in succession were used to treat wastewater. However, *Salmonella* and enteric viruses could be isolated from all ponds, especially in cold (1-10°C) water. Such findings are important relative to the oyster harvest season in Great Bay, which spans the cold autumn through spring months and is only closed during the warm summer months. More recent studies on pathogens in oysters from the Piscataqua River showed no detectable *Salmonella* sp. in shellfish prior to processing at a commercial shellfish depuration facility in Maine (Jones et al., 1991).

Presently accepted methods for detecting enteric viruses are too expensive, slow, and complex to be adopted for routine analysis of water and shellfish. However, more rapid and precise methods for detecting enteric viruses are being developed at UNH. For example, application of radioactively labeled cDNA probes for poliovirus and Hepatitis A virus showed the presence of these viruses in shellfish and water from closed areas in Great Bay (Moore and Margolin, 1993; Margolin and Jones, 1990; Margolin et al., 1990). Gene probe assays showed good agreement with traditional tissue culture methods for virus detection. Comparison of virus incidence with levels of bacterial indicators in the Oyster River revealed no clear trends. Levels of bacterial indicators were consistent with the classification of the river as prohibited for shellfishing, but showed little relationship to the presence or absence of enteric viruses.



A. REID

Water quality sampling

An ongoing study is focusing on viral contamination of groundwater in northern New England (D. Heath, personal communication). Total culturable enteric viruses and PCR analysis of poliovirus, hepatitis A and Norwalk virus are being measured in comparison to other microbial indicators and dissolved nutrients. Groundwater samples are being collected from drinking water wells located in close proximity to septic systems and that have had past contamination problems.

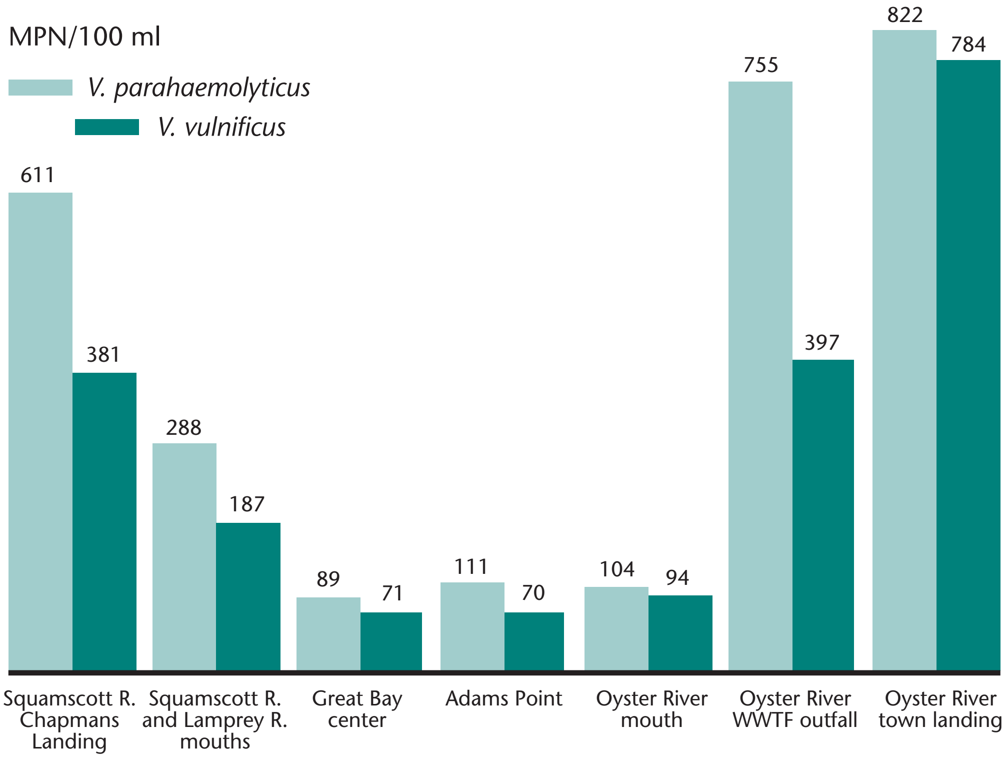
2.2.7 AUTOCHTHONOUS MICROBIAL PATHOGENS

Non-fecal bacterial pathogens that are indigenous to and common inhabitants of estuarine environments are also potential health hazards. In particular, the *Vibrionaceae* have been associated with shellfish-borne disease incidence and wound infections resulting from exposure to marine waters (Rippey, 1994). Bartley and Slanetz (1971) found *Vibrio parahaemolyticus* in oysters and estuarine water from Great and Little bays in September and at decreasing levels through November. *V. parahaemolyticus* has also been detected in oysters (Jones et al., 1991) and water (Jones and Summer-Brason, 1998; Summer-Brason, 1998; Jones et al., 1997) from the Estuary in more recent studies. Another vibrio, *V. vulnificus*, was detected in 1989 for the first time north of Boston Harbor in the Maine and New Hampshire waters of the Great Bay Estuary (O'Neill et al., 1990). This discovery did not necessarily mean that it was a new inhabitant of the estuary. Many other reasons are related to why it had not been previously detected, including no one had tried to detect it, it was only recognized as a bacterial species in the late 1970s and there was no incidence of *V. vulnificus*-related disease to cause alarm. It has since been detected routinely in all of the tidal portions of the major tributary rivers of the estuary, where shellfishing is not permitted, but detection is extremely rare and at low concentrations in the areas of Great Bay open to shellfishing (Figure 2.19; Jones et al., 1997; O'Neill et al., 1990; Jones et al., 1991). A relatively high incidence of hemolysin-negative, or potentially non-virulent strains of *V. vulnificus* have been isolated from the estuary (O'Neill et al., 1991).

More recent studies in Great Bay and the Oyster River helped to delineate the ecology of *V. vulnificus*. This is important for prediction of conditions that may result in higher concentrations of the organism and for developing post-harvest processing strategies for eliminating

FIGURE 2.19

Geometric mean Vibrio vulnificus *and* Vibrio parahaemolyticus *concentrations at low tide (MPN/100 ml) in Great Bay Estuary by site during June-September, 1993-95.*



TOXIC ORGANIC AND METAL CONTAMINANTS

Numerous historical and current studies have focused on organic contaminants, metals and metalloids in coastal New Hampshire, especially in Great Bay. The major sources of information can be found in reports from the 1991-93 ecological risk assessments for the Portsmouth Naval Shipyard, the Gulfwatch 1991-98 annual reports, the Army Corps of Engineers dredge project data, NPDES monitoring data, numerous reports by Normandeau Associates, reports from the former Pease AFB, and scientific papers from a few UNH laboratories in the departments of Chemistry, Earth Sciences and Microbiology. Numerous other studies conducted by private firms, the University, and both state and federal agencies also provide important information. Contaminants that have the most available information include chromium, mercury, tin and lead, based on their local distribution, historical and current sources, potential toxicity and scientific interest.

Small scale, light manufacturing is practiced in Portsmouth along the Piscataqua River and in many of the municipalities bordering the Great Bay and Hampton/Seabrook estuaries. There are no industrial activities on the shores of some coastal areas, such as Little Harbor. Other areas like the Portsmouth Naval Shipyard and Pease AFB have been the sites of significant historical storage and use of toxic contaminants. An environmental assessment of the shipyard and surrounding estuarine habitats has shown elevated levels of some toxic compounds in depositional areas and some biota (NCCOSC, 1997). Little evidence of actual toxic effects on biota was apparent. The urban areas in the coastal region have had a variety of industrial activities that have contributed unknown quantities of contaminants to surface waters over the last three centuries.

Studies have been conducted to determine the concentrations of contaminants in sediments, in organisms and in the water column, with some focusing on their effects on organisms. Information on the status and trends of toxic contaminants in these environmental compartments is presented below.

2.3.1 STATUS AND TRENDS FOR CONTAMINANTS IN WATER

Lyons et al. (1976) studied trace metal discharges into the Great Bay Estuary in the mid-1970s. Measurements were made of dissolved and “environmentally available” Fe, Mn, Cu, and Cr. Only Cr was present at levels in excess of the range found for other northern New England river systems. The data indicated a reduction of inputs to the estuary from industry compared with what had occurred in the previous decade. Scattered small projects involving analysis of tidal waters have also occurred. For example, water from the Taylor River in the Hampton/Seabrook Estuary was analyzed for nine metals and ten organic contaminants during 1985 (ESI, unpublished data). Nelson (1986) reported the analysis of water from four areas in the Great Bay Estuary for lead concentrations, which ranged from <0.05 to 0.14 mg/l.

More recent studies on contaminant concentrations in water have been conducted as part of the Portsmouth Naval Shipyard studies (Johnston et al., 1993). Initial measurements of metals in the Piscataqua River encountered problems, but samples of seep water from sites near suspected sources showed elevated concentrations of Pb, Hg, Zn, Cr and Cu, some of which may have been associated with suspended sediments inadvertently included in the samples.

Further sampling of the river and seep waters were conducted as part of the second phase of the project (NCCOSC, 1997). The data, when compared to Water Quality Criteria (WQC) for protection of both human health and aquatic life, showed measured contaminant concentrations except for copper were >10x lower than the marine chronic WQCs. All sites had copper concentrations ~10x lower than the 3.1 mg/l WQC with the highest concentration in the upper Great Bay Estuary of 0.49 mg/l, which is only ~6x lower.

NHDES measured concentrations of Al, Cu, Zn and Pb that exceeded standards in water samples from urban areas in the Lamprey River (NHDES, 1994b). They compared concentrations from samples in 1987-92 at rural sites with samples from 1992 and 1993 at urban sites. The results indicated that the metals were present at concentrations higher than elsewhere in New Hampshire. The report recommended more intensive monitoring for metals in the Lamprey River and in other rivers to help put the results into a broader context. In addition, toxicity assessments in trouble areas were also recommended. In follow-up studies, the NHOSP found Al, Zn and Cu concentrations in water samples from the Exeter River to be greater than state standards at many sites during storm events (NHOSP, 1995a), and frequent exceedences for Pb, Zn and Cu during storm events at numerous sites in the Oyster River watershed (NHCP, 1996). Elevated concentrations of trace metals in stormwater runoff in Dover and Exeter have been measured, especially during significant storm/runoff events (Jones et al., 1999).

It appears that tributaries to estuarine waters have storm-related problems with trace metal contamination. In addition to their impact in the freshwater tributaries, the contaminants potentially may be transported to estuarine waters and pose risks to estuarine biota. The high copper concentrations in the tributaries and in the upper Great Bay Estuary are good evidence that transport is occurring.

2.3.2 STATUS AND TRENDS FOR CONTAMINATED SEDIMENTS

Many studies have focused on contaminants in sediments in coastal New Hampshire. Recent efforts are providing an update to many areas not surveyed since the 1970s (Bonis and Gaudette, 1998). A comprehensive database for contaminated sediments in coastal New Hampshire areas has been compiled by the USGS and will soon be available on CD and through the Internet (Buchholtz ten Brink et al., 1994 & 1997). Data from the PNS estuarine ecological risk assessment (Johnston et al., 1994), the Army Corps of Engineers dredging projects (NAI, 1994) and various scientific papers, consulting firm reports and theses are included. In all, the database includes data for 199 samples from New Hampshire, 452 samples from Maine and 993 samples from USACE permit applications and federal navigation projects. Information in the database is from reports and papers dating from 1973 to 1994, providing the opportunity in the future to determine trends for sediment contaminants at specific sites. The data, along with data from the rest of the Gulf of Maine, are presently being validated and interpretive maps are being produced.

The trace metal at highest concentration in New Hampshire's estuarine sediments is chromium. The range of chromium concentrations in sediments is 12-2300 mg/l. The highest chromium concentrations are found in the Cocheco River, where tannery waste with high levels of chromium were discharged. Chromium concentrations in Cocheco River sediments are commonly greater than the ER-M of 145 mg Cr/l. Chromium from the Cocheco River has been transported throughout the estuary (Capuzzo and Anderson, 1973).

Examples of the latest draft versions of the USGS maps for New Hampshire are presented in Figures 2.21-23 for mercury, lead and chromium, along with an example map of lead concentrations in the US portion of the Gulf of Maine (Figure 2.24) to provide a regional perspective to New Hampshire data. Data and maps are also available for nickel, cadmium, zinc, copper, phenanthrene, fluoranthene and pyrene in both the Gulf of Maine and in the Great Bay Estuary. The three example maps presented are useful to see general patterns in contaminant concentrations. The data are comprehensive and do not distinguish between older and newer data, analytical methods, sampling methods, or sample replication. Validation of data and maps is ongoing, along with the

FIGURE 2.21

Mercury concentrations in sediments in coastal New Hampshire waters: 1973-1994.

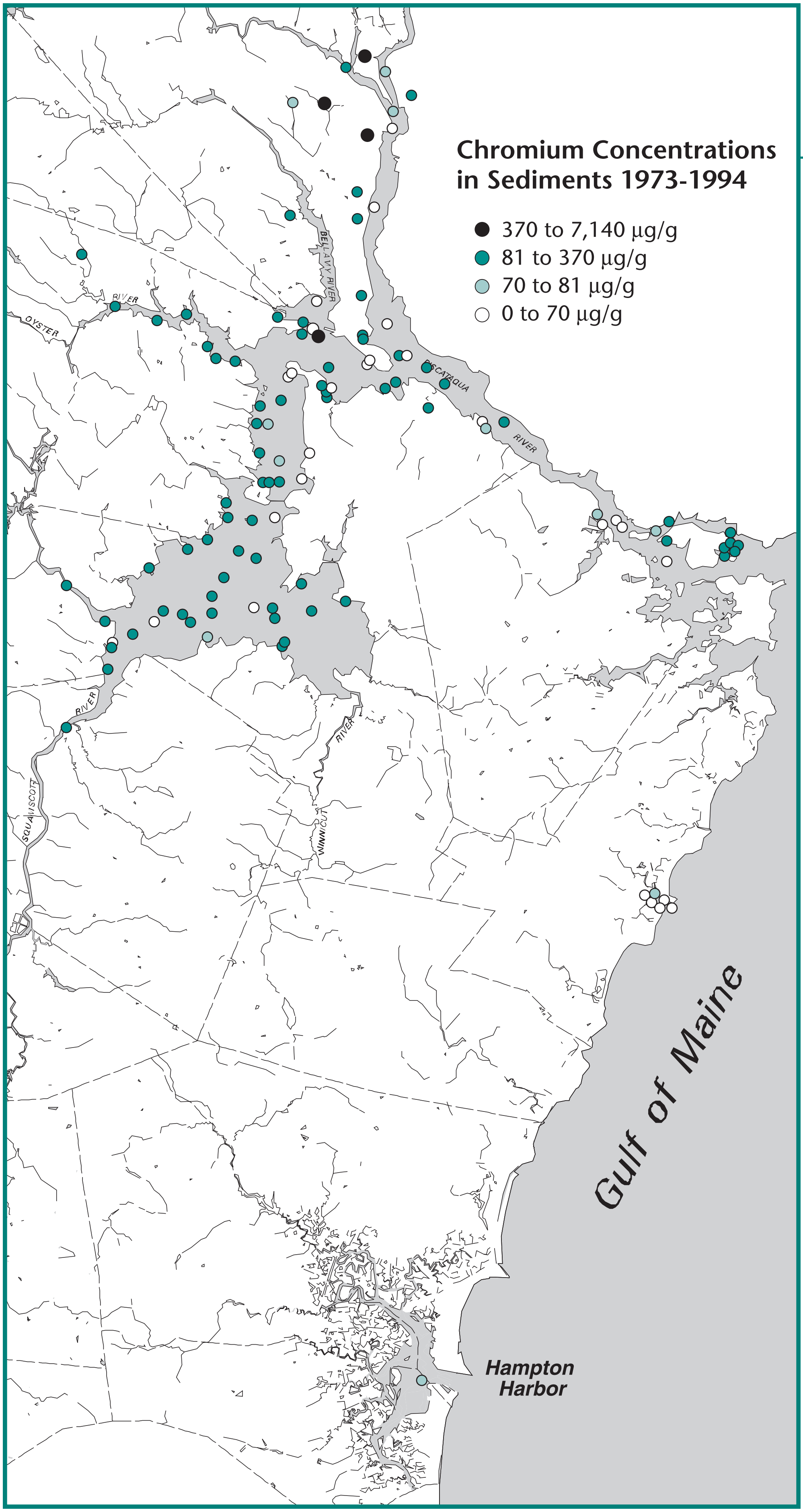
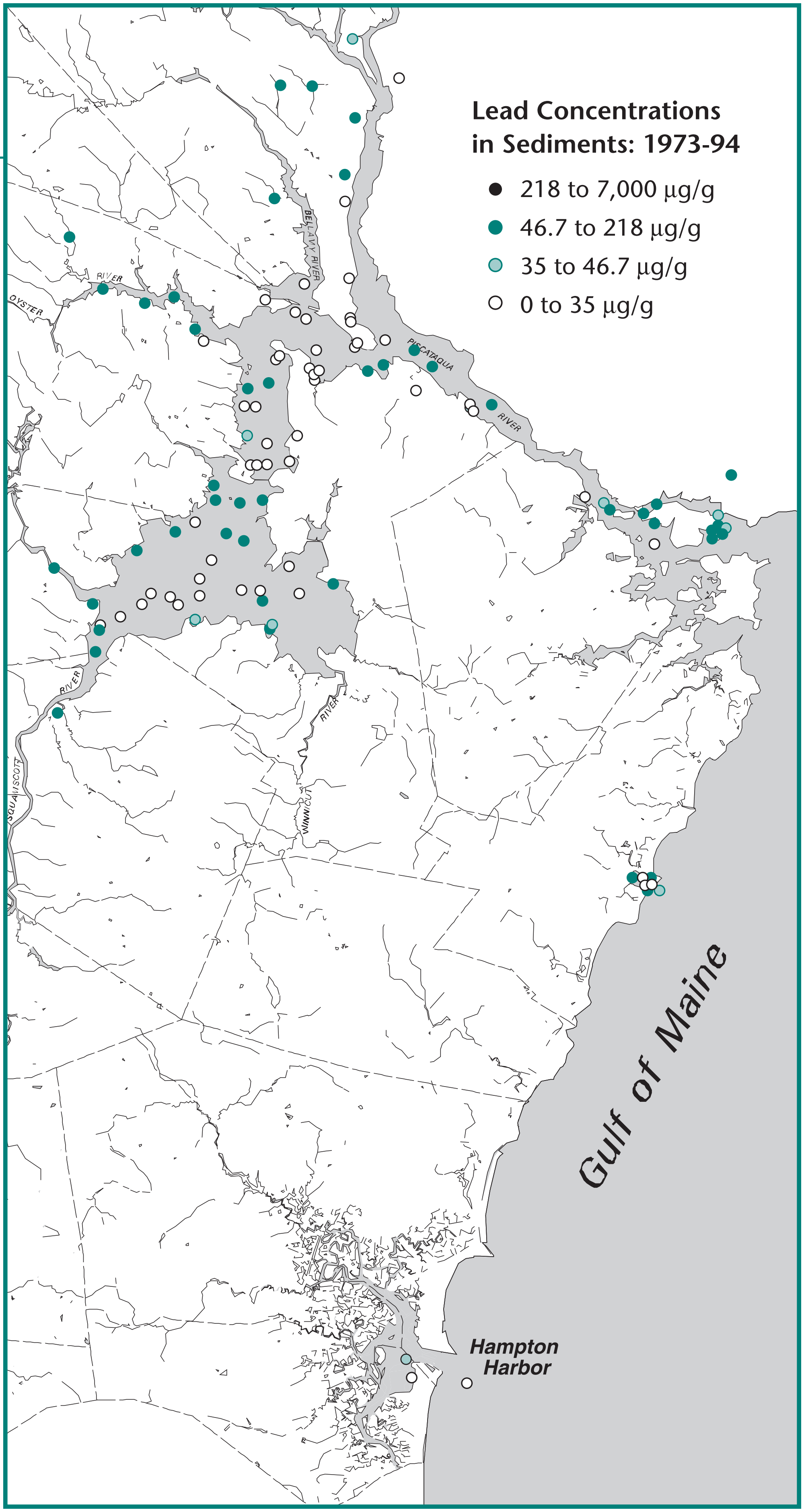


FIGURE 2.22

Chromium concentrations in sediments in coastal New Hampshire waters: 1973-1994.

FIGURE 2.23

Lead concentrations in sediments in coastal New Hampshire waters: 1973-1994.



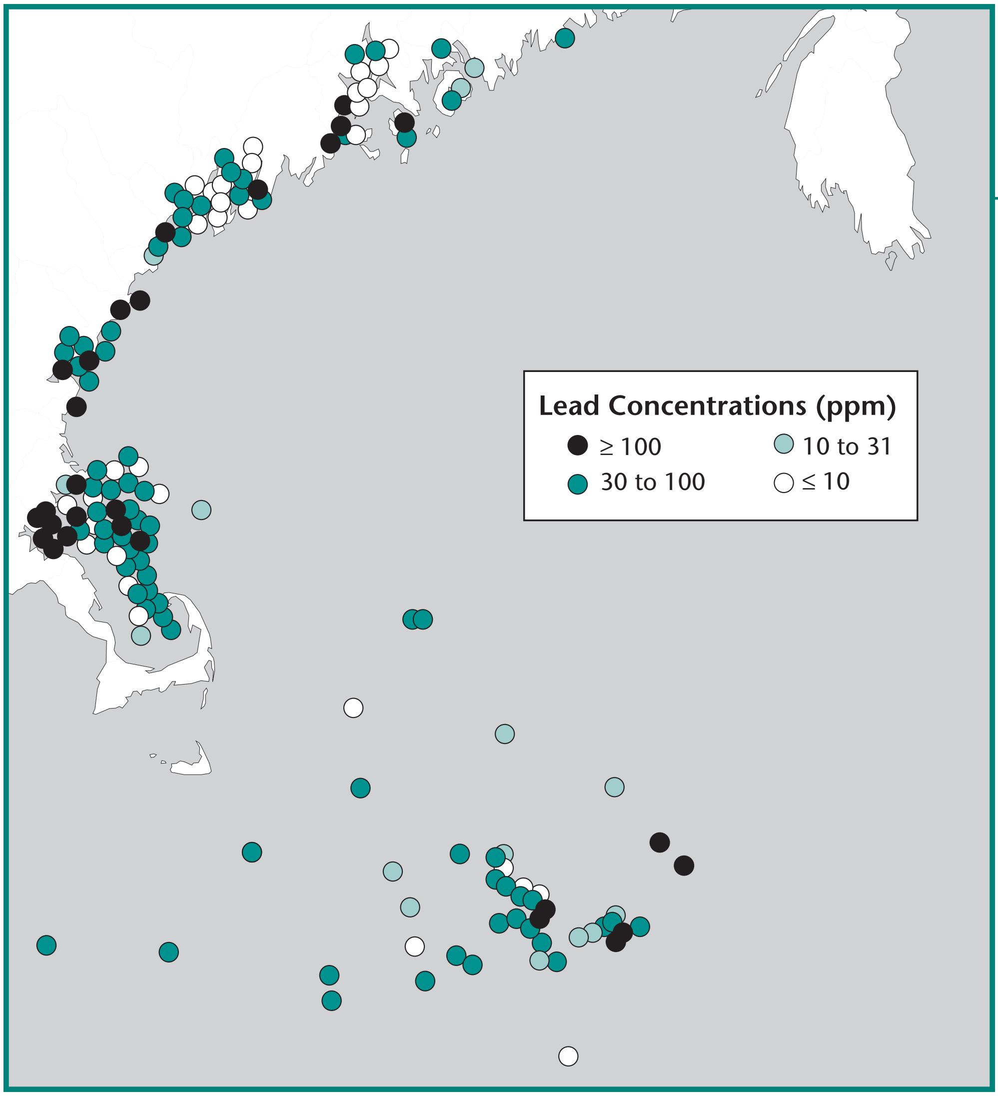


FIGURE 2.24

Lead concentrations in sediments in the U.S. portion of the Gulf of Maine and Georges Bank.

databases for organic contaminants and sediment texture.

Figure 2.21 shows numerous sites in the lower Piscataqua River and Rye Harbor that have Hg concentrations that exceed the ER-L sediment quality criterion of 0.15 µg/g (Long and Morgan, 1990), but no sites that exceed the ER-M criterion of 1.3 µg/g. The upper Great Bay Estuary generally had lower levels of mercury. Sites with lead concentrations that exceed the ER-L criterion of 35 g/g are numerous and spread throughout the entire coastal New Hampshire area (Figure 2.22). Three sites had lead concentrations greater than the ER-M level of 110 µg/g. The sites were near Seavey Island in Portsmouth Harbor and in the Squamscott River. Many sites with lower concentrations (<31 µg/g) were concentrated around Adams Point and Little Bay areas. Only four sites had concentrations of copper at or near the ER-L concentration of 70 µg/g. The sites included the same two sites that had high lead concentrations near Seavey Island, and two other sites in Great and Little bays. Relatively high (>81 µg/g) chromium concentrations are spread throughout the Great Bay Estuary (Figure 2.23), with the highest concentration in the Cocheco River. The Gulf of Maine map presents lead concentration in relation to background concentrations (20 µg/g), with values up to 2-3 orders of magnitude greater than background (Figure 2.24). Only one site (near Seavey Island) had a concentrations as high as 2.5 orders of magnitude greater than background.

As a means of assessing the impact of oil spills on sediments, sediments were collected monthly at 24 intertidal and subtidal sites throughout the Great Bay Estuary and analyzed for hydrocarbons

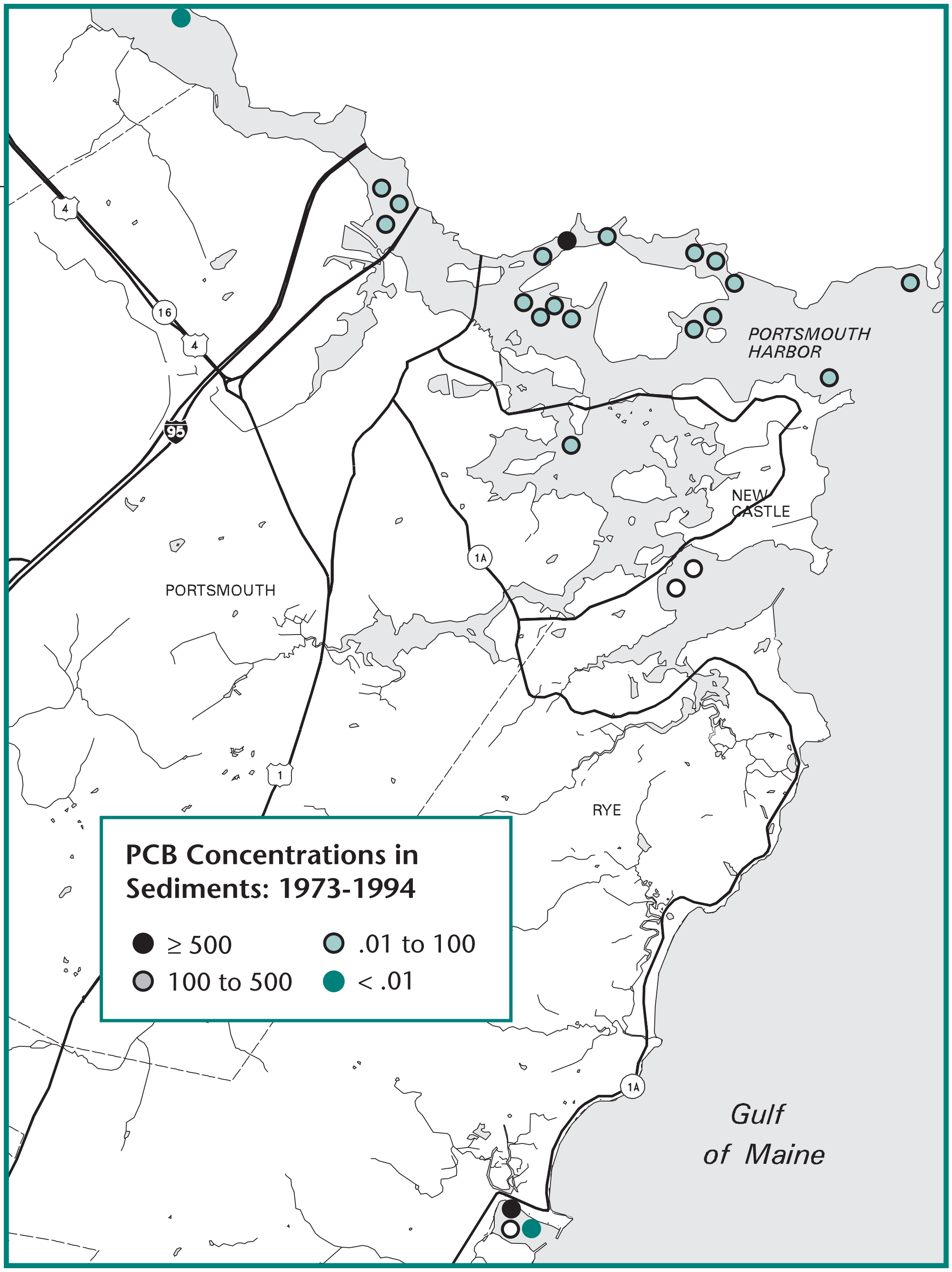


FIGURE 2.25

PCB concentrations in sediments in coastal New Hampshire waters: 1973-1994.

(Nelson, 1982). Nelson (1982) reported the results of analyses for PAHs and alkanes for February, 1981 at both intertidal and subtidal sites at eight different stations. Concentrations were reported for 13 different PAHs, ranging from 0 for numerous PAHs to >1000 mg/g sediment for chrysene and benzo[a]anthracene at Nobles I., Cedar Pt., Royall's Cove and Fox Pt. Alkane analysis was reported as concentrations for even and odd-numbered carbons in chains ranging from 14 to 32 carbons. Total alkane concentrations ranged from 707 ng/g sediment to 24,960 ng/g sediment. Sites with the highest concentrations included Rollins Farm (>14,800 ng/g), Broad Cove (>17,000 ng/g) Royall's Cove (>24,900 ng/g) in either intertidal or subtidal sites. Evidence of contamination from oil spills was evident at all sites, suggesting that oil spilled mainly in the lower estuary is likely transported to the upper estuary.

Dredge materials in New Hampshire have been disposed of in intertidal, nearshore, open water, upland or unknown locations (NAI, 1994). Much of the material dredged was disposed of at the Cape Arundel open water site. Some of the Rockingham County material was

2.3.3 SOURCES OF TOXIC CONTAMINANTS

Current industrial discharges of toxic contaminants are significantly less than the historical discharges that are probably the cause of much of the existing contaminants in New Hampshire sediments. Most current sources of toxic contaminants are suspected to be more diffuse sources such as urban stormwater runoff, atmospheric deposition, oil spills, and runoff plus groundwater infiltration from Superfund sites, golf courses and landfills. Stormwater runoff is the most frequently cited existing source of toxic contaminants in coastal New Hampshire (Jones et al., 1999). Stormwater runoff and associated storm event effects may also enhance contamination for some of the other sources of contaminants detailed below.

2.3.3.1 Stormwater Runoff

Stormwater runoff is the most frequently cited existing source of toxic contaminants in coastal New Hampshire. Significantly elevated concentrations of aluminum, lead, copper and zinc have been documented in freshwater tributaries (NHDES, 1994; see Status and Trends of Contaminants in Water section). Much of the stormwater and associated contaminants probably enter surface waters via stormdrains in urban areas (Jones et al., 1999; Jones, 1998b; Landry, 1997). This is currently the focus of a study supported by the NHCP. Stormwater is also suspected to enter the Great Bay Estuary directly through various streams and brooks throughout each bordering town. The area around the former Pease Air Force Base (PAFB) has been well documented. There are two drainage streams in Newington that are permitted NPDES outfalls, both formerly used by PAFB and presently used by the Pease International Tradeport (Figure 2.26). Flagstone Brook flows north from the site and eventually discharges into lower Little Bay (Tricky Cove) while McIntyre Brook flows from the runway into southeastern Great Bay. Both brooks are used for disposal of "stormwater runoff from airport activities" according to the NPDES, EPA-issued permit. Activities resulting in the production of this waste include aircraft maintenance, aircraft fueling, painting and stripping, aircraft washing and most significantly, aircraft de-icing. McIntyre Brook has the potential for having a more direct impact on the growing area than Flagstone due to the location of the discharge relative to shellfish resource areas. Major effluent characteristics that require monthly monitoring in McIntyre Brook include pH, oil and grease, primary deicing chemical, surfactants, trichloroethylene (quarterly), and total recoverable iron and zinc. Most of the runway and aircraft parking apron, industrial shop area and the entire flightline area drain into McIntyre Brook. There is an oil/water separator located near the origin of McIntyre Brook and a newly installed separator on Flagstone Brook. One of the main concerns with McIntyre Brook has been the propylene glycol content in the discharged water. This product is used in deicing aircraft and can potentially decrease the amount of dissolved oxygen in water. In 1992, as a part of the Air Force Installation Restoration program, shellfish tissue analysis was performed on samples collected in the vicinity of the Air Force Base. In an effort to evaluate the potential impacts of contaminants released from the Air Force Base into McIntyre Brook, American oysters, softshell clams, ribbed mussels and mummichogs were collected at the mouth of the brook where it discharges into Great Bay. Results of these analyses concluded that aluminum, arsenic and potassium concentrations in shellfish tissue samples exceeded background concentrations. However, the presence of these metals and the concentrations in which they were detected, do not pose a significant health risk to humans and were not concluded by the NHDES to be potential health risks.

In addition to McIntyre and Flagstone brooks, there are two non-permitted drainage brooks located on the Pease International Tradeport property which drain into the southeast portion of Great Bay. They are Peverly Brook and Picker-

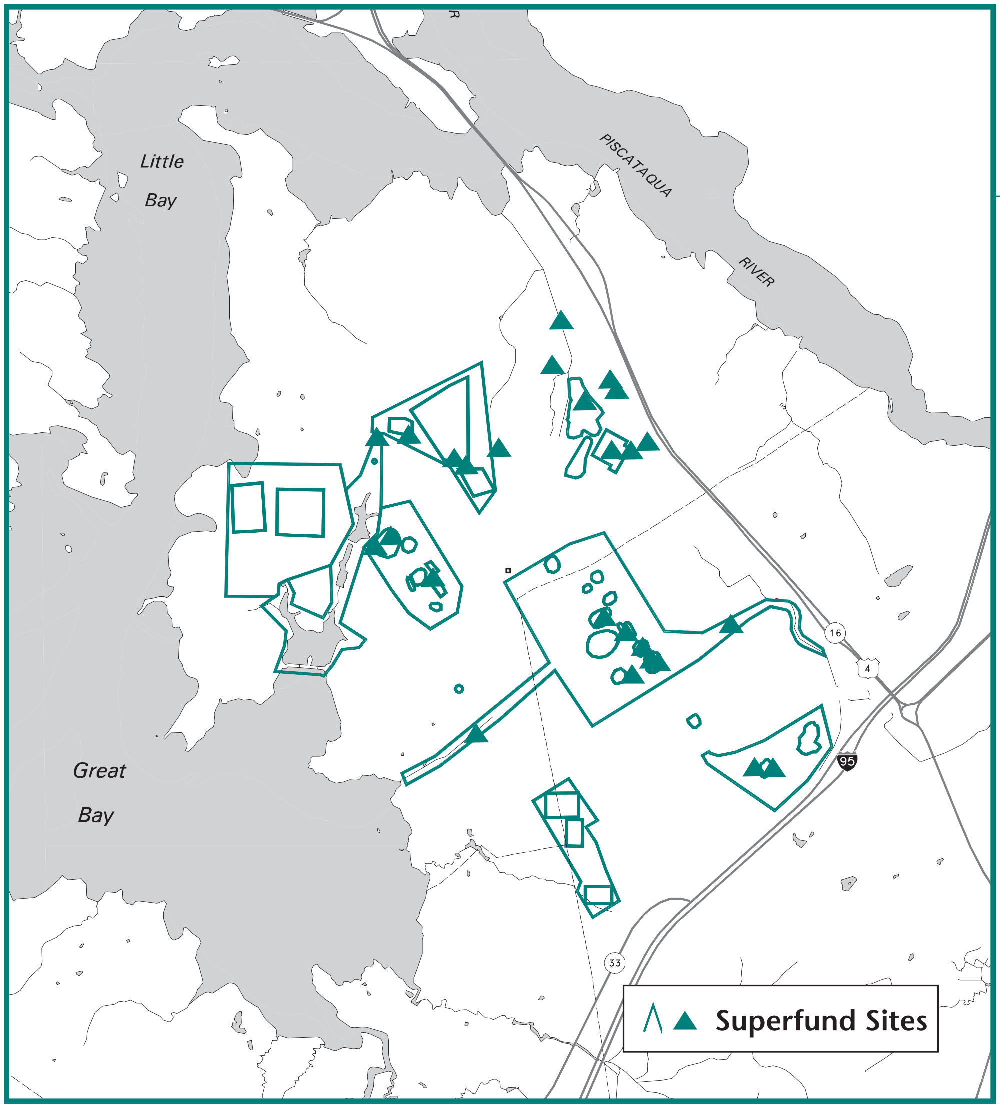


FIGURE 2.26

Superfund sites and surface waters in the former Pease Air Force base.

ing Brook. Runoff is characterized predominantly by overland flow to these streams. The Pease International Tradeport has adopted a Stormwater Best Management Practices Plan in order to properly handle all stormwater waste originating at the facility.

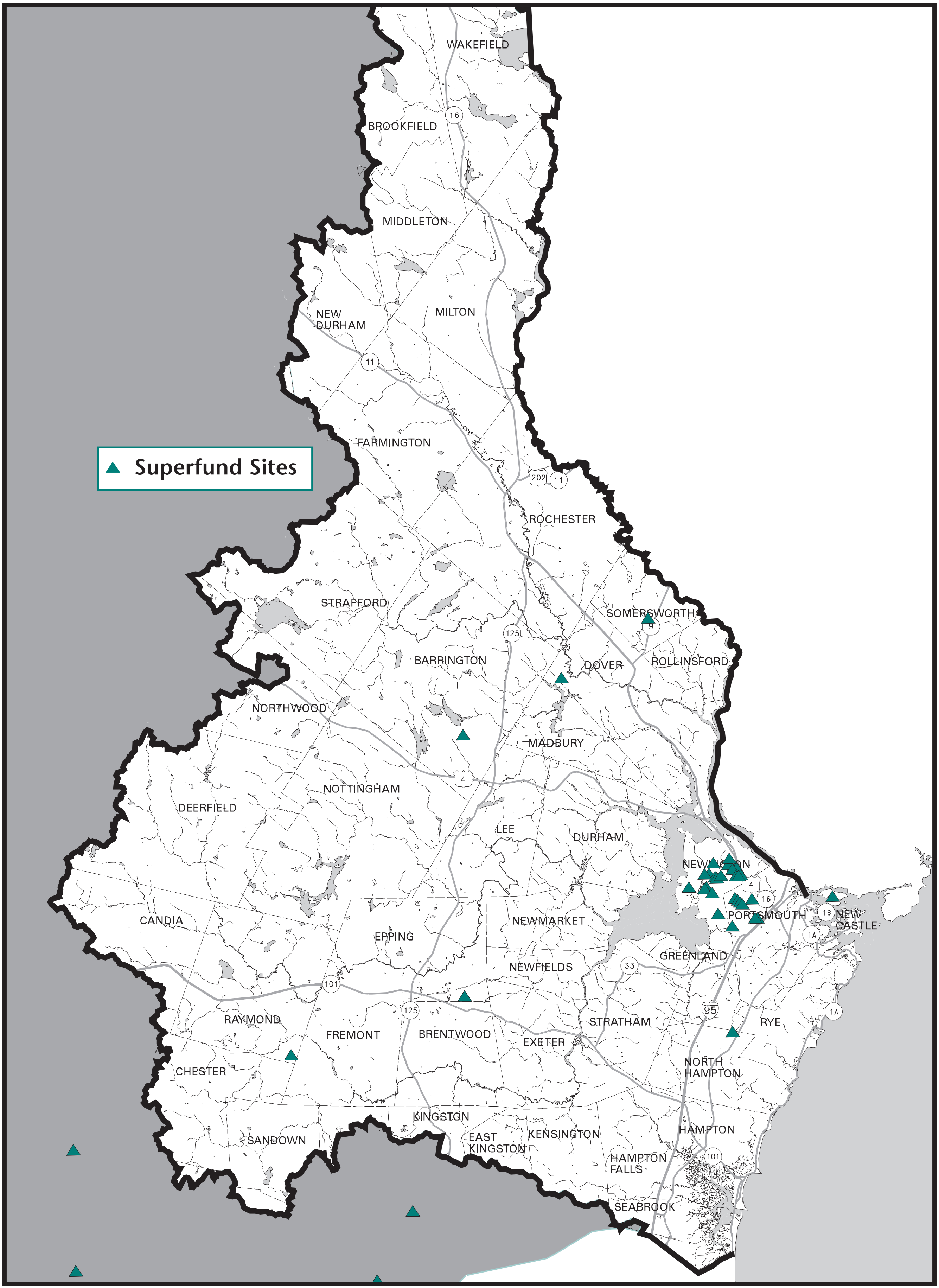
A joint UNH-JEL/NHDES study on stormwater control systems in the coastal area assessed the effectiveness of the systems to remove Al, Cd, Cu and Zn (Jones and Langan, 1996b). Concentrations of Al, Cu and Zn in the effluent from all of the systems exceeded the New Hampshire acute water quality standards for protection of aquatic life (NHDES, 1996b) during at least one storm event, especially during storms that occurred in winter. Cadmium concentrations rarely exceeded the acute standard, and exceeded the chronic standard less frequently than for other metals.

2.3.3.2 Superfund Sites

There are Superfund sites in coastal New Hampshire (Figure 2.27) with the Portsmouth Naval Shipyard, the former Pease Air Force base and Coakley landfill being of most concern to estuarine environmental quality. Copious amounts of information have been generated on environmental concentrations of contaminants, cleanup strategies, and toxicity to biota for both the Portsmouth Naval Shipyard (NCCOSC, 1997; Johnston et al., 1994) and the former Pease Air Force Base (Earth Tech, 1995). A large number of studies for these sites have been reviewed and synthesized (NCCOSC, 1997; Earth Tech, 1995).

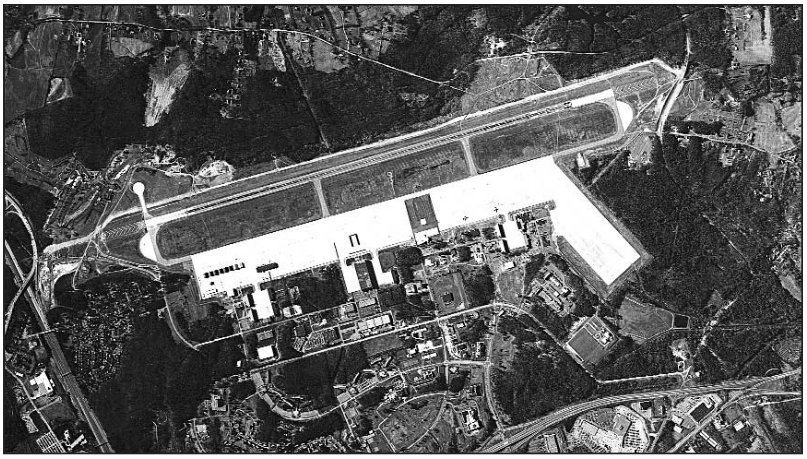
At PAFB, elevated concentrations of contaminants have been found in the sediments of some small streams, in groundwater plumes, in some biota, and

FIGURE 2.27 *Superfund sites in the coastal region of New Hampshire.*



in soil (Weston, 1992), mostly in close proximity to known sites of hazardous waste storage, disposal or discharge. Extensive measurements of contaminants in surface water, sediments and fish have been made (Weston, 1992). In addition, extensive analysis of surface water at two small rivers and sediments at three wetlands, all considered to be unimpacted by pollution, were conducted to establish naturally occurring background concentrations of contaminants as a basis for establishing remediation goals for Pease (NHDES, unpublished data). Elevated concentrations of DDT compounds reflect local deposition or application probably from the 1950s and 1960s (Weston, 1994). Detailed summaries of environmental factors at each of 48 Installation Restoration Program sites have been compiled (USAF, unpublished report). On the basis of extensive assessments of sediment and water contaminant analysis and toxicity assays, remedial alternatives for sediments were evaluated (Weston, 1996). Cleanup and remediation of stream sites with contaminated sediments include Paul's and McIntyre brooks, which had elevated concentrations of pesticides, metals and PAHs of concern to ecological receptors, though not to humans (USAF, 1997). Contaminants in Lower Newfields Ditch and Flagstone Brook have been determined to pose no risk to humans or ecological receptors, and no further action has been recommended.

The Coakley Landfill is located in North Hampton 6 miles up the freshwater portion of Berry Brook. It received municipal and industrial wastes from the Portsmouth and Pease Air Force Base area between 1972-1985. In 1983, the NHDES found groundwater and surface water contamination with volatile organic compounds (VOCs) at numerous sites in the area (see Hughes and Brown, 1995). The site was added to the USEPA National Priority List in 1983, ranked number 680. The site has undergone remediation, yet VOCs are still being detected in some locations near the landfill (1993 EPA data). This became a concern to the Town of Rye and they undertook a small investigation of water quality along the whole length of Berry Brook. They sampled twice during the spring of 1995, and had samples from 9 sites along the stream, from the Coakley Landfill to the Estuary, analyzed for a wide range of contaminants (Hughes and Brown, 1995). These included 10 metals, 60 VOCs, 20 pesticides and 7 PCBs. None of the toxic organic compounds were detected in any sample. The metals were all present at low concentrations or undetectable. They found dissolved oxygen to be low near the landfill, but satisfactory at other sites. Suspended solids, dissolved inorganic nitrogen and phosphorus, and fecal indicator bacteria concentrations were all low.



Pease International Tradeport

Other Superfund sites are located within close proximity to the Great Bay Estuary. The Tolend Road site in Dover is located near the upstream portion of the Bellamy River. The Somersworth landfill is located near the Salmon Falls River.

2.3.3.3 Documented Groundwater Pollution Sources

Landfills, fuel storage, hazardous waste generators and documented groundwater pollution sources are all in GIS on the GRANIT system (Figure 2.28). A recent compilation of landfills located within the Great Bay Estuary watershed was provided by NHDES, and is presented in Table 2.5. Most of the landfills have a Groundwater Management Permit. This requires leachate monitoring, and information on flow and analytical composition are routinely submitted to NHDES for review.

TABLE 2.5 *Conditions and characteristics of active and closed landfills in the coastal region of New Hampshire.*

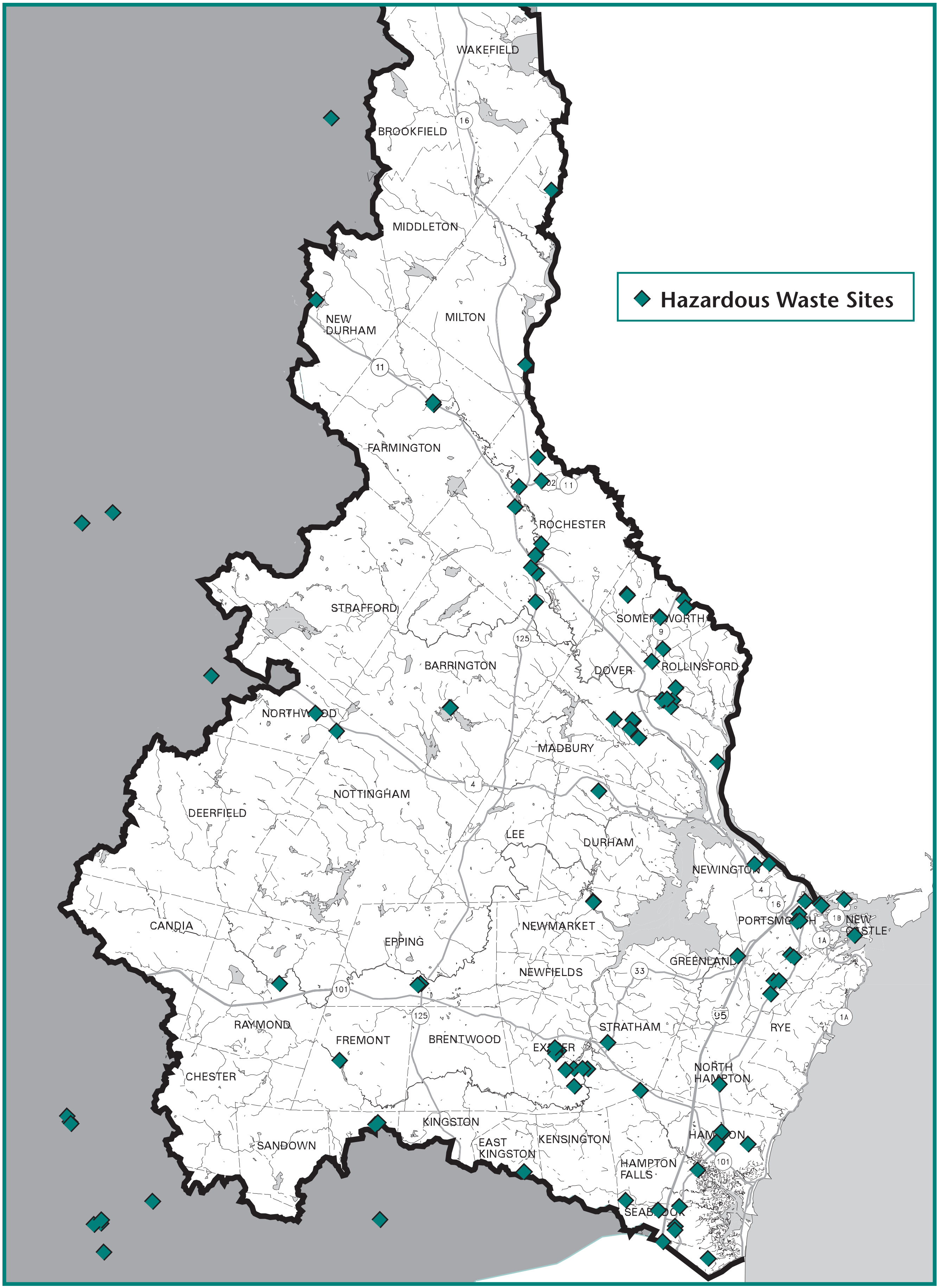
Town	Location	Start-up[1]	Active vs Closed	Lined vs Unlined	Leachate Monitored[2]	Hydraulic Connection
Barrington	Smoke St.	Early 1950s	Inactive since 1980	Unlined	Yes	
Brentwood	NO MSW 3	N/A	N/A	NIA	N/A	N/A
Brookfield	NO MSW LANDFILL	N/A	N/A	N/A	N/A	N/A
Candia	New Boston Rd.		Inactive	Unlined	Yes	
Chester	Route 102	Mid. 1950s	Active	Unlined	Yes	
Deerfield	Brown Rd.	1970s	Closed[4] 1996	Unlined	Yes	
Dover	Toland Road	1960	Inactive	Unlined	Yes	
Durham	Durham Pt. Rd.	1950	Inactive	Unlined	Yes	Adjacent to Horsehide Brook
East Kingston	NO MSW3 LANDFILL	N/A	N/A	N/A	N/A	N/A
Epping	Old Hedding Rd.		Inactive	Unlined	No	
Exeter	Cross Rd.	1976	Closed 1995	Unlined	Yes	
Farmington	Watson Corner Rd. (Municipal)	1940s	Active	Unlined	Yes	Water flows toward the Cocheco R.
	Watson Corner Rd. (Private)	Late 1960s	Inactive (Cardinal Landfill)	Unlined	Yes	Water flows toward the Cocheco R.
Fremont	Danville Rd.	1960s	Inactive since 1978	Unlined	Yes	Is adjacent to the Exeter R.
Greenland	Cemetery Ln.	Pre. 1900	Inactive	Unlined	No	
Hampton	Tide Mill Rd	1963	Closed 1996	Unlined	Yes	
Hampton Falls	NO MSW LANDFILL	N/A	N/A	N/A	N/A	N/A
Kensington	NO MSW LANDFILL	N/A	N/A	N/A	N/A	N/A
Kingston	Route 125	1920s	Active	Unlined	Yes	
Lee	Mast Rd.		Inactive	Unlined		
Madbury (Madbury Metals)	Route 155	Late 1970s	Closed[1] 1995	Unlined	Yes	
Middleton	NO MSW LANDFILL	N/A	N/A	N/A	N/A	N/A
New Castle	NO MSW LANDFILL	N/A	N/A	N/A	N/A	N/A
New Durham	Old Rte 11	Early 1970s	Inactive	Unlined	No	

Conditions and characteristics of active and closed landfills in the coastal region of New Hampshire (continued).

Town	Location	Start-up[1]	Active vs Closed	Lined vs Unlined	Leachate Monitored[2]	Hydraulic Connection
Newfield	NO MSW LANDFILL	N/A	N/A	N/A	N/A	N/A
Newington	Pease Tradeport	Mid. 1950s	closed[6] 1996	Unlined	Yes	
Newmarket	Ash Swamp Rd	1950	Closed 1995	Unlined	Yes	
Northwood	Route 4		Inactive	Unlined	No	
North Hampton	Coakly Superfund Site	1972	Inactive closure expected 1997	Unlined	Yes	
Nottingham	Freeman Hall Rd	1973	(Ash Pile] Active	Unlined	No	
	Freeman	1960s	Active[8]	Unlined	Yes	
Portsmouth	Mirona Rd	1950s	Inactive	Unlined	No	
	Jones Ave. Ash LF	1940s	Closed 1991	Unlined	Yes	
	PSNH Schiller Sta Woodbury Ave		Closed 1980s	Unlined	Yes	
Raymond	Prescott Rd.		Closed	Unlined	Yes	
Rochester	Turnkey LF	1980s	Active	Double Lined	Yes	
	Old Dover Rd	Closed	1980s	Unlined	Yes	
Rollinsford	NO MSW LANDFILL	N/A	N/A	N/A	N/A	N/A
Rye	Breakfast Hill Rd		Closed 1988	Unlined	Yes	
	Grove Rd		Inactive	Unlined	Yes	
Sandown	NO MSW LANDFILL	N/A	N/A	N/A	N/A	N/A
Seabrook	Rocks Rd.		Inactive	Unlined	No	
Sommersworth	Blackwater Rd.	1930s	Inactive Superfund Site	Unlined	Yes	
Strafford	Nelson Rd.		Inactive	Unlined	No	
Stratham	Union Rd.	1950s	Closed 1995	Unlined	Yes	
Wakefield	Route 153	1974	Active	Unlined	Yes	

1. A blank box indicates there is insufficient information on file to determine the date the landfill began accepting waste.
2. Leachate is monitored by the use of groundwater monitoring wells and surface water stations a: the landfill site.
3. MSW = Municipal Solid Waste.
4. Closed = Closed in accordance with State approved test” plans.
S. The Madbury Metals landfill c contains automobile shredder residue.
6. There were a total of five MSW, three Construction/Rubble Dump landfills and one paint can disposal area at the former Pease Air force Base. Four MSW landfills were combined and closed as one site, while the fifth is a stump disposal area which is inactive. Two of the Rubble Dumps and the Paint can area continue to be monitored.
7. A file review proved inconclusive on whether PSNH had received state approval for the landfill closure design.
8. The landfill in Nottingham is ~ construction and demolition debris landfill.

FIGURE 2.28 *Hazardous waste sites and landfills in the coastal region of New Hampshire.*



2.3.3.4 Oil Spills

There have been many oil spills of a wide range of volumes in coastal New Hampshire. During 1975-79 there were 103 oil spills in public waters in the 17 coastal communities (SRRC, 1981). The most significant spills included the tanker *Athenian Star* (10,000 gallons of diesel fuel) in 1975, Bouchard Barge #105 (8000 gal. #6 fuel oil) in 1978 and the tanker *New Concord* (25,000 gal. #6 fuel oil) in 1979, mostly associated with the oil terminals in Portsmouth and Newington on the Piscataqua River. Even though smaller spills were more frequent (94), nine spills of >500 gallons constituted 95.3% of the spilled oil. The impacts of the oil spills included fouling of beaches, shorelines, boats, docks, fishing gear and lobster traps. Many people reported that the shellfish beds in front of their houses were destroyed and that the marsh grass along the shoreline was removed because it trapped and retained oil. Many claims filed by lobstermen and shoreline residents were still pending a year and a half after some spills.

A 1981 NHF&G study (Nelson, 1982) was done specifically to serve as a baseline for assessing future oil spill impacts to estuarine resources. As a means of assessing the impact of oil spills on sediments, sediments were collected monthly at 24 intertidal and subtidal sites throughout the Great Bay Estuary and analyzed for hydrocarbons. Nelson (1982) reported the results of analyses for PAHs and alkanes for February, 1981 at both intertidal and subtidal sites at eight different stations. Concentrations were reported for 13 different PAHs, ranging from 0 for numerous PAHs to >1000 ng/g sediment for chrysene and benzo[a]anthracene at Nobles I., Cedar Pt., Royall's Cove and Fox Pt. Alkane analysis was reported as concentrations for even and odd-numbered carbons in chains ranging from 14 to 32 carbons. Total alkane concentrations ranged from 707 ng/g sediment to 24,960 ng/g sediment. Sites with the highest concentrations included Rollins Farm (>14,800 ng/g), Broad Cove (>17,000 ng/g) Royalls Cove (>24,900 ng/g) in either intertidal or subtidal sites. Evidence of contamination from oil spills was evident at all sites, suggesting that oil spilled mainly in the lower estuary was likely transported to the upper estuary.

At the present time, NHDES keeps records of all oil spills, including those that are spilled into surface waters. NHDES also has an oil spill clean up program. The NH Coastal Program keeps records of oil spills in the communities included on the coastal program.

The most recent significant oil spill in the coast of New Hampshire occurred in the Piscataqua River on July 1, 1996. It involved a spill of ~1,000 gallons of #6 fuel oil from the vessel Provence. The various types of compounds in the oil had different dispersion behavior, with some oil sinking and other fractions floating. The floating oil was collected along the shoreline of Little Bay, and the portion that sank is probably now associated with Little Bay sediments. Much of the oil sank in Little Bay, and the impact to biota was under investigated (NHF&G, 1996). Chase et al. (1997; 1998) reported elevated concentrations of PAHs in blue mussels at Dover Point 16 days after the spill in comparison to 1994 concentrations (Chase et al., 1996a). Low molecular weight PAHs decreased in concentration or disappeared in samples collected three and fifteen months after the spill, but concentrations of high molecular weight (> 5 rings) PAHs persisted and were still significantly higher than in 1994 tissue. Samples of both blue mussels and oysters from Fox Point collected 16 days after the spill had concentrations of PAHs approximately twice as high as seen at Dover Point. This difference is probably a function of where the oil was eventually deposited after initial transport via water currents soon after the spill.

In 1998, the NHDES joined efforts with the Gulfwatch program through UNH/JEL to expand the use of monitoring blue mussel tissue for toxic contaminants in New Hampshire waters (Jones and Landry, 2000). One key goal is to establish a baseline of data that could be used to monitor recovery in the event of a future oil spill. New monitoring sites have been established that bracket the major oil storage and off-loading facilities on the Piscataqua River and in other areas of the estuary that could be impacted by spills.

2.3.3.5 Fertilizer and Pesticide Applications

Historically, agricultural activities are associated with significant fertilizer and pesticide applications. The small number and sizes of crop-producing farms in coastal New Hampshire make agriculture less significant, and the contributions of golf courses and residential lawns has become relatively more significant. Use of all types of pesticides in Rockingham and Strafford counties has increased since 1965 (NHCRP, 1997). In 1994, 281,706 lbs of >250 pesticides were used in NH, with 1,000 to 10,000 lbs/y in estuarine drainage areas.

There are at least ten golf courses in the coastal communities of New Hampshire. Many are inland, but a few are in close proximity to estuarine surface waters. All golf courses need to use fertilizers and pesiticides to maintain the high quality turf on fairways and greens. Pesticides transported to estuaries via runoff or groundwater can cause harm to non-target estuarine organisms. Pesticide use at NH golf courses is regulated through a New Hampshire Pesticide Board (Department of Agriculture) permitting process. A survey of groundwater samples from 25 shallow wells at agricultural sites and golf courses, some of which were in the coastal area, showed no detectable pesticides, and metal concentrations were all within drinking water standards (NHDHHS, 1986).

Runoff and groundwater can also contain nutrients from fertilizers that may contribute to nutrient overenrichment. A drainage swale downgradient from the Rockingham Country Club in Newmarket had the highest loading rate for nitrate (~2.7 kg nitrate/d during high flow) than any other tributary to the Squamscott River (Jones and Langan, 1995c). Possible upstream sources were investigated and no significant source other than the golf course was apparent.

The Wentworth-by-the-Sea golf course uses a number of strategies to manage fertilizer and pesticide applications and minimize environmental impact because they use both on land that is immediately adjacent to Little Harbor (Rye-Wentworth Impact Assessment Report, 1990). A slow-release fertilizer (24-4-12) is applied to fairways, tees and greens in May, June and September at annual rates ranging from 130-218 lbs/acre of nitrogen and 22-36 lbs/acre phosphorus. Roughs are not fertilized. Grass clippings are returned directly (mulched) onto fairways. Tee and green clippings are collected and spread on the roughs. Water sample analysis suggested that the fertilizers applied at the course have little impact on the water quality of the harbor (Jones and Langan, 1995c). Insecticides are not used routinely or on a large scale. Instead, an integrated pest management system is employed and pesticide application is limited to spot application to control grub infestation. Preventative treatment for snow mold fungus is applied only to tees and greens. Heavy metal (mercury) based compounds are not used. All materials are applied conservatively with particular caution paid to adjacent surface waters and wetland buffer zones. Equipment used for applications is field-rinsed, and the diluted rinse water is sprayed onto the fairways to prevent a large volume of this water being washed into maintenance facility storm drains (Rye-Wentworth Impact Assessment Report, 1990).

Some other golf courses are in relatively close proximity to estuarine waters and tributaries. Portsmouth Country Club is located in Greenland on the southeastern shore of Great Bay, the Rochester, Farmington and Cocheco country clubs are near the Cocheco River, the Exeter Country Club is near the Squamscott River, and Pease Golf Course is near the shores of Great Bay.

Within salt marshes, human nuisances such as mosquitos and green-head flies are managed by seacoast towns that collectively spend approximately $100,000 each year (USDA 1994); ironically, most of the effort to control these pests occurs in degraded marshes (see habitat loss section). The NH Division of Pesticide Control has provided information on the coastal towns involved and the major contractors. The towns include Newcastle, Newfields, Stratham, Hampton Falls, Portsmouth, Hampton, Rye, Newmarket, Exeter, Newington, Seabrook and the Great Bay National Refuge. The towns conduct integrated systems of control, using both adulticiding and larviciding techniques. Insecticides used include GB-111 and VectoBac 12AS, CG and G. The larvicidal insecticides used typically depend on the activity of the bacterium *Bacillus thuringiensis* var. *israelensis*, and the adulticides are often pyrethroids.Organophosphate insecticides are also used.

2.3.3.6 Atmospheric Deposition

In an effort to refine and regionally focus the issue of atmospheric deposition of mercury, representatives of the regions state air, water, waste and public health divisions and Environment Canada formed a Mercury Workshop. This group recently published their findings (NESCAUM, 1998). The Workshop concluded that about 47% of mercury deposition in the region originated from sources within the region, 30% from U.S. sources outside the region, and 23% from the global atmospheric reservoir. This report has provided the impetus for a concerted regional effort to reduce mercury emissions. On June 8, 1998, the New England governors and eastern Canadian premiers agreed to cut regional mercury emissions from power plants, incinerators, and other sources in half by the year 2003 (Boston Globe -6/9/98).

The USEPA has monitored 70 toxic volatile compounds, including 56 volatile organic compounds (VOC) at Portsmouth and three other sites statewide since 1989 (NHCRP, 1997). Anthropogenic sources of VOCs include industrial processes, solvents, oil-based paints and automobiles. In 1994, the volume decreased to 23,174,000 tons, down from 30,646,000 tons in 1970. Most of the reduction came from automobiles, as the amount decreased from 12,972,000 to 6,295,000 from vehicles. Of the 70 compounds monitored, 37 have disappeared since 1987, and 15 have decreased in concentration.

A summary of recent existing input and output data for four inorganic and nine organic contaminants in the Gulf of Maine identified major data gaps in the current understanding of atmospheric deposition of contaminants (McAdie, 1994). Numerous papers were presented at a recent conference on regional atmospheric Hg deposition (EMAN, 1996). Gaseous mercury concentrations in the atmosphere over the Gulf of Maine were reported to range from 0.4 to 2.0 ng/m3. The concentrations generally vary inversely with altitude. Municipal and medical waste incineration is probably a significant localized (30-50 mile radius) source of Hg deposition in New Hampshire. In Maine, measurements of mercury in rain and snow showed ranges of 5-15 ng/L, giving wet deposition values of about 6-10 µg/m2/y. A new atmospheric monitoring station has been established at Newcastle, NH. Data collected are providing information on atmospheric mercury deposition in the coastal New Hampshire area as part of the national Mercury Deposition Network (MDN). Comparison with an inland MDN site at Laconia, NH, suggested that New Castle may be receiving greater mercury deposition than inland areas, along with other coastal sites in new England (VanArsdale et al., 1998).

2.3.3.7 Summary

Aside from historically resuspended contaminated sediments, the most significant documented sources of contaminants are stormwater runoff, oil spills and Superfund sites located adjacent to the Great Bay Estuary. All three source categories are receiving attention by state, federal and private agencies to mitigate contamination in the remaining source areas of New Hampshire. For some contaminants like mercury, atmospheric deposition is suspected to be a significant source, but is at present not well documented. Continued reductions of external sources of contaminants is important because of the existence of elevated contaminant concentrations from historical sources in some areas.

2.3.4 CONTAMINANT AND HYDRODYNAMIC MODELING

Mathematical computer modeling of circulation and tidal flow in the Great Bay Estuary was first done in the 1970s (Celikkol and Reichard, 1976; Brown and Arellano, 1979). The early two dimensional model examined the movement of water up the main stem of the Estuary and calculated the flushing time and tidal exchange for the various parts of the estuarine system (Swift and Brown, 1983; Short, 1992b). More detailed two dimensional models have been developed to examine the path that oil might take if a spill were to occur in the Estuary (Swift and Celikkol, 1983). The primary focus of the oil spill model was on the Piscataqua River near the oil loading terminals. The model included the upper Estuary, but it was never calibrated for Great Bay proper.

Recent efforts have begun to model the hydrodynamics and current flow patterns in Great Bay proper as part of an effort to develop modeling capabilities for simulating hydrodynamic flows in estuaries having intertidal areas (Ip et al., 1997). This model provided the first detailed hydrodynamic assessments for Great Bay and successfully simulated the movement of water on and off the extensive intertidal mudflats within that system. This two dimensional finite element model for Great Bay, currently under development at Dartmouth College, produces fine scale output of current velocities and tidal variations within Great Bay and upper Little Bay. The problems of model simulation within intertidal estuaries have been resolved, but the Great Bay model has not yet been field verified.

A finite element, two dimensional hydrodynamic model has been adapted to the entire Great Bay Estuarine system as part of the US Navy Ecological Risk Assessment Study (Pavlos, 1994). The WASP4 model, originally developed by the EPA, was used to estimate the distribution of lead throughout the Great Bay Estuary, assuming discharges were occurring at the Portsmouth Naval Shipyard (Chadwick, 1993; Pavlos, 1994). The model includes the simulation of dissolved substances within the water column throughout the lower portions of the Estuary (TOXIWASP, Pavlos, 1994). The TOXIWASP model was used to examine salinity distribution as well. The development of an improved version of the WASP model and the need for better accuracy in model predictions lead to the application of the WASP5 model to the Great Bay Estuary and a series of simulations, again looking at the transport of lead from sources around the shipyard as well as sources elsewhere in the Estuary (Scott, 1997). The focus of the WASP5 model was the Piscataqua River and Portsmouth Harbor although it was fit to the entire Estuary. This model was successful in predicting the transport of lead throughout the lower part of the Estuary and in determining sites where elevated concentrations of lead might accumulate.

WASP has recently been used to model nonpoint source pollution in the tidal portion of the Oyster River (Swift et al., 1996). Different programs within WASP were used to model currents and water levels, salinity, bacteria, nutrients and dissolved oxygen. The model exercise found that the flushing time of the river is 3 days. The model was also used to simulate contaminant distributions for an effluent release from the Durham WWTF, a significant rainfall event, and for average conditions. The results were relatively effective for simulating trends and processes when compared to field data collected as part of two previous studies (Jones and Langan, 1993a, 1994c).

WASP was also used by the State of Maine (Mitnick, 1994) to determine the reduction in phosphorus from WWTF required to meet the strict Maine WQCs for chlorophyll in the freshwater portions of the Salmon Falls River. The major WWTF included were at Berwick, ME and Somersworth, NH. The results suggested drastic reductions in phosphorus discharges would be needed. Experimental reductions in phosphorus at the WWTF confirmed that reductions in chlorophyll in the freshwater portion of the river were possible (Mitnick, 1994).

2.3.5 PUBLIC HEALTH RISKS AND ECOLOGICAL IMPACTS

New Hampshire coastal waters are popular areas for commercial and recreational fishing and recreational shellfishing. In addition, the area is noted and valued for its relatively pristine conditions, and the ecological integrity of the coast is an important resource. One threat to both public health and ecosystem integrity is the presence of toxic contaminants. The NHDHHS and other state agencies monitor contaminants and assess the risks to humans. They provide direct access to consumption advisory information via 1-800-852-3345 ext. 4664. At present, there are advisories based on elevated Hg in inland lakes and rivers, and two advisories in New Hampshire related to consumption of marine fish, both based on elevated PCBs (Table 2.6; NHDES, 1996b). These advisories are based on three studies conducted more than nine years ago. One of the first studies for shellfish from coastal New Hampshire was by Isaza et al. (1989). The results suggested that lead, PCB and PAH concentrations were elevated and warranted further study. To further determine how shellfish may impact human health, another study was conducted by NHDHHS (Scwalbe and Juchatz, 1991). As a result of the PCB concentrations found in lobster tomalley in their study, DHHS issued a consumption advisory for lobster tomalley in the Great Bay Estuary. There was also an advisory for consumption of coastal bluefish in New Hampshire issued in 1987 because of elevated PCB concentrations found in bluefish from sites along the Atlantic Coast (NOAA, 1987). These advisories are thus based on small, relatively old databases. More recent studies have provided newer and more comprehensive information on tissue body burdens of

Recommended consumption advisories for fish from the New Hampshire Department of Health and Human Services. From NHDES (1996b). **TABLE 2.6**

	Who We're Concerned About	Species of Concern	Recommendations
General Advisory For All Inland Freshwater Bodies	• Women of reproductive age	All species	Limit to one 8-oz. meal per month
	• Children 6 years of age or younger	All species	Limit to one 3-oz meal per month
	• All other consumers	All species	Limit to four 8-oz meals per month
Androscoggin River (from Berlin to the Maine border)	• Pregnant and nursing women	All species	Avoid consumption
	• All other consumers	All species	Limit to one or two 8-oz. meals/year
Great Bay Estuary	• Pregnant and nursing women	Lobster Bluefish	Limit consumption; avoid tomalley Avoid consumption
	• Children under 15	Lobster Bluefish	Limit consumption of tomalley Avoid consumption
	• All other consumers	Lobster Bluefish	Limit consumption of tomalley Avoid fish over 20 in. or 4 lbs; prepare according to guidelines
Connecticut River	• All consumers	All species	Prepare according to guidelines
Horseshoe Pond	• All consumers	Largemouth Bass	Avoid consumption

contaminants for a variety of animal and plant species.

Contaminant concentrations in blue mussels, other shellfish, lobsters, winter flounder and marine plants have been reviewed and summarized. The database available for blue mussels (*Mytilus edulis*) is the largest of any organism, with up to 85 sample analyses for each contaminant (Table 2.7. A more detailed summary is presented in Appendix H. Blue mussels are commonly used as an indicator for habitat exposure to organic and inorganic contaminants. Bivalves such as *M. edulis* have been successfully used as indicator organisms in environmental monitoring programs throughout the world (NAS, 1980; NOAA, 1991; Widdows and Donkin, 1992; O'Connor, 1992; O'Connor and Beliaeff, 1995; Widdows et al., 1995; Jones et al., 1998) to identify variation in chemical contaminants among sites and contribute to the understanding of trends in coastal contamination.

Blue mussels are a useful indicator organism for the following reasons: they are abundant within and across coastal New Hampshire; they are easy and inexpensive to collect and process; much is known about mussel biology and physiology; mussels are a commercially important food source (although in New Hampshire there is only recreational harvesting of mussels) and therefore a measurement of the extent of chemical contamination is of public health concern; adult mussels are sedentary, thereby eliminating the complications of interpreting results introduced by mobile species; mussels are suspension-feeders that pump large volumes of water and concentrate many chemicals in their tissues making it easier to detect trace contaminants; and the measurement of chemicals in bivalve tissue provides an assessment of biologically available contamination that is not always apparent from measurement of contamination in abiotic environmental compartments (water, sediment, and suspended particles). They also have well-defined limitations. One limitation is that they are only mildly tolerant of low salinities, and alternative shellfish (oysters, clams) may be required for areas such as Great Bay and some tributaries where salinities can be too low.

A summary of the data for mussels in coastal New Hampshire and nearby areas in Maine and Massachusetts is presented in Table 2.7. More detailed presentation of specific organic contaminants is available in Appendix H and in the reports that served as sources of this information. A series of "Guidance Documents" have recently been published by the USFDA (1993) for cadmium, chromium, lead and nickel "alert" levels. The levels do not warrant issuance of health advisories, but serve as useful target concentrations for assessing potential health risks from seafood consumption. The data in Table 2.7 show no metal other than lead came close to the alert levels. Lead concentrations in mussels exceeded the guideline level of 11.5 µg/g dry weight in nine samples at five sites around Seavey Island in Portsmouth Harbor and at one site in the Lamprey River. The highest concentration was 76 µg/g at Henderson Point on the southern end of Seavey Island. The other sites with concentrations >11.5 µg/g had values of 12.0-32.4 µg/g.

In 1997, mussels from Rye Harbor, Dover Point and Clarks Cove on Seavey Island had greater tissue Hg levels (>0.64 µg/g) than any of the other 22 sites monitored (Chase et al., 1998). An analysis of the Gulfwatch data from 1995 showed that the highest concentrations of cadmium and chromium from amongst the 14 sites monitored throughout the Gulf of Maine were found in mussels from Dover Point (Chase et al., 1996). For the first five years, 1991-1995, samples from Shapleigh I., Dover Point and Clark Cove had the 2nd, 4th and 7th highest chromium concentrations in the Gulf of Maine from amongst 59 sites (Jones et al., 1998). Samples from the same three sites and Little Harbor had amongst the top ten concentrations in the Gulf of Maine for lead, mercury, nickel, zinc, aluminum and iron, while the 1995 Dover Point sample with a high cadmium concentration was the highest in the Gulf for the five year period.

Toxic contaminant concentrations in bivalve shellfish tissue from sites in Coastal New Hampshire and in Maine sites in Portsmouth Harbor: 1985-1997.

TABLE 2.7

		Blue mussels *Mytilus edulis*			**American oyster** *Crassostrea virginica*			**Soft shell clam** *Mya arenaria*		
	USFDA Action Level for shellfish	Tissue Concentrations Average	Range	No. of samples	Tissue Concentrations Average	Range	No. of samples	Tissue Concentrations Average	Range	No. of samples
Trace metals		μg/g*	μg/g		μg/g*	μg/g		μg/g*	μg/g	
Ag		0.5	0.03 to 2.8	66	17.0	12.3 to 22.6	5			0
Al		282	77 to 650	40						
As		8.5	5.1 to 13.5	36	6.5	4.1 to 10.1	13	20.6	20.6	1
Cd	25	2.3	0.1 to 9.3	85	4.5	3.5 to 6.8	5	1.0	0.3 to 1.4	8
Cr	87	5.1	1.5 to 57	85	2.7	1 to 4.5	15	11.1	4.3 to 26.7	8
Cu		9.6	5.5 to 45.5	83	215	114 to 301	7	13.3	11 to 15	2
Fe		572	209 to 1,300	46						
Hg	6.7	0.47	0.13 to 1.1	73	0.61	0.07 to 1.1	13	0.35	<0.2 to 0.42	9
Ni	533	2.6	1.1 to 16.7	72	3.2	2.7 to 4.1	5	9.3	9.3	1
Pb	11.5	8.4	1.9 to 76	85	2.2	0.61 to 5.2	17	13.1	5.6 to 36	9
Zn		122	80 to 270	85	5383	3,770 to 6,000	7	70	59 to 80	2
Toxic Organics			ng/g	ng/g		ng/g	ng/g		ng/g	ng/g
PCBs	13000	339	5 to 2,540	42	199	189 to 246	6	161	<67 to 247	8
PAHs		3831	69 to 73,300	42	628	442 to 1145	8	26,013	<0.67 to 38,000	7
Cl'd pesticides	33000	20	3.5 to 51.8	24	105	88.4 to 159	6			0
Dioxins, Furans, Planar CBs										
CA tolerance level=133pg/g[†]		pg/g	pg/g							
CB/PCDD/ PCDF TEQ[††]		8.27	1.70 to 17.5	4						

* Dry tissue weight. To convert original data expressed as wet weights, assume 12% (oysters), 15% (mussels) and 16% (clams) dry weight.

† CA tolerance level (133 pg/g): Health Canada tolerance level for seafood consumption for 2,3,7,8-TCDD (133 pg/g DW = 20 pg/g WW; assume 15% solids).

†† Toxic Equivalency Concentrations for planar chlorinated biphenyls (CBs), dibenzo-dioxins (PCDD) and dibenzo-furans (PCDF) are based onn standardized factors for determining additive relative toxicities of these compounds that share a similar mode of toxicity.

Concentrations of organic contaminants in mussels in Table 2.7 are compared to FDA Action Levels for fish and shellfish. The organic contaminants analyzed that have Action Levels included PCBs, dieldrin, aldrin, chlordane, heptachlor, heptachlor epoxide, DDT and methyl mercury. Action Levels for total PCB and DDx are presented in Table 2.7. All reported organic concentrations are less than, and in most cases, far below the action levels. However, the PCB concentrations at the Dry Docks on Seavey Island and at sites in the upper Piscataqua River were only 5-8 times lower than the action limit of 13 µg/g.

The effects of contaminants on the physiology of mussels has also been assessed in a few studies. Gilfillan et al. (1985) found effects of contaminants on mussel physiology assays were more related to metals than to aliphatic or aromatic hydrocarbons in Portsmouth Harbor. They found Cd, Zn, Ag, Cr and Cu affected activities of glucose-6-phosphate dehydrogenase, aspartate amino transferase and scope for growth assays in mussels for some sites some of the time, although effects were not consistently measured at any specific site. Jones et al. (1998), reported that copper and zinc concentrations in mussel tissue from Little Harbor and Shapleigh Island in 1991 and 1992 exceeded critical body residue levels, or the lowest concentrations at which observed toxicity effects have been observed. Gulfwatch and Portsmouth Naval Shipyard studies have also reported extensive information on mussel growth and condition index, as well as limited information on scope for growth of mussels. The condition index data for indigenous and deployed mussels in New Hampshire indicate mussel growth and physiological condition are within normal ranges, although somewhat lower than other areas of the Gulf of Maine (Chase et al., 1997; 1998; Jones et al., 1998). The scope for growth measured in deployed (caged) mussels in Cutts Cove was the only indication of stress in deployed mussels in Portsmouth Harbor (NCCOSC, 1997).

A recent report from the USEPA (Metcalf and Eddy, 1995) reviewed published contaminant databases and determined background concentrations for contaminants in shellfish in New England and the North Atlantic continental shelf areas. Comparison of the lowest observed contaminant concentrations in New Hampshire mussels to the regional background concentrations showed concentrations of cadmium, PAHs, PCBs and DDx were close to background concentrations at some New Hampshire sites (Table 2.8). Other contaminants, especially arsenic, mercury and zinc, were present only at much higher concentrations, suggesting ubiquitous, regional sources of these contaminants.

Other studies have reported contaminant concentrations in different shellfish species. These data are summarized in Tables 2.7 and 2.9, and in greater detail in Appendix H. Isaza (1989) also analyzed clams (*Mya arenaria*), lobsters and sediments. Nelson (1986) analyzed oysters from four sites in the Great Bay Estuary for chromium and lead. Oysters were analyzed for a range of contaminants as part of the Portsmouth Naval Shipyard study (Johnston et al., 1994; NCCOSC, 1997). Langan and Jones (1995c) analyzed oyster (*Crassostrea virginica*) samples from Great Bay, and compared results to previous studies. Comparison of concentrations to USFDA Action Levels shows only lead in the clams from Hilton State Park at Dover Point exceeded the 11.5 µg/g Action Level. Relatively high concentrations of mercury in oysters, PAHs in clams and chromium in clams were also observed (Table 2.7). The lowest DDx concentrations in oysters were relatively close to background concentrations while concentrations of cadmium, chromium and PCBs were relatively high. Conversely, most contaminants that could be compared showed relatively low, and sometime lower, concentrations compared to background concentrations.

Numerous studies have reported contaminant concentrations in different types of lobster tissue (Table 2.9). PCB

Published background concentrations in New England waters (Metcalf and Eddy, 1995) and observed lowest concentrations for contaminants in blue mussels from coastal New Hampshire and Portsmouth Harbor. **TABLE 2.8**

	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	PAHs total	PCBs total	DDT and metabolites
Background concentrations* (Gulf of Maine)	0.23	0.20	0.30	1.40	0.01	0.30	0.60	3.70	0.04	0.01	0.01
Lowest concentrations† (New Hampshire)	5.10	0.10	1.50	5.50	0.13	1.30	2.10	80	0.07	0.01	0.01
USFDA Action Levels		25	87		6.7	533	11.5			13	33

* Background concentrations of contaminants in shellfish in New England and North Atlantic continental shelf area. From Metcalf and Eddy (1995).

† Lowest (background) concentrations of contaminants in shellfish in New Hampshire/Portsmouth Harbor.

concentrations in adult muscle and viscera tissue from Pierces Island in Portsmouth Harbor were in excess of the 13 μg/g action limit. These data are from the initial study that served as the basis for the lobster consumption advisory in New Hampshire (Isaza et al., 1989). Relatively high concentrations of cadmium and mercury were also observed in some different lobster tissue from various areas around Portsmouth Harbor.

Plant tissue levels of contaminants have also been reported (Table 2.10). As part of the Portsmouth Naval Shipyard study (Johnston et al., 1994), contaminants were measured in eelgrass (*Zostera marina*), fucoid algae (*Ascophyllum nodosum*) and winter flounder (*Pleuronectes americanus*). In the winter flounder samples, contaminant concentrations were well below FDA action levels. Concentrations of metals in eelgrass and fucoid algae showed elevated concentrations of some metals, and apparently different accumulation rates for some metals compared to mussels. Fish tissue from Peverly Ponds and Bass Pond at Pease AFB indicated all organic contaminants were below detection limits, except for DDT compounds (NHDES, unpublished data).

Sowles et al. (1996) reported heavy metal and organic contaminant concentrations in small mouth bass and white suckers from the Salmon Falls River. Mercury concentrations were similar to concentrations found in fish from lakes and ponds that prompted a fish consumption advisory in Maine. PCB and DDT concentrations also exceeded some human health threshold levels, and both metal and organic contaminant concentrations at some sites were near concentrations considered harmful to wildlife.

There have been numerous studies on contaminant concentrations and impacts on birds in the Gulf of Maine region. In addition, NHDES contracted in 1997 with a private company to provide wildlife rescue and rehabilitation in response to oil spills.

In general, only rare occurrences of tissue contaminant concentrations exceeded USFDA Action Levels. However, USFDA Action Levels may be higher than concentrations that can cause human and wildlife health problems. The relatively high concentrations for several trace metals and toxic organic contaminants are a concern, especially when they are consistently well above regional background concentrations. The cumulative effects of elevated concentrations of multiple contaminants are not well characterized, but certainly present a problem for the living resources and humans that inhabit the coastal areas of New Hampshire. Recent studies on the role of

TABLE 2.9 *Toxic contaminant concentrations (dry weight) in lobsters and winter flounder tissue from sites in New Hampshire, Portsmouth Harbor and the Isles of Shoals: 1985-1997.*

		Lobster *Homarus americanus*			Winter flounder *Pleuronectes americanus*		
		Tissue Concentration		# of	Tissue Concentration		# of
Contaminant	USFDA Action Level	Average*	Range	samples	Average	Range	samples
Trace metals	µg/g	µg/g	µg/g		µg/g	µg/g	
Ag		1.0	0.25 to 3.01	24	0.3	0.008 to 0.66	4
As		13	4.35 to 19.7	24	4.4	2.10 to 6.41	4
Cd	25	4.7	0 to 15.4	27	0.1	0.01 to 0.16	4
Cr	87	0.4	0.12 to 1.6	28	0.4	0.23 to 0.73	4
Cu		112.3	15.3 to 332	25	10.3	0.27 to 22	4
Hg	6.7	0.6	<0.14 to 2.39	26	0.15	0.10 to 0.21	3
methyl Hg	6.7	1	0.07 to 4.61	11	0.15	0.05 to 0.25	2
Ni	533	0.67	0.41 to 1.81	27	0.49	0.18 to 0.65	4
Pb	11.5	0.2	0.04 to 0.41	28	0.2	0.06 to 0.37	4
Zn		95.3	58.5 to 147	28	64.6	16.4 to 114	4
Toxic organics	ng/g	ng/g	ng/g		ng/g	ng/g	
PCBs	13000	1561	11.3 to 66,400	27	281	51.5 to 938	4
PAHs		588	47.2 to 87,600	24	479	17.2 to 531	4
Cl’d pesticides	33000	269	2.01 to 791	28	97	6.61 to 192	4

* Lobster tissue includes samples of tail, claw, hepatopancreas, viscera, cooked meat, cooked tomalley, for adults and juvenile animals.

TABLE 2.10 *Trace metal contaminant concentrations (µg/g dry weight) in marine plant tissue at sites in Portsmouth Harbor and Great Bay Estuary. Data from NCCOSC, 1997.*

Trace metal	*Zostera marina* leaves	*Zostera marina* roots	*Spartina alterniflora*	*Spartina patens*	*Ascophyllum nodosum*
Ag	0.68	0.66	0.22	0.14	0.49
As	1.3	4.5	1.2	1.2	15.2
Cd	1.25	0.53	0.07	0.10	0.55
Cr	1.7	9.2	2.0	2.3	0.73
Cu	15.5	16.9	2.1	2.8	16.9
Hg	0.02	0.05	0.01	0.02	0.04
Ni	1.82	3.09	0.69	0.98	1.83
Pb	2.4	10.9	0.97	1.8	2.3
Zn	72	57	31	27	78

*From NCCOSC, 1997.

many of the same contaminants as endocrine disruptors, especially during critical early life stages of biota, is cause for concern for very low contaminant concentrations. Continued assessments of contaminants in biota, like the Gulfwatch program, are important tools for assessing potential risks and determining trends in contaminant distribution and fate. More studies of biological effects would be useful to determine the overall toxicity of contaminants in the environment in the more contaminated estuarine areas. The detection of contaminants in New Hampshire shellfish that are close to background concentrations suggests that sites where these same contaminants are present at elevated concentrations may indicate localized sources.

INORGANIC AND ORGANIC NUTRIENTS

Eutrophication of estuarine and coastal waters resulting from excess nutrient input from anthropogenic sources has emerged as a significant problem for many coastal areas. The two most important nutrients in terms of pollution are nitrogen and phosphorus, since they are most commonly the limiting nutrients in aquatic ecosystems, though carbon, silica and trace metals such as copper and iron also play a role in primary productivity. In marine and estuarine waters, nitrogen is generally believed to be the primary limiting nutrient, though phosphorus has been identified as the limiting factor in some systems. In addition to the concentrations of nitrogen and phosphorus, the N:P ratio may also be important for some species of algae.

The biological effects of nutrient enrichment can range from subtle to extreme. Species shifts in phytoplankton communities can result in unfavorable conditions for estuarine biota, particularly for filter feeders such as bivalve molluscs. Massive blooms of phytoplankton can reduce water clarity, shade submerged aquatic vegetation (SAV), and reduce water column oxygen concentration due to nighttime plant respiration and oxygen consumption. Blooms of nuisance macroalgae can replace more desirable forms of vegetation and create hypoxic or anoxic conditions that can impact fish and invertebrates. Conditions resulting from nutrient enrichment can affect recreational activities such as fishing, boating and swimming as eutrophic systems can be most unappealing for these activities. Nutrient enrichment is also suspected to be a factor in blooms of harmful, toxin-producing algae in coastal and offshore waters. Finally, sources of biodegradable organic nutrients can be a direct cause of hypoxia and anoxia as heterotrophic bacteria can rapidly consume dissolved oxygen as they decompose organic substrates.

Assessing the trophic status or the degree of nutrient enrichment of any water body necessitates the measurement of a suite of parameters, since no single measurement can clearly depict trophic status (Kelly, 1991). In addition, the geometry (depth, width, length) and flushing characteristics or residence time of water masses are important factors in determining the susceptibility of any water body to eutrophication (Kelly, 1997). Measurements of dissolved nitrogen and phosphorus (inorganic and organic), turbidity or suspended solids, particulate organic matter, chlorophyll *a* (as a measure of phytoplankton primary productivity), dissolved oxygen, salinity and temperature are useful parameters for assessing eutrophication. Other indications of eutrophication involve measurements of changes in biota over time, such as areal coverage, distribution and condition of seagrass and macroalgal habitats, as well as species shifts in microorganism and macroalgal populations. Nutrient monitoring programs have been conducted both historically (1973-1981) and more recently (1988-1996) in the Great Bay Estuary by UNH researchers, and as part of the Seabrook Station Environmental Studies in Hampton Harbor by Normandeau Associates, Inc. Additionally, nutrient concentrations have been included in studies of nonpoint source pollution in the Great Bay Estuary (Jones and Langan 1993a; 1994a, b, c; 1995a, b, c; 1996a, b, c), and as part of a project assessing contamination of groundwater and surface waters by onsite sewage disposal (septic) systems in Seabrook and Hampton, NH (Jones et al., 1995, 1996). The monitoring and research studies are discussed here relevant to nitrogen, and to a lesser extent phosphorus, concentrations in New Hampshire estuaries.

2.4.1 NUTRIENT CONDITIONS IN NEW HAMPSHIRE'S ESTUARIES

The issue of nutrient overenrichment has been addressed in the Great Bay Estuary through monitoring programs dating back to the early 1970s as well as more recently in targeted studies of point and nonpoint nutrient inputs. Some of the data includes measures of organic nitrogen and phosphorus, however, the most temporally and spatially expansive data sets include inorganic forms of nitrogen (NH_4, NO_2^+ NO_3^-) and phosphorus (PO_4), forms which are most readily available for use by primary producers.

The Great Bay Monitoring Program supported by the GBNERR has included measurement of inorganic nitrogen and phosphorus concentrations at three sites in the Great Bay Estuary (Langan and Jones, 2000). Sites in the tidal portion of the Squamscott River and at Furber Strait (junction of Little Bay and Great Bay) have been sampled at high and low tide since 1988, while a site in the Lamprey River has been sampled since 1992. Though spatially somewhat limited, these data provide an excellent database from which short term changes in nutrient concentration can be detected. In addition, a substantial database generated between 1973-1981, which includes data from the Furber Strait/Adams Point site, allows for longer term trend analysis. The state shellfish program recently began monitoring shellfish growing waters for nutrients and other parameters, in addition to fecal indicator bacteria (Langan et al., 1999a).

Though concentrations differ between stations, the seasonal patterns are similar. Highest concentrations of inorganic nitrogen occur late fall through early spring, while the lowest concentrations occur in late spring through early fall. The seasonal pattern for PO_4 is somewhat similar, though following an initial drop during spring phytoplankton blooms, phosphate concentration often rebounds in summer. The timing of the spring phytoplankton bloom can vary considerably, depending on annual weather conditions, therefore the drop in N and P concentration can occur from late March to mid-May. At the Furber Strait site, maximum dissolved inorganic nitrogen ($DIN=NH_4 + NO_3 + NO_2$) can be as high as 20 µM in winter months, while minimum concentrations are generally < 1 µM at times in the spring and summer. Annual mean DIN at this site ranged from 7-11 µM from 1988 to 1996, with an eight-year mean of 8.8 µM. Interannual variation has been considerable and no long-term trend in concentration from 1988-1996 has been observed. Orthophosphate at Furber Strait has ranged seasonally from <0.10 µM to 1.5 µM with the annual mean ranging from 0.70 µM to 1.0 µM. The eight year mean is approximately 0.85 µM. Though at times the N:P ratio can range from as high 40:1 to as low as 1:1, the long term mean N:P ratio at this site is ≈ 10.6:1, indicating possible nitrogen limitation when compared to the Redfield ratio of 16:1. High tide concentrations of nitrogen at this site are slightly higher than at low tide, though this difference is inconsistent and statistically not significant. Orthophosphate concentrations are similar at high and low tides.

At the Squamscott River site (Chapman's Landing), nitrogen concentrations are much higher than at Furber Strait. DIN concentrations at this site can reach 40 µM during the winter and are generally <5 µM in spring and summer. The rapid drop in nutrient concentration in spring measured at Furber Strait is not as dramatic in the Squamscott River station, as spring turbidity, resulting from spring winds and freshwater runoff, often limits phytoplankton production. Therefore, nitrogen concentrations do not reach minimum concentrations until summer. The annual mean DIN from 1988 to 1996 at this site is ≈ 20 µM. DIN concentrations are generally higher in low tide samples, indicating an upstream riverine source of nitrogen in the Squamscott River. As was the case with the site at Furber Strait, there is considerable interannual variation in DIN concentration, though significant differences between years and trends in concentrations have not been evident in the eight year period. Orthophosphate concentrations have ranged from <0.3 µM to nearly 2 µM, with the overall mean of ≈ 1.25 µM. Though the N:P ratio can vary widely during the year, the overall eight-year N:P ratio is approximately 11:1, indicating some degree of nitrogen limitation like that at Furber Strait.

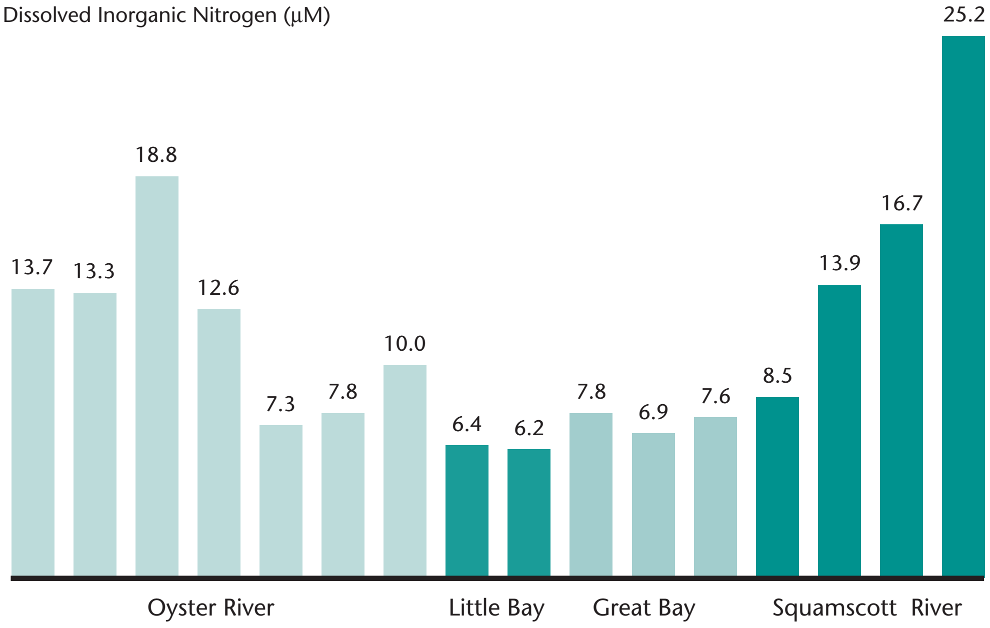
Nitrogen concentrations measured at the Lamprey River sample site are slightly higher than at Furber Strait, and lower than the Squamscott River. Concentrations of DIN can range from <1 µM to 30 µM, with annual means from 1992-1996 ranging from 10-14 µM. Orthophosphate is lower at this site than at the two other long term monitoring station, with a mean concentration of ≈ 0.6 µM. N and P concentrations at this site vary widely during the year, however, the mean ratio is ≈20:1.

Two separate field programs conducted concurrently from 1993 through 1995 (Jones et al. 1997) included measurements of nitrogen and phosphorus in samples taken on a transect beginning at the head of tide in the Oyster River, running south through Little Bay into Great Bay and terminating near the Newfields boat launch on the Squamscott River (Figure 2.29). Samples were taken monthly from a subset of stations with increased frequency at all stations during spring, summer and fall. Mean DIN concentration was highest at the station located at the Durham WWTP outfall in the Oyster River, and the influence of the treatment plant outfall was observed in the increased DIN concentration (18.8 µM) just downstream during low or falling tide. Otherwise, the highest concentration of DIN was measured at the most upstream site in the Squamscott River (25 µM), with decreasing concentrations (5-8 µM) through Great Bay into Little Bay. At the head of tide in the Oyster River, mean DIN was ≈ 13 µM, while at the mouth of the river, mean DIN was 10 µM. A short distance from the river mouth into Little Bay, mean DIN concentration (≈ 6 µM) was similar to Furber Strait and mid-Great Bay. Orthophosphate concentrations exhibited a similar pattern, with upstream stations as well as stations downstream of the Durham WWTF having the highest concentrations. Annual mean N:P ratios ranged from 7:1 to 11:1, indicating nitrogen limitation.

A three year project designed to assess the effect of storm events on concentrations of a suite of contaminants in the tributaries to Great Bay provided an excellent database for assessing spatial distribution of nutrient concentrations in the freshwater and tidal portions of the tributaries (Jones and Langan, 1994a, 1995a, 1996a). In addition to the inorganic forms of nitrogen and phosphorus, particulate nitrogen was measured in year two of the study, and dissolved organic nitrogen was measured in years two and three. Sampling was conducted at the same sites used in Figures 2.6 and 2.7 during dry periods (no precipitation for five days prior to sampling) and during

Dissolved inorganic nitrogen (DIN) concentrations at sites along a transect from the Oyster River through Little and Great Bays to Newfields on the Squamscott River.

FIGURE 2.29



the first low tide occurring within 24 hrs of a rainfall event of 0.5” or more. In year one, eight dry and eight storm events were sampled, while in years two and three, four storms were sampled on two consecutive days following storms. In addition to the tributaries, years one and two included stations in Hampton Harbor and the lower Piscataqua River. Though consistent effects of rainfall events on nutrient concentrations were not found, the dataset provides an excellent record of the spatial distribution of nutrient concentrations and a means of evaluating nutrient loading from point and nonpoint sources. The highest nutrient concentrations were consistently found in the freshwater and tidal portions of the Cocheco and Salmon Falls rivers. Relative to other sites, nutrient concentrations were also elevated in the freshwater portions of the Oyster River and in the tidal portion of the Squamscott River. Nutrient concentrations were consistently low in Hampton Harbor and the Piscataqua River. Relative to the forms of nitrogen, particulate nitrogen was generally a small fraction of the total, and exceeded 10% of the total nitrogen only during phytoplankton blooms at some sites. Dissolved organic nitrogen (DON) concentrations often exceeded DIN concentrations, however, DON represented a smaller fraction of the total at sites with the highest combined nitrogen concentrations.

Nonpoint source pollution assessments in the Oyster and Squamscott Rivers (Jones and Langan 1994a,c; 1995a,c; 1996a) included measurement of inorganic nutrients at sites along the tidal mainstem of the two rivers, sites in the freshwater portions of the rivers, small streams entering both portions of the rivers, and adjacent to suspected pollution sources such as developments and agricultural sites. In the Oyster River, the highest concentrations of dissolved nitrogen and phosphate were found in the vicinity of the Durham WWTF outfall and immediately above the tidewater dam in the Mill Pond. The greatest influence on overall nitrogen concentration, however, was from the treatment plant. A nitrogen and phosphorus plume was detectable at upstream stations all the way to the head of tide during flood tides, and as far downstream as Johnson Creek and sometimes Bunker Creek during ebb tides. The high nutrient concentration from the WWTF plume made it difficult to determine the relative strength of other tidal sources. Samples taken upstream of the Mill Pond, in both the main stem of the river and in smaller tributaries such as College Brook and Pettee Brook frequently had higher nitrogen concentrations than the water coming over the dam. A similar situation was found in Beards Creek which has a small impoundment before reaching the tidal portion of the river. The data indicates that impoundments can potentially remove nitrogen either via uptake by phytoplankton and macrophytic aquatic vegetation, or by biogeochemical processes such as denitrification or burial.

In the Squamscott River, a trend of decreasing nutrient concentration was identified from the head of tide in downtown Exeter to the mouth of the River in southwestern Great Bay (Jones and Langan, 1995c). Freshwater concentrations of nutrients were lower than tidal concentrations, indicating that the primary sources of nutrients were downstream of the tidal dam and may include the Exeter WWTF, runoff from the urban portion of Exeter, overflow from a CSO impoundment, dairy farms such as the Stuart Farm in Stratham and possibly the Rockingham Country Club golf course. Elevated nitrogen concentrations at the mouths of some marsh creeks whose drainage was undeveloped indicated that marshes may be exporting nitrogen.

Water column nutrient concentrations in the lower estuary were measured as part of the Ecological Risk Assessment Study for the Portsmouth Shipyard (Langan, 1994). This project included an initial set of replicate samples taken at 21 stations in the Piscataqua River, followed by monthly samples taken at low tide for a two year period at a subset of six stations. Nitrogen concentrations followed a seasonal pattern similar to the upper estuary, with the highest concentrations occurring in late fall through early spring, and the lowest concentrations (0-1 μM) measured from late spring through fall. Annual mean DIN for the six stations on the harbor area ranged from ≈ 7-10 μM. The highest concentrations of NH_4 and NO_3 were measured in Cutts Cove, which receives ebb tide waters from North Mill Pond, and at the Sarah Long Bridge, close to the Kittery, ME shore, just downstream from the Kittery WWTF. Orthophosphate concentrations were similar at all stations with the annual means ranging from 0.6 to 0.8 μM and individual measurements ranging from 0.2 to 1.2 μM.

The Portsmouth Shipyard Risk Assessment project also included three fixed station tidal stage studies, four crosssectional transects and high and low tide longitudinal transects conducted in July 1993. Data from transects and fixed station studies in the lower river and at the mouth of the Harbor indicated that nitrogen concentrations were very low, and generally on the order of 0-1 μM regardless of tidal stage. All lower estuary samples had low PO_4 concentrations as well, ranging from 0.3 to 0.6 μM. Nitrogen concentrations were generally higher for the Dover Point crosssectional transect, with NO_2 + NO_3 ranging from 1-5 μM, and NH_4 concentrations ranging from 1-4 μM. The highest concentrations were measured in the upper Piscataqua River during mid-ebb tide, indicating an upstream source of nitrogen. Longitudinal transects beginning at the mouth of Portsmouth Harbor to the railroad bridge on the Squamscott River were conducted at high and low tides on consecutive days. NO_2 +NO_3 concentrations on the high tide transect ranged from 0-1 μM from the harbor mouth to Dover Point and from 1-2 μM from Dover Point to the Squamscott River. For the low tide transect, NO_2 +NO_3 concentrations were similar to those measured at high tide in the lower estuary, and with the exception of samples taken in the upper Piscataqua River and at the mouth of the Squamscott River, were slightly lower (0-1.5 μM) through Little and Great Bay. Ammonium concentrations were more variable for both tidal longitudinal transects, ranging from 0-5 μM. The lowest concentrations were measured in the lower Piscataqua River and upper Great Bay at both tides, while the highest concentrations were measured at low tide in the upper Piscataqua and Squamscott rivers. The longitudinal transect data indicates possible sources of nitrogen from these two general (upstream) sources. Orthophosphate concentrations, though low throughout, increased from the harbor mouth to the upper estuary at both tides, with concentrations ranging from 0.3 to 0.8 μM.

A study of the sanitary quality of the shellfish growing waters in Little Harbor (Jones and Langan 1995c) included measurement of nutrient concentrations at sites in the vicinity of the Wentworth by the Sea golf course. Samples were taken in the spring following fertilizer application and during a period of wet weather. Mean DIN concentrations at three sites ranged from 6.16 μM to 10.2 μM while mean PO_4 concentrations ranged from 0.32 to 0.49 μM.

Based on the studies reviewed for this document, some general statements can be made regarding temporal and spatial patterns of nitrogen and phosphorus concentrations in the Great Bay Estuary. Throughout the estuary, the highest nutrient concentrations occur in late fall through early spring and the lowest concentrations occur in late spring through early fall. This pattern is more well defined for NO_2 + NO_3 than for NH_4 and PO_4. Spatially, the highest nitrogen concentrations generally occur near the heads of tide, due either to freshwater influences (Cocheco, Salmon Falls, Oyster Rivers) or to the location of municipal WWTF outfalls near the heads of tide (Oyster River, Exeter/Squamscott River, Salmon Falls River). Spatially, phosphate concentrations are low in most of the freshwater portions of the tributaries, highest in the upstream portions of the tidal rivers, and lower through Great Bay, Little Bay and down to the harbor mouth. There is an inverse relationship of salinity with nitrogen concentration, with the lowest concentrations occurring in the lower Piscataqua and Little Bay. By comparison with nutrient concentrations in other estuaries in the Northeast U.S., the Great Bay Estuary probably falls somewhere in the middle of the field.

By comparison to the Great Bay Estuary, very little data on nutrient conditions exists for the Hampton/Seabrook Estuary. A long term dataset has been established by Normandeau Associates (NAI, 1996), however, only one station outside the Harbor has been monitored and the data do not accurately represent conditions in the estuary. As part of a two year study of the potential for groundwater and surface water contamination from septic systems (Jones et al., 1995; 1996), nutrients were measured in groundwater and surface water at sites in Seabrook and Hampton. At eleven sites in Seabrook, groundwater wells were sampled in and around the effluent disposal areas (EDA) of residential homes. Surface waters down gradient of the EDAs, which were either fresh or brackish streams, marsh creeks or the Harbor itself, were also sampled. DIN concentration in the wells ranged from 0.15 to 36 mg/L, while the annual mean DIN concentration in surface waters ranged from 0.06 mg/L in the mouth of the Harbor to 2 mg/L in some of the small freshwater creeks. There was a decreasing nitrogen concentration with increasing salinity for the surface water samples. Based on the nitrogen concentrations and the direction of flow determined in the hydrological studies, it appears that nitrogen is transported from EDA to surface water, however the resulting low nitrogen concentrations in the harbor and the absence of any signs of potential eutrophication (low dissolved oxygen, algal mats, extreme phytoplankton blooms, etc.) indicate that there is little observable impact to the estuary. Though phosphate was detected in high concentrations in and around the EDAs, it did not appear to be as readily transported in the groundwater to surface waters. PO_4 concentration ranged from 0.01 to 8.9 mg/L in the EDA and from 0.01 mg/L to 0.06 mg/L in surface waters. A follow-up study in 1996-97 showed nutrient concentrations in the same surface waters were not significantly different from previous years, even though septic systems were being disconnected throughout Seabrook (Jones, 1997).

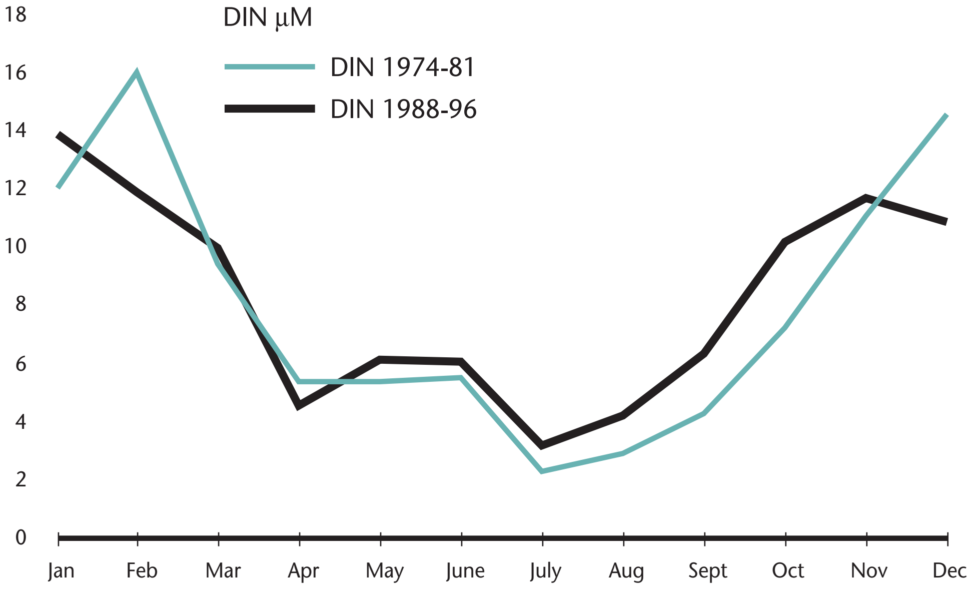
2.4.2 TRENDS IN NUTRIENT CONCENTRATIONS

Assessing long term trends in nutrient concentrations requires consistent sampling and analytic protocol over an extended period of time. Though some of the studies described above were conducted for two or three consecutive years, normal variation in water column concentrations makes it difficult to detect trends. Nutrient data generated for the Great Bay NERR Monitoring program, which has included sampling and analysis for eight years at two of the three stations indicates that there is considerable interannual variation in nutrient concentrations. However, statistical analysis of the eight years of data (ANOVA) does not indicate any significant differences in either nitrogen of phosphate concentrations between years nor are any trends of increasing or decreasing concentrations evident. The data collected as part of the Great Bay Field Program (Loder and Gilbert 1977; 1980; Loder et al., 1983; Daley et al., 1979; Norall, et al., 1982) included low tide sampling and analysis at stations that included a site at Furber Strait, identical to the 1988-1996 site sampled in the GBNERR monitoring program. Analytical methods for the earlier and more recent datasets were not identical, however, they were sufficiently similar to enable comparisons of nutrient concentrations. When all compatible (depth sampled) data for the earlier and more recent datasets were compared, mean NH_4 concentration was slightly higher in 88-96 dataset (3.51 µM) than in the 1973-1981 dataset (2.57 µM). Conversely, mean NO_2 +NO_3 concentration was slightly lower from 1988-1996 (5.25 µM) than 1973-1981 (5.60 µM). Mean dissolved inorganic nitrogen (NH_4 + NO_2 +NO_3) at the Furber Strait site is therefore slightly higher from 1988-96 (8.76 µM) than from 1973-1981 (8.17 µM). The datasets were compared statistically using both parametric (t-test) and non-parametric methods and no significant difference in DIN concentration was found. Seasonal patterns were also analyzed. There was considerable variation between years for samples taken during a particular month, therefore monthly means for the earlier and recent datasets were used for the purpose of comparison. The seasonal patterns for NH_4, NO_2 +NO_3 and DIN for the two datasets were remarkably similar to the data for DIN presented in Figure 2.30. As was the case when all data were compared, monthly mean NH_4 concentrations were slightly higher in the more recent dataset, and NO_2 +NO_3 were slightly lower.

Two additional studies conducted in 1976-1977 (Daley and Mathieson, 1979; Loder et al., 1979) allow an evaluation of changes in riverine nitrogen concentrations over a nearly 20-year period. Hourly water samples were collected throughout full tidal cycles in July and August in 1976 and 1977 (Daley and Mathieson, 1979) immediately seaward of the tidal dams and at sites downstream of the tidal dams and analyzed for NO_2 +NO_3. The mean concentrations were compared to July and August means for equivalent sample sites collected for various studies from 1993-1996. These data are presented in Figure 2.31 and 2.32. Increased concentrations over the nearly 20 year period are observed in the freshwater sites in the Cocheco and Salmon Falls rivers (Figure 2.31) while nitrite-nitrate concentrations are lower in the freshwater and estuarine portions of the Oyster and Bellamy Rivers (Figure 3.32). Similar concentrations for the two periods were observed in the Lamprey and Squamscott rivers.

Monthly data were collected and analyzed for nitrate-nitrite at the terminal freshwater areas of the Great Bay tributaries from February 1976 through June 1978 as part of study on nutrient flux processes in the estuarine system (Loder et al., 1979). Sample means were calculated and compared to data collected for several studies at identical sites from 1993-1996 (Jones and Langan, 1996a; Langan and Jones, 1996; Jones et al., 1997). The results are similar to the July-August data comparisons. Nitrate-nitrite concentrations at all sites with the exception of the freshwater areas of the Cocheco and Salmon Falls rivers are either similar to or lower in the more recent dataset, indicating improvements or no change in all tributaries except the Salmon Falls and Cocheco rivers, where concentrations have increased. Statistical

Monthly mean dissolved inorganic nitrogen at Adams Point in Great Bay for the years 1973-81 and 1988-96. **FIGURE 2.30**



analysis (t-tests as well as nonparmetric tests) indicate significantly higher concentrations of nitrate-nitrite in the freshwater portions of the Cocheco and Salmon Falls rivers, significantly lower concentrations in the freshwater and estuarine portions of the Oyster and Bellamy rivers, and no significant differences for the Lamprey and Squamscott rivers between data from the mid-1970s and the mid-1990s.

Based on the data reviewed for this report, it is possible to make some general statements regarding trends in nutrient concentrations in the Great Bay Estuary. Despite a dramatic increase in population from 1970 to 1990 (and a slower increase since 1990) throughout the Great Bay watershed, and therefore an expected increase in nitrogen loading,

FIGURE 2.31

Nitrate/nitrite concentration trends in freshwater portions of tributaries to the Great Bay Estuary.

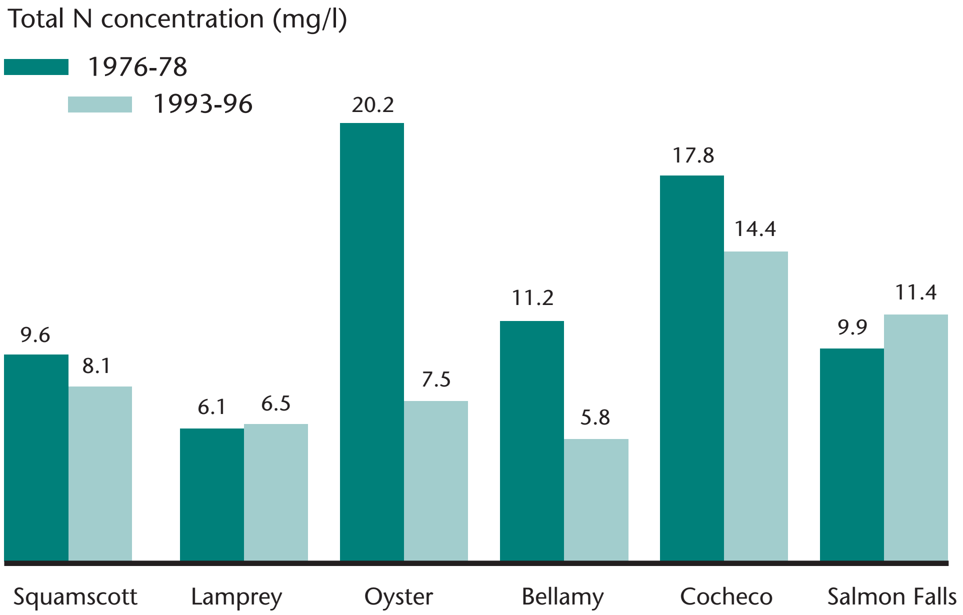
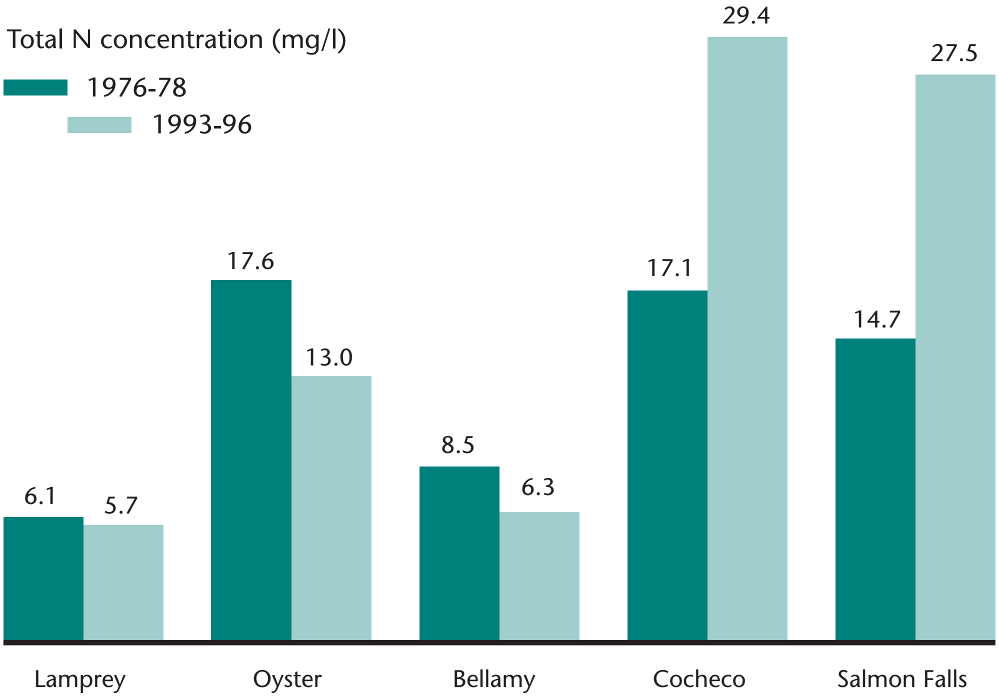


FIGURE 2.32

Nitrate/nitrite concentration trends in saltwater portions of tributaries to the Great Bay Estuary.

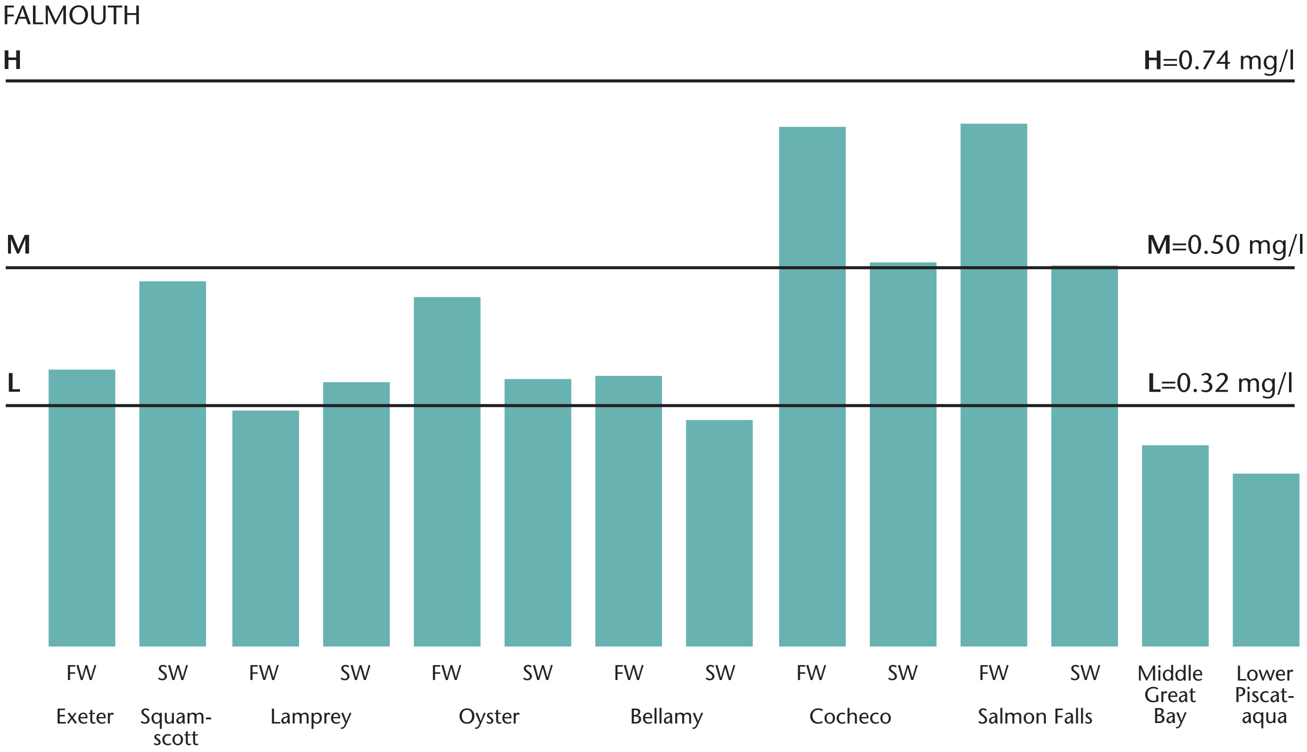


recent data indicate that current nutrient concentrations (annual means, seasonal patterns, minimum and maximum concentrations) in most areas of the estuary, including the tidal tributaries are similar to or lower than that which was observed in the 1970s. The exceptions are the Cocheco and Salmon Falls rivers, and in particular the freshwater portions of those rivers, where concentrations have increased in recent years. One possible explanation is that the expected increased loading from increased population has been offset by improvements in municipal wastewater treatment in most areas.

2.4.3. RELATIONSHIP TO WATER QUALITY STANDARDS

Though water quality criteria for estuarine waters have been established for some parameters such as metals, fecal indicator bacteria and dissolved oxygen, examples of concentration limits for nitrogen are rare. The Town of Falmouth, Massachusetts (1994) adopted a three tiered nitrogen concentration approach intended to limit future nitrogen inputs. Total nitrogen concentrations of 0.32, 0.5 and 0.75 mg/L total N were established as critical concentrations for water bodies of varying usage and classifications. Though the Great Bay Estuary has different characteristics than water bodies in the Town of Falmouth, it is useful to compare nitrogen concentrations in Great Bay to the standards established for Falmouth. Total nitrogen data for Great Bay locations were obtained from several studies described above, including the three year study of the tributaries (Jones and Langan (1994a, 1995a and 1996a) and data from a nonpoint source assessment extending from Oyster River through Squamscott River (Jones et al., 1997). Results are presented in Figure 2.33. None of the mean concentrations of total N, including the freshwater portions of the Cocheco and Salmon Falls rivers, exceed the 0.75 mg/L upper limit set for Falmouth. Sites exceeding the Falmouth medium concentration criteria (0.5 mg/L) include both the freshwater and tidal portions of

Comparison of total nitrogen concentrations for Great Bay Estuary and its freshwater and estuarine tributaries with Falmouth, MA water quality benchmarks. **FIGURE 2.33**



the Salmon Falls and Cocheco rivers. Sites exceeding the Falmouth low limit (0.32 mg/L) include the freshwater and tidal sites in the Exeter/ Squamscott River, the tidal sites in the Lamprey and Oyster rivers, and the freshwater site in the Bellamy River. Sites in the freshwater portion of the Lamprey River (0.30 mg/L), Little Bay/Bellamy River (0.29 mg/L) mid-Great Bay (0.27 mg/L) and the Piscataqua River (0.23 mg/L) are all lower than the Falmouth lower limit of 0.32 mg/L. The Great Bay Estuary could generally be characterized as having higher turbidity, greater flushing and greater depth than the water bodies surrounding Falmouth, therefore it is likely that it is less sensitive to higher nitrogen concentrations (Nixon and Pilson 1983).

2.4.4 POLLUTION SOURCES AND NITROGEN LOADING ESTIMATES

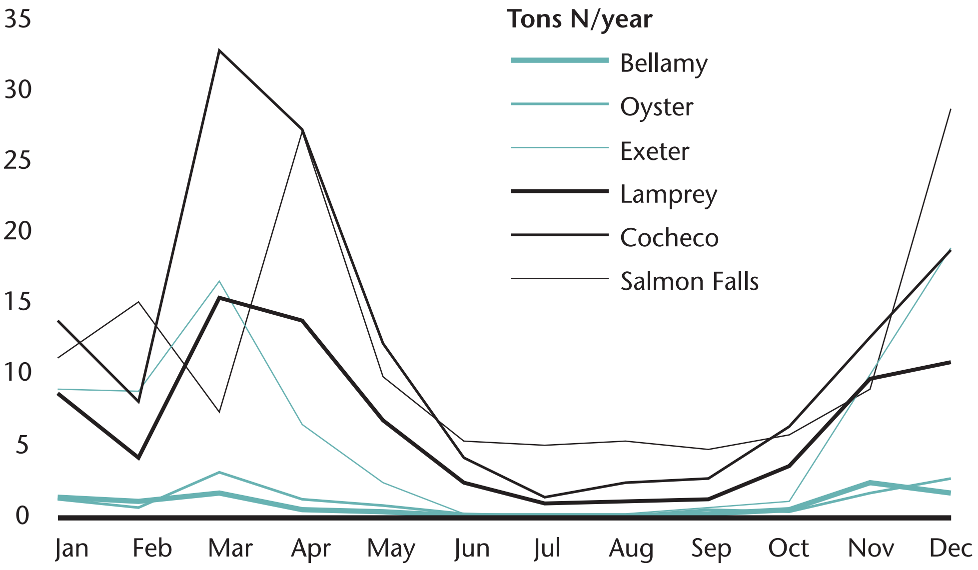
In general, sources of nutrients to estuaries include natural sources such as watershed sediments, organic debris (leaves and other vegetation) and groundwater, as well as point and nonpoint sources of anthropogenic origin. Anthropogenic point sources include industrial and municipal wastewater while nonpoint sources include urban and agricultural runoff, stormwater conduits, on-site wastewater treatment (septic) systems, lawn fertilizers and atmospheric deposition of nitrogenous compounds that result from burning of fossil fuels.

Loading estimates to water bodies are frequently based on modeling exercises. Values for nitrogen contribution, either measured from previous studies or estimated from literature values, can be assigned to all types of land use and cover (urban, forested, wetland, active agriculture, lawns, impervious surfaces), population and method of waste disposal in a watershed. Coupled with meteorological (rainfall) and other physical data (soil type, river discharge) the land use and land cover data can be used to estimate annual loading of nutrients. The NOAA Status and Trends Branch (NOAA, 1989), estimated annual loading to the Great Bay Estuary of 636 tons of nitrogen and 204 tons of phosphorus. Of these totals, it was estimated that point sources are responsible for 242 tons of nitrogen and 161 tons of phosphorus, while nonpoint sources are responsible for 394 tons of nitrogen and 43 tons of phosphorus. The method used to make these estimates is unclear, but it is assumed that it was some type of modeling study based on satellite derived (GIS at 1:24,000) land use/land cover data and predetermined values for nitrogen contribution. Another NOAA publication from the Strategic Assessment Branch (NOAA, 1994) estimated the total nitrogen input from point sources to be 317 tons per year. This estimate was based on effluent volume monitoring and typical wastewater concentrations of nitrogen.

Sources in Great Bay include municipal wastewater treatment plants, septic systems, urban and suburban (lawn fertilizer) runoff, and atmospheric deposition. Though agriculture is often cited as a major source of nutrients to estuaries, this is probably not the case in Great Bay. Though some farms may input nutrients at specific locations (i.e., Aikman Dairy Farm on the Salmon Falls River and Stuart Farm on the Squamscott River) there is very little active agriculture in the watershed, and therefore little possibility for system-wide loading of nutrients from agricultural sources. The models that use current GIS data to estimate nutrient loading may tend to overestimate the contribution of agriculture, since some of the land identified as active agriculture has not been farmed for many years. Additionally, some of the larger farms adjacent to the estuary (those mentioned above) have recently adopted, with the assistance of the NH Coastal Program and the Natural Resource Conservation Service (NRCS), best management practices to reduce contamination from animal wastes and fertilizer application.

The numerous studies on nutrient concentrations described in the earlier section of this report, in addition to studies on streamflow and river discharge (Pappas, 1996), atmospheric deposition (Mosher, 1995), and on effluent quality from local sewage treatment plants (Mitnik, 1994) have made it possible to esti-

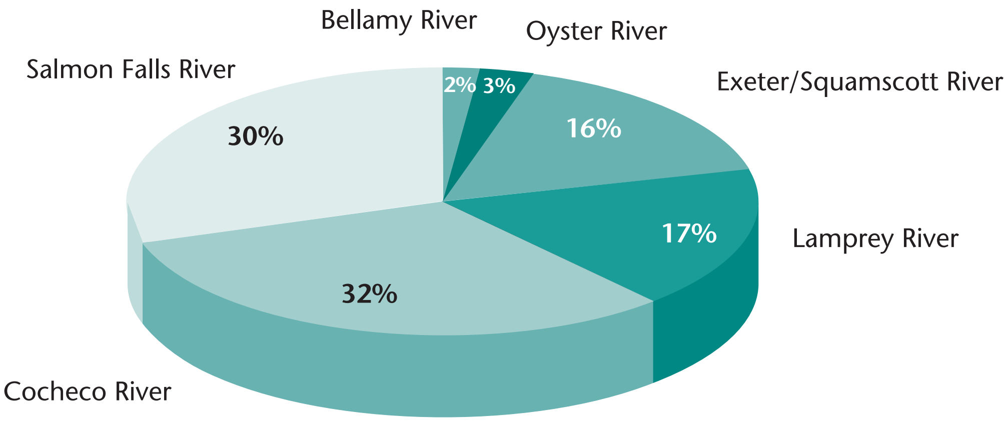
Annual loading of nitrogen from fluvial (riverine) sources to the Great Bay Estuary. **FIGURE 2.34**



mate loading to the Great Bay Estuary from actual measured data. There is also some data available on urban stormwater (Jones, 1998b; Jones and Langan, 1996a), however most of the urban development in the NH Seacoast is located at the heads of tide, and most stormwater is diverted to the freshwater portions of the tributaries and would therefore be included in the fluvial (riverine) loading estimates. For the purposes of this report, this exercise was limited to nitrogen, since it has been identified as the limiting nutrient in most estuaries, including Great Bay.

Fluvial (riverine) loading, which includes both natural and anthropogenic sources, was calculated by using mean monthly concentrations of total nitrogen (DON + DIN + PN) measured over a three year period in the tributaries to Great Bay (Jones and Langan 1994a, 1995a, 1996a) and river discharge measured and calculated by Pappas (1996). These data are presented in Figure 2.34. Nitrogen loading estimated for tributaries to the tidal portions of the Oyster River (Jones and Langan 1993a, 1994c) and Squamscott River (Jones and Langan 1995c) were small (on the order of < 1 ton annually from all tributaries) by comparison to the main stem of each river and to WWTFs, and were therefore not used in the calculations. Throughout the year, the months with the greatest loading are understandably the months of great-

Nitrogen loading to the Great Bay Estuary from fluvial (riverine) sources. **FIGURE 2.35**

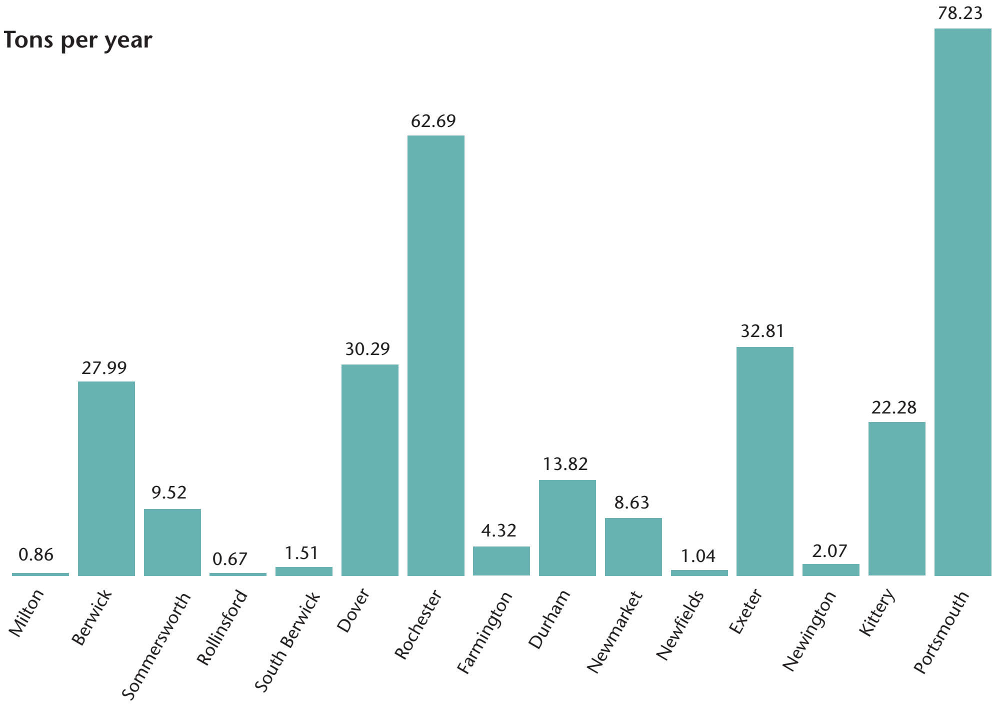


est river discharge. Peaks in loading occur in March and April and in November and December (Figure 2.34). Riverine nitrogen contribution to the Great Bay Estuary is greatest from the Cocheco and Salmon Falls rivers, followed by the Exeter and Lamprey rivers, with the smallest amount from the Oyster and Bellamy rivers (Figure 2.35). Nitrogen loading in the summer, or during dryer periods of the year, is greatest in the Salmon Falls River, followed by the Cocheco and Lamprey rivers. On an annual basis each river contributes the following in tons of N and % of total: Cocheco 143 (32%); Salmon Falls 134 (30%); Lamprey 78 (17%); Exeter 74 (30%); Oyster 12 (3%) and Bellamy 9 (2%) for a total of 450 tons of nitrogen per year.

Point source contribution was calculated using total nitrogen concentrations measured in wastewater effluent from the Milton, Berwick, South Berwick, Somersworth, Rollinsford and Dover WWTFs (Mitnik 1994) and the Durham WWTF (Jones and Langan 1994c) and average effluent volume reported by the treatment plants. For those plants where nitrogen concentration was not measured, a mean nitrogen concentration calculated from the treatment plants with measured data were applied. Point source loading from municipal WWTFs is presented in Figure 2.36. The largest nitrogen input, in descending order, is from the Portsmouth, Rochester, Dover, Exeter Berwick and Kittery WWTFs. Even though the volume from the Berwick plant is relatively small, the nitrogen contribution is high due to high nitrogen (especially ammonium) concentration in the effluent. From these data, it is estimated that the total point source (WWTF) contribution of nitrogen to the Great Bay Estuary is 296 ton of nitrogen per year. This figure is greater than the 1990 NOAA estimate of 242 tons and slightly less than the 1994 NOAA estimate of 317 tons, although it does not include loading from six industrial NPDES dischargers to the Estuary (Table 2.1).

In order to calculate point and non-point nitrogen loading, nitrogen contribution from treatment plants upstream of the tidal dams (Farmington and Rochester on the Cocheco River; Milton, Berwick, Somersworth and Rollinsford on the Salmon Falls River) was subtracted from the annual fluvial loads calculated for the rivers. This results in a total of

FIGURE 2.36 *Nitrogen input to the Great Bay Estuary from municipal wastewater treatment plants.*

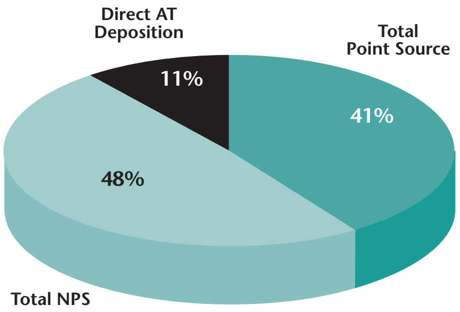


296 tons/year from municipal point sources, and 345 tons per year from fluvial sources (nonpoint sources).

Atmospheric deposition was calculated by Mosher (1996) for the Great Bay watershed. Since nitrogen loading from land deposition would be included in the fluvial source estimates, only direct deposition (to the water surface) was considered. The estimate for direct deposition was 77 tons/yr, which in addition to the point and nonpoint loading, totals 718 tons per year of nitrogen. The percentage contribution from the three sources is 48% from nonpoint sources, 41% from point sources and 11% from direct atmospheric deposition (Figure 2.37). The 718 tons per year is slightly greater than the 640 tons per year estimated by the NOAA Strategic Assessment Branch in 1990. In a smaller study conducted as part of a nonpoint sources assessment of the Oyster River in 1994, remarkably similar results with regard to the ratio of point and nonpoint contributions were obtained. Data generated by that study (Jones and Langan 1994c) estimated that 42% of the nitrogen loading to the Oyster River was from the Durham WWTF which contributed approximately 11 tons of total N per year.

It should be noted here that some liberties were taken in assignment of nitrogen inputs as either point or nonpoint. It is unlikely that the entire nutrient load from sewage treatment plants located well upstream of the estuary (Farmington, Rochester, Milton, etc) is delivered to the estuary. Therefore, attributing all of the nitrogen from these plants to point sources may result in an overestimate of point source contribution, and an underestimate of nonpoint source contribution. The total would not differ, however, since nonpoint was determined by subtracting the nitrogen contribution of upstream WWTFs from the total fluvial load. On another note, including the entire annual nitrogen contribution of the Portsmouth WWTF to estuarine loading may overestimate actual nitrogen loading to the estuary. The subsurface diffuser on the discharge pipe ensures rapid dilution, and the location of the outfall (near the mouth of the harbor), plus the characteristics and residence time of the receiving waters makes it unlikely that all or most of the nitrogen is transported upstream to the estuary, and that possibly up to 50% of the nitrogen is carried out of the estuary into the Gulf of Maine.

Sources of nitrogen loading to the Great Bay Estuary. **FIGURE 2.37**



Although nonpoint (riverine) and atmospheric sources exceed point source inputs of nitrogen, these sources include natural as well as anthropogenic sources. Point sources (WWTFs) on the other hand, are almost entirely of anthropogenic origin. Therefore, loading from these sources becomes much more important when planning for future development and if it becomes necessary to consider nutrient reduction strategies.

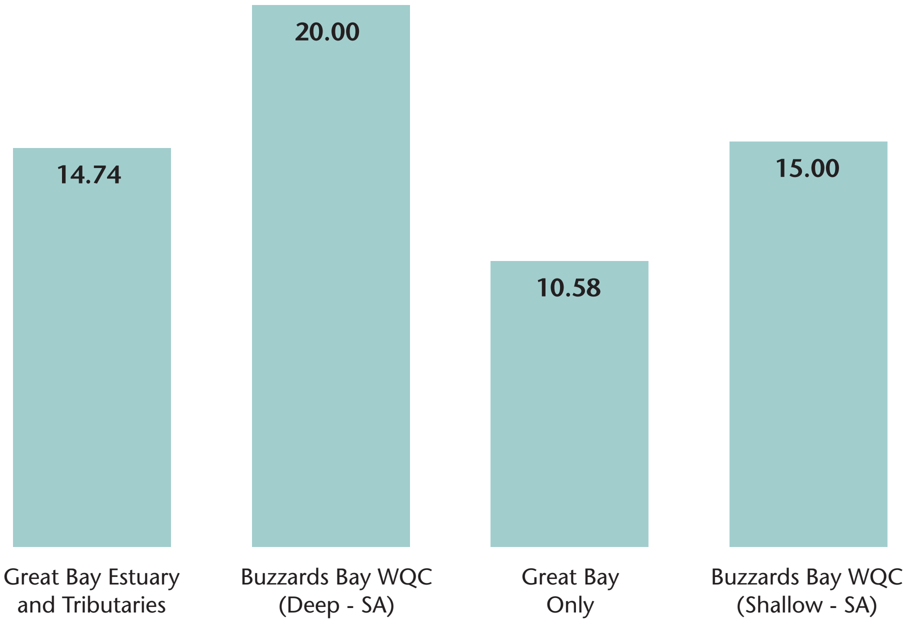
As was the case with nutrient concentrations, nitrogen loading limits have not been established for the Great Bay Estuary. The State of Maine DEP (Mitnik and Valleau, 1996; Mitnik, 1994) has conducted a WASP modeling and Total Maximum Daily Limit study (TDML) on the Salmon Falls River, and found that there are nitrogen and phosphorus impacts (excessive phytoplankton and depressed oxygen) in the freshwater impoundments, and phytoplankton impacts (depressed oxygen) to a small portion of the tidal section of the river during dry periods in summer. This study will be discussed in the section detailing impacts of eutrophication.

The Buzzards Bay NEP established loading limits (expressed in g/m2 of water surface area/year) for anthropogenic nitrogen to the estuary. Similar to the Falmouth, MA concentration limits, a tiered approach to nitrogen loading was established depending on the depth and flushing characteristics of sections or subunits (subwatersheds of Buzzards Bay). Loading per unit area to the Great Bay Estuary was determined by using the estimates previously described (718 tons), and dividing by the surface area of the estuary (10,900 acres). The results were compared to the loading limit established for deep, SA (class A waters) in Buzzards Bay with a flushing time of >5 days. This would represent an average estimate for the Great Bay Estuary, since the depth range is very broad, and flushing time can range from hours to weeks, depending on the exact location in the estuary. Loading to Great Bay (Lower Little Bay and all of Great Bay) was also calculated, using the area (approximately 5,000 acres) and loading from the Exeter, Lamprey, and Oyster rivers (fluvial) and WWTFs in Exeter, Newfields, Newmarket and Durham. Direct deposition of nitrogen from atmospheric sources in proportion to the surface area was also considered. The Buzzards Bay limit for shallow class A waters with a flushing time > 5 days was used for comparison. Results of these calculations and comparison to loading limits established for Buzzards Bay are presented in Figure 2.38. Loading to the entire Great Bay Estuary was calculated to be 14.5 g/m2/year and loading to Lower Little Bay and Great Bay was calculated to be 10.4 g/m2/year. Both these figures are below the 20 g/m2/year for deep water and 15 g/m2/year for shallow water established for Buzzards Bay.

It must be stated, however, that these estimates are a first attempt to assess the nitrogen loading to the Great Bay Estuary from actual water quality data. Since loading was based on mean nitrogen concentrations, which can be highly variable in riverine waters as well as in wastewater, there is a degree of uncertainty for those areas where sample size was small or where the effluent concentration was estimated. The contribution of nitrogen from groundwater sources directly to the estuary is unknown. Though soils in the Great Bay Estuary differ from those estuaries that have significant input of nitrogen from groundwater (Buttermilk Bay and Waquoit Bay, MA), it may be possible that additional nitrogen loading occurs through direct groundwater input to the estuary. Since groundwater loading is not considered, this could result in an underestimate of the total

FIGURE 2.38

Comparison of nitrogen loading in the Great Bay Estuary with water quality criteria standards established for Buzzards Bay, MA.



loading. There is also a degree of uncertainty in the validity of Great Bay to Buzzards Bay comparisons due to differences in hydrographic condition, watershed geology and topography. Mean tidal height at the mouth of the Great Bay Estuary is approximately 2.7 meters, considerably greater than in Buzzards Bay (1.7 meters), and there is also greater mean water depth in some sections of the Great Bay Estuary. Though these differences would suggest that the Great Bay Estuary can handle a greater amount of nitrogen loading than Buzzards Bay, the uncertainties mentioned, in addition to the absence of a nitrogen budget for the Great Bay Estuary that includes accurate estimates of rates of nitrogen processes (uptake, burial, remineralization, denitrification), would make a definitive statement of that nature premature. Also, the limitations for Buzzards Bay were for anthropogenic nitrogen, whereas all sources of nitrogen were considered for the Great Bay analyses.

Nutrient loading has not been estimated for the Hampton/Seabrook Estuary. Sources of nutrients include groundwater contaminated by septic systems, the Hampton WWTF located on Tide Mill Creek, some small amount of active agriculture, and urban and suburban stormwater runoff. Hampton Harbor is quite unique in that it receives an 88% exchange of water on each tide (twice daily). Therefore, the residence time of the water in the estuary is on the order of hours, even for the upstream areas. This residence time is probably too short to support intense phytoplankton blooms, and indeed there is no evidence of these occurring (Jones, 1997). The nitrogen concentrations measured in the estuary and outside the harbor mouth (NAI, 1996) indicate that despite the probability that the estuary receives nitrogen input from point (WWTF) and nonpoint sources (septics, stormwater, etc.), there appears to be sufficient dilution to reduce concentrations of nitrogen to low levels. The absence of other indicators of nutrient overenrichment such as poor water clarity, low dissolved oxygen, dense macroalgal mats and proliferation of opportunistic algal species supports the finding that excess nutrient input is not a problem in Hampton Harbor. Additionally, the town of Seabrook has recently finished the process of linking all the residences to a centralized municipal sewage system. The outfall for the WWTF is located in the Atlantic Ocean, therefore the possibility of any impact from contaminated groundwater (from septic systems) will be permanently removed.

2.4.5. DOCUMENTED IMPACTS ON WATER CHEMISTRY AND NATURAL RESOURCES

The biological effects of nutrient enrichment can range from subtle to extreme. Species shifts in phytoplankton communities can result in unfavorable conditions for estuarine biota, particularly for filter feeders such as bivalve molluscs. Massive blooms of phytoplankton can reduce water clarity, shade submerged aquatic vegetation (SAV), and reduce water column oxygen concentration in the dark via respiration. Blooms of nuisance macroalgae can replace more desirable forms of vegetation and create hypoxic or anoxic conditions that can impact fish and invertebrates. Conditions resulting from nutrient enrichment can affect recreational activities such as fishing, boating and swimming as eutrophic systems can be most unappealing for these activities.

2.4.5.1 Dissolved Oxygen

One of the principal concerns associated with nutrient overenrichment and eutrophication is reduction in dissolved oxygen (D.O.) due to elevated aerobic metabolism. Low D.O. (hypoxia) or the total absence of D.O. (anoxia) can severely impact aerobic marine and estuarine organisms and threaten the vitality of aquatic ecosystems. Dissolved oxygen is an important indicator and one of a suite of ecological endpoints for eutrophication.

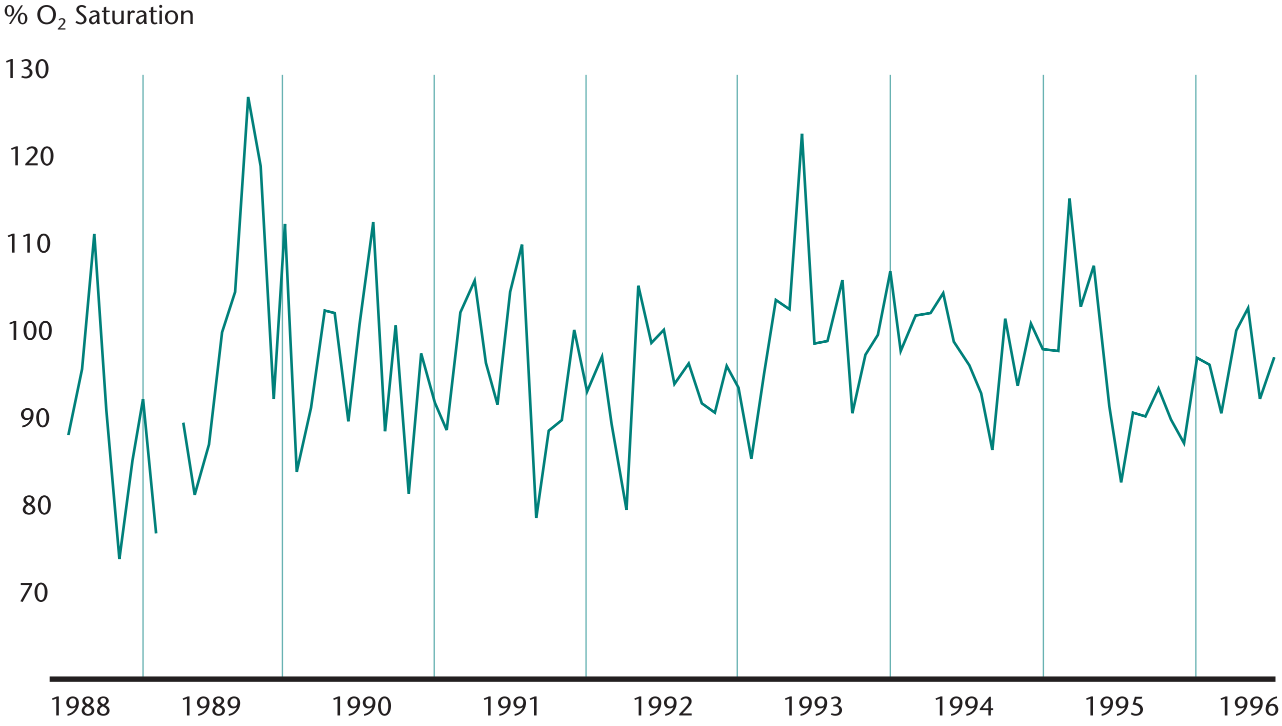
Dissolved oxygen has been measured in association with many monitoring and research programs. In the Great Bay Estuary, dissolved oxygen can vary at all times of the year depending on temperature of the water. Colder, fresher water, has a great capacity for dissolved oxygen. Therefore, in winter, dissolved oxygen will be higher in the upper reaches of the estuary than in the more oceanic lower portions of the estuary. As the waters warm and salinity increases in summer in the upper estuary, dissolved oxygen will be lower than in the cooler lower estuary. Thus, the annual variation is expected to be greater in the upper tidal reaches of the estuary. Dissolved oxygen concentration is also affected by the depth of the water, the amount of mixing, residence time of the water, tidal stage and at certain times of the year, the time of day.

Though the absolute value of dissolved oxygen (measured in mg/l) is important, the degree or percent of oxygen saturation is a more accurate measure of the potential for biological effects. In general adverse biological effects are not evident unless dissolved oxygen drops below 5 mg/L for an extended period of time. The State of New Hampshire has established 75% saturation as the water quality standard for D.O. for not less than 16 hours per day and not less than 6 mg/l at any time except as naturally occurs. It is suspected that some shallow upper estuarine systems may drop below 75% saturation in the absence of eutrophication related impacts (Kelly, 1995).

Even though sites in mid-Great Bay can have dissolved oxygen ranging from 6 to 15 mg/liter throughout the year, percent oxygen saturation is usually between 90-110% (Figure 2.39) (Langan and Jones 1996). Lower estuary measurements vary similarly and are almost always near 100% saturation (Langan, 1994). Water column measurements indicate that there is little stratification and that dissolved oxygen is similar in value and percent saturation throughout the water column. In the tributaries to Great Bay, dissolved oxygen can vary from 5 mg/l during early morning low tides in summer to 16 mg/l in winter. Percent saturation in the Squamscott River, for example, can range during the year from

FIGURE 2.39

Monthly measurements (high and low tide average) of percent oxygen saturation at the Adams Point station from July, 1988 to June, 1996.



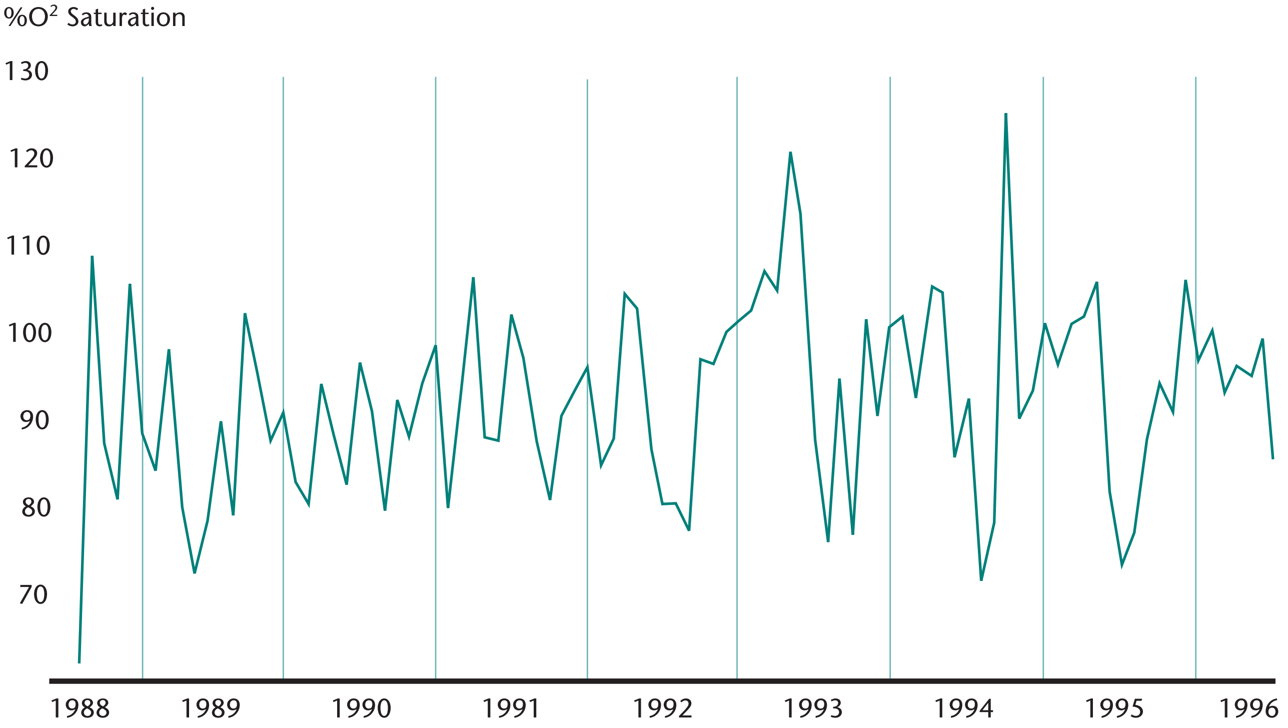
70% to 120%, depending on the time of day, tidal condition, and time of year (Figure 2.40).

In a three year project designed to assess the effect of stormwater runoff on contaminants in tributaries to Great Bay, measurements of dissolved oxygen were made in the freshwater portions of the tributaries and in the mouths of the tidal portions (Jones and Langan, 1994a, 1995a, 1996a). Data from this study indicates that dissolved oxygen in the freshwater portions of the rivers can get quite low, particularly at times of low flow. Freshwater measurements of D.O. often failed to meet the New Hampshire water quality criteria (WQC) of 75% saturation. Saturation in the tidal sites was generally 70% to 100% with few NH WQC violations. Though the water quality problems in the freshwater portions of the river may be related to eutrophication, it is likely that the summer low flow conditions result in stagnant conditions in the impoundments above the dams and that the sediment oxygen demand as well as respiration exceeds the oxygen repletion rates in water with poor rate of exchange. This condition is also acknowledged in the New Hampshire WQC, which includes a statement that WQC be met, "...except as naturally occurs". The low dissolved oxygen conditions measured in point samples in the Exeter River was verified in the summer of 1995 using a continuous datalogger. In August, 1995, dissolved oxygen ranged from 3 to 4 mg/L and 35% to 60% saturation. It should be noted however, that the summer of 1995 set a record for low rainfall and that the section of the river where the instrument was deployed was completely stagnant for weeks. Autumn storms, which produced increased flow, improved oxygen saturation to 80% by late October.

A study conducted by the Maine DEP (Mitnik and Valleau, 1996; Mitnik, 1994) measured dissolved oxygen at a series of stations in the freshwater and tidal portions of the Salmon Falls Rivers. These studies were conducted during the summers of 1993 and 1995, both of which were extremely dry. Depressed oxygen

Monthly measurements (high and low tide average) of percent oxygen saturation at the Squamscott River station from July, 1988 to June, 1996.

FIGURE 2.40



conditions were detected at several stations in the freshwater portion of the river and near the bottom of a deep site (Hamilton House) in the upper tidal portion of the river. In 1959, average D.O. was less than 6 mg/l at sites along the lower seven miles of the freshwater portion of the river, with minimum values of 0 mg/l, and much higher levels in tidal and upstream freshwater sections of the river (NHWPC, 1960). In the the Maine DEP studies, the remaining stations in the tidal portion of the Salmon Falls River and in the Piscataqua River ranged from 80%-100% saturation at all depths. At the tidal site near Hamilton House in South Berwick, ME, the surface D.O. was usually near 100% saturation while the 5 meter depth D.O. was frequently below 50% saturation and was actually anoxic on one occasion in August. The low dissolved oxygen in the Salmon Falls River was attributed to eutrophication (intense plankton blooms) in the freshwater portion of the river, sediment oxygen demand (in deeper water) and stagnation caused by the series of impoundments on the river and extremely low flow conditions. The eutrophic conditions were attributed to excessive phosphorus from the four sewage treatment plants discharging to the river. An experimental phosphorus limitation period in 1995 resulted in significant reduction in phytoplankton in the impoundments. Based on recommendations from the Maine DEP study, upgrades of WWTFs in Berwick, ME, South Berwick, ME, Rollinsford, NH Milton, NH and Somersworth, NH are required to limit phosphorus discharges to the Salmon Falls River over the next few years.

Based on the existing data, it can be summarized that, in general, the Great Bay Estuary does not exhibit low dissolved oxygen conditions in the tidal waters. Even the shallow upper tidal reaches of the rivers exceed 5 mg/L in worst case scenarios (early morning low tides in mid to late summer), with an occasional measurement between 4.5 and 5 mg/L. It should be noted, however, that at some of these sites the periodic drops in oxygen at low tide in early morning may be a natural phenomena, particularly in very shallow water near marshes (Stanley and Nixon, 1992; Stokesbury et al., 1996). The warm temperatures and rich organic sediments result in high benthic respiration rates and could potentially draw down water column oxygen. The duration and spatial distribution of hypoxic effects are of greater importance with respect to biological effects than the instantaneous measurement of the level of dissolved oxygen (Stokesbury et al., 1996). Continuous attainment of the WQC for dissolved oxygen set by Maine DEP (85% saturation) and New Hampshire (75%) may be unrealistic and not achievable in certain water bodies, even in undisturbed estuarine systems. Perhaps a tiered approach similar to the Falmouth, MA nitrogen concentration standards would be appropriate.

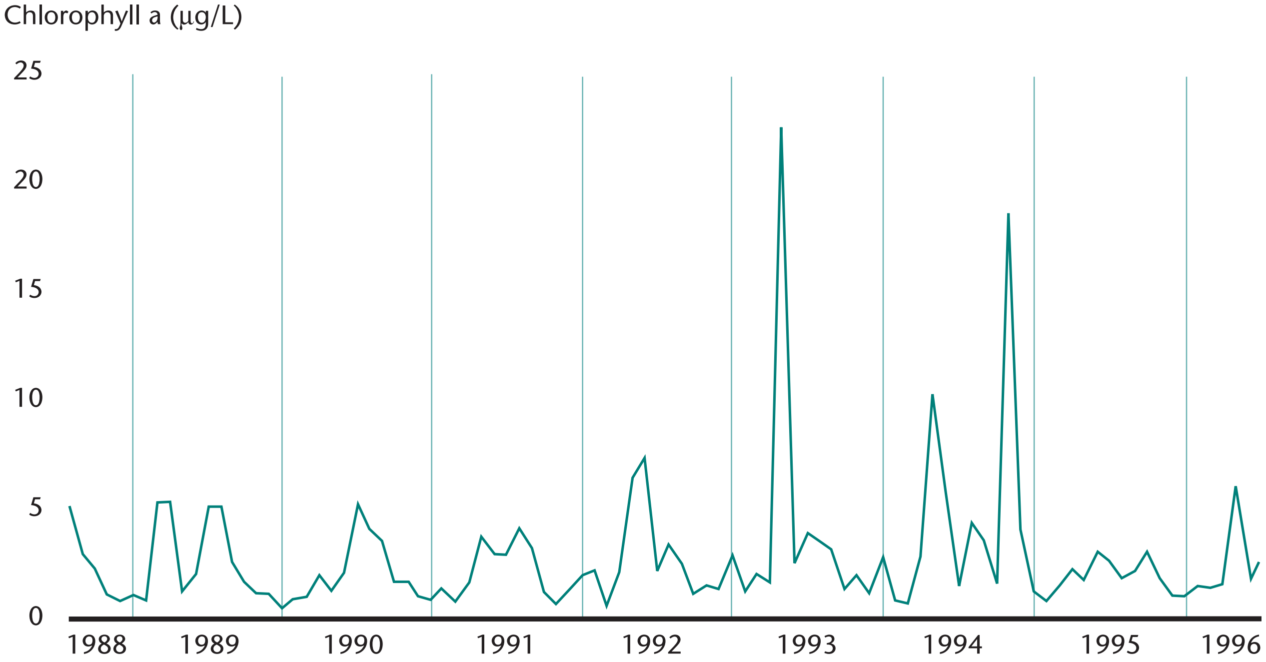
A review of available data does indicate, however, that the freshwater portions of some of the rivers (Salmon Falls, Exeter) can experience low dissolved oxygen episodes, and often for periods of up to several weeks during very low flow conditions in the summer. For the Salmon Falls River, the low dissolved oxygen can be attributed to excess nutrient input from WWTFs exacerbated by stagnant, impounded waters (Mitnik and Valleau, 1996; Mitnik 1994; Jones and Langan 1994a, 1995a, 1996a). It is unknown if there are present biological impacts associated with the low dissolved oxygen conditions in the freshwater impoundments. Historically, the existence of stretches of downstream, freshwater portions of the river being “devoid of fish due to lack of oxygen” was noted in the report by NHWPC (1960).

As is the case with nutrient data, there is considerably less data on dissolved oxygen in the Hampton/Seabrook Estuary than in Great Bay. As part of the Seabrook Station Environmental Studies Program, Normandeau Associates, Inc. has maintained a long term record of surface and bottom dissolved oxygen at a site outside the Harbor, but none in the estuary itself. The study of the potential of groundwater and surface water impacts from on-site sewage disposal systems described in an earlier section (Jones et al., 1996) was extended to include measurements in the summer of 1996 of dissolved oxygen in a number of small freshwater streams, marsh creeks, larger tributaries and in the Harbor itself (Jones, 1997). Out of a total of 139 samples taken in tidal streams and small marsh creeks from July, 1996 to June, 1997, seven D.O. measurements below 5 mg/l were recorded, all at low tide during the summer and early fall early in the day in small tidal creeks. All of the forty-seven measurements in the larger tributaries and in the Harbor itself were > 5 mg/l and generally greater than 75% saturation. Although the dataset is limited, it indicates that there are no low dissolved oxygen conditions that could result in biological impact in the Hampton/Seabrook Estuary.

2.4.5.2 Phytoplankton Blooms

The timing and intensity of phytoplankton blooms (as measured by water column chlorophyll) varies spatially in the Great Bay Estuary. Blooms in Great Bay and Little Bay generally occur in spring and fall, with variation between these two seasons as to when peak concentrations occur. Summer concentrations are generally lower than these peaks due to grazing, but are higher than winter concentrations. Peak concentrations at Furber Strait can reach as high as 20 µg/l (on one occasion in 1993 and one in 1994) but are usually on the order of 5-10 µg/l. Figure 2.41 represents chlorophyll concentrations averaged for high and low tides at the Furber Strait site. The average annual chlorophyll concentrations have ranged from < 2µg/l to > 3.5 µg/L with an eight year mean concentration of 3.2 µg/l. Chlorophyll concentrations in the lower estuary have a similar seasonal pattern (Langan, 1994), with blooms occurring in spring and fall. However, the peak concentrations are lower than in Great Bay, rarely exceeding 3 µg/l. Continuous measurements of chlorophyll were made on flood tide and ebb tide cruises in July, 1992, from the mouth of the harbor to the railroad bridge on the Squamscott River (Chadwick et al., 1993). On the flood tide, chlorophyll concentrations ranged from 1 to 1.5 µg/l from the harbor mouth to Dover Point; 2.5 to 3 µg/l in the upper Piscataqua River; 2-3 µg/l in lower Little

Monthly measurements (high and low tide average) of chlorophyll a at the Adams Point station from July, 1988 to June, 1996. **FIGURE 2.41**



Bay and 3-3.5 µg/l through upper Little Bay and Great Bay. Concentrations were slightly higher in some areas during the ebb tide cruise, however, the range of 1-3.5 µg/l was similar.

Peak concentrations in the tidal rivers follow a different pattern than areas in Great Bay, Little Bay and the lower Piscataqua River. Rather than a distinct spring bloom, chlorophyll concentrations gradually increase through the spring, and peak concentrations occur at some point from August through October. In the Squamscott River, peak concentrations for the period 1988 through 1996 were ≈ 30 µg/l, however, the peak in August, 1994, was 80 µg/l. The later blooms in the rivers are probably due to light limitation (from higher turbidity) in the spring.

Spinney Creek, a salt pond in Eliot, Maine, is susceptible to intense phytoplankton blooms by nature of its limited exchange of water (long residence time) with the Piscataqua River and elevated temperatures. The blooms can occur at any time from spring through fall and, the fall blooms are often the most intense. In the fall of 1996, a bloom of the naked dinoflagellate *Protocentrum spp*. lasted for several weeks and caused mortalities in oysters (*Ostrea edulis*) being raised in the creek. The cause of the bloom was attributed to regeneration of nutrients from macrophyte decay and little to no water exchange.

Bloom conditions in the other tributaries are best illustrated by examining data collected as part of a three year project to assess the effect of stormwater runoff on contaminant concentrations (Jones and Langan, 1994a, 1995a, 1996a). Intense blooms were recorded for two consecutive days after a rainstorm that followed an extended dry period in September, 1995. Highest intensities were recorded in the freshwater and tidal portions of the Salmon Falls and Cocheco rivers, suggesting that there may be periodic intensive bloom conditions in the freshwater and upper tidal reaches of these Rivers. These data are confirmed by Maine DEP studies in the Salmon Falls River (Mitnik and Valleau, 1996; Mitnik, 1994) where intense blooms were recorded in the freshwater impoundments and spilled over into the upper tidal portion of the river. Impacts to the tidal portion of the river were limited to low D.O. in bottom waters in a deep hole (6 m) adjacent to the Hamilton House. The low D.O. in the surface waters (fresh) was attributed to the respiration from phytoplankton bloom (caused by excess phosphorus and nitrogen from point sources), high water temperatures and long residence time of the water in the impoundments due to very low flow conditions, while the low bottom water D.O. was attributed to sediment oxygen demand.

Chlorophyll data collected at Furber Strait from 1973 to 1981 was compared to the 1988-1996 dataset. Means for the two periods were very similar: 3.4 µg/l for the 1973-1981 period and 3.2 µg/l for the 1988-1996 period. Seasonal patterns were also similar, as were minimum values (0 µg/l). The maximum value for the earlier data was 14 µg/l, and 20 µg/l in the more recent dataset. This comparison indicates that there has been little or no change on water column chlorophyll concentration over the 22 year period at this site.

Phytoplankton primary productivity, as measured by chlorophyll concentration, has been measured for many years outside the Hampton/Seabrook Estuary (NAI, 1996), however, it has been only recently that chlorophyll has been measured at sites within the estuary. Jones et al. (1997) measured chlorophyll concentrations in a number of small freshwater streams, marsh creeks, larger tributaries and in the harbor itself beginning in July 1996. Peak chlorophyll concentrations in the summer were approximately 3 µg/l in the larger tidal rivers and in the Harbor, and up to 28 µg/l in the small tidal creeks. Concentrations at all sites dropped through the fall and winter. Additional samples have been collected as part of the New Hampshire Estuaries Program to provide an improved spatial and temporal representation of the chlorophyll concentrations in Hampton Harbor.

2.4.5.3 Eutrophication

The Great Bay Estuary and other estuarine areas in New Hampshire had no cited incidences of eutrophic or hypoxic problems prior to 1985 (Whitledge, 1985). This report was a review of eutrophic or hypoxic estuaries nationwide, and more detailed New Hampshire information is provided below.

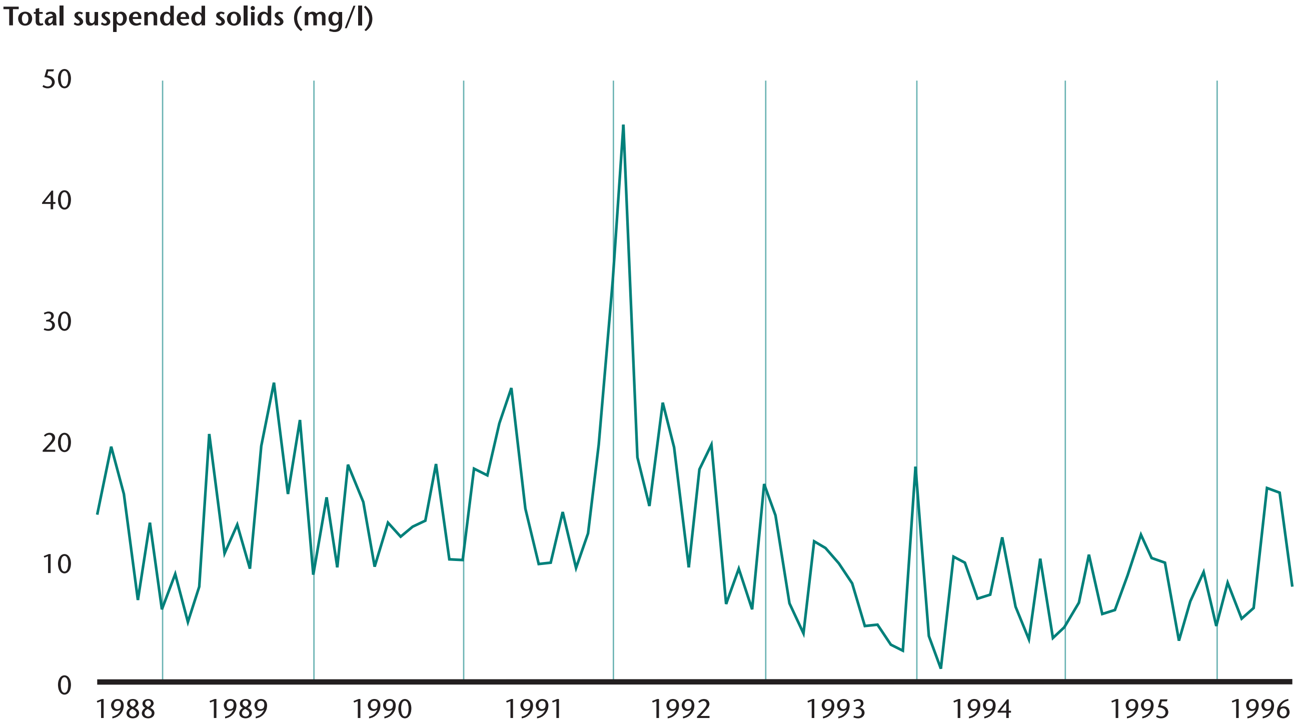
In addition to elevated nutrients, depressed dissolved oxygen conditions and phytoplankton blooms, other potential indicators of eutrophication include proliferation of opportunistic (green) macroalgae, reduction in water clarity, and loss of eelgrass. There has been some speculation that opportunistic macroalgal populations have increased in recent years (A. Mathieson, personal communication), however, this has not been substantiated with measured data. A project conducted during the summer of 1997 as part of the GBNERR monitoring program examined areal coverage and biomass of macroalgal species along an intertidal gradient for which an excellent baseline was established in 1973 (Chock and Mathieson, 1979). No changes in species, biomass and percent cover were documented (Langan and Jones, 1999).

Water clarity in the Great Bay Estuary is most affected by resuspension of fine grained sediments. Resuspension of sediments can result from human activities, such as dredging and boating in shallow water, however, natural causes, and in particular wind driven waves are the primary cause of resuspension (Anderson, 1974, 1975). Suspended sediments will be discussed in another section of this report, however it is useful to note here that at the two long-term monitoring sites in the Great Bay Estuary, suspended sediment concentration has decreased in recent years, and the annual mean is significantly lower at Furber Strait in the years 1993-1996 than from 1988 through 1992 (Figure 2.42).

Relative to eelgrass, a decline in the late 1980s in Great Bay attributed to the wasting disease, was followed by recovery in the 1990s. Areal coverage, density

Monthly measurements (high and low tide average) of suspended solids at the Adams Point station from July, 1988 to June, 1996.

FIGURE 2.42



Rochester Wastewater Treatment Facility discharge

and biomass now exceed the early 1980s. Eelgrass has also been observed recently in areas where it has been absent for many years. It appears that eelgrass populations in the Great Bay Estuary are in good condition.

Based on the nutrient, dissolved oxygen and chlorophyll conditions, as well as the other potential indicators, there is no indication of system-wide eutrophication in the Great Bay Estuary, nor are there any documented trends that would indicate increasing nutrient enrichment. The physical characteristics of the estuary, including tidal height, relative flushing, a vertically mixed water column and high turbidity, in addition to the suite of parameters examined, would indicate that eutrophication in Great Bay is not an imminent problem. Though the data indicate that nitrogen may be limiting, light is also an important limiting factor due to resuspension of sediments and vigorous vertical mixing. There are indications, however, of potential problems in the freshwater portions of some of the tidal rivers and in the upper tidal reaches of the Salmon Falls and Cocheco rivers. Though both point and nonpoint sources may contribute to the problems observed there, low water flows and dams (impounded stagnant waters) contribute to water quality impacts. The location of a large point source on the Cocheco River (Rochester WWTF) and several smaller point sources (several WWTFs) on the Salmon Falls River are no doubt responsible for a large portion of anthropogenic nitrogen loading to these rivers. Though the potential for system-wide impacts from these rivers is remote, increasing the nitrogen load in the upper tidal reaches of these rivers could impact water quality in longer tidal stretches of both rivers, and potentially the upper Piscataqua River as well. Residence time is an important factor in determining sensitivity to nutrient overenrichment. For that reason, the tidal portions of the Lamprey and Squamscott rivers and areas in the southern portions of Great Bay would be considered areas susceptible to nutrient overenrichment since flushing times (complete water exchange) can be from two to three weeks for these areas in dry conditions. Therefore potential water quality impacts should be considered before this area is subjected to additional loading.

Based on the nutrient, chlorophyll and dissolved oxygen data reviewed, in addition to the lack of any indicators of eutrophication, there is no reason to believe that nutrient overenrichment is an issue in Hampton Harbor. Additionally, the rate of water exchange and short residence time of the water in the harbor would make it difficult for eutrophic conditions to develop in the estuary. With Seabrook-wide hook up to the new WWTF, future conditions are expected to be even better.

SUSPENDED SEDIMENTS AND TURBIDITY

Three review articles chronicle and synthesize most of the information available concerning suspended sediments and turbidity in the Great Bay Estuary. The Bibliography of the Geology of the Continental Shelf, Coastline and Estuaries of New Hampshire and Adjacent Regions (Ward and Pope, 1992) is a comprehensive report of all available literature up to 1992 concerning the geology and sedimentology of the New Hampshire region. An annotated bibliography for sediment based studies is included. A synthesis of the relevant research concerning the sedimentology (including the bottom and the water column) of Great Bay was presented by Ward (1992) and Short (1992). The most recent and up to date synthesis of research on suspended sediments and turbidity in the Great Bay Estuary is presented in A Monitoring Plan for the Great Bay National Estuarine Research Reserve: Final Report for the Period 07/01/95 through 06/30/96 (Langan and Jones, 1996). The synthesis of relevant research, annotated bibliography of relevant studies, and complete bibliography of known information presented here is based on these reports. Ward and Pope (1992) forms the basis of the complete bibliography up to 1992. The synthesis by Ward (1992) forms the framework for the review of existing information for suspended sediments and turbidity in the Great Bay Estuary. Where appropriate, segments of these reports are repeated here, as well as updated. Langan and Jones (1996), along within other recent reports, are used to update the synthesis and bibliographies.

2.5.1 SURFICIAL SEDIMENTS AROUND GREAT BAY ESTUARY

The surficial sediments in the Great Bay area have been strongly influenced by glacial advances and retreats during the Quaternary period (the last two or three million years of the Earth's history). During the last major glaciation (referred to as the Wisconsin), which began ~85,000 years ago and was at a maximum ~18,000 years ago (Flint, 1971), the large ice sheets removed much of the overlying soils and eroded the underlying bedrock (Chapman, 1974). Subsequently, extensive tills (unsorted sediments) and marine sands, silts and clays were deposited by the retreating glaciers (Delcore and Koteff, 1989). More recently, modern tidal flats, salt marshes and muddy to cobble beaches have developed adjacent to the estuary and its tributaries.

2.5.2 SHORELINE CHARACTERISTICS IN THE GREAT BAY ESTUARY

The intertidal shoreline of the Great Bay Estuary probably arrived close to its present day position a few thousand years ago when the rise of sea level slowed down. Since that time the estuary has been continuously modified by a slow sea level rise (presently about 1.5 mm/y, Hicks et al., 1983), wave effects, tidal action, biological processes, ice impact, and humans. Wave impacts in Great Bay Estuary are most important on the mudflat areas that often front the rocky or gravel shorelines (especially in the many embayments). Resuspension of fine-grained sediments from mudflats occurs during frequent wind events, increasing the turbidity of the nearshore and the overall estuary. These processes are discussed in more detail below. However, the wave energy is usually low and impact on the coarse-grained (gravel) beach sediments is probably small in many places.

Although no quantitative assessment of shore types has been done for the Great Bay Estuary (with the exclusion of the tidal marshes), qualitative observations based on aerial photographs and field observations have been made. Such studies indicate that exposed bedrock shorelines fronted by shingle beaches, small pocket beaches composed of sand to cobble size sediments, eroding till bluffs of little relief, muddy tidal flats, fringing marshes located on bedrock or coarse sediment, and large marshlands are all commonly found. Most frequently, the shoreline is exposed bedrock either fronted by cobble beaches, fringing marsh, relatively wide tidal flats, or large marshes. Large tidal flats dominate the intertidal and subtidal portions of Great and Little bays. Consequently, the surface area of the bays changes dramatically from high to low tide.

2.5.3 SOURCES OF SEDIMENTS

The sources of sediments for the intertidal and subtidal portions of Great Bay Estuary originate primarily from shore erosion, runoff from the watershed via inflowing rivers, and biological productivity. Erosion of the exposed bedrock surrounding much of the Bay provides irregularly shaped cobbles that form narrow shingle beaches. Some minor sandy beaches are located adjacent to eroding till deposits (e.g. Fox Point). Due to the rocky nature of the land surrounding the estuary and the relative thinness of the till deposits, it is unlikely substantial amounts of fine-grained sediment are contributed from shore erosion. Consequently, the source of new fine-grained sediments and turbidity is likely from freshwater tributaries. The impact of riverine inputs is most important following heavy rains which are more frequent in the spring. Jones and Langan (1996a) found the total suspended sediment concentrations in all the tributaries entering Great Bay following rain events to be higher than concentrations during dry periods, although the differences were less than 5 mg/l and usually not statistically significant. In addition, all of the associated rivers are dammed, reducing this potential source. The source of suspended sediments and turbidity on a day to day basis is more likely due to wind and tidal resuspension of the extensive subtidal and intertidal mudflats.

2.5.4 SUSPENDED SEDIMENTS

Spatially, the lowest suspended sediment concentrations occur in the lower estuary, while the highest generally occur in the upper estuary or within the tidal portions of the estuarine tributaries (Squamscott, Lamprey, Oyster, Bellamy, Cocheco, Salmon Falls or upper Piscataqua rivers). Ward (1994) measured the suspended sediment concentrations in the lower estuary (Portsmouth Harbor) and near the mid-estuary (Dover Point) over a number of tidal cycles in July, 1992. The concentrations were low and varied little across the channel and with depth in Portsmouth Harbor. The total suspended sediment concentrations ranged from 1.1 to 3.7 mg/l over a complete tidal cycle at the mouth of the Harbor and from 1.5 to 5.9 mg/l at a cross-section near Seavey Island. Similarly, Shevenell (1974) found suspended sediment concentrations were generally less than 3 mg/l at a station in the mouth of the Piscataqua River in 1972-1973, except during winter when concentrations exceeded 6 mg/l. According to Shevenell (1974), the main sources of particulate matter in the coastal shelf waters adjacent to the Piscataqua River were biological productivity, resuspension of bottom sediments and estuarine discharge from the Piscataqua River. Shevenell (1974) also noted particulate matter concentrations fluctuated seasonally and spatially due to meteorological effects (e.g., storms, high river discharges).

Total suspended sediment concentrations were higher in the mid-estuary, ranging from 2.4 to 12.7 mg/l over a tidal cycle at a cross-section at Dover Point in July, 1992 (Ward, 1994). The increase in total suspended sediments in the mid-estuary over the concentrations measured near the mouth reflects the impact of higher suspended sediment inputs from the upper estuary (e.g., Great Bay, upper Piscataqua River, tributaries).

The spatial pattern of the total suspended sediment concentrations from the mouth of the estuary in Portsmouth to the upper estuary is reflected in the results of transects run in July, 1992 (Ward, 1994). The concentrations measured at ~high tide or early ebb ranged from 1.3 mg/l at the mouth to 17.7 mg/l at the entrance to the Squamscott River. Concentrations along the same transect run at ~ low tide and during the early flood ranged from 2.4 mg/l to over 50 mg/l at the Squamscott River.

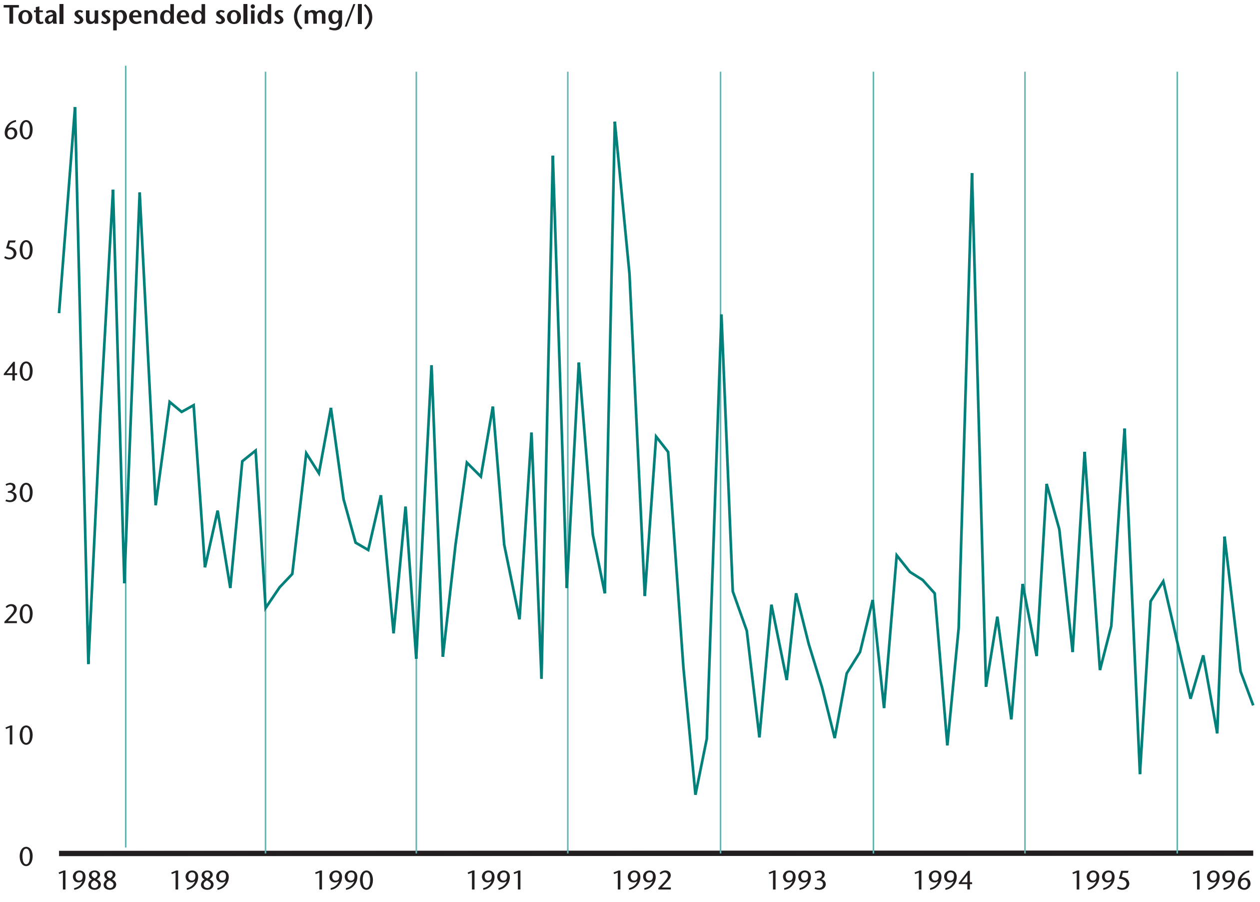
Temporally, the highest concentrations occur in spring and fall, while summer and winter have lower concentrations (data from Loder et al. 1983, in Short, 1992). The total suspended sediment concentration off Furber Strait in the Great Bay averaged 11 mg/l from 1976 to 1978, with the lowest values in fall and winter. Unpublished data from Ward during 1991 to 1992 shows a similar pattern for Furber Strait. Short (1992) indicated the maximum suspended sediment concentrations occurred in the 1970s, although the averages are similar.

Langan and Jones (1996), focusing on the upper estuary, found that the suspended sediment concentrations from summer, 1995 to summer, 1996 were highest in the lower reaches of the Squamscott River (measured at Chapmans Landing) ranging from 5.8 to 42.7 mg/l and averaging 20.5 and 15.1 mg/l at low and high tide, respectively. The suspended sediment concentrations at Furber Strait ranged from 3.3 to 22.8 mg/l and averaged 9.8 and 7.5 mg/l at low and high tide, respectively. These averages are slightly lower than measured in the mid to late 1970s and in 1991/1992. Langan and Jones (1996) found the suspended solids concentrations at sites at Chapmans Landing and Furber Straits decreased from 1988 to 1996, significantly in some cases. Clear seasonal patterns were not apparent at these sites (Figures 2.42 and 2.43).

Lower concentrations for the 1995-1996 period were measured in the Lamprey River than in either the Squamscott River or at Furber Strait (Langan and Jones, 1996). Suspended sediment concentrations averaged 3.8 mg/l at both high and low tide in the Lamprey at the Town Landing. The suspended sediment

Monthly measurements (high and low tide average) of suspended solids at the Squamscott River station from July, 1988 to June, 1996.

FIGURE 2.43



Adams Point in winter

concentrations in the Oyster River appeared to be similar to values measured for the Squamscott River (Jones and Langan, 1993a). Interestingly, there were no distinct differences on a seasonal bases in the Oyster River, nor were there consistent spatial variations. The average concentration in Oyster River were high, with a low tide mean of nearly 35 to 40 mg/l. However, this mean included samples taken in shallow water stations in the upper tidal reaches where local wind resuspension and other processes biased the results. The overall changes with time in the Great Bay Estuary need to be examined further.

The periodic nature of the suspended sediment load in the estuary has been described by Anderson (1970) who demonstrated large changes in concentrations over tidal cycles and over seasons. Suspended sediment concentrations ranged from ~2 to 18 mg/l in the channel at the entrance to the Bellamy River in Little Bay in response to tidal currents, resuspension events, spring discharge and ice effects. Large increases in the suspended sediment load can occur over tidal flats due to small amplitude waves (Anderson, 1972, 1973), extreme water temperatures caused by tidal flat exposure during summer months (Anderson, 1979; 1980), desiccation of the tidal flat (Anderson and Howell, 1984), rain impact (Shevenell, 1986; Shevenell and Anderson, 1985) and boat waves (Anderson, 1974; 1975). Webster (1991) investigated bedload transport on a tidal flat in Great Bay and found that the transport rates were related primarily to wind wave activity, although tidal currents may have enhanced movement. Webster (1991), also found that the benthic community appeared to affect bedload transport by disturbing the tidal flat surface (pellet mounds and feeding traces). Sediments resuspended along the shallow flats mixes with the channel waters, resulting in higher turbidity in the estuary. Thus, sedimentary processes which occur along the shallow flanks of the estuary have a large impact on the overall water quality.

2.5.5 SEDIMENTATION PROCESSES ON GREAT BAY TIDAL FLATS

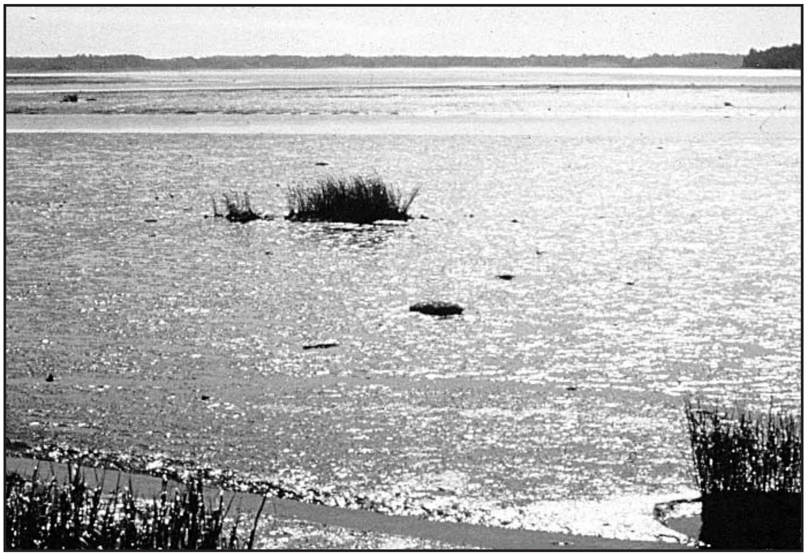
Anderson (1983) summarized the physical and biological processes influencing muddy intertidal flats, emphasizing the Great Bay. Anderson (1983) concluded that the main physical factors were: effects of ice, waves, sediment dewatering, mud and water temperatures, and rain. Biological factors included growth of benthic diatoms, algal mats, macrovegetation, bioturbation, pellet formation, biodeposition and changes in mudflat microrelief. Ice effects dominate in winter and early spring with breakup causing erosion. Wind resuspension was common much of the year. During summer, biologic processes dominate and deposition is more common. Storm activity in fall as biologic processes slow causes increased tidal flat erosion.

Wave action on the muddy intertidal flats causes erosion, resuspension, and subsequent transportation of the sediments. Tidal currents serve to distribute the sediments which are introduced via riverine sources, from bluff erosion, or from resuspension episodes on intertidal flats. In addition, strong tidal currents limit the seaward expansion of the tidal flats.

Sedimentation processes on the shallow tidal flats around the Great Bay are strongly influenced by biologic processes. Black (1980) found deposit feeders ingest muddy sediments, creating fecal pellets that behave hydraulically like fine-sand grains. Estimated feeding rates, for example, of *Macoma balthica* indicate the surface sediments are turned over 35 times per year (Black, 1980). Sickley (1989) demonstrated that tidal flat erosion was related to decreases in microbial populations and to the grazing activity of epibenthic macroorganisms. Sickley (1989) also showed suspended sediment concentrations to be related to benthic algal populations, which tend to bind the sediment.

Because of the temperate climate of the estuary, ice plays an important role in shaping the geomorphic and sedimentologic characteristics of the shoreline. During most winters much of the shoreline and intertidal regions of the bay are covered with ice. Ice tends to modify the shoreline by pushing sediments about and by forming gouges in the softer, muddy tidal flats. In winter during periods of ice movement, large amounts of sediment, clumps of marsh, and seaweeds are transported and eventually deposited elsewhere in the Bay (Mathieson et al., 1982; Hardwick-Witman, 1986; 1985; Short et al., 1986). Thompson (1975) found that ice on a tidal flat near Adams Point contained 0.58 to 27.2 grams of sediment per liter of ice. According to Thompson (1975), up to 50 cm of sediment was eroded from inner portions of the tidal flat, while up to 25 cm was deposited along the outer portion. Overall, the ice impact appeared to be erosional.

Suspended sediments have been measured in the Hampton/Seabrook Estuary as part of the 1994 Sanitary Survey (NHDHHS, 1994a), and was included in surface water sampling for studies on potential surface water contamination from septic systems (Jones, 1997). Samples have also been collected and analyzed from sites in the estuary as part of the monitoring supported by the NHEP. Total suspended solid concentrations in the Harbor are generally quite low, ranging from 1 to 6 mg/L, while in the smaller tidal creeks concentrations can be considerably higher, depending on tidal stage and wind speed and direction.



2.6

OTHER CONTAMINANTS OF POTENTIAL CONCERN

2.6.1 RADIONUCLIDES

The US EPA has published radiological surveys of the Portsmouth Naval Shipyard. Two of these documents have been obtained (USEPA, 1979; 1991). For both the 1977 and 1989 samples, materials from sites around Seavey Island and the Great Bay Estuary included sediments, sediment cores, biota and water. The 1977 study also included samples of vegetation and air samples. The results of both studies showed no evidence of radioactivity released as a result of Naval nuclear propulsion plant operations, based on cobalt-60 analyses. Detectable radioactivity in the biota and the environment surrounding the shipyard was attributed to naturally occurring isotopes or atmosphere-borne isotopes indicative of past nuclear weapons testing.

Seabrook Station has an extensive radiological monitoring program of the marine environment around Seabrook Station. The monitoring program includes sampling and radiological analysis of seawater, sediment, fish, lobster, mussels and algae in the area near Seabrook Station and the offshore cooling system discharge area, as well as control stations of similar environmental media collected in Ipswich Bay, Massachusetts. Continuous air samples are also collected at eight locations and direct radiation is measured at 42 locations around Seabrook Station. This is augmented by 16 additional direct radiation monitoring locations along the immediate Station fence line. All direct radiation monitoring locations include the use of six separate passive detectors. In addition, milk is collected from seven milk farms around Seabrook Station.

The program began in 1984, more than five years before Seabrook Station began operation. No radionuclides attributable to the operation of Seabrook Station have been detected. Naturally occurring radionuclides have been identified by the program including K-40, Be-7, Th-232 and its daughter products. Cesium-137 was detected in milk in very small quantities as the result of fallout from atmospheric nuclear weapons testing. The levels of radionuclides are consistent with those measured during the preoperational phase of the monitoring program. All analytical results are submitted to the U.S. Nuclear Regulatory Commission in the Annual Radiological Environmental Monitoring Report.

2.6.2 BIOTOXINS

Paralytic shellfish poisoning (PSP) was first recorded in 1972 in this portion of the Gulf of Maine (GOM). *Alexandrium* spp., blooms are probably transported south to New Hampshire coastal waters from a source population near the mouth of the Kennebec/Androscoggin rivers in Maine (Franks and Anderson, 1992). Local conditions may have some effect on blooms even though occurrences in NH are typically associated with large regional occurrences in ME & MA.

The NHDHHS, with support from NHF&G, conducts weekly sampling of mussels (*Mytilus edulis*) for PSP analyses at one site in Hampton Harbor. Since 1983, blooms have occurred during late spring to late summer. During 1983-89, the average weekly PSP levels were periodically >44 µg PSP/100 g tissue (the detection limit) & over the closure limit of 80 µg PSP/100 g tissue (NAI, 1996). Red tide blooms were reported to occur on a regular basis in 1989 (NHDES, 1989a), but only rarely since 1991 (NAI, 1996). PSP was detected at >44 µg PSP/100 g tissue in 1991, 1993 & 1994, but only during May-early June. PSP was detected at increasing concentrations on 3 consecutive occasions in May, 1995. Even though concentrations were below the closure limit, flats were closed because of the trend and some ME flats had already been closed. In 1996, there were no closures (NHDHHS, unpublished data). Concentrations of PSP remained at <44 µg/100 g mussel tissue from 4/1/96 to 10/27/96 in Hampton Harbor. Monitoring programs in both Maine and Massachusetts provide useful additional information. Little other information is available to document other harmful algal bloom events.

2.6.3 ACID RAIN

The NHDES has a database for acid rain at NH lakes and ponds (NHDES, 1996c). The results show an increase in pH in precipitation over the past 15 years from 4.0 to 4.3, and a significant increase in alkalinity over the past 15 years in some ponds. Even though most New Hampshire lakes showed no significant change in pH over the past 15 or 50 years, many lakes are still vulnerable to acid rain and have pH values of <6.0. No data are collected for tidal waters.

Acid deposition is primarily a result of emissions of nitrogen (NOx) and sulfur (SOx) oxides into the atmosphere. Monitoring of NOx has been conducted by the NHDES Air Resource Division at Manchester and Portsmouth since 1986, and SOx has been monitored at fourteen locations since the mid-1970s (NHCRP, 1997). Power generation produces 90% of SOx and 39% of NOx emissions in NH, while mobile sources produce 51% of the NOx. National Ambient Air Quality Standards are 80 µg/m3 for SO_2 and 53 ppb for NO_2. The annual mean concentrations for these two gases have decreased since 1990, from 10.63 to 18.58 µg/m3 for SO_2 and from 24 to 12 ppb for NO_2.

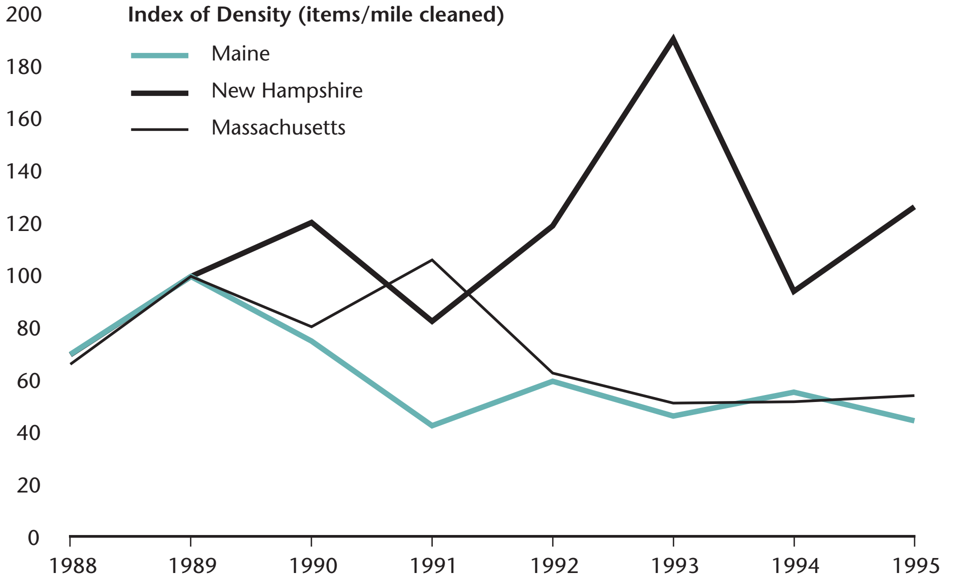
2.6.4 MARINE DEBRIS

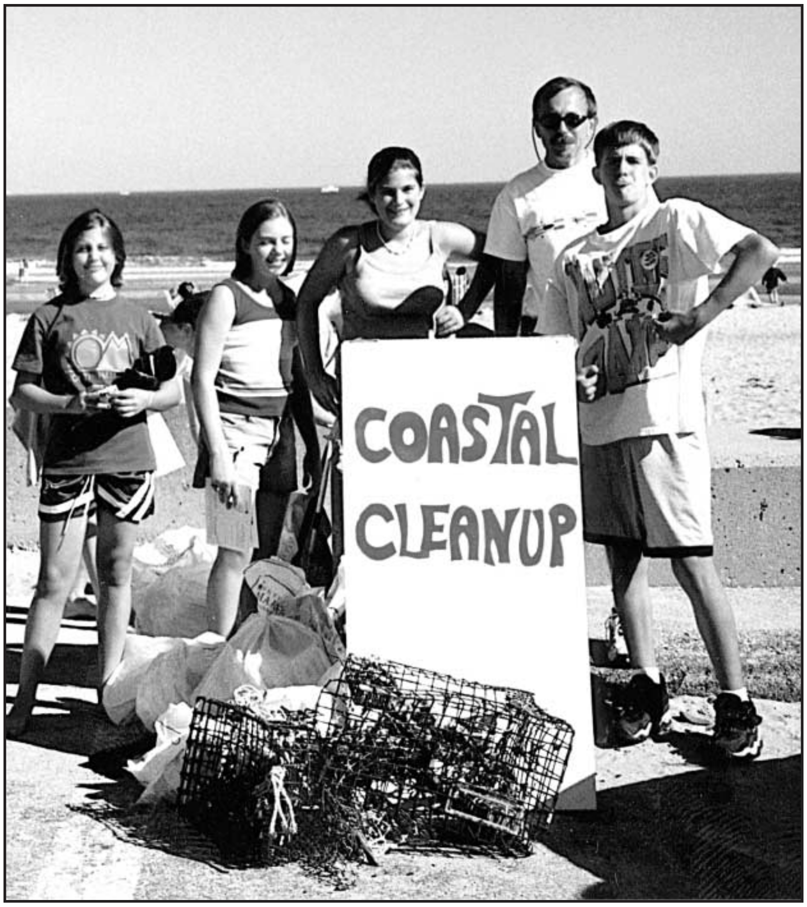
Data on marine debris clean up efforts since 1992 have been summarized by Salem High School (SHS, 1996). The information includes collection sites, numbers of debris items, type of debris, temporal trend analysis, and other data analyses. The New Hampshire clean up data are also analyzed in briefer fashion relative to the whole U.S. (Sheavly, 1996a) and international (Sheavly, 1996b) clean up efforts. The Piscataqua River Watershed Council is currently conducting a project with the Piscataqua Region Council on Marine Debris to reduce marine debris, especially bulk debris, through educational efforts (GOMC, 1997).

A recent review of historical marine debris distribution, temporal trends and sources of marine debris in the Gulf of Maine provides further analysis of data from New Hampshire, as well as identification of a range of policy approaches for addressing the issue (Hoagland and Kite-Powell, 1997). In general, it appears that New Hampshire, along with northern Massachusetts and parts of Nova Scotia, have relatively high densities of nearshore debris compared to Maine and southern Massachusetts. Since 1989, both

FIGURE 2.44

Index of bottles and associated items in marine debris from Maine, New Hampshire and Massachusetts, based on CMC data.





Maine and Massachusetts, which have bottle container laws, had slight reductions in beverage container debris while New Hampshire showed no reduction (Figure 2.44). Onshore sources of debris accounted for 80-85% of all debris, with much less coming from offshore sources (including commercial fishing gear).

2.6.5 OTHER CONTAMINANTS

The highest levels of ground-level ozone (O$_3$) in New Hampsire are in the Seacoast, where transport from large upwind urban areas is the greatest (NHCRP, 1997). The statewide average level, 0.047 ppm, has not changed much since 1990, and the range has been 0.45 to 0.5 ppm. The annual frequency of exceedences at individual locations has ranged from 0 in 1992 to 4 in 1991, with 3 in 1995.

Carbon monoxide (CO) is monitored in Manchester and Nashua. Levels appeared to improve during the 1990s. Air particulates have been monitored at 15 stations. From 1990-1995, none of them exceeded the standard. Particulate lead was monitored at 5 stations up to 1993, when monitoring ceased due to documented declines in response to removal of lead from gasoline.

Radon has been tested using home test kits since 1987. The action guideline is 4.0 pCi/l. Statewide, the geometric mean level is 2.8 pCi/l, and 36% of samples were > 3.9 pCi/l (NHCRP, 1997). The geometric means and percentage of samples > 3.9 pCi/l are 3.0 pCi/l and 38% for Rockingham County, and 3.6 pCi/l and 44% in Strafford County. Strafford County ranks second and Rockingham County is fourth amongst other state counties.

Data are kept on accidental chemical releases, which includes infectious agents, chemicals or radiological hazards. These usually occur at fixed sites or on roadways. The accidents usually involve release of petroleum products (77%) and toxic materials (15%). In 1993, Rockingham County had 138 events, the most of any county in the state, and Strafford County had 61. The statewide average from 1990 to 1994 was 373 events.

Chlorine is added to municipal drinking water (and WWTF effluent) as a necessary disinfection agent to kill possible microbial pathogens. However, the chlorine is highly reactive and can form potentially toxic chlorinated organic compounds, including chloroform, in the presence of naturally occurring organic compounds in water. The Maximum Contaminant Level (MCL) for chloroform is 5 µg/l. Chloroform was monitored in 12 municipal drinking water systems, including six in the coastal region, during 1995-1996 (NHCRP, 1997). The average chloroform concentration and risk (as number of excess cancers in one million people) were 44.2 µg/l and 3.17 cancers in Somersworth, 35.8 µg/l and 2.56 cancers in Exeter, 33 µg/l and 2.36 cancers in Portsmouth, 20.2 µg/l and 1.45 cancers in Rochester, and 17.7 µg/l and 1.28 cancers in Durham. All of these concentrations were greater than the MCL. The highest levels statewide were detected at Keene (49.8 µg/l), and Clairmont had the lowest levels (1.1 µg/l) and the only one under the MCL.

SUMMARY OF FINDINGS

The review of technical information on the status and trends for water quality in coastal New Hampshire showed a great deal of existing information for the different issues involved. Despite the abundance of information, much is still not understood and a number of issues are still significant. This section is a summary of what is known and what information gaps still exist.

FINDINGS

- There has been a general improvement in water quality in freshwater rivers and streams in coastal New Hampshire, in large part due to improvements in sewage treatment facilities. In 1996, all uses are fully supported in 100% of Coastal Basin and 99% of the Piscataqua River Basin streams and rivers.
- The water quality in the coastal shoreline and open ocean areas of the State's waters has improved to where they are also fully supporting all uses in 1996. Slower progress in estuarine waters, where uses are limited by numerous contaminants, has occurred.
- Fecal contamination levels have decreased in all coastal waters during the last decade as a result of improvements in wastewater treatment facilities.
- The spatial and temporal distribution of bacterial indicators in estuarine waters has been well documented in most areas. There are clearly sources of fecal contamination that persist in all areas of coastal New Hampshire.
- Fecal bacterial contamination is typically present at higher concentrations during low tide and after significant rainfall/runoff events.
- The major source of fecal contaminants in runoff is direct sewage contamination from leaky pipes and illicit connections in urban sewage pipe systems. These sources are also significant during dry weather.
- Other documented sources of fecal contamination include wastewater treatment facilities, septic systems, stormwater control systems and agricultural activities. Significant non-human sources of contamination other than from agricultural activities have not been documented.
- Recent sanitary surveys have expanded shellfish harvesting in areas with suitably low levels of fecal contamination.
- Indigenous bacterial pathogens, especially *Vibrio* spp., are present at relatively high levels in the Great Bay Estuary when water temperatures are warm.
- Tributaries to New Hampshire's estuaries have storm-related problems with trace metal contamination. Studies have shown how these contaminants have been transported, often in association with suspended sediments, throughout the downstream waters from tributaries.
- An historical database for sediment contaminants provides evidence for widespread contamination with trace metals and toxic organic compounds, and localized areas of high concentrations of these contaminants.
- Runoff from impervious surfaces is a significant source of both trace metal and toxic organic contaminants.
- Superfund sites located in close proximity to estuarine waters have had significant historical contamination and may continue to be sources affecting water quality.

- The large volume and trafficking of petroleum products through the Port of New Hampshire has resulted in numerous significant oil spills that have had directly adverse effects on estuarine biota.
- Atmospheric deposition of mercury is a significant concern in New Hampshire, while VOC emissions have been reduced.
- Models for predicting the fate of oil spills, trace metals and fecal contamination have been developed for numerous areas.
- Elevated tissue concentrations of toxic contaminants in estuarine biota have caused several consumption advisories. The relatively elevated levels of a number of contaminants is a critical concern.
- The highest levels of nitrogen and phosphorus occur in late fall through early spring throughout the Great Bay Estuary. The lowest levels occur in late spring through early fall.
- The highest levels of nutrients occur at the heads of tide in the tributaries, where sources such as upstream freshwater and WWTFs are most prevalent.
- Phosphate concentrations are usually low in freshwater, highest in upstream tidal rivers and low in Great Bay, Little Bay and Portsmouth Harbor.
- There is an inverse relationship between nitrogen concentration and salinity in Great Bay Estuary.
- Elevated nutrient levels occur in the tributaries of Hampton Harbor, but the concentrations in the Harbor itself are low. Conditions are expected to improve with the recently completed disconnection of septic systems in Seabrook.
- Current nitrogen concentrations, including annual means, seasonal patterns, and minimum and maximum concentrations, are similar to or lower than levels in the 1970s in most parts of the Great Bay Estuary and its tributaries. The exceptions are the freshwater portions of the Cocheco and Salmon Falls rivers, both of which are significantly impacted by WWTF effluent.
- Significant sources of nutrients include WWTFs, stormwater conduits, septic systems, lawns and golf courses, atmospheric deposition, natural organic debris and sediment recycling.
- Nitrogen loading from riverine sources is highest during late fall and early spring during times where rainfall events are more likely to cause runoff from land surfaces.
- The total nitrogen loaded to the Great Bay Estuary in 1996, based on some measurements and other estimations, was 718 tons. Nonpoint sources accounted for 48%, point sources 41% and atmospheric deposition 11% of the total. Similar contributions from different sources were determined for the Oyster River watershed.
- The estimated nitrogen loading, 718 tons/y, was slightly higher in 1996 than the NOAA estimate of 640 tons/y, published in 1990.
- Loading estimates for the Great Bay Estuary were below limits established for Buzzards Bay, MA.
- In general, the Great Bay Estuary does not exhibit low dissolved oxygen conditions in the tidal waters. D.O. can vary from 5 mg/l in summer during early morning low tides to 16 mg/l in winter.

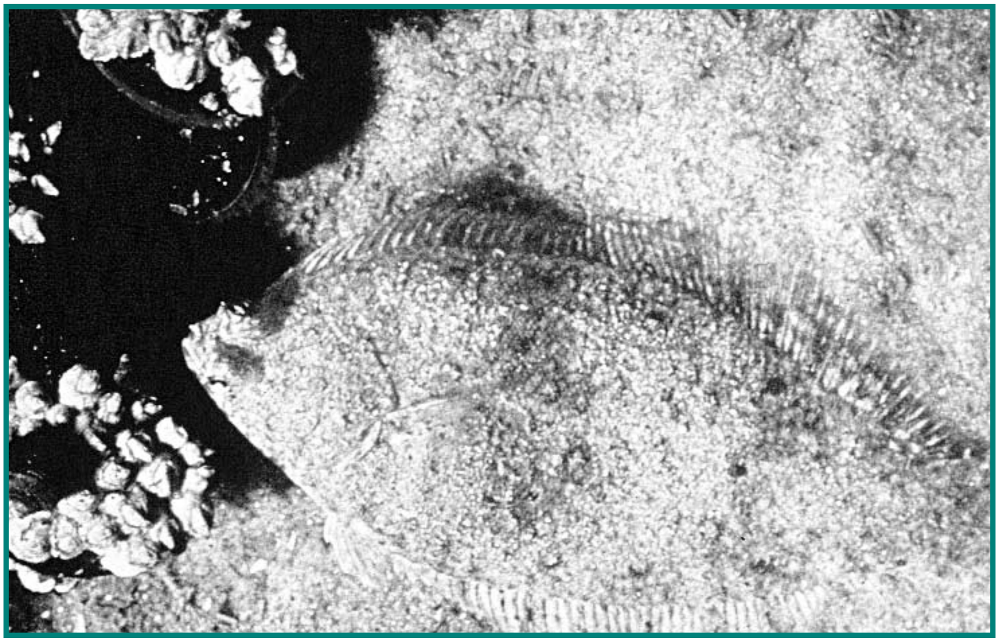
- Areas in the Salmon Falls River can have exceptionally low D.O. and even anoxia, especially in the downstream freshwater and the upstream tidal portions during low flow periods in summer.
- Phytoplankton blooms in Great and Little bays can occur in spring and fall. Rather than experiencing distinct peaks, blooms in tidal rivers typically exhibit gradual increases in chlorophyll a concentrations with peaks in late summer or early fall.
- Intense bloom events have been observed in the Salmon Falls River coinciding with low D.O. conditions.
- There is no indication of system-wide eutrophication in the Great Bay and Hampton/Seabrook estuaries. Increased nutrient loading could cause problems in the upper tidal reaches of some of the tributary rivers.
- The major source of suspended sediments in the Great Bay Estuary is probably wind and tidal resuspension of subtidal and intertidal mudflat sediments.
- Paralytic shellfish poisoning levels have occasionally exceeded the closure limit of 80 µg PSP/100 g tissue in Hampton Harbor, the only monitoring site in New Hampshire. Little other information is available to document other harmful algal bloom events.

NEEDS

- With increasingly sophisticated monitoring and analytical methods being used, previously unidentified contaminants and sources are being detected. Thus, there is a continuing need to identify and eliminate sources of fecal and other contaminants that limit uses if coastal and estuarine waters.
- Establishment of a spatially comprehensive water quality monitoring program is needed to maintain existing harvestable shellfish areas and expand harvesting to new areas as management strategies to reduce contaminants are implemented.
- Continuing increases in human population and associated development, impervious surfaces and wastewater treatment demands will modify the capacities for watersheds to process contaminants. A better understanding of watershed factors and processes that affect the fate and transport of fecal and other contaminants is needed to frame effective strategies for managing transport of contaminants to surface waters.
- Studies on the occurrence of indigenous pathogens like *Vibrio* spp. and biotoxin-producing organisms would be useful for establishing baseline data and predicting potentially harmful conditions.
- A coordinated monitoring program that includes periodic analysis of sediments is needed to determine temporal trends for sediment contaminants. Monitoring for oil spills and atmospheric contaminants should be continued.
- Studies on the biological effects of single and multiple toxic contaminants are needed for some ‘hot spot’ areas of New Hampshire’s estuaries.
- With increasing human populations in the Seacoast, it is important to continue monitoring nutrient levels and dissolved oxygen, especially in the tidal river tributaries of the State’s estuaries.

3 LIVING RESOURCES

The Great Bay and Hampton/Seabrook estuaries support a great diversity of plant and animal taxa including some rare and endangered species. The estuarine habitats that provide important functions to the seacoast are: shellfish beds, mud and sandflats, salt marshes, eelgrass beds, algal beds including rocky intertidal areas, barrier beach and dune systems, subtidal bottom with substrate ranging from mud to cobble and boulders, and tidal channels. Inventories of resident and migratory plant and animal species, information on habitats, communities biology and ecology can be found in a variety of previously published documents (Nelson, 1982; Short et al., 1992; NAI, 1977 and 1996; Sprankle, 1996; Banner and Hayes, 1996). The latter two studies provide excellent characterizations of important habitats for selected species. The selection of species discussed was based on a variety of criteria such as being listed as endangered or threatened, economic importance, inclusion by other significant inventories, etc. The approach used as the basis for the Banner and Hayes (1996) report was developed by the US Fish and Wildlife Service with the Gulf of Maine Council on the Marine Environment; a detailed description of their approach is provided in the report. The purpose of this chapter is to provide an up to date and comprehenisve description of New Hampshire's estuarine biota and to report on the status and trends of species and communities for which there is information. The communities and species described here were selected based on abundance, availability of information and on ecological and economic importance.



GBNERR

Flounder

ESTUARINE INVERTEBRATES

Estuarine invertebrates consist of pelagic forms (zooplankton) as well as benthic (bottom dwelling) forms. The occurrence and distribution of species varies both temporally and spatially and are influenced by several factors including season, water depth, temperature, salinity, and for benthic forms, substratum type (i.e. mud/sand versus rock) is also a major factor.

3.1.1 ZOOPLANKTON

Zooplankton communities have been examined in the Great Bay Estuary by groups including Normandeau Associates, Inc. as part of the impact assessment for the Newington Generating Station (NAI, 1976), the University of New Hampshire (Turgeon, 1976), and in the Hampton/Seabrook Estuary (NAI, 1996) as part of the Seabrook Station Environmental Monitoring Program. Lists of zooplankton species for both estuarine areas can be found in Appendix I. In general, the zooplanktionic community can be partitioned into groups that exhibit three basic life history strategies. The holoplankton (e.g. copepods) are planktonic throughout their entire life cycle, while the meroplankton include the swimming larvae of species that are benthic as juveniles and adults (eg., bivalves, gastropods, decapod crustaceans). The tychoplankton include species such as mysids and harpactacoid copepods that alternate between a benthic and pelagic/planktonic existence.

The abundance and species composition of the zooplankton communities are temporally and spatially variable. Seasonally, their abundance increases throughout the spring, peaking in early summer and declining sharply in later summer. Spatially, the number of species decreases with distance from the open ocean. Data gathered by NAI (1976) in Great Bay indicate that holoplankton accounted for 73% of the taxa. The dominants holoplankton were copepod nauplii (29%), *Pseudocalanus minutus* (14%), *Oithona similis* (8%), tintinnid protozoans (7%) and *Temora longicornis* (2%). Meroplankton forms that only enter the zooplankton for reproduction comprised 22% of the zooplankton, including polychaete (11%), gastropod (5%), bivalve larvae (5%) and cirriped (barnacle) larvae (2%). Tychoplankton, primarily harpacticoid copepods which are only temporarily suspended in the plankton, represented 5% of zooplankton (NAI 1976).

Turgeon (1976) monitored meroplanktonic abundances within the Great Bay Estuary between 1970 and 1973. Bivalve larvae generally decreased from the mouth of the Estuary into Great Bay (Turgeon, 1976), and their numbers were greatest in July and September. Early stages of bivalve larvae occurred in the near-surface, while later stages occurred in deeper waters.

Barnacle nauplii (*Semibalanus balanoides*) are one of the first meroplankton forms to appear seasonally, during February, coinciding with the beginning of the spring phytoplankton bloom (Turgeon, 1976). Trochophores and early stage spionid polychaete larvae appear from April through May, having highest densities within the inner estuary (Turgeon, 1976). Mollusc larvae are most abundant during June through July with a second peak in abundance during September. Prosobranch veliger numbers were greatest during June and July being most abundant within Great Bay. Up to 25 veligers/l may occur within Great Bay, predominantly *Ilyanassa obsoleta* (Turgeon, 1976). These patterns were consistent during 1970-1973 (Turgeon, 1976), although absolute numbers varied from year to year.

Two distinct meroplanktonic communities were identified by Turgeon (1976), one predominating in the outer estuary and the second in Great Bay, with the two overlapping in the middle of the estuary. Larval populations were most dense and species composition most varied during February to July and September through November, e.g., the periods occurring between the winter minimum and summer maximum temperatures.

Larval abundances of soft-shell clam, *Mya arenaria*, are seasonally bimodal (Turgeon, 1976). Oyster larvae, as well as the larvae of several other bivalves, migrate vertically depending upon the tidal stage. Upward movement in the water column on flood tides and downward movement during ebbing tide promoted retention of larvae within Great Bay (Turgeon, 1976).

In the Hampton/Seabrook Estuary, zooplankton communities are similar to the Great Bay Estuary relative to temporal abundance patterns and dominance by the holoplanktonic copepods *Pseudocalanus sp.* and *Oithona sp.* (NAI, 1996). The meroplanktonic community is highly seasonal, with the greatest abundances occurring spring through fall. Dominant meroplanktonic species include the crustaceans *Balanus sp.* and *Carcinus meanas* and the bivalves *Hiatella sp., Anomia squamula* and *Mytilis edulis.* Little change in seasonal patterns and community composition has been observed in the past decade.

3.1.2 BENTHIC INVERTEBRATES

Benthic invertebrates include epibenthos such as motile bottom dwelling taxa (e.g snails, crabs and lobsters) and sessile taxa that attach to hard substrates (e.g. oysters, barnacles) as well as infaunal benthos that burrow in the sediments. Environmental conditions that are important in influencing invertebrate occurrence include water depth, substratum, temperature, salinity, etc. Of these, tidal regulated depth creates a division between intertidal and subtidal populations. Substratum type is a major determinant of species composition. Rock and shingle substrata are populated by epibenthic organisms, while mud and sand have both epibenthic and infaunal components.

Infaunal benthic populations can provide information that is integral to determining the ecological condition of estuaries. They are important regulators of the deposition and resuspension of bottom sediments and the exchange of constituents between bottom sediments and overlying water. Because of their burrowing and feeding habits, benthic animals affect the geochemical profiles of sediments and pore waters, particularly in higher salinity habitats with fine grained sediments. Extensive data bases on infaunal macrobenthos for most areas of the Great Bay Estuary have been compiled over the years. During a 1980-1981 monitoring program, 91 intertidal and 114 subtidal infaunal species were collected from 8 stations throughout the Great Bay Estuary (Nelson, 1981). A species list of Great Bay benthic infauna appears in Appendix E. Additional species lists, community analyses, temporal and spatial abundances can be found in NAI (1972-1980), Nelson (1982) and Webster (1991). More recent data (Armstrong, 1995; Johnston et al., 1994; Grizzle et al, manuscript in preparation; Langan, 1995, 1996) indicate that species richness and dominant species are essentially unchanged over the twenty plus year period (1972-1995). Grizzle et al. (manuscript in preparation) used three years of monthly data from four sites in the Great Bay Estuary to determine that throughout the year, biomass and the number of individuals can change dramatically, with peaks in both numbers and total biomass occurring in spring and fall. They attribute the low summer populations to predation. They also found, as did Nelson (1981), that community composition is determined to a great extent by sediment grain size. Although species dominance can vary spatially and temporally, generally speaking the dominant taxa in the Great Bay Estuary are the polychaetes *Streblospio benedicti*, *Heteromastus filiformis*, *Scolopos sp.*, *Pygospio elegans*, *Aricidea catherinae*, oligochaetes, the amphipod *Ampelisca abdita/vadorum*, and the bivalves *Gemma gemma* and *Macoma balthica*. Abundance, number of taxa and species diversity generally increase with decreasing distance from the open coast, indicating that fewer species are tolerant of the seasonal temperature extremes and daily tidal salinity changes, which can be as much as 18 ppt, in the upper reaches of Great Bay's tidal tributaries (Langan and Jones, 1996).

The species composition and abundance of benthic macrofaunal communities were examined at two sites in the Hampton/Seabrook Estuary from 1978-1995 to assess changes in the benthic community that could be attributed to the Seabrook Station's treatment plant discharge to Brown's River (NAI, 1996). Sampling was discontinued in May, 1995 due to the diversion of the treatment plant outfall to the offshore cooling water tunnel. Sample sites were located in the Brown's River and in Mill Creek. The dominant taxa at both sites included the polychaetes *Streblospio benedicti*, *Capitella capitata,* and *Hediste diversicolor* and oligiochaetes. Other common taxa included the polychaetes *Tharyx acutus* and *Spio setosa* and the soft shelled clam, *Mya arenaria.* These species are typical for East Coast estuarine areas with fine grained sediments (Watling, 1975) No significant differences in density, species composition or species diversity were found between sample sites or sample years for the study period. The data also indicated that the treatment plant outfall had little impact on the infaunal community in Brown's River. The clam worm, *Neanthes virens*, is also common in the intertidal areas of Hampton Harbor and supports a limited commercial bait industry.

Hardwick-Witman and Mathieson (1983) compared the epibenthic species composition of the rocky intertidal zone over a gradient extending from the mouth of the Piscataqua River into Great Bay. Within Great Bay, the dominant epibenthic intertidal invertebrates were *Ilyanassa obsoleta*, *Geukensia demissa*, *Crassostrea virginica*, *Balanus eberneus*, *Littorina littorea*, *L. saxatilis* and *L. obtusata.* Large beds of Eastern oysters, *Crassostrea virginica*, occur within Great Bay Estuary. This species, along with soft shelled clams, blue mussels and sea scallops will be discussed in more detail in a later section of this report. Other common epibenthic species in the Great Bay Estuary include horseshoe crabs (*Limulus polyphemus*), green crabs (*Carcinus meanas*), mud crabs (family Xanthidae), rock crabs (*Cancer irroratus*) and American lobsters (*Homarus americanus*).

The warm summer waters within Great Bay allow the persistence of several invertebrate species that are more common further south along the open Atlantic coast (Bousfield and Thomas, 1975). One example of such a disjunct warm-water taxon is the salt marsh amphipod *Gammarus palustris*; its northern distribution limits on the East Coast of the US are within Great Bay (Gable and Croker, 1977, 1978). Other examples of disjunct invertebrate species occurring within the Great Bay include *Balanus improvisus*, *Crassostrea virginica*, *Urosalpinx cinerea*, *Tellina agilis*, *Molgula manhattensis*, *Cliona* sp. and *Polydora* sp. (Turgeon, 1976). Such disjunct taxa may represent relict populations from a warmer period 10,000 to 6,000 yr B.P. (Bousfield and Thomas, 1975).

3.1.3 SELECTED INVERTEBRATE SPECIES

3.1.3.1 Molluscan Shellfish

The estuaries of New Hampshire are ideal habitat for a number of molluscan shellfish species. The Great Bay Estuary, including Little Harbor and the Back Channel area, supports populations of the eastern oyster (*Crassostrea virginica*), European flat or Belon oysters (*Ostrea edulis*), softshell clams (*Mya arenaria*), blue mussels (*Mytilus edulis*), razor clams (*Ensis directus*), and sea scallops (*Placopecten magellanicus*). Hampton Harbor supports populations of softshell clams and blue mussels. Molluscan shellfish are not only of economic importance for commercial and recreational harvesting, they are excellent bioindicators of estuarine condition because they are relatively long lived and integrate their environment over time. Additionally, because they are filter feeders, they play an important role in nutrient cycling, improving water clarity, and in removing significant quantities of nitrogen and phosphorus from the water column via phytoplankton and organic detritus consumption. Epibenthic shellfish such as mussels, oysters and scallops provide valuable habitat for a rich assemblage of invertebrates and fish while large infaunal bivalves oxygenate soft sediments with their burrowing activities. Oysters are considered by many estuarine ecologists to be a "keystone" species, and oyster beds in temperate estuaries are considered the equivalent of coral reefs in tropical seas. Many studies have shown that species density, diversity and biomass are significantly greater in oyster beds than on equivalent bottom without oysters. Molluscan shellfish play an important role in the ecology of estuaries and in the local and regional economies.

Eastern Oyster (Crassostrea virginica)

Eastern oysters range from the Gulf of Mexico to Atlantic Canada, though their occurrence is continuous only as far north as Cape Cod. North of Cape Cod, disjunct populations can be found in New Hampshire, Maine, the Canadian Maritimes and the province of Quebec. They are primarily an intertidal and shallow subtidal species and are most abundant in estuarine areas with firm substrates. Ice scouring in more northern regions limits their occurrence to shallow subtidal areas. Eastern oysters can tolerate salinities ranging from 2-3 ppt to full seawater salinity (34 ppt) though reproduction is depressed at low salinities. They can also tolerate temperatures ranging from -2°C to >30°C, however, feeding ceases and respiration is greatly depressed below 5°C. Unlike some bivalve species such as bay and sea scallops, they thrive in areas of high turbidity. Spawning occurs when water temperatures reach approximately 20°C, though in the more northern portion of their range, annual spawning may not always occur. The planktonic larvae remain in the water column for 14-20 days and settle on hard substrate, with a noticeable preference for the shells of their own species. Accounts of early European settlers reported that oysters were very abundant in the Great Bay Estuary, and shell middens indicate that oysters were consumed by native Americans. Though once harvested commercially, they now support a popular recreational fishery in New Hampshire.

The location and dimension of oyster beds in the Great Bay Estuary has been discussed in a number of publications dating back to the late 1940's. The present beds are shown in Figure 3.1. Maps of oyster bed locations can be found in Ayer et al. (1970), Nelson (1981) and Sale et al. (1992). Oyster habitat based on occurrence and suitability modeling has been recently mapped by the U.S. Fish and Wildlife (Banner and Hayes, 1996). A map depicting the location of these beds in 1980 is shown in Figure 1.5. Jackson (1944) gave a general description of the locations of oyster beds, and described reduction in oyster populations due to siltation and pollution. He recommended rejuvenation of the oyster beds through shell planting and cultivation and suggested that Great Bay oysters could become of considerable commercial importance. Though numbers for acreage and density from that period are not reported, it is obvious from Jackson's description that even in the 1940's, much of the oyster habitat in the Great Bay Estuary had already been lost. Ayer et al (1970) described the location, acreage and population structure of Great Bay oysters and estimated a standing crop of market sized oysters of 38,000 bushels. This estimate was calculated using the areal coverage of the all beds and density and size frequency of oysters in the Oyster River only, assuming equal density and size structure for all beds. Ayer et al. (1970) also studied spatfall and growth in various locations and explored the possibility of a seed oyster industry in New Hampshire. Spatfall was highly variable both spatially and temporally. He also found that although all bivalve shell caught spat, oyster shell produced the best results. Additionally, he recommended the use of hatchery reared larvae for seed production as a means of producing marketable oysters in a shorter period of time.

Nelson (1982) estimated the density and standing crop of market-sized oys-

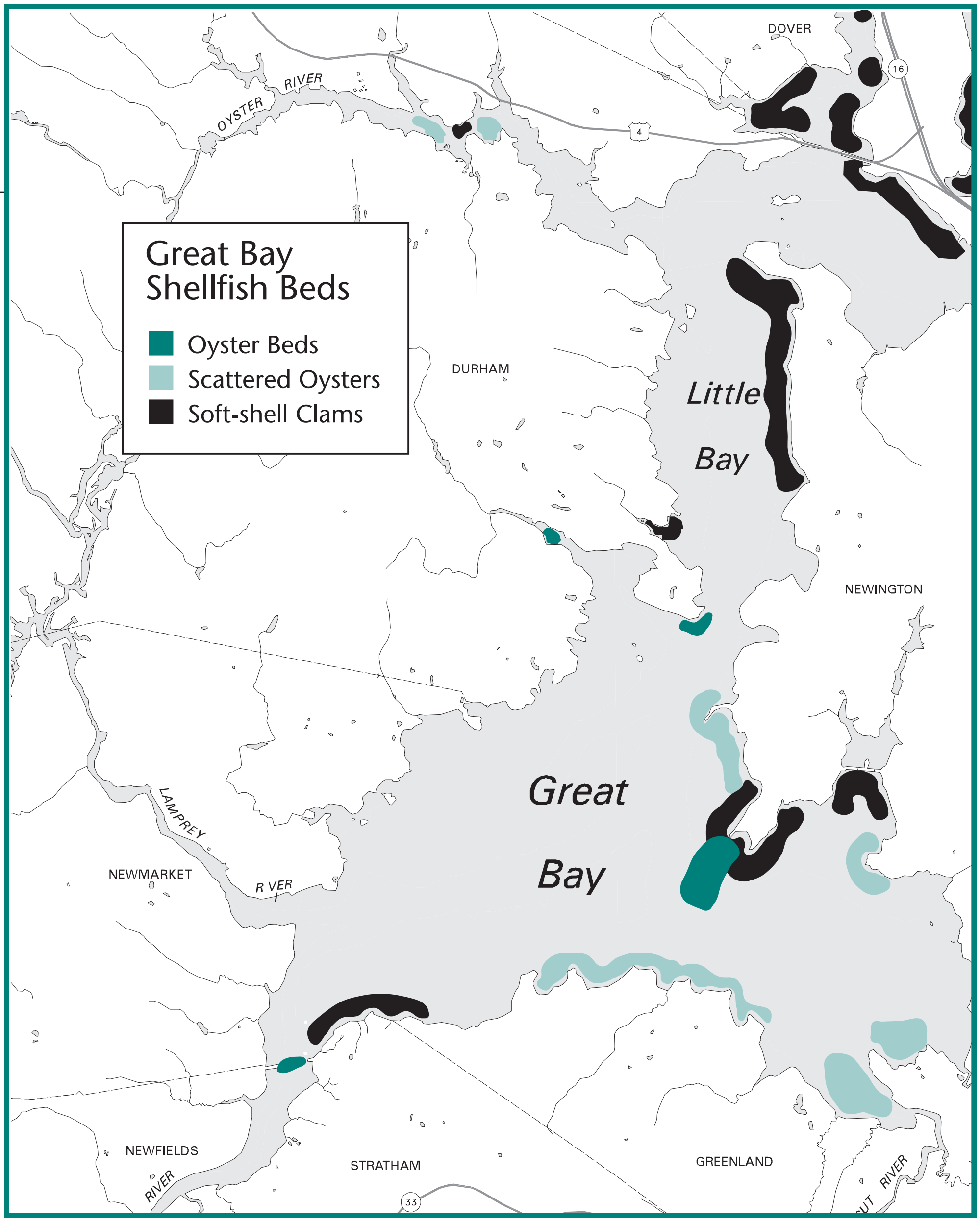


FIGURE 3.1

Shellfish resources in Great Bay, Little Bay and tributaries.

ters, and NH F&G conducted additional estimates on selected beds in 1991 and 1993. These data are presented in Table 3.1. It is very difficult to determine change over time from these data. The 1970 estimate only calculated standing crop/acre for the Oyster River bed and applied this density to a total of 50 acres in the estuary, though the number of acres for each bed were not defined. The Adams Point bed, one of the most popular harvest spots in Great Bay, is not included in the 1981 estimate, but appears in 1991 and 1993. The 1981 data reports a great abundance of oysters in southwest Great Bay, a 90% reduction from 1981 to 1991, and no mention of this bed in 1993. More recent survey work (1996-1997) has failed to locate a large concentration of oysters in the southwest portion of Great Bay, though a small concentration can be found in the vicinity of the railroad bridge that crosses the Squamscott River. Reduction in areal coverage of some beds is indicated by the data from for the Bellamy and Oyster river beds from 1991 to 1993, with a 67% reduction in the Bellamy River and a 19% reduction in the Oyster River. Jackson (1944) also mentions a significant reduction in the size of Oyster River bed, though precise changes in dimension are not reported. Density data for all sizes of oysters were obtained for

Acreage and standing crop of adult oysters in the Great Bay Estuary. **TABLE 3.1**

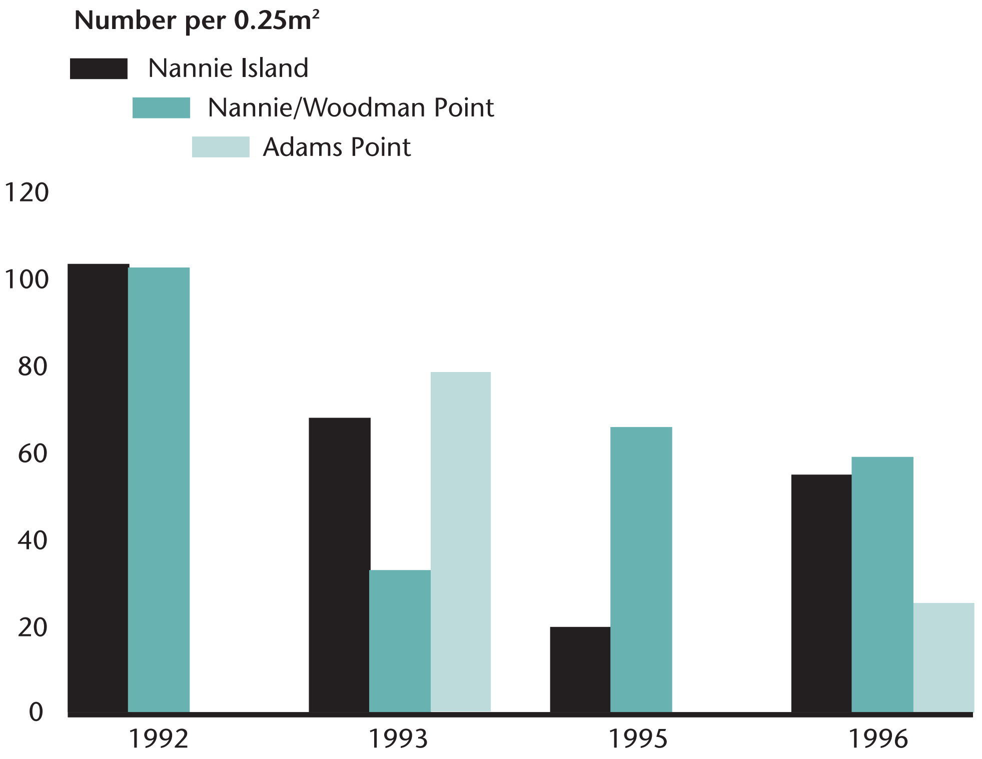
Location	1970		1981		1991		1993	
	acres	bushels	acres	bushels	acres	bushels	acres	bushels
Nannie Island	?	?	18.5	18193	?	?	18.5	20,615
Adams Point	?	?	?	?	?	?	5.1	8,358
Oyster River	7.4	5594	7.4	12,062	7.4	3,369	6	10,038
Southwest Great Bay	?	?	9.8	59,122	9.8	6,389	?	?
Bellamy River	?	?	3.1	3,891	3.1	6,865	1	1,074
Piscataqua River	?	?	12.3	23,735	12.3	13,135	12.3	5,412
Total Estimated	50	37,800	51.1	117,003	NA			45,497

the years 1991, 1993, 1995 and 1996 for two beds near Nannie Island and for 1993 and 1996 for Adams Point by personnel from the NH Fish and Game. These data are illustrated in Figure 3.2. According to the data, from 1991 to 1996, there has been a 46% reduction in the Nannie Island south bed, a 42% reduction in the Nannie Island/Woodman Point bed and a 69% reduction in the Adams Point bed.

These data suggest a decline in oyster populations in Great Bay. With the exception of the 1970 data, however, all these estimates are based on a relatively small number of samples and should be considered rough estimates at best. More recent studies provide improved information on oyster resources (Langan, 1997) and harvest (NHF&G, 1997c).

It is also useful to examine other sources of information when trying to determine trends in oyster populations. A survey of recreational harvesters conducted by Manalo et al (1991) asked the recreational license holders for an esti-

Density of oyster beds in Great Bay: 1991-1996. **FIGURE 3.2**



mate of the amount of time it took to harvest one bushel of oysters prior to and after 1989. Seventy four percent of the respondents indicated that it took them longer to harvest their limit after 1989. A more recent survey in 1997 by NHF&G asked recreational harvesters their opinion about the general abundance of oysters in Great Bay. Fifty five percent expressed the opinion that the abundance was lower than in prior years, six percent thought is was higher, eighteen percent reported no change and seventeen percent didn't know. A commercial oyster harvester on the Maine side of the Piscataqua River ceased harvesting operations in 1995 after an epizootic of MSX caused mass mortalities of oysters in the Salmon Falls and Piscataqua rivers. Spinney Creek Shellfish, Inc. estimated 90% mortality in the Salmon Falls River beds, and 50-70% mortality in the Piscataqua River beds (T. Howell, personal communication). Data collected in the Salmon Falls and upper Piscataqua rivers in 1997 support these mortality estimates (Langan, unpublished data). Though systemic MSX infections in the Oyster River and Great Bay were lower, there is strong evidence, in the form of hinged or "boxed" oysters, to suspect that considerable disease related mortalities occurred in all areas of the Great Bay Estuary. More recent studies report the presence of MSX and dermo to be throughout the estuary (NHF&G, 1999).

As stated in another section of this report, larval recruitment and juvenile survival are important factors in maintaining oyster populations. Ayer et al. (1970) indicated that spat settlement in Great Bay was highly variable both spatially and temporally. They also reported that the percent of adult oysters spawning varies from year to year. Data collected by the Jackson Estuarine Laboratory from 1991 through 1996 indicates that light sets occurred in 1991, 1992 and 1996, a heavy set occurred in 1993 and virtually no set occurred in 1994 and 1995 (Dr. R. Langan, unpublished). The reasons for poor sets may be related to meteorological (temperature and salinity) and biological (sufficient food for adults and larvae, disease) conditions, but may also be related to the amount of available substrate for larval attachment. MacKenzie (1989) reported that the primary limiting factor in determining oyster recruitment is the amount of clean, hard substrate for larval attachment. With this in mind, it is interesting to note that the 1997 oyster harvester survey conducted by the Fish and Game found that only 27% of recreational harvesters return shell to the oyster beds. This would certainly support the concept that lack of available substrate for larval settlement is contributing to the poor spat settlement and juvenile recruitment. Though the lack of consistency in data collection makes it very difficult to be scientifically certain, it appears that oyster populations in the Great Bay Estuary have declined in recent years due to a combination of inconsistent recruitment and disease.

A long-term trend in oyster populations in the Great Bay Estuary is also difficult to determine since there is a lack of historical data. The report by Jackson (1944) certainly indicates that by the mid-twentieth century, oysters populations had declined significantly due to overharvesting, pollution and siltation. Though these conditions have improved greatly in recent years, it is unlikely that oyster populations have increased much since the 1940's. We may never know the original baseline of oyster abundance, however, it is probably safe to say that oyster populations in the Great Bay Estuary are a fraction of what they once were.

Diseases of the Eastern Oyster in New Hampshire

The oyster diseases MSX and Dermo, caused by the protozoan parasites *Haplosporidium nelsoni* and *Perkinsus marinus,* respectively, have recently been detected in oysters from the Great Bay Estuary. These diseases were once thought to be limited in their range by temperature and salinity to the mid-Atlantic region of the U.S., however their occurrence has expanded in recent years through New England and the disease organisms have been identified as far

Prevalence, systemic infection and MSX mortalities of oysters in the Great Bay Estuary, 1995. **TABLE 3.2**

Location	Date	Mean Shell Height (mm)	Prevalence %	Systemic Infections %	Dead %
Salmon Falls	10/27/95	81	81	50	83
Piscataqua (Power Lines)	10/27/95	74	70	25	64
Piscataqua (Sturgeon Creek)	10/27/95	75	65	40	42
Piscataqua (Stacy Creek)	10/27/95	77	45	10	25
Oyster River	12/18/95	103	50	30	NA
Adams Point	11/06/95	95	40	15	NA
Nannie Island	11/06/95	96	15	5	NA

north as the Damariscotta River in Maine. These diseases have had a major impact on oyster populations in the Gulf of Mexico (Dermo) and have crippled the oyster industries in Delaware and Chesapeake Bays (MSX and Dermo). Both diseases become more virulent during dry periods in the summer, when high temperature and salinity conditions persist. The method of transmission of MSX is unknown, though it is suspected that an intermediate host for the infectious life stage may be involved. Dermo can be transmitted directly from one oyster to another as well as by a wide variety of organisms included many bivalve species, though it appears to be infectious only to Eastern oysters

The first recorded MSX epizootic caused by the oyster parasite *Haplosporidium nelsoni* occurred in 1995 in the Great Bay Estuary (Barber et al., 1997), even though the parasite was identified in Piscataqua River oysters in 1983 (Sherburne and Bean, 1991) and again in 1994 (B. Barber, unpublished data). Unusual mortalities were observed in the Piscataqua River by Maine harvesters in August, 1995, and samples were examined for the *H. nelsoni* parasite. Samples of adult oysters (74-102 mm) were examined from beds in the Salmon Falls River, three sites in the Piscataqua River, the Oyster River, Adams Point and Nannie Island. The disease prevalence, percent of systemic infections and % dead from the disease are shown in Table 3.2. The disease caused the greatest mortalities in the Salmon Falls River and farthest upstream beds in the Piscataqua River, with lower prevalence and % systemic infections with increasing distance from the Piscataqua River. An examination of the climatological data, water temperature and salinity indicates that the conditions in 1995 were favorable for an MSX epizootic. Both temperature and salinity increased in all areas of the estuary from 1993 - 1995 due to drought conditions. The disease caused mortalities in all oyster beds and significant mortalities in some, and has had an impact on oyster populations that has not been fully assessed. Oyster samples from Nannie Island and Fox Point were analyzed in April, 1996. A 10% prevalence and no systemic infections were found. Samples of April, 1997, broodstock oysters from Fox Point were examined and a 17% prevalence of light infections was found. Observations of gaping and recently dead oysters from Nannie Island and Adams Point in the spring of 1997 (R. Langan, personal observation) indicates the possibility of continued mortalities from the disease despite the lower than average salinities in 1996 and the first half of 1997. A regular program of monitoring for *H. nelsoni* and *P. marinus* is underway (NHF&G, 1999).

The protozoan oyster parasite *Perkinsus marinus*, the causative agent of the Dermo disease, was identified in oysters from Spinney Creek, Maine in September, 1996. A large percentage of the oysters were infected, and some had heavy infections. No mortalities were attributed to the disease at that time. Additional samples were obtained in

December, 1997, from two sites in the Piscataqua River and Nannie Island in Great Bay. A "dermo-like" body was found in one of 25 oysters from Nannie Island, and 2 of 25 oysters from at Sturgeon Creek. A heavy infection was found in one of 25 oysters near the "three rivers" point in the Piscataqua River. No infected oysters were found (out of 25) at Seal Rock in the Piscataqua River. Thirty oysters from Fox Point were examined in March, 1997 and no infected oysters were found. Additional diagnostics have been conducted in the summer and fall of 1997. A low prevalence of light Dermo infections have been found in oysters from Adams Point, Nannie Island, and the Oyster River, while a higher prevalence and one oyster with advanced infection was found in the Piscataqua River. A neoplasia-like body was seen also by tissue examinations.

Belon or European Flat Oyster *(Ostrea edulis)*

The Belon oyster, native to Western Europe and the British Isles, was introduced into the Great Bay Estuary in the late 1970's by two commercial companies as an aquaculture species, and was grown in suspension culture in Little Bay, the Piscataqua River and Little Harbor, and in bottom culture in Spinney Creek. The Belon oyster prefers lower temperatures and higher salinities than the indigenous eastern oyster, and therefore habitat overlap is unlikely. Though similar in many respects to the Eastern oyster, *O. edulis* broods fertilized eggs internally, and releases larvae at the trochophore stage. Spinney Creek, where there is still active aquaculture of this species, has a spawning adult population capable of producing large natural sets of oysters, though few juveniles survive in Spinney Creek due to unfavorable temperatures in late summer. "Escapees" of this species have established natural, reproductive populations in the Piscataqua River, Portsmouth Harbor, Little Harbor, Rye Harbor, areas of the Back Bay in Portsmouth and more recently in Gosport Harbor at the Isles of Shoals. Though the actual numbers of this species is unknown, the fact that conditions are favorable for maintaining natural populations is interesting from a perspective of commercial aquaculture, since this species is highly valued and in great demand.

Softshell Clams *(Mya arenaria)*

Softshell clams are an infaunal bivalve that range from the mid-Atlantic region of the U.S. through the Canadian Maritimes. They can be found in substrates ranging from gravel to very soft mud, but appear to be most abundant in muddy or silty sand. Adults may burrow as deep as 20 cm into the substrate. They inhabit the intertidal and shallow subtidal areas of estuaries and coastal bays, and can tolerate a wide range of temperature and salinity. Though usually not a numerically dominant member of the infaunal community, in areas of high abundance they can represent a very large fraction of the infaunal biomass. Spawning occurs during two periods, spring and late summer-fall, though the greatest larval densities and greatest spat settlement occurs during the later spawning period. The larvae are planktonic for approximately 21 days. This species was also harvested commercially up to the mid 20th century, and is now the most popular recreational shellfish species in New Hampshire.

There is a great deal of uncertainty regarding abundances of softshell clams in the Great Bay Estuary. The locations of clam beds were reported by Nelson (1981) (Figure 3.1) and clam habitat, based primarily on suitability indices was recently mapped by the U.S. Fish and Wildlife (Banner and Hayes, 1996). Though clams can be found in most intertidal flats, densities are generally sparse and are spatially and temporally variable. There is some amount of recreational clamming in Great Bay, however, if a clammer were asked for his or her preferred location in New Hampshire, they would undoubtedly choose Hampton Harbor. Jackson (1944) reported acreage of flats in the Great Bay and the NH Fish and Game reported the location and abundance of clams in Great Bay (Nelson, 1981), Though seed clams were abundant at most sites, it appears that few survive since the abundance of larger size classes was low at all sites. The abundance of seed clams may have also been the result of a particularly heavy set that year. NH Fish and Game (1991) also reported acreage and standing crop of clams in the Great Bay Estuary in 1991. These data are presented in Table 3.3. A recent study provided more recent data on clam populations in the Great Bay Estuary (Langan, 1999). Results show moderate to high density of clams on the western flats of the Salmon Falls River and near Sandy Point in Great Bay, and low density on the eastern shore of lower Little Bay and along southern shoreline of Dover Point in Little Bay.

Jones and Langan (1996c) estimated clam abundance and spatfall on several flats in the Little Harbor area. They found that densities were generally low, despite the presence of suitable habitat, and that recent spatfall was poor. These data are presented in Table 3.4 and the locations of shellfish resources are shown in Figure 3.3. NH Fish and Game (1991) reported that there were 400 acres of clam flats in Little Harbor, the Back Channel area and in Sagamore Creek and a standing stock of 1,600 bushels of adult clams. A more recent report provides an updated database on clam populations in Back Channel (Langan et al., 1999b).

There is currently insufficient data to establish any trends in clam populations in Great Bay or Little Harbor. For a historical perspective, the report by Jackson (1944) stated that clams declined steadily in number between 1900 and 1944, and at that time there was "only a vestige of their former abundance," though no quantitative

Softshell clam flat acreage and abundance in Great Bay Estuary. **TABLE 3.3**

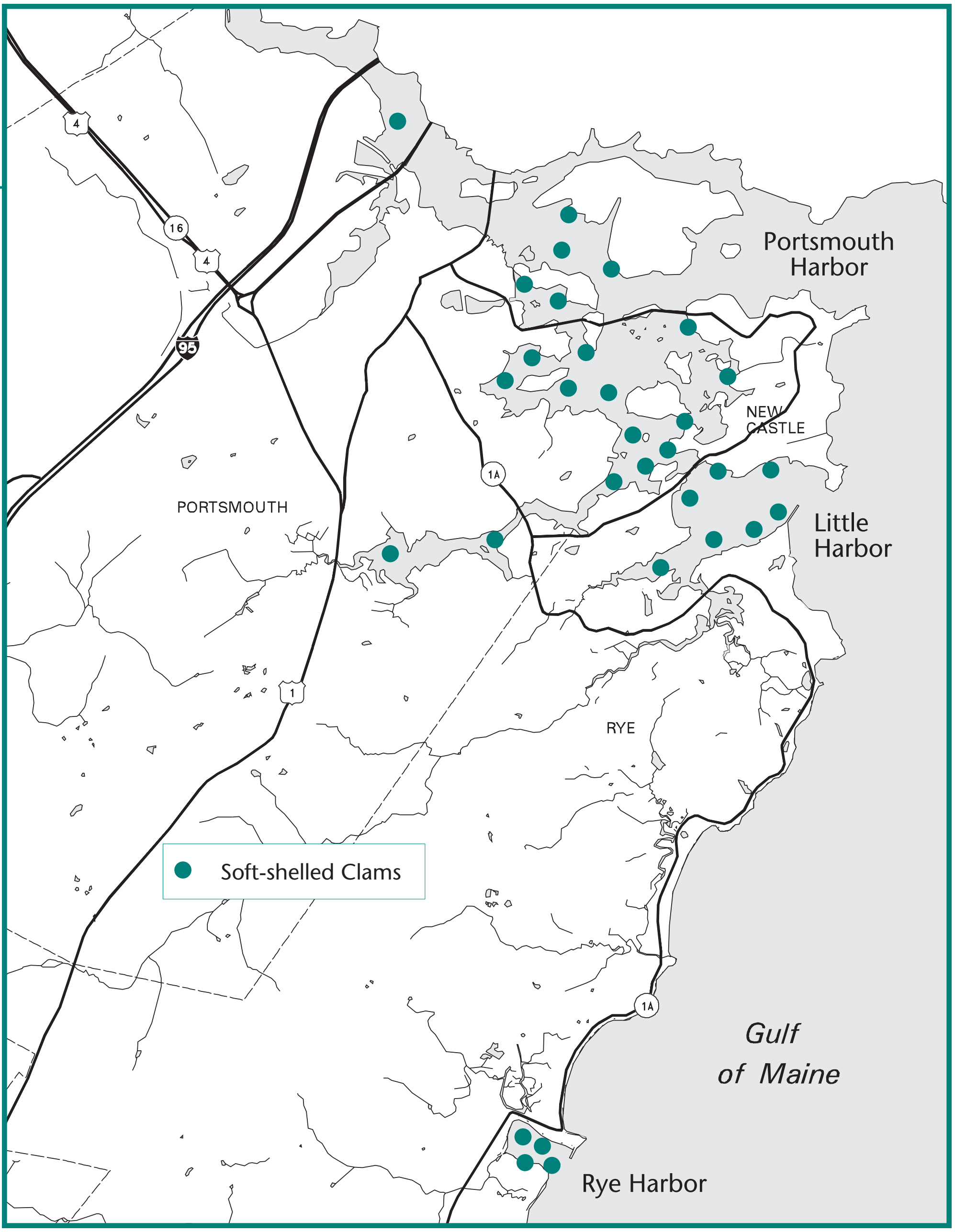
Location	Jackson (1944) Acreage	NH F&G (1991) Acreage	NH F&G (1991) Total Bushels
Salmon Falls River	125	125	500
Cocheco River	140	140	560
Piscataqua River	265	265	1060
Bellamy River	300	300	1200
Oyster River	225	225	900
Lamprey River	60	60	240
Squamscott River	180	180	720
Little Bay	430	380	1520
Great Bay	1000	500	2000
Total	2725	2175	8700

Softshell clam flat density and abundance in Little Harbor. **TABLE 3.4**

Clamflat No.	**Location**	**Acres**	**Density** #/m^2	**Total Area** m^2	**Abundance**	**# Bushels** 1200 clams/bu
1	Odiorne: West	0.4	1.6	1,618	2,589	2
2	Odiorne: East	8.6	4.4	34,796	153,102	18
3	Witch Creek: *Unsuitable substrate*					
4	Triangle	3.2	12:53	12,950	162,264	135
5	Wentworth	12.1	2.02	48,968	98,915	82
6	Seavey	6.4	5.07	25,900	131,313	1 09
7	Berrys Brook	4.2	4.65	18,817	87,499	73
Total		34.9	5.0	143,049	635,682	530

FIGURE 3.3

Shellfish resources in Portsmouth, Rye, and Little Harbors.



data are available for that period.

The locations of clam resources in Hampton Harbor are illustrated in Figure 3.4. Abundance and age composition of clams from the Hampton River Confluence, Common Island and Seabrook (middle ground) clam flats in Hampton Harbor have been monitored since 1974 by Normandeau Associates for the Public Service Company of New Hampshire as a requirement of their license to operate the Seabrook nuclear power plant. Larval abundance has been monitored for the same time period at a nearfield station outside the Harbor. This is without a doubt the most complete dataset for shellfish in New Hampshire and the long term data are presented in detail in the utilities' 1996 environmental report (NAI, 1996). Since only a summary of the information is presented here, the reader is referred to the referenced document for more detail.

Larval Abundance

Mya larvae are present in the water column from May through October and maximum densities are typically recorded in late summer or early fall with a secondary peak in early summer. This timing of the peak density can vary in timing and magnitude. Larval density has

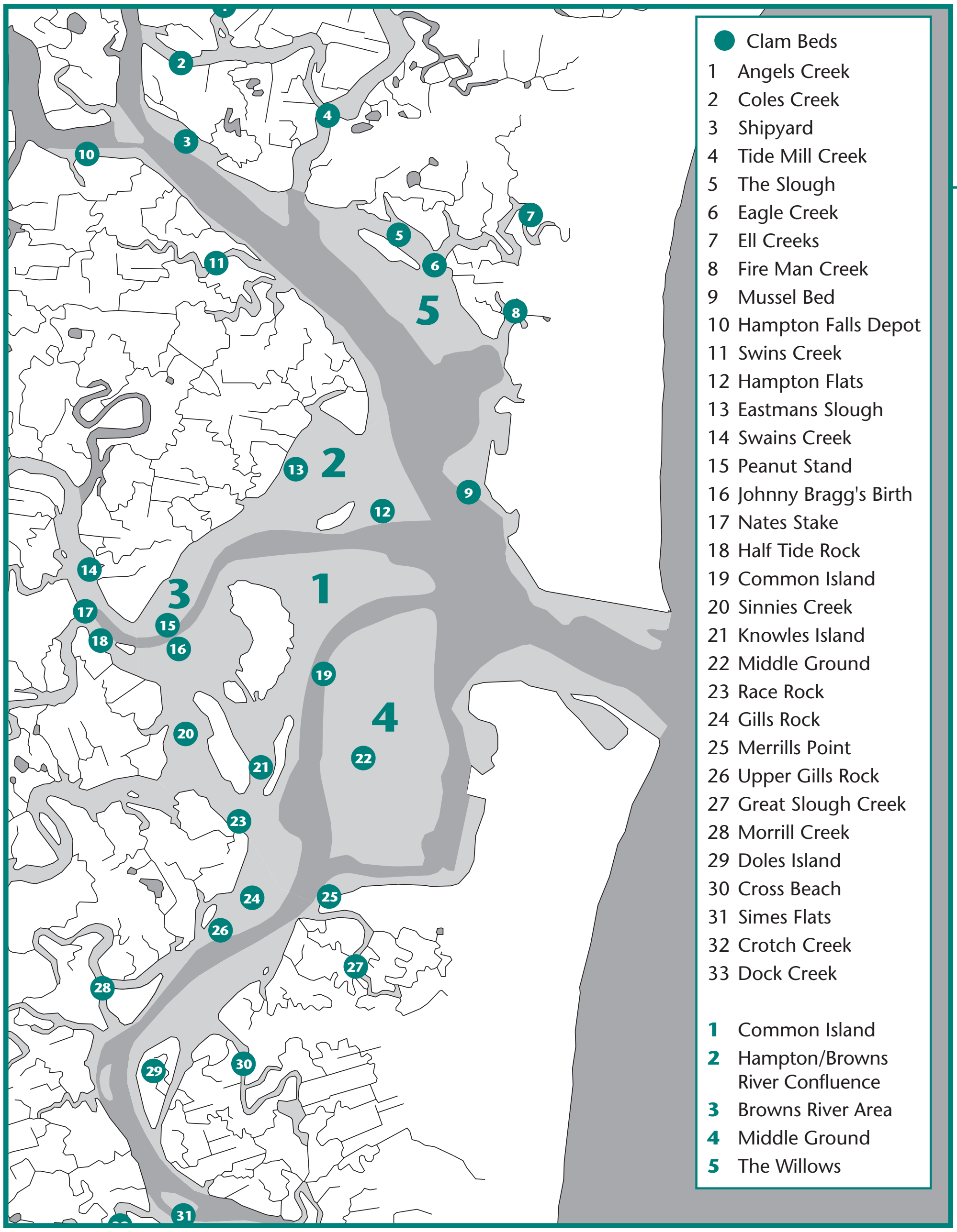


FIGURE 3.4

Shellfish resources in the Hampton Harbor Estuary.

been generally lower in the years 1991-1995 than in the period from 1978-1981. Gonadal studies indicate that spawning in Hampton Harbor usually follows the appearance of larvae at offshore stations, indicating that the early larvae are not produced by local broodstock. Based on the current patterns in the area, it is likely that recruitment of larvae of non-local origin occurs.

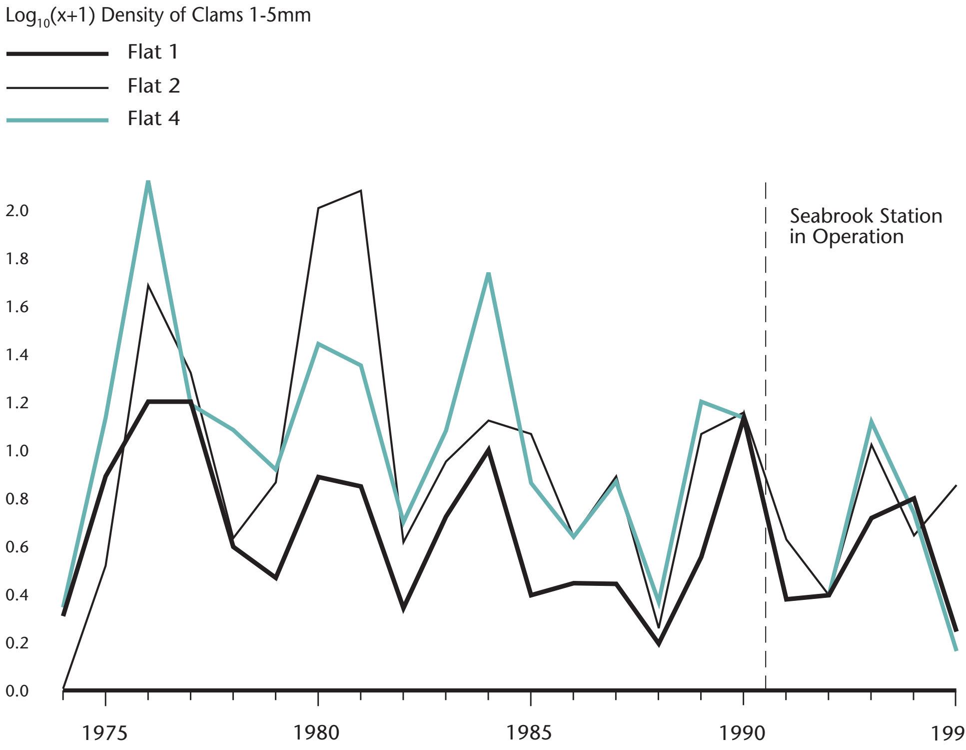
Young of the Year

Young of the year (YOY) clams are newly settled spat ranging from 1-5 mm. Historically YOY clam density has been highly variable both spatially and temporally in Hampton Harbor. In 1995, YOY density on the Seabrook Flat was lower than all years since 1974, while on the Hampton River confluence flat, density was higher than 1991-1994, but lower than the 1974-1989 average. Density was the second lowest since 1974 on the Common Island flat. Long term density appears to have declined slightly since 1974, and good sets appear to occur approximately every three to four years (Figure 3.5).

Spat

Density of spat (6-25 mm), or year one clams that have successfully overwin-

FIGURE 3.5 *Annual mean log10(x+1) density (number per ft2) of clams 1-5 mm length: 1974-1995. Data from NAI (1995)*



tered, has been variable for the study period, however, it can be stated that density on all flats was highest from 1977 through 1981, lowest from 1981 through 1989, and although much lower than the 1977-81 abundances, peaks in density occurred in 1990 and 1994. These peaks in density correspond well to the YOY densities except for the years from 1983 through 1987 where it appears that reasonably good sets did not survive the winter (Figure 3.6).

Juveniles

Juvenile clams (26-50 mm), are more than likely two year old clams. The annual density of juveniles corresponds well with spat density with a one year lag time. Clams of this size were most abundant from 1979-1981, and have declined steadily since, though smaller peak densities were recorded in 1990 and 1995 (Figure 3.7).

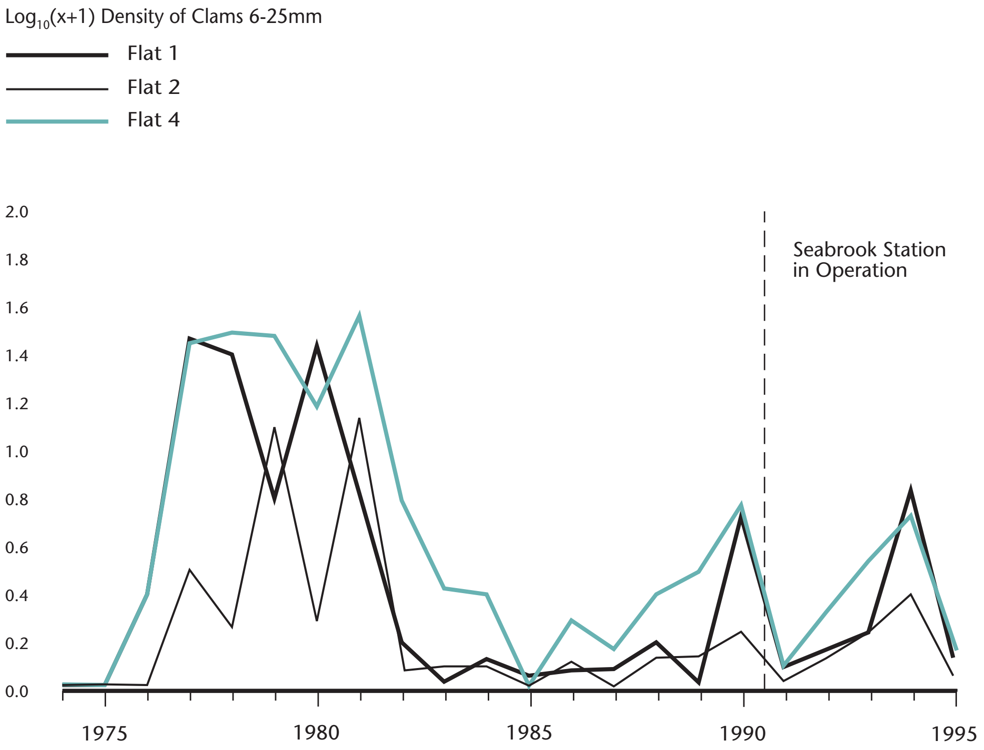
Adults

Adult clams (>50 mm) were abundant in 1971 through 1975 (Savage and Dunlop 1983), declined from 1976-1979, and reached peak abundances from 1980-1984. The steady sharp decline in abundance beginning in 1984 was very likely due to heavy harvest pressure. A classic predator prey relationship, where the change in density of prey is tracked by a change in predator density (with some lag period), exists between the clam population and the number of adult clam licenses sold (Figure 3.8). Closure of the flats in 1989 resulted in minor recovery of adult clam density on the Common Island flat from 1989 to 1995, a much greater increase in density in clams on the Seabrook flat, and little change on the Hampton River confluence flat, though an increase was recorded from 1994-1995. The Common Island flat was reopened in 1994, however the effects of recreational clamming in 1994 and 1995 appeared to have little effect on clam density (Figure 3.9). A recent study focused on removing blue mussels from flats to improve clam habitats (Langan and Barnaby, 1998).

Predation, particularly of small clams, can greatly affect the survival of clams to harvestable size. The green

Annual mean log10(x+1) density (number per ft2) of clams 6-25 mm length: 1974-1995. Data from NAI (1995).

FIGURE 3.6



Annual mean log10(x+1) density (number per ft2) of clams 26-50 mm length: 1974-1995. Data from NAI (1995).

FIGURE 3.7

FIGURE 3.8

Number of clam licenses and the adult clam standing crop (bushels) in Hampton-Seabrook Harbor: 1971-1987. Data from NAI (1995).

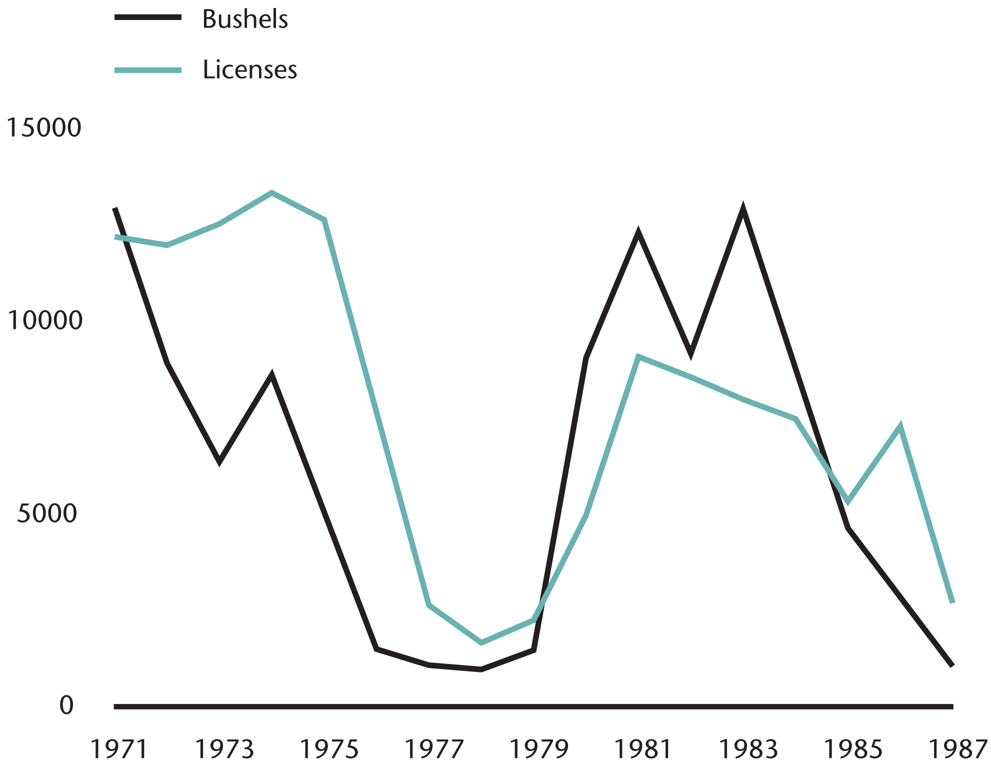
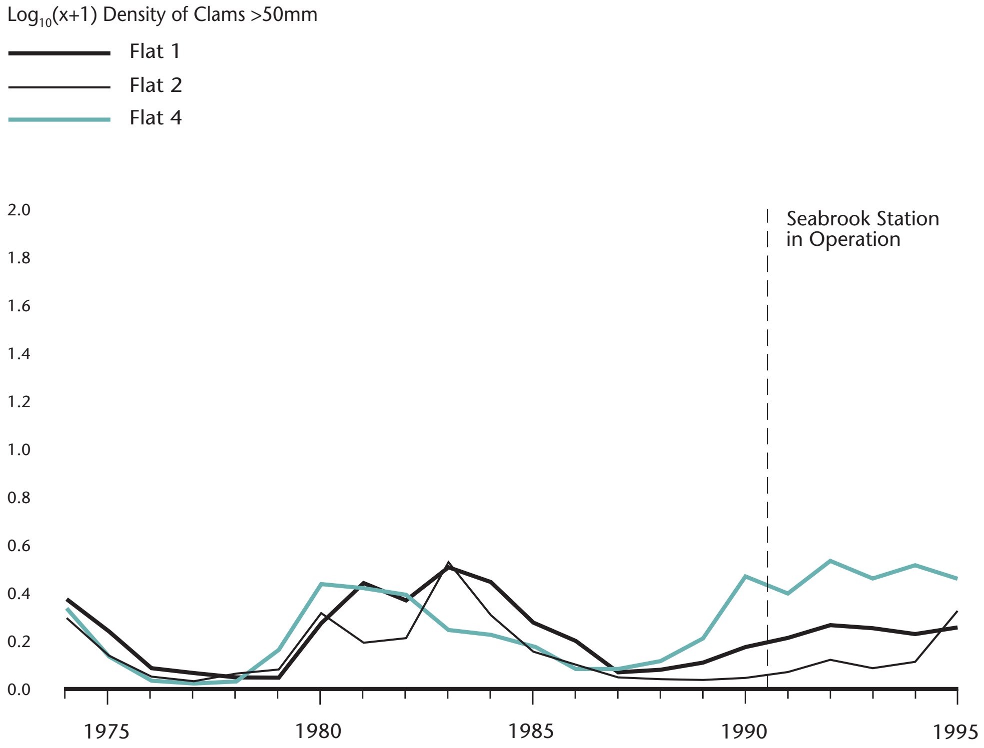


FIGURE 3.9

Annual mean log10(x+1) density (number per ft2) of clams >50 mm length: 1974-1995. Data from NAI (1995).



crab, a major predator of *Mya*, has been highly variable over time in Hampton Harbor, but unlike human predators, their numbers are influenced by minimum winter water temperatures rather than prey (clam) abundance. Even in years of low crab abundance, there appears to be sufficient numbers of crabs in the Harbor to impact juvenile clam abundance. Other predators include nematodes, horseshoe crabs and birds. Though massive sets of clams could "breakthrough" and overwhelm predation pressure, it is unlikely that this will happen without substantial natural or artificial reseeding and predator protection (Savage and Dunlop, 1983).

Ultimately, it appears that the controlling factors determining clam populations in Hampton Harbor are larval settlement, predation, prevalence of sarcomatous neoplasia (Hampton River flat) and harvest pressure. Savage and Dunlop (1983) stated that unless and seed clams are protected from predators and harvest pressure on adult clams is controlled, it would be very difficult for even large sets of clams to overcome the rate of predation and produce increased quantities of adult clams.

Softshell Clam Diseases: Sarcomatous neoplasia

Sarcomatous neoplasia, a lethal form of leukemia in clams, has the potential to cause serious mortalities in the softshell clams. The infection has been observed in relatively pristine waters, however it is suspected that the rate of infection is enhanced by pollution.

Sarcomatous neoplasia was observed in Hampton Harbor clam populations in October, 1986 and February, 1987 from the Common Island (6%) and Hampton River confluence (27%) flats (NAI, 1996). No infections were found on the Seabrook flat (middle ground). Clam surveys in 1987 indicated that juvenile and adult densities were reduced by 50% in the two flats where disease was identified, while the population was unchanged on the middle ground. It is suspected that the reduced densities resulted from disease related mortalities. In November, 1989, twelve of fifteen clams (80%) from the Hampton River were infected. From 1990-1995, adult clam densities quadrupled in the middle ground, while Common Island densities did not change, and Hampton River density decreased by 50%. It is suspected that disease may have contributed to the observed reductions. Clams in the Great Bay Estuary have not been examined for neoplasia.

Blue Mussels *(Mytilis edulis)*

The blue mussel is widely distributed in the North Atlantic and occurs in Europe as well as North America. On the East Coast of the U.S., it ranges from Cape Hatteras to the Arctic Circle. Mussels inhabit the intertidal and subtidal zones of estuaries and the open coast. Though primarily a shallow water species, they are sometimes found at considerable depths. They can tolerate temperatures ranging from -2°C to 25°C and salinities ranging from 5 ppt to 35 ppt, though prolonged expose to salinities below 15 ppt are lethal. Spawning can occur year round, though the peak spawning period is June through August. Like other bivalves, the larvae are planktonic and remain in the water column for three to five weeks. Initial settlement occurs in shallow water on any firm substrate, however, newly attached juvenile mussels can detach their byssal threads and drift with the currents in search of other suitable attachment surfaces. Though mussels are harvested in large quantities and are an important aquaculture species in Europe, Canada and other parts of the world, they are largely ignored as a food species in New England. They are considered by many to be a nuisance species since colonization leads to fouling of industrial and coastal structures, as well as the hulls of ships.

Blue mussels can be found in the Great Bay Estuary attached to any hard substrate in the intertidal and subtidal zones, and also colonize intertidal flats in scattered clumps and contiguous mats. Though during high salinity periods mussels may be found in most areas of the estuary, their limited tolerance for low salinity limits their permanent upstream distribution to the area around Dover Point. Mussels are most abundant in the lower Piscataqua River, Portsmouth Harbor and Little Harbor. The location of some mussel beds in the lower estuary was identified as part of the Ecological Risk Assessment study for the Portsmouth Naval Shipyard. Density, size and condition index of mussels from a number of sites was measured for this study (Johnston et al., 1994). Banner and Hayes (1996) mapped blue mussel habitat using a suitability index model, however, the lower estuary where mussels are most abundant was not included in their study.

Long term records of larval abundance and juvenile settlement of blue mussels have been maintained as part of the PSNH environmental studies program by Normandeau Associates (NAI, 1996). Mussel larvae are a dominant taxon in the nearshore plankton community and are the dominant noncolonial taxon on shallow depth fouling panels. Density of larvae has increased in recent years, and though settlement varies annually, in general it has increased in recent years as well. Mussels can be found in the estuary attached to hard substrate in both the intertidal and subtidal zones, and can form extensive beds on tidal flats. Banner and Hayes (1996) have mapped mussel habitat using occurrence and suitability indices. The most prominent beds are located in the Hampton River, Blackwater River, and on the Seabrook middle ground clam flat. There is no scientifically documented change in abundance, though there is information (P. Tilton, personal communication) that the coverage of mussels on the Seabrook flat has increased in recent years. Mussel density on the flats in Seabrook can be as high as $3500/m^2$ (Langan and Barnaby, 1998). Recent developments in new culture techniques, combined with increased market value and an abundant natural seed supply makes this species an ideal candidate for aquaculture development.

Sea Scallops *(Placopecten magellanicus)*

Though primarily an oceanic species, sea scallops can be found in the higher salinity areas of bays and estuaries in New England below a depth of 5 meters. Several scallop beds are located in the lower Piscataqua River and Portsmouth Harbor and include the area between Salamander Point and Fort Point, in Spruce Creek and off Fort McClarey in Kittery, Maine. Langan (1994) examined the density, size structure and movements of scallops in the Fort Point area using SCUBA surveys and mark and recapture studies. Mean density was 1.3 scallops/m2 and with the exception of few small (10-20 mm) individuals, the population had a normal distribution. Small scallops are difficult to see and may have been overlooked by divers. Scallop movement is greater for the 40-60 mm sized animals than smaller or larger individuals. Some large scallops were found within 100 meters of the release site a year after tagging. A project which began in 1996 (Langan 1997) is investigating the spawning time, spatfall and growth and mortality of scallops in suspension and bottom culture. The spawning period in 1996, based on gonadal/ somatic index (GSI), commenced in late July and spat settlement began in October. Onion bag/monofilament type spat collectors were used to capture larvae. Some collectors were retrieved in March and scallops from 4-10 mm were retrieved. These scallops and approximately one thousand 25 mm individuals were placed in suspension culture to measure growth and mortality. Natural enhancement of the bottom under the collectors was assessed in the summer of 1997.

Scallops are fished commercially with towed dredges from November 1 to April 14, and are harvested commercially and recreationally using SCUBA. Other than the 1994 survey at Fort Point, there is little information on scallop density or population change over time. Commercial fishermen indicate, however, that there is a great deal of variation in scallop abundance both temporally and spatially (P. Flanigan, personal communication).

Other Bivalve Species

Though there is no documented information on population densities and trends, several other bivalve species common to New Hampshire estuaries should be mentioned. The deposit feeding clam *Macoma balthica* is common in all areas of Great Bay and Hampton Harbor and the siphon of this clam is a favored prey item of juvenile winter flounder (Armstrong, 1996). Razor clams (*Ensis directus*) can be locally abundant in subtidal areas of Great Bay (Nelson, 1981), and the ribbed mussel (*Geukensia demissus*) is also common in lower salinity and marsh areas of the Great Bay (Nelson, 1981) and Hampton/Seabrook estuaries. The gem clam, *Gemma gemma*, a very small bivalve, can be the dominant infaunal taxon in the sandier areas of Great Bay.

3.1.3.2 Crustaceans

American Lobsters

The American lobster is the largest crustacean inhabiting New Hampshire's estuaries and coastal zone. They are the target of a large and valuable commercial fishery which will be discussed in a later section of this report. Though primarily a coastal and oceanic species, lobsters inhabit many coastal bays and estuaries. They range from the mid-Atlantic states through Newfoundland, though in their southern range, they are found in greatest abundance in deeper offshore waters. Though most often fished in shallow waters (<100 ft), lobsters inhabit waters as deep as 1,500 ft. Lobsters are omnivorous, feeding on molluscs, urchins, starfish, crabs and even other lobsters. They in turn are preyed upon by seals, groundfish (cod) and other large predatory fish such as striped bass. The adults undergo a seasonal migration, moving inshore in spring and offshore in the fall, though within that time period, they may move about a great deal within estuaries (Dr. S. Jury, personal communication). Spawning occurs by means of internal fertilization when the female has recently molted, and the fertilized eggs are extruded one year after molting. The females carry the fertilized eggs under their abdomen for up to one year. The eggs hatch and are released into the water column in late spring/early summer in near shore areas, and the planktonic larvae go through several molt stages before settling to the bottom. The preferred juvenile settlement substrate is rock-cobble, (Wahle and Steneck 1991, 1992) though older juveniles can be found inhabiting any type of substrate where shelter (boulders, rocks, cobble, mud burrows) can be found. Lobsters reach commercial size after 15-20 molts or in 6-9 years. Despite increased fishing pressure in recent years, lobster populations are relatively stable. More information on lobster abundance is presented in Chapter 4.

Crabs

Several species of crabs can be found in abundance in New Hampshire's estuaries and coastal areas. Most prominent are the rock crab (*Cancer irroratus*) and the green crab (*Carcinus maenas*) though the small mud crabs of the genera *Panopeus* and *Rhythropanopeus* are also very abundant. There is some commercial harvesting of rock crabs for human consumption and green crabs for bait, however, their economic importance is negligible.

3.1.3.3 Horseshoe Crabs *(Limulus polyphemus)*

The horseshoe crab (*Limulus polyphemus*) is not a true crab, and among the arthropods is more closely related to the arachnids (spiders, scorpions) than crustaceans. Horseshoe crabs are abundant in Great Bay and occur in lower numbers in Hampton Harbor. They are most conspicuous in the month of June, when they mate in large numbers during the spring flood tides and deposit their eggs on the beach. The eggs are preyed upon by several species of shore birds and represent a major food source for some species. Horseshoe crabs excavate large feeding pits in soft substrates, consuming the worms, molluscs and crustaceans.

mate of the amount of time it took to harvest one bushel of oysters prior to and after 1989. Seventy four percent of the respondents indicated that it took them longer to harvest their limit after 1989. A more recent survey in 1997 by NHF&G asked recreational harvesters their opinion about the general abundance of oysters in Great Bay. Fifty five percent expressed the opinion that the abundance was lower than in prior years, six percent thought is was higher, eighteen percent reported no change and seventeen percent didn't know. A commercial oyster harvester on the Maine side of the Piscataqua River ceased harvesting operations in 1995 after an epizootic of MSX caused mass mortalities of oysters in the Salmon Falls and Piscataqua rivers. Spinney Creek Shellfish, Inc. estimated 90% mortality in the Salmon Falls River beds, and 50-70% mortality in the Piscataqua River beds (T. Howell, personal communication). Data collected in the Salmon Falls and upper Piscataqua rivers in 1997 support these mortality estimates (Langan, unpublished data). Though systemic MSX infections in the Oyster River and Great Bay were lower, there is strong evidence, in the form of hinged or "boxed" oysters, to suspect that considerable disease related mortalities occurred in all areas of the Great Bay Estuary. More recent studies report the presence of MSX and dermo to be throughout the estuary (NHF&G, 1999).

As stated in another section of this report, larval recruitment and juvenile survival are important factors in maintaining oyster populations. Ayer et al. (1970) indicated that spat settlement in Great Bay was highly variable both spatially and temporally. They also reported that the percent of adult oysters spawning varies from year to year. Data collected by the Jackson Estuarine Laboratory from 1991 through 1996 indicates that light sets occurred in 1991, 1992 and 1996, a heavy set occurred in 1993 and virtually no set occurred in 1994 and 1995 (Dr. R. Langan, unpublished). The reasons for poor sets may be related to meteorological (temperature and salinity) and biological (sufficient food for adults and larvae, disease) conditions, but may also be related to the amount of available substrate for larval attachment. MacKenzie (1989) reported that the primary limiting factor in determining oyster recruitment is the amount of clean, hard substrate for larval attachment. With this in mind, it is interesting to note that the 1997 oyster harvester survey conducted by the Fish and Game found that only 27% of recreational harvesters return shell to the oyster beds. This would certainly support the concept that lack of available substrate for larval settlement is contributing to the poor spat settlement and juvenile recruitment. Though the lack of consistency in data collection makes it very difficult to be scientifically certain, it appears that oyster populations in the Great Bay Estuary have declined in recent years due to a combination of inconsistent recruitment and disease.

A long-term trend in oyster populations in the Great Bay Estuary is also difficult to determine since there is a lack of historical data. The report by Jackson (1944) certainly indicates that by the mid-twentieth century, oysters populations had declined significantly due to overharvesting, pollution and siltation. Though these conditions have improved greatly in recent years, it is unlikely that oyster populations have increased much since the 1940's. We may never know the original baseline of oyster abundance, however, it is probably safe to say that oyster populations in the Great Bay Estuary are a fraction of what they once were.

Diseases of the Eastern Oyster in New Hampshire

The oyster diseases MSX and Dermo, caused by the protozoan parasites *Haplosporidium nelsoni* and *Perkinsus marinus,* respectively, have recently been detected in oysters from the Great Bay Estuary. These diseases were once thought to be limited in their range by temperature and salinity to the mid-Atlantic region of the U.S., however their occurrence has expanded in recent years through New England and the disease organisms have been identified as far

Prevalence, systemic infection and MSX mortalities of oysters in the Great Bay Estuary, 1995. **TABLE 3.2**

Location	Date	Mean Shell Height (mm)	Prevalence %	Systemic Infections %	Dead %
Salmon Falls	10/27/95	81	81	50	83
Piscataqua (Power Lines)	10/27/95	74	70	25	64
Piscataqua (Sturgeon Creek)	10/27/95	75	65	40	42
Piscataqua (Stacy Creek)	10/27/95	77	45	10	25
Oyster River	12/18/95	103	50	30	NA
Adams Point	11/06/95	95	40	15	NA
Nannie Island	11/06/95	96	15	5	NA

north as the Damariscotta River in Maine. These diseases have had a major impact on oyster populations in the Gulf of Mexico (Dermo) and have crippled the oyster industries in Delaware and Chesapeake Bays (MSX and Dermo). Both diseases become more virulent during dry periods in the summer, when high temperature and salinity conditions persist. The method of transmission of MSX is unknown, though it is suspected that an intermediate host for the infectious life stage may be involved. Dermo can be transmitted directly from one oyster to another as well as by a wide variety of organisms included many bivalve species, though it appears to be infectious only to Eastern oysters

The first recorded MSX epizootic caused by the oyster parasite *Haplosporidium nelsoni* occurred in 1995 in the Great Bay Estuary (Barber et al., 1997), even though the parasite was identified in Piscataqua River oysters in 1983 (Sherburne and Bean, 1991) and again in 1994 (B. Barber, unpublished data). Unusual mortalities were observed in the Piscataqua River by Maine harvesters in August, 1995, and samples were examined for the *H. nelsoni* parasite. Samples of adult oysters (74-102 mm) were examined from beds in the Salmon Falls River, three sites in the Piscataqua River, the Oyster River, Adams Point and Nannie Island. The disease prevalence, percent of systemic infections and % dead from the disease are shown in Table 3.2. The disease caused the greatest mortalities in the Salmon Falls River and farthest upstream beds in the Piscataqua River, with lower prevalence and % systemic infections with increasing distance from the Piscataqua River. An examination of the climatological data, water temperature and salinity indicates that the conditions in 1995 were favorable for an MSX epizootic. Both temperature and salinity increased in all areas of the estuary from 1993 - 1995 due to drought conditions. The disease caused mortalities in all oyster beds and significant mortalities in some, and has had an impact on oyster populations that has not been fully assessed. Oyster samples from Nannie Island and Fox Point were analyzed in April, 1996. A 10% prevalence and no systemic infections were found. Samples of April, 1997, broodstock oysters from Fox Point were examined and a 17% prevalence of light infections was found. Observations of gaping and recently dead oysters from Nannie Island and Adams Point in the spring of 1997 (R. Langan, personal observation) indicates the possibility of continued mortalities from the disease despite the lower than average salinities in 1996 and the first half of 1997. A regular program of monitoring for *H. nelsoni* and *P. marinus* is underway (NHF&G, 1999).

The protozoan oyster parasite *Perkinsus marinus*, the causative agent of the Dermo disease, was identified in oysters from Spinney Creek, Maine in September, 1996. A large percentage of the oysters were infected, and some had heavy infections. No mortalities were attributed to the disease at that time. Additional samples were obtained in

December, 1997, from two sites in the Piscataqua River and Nannie Island in Great Bay. A "dermo-like" body was found in one of 25 oysters from Nannie Island, and 2 of 25 oysters from at Sturgeon Creek. A heavy infection was found in one of 25 oysters near the "three rivers" point in the Piscataqua River. No infected oysters were found (out of 25) at Seal Rock in the Piscataqua River. Thirty oysters from Fox Point were examined in March, 1997 and no infected oysters were found. Additional diagnostics have been conducted in the summer and fall of 1997. A low prevalence of light Dermo infections have been found in oysters from Adams Point, Nannie Island, and the Oyster River, while a higher prevalence and one oyster with advanced infection was found in the Piscataqua River. A neoplasia-like body was seen also by tissue examinations.

Belon or European Flat Oyster *(Ostrea edulis)*

The Belon oyster, native to Western Europe and the British Isles, was introduced into the Great Bay Estuary in the late 1970's by two commercial companies as an aquaculture species, and was grown in suspension culture in Little Bay, the Piscataqua River and Little Harbor, and in bottom culture in Spinney Creek. The Belon oyster prefers lower temperatures and higher salinities than the indigenous eastern oyster, and therefore habitat overlap is unlikely. Though similar in many respects to the Eastern oyster, *O. edulis* broods fertilized eggs internally, and releases larvae at the trochophore stage. Spinney Creek, where there is still active aquaculture of this species, has a spawning adult population capable of producing large natural sets of oysters, though few juveniles survive in Spinney Creek due to unfavorable temperatures in late summer. "Escapees" of this species have established natural, reproductive populations in the Piscataqua River, Portsmouth Harbor, Little Harbor, Rye Harbor, areas of the Back Bay in Portsmouth and more recently in Gosport Harbor at the Isles of Shoals. Though the actual numbers of this species is unknown, the fact that conditions are favorable for maintaining natural populations is interesting from a perspective of commercial aquaculture, since this species is highly valued and in great demand.

Softshell Clams *(Mya arenaria)*

Softshell clams are an infaunal bivalve that range from the mid-Atlantic region of the U.S. through the Canadian Maritimes. They can be found in substrates ranging from gravel to very soft mud, but appear to be most abundant in muddy or silty sand. Adults may burrow as deep as 20 cm into the substrate. They inhabit the intertidal and shallow subtidal areas of estuaries and coastal bays, and can tolerate a wide range of temperature and salinity. Though usually not a numerically dominant member of the infaunal community, in areas of high abundance they can represent a very large fraction of the infaunal biomass. Spawning occurs during two periods, spring and late summer-fall, though the greatest larval densities and greatest spat settlement occurs during the later spawning period. The larvae are planktonic for approximately 21 days. This species was also harvested commercially up to the mid 20th century, and is now the most popular recreational shellfish species in New Hampshire.

There is a great deal of uncertainty regarding abundances of softshell clams in the Great Bay Estuary. The locations of clam beds were reported by Nelson (1981) (Figure 3.1) and clam habitat, based primarily on suitability indices was recently mapped by the U.S. Fish and Wildlife (Banner and Hayes, 1996). Though clams can be found in most intertidal flats, densities are generally sparse and are spatially and temporally variable. There is some amount of recreational clamming in Great Bay, however, if a clammer were asked for his or her preferred location in New Hampshire, they would undoubtedly choose Hampton Harbor. Jackson (1944) reported acreage of flats in the Great Bay and the NH Fish and Game reported the location and abundance of clams in Great Bay (Nelson, 1981), Though seed clams were abundant at most sites, it appears that few survive since the abundance of larger size classes was low at all sites. The abundance of seed clams may have also been the result of a particularly heavy set that year. NH Fish and Game (1991) also reported acreage and standing crop of clams in the Great Bay Estuary in 1991. These data are presented in Table 3.3. A recent study provided more recent data on clam populations in the Great Bay Estuary (Langan, 1999). Results show moderate to high density of clams on the western flats of the Salmon Falls River and near Sandy Point in Great Bay, and low density on the eastern shore of lower Little Bay and along southern shoreline of Dover Point in Little Bay.

Jones and Langan (1996c) estimated clam abundance and spatfall on several flats in the Little Harbor area. They found that densities were generally low, despite the presence of suitable habitat, and that recent spatfall was poor. These data are presented in Table 3.4 and the locations of shellfish resources are shown in Figure 3.3. NH Fish and Game (1991) reported that there were 400 acres of clam flats in Little Harbor, the Back Channel area and in Sagamore Creek and a standing stock of 1,600 bushels of adult clams. A more recent report provides an updated database on clam populations in Back Channel (Langan et al., 1999b).

There is currently insufficient data to establish any trends in clam populations in Great Bay or Little Harbor. For a historical perspective, the report by Jackson (1944) stated that clams declined steadily in number between 1900 and 1944, and at that time there was "only a vestige of their former abundance," though no quantitative

Softshell clam flat acreage and abundance in Great Bay Estuary. **TABLE 3.3**

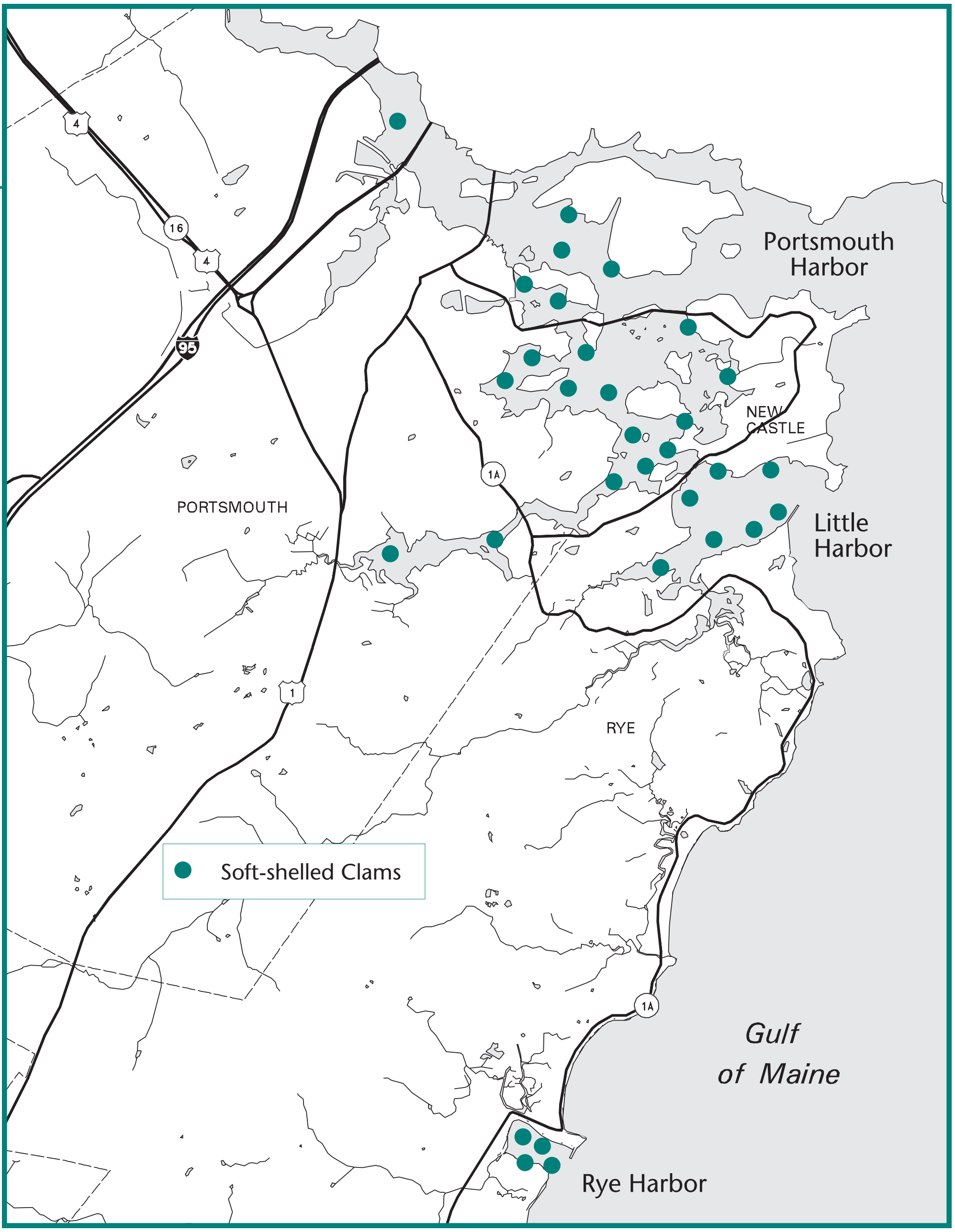
Location	Jackson (1944) Acreage	NH F&G (1991) Acreage	NH F&G (1991) Total Bushels
Salmon Falls River	125	125	500
Cocheco River	140	140	560
Piscataqua River	265	265	1060
Bellamy River	300	300	1200
Oyster River	225	225	900
Lamprey River	60	60	240
Squamscott River	180	180	720
Little Bay	430	380	1520
Great Bay	1000	500	2000
Total	2725	2175	8700

Softshell clam flat density and abundance in Little Harbor. **TABLE 3.4**

Clamflat No.	**Location**	**Acres**	**Density** $\#/m^2$	**Total Area** m^2	**Abundance**	**# Bushels** 1200 clams/bu
1	Odiorne: West	0.4	1.6	1,618	2,589	2
2	Odiorne: East	8.6	4.4	34,796	153,102	18
3	Witch Creek: *Unsuitable substrate*					
4	Triangle	3.2	12:53	12,950	162,264	135
5	Wentworth	12.1	2.02	48,968	98,915	82
6	Seavey	6.4	5.07	25,900	131,313	1 09
7	Berrys Brook	4.2	4.65	18,817	87,499	73
Total		34.9	5.0	143,049	635,682	530

FIGURE 3.3

Shellfish resources in Portsmouth, Rye, and Little Harbors.



data are available for that period.

The locations of clam resources in Hampton Harbor are illustrated in Figure 3.4. Abundance and age composition of clams from the Hampton River Confluence, Common Island and Seabrook (middle ground) clam flats in Hampton Harbor have been monitored since 1974 by Normandeau Associates for the Public Service Company of New Hampshire as a requirement of their license to operate the Seabrook nuclear power plant. Larval abundance has been monitored for the same time period at a nearfield station outside the Harbor. This is without a doubt the most complete dataset for shellfish in New Hampshire and the long term data are presented in detail in the utilities' 1996 environmental report (NAI, 1996). Since only a summary of the information is presented here, the reader is referred to the referenced document for more detail.

Larval Abundance

Mya larvae are present in the water column from May through October and maximum densities are typically recorded in late summer or early fall with a secondary peak in early summer. This timing of the peak density can vary in timing and magnitude. Larval density has

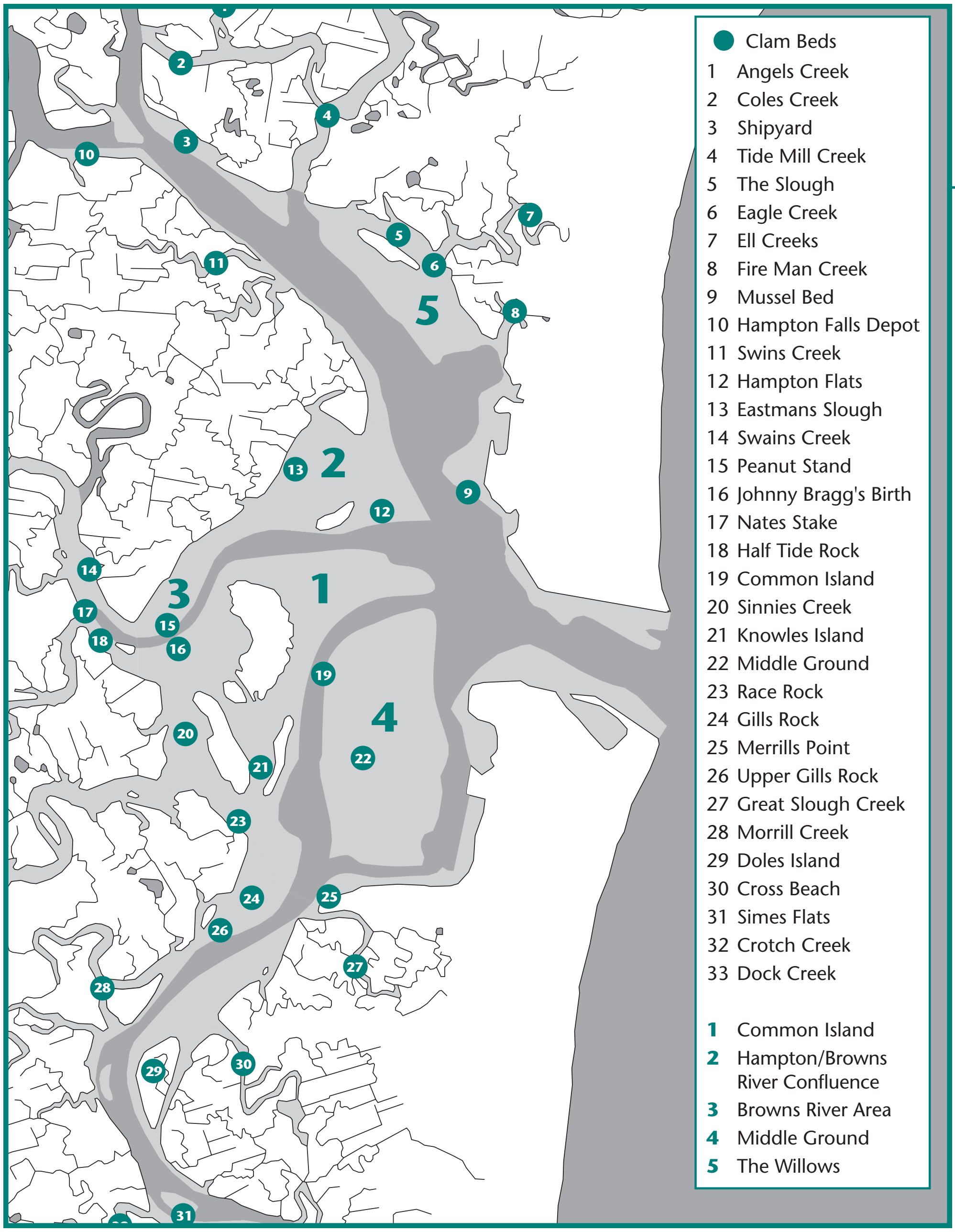


FIGURE 3.4

Shellfish resources in the Hampton Harbor Estuary.

been generally lower in the years 1991-1995 than in the period from 1978-1981. Gonadal studies indicate that spawning in Hampton Harbor usually follows the appearance of larvae at offshore stations, indicating that the early larvae are not produced by local broodstock. Based on the current patterns in the area, it is likely that recruitment of larvae of non-local origin occurs.

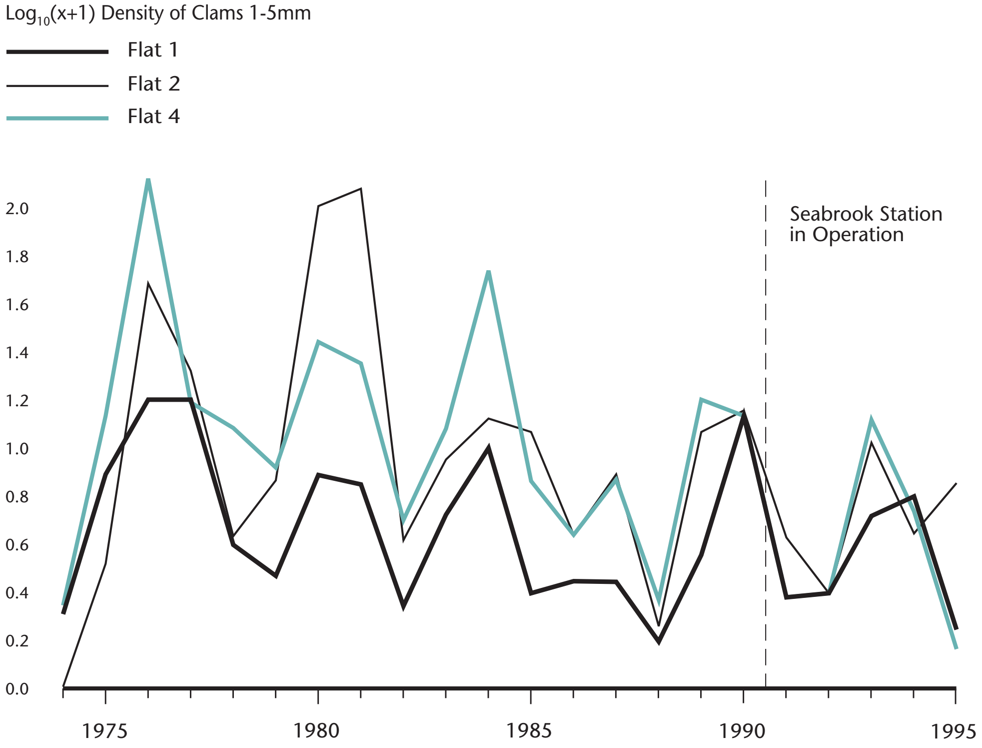
Young of the Year

Young of the year (YOY) clams are newly settled spat ranging from 1-5 mm. Historically YOY clam density has been highly variable both spatially and temporally in Hampton Harbor. In 1995, YOY density on the Seabrook Flat was lower than all years since 1974, while on the Hampton River confluence flat, density was higher than 1991-1994, but lower than the 1974-1989 average. Density was the second lowest since 1974 on the Common Island flat. Long term density appears to have declined slightly since 1974, and good sets appear to occur approximately every three to four years (Figure 3.5).

Spat

Density of spat (6-25 mm), or year one clams that have successfully overwin-

FIGURE 3.5 *Annual mean log10(x+1) density (number per ft2) of clams 1-5 mm length: 1974-1995. Data from NAI (1995)*



tered, has been variable for the study period, however, it can be stated that density on all flats was highest from 1977 through 1981, lowest from 1981 through 1989, and although much lower than the 1977-81 abundances, peaks in density occurred in 1990 and 1994. These peaks in density correspond well to the YOY densities except for the years from 1983 through 1987 where it appears that reasonably good sets did not survive the winter (Figure 3.6).

Juveniles

Juvenile clams (26-50 mm), are more than likely two year old clams. The annual density of juveniles corresponds well with spat density with a one year lag time. Clams of this size were most abundant from 1979-1981, and have declined steadily since, though smaller peak densities were recorded in 1990 and 1995 (Figure 3.7).

Adults

Adult clams (>50 mm) were abundant in 1971 through 1975 (Savage and Dunlop 1983), declined from 1976-1979, and reached peak abundances from 1980-1984. The steady sharp decline in abundance beginning in 1984 was very likely due to heavy harvest pressure. A classic predator prey relationship, where the change in density of prey is tracked by a change in predator density (with some lag period), exists between the clam population and the number of adult clam licenses sold (Figure 3.8). Closure of the flats in 1989 resulted in minor recovery of adult clam density on the Common Island flat from 1989 to 1995, a much greater increase in density in clams on the Seabrook flat, and little change on the Hampton River confluence flat, though an increase was recorded from 1994-1995. The Common Island flat was reopened in 1994, however the effects of recreational clamming in 1994 and 1995 appeared to have little effect on clam density (Figure 3.9). A recent study focused on removing blue mussels from flats to improve clam habitats (Langan and Barnaby, 1998).

Predation, particularly of small clams, can greatly affect the survival of clams to harvestable size. The green

Annual mean log10(x+1) density (number per ft2) of clams 6-25 mm length: 1974-1995. Data from NAI (1995).

FIGURE 3.6

Annual mean log10(x+1) density (number per ft2) of clams 26-50 mm length: 1974-1995. Data from NAI (1995).

FIGURE 3.7

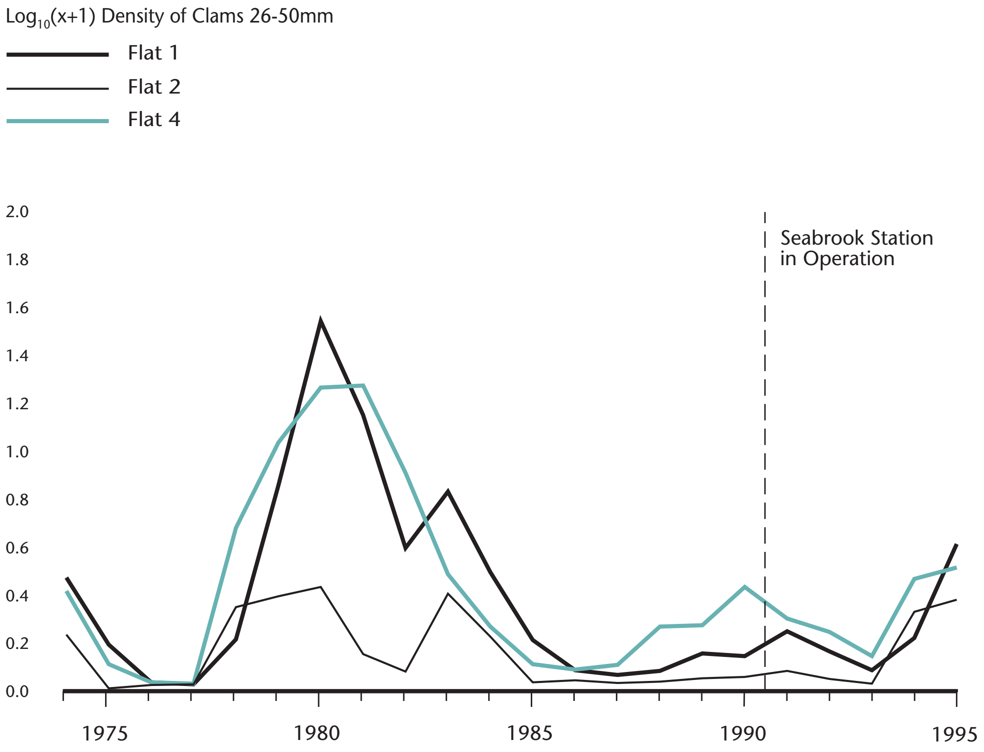


FIGURE 3.8

Number of clam licenses and the adult clam standing crop (bushels) in Hampton-Seabrook Harbor: 1971-1987. Data from NAI (1995).

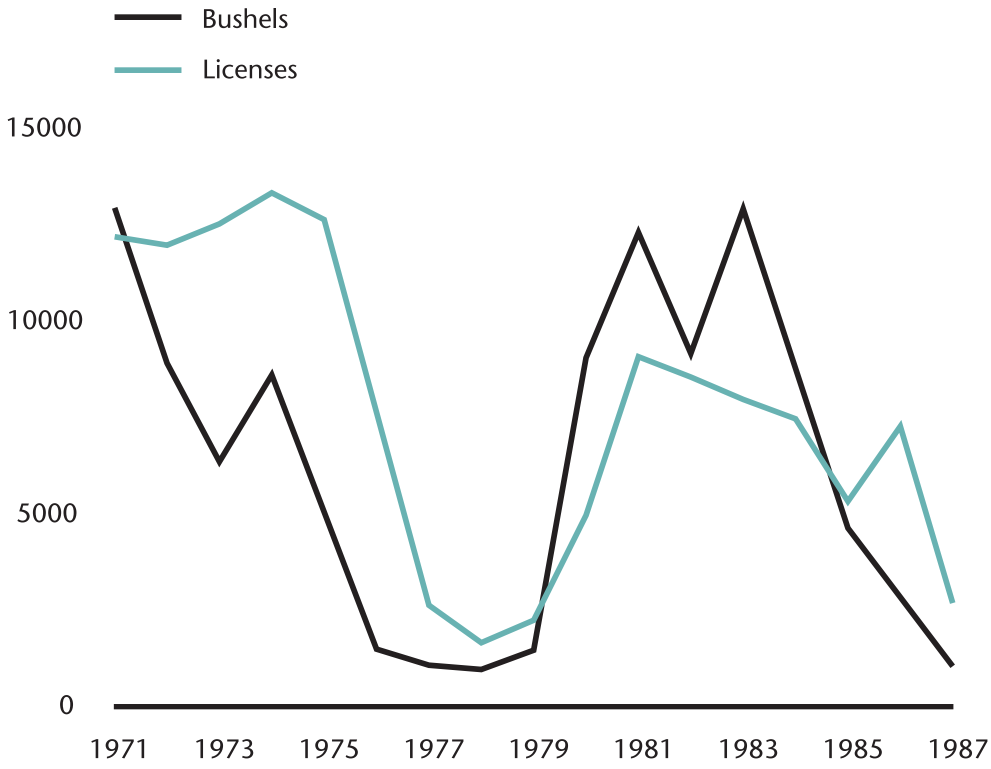
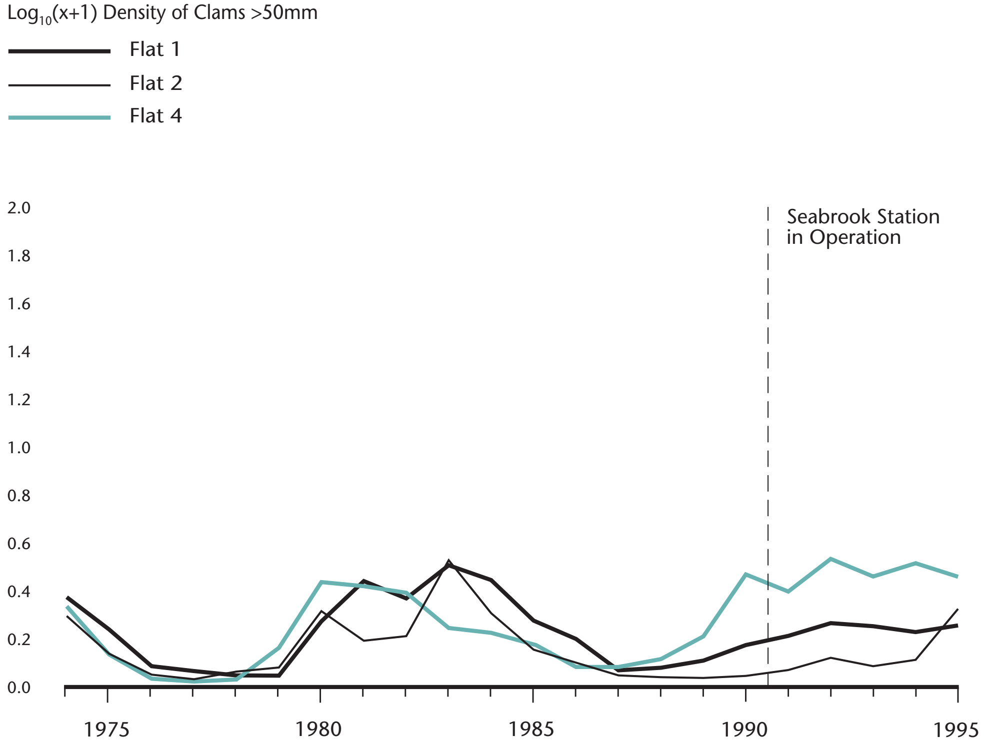


FIGURE 3.9

Annual mean log10(x+1) density (number per ft2) of clams >50 mm length: 1974-1995. Data from NAI (1995).



crab, a major predator of *Mya*, has been highly variable over time in Hampton Harbor, but unlike human predators, their numbers are influenced by minimum winter water temperatures rather than prey (clam) abundance. Even in years of low crab abundance, there appears to be sufficient numbers of crabs in the Harbor to impact juvenile clam abundance. Other predators include nematodes, horseshoe crabs and birds. Though massive sets of clams could "breakthrough" and overwhelm predation pressure, it is unlikely that this will happen without substantial natural or artificial reseeding and predator protection (Savage and Dunlop, 1983).

Ultimately, it appears that the controlling factors determining clam populations in Hampton Harbor are larval settlement, predation, prevalence of sarcomatous neoplasia (Hampton River flat) and harvest pressure. Savage and Dunlop (1983) stated that unless and seed clams are protected from predators and harvest pressure on adult clams is controlled, it would be very difficult for even large sets of clams to overcome the rate of predation and produce increased quantities of adult clams.

Softshell Clam Diseases: Sarcomatous neoplasia

Sarcomatous neoplasia, a lethal form of leukemia in clams, has the potential to cause serious mortalities in the softshell clams. The infection has been observed in relatively pristine waters, however it is suspected that the rate of infection is enhanced by pollution.

Sarcomatous neoplasia was observed in Hampton Harbor clam populations in October, 1986 and February, 1987 from the Common Island (6%) and Hampton River confluence (27%) flats (NAI, 1996). No infections were found on the Seabrook flat (middle ground). Clam surveys in 1987 indicated that juvenile and adult densities were reduced by 50% in the two flats where disease was identified, while the population was unchanged on the middle ground. It is suspected that the reduced densities resulted from disease related mortalities. In November, 1989, twelve of fifteen clams (80%) from the Hampton River were infected. From 1990-1995, adult clam densities quadrupled in the middle ground, while Common Island densities did not change, and Hampton River density decreased by 50%. It is suspected that disease may have contributed to the observed reductions. Clams in the Great Bay Estuary have not been examined for neoplasia.

Blue Mussels *(Mytilis edulis)*

The blue mussel is widely distributed in the North Atlantic and occurs in Europe as well as North America. On the East Coast of the U.S., it ranges from Cape Hatteras to the Arctic Circle. Mussels inhabit the intertidal and subtidal zones of estuaries and the open coast. Though primarily a shallow water species, they are sometimes found at considerable depths. They can tolerate temperatures ranging from -2°C to 25°C and salinities ranging from 5 ppt to 35 ppt, though prolonged expose to salinities below 15 ppt are lethal. Spawning can occur year round, though the peak spawning period is June through August. Like other bivalves, the larvae are planktonic and remain in the water column for three to five weeks. Initial settlement occurs in shallow water on any firm substrate, however, newly attached juvenile mussels can detach their byssal threads and drift with the currents in search of other suitable attachment surfaces. Though mussels are harvested in large quantities and are an important aquaculture species in Europe, Canada and other parts of the world, they are largely ignored as a food species in New England. They are considered by many to be a nuisance species since colonization leads to fouling of industrial and coastal structures, as well as the hulls of ships.

Blue mussels can be found in the Great Bay Estuary attached to any hard substrate in the intertidal and subtidal zones, and also colonize intertidal flats in scattered clumps and contiguous mats. Though during high salinity periods mussels may be found in most areas of the estuary, their limited tolerance for low salinity limits their permanent upstream distribution to the area around Dover Point. Mussels are most abundant in the lower Piscataqua River, Portsmouth Harbor and Little Harbor. The location of some mussel beds in the lower estuary was identified as part of the Ecological Risk Assessment study for the Portsmouth Naval Shipyard. Density, size and condition index of mussels from a number of sites was measured for this study (Johnston et al., 1994). Banner and Hayes (1996) mapped blue mussel habitat using a suitability index model, however, the lower estuary where mussels are most abundant was not included in their study.

Long term records of larval abundance and juvenile settlement of blue mussels have been maintained as part of the PSNH environmental studies program by Normandeau Associates (NAI, 1996). Mussel larvae are a dominant taxon in the nearshore plankton community and are the dominant noncolonial taxon on shallow depth fouling panels. Density of larvae has increased in recent years, and though settlement varies annually, in general it has increased in recent years as well. Mussels can be found in the estuary attached to hard substrate in both the intertidal and subtidal zones, and can form extensive beds on tidal flats. Banner and Hayes (1996) have mapped mussel habitat using occurrence and suitability indices. The most prominent beds are located in the Hampton River, Blackwater River, and on the Seabrook middle ground clam flat. There is no scientifically documented change in abundance, though there is information (P. Tilton, personal communication) that the coverage of mussels on the Seabrook flat has increased in recent years. Mussel density on the flats in Seabrook can be as high as $3500/m^2$ (Langan and Barnaby, 1998). Recent developments in new culture techniques, combined with increased market value and an abundant natural seed supply makes this species an ideal candidate for aquaculture development.

Sea Scallops *(Placopecten magellanicus)*

Though primarily an oceanic species, sea scallops can be found in the higher salinity areas of bays and estuaries in New England below a depth of 5 meters. Several scallop beds are located in the lower Piscataqua River and Portsmouth Harbor and include the area between Salamander Point and Fort Point, in Spruce Creek and off Fort McClarey in Kittery, Maine. Langan (1994) examined the density, size structure and movements of scallops in the Fort Point area using SCUBA surveys and mark and recapture studies. Mean density was 1.3 scallops/m2 and with the exception of few small (10-20 mm) individuals, the population had a normal distribution. Small scallops are difficult to see and may have been overlooked by divers. Scallop movement is greater for the 40-60 mm sized animals than smaller or larger individuals. Some large scallops were found within 100 meters of the release site a year after tagging. A project which began in 1996 (Langan 1997) is investigating the spawning time, spatfall and growth and mortality of scallops in suspension and bottom culture. The spawning period in 1996, based on gonadal/ somatic index (GSI), commenced in late July and spat settlement began in October. Onion bag/monofilament type spat collectors were used to capture larvae. Some collectors were retrieved in March and scallops from 4-10 mm were retrieved. These scallops and approximately one thousand 25 mm individuals were placed in suspension culture to measure growth and mortality. Natural enhancement of the bottom under the collectors was assessed in the summer of 1997.

Scallops are fished commercially with towed dredges from November 1 to April 14, and are harvested commercially and recreationally using SCUBA. Other than the 1994 survey at Fort Point, there is little information on scallop density or population change over time. Commercial fishermen indicate, however, that there is a great deal of variation in scallop abundance both temporally and spatially (P. Flanigan, personal communication).

Other Bivalve Species

Though there is no documented information on population densities and trends, several other bivalve species common to New Hampshire estuaries should be mentioned. The deposit feeding clam *Macoma balthica* is common in all areas of Great Bay and Hampton Harbor and the siphon of this clam is a favored prey item of juvenile winter flounder (Armstrong, 1996). Razor clams (*Ensis directus*) can be locally abundant in subtidal areas of Great Bay (Nelson, 1981), and the ribbed mussel (*Geukensia demissus*) is also common in lower salinity and marsh areas of the Great Bay (Nelson, 1981) and Hampton/Seabrook estuaries. The gem clam, *Gemma gemma*, a very small bivalve, can be the dominant infaunal taxon in the sandier areas of Great Bay.

3.1.3.2 Crustaceans

American Lobsters

The American lobster is the largest crustacean inhabiting New Hampshire's estuaries and coastal zone. They are the target of a large and valuable commercial fishery which will be discussed in a later section of this report. Though primarily a coastal and oceanic species, lobsters inhabit many coastal bays and estuaries. They range from the mid-Atlantic states through Newfoundland, though in their southern range, they are found in greatest abundance in deeper offshore waters. Though most often fished in shallow waters (<100 ft), lobsters inhabit waters as deep as 1,500 ft. Lobsters are omnivorous, feeding on molluscs, urchins, starfish, crabs and even other lobsters. They in turn are preyed upon by seals, groundfish (cod) and other large predatory fish such as striped bass. The adults undergo a seasonal migration, moving inshore in spring and offshore in the fall, though within that time period, they may move about a great deal within estuaries (Dr. S. Jury, personal communication). Spawning occurs by means of internal fertilization when the female has recently molted, and the fertilized eggs are extruded one year after molting. The females carry the fertilized eggs under their abdomen for up to one year. The eggs hatch and are released into the water column in late spring/early summer in near shore areas, and the planktonic larvae go through several molt stages before settling to the bottom. The preferred juvenile settlement substrate is rock-cobble, (Wahle and Steneck 1991, 1992) though older juveniles can be found inhabiting any type of substrate where shelter (boulders, rocks, cobble, mud burrows) can be found. Lobsters reach commercial size after 15-20 molts or in 6-9 years. Despite increased fishing pressure in recent years, lobster populations are relatively stable. More information on lobster abundance is presented in Chapter 4.

Crabs

Several species of crabs can be found in abundance in New Hampshire's estuaries and coastal areas. Most prominent are the rock crab (*Cancer irroratus*) and the green crab (*Carcinus maenas*) though the small mud crabs of the genera *Panopeus* and *Rhythropanopeus* are also very abundant. There is some commercial harvesting of rock crabs for human consumption and green crabs for bait, however, their economic importance is negligible.

3.1.3.3 Horseshoe Crabs *(Limulus polyphemus)*

The horseshoe crab (*Limulus polyphemus*) is not a true crab, and among the arthropods is more closely related to the arachnids (spiders, scorpions) than crustaceans. Horseshoe crabs are abundant in Great Bay and occur in lower numbers in Hampton Harbor. They are most conspicuous in the month of June, when they mate in large numbers during the spring flood tides and deposit their eggs on the beach. The eggs are preyed upon by several species of shore birds and represent a major food source for some species. Horseshoe crabs excavate large feeding pits in soft substrates, consuming the worms, molluscs and crustaceans.

ESTUARINE FINFISH

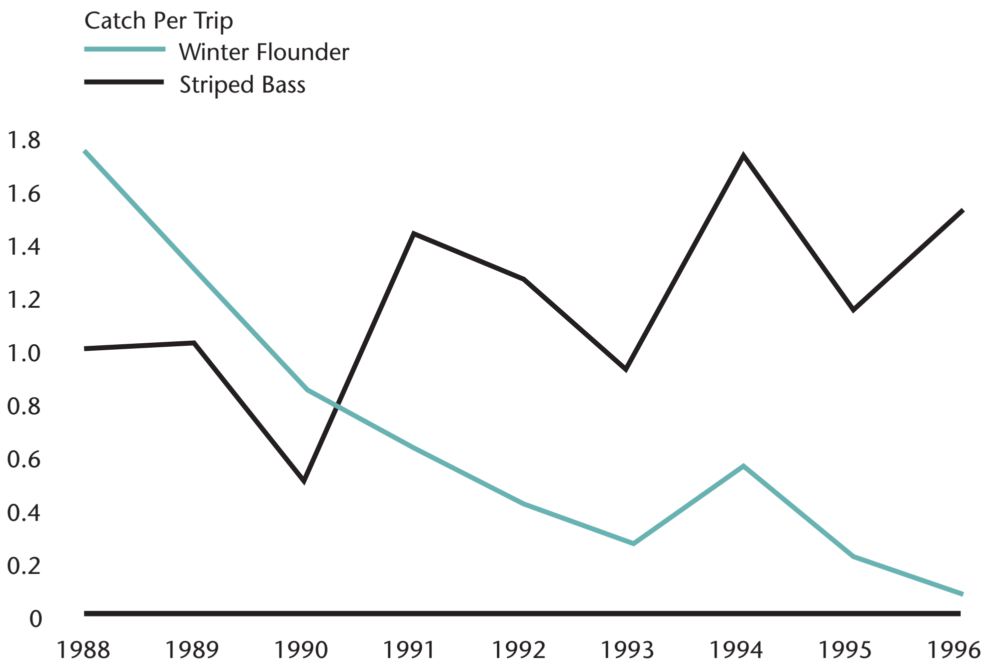
Coastal New Hampshire and its estuaries were well known for their variety and abundance of finfish species in colonial times. In fact, the area's earliest settlements were established in order to exploit the bountiful stocks of finfish. Throughout the eighteenth and nineteenth centuries, overharvesting, the construction of tidal dams, destruction of spawning grounds through sedimentation and municipal and industrial pollution greatly reduced their numbers in the Great Bay Estuary (Jackson 1944). As conditions improved toward the latter part of this century, many species have re-established themselves since 1900. Today the Great Bay Estuary supports 52 species of resident and migratory fish (Nelson, 1981) which are listed in Appendix E, while twenty eight species were reported for Hampton Harbor (NAI, 1977). Estuarine species include year round resident such as tomcod (*Microgadus tomcod*), mummichogs (*Fundulus* sp.) and silversides (*Menidia menidia*), seasonal migrants such as bluefish (*Pomatomus saltatrix*) and striped bass (*Morone saxatilis*) and anadromous fish such as the river herrings (*Alosa pseudoharengus* and *A. aestevalis*), shad (*Alosa sapisissima*) and lampreys (*Petromyzon marinus*) (Jackson, 1944; Nelson,1981, 1982; Sale et al., 1992; Jury et al., 1994). Fishways constructed on the Cocheco (2), Exeter (2), Oyster, Winnicut and Lamprey rivers in the Great Bay Estuary have enabled populations of several anadromous species to rebound, however, some species such as Atlantic salmon, and the common and shortnosed sturgeons (for which there is no reliable historic record of occurrence) and shad have not successfully been reestablished, despite stocking efforts for Atlantic salmon and shad. Commercially and recreationally important species, include smelt, (*Osmerus mordax*), winter flounder, *(Pleuronectes americanus*), smooth flounder (*Liopsetta putnami*), and striped bass, (*Morone saxatilis*). Finfish occurrence, abundance and ecology have been studies by many groups including the NH Fish and Game, Normandeau Associates, Inc, the University of New Hampshire, U.S. Fish and Wildlife, and the National Oceanic and Atmospheric Administration (NOAA) as part of natural resource inventories, impact assessments for power plants and ecological research projects. Detailed information on estuarine and coastal finfish species can be found in Jackson (1994), Nelson (1981, 1982), Sale et al. (1992), Jury et al. (1994), NAI (1977 and 1996) and fish habitat has been mapped in G.I.S. format by the U.S. Fish and Wildlife Gulf of Maine Project (Banner and Hayes, 1996). Finfish research and monitoring by NH Fish and Game, Normandeau Associates the University of New Hampshire continues today, and provides updated information on finfish abundance. The status and trends of finfish species selected for their commercial, recreational and ecological importance are described below.

3.2.1 SELECTED SPECIES

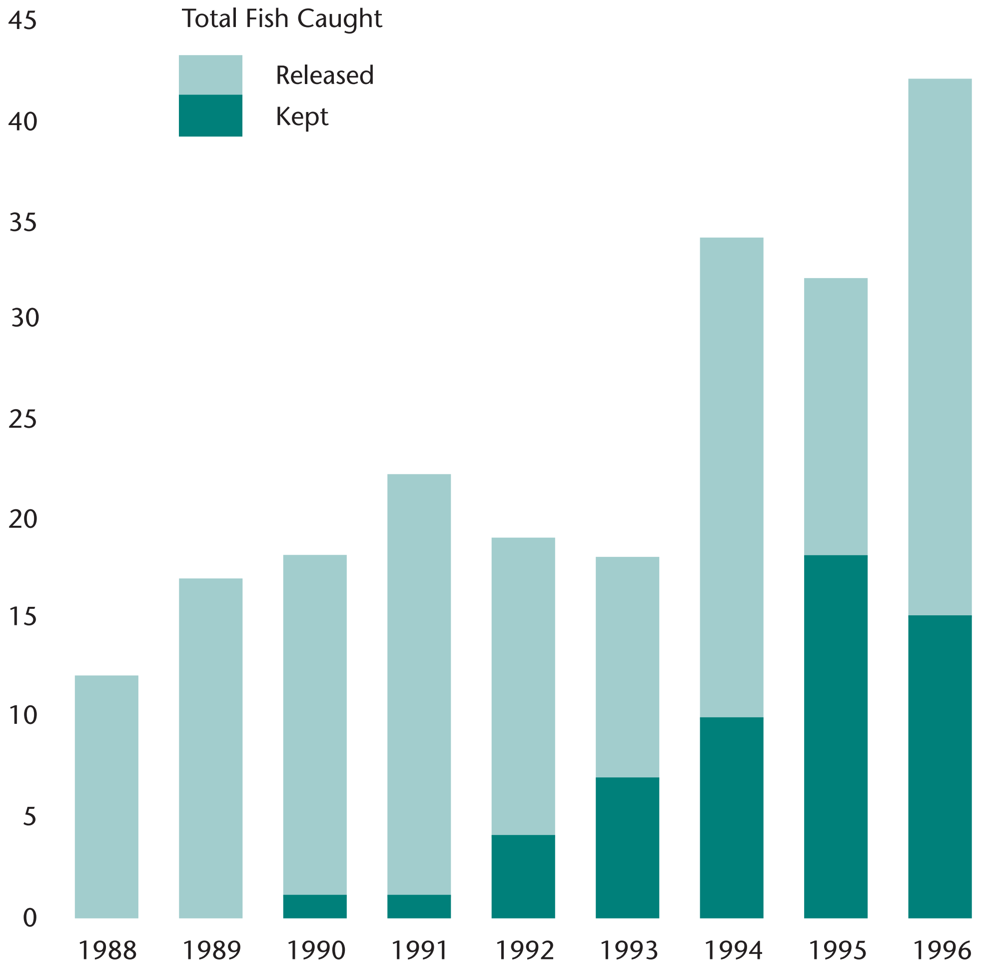
3.2.1.1 Striped Bass (*Morone saxatilis*)

As a result of the region-wide moratorium and subsequent harvest restrictions on striped bass in the 1980's and 1990's, New Hampshire waters have experienced a tremendous increase in the seasonal occurrence of this species. Striped bass abundance has increased steadily since 1988. Though the data presented in Figure 3.10 are based on NH Fish and Game creel surveys and the size frequency of the fish are not noted, there is general agreement among biologists and anglers that fish of all sizes have increased in abundance. Fish begin to arrive in mid to late May and remain in the estuary until October. It is not known if the same fish stay for the entire period or of there is a continual immigration and emigration of individuals during this period. Catches of fish in the winter and early spring indicate that some fish may overwinter in the Great Bay Estuary. Catches of legal (> 32") and undersized fish tagged by the U.S. Fish and Wildlife

Catch per trip of striped bass and winter flounder. Based on survey information. **FIGURE 3.10**



Striped bass caught in New Hampshire with U.S. Fish and Wildlife Service tags: 1988-96. **FIGURE 3.11**



Service have shown the same increase since 1988 (Figure 3.11).

Detailed information on striped bass population status and trends for Hampton Harbor is not available, though some of the data in Figures 3.5 and 3.6 would include fish captured in or near Hampton Harbor.

3.2.1.2 Winter Flounder *(Pleuronectes americanus)*

The recreational CPUE of winter flounder in Great Bay declined from 1988 to 1996, although CPUE was higher in 1995 and 1996 than in 1994 (Figure 3.10). Similar declines in abundance have been observed in Hampton Harbor. Larger individuals of this species are not year round estuarine residents and undertake regular migrations out of the estuary in the fall and return in the spring. Juvenile fish can be found in the estuary in all months, though their abundance is greatest from May through September. Winter flounder are subjected to very high fishing pressure in the nearshore (>3, <25 miles) and offshore (>25 mi) waters and the commercial CPUE in the Gulf of Maine has declined dramatically since 1982, after an increase from 1974 to 1982 (NOAA 1992). Studies by Armstrong (1995) and Langan (1994, 1996) found that juvenile winter flounder are abundant in the estuary in spring and summer, and forage in many different habitats. There is no clear preference for any one habitat and they can be found in the intertidal zone at high tide as well as in channel bottom in deeper areas of Great Bay. Using an otter trawl Armstrong (1995) averaged eight winter flounder per 10 minute tow in mid Great Bay from 1989 to 1992. Langan (1996), using the same type of fishing gear in the same location averaged 7.9 flounder per 10 minute tow in 1996. The size frequency distribution was similar for the two studies. Fish were collected in September, 1991 (Johnston et al., 1993) and in the spring of 1993 (Langan 1994) in the lower estuary as part of the Ecological Risk Assessment for the Portsmouth Naval Shipyard. In 1991, a series of five minutes tows yielded from 0 to 11 winter flounder per five minute tow. Highest densities were found in the Clark Island embayment and near Fishing Island. Mean length frequency varied by station, ranging from < 100 mm to nearly 300 mm. Trawls and seine hauls in 1993 at similar stations yielded up to fifty small flounder per seine haul in shallow water near Fishing island, the Kittery back channel, Clark Island embayment and the Police Dock area of Seavey Island. The mean size of fish captured in seine hauls was 57 mm. Larger fish were captured with an otter trawl in the back channel and Clark Island Embayment. A total of 48 fish were captured in 10 five minute tows, with a mean size of 366 mm.

Though juvenile fish appear to be abundant in the estuary, the recreational angler CPUE has declined in recent years. This is no doubt attributable to stock depletion from heavy commercial harvest pressure in the Gulf of Maine.

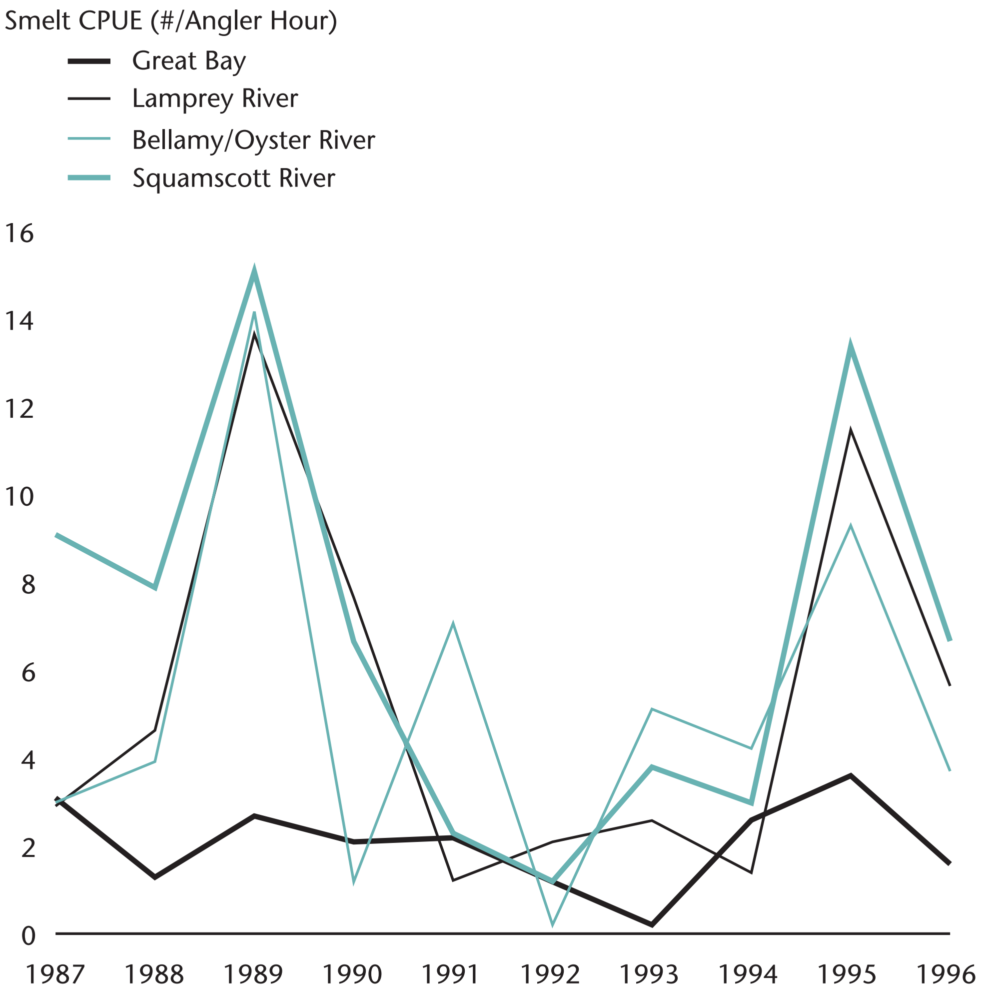
Catches of winter flounder at three stations in the Hampton/Seabrook Estuary have declined since 1980, though they have remained somewhat stable since 1987. The reason for the decline is attributable to overexploitation by commercial fishing in the Gulf of Maine (NAI, 1996)

3.2.1.3 Rainbow Smelt *(Osmerus mordax)*

The rainbow smelt is a common species in the Great Bay Estuary and is fished through the ice by commercial and recreational fishermen in the winter. They are an anadromous species that enter the estuary in fall and winter and ascend the tidal rivers in the Great Bay Estuary after ice-out to spawn. Based on angler CPUE, the abundance of smelt has been highly variable from 1987 to 1996 (Figure 3.12). CPUE reached a low point in 1992 and increased from 1993-1996. Average smelt egg deposition measured in the upper tidal reaches of the rivers from 1979 through 1996 has also been highly variable. Predation by striped bass may affect smelt populations.

Rainbow smelt abundance has been monitored by seine hauls at three sites in

Smelt CPUE by area (number caught per angler hour): 1987-1996. **FIGURE 3.12**



Hampton Harbor. Though abundance has been variable for the 19 year period (1976-1995), there is no discernible trend. The greatest abundances was measured in 1990, 1979, 1984, 1993 and 1994, and lowest abundances in 1978, 1980, 1992 and 1995.

3.2.1.4 River Herring: Alewife *(Alosa pseudoharengus)* and Blueback *(Alosa aestovalis)*

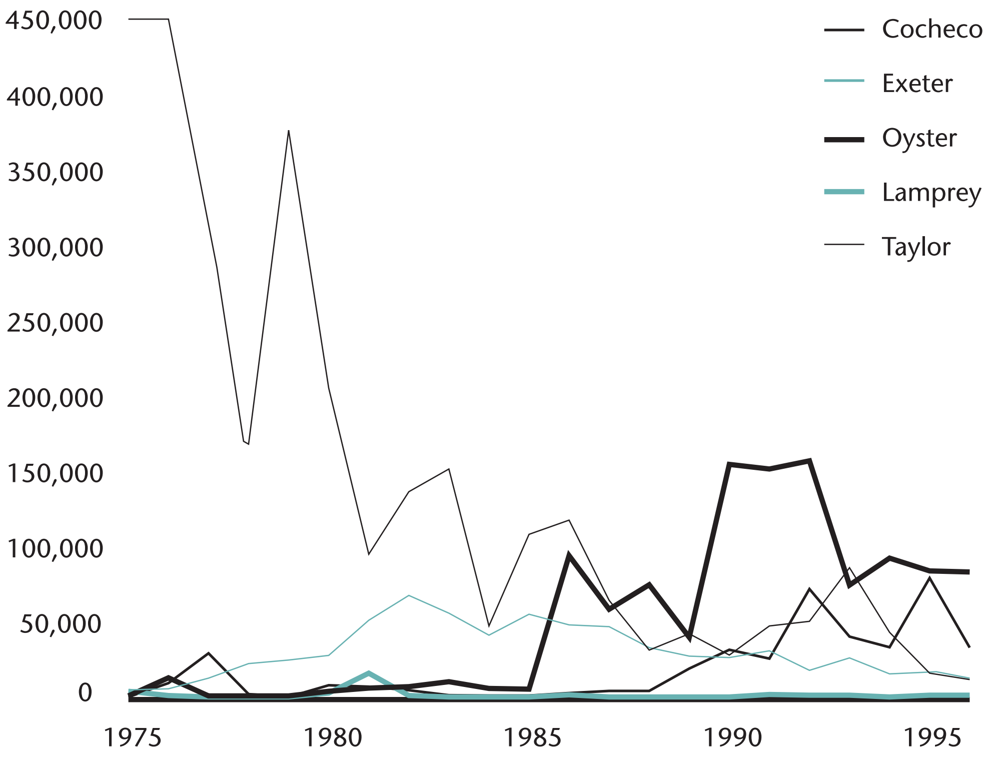
River herring (two species) are anadromous fish that migrate into the Great Bay Estuary in the spring and ascend the bay's tributaries to spawn. Though dams prevented these fish from reaching the freshwater portions of the rivers for many years, the construction of fishways in the 1970s has enabled passage of the fish to freshwater.

The NH Fish and Game has monitored spring returns of river herring at fishways in the Cocheco, Exeter, Lamprey, Oyster and Taylor (Hampton Harbor) rivers since 1975. Returns to the Exeter, Lamprey and Taylor rivers show a decline in numbers, while the Cocheco and Oyster rivers show an increase (Figure 3.13). The most dramatic decline has been in the Taylor River. The reason for the declines in some rivers is unknown, though predation by striped bass and changes in water flow may be factors. This species is also fished commercially for bait by offshore and inshore gillnetters. Records for catches by holders of inland netters permits are available.

3.2.1.5 American Shad *(Alosa sapidissima)*

Spawning adult American shad have been stocked from 1980 to 1995 in the Lamprey and Exeter rivers, and from 1980-1988 in the Cocheco and Lamprey

FIGURE 3.13 *River herring returns in Seacoast rivers: 1975-1996.*



rivers. Numbers stocked in the Exeter River increased each year since 1980, however this has not been reflected in the number of returning fish (Figure 3.14). A large number of fish returned to the Lamprey River in 1988, however few have returned since. The best ratio of returning to stocked fish has been realized for the Cocheco River, where the fewest adult fish were stocked. It may be possible that returning shad are intercepted by commercial gillnetters in the Gulf of Maine. Though the flesh is generally not consumed, the roe are considered a delicacy. The springtime harvest of shad in local offshore waters may be affecting the returns.

3.2.1.6 Atlantic Silversides *(Menidia menidia)*

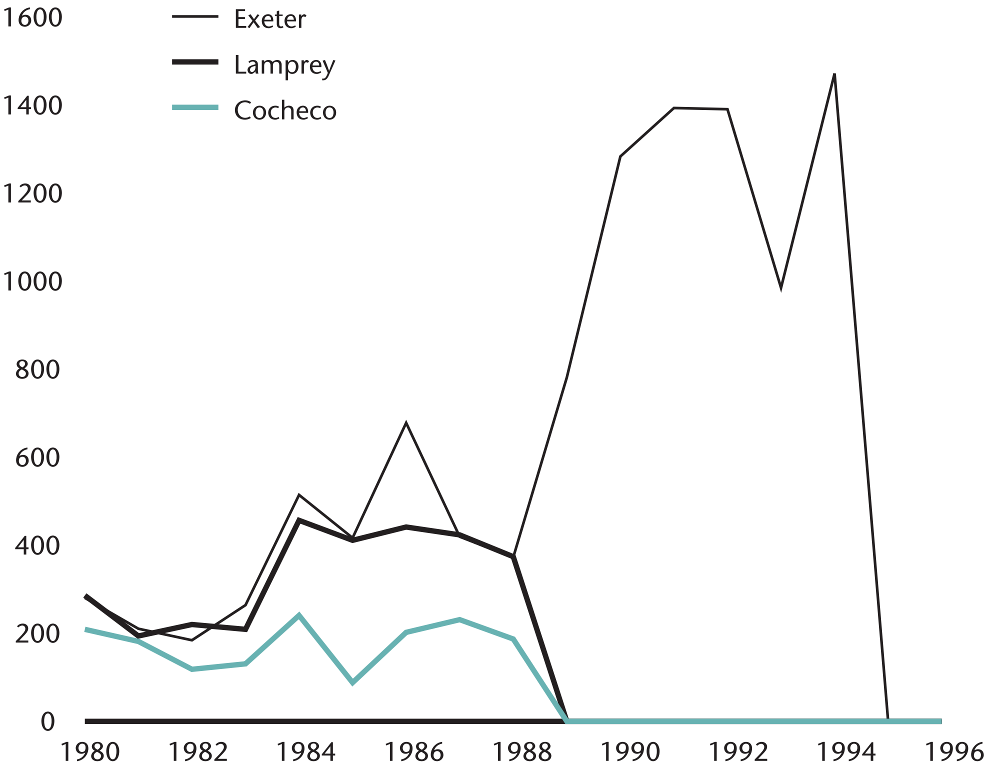
Silversides are a small, short-lived, and highly abundant estuarine species that are found in both Great Bay and Hampton Harbor. They generally inhabit shallow waters and are an important prey species for larger predatory fish. In the 1980-81 Fish and Game surveys (Nelson, 1982), they were the most abundant fish species captured in shallow waters and often represented >50% of the total catch. Young striped bass (12-24") have been observed to feed heavily on silversides in the Great Bay Estuary. The abundance of silversides has not been moni- tored in recent years, therefore it is not possible to determine trends in abundance.

The abundance of Atlantic silversides has been monitored by seining at three stations in Hampton Harbor from 1976 to 1995, though the years 1984-1987 were not sampled (NAI, 1996). A decline in abundance beginning in 1982 from the peak abundances during the period 1976-1981 was observed. Since 1982, the population has shown some interannual variation, but appears to have changed little to the present (Figure 3.15).

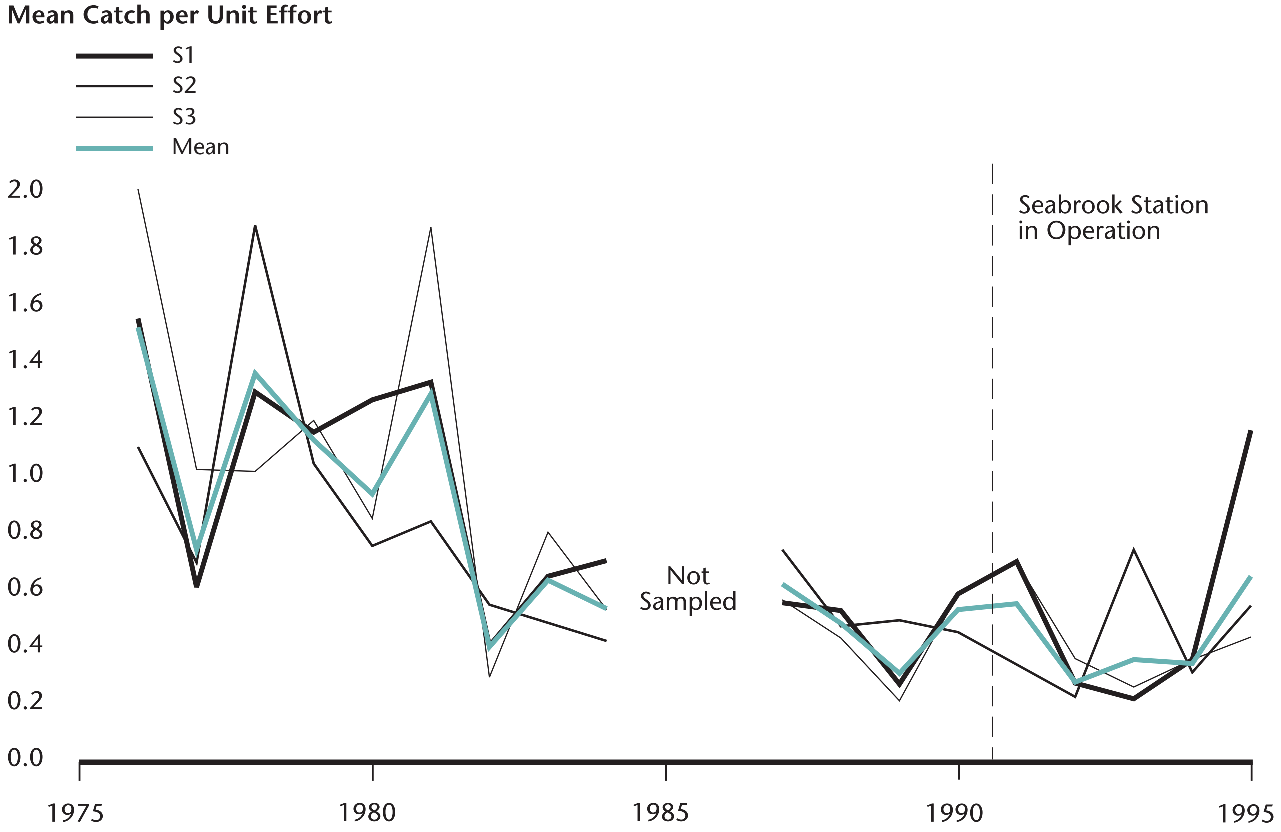
3.2.1.7 Atlantic Salmon *(Salmo salar)*

Although once abundant, the anadromous Atlantic salmon is uncommon in coastal New Hampshire, except as a stocked species. Overexploitation, the destruction of spawning grounds by sawdust and sediments in the 1800s, and

Number of spawning adult American shad stocked in the coastal rivers of New Hampshire: 1980-1996. **FIGURE 3.14**



Annual geometric mean catch of Atlantic silversides per unit effort in Hampton Harbor in seine samples (number per haul) for three stations and the combined mean of all stations: 1976-1995. **FIGURE 3.15**



dam construction resulted in the cessation of any natural runs of Atlantic salmon. The decline in Atlantic salmon populations is regional rather than local, and only a few native spawning runs remain in some Maine rivers. Atlantic salmon alevins have been stocked in tributaries to Great Bay since 1989, and some adults have been stocked in recent years. However the success of the program is yet to be determined.

3.2.2 Fish Kills

In the past several years three incidents of fish kills have been reported in the Great Bay Estuary, all involving alewives (*Alosa pseudoharengus*). In 1993, a school of alewives ascended a temporary spillway created by a pond draw down from the Exeter Water Works. The fish ascended the spillway to the pond from which there was no means of escape. The fish depleted the oxygen in the pool and 375-450 fish died as a result. Mr. Virgil Harris of the Exeter Water Department reported that similar incidents have occurred over the past twelve years due to pond draw downs. The NH Fish and Game Department recommended altering the draw down schedule to avoid subsequent alewife strandings.

The second incident occurred in the fall of 1995 when a private citizen reported approximately 100 dead alewives near Bay Ridge Road in Greenland. The cause of death was not identified, however, it was speculated that a short term stress from a drop in salinity caused by high freshwater inflow during the period or an isolated low dissolved oxygen condition caused the fish kill.

In October of 1997, nearly 2,400 juvenile alewives which were migrating from fresh to tidal waters were killed over a two day period by physical trauma caused by an hydroelectric turbine at the Cocheco River dam in downtown Dover. New Hampshire Fish and Game personnel reported that the mechanism that allows the fish to bypass the turbine was not operating properly. Corrective actions were initiated.

3.3.1 STATUS AND TRENDS OF SALT MARSH

Salt marshes are specialized habitats characterized by emergent vascular plants that extend within the intertidal zone from approximately mid tide height to just above the elevation of the normal spring tide line. The total area of tidal marshes within the entire state has been estimated at 7,500 acres in 1974 (3,040 ha; Breeding et al., 1974) and at 6,200 acres in 1994 (2,500 ha; USDA, 1994). The difference may not indicate an actual decline, since no significant losses in marsh acreage have been documented in ten years of 305b reports issued by NH DES. The ecology of salt marshes of the Great Bay Estuary has been reviewed by Short and Mathieson (1992), and plant species occurring in the salt marshes of New Hampshire have been listed in this (Appendix J) and earlier reports (NAI, 1988; Ward et al., 1993). The most common plant associated with the low marsh in New Hampshire is the tall form of *Spartina alterniflora* (salt marsh cordgrass); the most common high marsh species include *Spartina patens* (salt meadow cordgrass), the short form of *Spartina alterniflora, Distichlis spicata* (spike grass) and *Juncus gerardii* (black grass) (USDA, 1994). In addition, there is a list of all plant species that occur in New Hampshire wetlands (Reed, 1988).

3.3.1.1 Distribution, Standing Crop and Productivity

Salt marshes were identified and mapped for the National Wetlands Inventory (Tiner, 1984) and more recently in two studies that covered the tidal marshes of the state (NAI, 1988, Ward et al., 1993). No comparison of the inventories has been made, but the more recent work is more accurate and differences, if determined, may not actually reflect changes in salt marsh distribution. The tidal marshes within the Great Bay Estuary, including all tributaries, were mapped utilizing color infrared transparencies and extensive ground truth work (Ward et al., 1993). Based on this work, the location and areas of salt marshes and algal beds in the Great Bay Estuary were calculated by Weiss (1993). A total of 2,230 acres (9.025 km2) of tidal marsh are located in the Great Bay Estuary, with the lower Piscataqua River, the Squamscott River, and the Great Bay having the most extensive tidal marsh area. Coupled with the National Wetlands Inventory map, the Great Bay data provided the basis for another salt marsh map produced by USF&WS (Figure 3.16; Banner and Hayes, 1996).

Annual aboveground productivity of smooth cordgrass (*Spartina alterniflora*) was estimated by Chock (1975) to be approximately 604 g dry weight/m2/yr for a salt marsh at Cedar Point (Little Bay). No estimates of total annual productivity (including belowground production) have been reported for salt marshes in New Hampshire. However, some standing crop data, usually sampled during peak aerial biomass or at the end of the growing season, are available. Standing crop does not include the leaves and shoots produced that were eaten, dead, or otherwise removed over the course of the year. Peak standing crop measurements for high marshes dominated by salt meadow hay (*Spartina patens*) as well as low marsh areas of *S. alterniflora* are found in Table 3.5 and in the following references (Nelson, 1981; Short, 1987; Short and Mathieson, 1992; Burdick, 1992; Burdick and Dionne, 1994). In an examination of the relationship between above and belowground standing crop, Gross et al. (1991) report values for a high marsh dominated by short form *S. alterniflora* in Rye of 527 and 754 g dry wt/m2 of total above ground and live below ground standing crop, respectively.

Although often ignored, salt marshes can contain a significant macroalgal component. This is especially true of low marshes dominated by *S. alterniflora* occurring near extensive intertidal macroalgal beds (e.g., Little Harbor, Cutts Cove) where they may become

TABLE 3.5 *Standing crop of peak aboveground plant biomass in New Hampshire salt marshes (biomass = g dry wt/m²).*

Site [Years of data]	Habitat (n/yr)	*S. alterniflora*	*S. patens*	Other*	Algae	Total
Little Harbour[1] [1]	Low marsh (6)	512	0	0	1020	1532
	High Marsh (6)	28	614	12	3	657
North Mill Pond[2] [3]	Low marsh (8)	683	**	14	9	70
Cutts Cove[2] [3]	Low marsh (16)	322	**	35	818	117
Great Bay NERR[3] [1]	High marsh (5)	56	311	22	0	38
Rye Harbor[3] [1]	High marsh (5)	50	293	12	0	35

*Other vascular plants, including grasses and fortes, e.g., *Salicornia europaea.*

** *Spartina patens* was the predominant species in this category, but was lumped with Other.

1 = Burdick 1994, 2 = Burdick and Short 1997, 3 = Burdick, unpublished data

heavily colonized by fucoid algae with distinctive growth forms, called marsh ecads (*Ascophyllum nodosum* variety *scorpioides* and *Fucus vesiculosus* variety *spiralis*; Norton and Mathieson, 1983). In a study of seasonal trends in the standing crop of *S. alterniflora*, the associated ecads of fucoid algae were also assessed by Chock (1975), who concluded they contributed greatly to marsh productivity. A later study of eight coastal salt marshes near the mouth of the Piscataqua River found fucoid biomass ranged from 100 to over 1300 g dry weight per m2 with the algae averaging almost 60% of the total plant biomass found in the low marshes (Burdick, 1994).

3.3.1.2 Habitat Impacts and Losses

Threats to salt marshes in New Hampshire have been reviewed and summarized (USDA, 1994). Specific threats and impacts to marshes were categorized by human activities that are considered to be important. Currently, marine development poses the greatest threat to salt marshes through dredging, dock construction, shoreline development along the upper marsh edge, and development across marshes that result in tidal restrictions. Other potentially important impacts to marsh function include harvesting marsh resources and conflicting uses within these habitats.

Dredging Impacts and Harvesting Effects

Dredge and fill operations have altered marshes within all of the seacoast estuaries to some extent. Large areas of the Hampton-Seabrook marsh were dredged and filled for residential housing. Rye Harbor has been dredged on several occasions, and in 1941 and 1962 the spoil was placed on the salt marsh landward of the harbor. This transformed several acres of marsh into upland habitat and has negatively impacted over 10 additional acres. The ecological impacts at the sites of sediment dredging have not been assessed, but impacts to the marsh from disposal were reviewed by Burdick (1992). Elevating the surface and surrounding the area with earthen dikes severely reduced salt water flooding and increased fresh water flooding in the spring. These changes lowered soil salinity, led to the displacement of native marsh plants by *Phragmites*, *Typha* and upland plants, resulted in the formation of die-back areas and large pools of water, and caused a direct loss of fish habitat.

In addition to direct negative impacts, dredging may reduce sediment sources to marshes, leading to an inadequate sediment supply to support marsh maintenance and development. Dredging may also increase the wave energy environment, leading to increased ero-

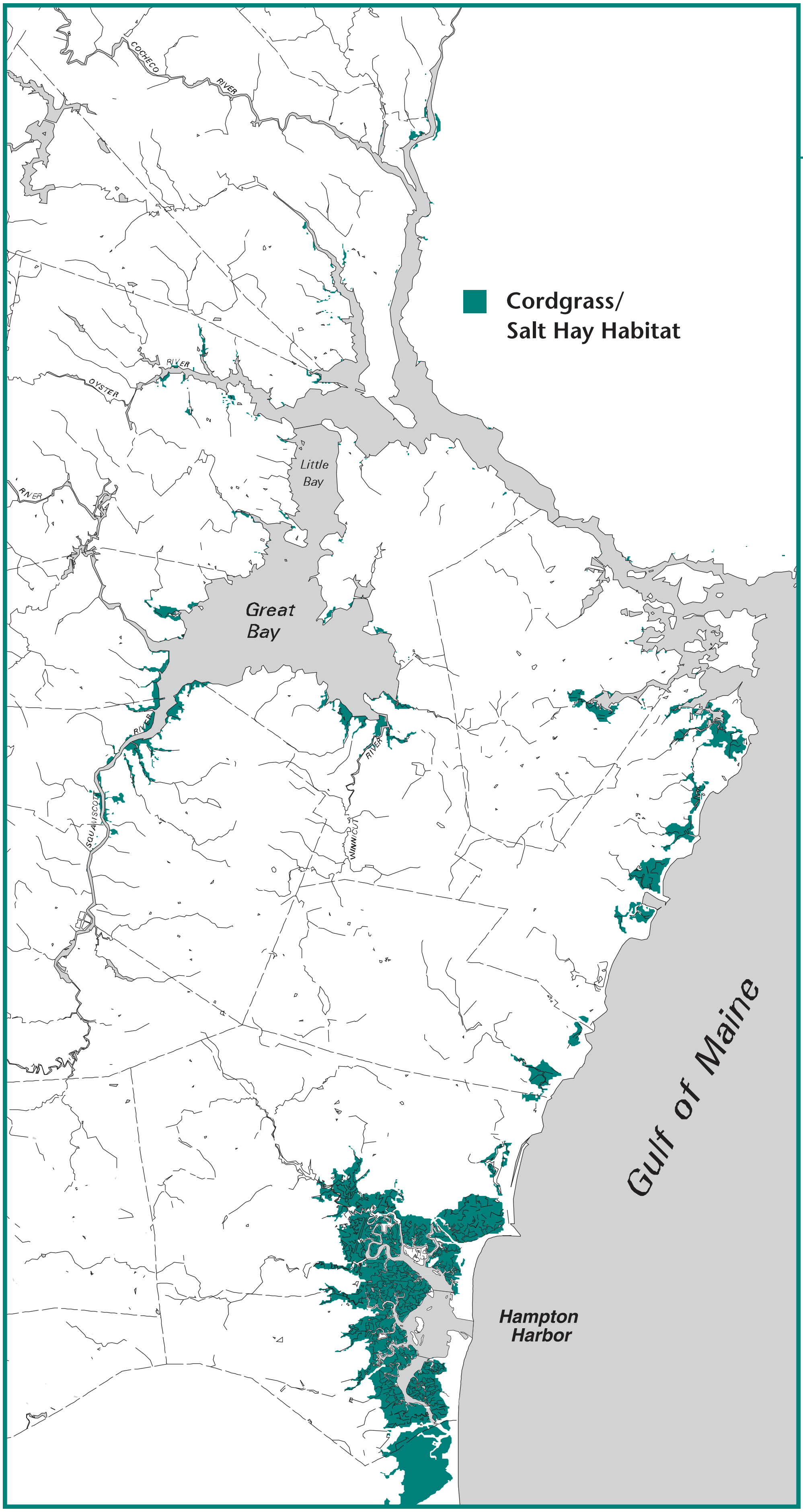


FIGURE 3.16

Habitat map for cordgrass/salt hay. From Banner and Hayes (1996).

sion at the seaward edge of marshes. On the other hand, increased sediment supply or a reduced wave environment from dredging may allow the expansion of a marsh at its seaward edge.

Although salt hay was harvested widely along the New Hampshire seacoast from the 17th to 20th centuries, the intensity of marsh management to improve yields and harvesting efficiency are poorly known (Breeding et al., 1974). Ditching to improve hay yields (not equivalent to mosquito ditching) was routine. Salt hay farming continues to this day and has experienced a small revival in northern Massachusetts, yet the impacts from salt hay farming on salt marsh ecosystems are unknown (Rozsa, 1995).

Impacts from Docks, Piers and Shoreline Development

Impacts from docks and piers on salt marshes have not been assessed in New Hampshire. Clearly, solid fill and crib structures built on marshes eliminates them and are discouraged, but open piers have also been shown to reduce productivity and viability of salt marshes in other New England States (Michael Ludwig, NMFS Milford, CT). The US ACOE has issued design guidelines for structures over marshes (height over sediment needs to be at least as great as width of the structure), but it is not clear whether such guidelines prevent degradation, nor have the dock impacts to marshes been assessed quantitatively and systematically.

Similar to docks, impacts from other forms of shoreline development are severe when structures are built upon and over marshes. However, structures placed at the landward edge of salt marshes can also have serious effects on marsh viability and maintaining these habitats in the near future (Pethick, 1983). Because sea level is rising, and marshes have traditionally migrated landward as well as built vertically to maintain themselves in the face of rising sea level (Redfield, 1965), increased local sea level is expected to be accompanied by landward migration of salt marshes. However, structures placed at the landward edge of salt marshes will prevent these habitats from migrating landward with local sea level rise (Pethick, 1983). Furthermore, the rate of sea level rise is expected to increase in New Hampshire from 1.2 to 7.5 mm/year. Structures that prevent marshes from migrating landward will result in marshes becoming narrow and lower in elevation. In time, waves reflecting from submerging marshes will erode the marsh peat and exacerbate local erosion and flooding problems (Smith et al., 1978).

Impacts from Tidal Restrictions

Tidal restrictions influencing estuarine circulation and other functions relating to water quality that have been caused by roads, railways, dikes and causeways have severe long-term impacts to salt marshes. Construction in the intertidal and subtidal areas of an estuary always influences circulation patterns to some extent (Miller and Valle-Levinson, 1996), but linear features built on or along salt marshes that restrict tidal flow have significant impacts (Marrone, 1990). Besides altering circulation, these structures reduce flooding by salt water and tend to retain fresh water (especially in the spring), and can ultimately result in a non-tidal freshwater marsh.

Restrictions to tidal flow in salt marshes lead to areal (if habitat becomes non-tidal) as well as functional losses. In New Hampshire, significant tidal restrictions have been fully documented (USDA, 1994) and there are indications that some marshes are deteriorating. Deterioration includes replacement of emergent salt marsh vegetation by open water, unvegetated flats, freshwater plant species or invasive species such as purple loosestrife and common reed. Marsh deterioration is a symptom of changes in local processes with the result that the marsh is unable to maintain itself. Besides reducing or even excluding fish access to their habitat (Burdick et al., 1997), tidal restrictions appear to lead to declines in productivity and habitat value for wildlife.

Impacts to water quality and soil chemistry from tidal restrictions are not well known, but serious negative impacts to water quality have been documented elsewhere (Portnoy, 1991). In New Hampshire, current knowledge is limited to soil and creek salinity, soil redox potential, soil moisture and soil organic matter (Short, 1984; Burdick, 1992; Burdick and Dionne, 1994; Ammann unpublished data; Burdick et al., 1997; unpublished data).

Salinity changes are the most obvious impacts, with restrictions generally leading to freshening of the marshes when compared to control marshes or the same marshes following restoration of tidal exchange (Table 3.6). Reductions in salt water flooding to restricted marshes allows for chemical and microbial oxidation of reduced soil constituents, leading to higher, more positive redox potentials, loss of soil organic matter, and lower pH (Burdick and Dionne, 1994). Furthermore, the ability of the marshes to remove suspended sediments from tidal waters is certainly curtailed by tidal restrictions, though these impacts from restrictions have not yet been quantified.

3.3.1.3 Habitat Change Analysis and Modeling

Large areas of salt marsh have been filled for residential and industrial development (Breeding et al., 1974) while other areas are deteriorating due to tidal restrictions commonly associated with roads. It is estimated that New Hampshire still has 50% of its 18th Century tidal wetlands and 90% of its 18th Century non-tidal wetlands (NHDES, 1996b). More recent data summarizing impacts of permitted projects and known violations on tidal and non-tidal wetlands are contained in the bi-annual 305(b) reports sent to Congress by NHDES. There has been very little net loss of tidal wetlands in the past 10 years (Table 3.7). The data indicate small losses have occurred in non-tidal wetland acreage statewide, although the most recent report states that "...there has been no measurable net loss of wetlands functional value" (NHDES, 1996b). Natural gains in wetlands through the activities of beaver as they dam creeks and flood forests is esti-

Soil salinity changes in salt marshes from hydrologic manipulations. **TABLE 3.6**

		Soil Salinity			
Estuary/Marsh name	**Type of Restriction**	Before Restriction	After Restriction	After Restoration	Reference marsh
Hampton Estuary					
Drakeside Rd Marsh[1]	Undersized Culvert	—	8.5	10.1	10.5
Rye Harbor					
Awcomin Marsh[2]	Diked dredge fill	—	6.5	21.6	24
Locke Road Marsh[3]	Undersized Culvert	—	16.4-27.0	NA	23.1
Great Bay Estuary					
Peverly Ponds[4] (GBNWR)	Causeway with Tidal Gate	—	NA	NA	
Sandy Point Marsh[1] (GBNERR)	Berm formed by debris	—	5.6	25.1	25.2
Mill Brook Marsh[5] (Stuart Farm)	Causeway with Tidal Gate	—	0.0	19.5	16.2

Approximately 50 other sites in New Hampshire are hydraulically restricted as determined by the NRCS (USDA 1994), but no data on soil chemistry at other sites is available at this time.

[1] Burdick, Unpublished data
[2] Burdick and Dionne, 1994
[3] Little, Unpublished data
[4] USF&W Service, Data unavailable at this time
[5] Burdick et al. 1997

TABLE 3.7 *Impacts of permitted projects and known violations on state-wide wetlands: 1988-1996. Data from NHDES (1996).*

	Tidal Wetlands (acres)		Non-tidal Wetlands (acres)	
Year	Impacted	Total	Impacted	Total
1987-88	0	7,500	25-50	95,000
1989-90	0	7,500	50	200,000
1991-92	0	7,500	150	192,500
1993-94	0	7,500	200-300	400,000-600,000
1995-96	0	7,500	150-250	400,000-600,000

mated to be in the tens of acres each year (NHDES, 1989a).

Specific restrictions causing deterioration of the salt marshes have been enumerated for the tidal wetlands of New Hampshire by the Natural Resource Conservation Service (USDA, 1994). They found 50 tidal restrictions in the state which encompass over 20% of the salt marsh area remaining in NH (1,300 out of 6,200 acres; USDA, 1994). The report shows that marshes deteriorating from tidal restrictions are more commonly found at the upland borders of large marsh systems (i.e., Hampton/Seabrook Estuary) and behind smaller barrier beach systems (i.e., Little River Marsh), but are spread throughout the state. As discussed previously, deterioration includes losses in salt marsh acreage as well as functional losses. Thus in contrast to the 305(b) reports (NHDES, 1996b), it appears that indirect losses of tidal wetland acreage as well as functions continue to occur. However, restoration of tidal exchange to some sites may be able to reverse some of these wetland losses (see restoration section).

Preliminary results of change analyses based on aerial photography of selected marshes in the tidal reaches of the Squamscott River indicated some increase in open water (salt pannes) in several marshes (Ward, in preparation).

The development and evolution of salt marshes in New Hampshire is thought to follow the widely held model developed in Massachusetts by Redfield in 1965, later verified by Keene (1980) in a Hampton marsh, and recently verified and modified for salt marshes in Maine by Kelley et al. (1995). Modern marshes began developing about 4,000 years ago when sea level rise slowed and low marshes became established on intertidal sediments. The low marshes expanded seaward and at the same time collected sediments to build vertically and become high marsh. The high marsh, in turn, expanded seaward following the expansion of low marsh and landward covering upland as sea level slowly continued to rise, resulting in the flat, high marsh habitat that is typical of New Hampshire salt marshes.

A conceptual model of the changes in marshes due to impacts from tidal restrictions has recently been proposed by Burdick et al. (1997), but estimation of rates within the model for simulating changes in tidally-restricted and restored marshes have not been made or verified. Furthermore, few of the marsh functions that are responsible for socially-esteemed values have been quantified. Increases in our understanding of habitat functions and change will support modeling and improve marsh management.

3.3.2 STATUS AND TRENDS OF MACROALGAE

3.3.2.1 Distribution, Standing Crop and Productivity

Macroalgal habitats are best characterized as those where seaweeds are found growing on rocky shorelines and into the subtidal zone to depths where the seaweeds, being light dependent, remain in the photic zone. Seaweeds also form important ecological components of salt marshes, seagrass beds, mudflats, channels, and artificial substrata such as pilings and rip-rap, but the focus in this report is on the rocky shorelines and channels dominated by seaweeds. There are a total of 219 seaweed species known from New Hampshire (Appendix J; Mathieson and Hehre, 1986; Mathieson and Penniman, 1991). In these reports, large-scale spatial and seasonal distributions are reported for many algal species and the factors that control the distributions are discussed. For example, some species were found to occur in Great Bay but not on the open Atlantic Ocean. Distribution maps showing species occurrences at specific sites were compiled from these earlier works by Banner and Hayes (1996) for knotted wrack (*Ascophyllum nodosum*), Irish moss (*Chondrus crispus*) and tufted red weed (*Macrocarpus stellatus*) (Figures 3.17; Banner and Hayes, 1996). At specific sites, changes in algal communities have been documented (e.g., Dover Point by Reynolds and Mathieson, 1975), and the potential for revisiting other previously sampled sites is very good. However, long term changes in algal distributions over time are not currently available.

A detailed study of the occurrence and standing crop of algal species along the shores of the Oyster River and its tributaries was conducted in 1993 (Mathieson, unpublished data). *Enteromorpha prolifera, Ulva lactuca, Ascophyllum nodosum* and *Fucus vesiculosus* were common to virtually all areas. The occurrance of *Polysiphonia harveyi, Ulva oxysperma, Chondrus crispus, Gracilaria tikvahiae* and unidentified cyanobacteria were also measured in a few tributaries. The location of the algae with respect to elevation within the intertidal zone was also noted.

Standing crop and growth estimates have been made for a few species of red and brown algae and these reports characterize the habitats as well (Mathieson and Burns 1975; Chock and Mathieson 1976; Mathieson et al. 1976; Josselyn and Mathieson, 1978). In 1993, a minor survey of algal species that estimated standing crop by species was conducted by Mathieson at Adams Point and reported in Langan and Jones (1993). Paired replicate clip plots at top, middle, and lower intertidal zones showed the dominance of the brown fucoid algae, *Ascophyllum nodosum*, with important contributions in the middle and lower zones by both red and green species.

3.3.2.2 Habitat Impacts and Losses

Channel work in the lower Piscataqua River has occurred on many occasions, and included blasting ledges, dredging in the river, as well as in Little Harbor at the turn of the century. Few studies are available that document impacts to intertidal and subtidal plant habitats, and impacts to benthic communities have been regarded as minor in the past (i.e., Brown and Fleming 1989). Dredging not only directly removes algal habitat, it reduces algal production and survival because suspended sediments from the dredging attenuates light needed for growth. Furthermore, the hard clean surfaces needed as sporelings attachment points become unsuitable for macroalgal recruitment after dredging activities cover them with fine sediments.

Shoreline development typically removes or buries algal beds in the intertidal zone. The extent of these impacts along our coasts has not been determined. However, placement of hard surfaces at these sites can often lead to new algal beds if algae can colonize the new surfaces (e.g., bridge abutments, rip-rap walls).

Algae has been harvested for various uses in New England, but such harvest in New Hampshire estuaries is poorly known and probably minimal. Algin and carrageenan are extracted from kelps, knotted wrack (*Ascophyllum nodosum*) and Irish moss (*Chondrus crispus*) and are used as additives in the food industry. Few algae are consumed directly in this country, but dulse (*Rhodymenia palmata*) and nori (*Porphyra sp.*) are harvested for consumption. Knotted wrack is also used for packing material to preserve live shellfish and worms. Impacts to the algal resources from experimental harvesting have been assessed for the red algae Irish moss (Mathieson and

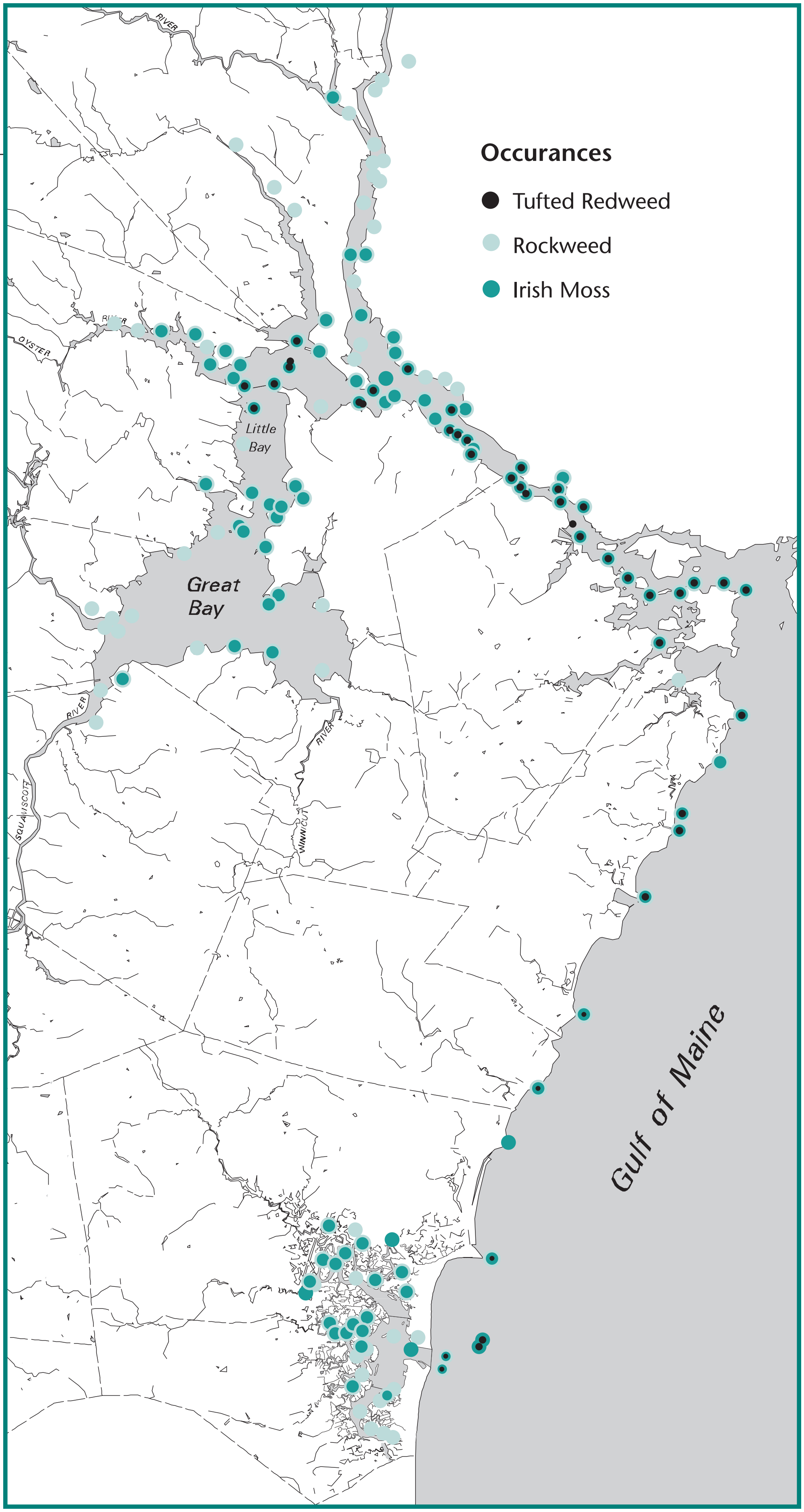


FIGURE 3.17

Habitat map for rockweed, Irish moss and tufted redweed. From Banner and Hayes (1996).

Burns 1975). They found that plants could recover in a year after carefully controlled harvesting, but winter harvesting had greater impacts and overharvesting could cause demise of the algal beds.

3.3.2.3 Habitat Change Analysis and Modeling

What little is known about habitat change regarding the macroalgal beds of New Hampshire estuaries includes studies on the destruction of estuarine and near shore populations of kelp by a small species of estuarine snail, *Lacuna vincta* (Fralick et al., 1974). The standing crop and assemblage of algal species may be used as an indicator of nutrient status of specific sections of estuaries. Nutrient poor areas support slow-growing long-lived species whereas over-enriched areas become less diverse and dominated by opportunistic species indicative of poor habitat health. Although no synthesis currently exists, analysis of existing data and revisiting sites sampled 20 years ago could provide interesting information on the status and trends of estuarine health in New Hampshire.

The use of models to describe changes in algal beds has received little attention. In 1978, Josselyn and Mathieson (1978) created a model to describe seasonal changes in living biomass, dead biomass found on the strand line as wrack, and decomposition of wrack for fucoid algae and eelgrass within Great and Little Bays.

3.3.3 STATUS AND TRENDS OF EELGRASS BEDS

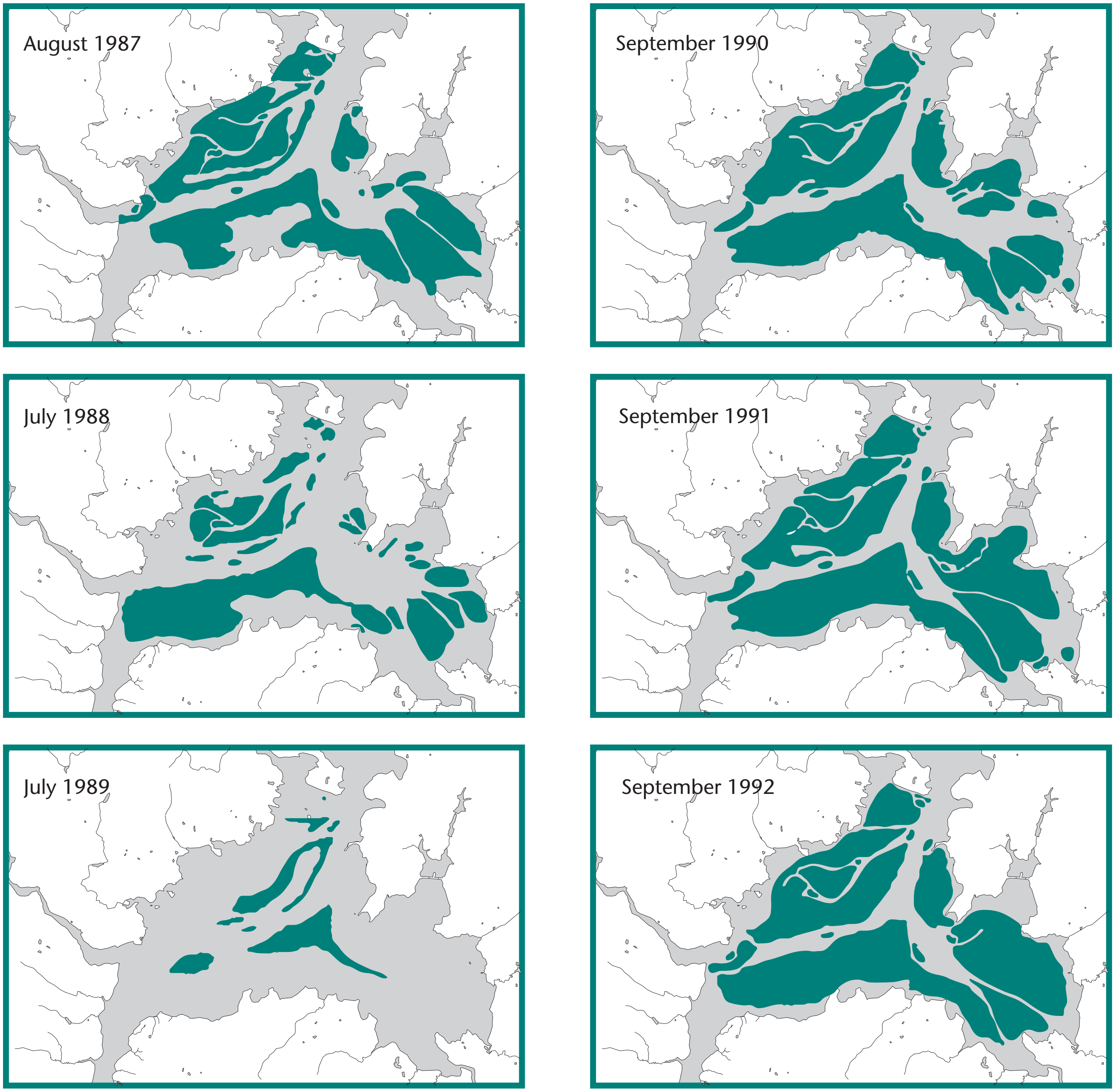
Eelgrass habitat provides the largest spatial distribution of any habitat within Great Bay (Short et al., 1992; Short and Mathieson, 1992). Eelgrass beds in the estuary occur as large meadows and small contiguous beds forming intertidal and subtidal seagrass habitats. Eelgrass habitat functions as breeding and nursery grounds for the reproduction of finfish, shellfish, and other invertebrates. Eelgrass meadows serve as a feeding area for many fish, invertebrates and birds. Additionally, eelgrass may act as a filter of nutrients, suspended sediments, and contaminants to the waters of the estuary.

3.3.3.1 Distribution, Standing Crop and Productivity

Distribution maps of eelgrass are available for most of the Great Bay Estuary for the mid-1980s (Short et al., 1986) for Great and Little bays through the 1990s (Short, unpublished) and for the mouth of Little Harbor in 1996 (Short, 1996). Most eelgrass habitat in New Hampshire has been surveyed within the last six years; however, a comprehensive map of these findings has not been compiled. A GIS layer of eelgrass habitat has recently been completed by the U.S. Fish and Wildlife Gulf of Maine Project (Banner and Hayes, 1996).

Eelgrass in the Great Bay Estuary has experienced fairly dramatic changes in population distribution and total productivity over the last two decades. Spatial and temporal changes in eelgrass populations prior to 1991 have been reported in numerous publications (Short et al., 1986; Short and Mathieson, 1992; Short et al., 1992; Short et al., 1993; Burdick and Short, 1995) and these data are shown in Figure 3.18. The Great Bay Estuary suffered from a decline in eelgrass populations during the 1980s resulting in a low point of eelgrass distribution in 1989. These decreases in population represent dramatic losses of eelgrass habitat as a result of wasting disease (Short and Mathieson, 1992). Similar problems and trends in eelgrass populations have been reported for the neighboring Annisquam Estuary at Cape Ann in Massachusetts (Dexter, 1985). The period of eelgrass decline in Great Bay was followed by rapid recovery where extensive seed production led to extensive revegetation within Great Bay proper. This recovery can be seen by comparing Figures 3.19 and 3.20. In contrast, some beds in Little Bay and along the Piscataqua River have not reappeared and efforts are underway to protect remaining beds from development and restore significant beds to these portions of the estuary.

FIGURE 3.18 *Time series of eelgrass distribution in Great Bay.*



Standing crop and other population characteristics of the eelgrass population near the red nun buoy at the mouth of Great Bay were made in 1987, 1989 and 1993 (Table 3.8; Langan and Jones, 1993). Both shoot and total (shoots, roots and rhizomes) standing crop data show increases between 1987 and 1993, the period when eelgrass was declining and then recovering from episodes of wasting disease. The Wasting Disease Index was measured for each year and showed the greatest levels of disease occurred in 1989, the year that most of the beds in Great Bay had succumbed to the disease (Short et al., 1993).

3.3.3.2 Habitat Impacts and Losses

Dredging Impacts on Benthic Habitats and Sediments

As previously mentioned, creation and maintenance of navigable channels in the Great Bay Estuary has occurred for

Population characteristics of eelgrass in the small beds at the mouth of Great Bay (near the red nun buoy): August 1987, 1989, 1993. **TABLE 3.8**

Year	Shoot Density #/m²	Rhizome Length cm/m²	Eelgrass Biomass grams dry wt./m² Shoots	R&R	Total	Algal Biomass g/m²	Morphology Length cm	Width mm	Leaves #/shoot	Wasting Disease Index %
1987	427		197	66	263		114	5.0	4.7	16.6
1989	504		249	128	377		125	5.2	4.8	43.5
1993	426	139	395	59	454	25	145	4.9	3.8	10.0

many years, though little information exists that describes impacts to eelgrass beds. In 1992, the threat to an eelgrass bed from dredging and constructing the new Port of New Hampshire pier facility was recognized as a serious ecological impact which required habitat mitigation. As a result, seven acres of eelgrass were transplanted into various sites within the estuary. A proposed dredging at the mouth of Little Harbor to deepen mooring areas may impact some of the twenty five acres of eelgrass beds.

Impacts of Boating, Docks, and Piers

In general, commercial boat operators have had little impact on submerged hazards, including submerged vegetation. However, recreational boaters are often unfamiliar with such hazards and have often been observed entangled in eelgrass or grounded on the shallow flats of eelgrass beds in Great Bay (Burdick, personal observation). Further evidence of boat damage in Great Bay includes boat scarring from propellers and damage from hulls during groundings, but the damage appears to be minor and the beds have rapidly revegetated (Burdick, personal observation). Continued recreational boat use in the estuary will pose continued risks to eelgrass meadows.

Because docks and piers cross shallow subtidal habitats to secure vessels in deeper waters, it is likely that these structures have crossed and impacted eelgrass beds and other habitats (Burdick and Short, 1995). However, no record remains for whatever impacts have occurred over the past three centuries from these structures. Currently, few docks appear to influence eelgrass beds. The large commercial dock being built for the expansion of the Port of New Hampshire will have significant impacts (see habitat mitigation section below) that is being assessed.

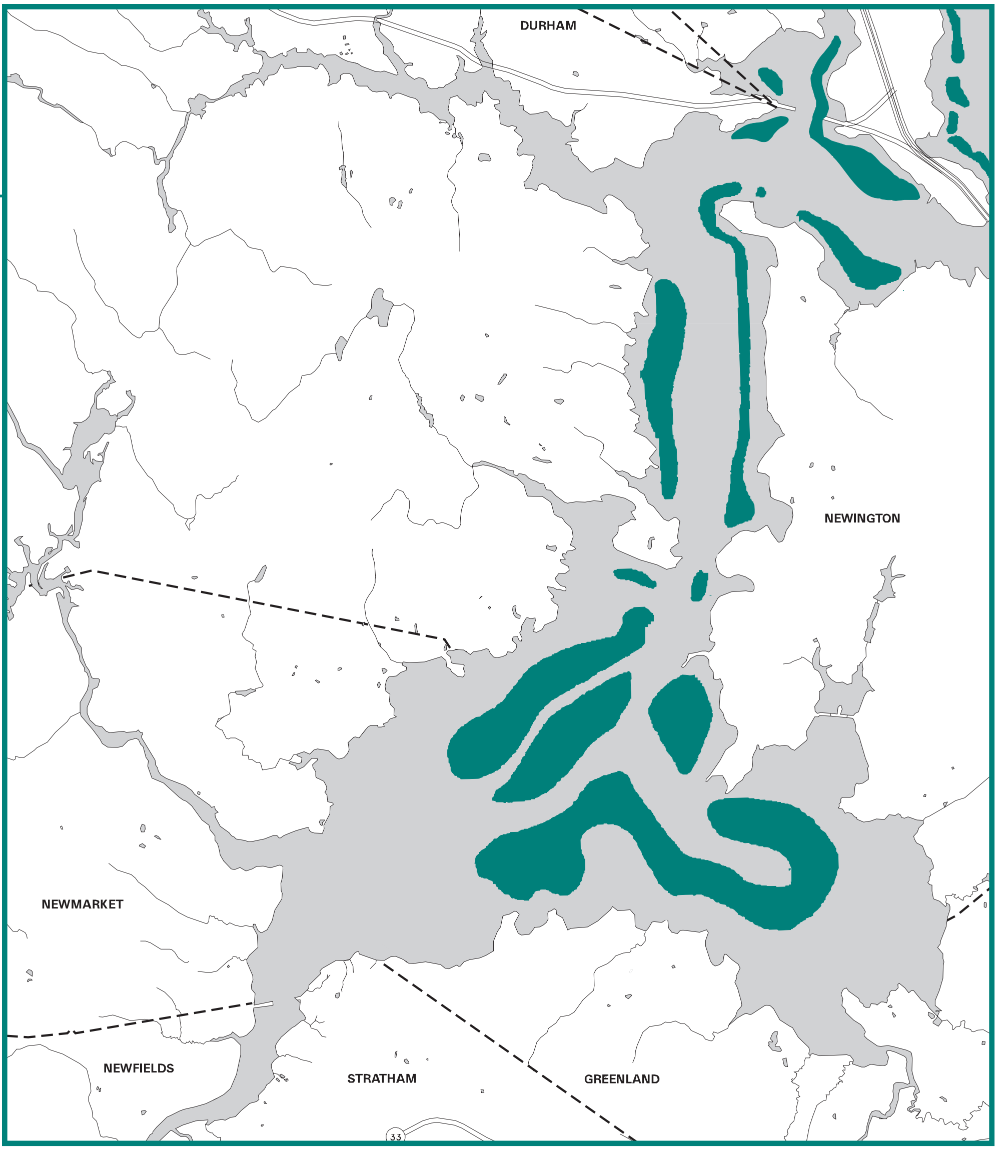
Impacts from Shoreline Development and Harvesting

Human development of the shoreline around Portsmouth Harbor, including the Portsmouth Naval Shipyard, has filled many acres of shallow estuarine habitat that was at least partly occupied by seagrass beds and salt marshes. Specific instances include the expansion of the Shipyard in the 20th century which connected several islands and most recently included filling marshes and mudflats for the Jamaica Island Landfill in the 1970s (Johnston et al., 1994). Similarly, development of transportation and marine facilities around Noble's Island resulted in filling of North Mill Pond and Cutts Cove. Bridges and causeways across river channels, bays and inlets as well as salt marshes have also probably led to the destruction of many seagrass beds and marshes along the seacoast. Shoreline development for marine related uses continues to impact marshes eelgrass beds today. For example, potential impacts from the Port of New Hampshire expansion are outlined in the mitigation plan (Short et al., 1992), which identifies specific eelgrass beds, mud flats and salt marshes as three estuarine habitats that may be impacted from port expansion (see habitat mitigation section below).

Anthropogenic inputs of contaminants to the estuary resulting from devel-

FIGURE 3.19

Eelgrass distribution in Great Bay and Little Bay: 1981.



opment within the watershed may have significant indirect impacts on eelgrass habitat. Potential impacts were outlined for Great Bay Estuary (Short, 1992), and have been documented in other New England estuaries (Short et al., 1995; Short and Burdick, 1996). They include eelgrass loss from nutrient over-enrichment and increased sediment input. The primary cause of these eelgrass losses is reduction in water clarity, a result of human impacts to the estuarine watershed. Anthropogenic impacts to eelgrass habitat within the Great Bay Estuary have not been documented.

Seagrass has been harvested in the northeast for building insulation, upholstery stuffing, but is probably most widely used for garden mulch and fertilizer. The scale of such activities in New Hampshire do not appear to have been large, and although their potential impacts are unknown, they are likely minor.

3.3.3.3 Habitat Change Analysis and Modeling

The spatial distribution of eelgrass habitat in Great Bay has been modeled using a spatial grid modeling structure (Short et al., 1996). The model calculates and predicts the changes in eelgrass habitat that result from poor water quality and wasting disease activity (Short et al., 1986; 1995) after incorporating tidal flows with distributions of water quality characteristics available from throughout the Great Bay Estuary (Jones and Langan, 1994a). Eelgrass habitat modeling in the Great Bay Estuary is now limited by the lack of

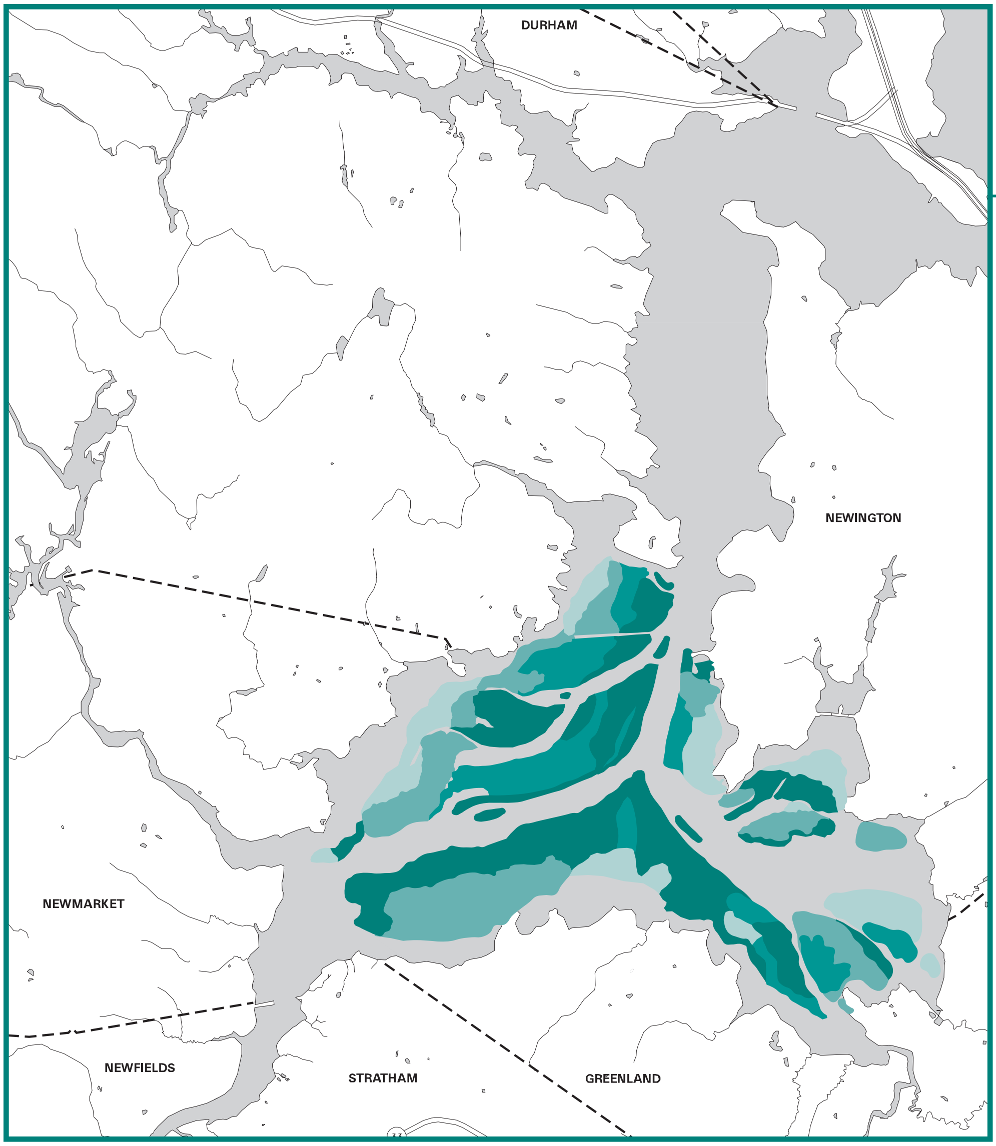


FIGURE 3.20

Eelgrass distribution and density in Great Bay and Little Bay: 1990.

adequate hydrodynamic information to fully implement the spatial distribution model. With such information, the model will continue to improve and become a useful predictor of eelgrass habitat distribution. This management tool can then be expanded to incorporate other estuarine habitats, including salt marsh, algal beds, and shellfish areas.

Change analysis of eelgrass distribution in the Great Bay Estuary has provided valuable information for understanding the dynamics of the eelgrass habitat. A loss of eelgrass distribution in Great Bay was documented between 1981 and 1984 for Great Bay, Little Bay and the upper Piscataqua River (Short et al., 1986). The dramatic losses of eelgrass over this time period signalled a recurrence of the wasting disease. This disease devastated eelgrass populations in the 1930s along both coasts of the North Atlantic (Short et al., 1988). The wasting disease was subsequently shown to result from a pathogenic infection of eelgrass populations by a marine slime mold *Labryrinthula zosterae* (Short et al., 1987; Muehlstein et al., 1991).

More recent change analysis in Great Bay has documented further loss of eelgrass through the remainder of the 1980s (Figure 3.18) to a low point in eelgrass distribution in July, 1989. This dramatic decline in eelgrass was followed by an equally dramatic increase and recovery of eelgrass beds that occurred between 1989 and 1990 (Burdick et al. 1993). The loss during the 1980s was determined to be caused by rapid infection and spread of *Labryrinthula zosterae*. The spread of the disease ceased in late 1988 following a rainfall event which decreased the salinity of the estuary and inhibited the growth of the pathogen. The recovery of eelgrass during 1989 through 1990 was the result of high levels of sexual reproduction and seed dispersal within the estuary producing extensive revegetation of mudflat areas by eelgrass seedlings.

The total area of eelgrass loss in Great Bay between 1986 and 1989 was 690 hectares (ha) and the area of recovery from 1989 to 1990 was 700 ha. This change analysis suggests that the loss of area was extremely rapid at 230 ha/y but that the recovery through seedling recruitment was even greater, over 600 ha/y. The rapid recovery due to recruitment of new shoots from seeds had actually begun in 1989, but did not show until the 1990 aerial photographs. The 1992 maps indicate more extensive eelgrass cover in Great Bay than was reported by Nelson (1981) (Figures 3.19 and 3.20).

As of 1990, distribution of eelgrass in Little Bay was approximately 2% (Figure 3.20) of what was reported in Little Bay in 1981 (Figure 3.19; Nelson 1981), however the source of the data and the methods used by Nelson (1981) are unclear. The most recent published map of eelgrass in Little Bay (Burdick et al. 1993) includes a persistent bed off Dover Point and a small bed just west of the General Sullivan Bridge in Newington. A decade prior to these observations, Nelson (1981) reported eelgrass along both sides of Little Bay and extending into the Bellamy River. Little Bay has been monitored annually from 1984 to the present, and no new patches of eelgrass were found prior to 1993. Since 1993, natural recruitment of new eelgrass beds has occurred at 3 sites in Little Bay. The loss in area of eelgrass in Little Bay from 218 ha in 1981 (Nelson 1981) to 3.7 ha in 1990 (Burdick et al. 1993) shows a loss of 98% of the eelgrass in Little Bay over that 9 year period. The increase from 1993 to the present has not been quantified. In 1997, an effort was begun to restore eelgrass to parts of Little Bay (see section on Habitat Restoration).

In the Piscataqua River, eelgrass is currently found in small beds along the shoreline in many areas. On the Maine side of the Piscataqua River, the most extensive bed of eelgrass exists off Addlington Creek just south of the confluence of Little Bay and the upper Piscataqua River. Small patches of eelgrass are found further down the Piscataqua River on the Maine side and adjacent to the small boat passage under the Memorial Bridge. On the New Hampshire side of the river, eelgrass is found in Outer Cutts Cove adjacent to the New Hampshire Port Authority construction and at several sites along the Piscataqua south of Dover Point where eelgrass restoration has taken place as part of the New Hampshire eelgrass mitigation project (Short et al., 1996; Davis and Short, 1997).

Using the 1981 NH Fish and Game map of eelgrass distribution in the Piscataqua River as a baseline, (Nelson, 1981) data from 1990 (Burdick et al., 1993) indicate that there was a loss of approximately 50 ha of eelgrass in a ten year period. The restoration of 3.5 acres of eelgrass habitat along the New Hampshire side of the Piscataqua River (Short et al., 1996) has increased the area of eelgrass in the river, however changes in the existing eelgrass areas from 1990 to 1997 have not been documented. In Portsmouth Harbor, eelgrass has not been carefully mapped and no historical data has been reported, but observations of eelgrass beds over the past decade suggest fairly consistent distribution (Short, 1992; Johnston et al., 1994) . Eelgrass has been found throughout many parts of Portsmouth Harbor with extensive beds at the mouth of the Harbor on both the New Hampshire and Maine side. At these sites, eelgrass grows to a maximum depth of 11 meters as a result of clear water from the Gulf of Maine entering the River. More comprehensive mapping of eelgrass distribution in the entire Great Bay Estuary is needed to establish baseline conditions for future habitat monitoring and change analyses.

WILDLIFE

Because of the diversity of habitats, New Hampshire's estuaries support an impressive array of living resources. In addition to the species described above, terrestrial wildlife, birds and marine mammals are also present. Mammals living within the Great Bay area include whitetail deer, beaver, red fox, mink, otter, muskrat, coyote and raccoon. In addition, Great Bay is part of the Atlantic flyway and an important migratory stopover as well as wintering area for many birds. As a result, there are substantial populations of both seasonal and year round birds that undoubtedly have a direct affect on water quality throughout the coastal zone.

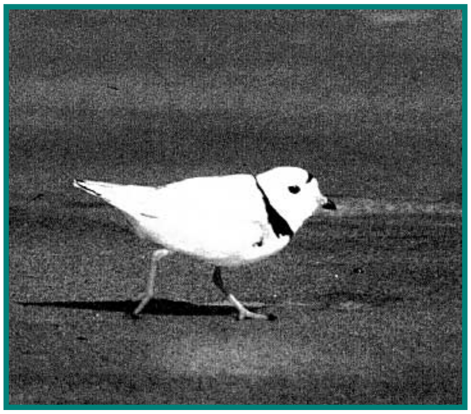
3.4.1 MARINE MAMMALS

Harbor seals (*Phoca vitulina*) may be found throughout the Great Bay Estuary, and are common in the lower portions of the estuary as well as in Rye Harbor and Hampton Harbor. A hooded seal was seen in Little Bay in 1998. Harbor porpoises (*Phocoena phocoena*) frequent the lower portions of the estuary and have been sighted in Little Bay. It is likely that some whales find their way into Portsmouth Harbor (e.g., a humpback whale, *Megaptera novaeangliae* sp. travelled up the Piscatatqua River to the mouth of Little Bay in 1995). There are also maps for sightings of 5 whale species in the Gulf of Maine that include sightings off the coast of New Hampshire (CeTAP, 1982 in NAI, 1994). Harbor seals (*Phoca vitalina*) were the only marine mammal observed in a study where weekly observations were made for 12 months during 1980-81 throughout the GBE (Nelson, 1982). Seals were sighted from November through April, most often during March and April. They were sighted most often in Little Bay, with infrequent sightings in Great Bay and the Piscataqua River. Data maintained by NOAA/NMFS indicates an increase in harbor seal populations throughout the New England region, confirming observations by local fishermen as well as impingement data from the Seabrook Station Environmental Studies (NAI, 1996).

3.4.2 WATERFOWL AND SHOREBIRDS

The Seacoast area is the principal wintering waterfowl location in New Hampshire (Vogel, 1995), with 75% of the wintering waterfowl in Great Bay. A recent mid-winter survey of mallards, black duck, greater/lesser scaup, goldeneye, bufflehead, red-breasted mergansers, Canada geese and other seaduck species showed Canada geese and black duck to be the most plentiful species around Great Bay (Vogel, 1995). The 1995 counts for most species were higher than the average count for the previous ten years. Recent counts for waterfowl by the Audubon Society in the Hampton Harbor area are presented in Table 3.9.

Great Bay is a focus area for the North American Waterfowl Management Plan (Vogel, 1995). There are two wildlife preserves in the Great Bay area. One is located in Newington at the site of the old Pease Air Force Base. It consists of a 1,054 acre area bordering Little Bay which has been designated as a Wildlife Sanctuary by the U.S. Fish and Wildlife Service. The other preserve is located at Adams Point and is administered by the NH Fish and Game Department as a Wildlife Management Area. In addition, the Great Bay Estuarine Research Reserve has over 5,300 acres of protected areas that include wetlands,



S. MIRICK

Piping plover chick

TABLE 3.9 *Summary of mid-winter survey and volunteer counts of waterfowl in Hampton Harbor: 1995. Data from Vogel (1995).*

Species		1995 Counts	10 Year Average (1985-1994)	Change from 10 Year Averages	1995 Volunteer Count Averages
Mallard	*Anas platyrhynchos*	511	288	77%	493
Black duck	*Anas rubripes*	1,846	973	90%	267
Greater/lesser scaup	*Aythya marila/affinis*	550	360	53%	114
Goldeneye	*Bucephala clangula*	200	79	153%	50
Bufflehead	*Bucephala albeola*	0	5	—	43
Seaduck species		513	436	18%	0
R.B. merganser	*Mergus serrator*	7	8	–13%	26
Canada goose	*Branta canadensis*	3,110	1,603	94%	1,821
Total		6,796	4,200	62%	—

Volunteer data based on the average counts of 6 surveys conducted January-March, 1995 at certain sites around Great Bay. Other species noted during the volunteer survey include domestic geese, mute swans, hooded mergansers, common mergansers, northern pintails, ruddy ducks, and ring-necked ducks.

saltmarshes, uplands and habitat for waterfowl. Other conservation areas include Audubon's Bellamy River property, Nature Conservancy land on Durham Point and other NH Fish and Game areas.

A detailed study of shorebird use of the Great Bay Estuary during the fall and spring migratory periods was conducted in 1990-91 (Miller and Miller, 1991). Data on the relative abundance of 16 shorebird species during a one year period were reported along with habitats used, locations, human influences, management options and research needs. There is a checklist for the birds of Great Bay that lists >170 species by season and abundance (GBNERR, 1993).

3.4.3 NON-GAME SPECIES

A summary of the amphibians, reptiles, mammals and wetland-associated birds in New Hampshire is included as a series of appendices in Chase et al. (1995). The appendices cover terrestrial and semi-terrestrial vertebrates with a few example descriptions of habitat use, survival needs and conservation issues. In New Hampshire there are 39 species of amphibians and reptiles, 55 native mammalian species and over 200 bird species, 51 of which they list as wetland-dependent or wetland-associated. Bald eagles, common terns, upland sand pipers, marsh hawks, ospreys and common loons are endangered and threatened bird species found in the Great Bay Estuary (Merrill, 1995). The bald eagle inhabits the shores of Little and Great Bay in the winter (NH Audubon Society, annual monitoring data).

A study consisting of weekly bird observations made for 12 months during 1980-81 throughout the GBE identified over 90,000 consisting of 71 species (Nelson, 1982). The birds were classified into four categories: seabirds, waterfowl, wading birds and terrestrial and shorebirds. Some species left the area during cold months and were replaced to some extent by other species. The total species in the estuary each month was fairly constant at ~20, ranging from 13 in January to 34 in August.

Great Bay is part of the Atlantic flyway and an important migratory stopover as well as wintering area for many waterfowl and wading birds. As a result, there are both substantial seasonal and year round populations of waterfowl throughout the Great Bay area. Common species include cormorants, Canada geese, bald eagles, sea gulls, terns, ducks, herons, snowy egrets, common loons and a large variety of perching birds.

Wildlife is well represented within the Little Harbor area, primarily at Odiorne State Park, and in the extensive salt marshes of Seavey Creek and Berry

Brook, part of which is owned and managed by Odiorne State Park. Habitat areas in Little Harbor have been mapped. Mammals living in the Little Harbor area include whitetail deer, beaver, fox, mink, otter, muskrat, squirrels, chipmunks, rabbits, moles, voles, rats, mice, bats, shrews, weasels, skunks and raccoons (Seacoast Science Center, 1992). Wildlife populations are not suspected to be large enough to impact water quality, especially considering that most of the shoreline is developed. In addition, the Little Harbor area is a seasonal stopover for many waterfowl and wading birds. Species seen or heard during one or more seasons include common loon, grebes, cormorants, bittern, brant, Canada geese, mallard, eider, oldsquaw, scoters, common goldeneye, bufflehead, mergansers, hawks, kestrel, plovers, killdeer, yellowlegs, willet, sandpipers, godwits, turnstone, dunlin, snipe, gulls, terns, dovekie, owls, whip-poor-will, swift, kingfisher, woodpeckers, flicker, flycatchers, phoebe, kingbird, swallows, jays, crows, chickadee, nuthatches, wrens, kinglets, wheatear thrushes, robin, catbird, mockingbird, cedar waxwing, starling, vireos, warblers, parula, warblers, redstart, yellowthroat, pine and evening grosbeak, towhee, sparrows blackbird, grackle, orioles, finches, crossbill, goldfinch, and a large variety of less common birds.

3.4.4 RARE AND ENDANGERED SPECIES

There are a number of threatened and endangered species in coastal New Hampshire. There are 23 threatened or endangered plant and animal species in the GBNERR. The shortnose sturgeon is a federal endangered species that probably occurs, although this is unproven (NAI, 1994). Detailed descriptions of the six endangered and threatened birds in the coastal region were given in NHOSP (1992). The bald eagle is federally listed as endangered and it occurs in the Salmon Falls, upper Piscataqua, Oyster, Cocheco and Bellamy rivers plus in Little Bay, Great Bay and tributaries, Portsmouth Harbor and Back Channel area, and in Hampton Harbor and its tributaries. It also probably occurs in the Exeter and Lamprey rivers plus Rye Harbor. The piping plover is federally listed as threatened and occurs in parts of Hampton Harbor and its tributaries. The peregrine falcon, once federally listed as endangered but now delisted, has documented occurrences in the upper Piscataqua River and in Hampton Harbor and its tributaries. A more comprehensive list of threatened or endangered species in the GBNERR is in Appendix L.

Foss and De Luca (1992) assessed the breeding season distribution, habitat use, status and nesting success of four threatened or endangered bird species in coastal New Hampshire. The species included common terns (state endangered), ospreys (state threatened), norther harriers (state threatened) and piping plovers (state endangered; federally threatened). Tern colonies were located in Hampton marsh, Back Channel and Little Bay. Northern harriers used coastal habitats in 1992, but there was no proof of nesting. Piping plover habitat exists on the southeast shore of Hampton Harbor, but no breeding was observed in 1992. Osprey nests in four locations were monitored and some breeding activity was observed. The report included monitoring and management recommendations for each species. Others have continued monitoring the four existing osprey nests around Great Bay (C. Martin, NH Audubon Society, personal communication).

In 1997, the NHOSP funded a project by the NH Audubon Society and the NHF&G Department Nongame Program to restore terns to the Isles of Shoals (NHF&G, 1997a). Seven chicks hatched from six nests, and efforts will be made to repeat this success next year. The NHF&G Nongame Program also protected and monitored five piping plover nests at Seabrook and Hampton beaches in 1997. Three of the seventeen chicks survived and fledged in August. The others either starved or were run over by vehicles or joggers. This was the first documentation of nesting piping plovers in New Hampshire since 1984.

INTRODUCED AND NUISANCE SPECIES

The objective of this section is to synthesize current information on selected species relevant to shellfish and other living resources, not necessarily to be a comprehensive review of all introduced and nuisance species.

3.5.1 GREEN CRABS
(Carcinus maenas)

Introduced and Nuisance

Green crabs were introduced into North America in the early 1900's and have been identified as a major predator of juvenile shellfish. In the Great Bay Estuary, green crabs are more abundant in the Piscataqua River and Little Bay than in Great Bay. Though there is some information on crab density at eelgrass mitigation sites in the Piscataqua River, the data are insufficient to establish the status and trends of green crab populations in Great Bay. Normandeau Associates Inc. has monitored green crab populations in Hampton Harbor since 1977 using baited traps (NAI, 1996). Their data show that crab density in a given year is highly dependent on the minimum winter temperature, and that colder temperatures result in fewer crabs the following spring (Savage and Dunlop, 1983). Survival of clam spat appears to be negatively correlated with crab density (NAI, 1996). Green crabs as well as rock crabs (*Cancer irroratus*) and mud crabs (all of which are abundant in Great Bay) also prey on juvenile oysters. Green crabs have been identified as serious pests that threaten efforts to restore eelgrass beds in the Great Bay Estuary. Descriptive study and mesocosm experiments have shown that their foraging and burrowing activities kill and dislodge planted shoots (Davis et al., in review).

Green crab

S. MILLER

3.5.2 EUROPEAN OYSTER
(Ostrea edulis)

Introduced

Discussed in another section.

3.5.3 COMMON PERIWINKLE
(Littorina littorea)

Introduced

This introduced species is highly abundant in coastal and estuarine waters. As a grazer, it is primarily herbivorous, but will scavenge on detritus as well. Through its foraging activities, the common periwinkle has a significant role in estuarine food webs, and influences (and may control) community patterns along rocky shorelines (Mathieson et al., 1991). However, the widespread distribution of this 19th century colonizer has left ecologists with little opportunity to collect evidence and test whether *Littorina littorea* has caused adverse impacts on coastal and estuarine ecosystems in the Gulf of Maine.

3.5.4 OYSTER DRILL
(Urosalpinx cinerea)

Nuisance

The oyster drill, a predatory gastropod, preys heavily on oysters in higher salinity waters. Intolerant of low salinities, drills typically cannot survive extended periods in areas of Great Bay where major oyster beds are located, although they have been found at Nannie Island and Adams Point. During extended high salinity periods, they can cause significant mortalities. The status and trends of drill populations, and their impact on oyster population has not been documented.

3.5.5 SEA LETTUCE *(Ulva lactuca)*

Nuisance

Proliferation of ephemeral green algae such as *Ulva latuca* due to nutrient overenrichment has caused serious ecosystem alterations in many areas of the world (Sawyer, 1965). Though severe impacts have not been documented in the Great Bay Estuary, anecdotal observations of increased abundance of *Ulva latuca* and other opportunistic green algae should prompt some analysis of the change in areal coverage and biomass of these so called “nuisance” macrophytic algae. A project that addresses this subject began in 1997 and is described in section 2.4.5.3.

3.5.6 OTHER INTRODUCED AND NUISANCE PLANTS

The major nuisance species associated with declines in seagrass habitats worldwide are various species of algae, including opportunistic red and green species that form mats and drift into beds, epiphytic species that cover individual blades, and phytoplankton that can shade entire beds (Short and Wylie-Echeverria, 1996). Although epiphytes and drift algae are known to occur in seagrass beds in New Hampshire’s estuaries, impacts to eelgrass beds do not appear to be significant at this time (Short et al., 1993; Langan and Jones, 1993). However, experimental model ecosystems of eelgrass beds indicate that nutrient additions can lead to algal dominance and seagrass bed collapse (Short et al., 1995).

In New Hampshire, Widgeon grass (*Ruppia maritima*) occurs primarily in creeks, ponds, and pannes of salt marshes (Richardson, 1980). However, it also occurs extensively in South Mill Pond, Portsmouth, where it must compete with various species of opportunistic macroalgae. What little is known about habitat change regarding the macroalgal beds of New Hampshire estuaries includes studies on the destruction of estuarine and near shore populations of kelp by a small species of estuarine snail, *Lacuna vincta* (Fralick et al., 1974) and previously mentioned increases in macroalgal habitat by *Ulva latuca* and other opportunistic species.

Several species of emergent plants are considered nuisances in tidal marshes. These include common reed (*Phragmites australis*, formerly *communis*), purple loosestrife (*Lythrum salicaria*), and sometimes cattail (*Typha angustifolia*) (USDA, 1994).These plants drastically reduce plant diversity in marshes, restrict bird and fish access to the marsh, and have been cited as a fire hazard to nearby homes (USDA, 1994; Rozsa, 1995). The presence and spread of these species can serve not only as indicators of impacts to marshes (USDA, 1994), but as indicators of losses in marsh functions and values (Morgan et al., 1996). Thus, these invasive plants are believed to reduce the economic value of salt marshes (USDA 1994). All three species are clearly increasing in coastal marshes (Dzierzeski, 1991; USDA, 1994; Tiner, 1996). Phragmites is cited as the “most significant problem confronting” salt marshes in Connecticut (Rozsa, 1995), and its continued spread and establishment in New Hampshire marshes is cause for concern. Management action plans have been developed and implemented to curb this problem. For example, where these plants have invaded tidally-restricted marshes, reestablishment of natural tidal regimes have reduced their distribution or vigor (Burdick and Dionne, 1994; Burdick et al., 1997).

Within salt marshes, human nuisances such as mosquitos and greenhead flies are managed by seacoast towns that collectively spend approximately $100,000 each year. Ironically, most of the effort to control these pests occur in marshes that have degraded, often as a result of efforts to manage such pests (USDA 1994).

3.6

SUMMARY OF FINDINGS

The review of technical information on the status and trends for living resources in coastal New Hampshire showed a great deal of existing information for a wide range of different species and communities. There are issues that emerge from analysis of the data for some species, while little is known about others. This section is a summary of what is known and what information gaps still exist.

- The species richness and dominant species found in communities of benthic invertebrates in the Great Bay Estuary were essentially unchanged from 1972 to 1995.
- A few benthic invertebrate and macroalgae species are disjunct warm-water taxa, with their northernmost contiguous distribution limit occurring south of New Hampshire.
- Eastern oysters are found mainly in the Great Bay Estuary in coastal New Hampshire.
- Eastern oyster populations in the Great Bay Estuary have undergone a marked decline during the past half century.
- The first recorded MSX epizootic in the Great Bay Estuary occurred in 1995. There was a high rate of mortality in the upper Piscataqua River and tidal Salmon Falls River, and a lower rate of systemic infections in the rest of the Estuary.
- The causative agent of Dermo disease in oysters, *Perkinsus marinus*,was identified in oysters from Spinney Creek in September, 1996. A low prevalence of Dermo infections have also been found in oysters from Great Bay and the Oyster River.
- European flat oysters, razor clams, ribbed mussels, the gem clam and rock, green, mud and horseshoe crabs are found in numerous areas of coastal New Hampshire.
- Softshell clams are found in high densities in Hampton Harbor and in moderate to high density in flats in the Salmon Falls River and near Sandy Point in Great Bay. Clams are present at low densities in Little Bay, Great Bay and Little Harbor.
- In the Great Bay Estuary and Little Harbor, clam populations are a fraction of their historical levels.
- In Hampton Harbor, clam populations were abundant in the mid-1970s and 1980s, with a sharp decline starting in 1984, likely due to heavy harvest pressure. The decline was also a result of sarcomatous neoplasia, a form of leukemia in clams.
- Blue mussels are found in all New Hampshire's estuaries and open coast, except in the upper reaches of tributaries where low salinity limits their survival. Their abundance has not been documented, and their density can be as high as 3500/m2 in Hampton Harbor.
- Sea scallops can be found in Portsmouth Harbor with an average density of 1.3 scallops/m2 and an even distribution of sizes.
- Lobster populations are relatively stable throughout coastal New Hampshire, despite increasing fishing pressure.

- A tremendous increase in the seasonal occurrence of striped bass has occurred in New Hampshire in the past decade, probably as a result of an earlier region-wide moratorium and other harvest restrictions.
- The recreational catch per unit effort of winter flounder has declined in Great Bay over the last decade, probably as a result of heavy commercial fishing in the Gulf of Maine.
- The abundance of rainbow smelt and river herring has been highly variable over the last decade.
- New Hampshire has approximately 50% of its 18th century tidal wetlands, or about 7,500 acres. Plants found in these areas include cord, spike and black grasses.
- Marine and terrestrial development pose the greatest current threat to salt marshes.
- Tidal restrictions are relatively widespread, affecting 21% of the salt marsh area in New Hampshire.
- There are 219 known species of seaweeds found along the rocky shorelines and the subtidal photic zones of areas throughout coastal New Hampshire. Dredging and development pose threats to macroalgal habitats.
- Eelgrass habitat is a significant component of the Great Bay Estuary ecosystem. Distribution maps, some over time, have been compiled for many areas of coastal New Hampshire.
- Eelgrass populations experience dramatic temporal and spatial changes. A dramatic decline occurred in the late 1980s in Great Bay at a rate of 230 ha/y, followed by a rapid recovery after 1989, at a rate of 600 ha/y. The decline was a result of a wasting disease.
- Harbor seals, harbor porpoises are commonly found, especially in lower Great Bay Estuary, Rye Harbor and Hampton Harbor. An occasional other marine mammal such as humpback whales has also been seen.
- The Seacoast area is the principal wintering location for waterfowl in New Hampshire, 75% of which are in Great Bay. Counts of most species made in Hampton Harbor during 1995 were higher than the average from the previous ten years.
- There are 23 threatened or endangered animal and plant species in the Great Bay National Estuarine Reserve. Monitoring and habitat restoration projects are being conducted for bald eagles, ospreys, common terns and piping plovers.
- Introduced and nuisance species of particular concern in coastal New Hampshire include green crabs, European oysters, common periwinkle, oyster drill, sea lettuce, common reed, purple loosestrife, mosquitos and greenhead flies.

4

HUMAN USES AND RESOURCE MANAGEMENT

The Great Bay and Hampton/Seabrook estuaries are extremely important to the local, regional, state, and national economies. From the time of first European settlement, the Great Bay Estuary has been a center of commerce for natural resource based industries such as commercial fishing and logging. During the 19th century, shoe and textile manufacturing became important and mills were built in all towns with access to navigable waterways. Today energy is produced in facilities located on the Piscataqua River and in Hampton Harbor, and the shipping of lumber, mineral salt, gypsum and other products is of significant economic importance. Several species of fish still support local and regional fisheries in the Gulf of Maine, and tourism and recreation are becoming increasingly important parts of the N.H. Seacoast economy. Many of these activities are dependent on good water quality and a healthy ecosystem. In particular, habitat degradation and declines in important fish and shellfish species remain a concern. This chapter summarizes what is known about human uses and resource management in Coastal New Hampshire to frame related issues and to assess the significance of problems and information gaps relative to the Seacoast's estuarine ecosystems.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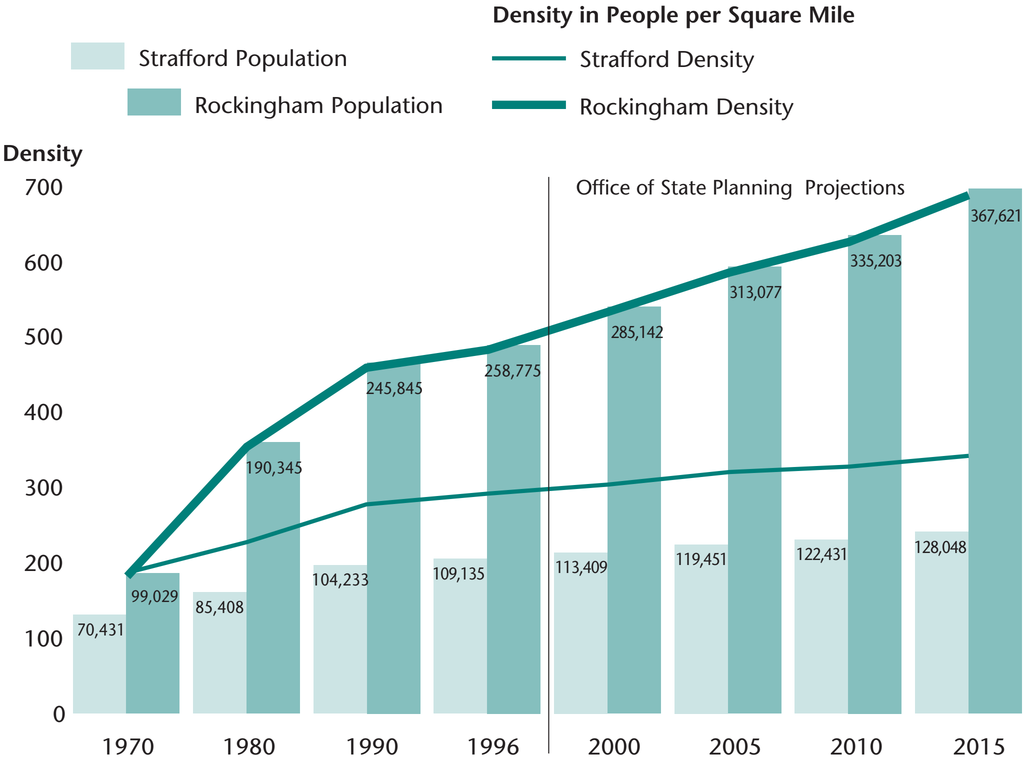
POPULATION TRENDS, EMPLOYMENT AND INCOME

4.1.1 POPULATION AND DENSITY TRENDS AND PROJECTIONS

The human population trends for Rockingham and Strafford counties from 1970 to 2015 (NHOSP, 1997a) are shown in Figure 4.1. Both Rockingham and Strafford counties had more dramatic increases in population from 1970-1990 compared to projected increases from 1990 to 2010. Rockingham County increased from 138,951 to 245,845 people from 1970 to 1990, a 77% increase while the increase was 36% in Strafford County. The populations are projected to increase from 1990 to 2010 by 48% in Rockingham County and by 18% in Strafford County. Throughout the 40 year span of data, the population of Rockingham County has been and is projected to continue to be greater than Strafford County.

Figure 4.1 shows population density trends and projected trends through 2015. The population density of Strafford County has been greater than for Rockingham County, with the difference projected to narrow as densities in both counties continue to increase through 2015. In 1990, 50.4% of the people in Rockingham County were female and 51.6% of the people in Strafford County were female (NHOSP, 1997a). The continuation of increases in population and density in New Hampshire's two coastal counties is a concern because of the accompanying increases in development, use of coastal resources and production of pollutants.

FIGURE 4.1 *Population growth in Rockingham and Strafford counties, New Hampshire: 1970-2015.*



4.1.2 EMPLOYMENT AND INCOME

The economic issues in coastal New Hampshire have been reviewed in numerous studies (Colgan, 1995; NAI, 1994; Ogrodowczyk, 1993). Much of the work focused on fisheries, but tourism, transportation, industries, and related issues were also discussed. Table 4.1, shows the harbor-related economic value and jobs generated by coastal industries (NAI, 1994). Table 4.2 shows where these activities occur in New Hampshire. The different activities take place throughout the Seacoast, but Portsmouth Harbor is the only place where all activities occur, while recreational boating is the only activity that occurs at all sites. Little Harbor anticipates an increase in recreational boating and Portsmouth Harbor anticipates an increase in commercial shipping; the rest of the harbors anticipate maintenance of similar levels of activities, which have been mostly recreational (NAI, 1994). Maintenance of current activities will require maintenance dredging, and reduced dredging would seriously impact cargo shipping, shipbuilding, cruise ship operations, and commercial fishing.

As shown in Table 4.1, commercial fishing is the industry type with the largest employment and economic activity. It encompasses the fishing, hunting, trapping, fresh or frozen prepared fish, and wholesale trade categories of economic activity. Rockingham County has the vast majority of jobs and economic activity. More information on the present status of the commercial fishing industry is provided below in the Commercial Fisheries and Aquaculture section (4.3.1.3).

The economic value and jobs generated by coastal New Hampshire industries.

TABLE 4.1

Industry	Value in $	Jobs
commercial fishing	160 million	1065
recreational boating	18 million	55
cargo shipping	12 million	91
boatbuilding and repair	2.1 million	56
water transportation/tourism	1.7 million	14
Total	193 million	1281

TABLE 4.2

Harbor-related activities in New Hampshire.

	Cargo terminal	Tourism	Commercial fishing	Boat yards	Ferry	Recreational boating	Other
River							
Squamscott R.	—	—	x	—	—	x	
Lamprey R.	—	—	x	—	—	x	
Oyster R.	—	—	—	—	—	x	
Cocheco R.	—	x	x	x	—	x	
Harbor/Bay							
Great Bay	—	—	—	—	—	x	
Little Bay	—	—	x	x	—	x	
Portsmouth Harbor	x	x	x	x	x	x	(tugs, barges)
Portsmouth back channels	—	—	x	—	—	x	
Little Harbor	—	x	x	—	—	x	
Hampton Harbor	—	x	x	x	—	x	
Isles of Shoals	—	x	x	—	x	x	

4.2

LAND USE AND DEVELOPMENT ISSUES

4.2.1 URBAN AND RURAL DEVELOPMENT

The assessment of water quality and living resources in coastal New Hampshire benefits from addressing issues at large scales. An assessment of the land use and human activities that occur on the uplands and in the watersheds adjacent to New Hampshire's estuaries helps in the understanding of processes that affect human health issues and the integrity of the estuarine ecosystems.

Published land-use change information is limited (Coppelman et al., 1978; Befort et al., 1987; NHCRP, 1997). Data from the Complex Systems Research Center at UNH are also available. Agricultural land in New Hampshire has decreased in Rockingham and Strafford counties from 472,000 acres in 1850 to 42,000 acres in 1996, while urban lands comprised 13.9 and 8.5% of Rockingham and Strafford counties, respectively, in 1996 (NHCRP, 1997).

A critical lands analysis project conducted for the NHEP by the Complex Systems Research Center at UNH is determined the potential for development in uplands classified by land use (Rubin and Merriam, 1998). The quantity and quality of the existing information varied for each town or city in the coast. In addition, policy and program reviews of local, state and federal regulations governing land use and human activities in the region have also been conducted (Carlson et al., 2000; 1997).

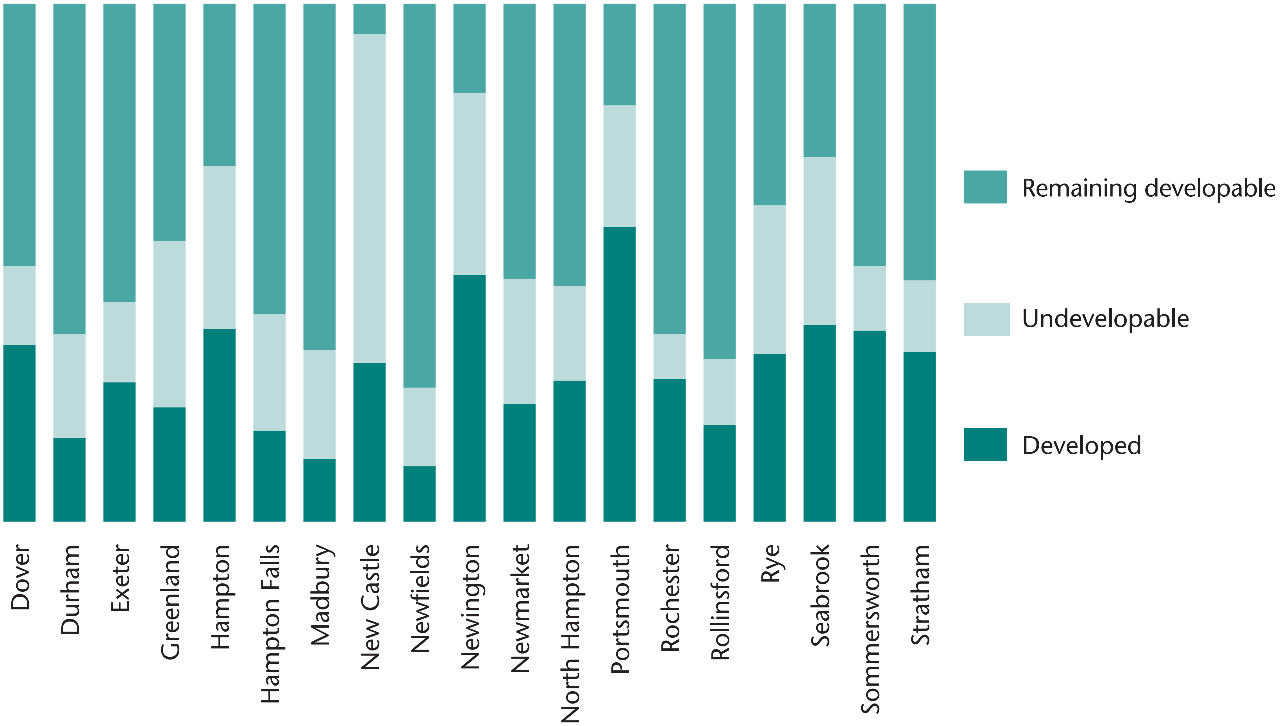
Some of the results of the critical lands analysis are summarized in Table 4.3. Data for all of the 19 coastal New Hampshire municipalities include popu-

TABLE 4.3 *Developed and undeveloped acreages in the 19 coastal New Hampshire municipalities.*

Town	Population 1992	Total area (acres)	Residential area (acres)	Ttl area developed (acres)	Remaining undevelopable (acres)	Remaining developable (acres)	Ttl developed area per capita	Ratio of remaining to ttl developable land
Dover	25114	18587	4318	6363	2826	9398	0.25	0.60
Durham	12348	15852	1865	2561	3181	10110	0.21	0.80
Exeter	12356	12813	2646	3452	1982	7379	0.28	0.68
Greenland	2790	8524	1259	1879	2719	3926	0.67	0.68
Hampton	12269	8901	2391	3319	2794	2788	0.27	0.46
Hampton Falls	1531	8078	948	1430	1797	4851	0.93	0.77
Madbury	1431	7799	649	954	1629	5217	0.67	0.85
New Castle	831	1218	301	372	773	73	0.45	0.16
Newfields	909	4647	340	491	703	3453	0.54	0.88
Newington	688	7916	578	3757	2784	1375	5.46	0.27
Newmarket	1796	9080	1715	2056	2195	4829	1.14	0.70
North Hampton	3642	8914	1913	2414	1637	4863	0.66	0.67
Portsmouth	22342	10762	2459	6123	2513	2127	0.27	0.26
Rochester	26640	29072	5252	8007	2504	18561	0.30	0.70
Rollinsford	2646	4840	178	896	619	3325	0.34	0.79
Rye	4555	8353	2205	2716	2375	3262	0.60	0.55
Seabrook	6537	5923	1407	2239	1920	1764	0.34	0.44
Sommersworth	11239	6396	1574	2351	801	3244	0.21	0.58
Stratham	5040	9902	2619	3226	1396	5280	0.64	0.62
Total	**154704**	**187578**	**35155**	**54607**	**37146**	**95825**	**0.35**	**0.64**

Notes:
"Developed" land data from regional planning commission land use maps, circa 1992.
"Remaining Undevelopable" land includes protected land, surface water, large wetlands, road and transmission rights of way, and other land types unsuitable for development.

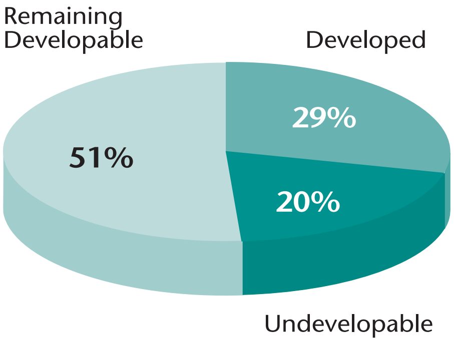
Percent land development and potential in the 19 coastal New Hampshire municipalities. **FIGURE 4.2**



lation, total acres, residential area, total developed area, and the remaining land that is either undevelopable or developable. For comparisons of different sized municipalities, a ratio of total developed area per capita is provided. Newington has the highest ratio (5.46) by far, reflecting both extensive development and a low population. Hampton Falls has the next highest (0.93) ratio, while Dover, Durham, Exeter, Hampton, Newmarket, Portsmouth, Rochester and Somersworth have low (≤ 0.3) ratios. The eight municipalities with the low ratios are also the eight with the highest populations.

Another way of comparing different municipalities is to calculate the fraction of remaining developable land compared the total area of developed and developable land (Table 4.3). A low ratio suggests that the municipality has less room to continue development. The communities with low (< 0.3) ratios are New Castle, Newington and Portsmouth. Communities with high (> 0.7) fractions are Durham, Hampton Falls, Madbury and Rollinsford. These trends are also illustrated in Figure 4.2, which also factors in undevelopable land. In the case of New Castle, the limited room to develop is a combination of having the smallest percentage of remaining developable land and the largest percentage of undevelopable land, along with a modest percentage of developed land. Portsmouth and Newington have the highest percentage (> 40%) of developed land and relatively small percentages of remaining developable land. The four communities with the smallest percentage of developed land also had the largest percentages of remaining developable land. For the whole Seacoast, 29% of the land has been developed while 51% remains developable, with 20% undevelopable (Figure 4.3).

Percent land development and potential for coastal New Hampshire. **FIGURE 4.3**



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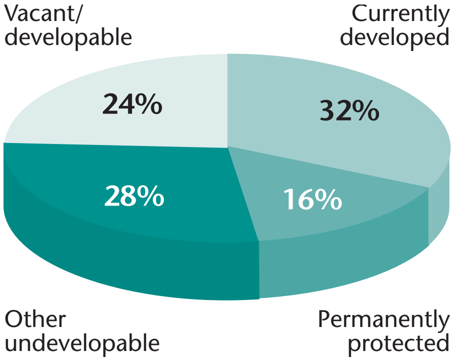
4.2.2 ESTUARINE SHORELAND

Figure 4.4 shows the percentage land use types within 300 feet of tidal waters. Comparison of Figures 4.3 and 4.4 shows that despite similar percentages of developed and undevelopable lands, there is a much lower percentage of estuarine shoreland that remains developable and much more that is undevelopable, in large part because of land that is permanently protected or extensively regulated along the state's shorelines. There is 51% of the land in all 19 coastal communities that remains developable (Figure 4.3) compared to only 24% of the land within the 300 foot shoreline buffer zone (Figure 4.4). The 16% of shoreline buffer zone lands that are permanently protected or extensively regulated constitutes 40% of the land that would otherwise be considered developable.

FIGURE 4.4

Land use types within a 300-foot shoreline buffer in New Hampshire tidal waters.



4.2.3 HABITAT LOSS AND FRAGMENTATION

Forest fragmentation is the major cause of land habitat degradation in New Hampshire (NHCRP, 1997). It is highest in Rockingham County compared to all New Hampshire counties. The average forest patch size is also smallest (39.8 A). In terms of road density, Rockingham and Strafford counties are second and third highest in the state, with 5.6 and 4.7 mi/1000 A, respectively. Not only does road density help to further fragment habitats, but roughly 10% of the total annual kills for bear and deer statewide were by roadkill. Cars killed an average of 18 bears, 153 moose and 861 deer per year from 1984-1995 (NHRCP, 1997).

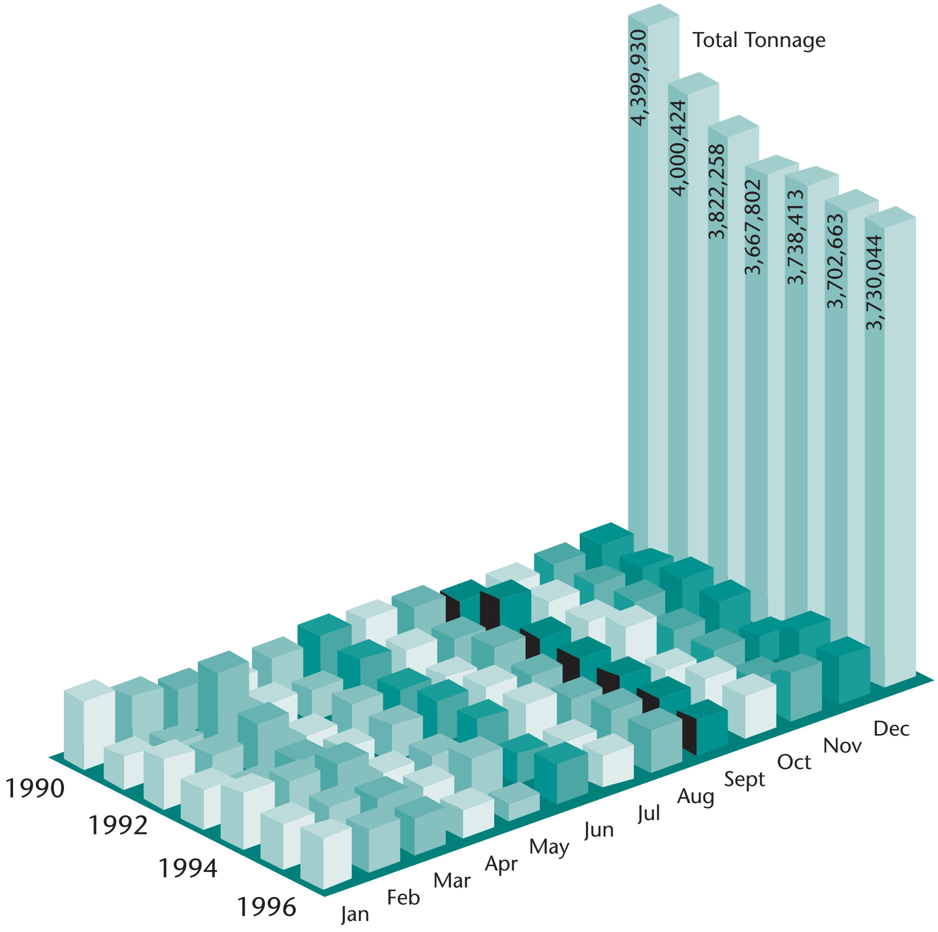
4.3.1 COMMERCIAL USES

4.3.1.1 Shipping and Commercial Vessel Traffic

Information on shipping is available through the New Hampshire Port Authority (NHPA). Monthly records of vessel arrivals and departures are recorded, along with type of vessel, home port, name, cargo, tonnage loaded and tonnage unloaded. Based on the NHPA data, the total tonnage decreased from 1990 to 1996, with a relatively consistent tonnage being shipped during all months (Figure 4.5).

NAI (1994) summarized the total shipping tonnage for New Hampshire by different categories for 1980 and 1992. The total shipping tonnage increased from 2.8 million tons in 1980 to 4.2 million tons in 1992. The largest commodity was oil, comprising approximately 2 million tons during both years. The increase from 1980 to 1992 was from increases of shipping for dry and bulk tonnage. During 1980, the dry and bulk commodities included salt, gasoline and scrap metal, with propane, asphalt and gypsum being prominent in 1992. Data from these more recent studies can be compared to earlier data. Total shipping tonnage in Portsmouth Harbor was 505,000 tons in 1949, increasing to 1.2 million tons in 1958 (NHWPC, 1960). The major commodity in 1958 was residential fuel oil (~400,000 tons), followed by gasoline, gas oil, wood manufacturing, coal and gypsum, all with greater than 100,000 tons. The new NHPA docking and storage facilities should eventually allow an

Monthly and annual shipping tonnage recorded by the New Hampshire Port Authority: 1990-1996. **FIGURE 4.5**



increase in cargo handled at the NHPA facility from 300,000 to 1 million tons (NAI, 1994).

The most widespread harbor-related activity in New Hampshire is commercial fishing. There were 428 commercial fishing vessels in New Hampshire in 1992, 264 at slips and 139 at moorings (Table 4.4; NAI, 1994). The highest number of commercial vessels were in Portsmouth (200) and Hampton (100) harbors. There were also 80 sports fishing, eight whale watching, eight windjammer/charter sail and 13 harbor tour cruise vessels in New Hampshire during 1992 (Table 4.5; NAI, 1994).

4.3.1.2 Dredge and Disposal

All known dredging in New Hampshire coastal waters since 1950 has been summarized by NAI (1994). Dredging in tidal waters is restricted to November 15-March 15 (seasonal restrictions), and does not occur during periods of fish migration or larval settlement of shellfish. NHF&G will allow exceptions to dredge schedules outside of the target dates when necessary. Most dredging has occurred to maintain and expand the commercial and recreational uses of New Hampshire's harbors (NHOF, 1979). The NAI (1994) report recommended

TABLE 4.4 *Private commercial vessels in coastal New Hampshire in 1992 (NAI, 1994).*

	Total Commercial Vessels	Commercial at Slips	Vessels at Moorings
River			
Squamscott R.	33	15	17
Lamprey R.	10	5	5
Oyster R.	3		
Cocheco R.	20	10	
Harbor/bay			
Great Bay			
Little Bay	20	16	4
Portsmouth Harbor	200	173	27
Portsmouth back channels	12		12
Little Harbor	30	20	10
Hampton Harbor	100	25	61
Total	**428**	**264**	**136**
Rockingham county	385		
Strafford county	23		
Both counties	20		

TABLE 4.5 *Tourist-related vessels in New Hampshire in 1992 (NAI, 1994).*

	Sport Fishing	Whale Watching	Windjammer/ Charter Sail	Harbor Tours/ Day Cruises
River				
Squamscott R.				
Lamprey R.				
Oyster R.				
Cocheco R.				
Harbor/bay				
Great Bay				2
Little Bay				
Portsmouth Harbor	10	3	2	5
Portsmouth back channels				
Little Harbor	30	0	4	4
Hampton Harbor	20	5	2	2
Isles of Shoals				
Total	**80**	**8**	**8**	**13**

expanded dredging in Rye, Hampton and Portsmouth harbors to enhance safety of navigation, improve recreational and commercial facilities and expand mooring spaces. It also provides a summary of historical dredging and disposal activities, regulatory programs, a valuation of harbor economic uses and a projection of future disposal needs in Maine and New Hampshire. Most of the 2.9 million cubic yards of dredging material was dredged in Rockingham County, with this material being dredged from five water bodies during 66 dredging events (Table 4.6). There were also two events in Strafford County (Little and Great bays), amounting to only ~16,000 cubic yards of material.

Dredge materials have been disposed of within intertidal, nearshore, open water, upland or unknown locations (NAI, 1994). Much of the material was dumped at the Cape Arundel, ME open water site. Some Rockingham County material was subject to chemical analysis (see Chapter 2). Most samples had low to moderate concentrations of metals, DDT and PCBs. A high PCB concentration (>2.9 ppm) was found in one sample from Hampton Harbor, and a high concentration (>125 ppm) of vanadium was found in two samples from Rye Harbor. On the Maine side of Portsmouth Harbor, high concentrations of copper (>342 ppm), lead (>285 ppm), mercury (>3.0 ppm) and zinc (>43.6 ppm) were measured in numerous samples from the Portsmouth Naval Shipyard. As in the past, much of the future dredged material in Hampton and Little harbors will be available for beach nourishment or nearshore disposal; otherwise, it will be hauled to offshore disposal sites.

4.3.1.3 Commercial Fisheries and Aquaculture

Lobsters

The commercial lobster industry in New Hampshire coastal waters, which includes Great Bay and Hampton/Seabrook estuaries, consists of 300 lobster fishers harvesting approximately $5-6 million in ex-vessel value of lobsters annually. Despite heavy fishing pressure, the lobster catch has been stable for a number of years. Commercial landings of lobsters solely from the Great Bay Estuary and Hampton Harbor were not available, but lobsters are fished commercially in all but the upper tidal reaches of the estuaries. Including all lobsters caught by the New Hampshire fishing fleet, there have been 1.1 to 1.8 million pounds of lobster landed between 1992 and 1997 (Table 4.7), valued at $4.6-6.7 million (Table 4.8), based on National Marine Fisheries Service (NMFS) data. Research programs conducted by UNH and Sea Sampling programs and dive surveys conducted by the NH Fish and Game Department and Normandeau Associates provide information on lobster populations, lobster habitat, and seasonal movements of

Frequency and volumes of dredging at harbors in New Hampshire: 1950-1993 (NAI, 1994). **TABLE 4.6**

Harbor	Number of Events (cy)	Aggregate Volume
Rockingham County		
Portsmouth Harbor and Piscataqua River		
Deep draft channels	28	1,708,006
Portsmouth Back Channel areas	3	900
Little Harbor	2	176,609
Rye Harbor	6	244,051
Hampton Harbor and tributaries	27	819,142
Strafford County		
Little Bay	1	556
Great Bay and minor tributaries	1	15,000

TABLE 4.7 *Recorded fish landings (landed pounds) in New Hampshire: 1992-1997.*

	1992	1993	1994	1995	1996	1997
Fish						
Alewife	9,802	2676				
Cod	3,076,564	2,525,274	2,576,567	2,362,707	2,384,561	1,712,106
Dogfish Spiny	402,184	1,641,614	2,597,792	2,106,255	1,079,522	1,009,140
American Eel	285	1384				
Winter Flounder	125,714	85,869	80,684	63,729	61,857	30,429
Hake Mix Red & White	23,231	8881	15,068	11294	30,295	36,629
Atlantic Herring	562,413	774,292	435,200	56,775	33,655	152,431
Pollock	1,028,452	1,082,602	886,582	745604	724,008	1,141,699
American Shad	9,903	6549	28,226	30561	35,561	25,436
Atlantic Silverside		8,888				
Smelt	36				346	
Tuna, Bluefin	146,042	102,881	110,654	83,716	85,203	
Shellfish and Worms						
Green Crab	3,515					
Rock Crab				24	118	
Lobster	1,529,292	1,693,347	1,650,751	1,834,794	1,632,829	1,166,068
Mussels						115
Sand Worms						599
Sea Scallop			442	256	256	1,065
Sea Urchins	102,494	46,163	12,117	4074	10,410	18,337
Shrimp (Pandalid)	220,733	972,705	1,148,571	1,658,588	1,692,017	1,225,021
Totals*						
Landed Pounds	9,471,438	10,474,945	12,155,643	11,723,114	10,123,219	9,398,882
Live Pounds	10,573,844	11,364,472	13,207,785	12,779,960	11,098,224	10,321,230

*Includes angler, bluefish, bonito, butterfish, crabs (Jonah, others) conchs, cunner, cusk, conger eel, flounder (Am. plaice, sand-dab, summer, witch, yellowtail), haddock, hagfish, silver hake, halibut, john dory, lumpfish, mackerel, menhaden, ocean pout, redfish, scup, sea raven, sharks, skates, squids, tautog, tilefish, yellowfin tuna, wolffishes.

lobsters. Banner and Hayes (1996) mapped potential lobster habitat in Great Bay in 1996 using a suitability index model, however, the lower estuary where lobsters are most abundant was not included in the study. Lobsters undergo a seasonal migration into the Great Bay Estuary in late spring and migrate well into Great Bay in the summer and early fall. Migrating lobsters only include lobsters at or near legal size, i.e., ≥40 mm carapice length. Many juvenile lobsters overwinter in the lower Piscataqua River and the near coastal area of New Hampshire. It is hypothesized that lobsters may take advantage of accelerated growth rates in the Great Bay Estuary in summer (Dr. W. Watson, UNH, personal communication). Though juvenile lobsters can be found in many habitats from the shallow subtidal zone and in the deepest channel areas of the estuaries, dive surveys and trap research indicate that their preferred habitat is rock-cobble bottom (Dr. Hunt Howell, UNH and Mr. Bruce Smith, NH Fish and Game, personal communication).

The NH Fish and Game Lobster Program study areas for both juvenile and adult lobsters include the Piscataqua River south of Dover Point, the lower river, outer Portsmouth Harbor and coastal area, and the Isles of Shoals. Sea sampling data indicates that catch per unit effort (CPUE) from 1992 to 1996 has been stable for all areas, with higher catch rates in the river and coastal area than at the Isles of Shoals (Figure 4.6). Dive surveys indicate that lobsters are most abundant from June through

Value ($) for recorded fish landings in New Hampshire: 1992-1997. **TABLE 4.8**

	1992	1993	1994	1995	1996	1997
Fish						
Alewife	4,900	576				
Cod	3,169,995	2,673,803	2,708,000	2,469,878	2,143,393	1,635,941
Dogfish Spiny	50,638	252,983	393,548	397,812	189,537	145,723
American Eel	430	2,076				
Winter Flounder	134,087	88,709	87,114	69,353	67,904	38,368
Hake Mix Red & White	6,469	1,972	3,366	2,541	6,250	7,242
Atlantic Herring	50,681	87,085	44,448	5,512	3,050	14,237
Pollock	743,414	837,745	803,698	725,822	578,714	780,992
American Shad	2,429	1,764	8,850	7,789	9,039	4,794
Atlantic Silverside		4,616				
Smelt	43				395	
Tuna, Bluefin	1,208,612	1,299,083	1,231,522	1,197,550	849,403	
Shellfish and Worms						
Green Crab	1,177					
Rock Crab				13	60	
Lobster	5,033,198	5,567,109	5,566,282	6,655,660	6,563,641	4,636,975
Mussels						12
Sand Worms						2,138
Sea Scallop			772	1,386	1,271	8,077
Sea Urchins	49,589	26,501	6,648	3,359	11,604	16,870
Shrimp (Pandalid)	252,492	932,247	818,524	1,420,581	1,274,983	1,047,257
Totals*						
Value ($)	12,054,527	12,941,155	13,397,832	14,925,401	13,531,968	10,500,781
Landed Pounds	9,471,438	10,474,945	12,155,643	11,723,114	10,123,219	9,398,882

*Includes Angler, Bluefish, Bonito, Butterfish, Conchs, Crabs (Jonah, Others) Cunner, Cusk, Conger Eel, Flounder (Am. Plaice, Sand-Dab, Summer, Witch, Yellowtail), Haddock, Hagfish, Silver Hake, Halibut, John Dory, Lumpfish, Mackerel, Menhaden, Ocean Pout, Redfish, Scup, Sea Raven, Sharks, Skates, Squids, Tautog, Tilefish, Yellowfin Tuna, Wolffishes

October. Lobsters were sampled using an otter trawl in the Portsmouth Harbor area in 1991 and the data indicate that juvenile lobsters are abundant (Johnston et al., 1994). The number captured per five minute tow at eight stations ranged from three to thirty three. Lobsters can also be plentiful in Great Bay at certain times of the year. Langan (1996) caught as many as 26 juvenile lobsters per 10 minute tow in the mid-Great Bay channel in July.

Lobsters and other marine organisms at sites outside Hampton Harbor have been monitored by NAI since 1975 as part of environmental assessments designed to determine the impacts of the Seabrook nuclear power station. The station became operational in August, 1990, and data can be categorized as pre-operational (1975-1989), operational (1991-present) and 1990 data during the transition. Nearfield sampling off Hampton Harbor (NAI, 1996) indicates that lobster abundance has been stable since 1982, however 1995 CPUE of all lobsters (legal and sublegal) was higher than all previous years. The high CPUE in 1995 could be related to elevated temperatures during 1995 (NAI, 1996). Changes in the legal size limit in 1984, 1989 and 1990 have resulted in a decrease in the capture of legal size lobsters and an increase in the number of juvenile lobsters caught (Figure 4.7).

In 1996, an oil spill in the Piscataqua River had a negative impact on lobsters, particularly those that were in traps at the time of the spill. An estimate of the number of lobsters killed from the oil spill is not available. A major rainstorm

FIGURE 4.6 *Comparison of sea sampled lobster catch per unit effort 1992-1996 (NHF&G Lobster Program).*

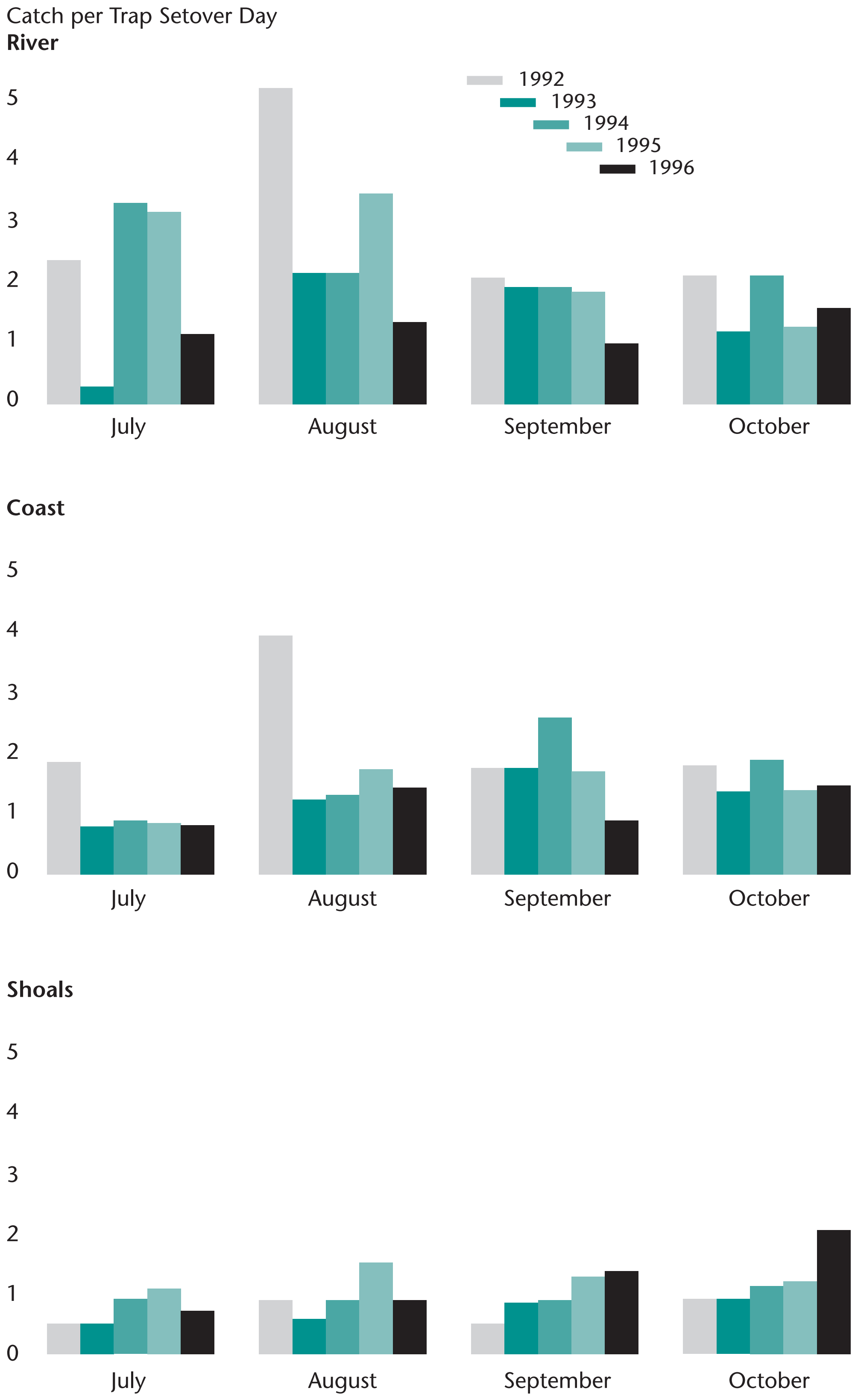
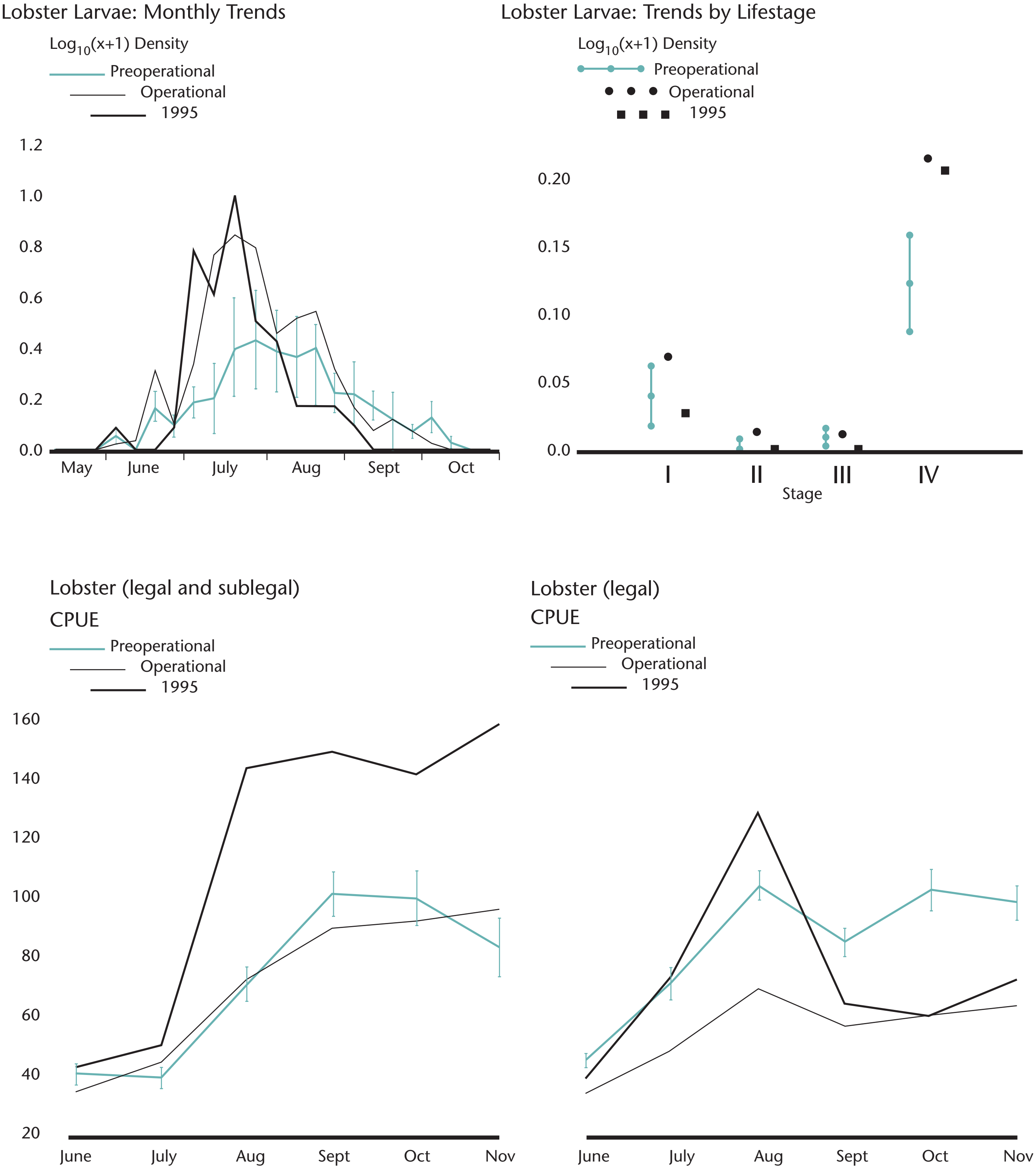


FIGURE 4.7

Preoperational (1975/78-1989), operational (1991-1995) and 1995 means of: a. Weekly density (no./1000 m2) of lobster larvae at Station P2, b. Lobster larvae density by life stage at P2, c. Monthly CPUE (15 traps) of total (legal and sublegal) lobsters at Station L1, and d. Monthly CPUE (15 traps) of legal-sized lobster at Station L1. Seabrook Operational Report, 1995. Vertical bars are 95% confidence limits.



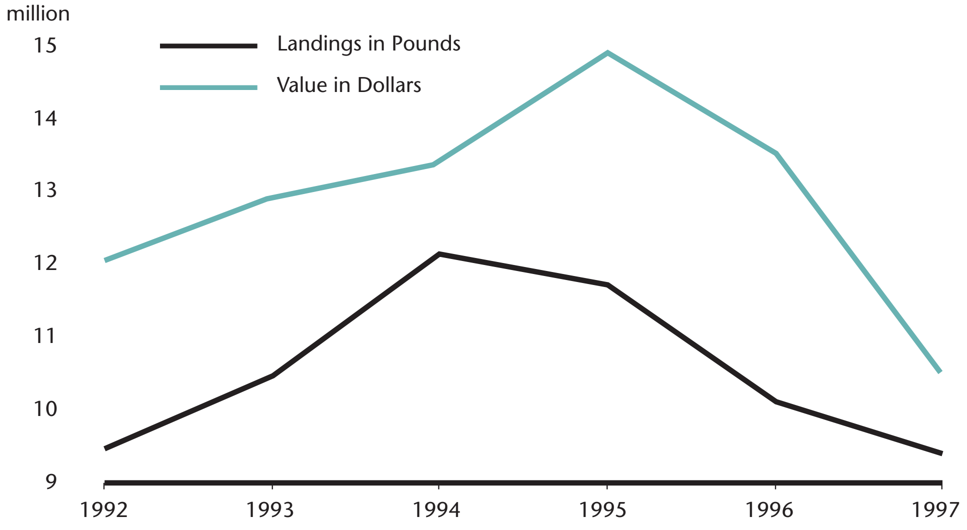
in October, 1996 dumped up to 12” of rain on the NH Seacoast on October 19 and 20. The sudden drop in salinity killed lobsters that were in traps as far down the estuary as Portsmouth. The total number of lobsters that succumbed to the massive freshwater input is not known, although this may in part explain the lower landed pounds and value for lobster in 1997 (Tables 4.7 and 4.8).

Other Commercial Fisheries

Other commercial fisheries in the Great Bay and Hampton/Seabrook estuaries include baitfishing for alewives, mummichogs (*Fundulus sp.*) and tomcod using gillnets, seines and minnow traps; trapping for eels, and angling and dipnetting for smelt. The landings and dollar value of these fisheries in the estuaries are not known, although limited data on the total catch of alewives, eels and smelt in New Hampshire are presented in Tables 4.7 and 4.8. There is also a commercial fishery for sea urchins, though this activity takes place primarily outside the estuaries in near coastal waters. Harvest methods include SCUBA and trawling with an urchin sled. Concern by some that the sled was disturbing bottom habitat prompted the NH Fish and Game to assess the impact caused by urchin dragging. Though the sled disrupted macroalgae, they found that the sled had little impact on nonvegetated hard bottom (Mr. Bruce Smith, NH F&G, personal communication). Thus, sleds can be used anywhere seaward of the Piscataqua River bridges and outside of the other New Hampshire harbors. The inshore/estuarine commercial scallop fishery was discussed in another section. It should be noted here that the inshore (>3 mi, < 25 mi) and offshore (>25 mi) groundfish populations have been in severe decline since the early 1980’s due to overexploitation (NOAA 1992). The reduced stocks and the strict regulations imposed on commercial fishermen has had a tremendous impact on coastal economies.

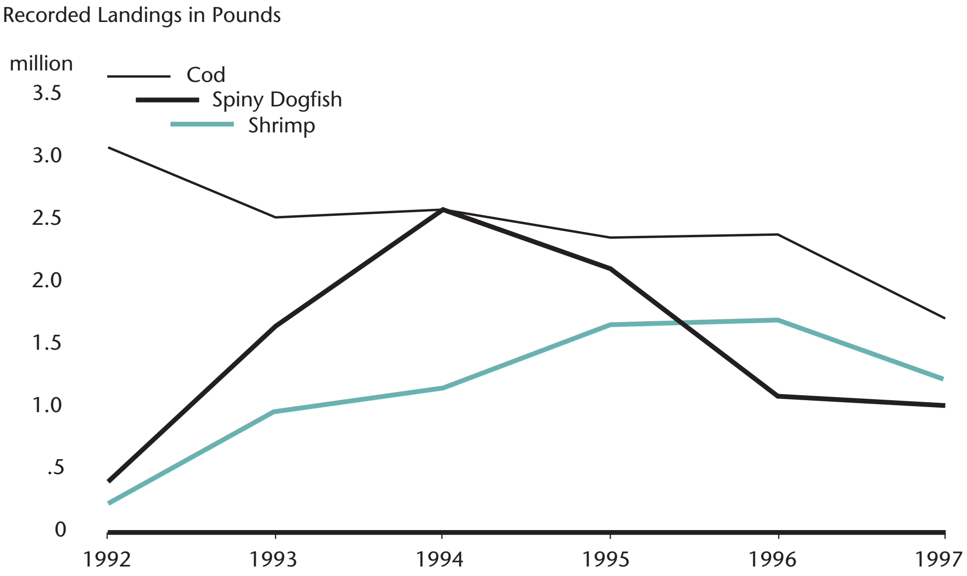
The commercial fishing fleet of New Hampshire also fishes in the Gulf of Maine outside the estuarine environment. The total recorded weight of fish landings caught by the New Hampshire commercial fishing fleet, and the value at the pier from 1992 to 1997 are summarized in Tables 4.7 and 4.8, respectively, based on NMFS data. The landed pounds have declined somewhat from highs of 12.1 million pounds in 1994, but are essentially the same as 1992 levels (Figure 4.8). The value of the fish declined to $10.5 million in 1997, the lowest recorded since 1992. Some of this may be attributed to the decrease in landings and value of lobsters in 1997.

FIGURE 4.8 *Total recorded fish landings and value in New Hampshire: 1992-1997 (NMFS).*

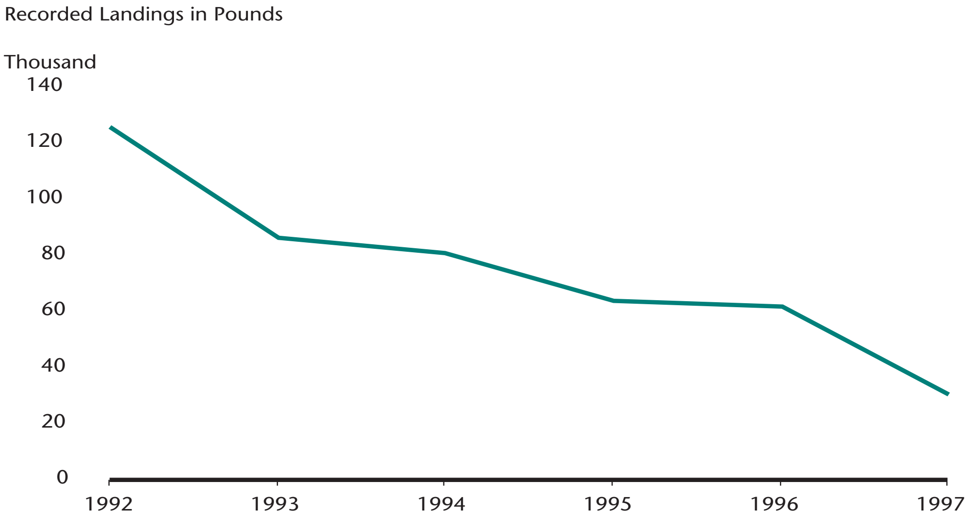


The landings and values of twenty finfish and shellfish species are listed in Tables 4.7 and 4.8. The most consistently important species are lobsters and cod, both in terms of value and landings. Whereas the landings of lobsters had been relatively constant until 1997, the cod landings have declined steadily since 1992, from 3.1 million to 1.7 million landed pounds (Figure 4.9). A similar trend is apparent for winter flounder (Figure 4.10). However, other species have exhibited different trends. The landings of spiny dogfish increased dramatically from 1992 to 1994, then declined sharply until leveling off after 1996 (Figure 4.9). Shrimp landings exhibited a steady increase from 1992 to 1996 (Figure 4.9). Sea urchin landings declined sharply from 102,494 pounds in 1992 to 4074 pounds in 1995, with a slow rebound since (Table 4.7). Other trends are also apparent, and these all reflect changes in world market prices, harvest pressure, government regulations and abundance of wild stocks. For example, the value of the lucrative tuna fishery was adversely affected in 1998 by the Asian financial crisis.

Recorded landings of cod, spiny dogfish and shrimp in New Hampshire: 1992-1997 (NMFS). **FIGURE 4.9**



Recorded landings of winter flounder in New Hampshire: 1992-1997 (NMFS). **FIGURE 4.10**



Aquaculture

Though aquaculture is one of the fastest growing industries in North America and globally, it has been slow to take hold in New Hampshire. In the early 1980's there were four commercial shellfish aquaculture operations in the Great Bay Estuary, engaged in the culture of indigenous (Eastern) oysters, the European flat oysters and hard clams (*Mercenaria mercenaria*). Three of these operations were located in New Hampshire and one in Maine, and only the Maine company is still in operation in 1998. Failure of the state shellfish sanitation program to meet the requirements of the National Shellfish Sanitation Program (NSSP) resulted in closure of all commercial marine aquaculture operations in New Hampshire by the U.S. Food and Drug Administration (USFDA) in 1989, and the three NH companies were forced to cease operations. To date, New Hampshire has been unsuccessful in gaining endorsement of its growing waters program (NSSP, 1995) from the USFDA, though the State's shellfish sanitation program has improved in recent years.

In 1996, a commercial oyster aquaculture permit was granted to three commercial fishermen participating in a research program associated with UNH. The project was funded by the NOAA/NMFS Fishing Industry Grants Program which was created to provide commercial fishermen with alternative business opportunities. The project produced nearly 730,000 oyster seed in 1996, which were planted at a five acre site near the mouth of the Oyster River in Little Bay. The project has continued to the present. The same program (NOAA/FIG) has funded a fisherman to research sea urchin culture, and commercial permits were granted to him in 1996, and to another individual in 1997. One of these operations was located in Hampton Harbor.

Other activity in shellfish culture includes a UNH sea scallop research project which is evaluating culture and stock enhancement techniques for scallops and several UNH sea urchin projects. In 1998, Spinney Creek Shellfish Co. in Eliot, ME, began operating a softshell clam hatching facility and successfully produced seed for outplanting experiments in flats on the Maine side of the Great Bay Estuary. UNH Cooperative Extension has also operated a culture facility for softshell clams in Seabrook. The facility is primarily used for 4H educational programs.

There has also been a great deal of activity in the past few years associated with finfish culture. A commercial summer flounder hatchery and nursery began operation in 1996. The company, Great Bay Aquafarms, is currently producing fingerlings for growout at other locations but plans to construct a growout facility on site in the near future. The company's operations are based in a warehouse on the PSNH power generation site in Newington, NH and are entirely indoors, using sophisticated recirculating and biofiltration technology to grow fish in land based tanks. It is the first commercial summer flounder operation in the U.S. More than 250,000 fish were produced in 1996. Research on lumpfish, several flounder species, cod and haddock is being conducted at the UNH Coastal Marine Laboratory. Engineering research on offshore fish pens has been conducted in association with one of the finfish projects by the UNH Ocean Engineering Department.

New Hampshire has the opportunity to develop a viable aquaculture industry. As far back as the 1940's Professor C. Floyd Jackson recommended developing aquaculture of clams and oysters in Great Bay (Jackson 1944). Ayer et al. (1970) determined that a seed oyster industry in Great Bay could be viable if hatchery reared seed were used. More recently, a NH legislative study committee on aquaculture (NH Legislative Committee, 1993) recommended development of an oyster culture industry. Research and development in other parts of the country and abroad have resulted in technologies that are suitable for New Hampshire. There are opportunities in the high technology, land-based finfish operations similar to Great Bay Aquafarms, as well as in environmentally friendly and ecologically beneficial shellfish culture. Mussels, scallops, oysters, clams and seaweeds are all excellent candidates for culture in New Hampshire and would provide economic as well as ecosystem benefits. Aquaculture could provide a means of maintaining seafood production in the New Hampshire Seacoast, and provide the beleaguered fishing industry with an alternative to harvest fisheries. A recent UNH Sea Grant Document (Howell et al., 1997) outlines the potential and benefits of aquaculture development in New Hampshire.

4.3.1.4 Marine Products

The NAI (1994) report identified three seafood processing facilities in New Hampshire. The Yankee Fisherman's Coop Pier in Hampton Harbor handles both shellfish and finfish, the Portsmouth Fish Co-op handles groundfish and Little Bay Fisheries in Portsmouth Harbor handles lobster.

4.3.1.5 Marine Plant Harvesting

Salt hay farming continues to this day and has experienced a small revival in northern Massachusetts, yet the impacts from salt hay farming on salt marsh ecosystems are unknown (Rozsa, 1995). Algae have been harvested for various uses in New England, but such harvest in New Hampshire estuaries are poorly known and probably minimal. Impacts to the algal resources from experimental harvesting have been assessed for the red alga, Irish moss (Mathieson and Burns 1975). They found that plants could recover in a year after carefully controlled harvesting, but winter harvesting had greater impacts to the algal beds. Seagrass has been harvested in the northeast for building insulation and upholstery stuffing, but it is probably most widely used, as wrack collected from shorelines, for garden mulch and fertilizer. The scale of such activities in New Hampshire does not appear to have been large, and although their potential impacts are unknown, they are likely minor.

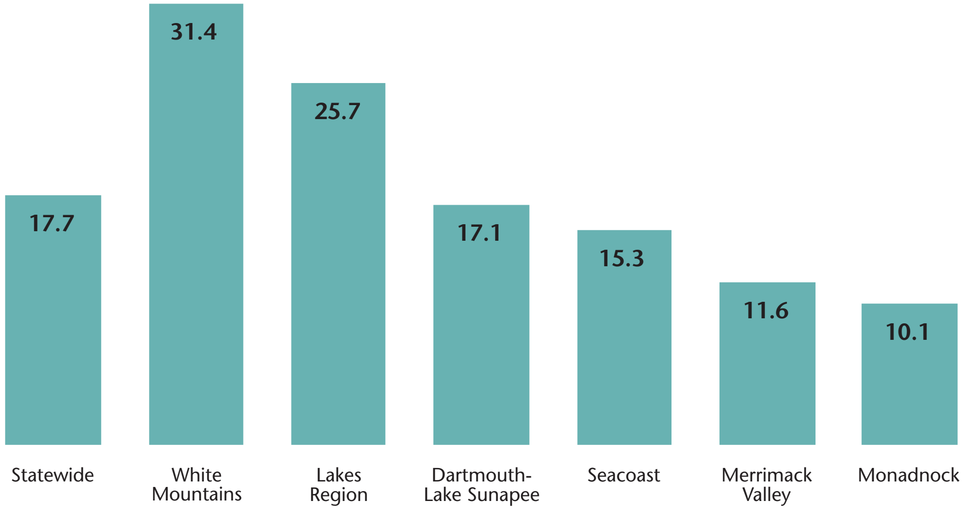
4.3.2 RECREATIONAL USES

4.3.2.1 Tourism Economics

Tourism and travel are important to the Seacoast economy (Okrant et al., 1994). Statewide in FY 1992, 10.3% (57,740) of all jobs were directly dependent on travel/tourism, and associated payrolls totaled $770 million, or 4.8% of all New Hampshire payrolls. In the Seacoast, 16% of the region's jobs were supported by tourism (Figure 4.11). Monthly spending for rooms and meals in the Seacoast during the six months from May-October

Percentage of jobs supported by travel and tourism in New Hampshire regions in 1992 (Okrant et al., 1994).

FIGURE 4.11



was higher than during November-April, with a peak spending of >$20,000,000 in August.

There are numerous tourist-related activities in the Seacoast that involve use of charter boats. These activities include sport fishing, whale watching, windjammers/charter sailing, and harbor tours/day cruises. The numbers of vessels involved with these activities and their locations in the Seacoast are summarized in Table 4.5. None of the vessels are located in the tidal rivers, with a relatively even spread of locations for the different activities across the Seacoast.

4.3.2.2 Boating and Related Activities

The State of New Hampshire Department of Safety records boat registration and provides annual summaries. Boats are recorded by size, hull material and type (inboard, outboard, etc.). No differentiation by tidal and freshwater use is provided. A survey by NAI (1994) of harbor officials in New Hampshire showed 8,522 and 341 recreational vessels operated during 1992 in Rockingham and Strafford counties, respectively (Table 4.9). The NHDES used 1993 NH Department of Safety data to estimate that 3,468 vessels were tidal water registrations having marine sanitation devices.

Of the 8,863 total recreational vessels in 1992, 335 were at slips and 738 at moorings (Table 4.9). There were also nine marinas or yacht clubs in Rockingham County, plus four in Strafford County. In 1995, the NHDES counted nine marinas/yacht clubs. The New Hampshire Port Authority has authority over moorings. Permits are granted for moorings at 22 sites. Waiting lists are maintained for moorings at the different sites, with as many as 211 people waiting for Little Harbor moorings in December, 1996, and an estimated 20 years wait at Rye Harbor. Mooring holders are classified as resident and non-resident, as well

TABLE 4.9 *Private recreational vessels in coastal New Hampshire in 1992 (NAI, 1994).*

		Recreational Vessels	
Site*	**Total No.**	at slips	at moorings
River			
Squamscott R.	80	15	4
Lamprey R.	45	30	14
Lamprey River Marina	30	30	0
Oyster R.	41	0	41
Cocheco R.	50	30	4
George's Marina	30	30	0
Harbor/Bay			
Great Bay	7	0	7
Little Bay	500	130	248
Great Bay Marina	158	100	58
Little Bay Marina	50	30	20
Portsmouth Harbor	7500	40	140
Portsmouth Yacht Club	25	20	5
Kittery Yacht Club	26	20	6
Portsmouth Back Channels	30	0	30
Little Harbor	330	160	120
Wentworth Marina	160	160	0
Hampton Harbor	280	50	130
Hampton River Marina	150	40	110
Total	8863	445	738
Rockingham County	8522		
Strafford County	341		

*Sites include 13 marinas, 9 in Rockingham County and 4 in Strafford County.

as mooring either pleasure or commercial boats. In 1991, there were 1390 mooring permits sold (Figure 4.12). The rapid increase from 1976 to 1991 leveled off after the NHPA adopted and implemented a harbor management plan in 1989. Mooring field parameters are set by the US Army Corps of Engineers, and current space for new mooring permits is extremely limited. In 1996, the areas with the most permits were Little Bay (222), Hampton (193), Little Harbor (131), Rye (129) and the Piscataqua River (119), with 268 permits spread around eight specific areas in Portsmouth Harbor, the Back Channel and other areas in Portsmouth. Very few new permits are expected in the near future.

Another means of assessing boating activity can be found in data from the New Hampshire Bridge Authority for openings at the Memorial Bridge in Portsmouth. The openings are a measure of traffic for vessels greater than 11 feet in height, and include sailboats, commercial tugs, barges, freighters and many pleasure craft. The monthly and annual counts for boats under the bridge from 1989 to present are shown in Figure 4.13. Recently there has been a slow, steady decrease in traffic, from 7470 in 1990 to 5860 in 1996. Figure 4.13 shows that the greatest traffic occurs during the summer months of July and August, whereas the lightest traffic occurs during winter months.

4.3.2.3 Recreational Fishing

The Great Bay Estuary supports a diverse community of resident, migrant, and anadromous fishes, many of which are pursued by recreational fishermen. Recreational fishermen mainly pursue striped bass, bluefish, salmon, eels, tomcod, shad, smelt, and flounder. Fishing is not limited to boat access, as cast or bait fishing is done from the shore in many places, from the bridges crossing the

Annual mooring permit sales by the New Hampshire Port Authority: 1976-1996. **FIGURE 4.12**

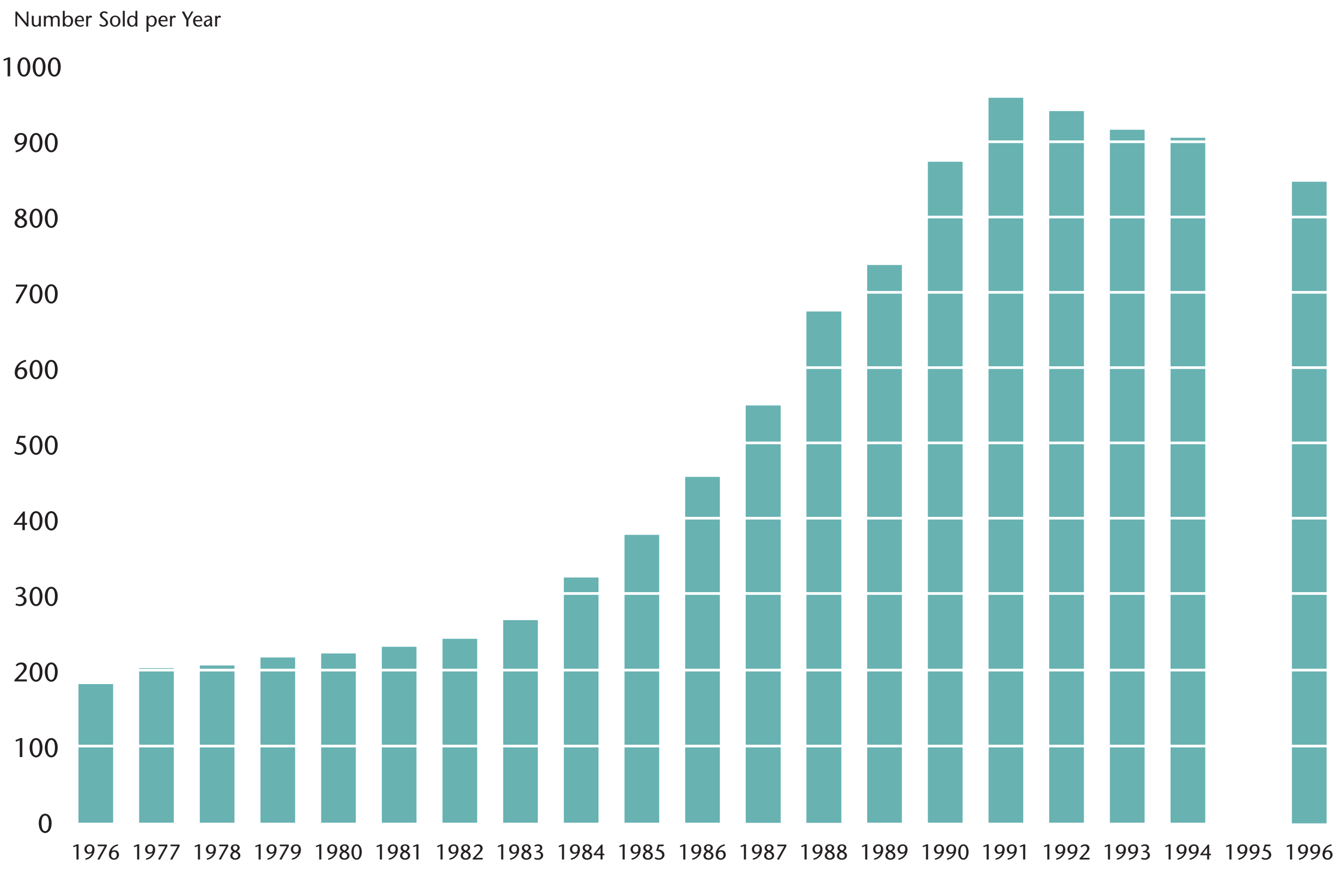
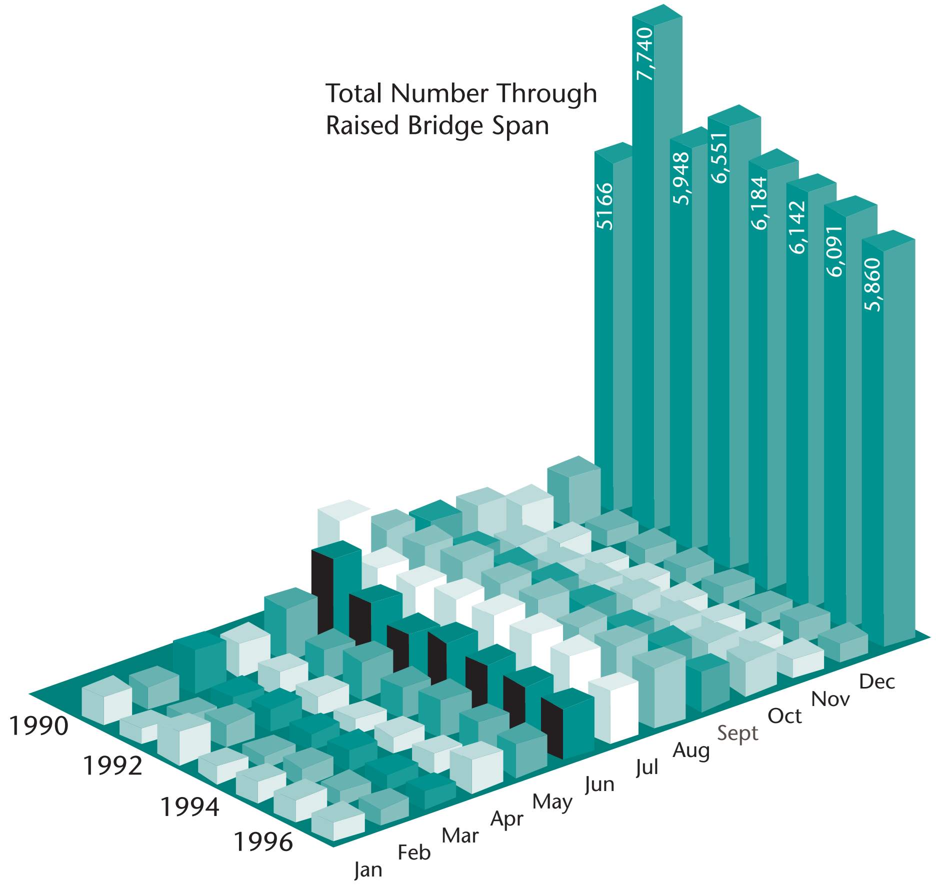


FIGURE 4.13 *Monthly and annual vessels passing under the raised span of the Memorial Bridge, Portsmouth, New Hampshire: 1989-1996.*



estuary, and ice fishing is popular in the tidal rivers. Recreational fishing in salt water does not require a license except for smelt in Great Bay Estuary; trout, shad and salmon in all state waters; and to take any fish species through the ice.

The yearly New Hampshire Recreational Saltwater Fishing Digest (NHF&G, 2000) provides profiles of the eight primary game fish species: striped bass, bluefish, Atlantic mackerel, rainbow smelt, winter flounder, Atlantic codfish, haddock and pollock, as well as profiles on twenty other game fish species that may be found in coastal New Hampshire. The digest also provides information on the ethics of recreational fishing, the 'Let's go Fishing' program, safe boating, a list and maps of coastal access sites, instructions on catch and release techniques, proper digging of clams and requirements for recreational lobstering.

Several charter boat companies in the Great Bay Estuary take fishermen to pursue striped bass, bluefish, and pollack, while companies operating out of Hampton Harbor carry fishing parties to inshore waters for clams and to the offshore waters to pursue cod, flounder, mackerel, and other fish. One of the major winter activities in Great and Little Bays is ice fishing for smelt. The smelt fishery in Great Bay occurs primarily in the Greenland Cove and the Lamprey, Squamscott and Oyster river areas from early January to March. Numerous businesses cater to smelt anglers, and access sites for smelt fishing are available. The NHF&G Department has pursued stocking and monitoring efforts on selected fish stocks (e.g., shad and Atlantic salmon; see section 4.4.3.1: Anadromous Fish Restoration) in order to enhance recreational fisheries (NHF&G, 1989). Another important recreational fishing activity is trap fishing for lobsters. Almost 150 recreational lobstermen set traps throughout the Great Bay and Hampton/Seabrook estuaries, with the Portsmouth Harbor area being a rather popular location.

Studies by NHF&G Department consultants identified substantial sums of monies spent on marine recreational fishing. An estimated 88,000 saltwater anglers spent over $52 million dollars in 1990 on fishing-related activities (approximately $600 per person). The largest expenditures were for food and beverages, automobile fuel, charter/party boat fees, bait and fishing tackle, and boat fuel. A substantial amount of that total is estimated to come from expenditures in Great Bay estuarine activities. More information on recreation fishing is presented in the Living Resources section (see Striped Bass, 3.2.1.1).

4.3.2.4 Shellfish Resource Management and Recreational Harvesting

Shellfishing is an important and popular recreational activity in the estuaries. The Great Bay Estuary supports a large recreational shellfishery for oysters, clams and mussels. Oysters are the predominant shellfish resource utilized in Great Bay, although Little Harbor supports more concentrated populations of clams. Major oyster beds are located in Great Bay proper, as well as in the Piscataqua, Bellamy, and Oyster rivers, with scattered pockets of oysters also found throughout the estuary (Figure 1.7). Though only recreational harvesting is allowed, the estimated dollar value of oysters in major beds was nearly $1.6 million in 1981 and $3 million in 1994. Approximately 5,000 bushels of oysters, valued at $300,000 are harvested annually by the 1,000 license holders (Manalo et al., 1991). Recreational harvesting of shellfish in the Great Bay Estuary is currently limited to most of Great Bay and Little Bay, with the Piscataqua River (including Little Harbor), and the smaller tidal rivers closed to harvesting due to bacterial pollution (Figure 1.8). The harvesting of softshell and razor clams in Great Bay, though difficult, became intensified in recent years because of limitations on harvesting of more popular clamming areas such as the flats in Hampton and Little harbors.

The principal shellfish resource in Hampton Harbor is the softshell clam, found in five major resource areas (Figure 1.9). These flats were closed in 1988, but with the conditional reopening of some of the flats in the fall of 1994 and further openings in 1998, almost 3,000 clamming licenses were sold in 1994 (up from 239 licenses in 1993). Prior to clam bed closures in 1988, the average number of licenses sold in the State between 1971-1987 was 6,400. Rye Harbor clam flats remain completely closed (Figure 1.11). The contribution of recreational shellfishing in Hampton Harbor to the local and state economy has been estimated to be $3 million per year (Manalo et al., 1992).

Effects of Classification on Shellfish Resource Productivity

Resource productivity of shellfish beds is determined by management of harvesting pressure and by the natural mortality, reproductive capacity and recruitment of the shellfish themselves. Causes of natural mortality include predation, disease, and siltation (in the case of oysters). Recruitment (addition of new individuals) depends on reproductive success, larval survival and successful metamorphosis. Classification of shellfish growing areas, which determines where shellfish can be harvested, plays an important role in shellfish resource productivity.

Oysters thrive in lower salinity waters than other important species of shellfish, and therefore are often found near sources of freshwater inflow such as tidal rivers. The locations of major oyster beds have been described in several publications dating back to the 1940's (Jackson 1947, Ayer et al 1970, Nelson 1981) and the current locations of beds are shown in Figure 1.7. Due to their proximity to pollution sources and associated higher than acceptable levels of fecal bacteria, all oyster beds in the Bellamy, Oyster, Piscataqua and Salmon Falls rivers, as well as those in southwest Great Bay have been closed since 1989, and some have never been open to direct harvest. In a turbid estuary like Great Bay, undisturbed (unharvested or uncultivated) oyster beds tend to accumulate silt which can result in burial in areas with low current velocities, and in impairment of larval attachment because of a lack of clean substrate even in beds with high flows. MacKenzie (1989) found that even a millimeter of silt on an oyster shell can deter larval settlement. The action of harvesting, whether by tongs or dredge, or cultivation with some sort of mechanical device, helps to remove silt, expose buried shell and provide a favorable substrate for larval settlement. A study conducted in 1991 (Sale et al. 1992) found that oyster beds at Nannie Island and Adams Point which are harvested recreationally with tongs and rakes, and beds on the Maine side of the Piscataqua River which are harvested with a small hand drag, showed major differences in population structure than beds in the Oyster River and on the New Hampshire side of the Piscataqua River which had been closed to harvest. The harvested beds showed higher relative densities of smaller oysters indicating better recruitment, while the populations in closed areas were skewed toward larger, older individuals. These findings are well supported in the literature (MacKenzie 1989, Visel 1988). Lack of harvesting and cultivation in some of the oyster beds in the Great Bay Estuary has probably contributed to significant loss of oyster areal coverage and density in the Oyster, Bellamy, and Piscataqua rivers and in southwest Great Bay (NHF&G, 1991).

Closure of the clam beds, and resulting absence of harvest pressure can have variable effects on clam populations. Besides the depletion of approximately 80% of adult clams, standard digging practices can reduce juvenile clam density by 50% through physical damage and exposure to predators (NAI, 1996). On the other hand, harvesting, which causes a change in sediment density and texture, can enhance settlement of larval *Mya*. Also, when tidal flat areas are undisturbed, blue mussels can form dense beds, sometime up to a foot thick, that can prevent settlement of clam larvae. In Hampton Harbor, closure of all flats in 1989 resulted in an overall increase in clam density, indicating that recreational clam digging was a significant source of mortality from adult and juvenile clams prior to April 1989 (NAI, 1996). The changes in clam density, however, varied from flat to flat. From 1990-1995, adult clam densities quadrupled in the middle ground, while Common Island densities did not change, and Hampton River density decreased by 50%. The effect of clam digging on the Common Island and Browns River flats, which reopened in 1994, was not apparent in 1995, as clam densities were similar in the two years. Though predation, disease and spatfall play a major role in determining clam densities in Hampton Harbor, a report by Savage and Dunlop (1983) clearly demonstrates the effect of clam digging on clam populations. Therefore closure of areas, whether for resource management or public health reasons, generally results in greater density of adult and juvenile clams.

Harvesting Effects on Other Wildlife

Though there is general agreement in shellfish producing states that oyster and some types of clam harvesting improve shellfish productivity (Visel 1988, MacKenzie 1989, Rask 1986) and do not harm benthic or pelagic species, there are few scientific studies that have dealt specifically with the effects of oyster harvesting on benthic populations. Dumbauld (1997) reviewed a number of studies of the impact of oyster culture and harvesting on benthic communities on the west coast of the U.S. and concluded that mechanical harvesting had no long term effects on benthic populations. Langan (1995) found no differences in density or species diversity of benthic invertebrates between an unharvested oyster bed in the Piscataqua River and one which was harvested with a towed hand drag.

There have been no documented adverse effects of scallop dredging on benthic populations, though Caddy (1973) reported damage to juvenile and adult scallops by a large, heavy offshore scallop dredge. It is unlikely that the smaller sized dredges used for inshore scalloping in New Hampshire cause the same magnitude of damage.

The effect of clam digging on undersized clams was discussed earlier, and there have been no documented studies of effects of clam harvesting on other wildlife in Hampton Harbor.

Siltation and Harvesting Effects

The effect of siltation on unharvested oyster bed productivity was addressed in an earlier section. It is reasonable to assume that mechanical or even hand harvesting of oysters will release sediment into the water column. No studies have been done in the Great Bay Estuary to assess the impact of resuspended sediments from oyster tonging, however, Langan (1995), measured suspended sediments in the track of a towed oyster drag on a Piscataqua River oyster bed. Water samples were taken with a submersible pump approximately 0.25 m from the bottom every 20 meters for a distance of 110 meters of the drag track. Ambient suspended sediment concentration was 10 mg/L. This concentration increased to 22 mg/L at a 10 m distance behind the drag and gradually decreased with distance before returning to ambient conditions at a distance of 110 meters. The study indicates that the disturbance of a towed drag is localized and suspended sediment conditions quickly return to ambient levels.

Though sediment disturbed by clam digging undoubtedly results in some resuspension of sediments when the tide begins to cover the clamflats, there has been no documentation in New Hampshire of adverse effects of resuspension from clam digging.

Management Strategies for Recreational Beds and Flats

Management strategies for recreational oyster beds consist of a daily harvest limit of one bushel of unshucked oysters per day per license holder, and a closed season in July and August. Oyster licenses may only be obtained by New Hampshire residents, and harvesting may only be done between sunrise and sunset by hand, rake or tong. The license must be displayed on the container and oysters may not be shucked on site. Areas open to harvest are determined by the NH Department of Health and Human Services and area closures are enforced by the NH Fish and Game Law Enforcement division. Oyster densities and sizes are monitored periodically by the Marine Fisheries Division of the New Hampshire Fish and Game. The recreational harvest is not recorded, therefore it is difficult to assess the effect of harvesting on oyster populations. Ayer (1970) estimated that annual harvest in the late 1960's to be approximately 3,000 bushels. An oyster survey by Manalo et al. (1991) estimated the harvest to be about 5,000 bushels based on responses from one third of license holders. A 1997 survey by NH Fish and Game estimates an annual harvest from 1993 to 1996 of approximately 3,000 bushels. Recreational license sales, which had been stable for may years at about 1000 licenses, declined to <800 licenses in 1996.

Recreational oyster management has also included an enhancement program undertaken by NH Fish and Game (Nelson 1989). Approximately 1000 bushels of surf clam shell were planted near Nannie Island and 500 bushels at Adams Point on firm bottom sparsely populated by oysters. Spatfall on the clean surf clam ($238/m^2$) was significantly higher than on existing shell ($8.2/m^2$). The project demonstrated that shell planting is an effective means of enhancing oyster populations. It should be noted that in high sediment areas, surf clam shells act similarly to sediment collectors as they almost always land cup up and fill with sediments, thereby reducing their effectiveness in catching oyster spat over time. Experiments with different types of shell as a spat attractant (Ayer 1970, Langan 1996) indicate that oyster shells and scallop shells are more effective.

Commercial harvest of clams in New Hampshire ceased in the 1950's. Regulations for management of softshelled clams have changed considerably over the years, with recreational harvesting becoming more restrictive in order to protect the resource. Clamming is permitted in daylight hours on Friday and Saturday from the day after Labor Day to May 31, with Hampton/Seabrook Harbor flats not opening until November 1. Clammers must have a valid license, available only to New Hampshire residents. Daily limit is a 10 quart pail of unshucked clams. The clam harvest has been estimated by head counts of clam diggers. During the period 1980-1982, at a time when there were 5,000 to 6,000 licenses, it was estimated that the annual harvest ranged from 2,000 to greater than 6,000 bushels (Savage and Dunlop 1983), though some documents report as many as 16,000 bushels harvested in the early 1970's. With the current rainfall condition (< 0.1 " of rain in the preceeding five days, except <0.25 " during December through March, or any occurrence of $\geq$0.1" rain in 24 h), the reduced season in Hampton Harbor, and fewer licenses sold since the 1989 closure, it can be surmised that current harvest is lower than the in previous 80-82 years. License sales peaked at nearly 14,000 in the 1975, dropped to less than 300 in the early 1990's and have rebounded in 1994-1996 due to the reopening of Hampton Harbor. During the 1996-97 clamming season (November 8, 1996 to May 30, 1997) in Hampton Harbor, clamflats were open for 19 days, during which an estimated 900 bushels of clams were harvested by an estimated 2,880 recreational harvesters (NHF&G, 1997b).

A clam enhancement study was undertaken by the New Hampshire Fish and Game in 1988 on the Willows clam flat in Hampton Harbor (Nelson 1989). Approximately 30,000 seed clams were planted at a density of 15 spat/m^2 under predator exclusion netting, and at 3.4 spat/m^2 in an adjacent area. Additional netting was placed on the flat to protect any natural spat that might settle. A little over two months after planting, the area was sampled and only two seed clams were recovered. It was determined that natural spatfall was very poor and that the planted clams either moved or were eaten by predators.

Illegal Harvesting

Illegal harvest of clams occurs in the Hampton/Seabrook Estuary. Over the past several years, there have been arrests to discourage illegal harvest. However, the activity, which is conducted under cover of darkness, is very lucrative and difficult to control, even though law enforcement is also concentrated on nighttime activity. Removal of large quantities of clams by illegal commercial digging presents a problem for resource management, and represents a public health threat if the clams are harvested from closed areas and sold to an unsuspecting public. Illegal harvesting of clams, oysters and other shellfish in other areas has not been documented.

Post-harvest Processing

The University of New Hampshire has a long history of scientific studies on post-harvest processing of shellfish to remove microbial pathogens. In addition, the existence of Spinney Creek Shellfish, Inc. (SCS), a commercial shellfish facility in Eliot, ME, has provided an excellent venue for scientific and applied studies on the post-harvest processing of shellfish. The potential for contamination problems in each step of their process has been evaluated (Howell et al., 1995). The effectiveness of ultraviolet depuration on oysters, clams and mussels has been confirmed at SCS and in laboratory-scale depuration tanks (Jones et al., 1991a&b; Panas et al., 1986). Although depuration is not effective for removing pathogenic vibrios from shellfish (Jones et al., 1991a&b), relaying shellfish into unfiltered estuarine water that does not contain pathogenic vibrios has been effective in reducing vibrio levels to low levels (Jones et al., 1995). Viruses are also generally resistent to removal via traditional depuration. Current research is underway at UNH/JEL to determine the potential for depuration of the human parasites *Cryptosporidium* and *Giardia* spp. (Dr. S. Torosian, personal communication).

4.4.1 BASE PROGRAM ANALYSIS

The following sections review the technical information that is available for various aspects of issues related to management of human uses of New Hampshire's Seacoast. Another NHEP document, the Base Programs Analysis (Carlson, 2000), reviews existing local, state and federal regulatory measures and natural resource management or education programs which impact estuarine resources. Thus, those topics are not included in this document.

4.4.2 LAND PROTECTION

The percentage (16%) of permanently protected land within 300 feet of the shoreline of New Hampshire's tidal waters (Figure 4.4) is significant in that a much lower percentage of shoreland is available for development than in inland areas. Much work to prioritize land areas, based on evaluation of habitat value, has been completed.

Various strategies have been used to help identify and prioritize important habitat areas in coastal New Hampshire. Important habitats in coastal New Hampshire have been identified using a GIS (Sprankle, 1996). All habitat was ranked based on the habitat requirements of 55 species of concern. Ranks were summed for all species and habitats potentially important for the target species were mapped. In a related effort, New Hampshire's most important natural resources were identified (Ueland et al., 1995). The Seacoast and Great Bay were identified as high priority areas, based on the value of their natural resources. The GIS maps include a delineation of important natural resources and habitats. Banner and Hayes (1996) conducted a pilot study in coastal New Hampshire to develop methods for selection of evaluation species, assessing habitat suitability and mapping habitat, as well as to identify and facilitate protection of important habitats using that information. They mapped the habitats for 25 species that were selected based on local concerns and a species priority list for the Gulf of Maine.

GIS Surveying in process

4.4.3 HABITAT RESTORATION AND MITIGATION

Human development and pollution of estuaries and coastal areas has led to the destruction of important habitats throughout the world. Though New Hampshire's estuaries are in good condition relative to many other estuaries on the east coast of the U.S., human activities that occurred prior to the realization that natural habitats play an important role in the ecology and economy of the region have resulted in impacts to important estuarine habitats. Many tidal marshes have been filled and tidal flow restrictions caused by road construction has degraded others. Dams constructed on tidal rivers prevent passage of anadromous fish. Sediment erosion from clearcutting, and sawdust from lumber mills has smothered some shellfish beds, while historical direct dumping and discharge of untreated industrial and municipal waste has contaminated others. Though the regulatory framework for protecting further habitat destruction has been established, restoration of habitats that were destroyed or adversely impacted by past activities has been and will continue to be a priority in New Hampshire's estuarine and coastal areas. Over the past two to three decades, the development of techniques for habitat restoration has made the prospect of restoring or creating habitats a viable option for coastal resource management.

A mitigation process is required in federal regulations for major development projects that impact legally protected environments (e.g., wetlands). The regulation requires three steps: investigation of alternative sites, reduction of the proposed impacts, and compensatory action to replace the functions and values of the habitats to be impacted by the development. When estuarine or coastal habitats are involved in such a development, habitat restoration is the preferred mechanism of compensatory mitigation.

4.4.3.1 Anadromous Fish Restoration

During the industrial development period in the 18th and 19th centuries, dams were constructed on nearly all of New Hampshire's tidal rivers. The dams prevented access by anadromous fish to their freshwater spawning grounds. Beginning in the 1970's, fishways or fish ladders were constructed on the Cocheco, Lamprey, Oyster, Taylor, Winnicut and Exeter rivers (Figure 4.14). The fishways now allow passage of river herring, shad, lampreys and many other species from tidal to fresh waters to spawn.

Currently, the NH Fish and Game Department is maintaining fishways and monitoring the spawning runs of several species. They are also working to restore anadromous fish populations through their Coastal Anadromous Fish Species Program. The goals of this program include raising sea-run salmon for stocking coastal rivers; the transfer of spawning shad into coastal rivers; and construction of fish passage systems. Approximately 250,000 salmon fry were stocked into the Lamprey and Cocheco rivers with the help of 50-100 volunteers in 1996 and 1997 (Cornelisen, 1998), a practice that has occurred yearly since the 1980s. Ongoing NHF&G monitoring is tracking the progress of these efforts and provides valuable data on numbers, size, sex and age of returning fish populations.

4.4.3.2 Shellfish Restoration

Restoration of degraded or depleted shellfish beds has become a major focus in the United States and abroad. There is not only an economic incentive, but an ecological one as well. Areas that have lost the majority of their shellfish resources (Chesapeake Bay, Delaware Bay) are experiencing severe water quality problems due to a large extent to the loss of filter feeders. Oysters in the Chesapeake Bay in 1900 were capable of filtering the entire water volume of the bay in 24 hours. The reduced number of oysters (due to disease and overharvesting) would now take nearly a year to filter the same volume.

The application of techniques developed by the aquaculture industry has made restoration of natural oyster beds

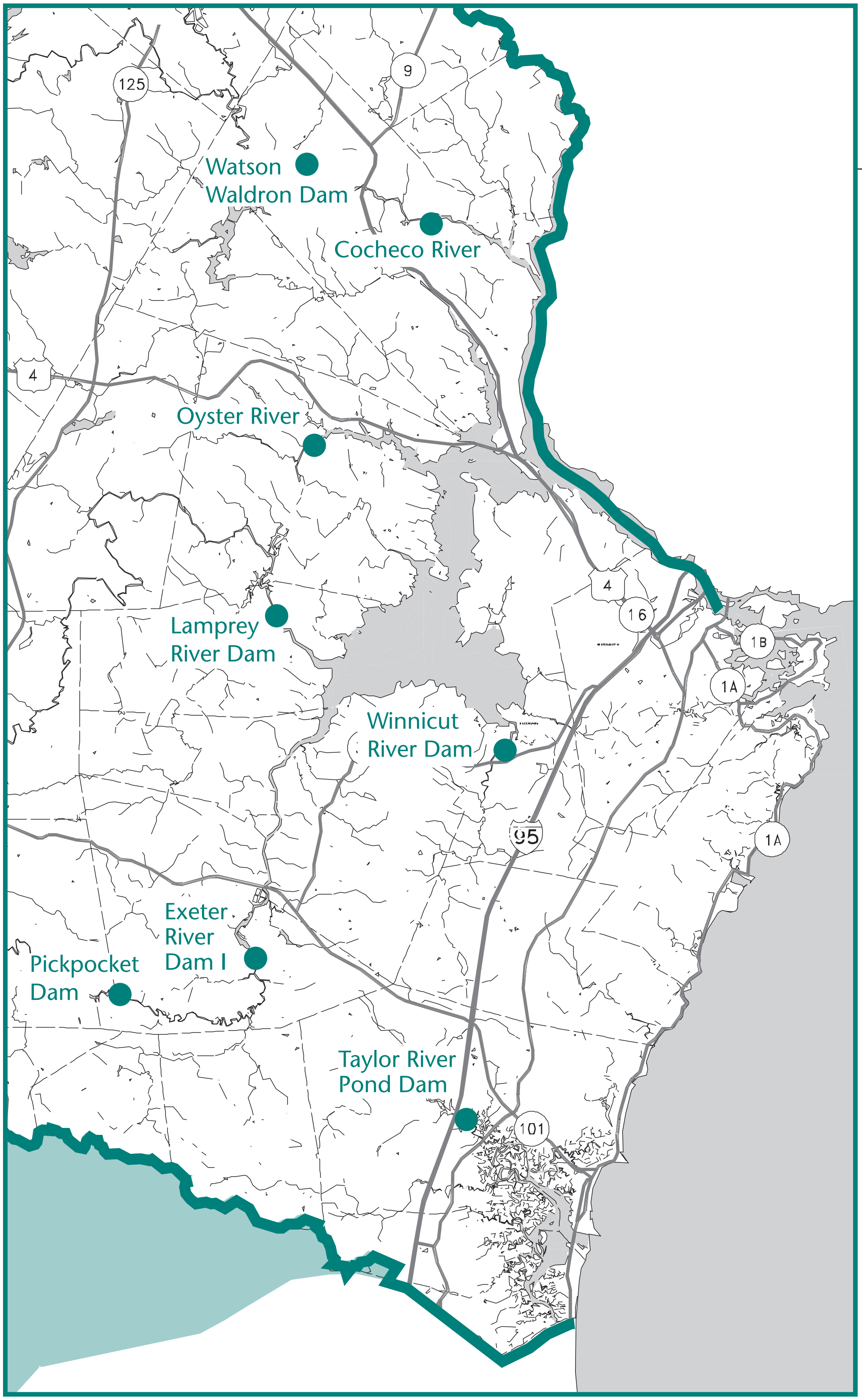


FIGURE 4.14

Fish ladders in the New Hampshire Coastal region.

Spat collectors

R. LANGAN

possible. Shell planting (described in section 4.2.1.4), remote setting using hatchery reared larvae and construction of artificial and shell reefs have all proven successful in oyster restoration. In areas where oyster diseases are present, resistant strains of oysters may be introduced. An aquaculture project by researchers at UNH/JEL which began in 1996 to determine whether oyster aquaculture is a feasible alternative for commercial finfish harvesters has employed remote setting of hatchery reared larvae on natural and artificial cultch. Good results were obtained using French spat collectors called “Chinese hats”, and 130,000 spat were produced on 30 Chinese hat units and planted in the fall of 1996. An additional 600,000 spat set on shell were also planted. Growth and mortality of the oyster seed is being monitored, and a second year of setting commenced in May, 1997. These same techniques can be used to restore public recreational beds. In addition, oysters in suspended culture can be used to filter phytoplankton from waters such as the Salmon Falls River where intense blooms occur in summer. A current UNH project has established two new oyster beds in the Salmon Falls River and will determine beneficial impacts on water quality.

Softshelled clam restoration is not quite as advanced as oyster restoration. A past restoration effort was described in section 4.2.1.4. A number of techniques ranging from planting hatchery reared clams to manipulating the flats to enhance natural settlement have met with mixed success. There are several techniques that have been used in Maine and Cape Cod that have shown excellent results (Beal 1994; Leavitt, personal communication; Gowell, personal communication).

Though the amount of estuarine habitat suitable for sea scallops is small, sea scallops are an important winter fishery for some NH lobstermen and an active recreational fishery for SCUBA divers. Sea scallop beds are located at the mouth of Portsmouth Harbor from Salamander Point to Fort Point near Fort McClarey, in Spruce Creek and from Fort Point to Jaffrey Point along the New Castle shore. Density, size (age) distribution and movement of scallops was studies by Langan (1994) in the lower Piscataqua River. In 1996, artificial spat collectors were deployed in the river to test the feasibility of spat culture and natural enhancement using non-destructive methods to collect natural scallop spat. Similar techniques are practiced in Canada, New Zealand and Japan. These methods form the basis of sustainable commercial scallop fisheries in those countries, and have been shown to enhance natural populations by increasing recruitment in the vicinity of the collectors. Spat settlement in the area under the collectors were monitored in June, 1997, and compared to adjacent areas to determine the effectiveness of the collectors for enhancing natural populations.

4.4.3.3 Saltmarsh Restoration

Restoration of many salt marshes in New Hampshire has focused on reestablishment of tidal exchange to marshes where tides have been restricted by undersized and damaged culverts (Drakeside Road Marsh, Locke Road Marsh), water control structures such as flap gates (Mill Brook Marsh Stuart Farm), and berms of debris or dredge spoil (Awcomin Marsh in Rye Harbor, Sandy Point Marsh at Great Bay NERR) (Morgan et al., 1996). Reestablishment of tidal regimes similar to those found downstream of the restriction has resulted in rapid recovery of several functions and successful restoration projects (Burdick et al., 1997). Restoration activities at 6 restrictions has improved tidal flooding to approximately 60 acres of impacted salt marshes in New Hampshire by 1997. Other areas present unique problems. For example, a small salt marsh (<1 acre) was created on New Castle Island at the southern entrance to Little Harbor as mitigation for the Wentworth Marina. The marsh failed but was replanted by a new contractor following regrading and deployment of wave barriers to reduce wave exposure. The marsh was replanted in stages (from 1988 to 1992) and is gradually developing (Dr. D. Burdick, UNH, unpublished data).

Information on nineteen recent salt marsh restoration projects is presented in Table 4.10. These data have been compiled as part of a Gulf of Maine-wide project (Cornelisen, 1998). The cited projects were supported by many different agencies for a range of different purposes. The total estimated acreage of saltmarshes that have been targeted is 433 acres, and the cost per acre ranged from $800 to $236,000. The high per acre cost of some of the compensatory projects may be because of the requirement of the permit applicant to replace habitat

Recent saltmarsh restoration projects in New Hampshire (Cornelison, 1998). **TABLE 4.10**

Project Title	Funding Agency	Town	Area (acres)	Cost/acre	Project Type*
Sandy Point salt marsh	NHOSP/CP	Stratham/Greenland	5.0		r
Little River salt marsh		North Hampton	156.0		r
Bass Beach salt marsh		North Hampton	10.0		r
Awcomin salt marsh	NHOSP/CP; USACE;USFWS	Rye	35.0	$3,167	r
Locke Road	NH OSP/CP	Rye	53.0	1,806	r
Haul Road salt marsh		Seabrook	0.5		c, r
Wentworth Marina		New Castle	1.0		c, cr
Mill Brook salt marsh restoration		Stratham	10.0		r
N.H. marine terminal mitigation	NHPA	Portsmouth	1.6	236,220	r, cr
Seabrook wastewater treatment facility		Seabrook	0.6		c, r
Rye Harbor		Rye	15.0		r
Route 101: Squamscott River bridge	NHDOT	Stratham	3.7	81,071	c, r
Winnicut River salt marsh		Greenland	?		r
Fairhill saltmarsh restoration project		Rye	12.2		r
Landing Road salt marsh		Hampton	?		r
Stuart Farm	NHOSP/CP	Stratham	4.0	5,536	
Route 1-A	NHOSP/CP	Rye	40.0	1,229	
Drakeside Road	NHOSP/CP	Hampton	22.0	1,392	
Marsh Road	NHOSP/CP	Rye	50.0	800	
Total			**419.6**		

* c= compensatory; r= restoration; cr= creation.

Salt marsh restoration at Fairhill Marsh.

GBNERR

function, often in close proximity to the site of habitat loss (Cornelisen, 1998). High costs are a function of the removal of fill, planting, land acquisition and other expensive requirements. There is a stark contrast in cost between low-cost habitat restoration projects, which are not only lower cost projects but also can result in much more acreage restored, and habitat creation projects.

4.4.3.4 Eelgrass Restoration

In addition to the mitigation activities described below, eelgrass restoration efforts have been conducted on an experimental scale at several sites in the Great Bay Estuary (Carlson, 1997) and several more recent eelgrass restoration projects have been funded by the USEPA. One project is located in the Bellamy River and another is in Little Bay, where eelgrass beds, possibly killed by the “wasting disease”, have not become reestablished for over 10 years.

In Rye Harbor, another US EPA-funded eelgrass restoration is designed to create eelgrass habitat and potentially benefit the ecological health of the harbor. The eelgrass distribution in Rye Harbor has been limited to a series of small beds in a perched intertidal tide pool. Reconfiguration of the storm-distributed rock and sediment material across a broad area in the inner harbor will allow the expansion of the tidepool eelgrass habitat. To encourage this expansion, some transplanting will be done.

4.4.3.5 Port of New Hampshire Mitigation

When the N.H. Port Authority decided to expand the State Port Facility by adding a new pier, containment structure, wharf, and two-lane connecting bridge, it was clear that some estuarine habitat would be destroyed or affected in the process. The U.S. Army Corps of Engineers and the N.H. Wetlands Board issued a permit for the $18 million construction, with State and Federal resource protection agencies stipulating that the permit include provisions for mitigation of the projected habitat loss (Short and Short, 1997). Additionally, as an unusual provision, the mitigation was required to meet specific success criteria before actual port construction could begin. The NHPA Mitigation Project cost $1.8 million. It is a large and successful compensation for environmental impacts to the estuary with sites located along the Piscataqua River and in Little Bay.

The multi-year mitigation project combined the efforts of the University of New Hampshire, the private consulting firm of Dames and Moore, and a salt marsh restoration company based in Massachusetts called Great Meadow Farms. Eelgrass, salt marsh, and mud flat habitats were created during the three-year effort. The three-habitat mitigation was meshed where possible, so that the habitats could develop in proximity, as they often do in nature. Finding sites for the various mitigation was a major preliminary task. The mitigation work is now complete and has entered a 15-year monitoring phase; this long-term monitoring is another unique aspect of the project.

More of each habitat was created or enhanced than was projected to be lost to construction of the new port facility. For eelgrass, the created:impacted ratio was 1.4:1; for salt marsh the ratio was 2:1; and for mud flats the ratio was 1:1. In part, these ratios were designed to compensate for the gap in overall habitat values to the estuary as the newly created habitats established themselves. Transplanted salt marsh is particularly slow to redevelop all of its functions and values, and therefore had the highest ratio.

Mitigation success criteria were based largely upon "best estimate" and were without strong scientific foundation. The mitigation project was held to success criteria that included plant survival and plant coverage. A NOAA-funded research project based in part on the port mitigation determined what kinds of criteria are most effective in judging mitigation success.

A total of 6.5 acres of eelgrass was transplanted into the estuary, making this the largest eelgrass transplanting project ever done on the east coast. Several locations were chosen along the Piscataqua River and in Little Bay, i.e., in quieter areas of these heavily travelled waters. Transplants put into intertidal sites largely failed, as eelgrass was scraped away during the following severe winter by large sheets of tidally-driven ice. Subtidal sites were largely successful and have filled in to create new eelgrass habitat. The mitigation efforts have resulted in the development of new, more effective methods for transplanting eelgrass (Davis and Short, 1997).

A unique aspect of the Port mitigation project was its replacement not only of eelgrass habitat, but of potential habitat as well. The Port construction was due to impact areas where no eelgrass grew, but that were very suitable for eelgrass growth and that likely sustained eelgrass habitat in the past. Therefore, compensating for the loss of such potential habitat was considered by the regulatory agencies as they formulated the permit for Port construction.

Creating new mudflat areas required finding previously-filled upland areas that could be excavated and put back under water. Over 5 acres of mudflats were enhanced by increasing tidal flooding to a cove. A dam was removed and the channel deepened, so that a previously rarely flooded area that often smelled bad is now flushed by tidal waters twice daily. New mudflats were also created (1.4 acres) by excavating previously filled upland, resurfacing it with mudflat sediment, and grading it to intertidal elevations (Grizzle, 1997).

Kelp beds were created along the boulder borders of the Port mitigation terrace on the Piscataqua River. Propagules set on the boulders and grew rapidly over the two years since the terrace was installed, creating a new kelp forest habitat.

Salt marsh was transplanted into two sites near the proposed Port expansion project (Burdick, 1997). The salt marsh sites were both chosen as being heavily degraded estuarine shoreline in need of enhancement and reconstruction. At each site, degraded estuarine shoreline was reconfigured to conform to the tidal regimes required by salt marsh plants, which are very sensitive to submersion times and frequency. A total of 1.6 acres of salt marsh was transplanted (Table 4.10), transforming a debris-strewn stretch of shoreline near an old railway bed and a much-altered roadway and bridge abutment back into productive estuarine habitat.

4.5

SUMMARY OF FINDINGS

The review of technical information on human uses and resource management in coastal New Hampshire showed varying amounts of information are available for the different areas of concern. The important observations on trends and information gaps are presented below.

- The population and density of the two coastal counties in New Hampshire have exhibited steady increases over the past twenty years, and this trend is projected to continue at a somewhat slower pace. The continuation of increases in population and density in New Hampshire's two coastal counties is a concern because of the accompanying increases in development, use of coastal resources and production of pollutants, and the potential adverse impacts these factors can have on environmental quality.
- Commercial fishing is the coastal industry with the most significant economic activity and employment. This industry is subject to destabilizing influences such as world market prices, harvest pressure, government regulations, weather and abundance of wild stocks.
- Commercial lobstering has been the highest value fishery in New Hampshire. Landings have been relatively stable over the past decade, although extreme weather events have had adverse effects on the harvest in estuaries.
- There are some coastal communities that have high percentages of developed land and little more area available for development. In addition, much (40%) of the remaining developable land within 300 feet of tidal waters is permanently protected.
- There is a wide variety of important vessel-related activities, including commercial fishing, shipping and recreational boating, the latter two of which may exhibit further increases in activity.
- Dredging activities are well coordinated and regulated and will continue to be important for maintenance of safe and accessible harbors.
- Aquaculture is beginning to become established in New Hampshire. The successful four-year operation of a land-based summer flounder facility is complemented by research and pilot projects on other finfish, shellfish and a variety of types of aquaculture operations.
- Recreational activities such as boating, fishing, shellfishing and tourism are growing in importance as economic activities in coastal New Hampshire.
- Recreational shellfishing is currently limited by water quality. Improvements in water quality and management of shellfish resources that are anticipated as part of a bolstering of the State's shellfish program will benefit all forms of recreational and commercial uses and the environmental quality of coastal New Hampshire.
- Numerous recent and on-going studies have provided information to help planners of future development to identify and prioritize ecologically important habitats for potential protection and conservation.
- Improvements in environmental quality and ecosystem integrity have been realized through efforts to restore habitats and species such as saltmarshes, eelgrass and anadromous fish. Other important habitats like shellfish beds are currently the subjects of research and will greatly benefit and provide enhanced estuarine-wide environmental quality from future significant restoration efforts.

5 SUMMARY OF FINDINGS

This report has been organized into four chapters, including an introductory chapter and three chapters covering the broad topics of water quality, living resources, and human uses and management of resources. At the end of each chapter are summary lists of the significant finding within the chapter. No prioritization was made beyond separation of the listed, more significant findings from the rest of the information in the chapters.

This chapter presents the findings from the whole report in three tables that serve as a framework for prioritizing identified problems. Issues are listed and identified as either being a problem or not in Table 5.1. Their causes, impacts and locations are identified along with trends, solutions and agencies or organizations involved in addressing the problems. The information in Table 5.1 is further distilled into a list of priority documented problems in Table 5.2. These problems are considered to be the most significant because impacts have been documented and either human uses or environmental quality are directly affected. Thus Table 5.2 serves as a summary of the highest priority problems that could be addressed through NHEP activities. Table 5.3 is a list of potential problems that have a lower priority for immediate action but could be significant in the future or under the right circumstances. The problems identified in these tables are presented in the same order in which they appear in the first four chapters. Review of the appropriate chapter will provide further details on any given problem.

J. PETERSON

Storm drain stencilling.

ENVIRONMENTAL ISSUES AND TRENDS

Issue	Problem	Isolated Locations within NH estuaries	Throughout NH Estuaries	Impacts
Water/ Sediment Quality Microbial Pathogens/ Fecal Bacteria	Elevated concentrations	Cocheco R. Dry weather	Yes (during wet weather)	Public health risk and shellfish closures
Nutrients	Loading to some rivers	Salmon Falls & Cocheco Rivers	No	Intense blooms (Freshwater), isolated low dissolved oxygen (Salmon Falls River)
Trace metals: Chromium (Cr), Lead (Pb), Mercury (Hg)	Elevated concentrations in sediments	Cr (Great Bay), Hg (Piscataqua R.)	Pb	Unknown
Polyaromatic Hydrocarbons (PAHs)	Unknown	Little Bay, Piscataqua R.	Unknown	Unknown
Polychlorinated Biphenyls (PCB)	PCB residues elevated in lobster tomally		Yes	Lobster tomally consumption warning
Suspended Sediments	Unknown	Seasonal occurrences in tidal tribs to Great Bay & Piscataqua R.	Unknown	
Toxic Algal Blooms	Coastal		Throughout the Gulf of Maine	Shellfish closure (mussels), potential public health risk
Living Resources: Shellfish Oysters	Low oyster population densities, reduced bed area	Great Bay and tributary rivers	No	Loss of critical habitat, ecosystem functions, and economic activity
Soft Shell Clams	Decreasing density		Unknown	Loss of ecosystem function, and economic activity
Blue Mussels	Unknown		Unknown	Unknown
Scallops	Unknown		Unknown	Unknown
Lobsters	Catch stable, some die off			Some dead from oil, more from freshwater
Finfish Striped bass	No			
Winter flounder	Declining population, commercial and recreational catch		Throughout the Gulf of Maine	Loss of important commercial and recreational resource
Smelt	Unknown		Unknown	Unknown
River herring	Unknown		Unknown	Unknown
Shad	Decreasing returns		Unknown	Unknown
Silversides	Unknown		Unknown	Unknown
Infaunal Benthos	No			
Eelgrass		Little Bay, Rye Harbor		
Saltmarshes	Restricted tidal flow and changes in vegetation		Yes	Loss of salt marsh function
Macroalgae	Loss of habitat	Unknown	Unknown	Unknown

Documented	Trend	Suspected/Documented Causes	Potential Solutions
Yes	Decreasing	Stormwater, Waste water treatment facilities bypasses and malfunctions, possible failing septic systems, and possibly illegal direct discharges of septage	Point source identification, stormwater management, monitoring, local code enforcement and innovative treatment technologies
Yes	Unchanged	Waste water treatment facilities effluent, stormwater runoff	Reduce point source loading, stormwater management
Yes	Decreasing	Historical sources, stormwater, municipal and industrial discharges, and atmospheric deposition	Continued sediment and water quality monitoring
Yes	Down/episodic inc.	Stormwater, vessels, oil spills	Continued sediment and water quality monitoring and spill prevention
Yes	Decreasing	Historical discharges	Unknown
Yes	Decreasing 93-96	Resuspension by wind, waves, tides and ice	Continued sediment and water quality monitoring
—	Unknown	Circulation patterns and toxic algae distribution in the Gulf of Maine	Continued phytoplankton and water quality monitoring
Yes	Decreasing	Sediment accumulation, cultch removal, disease, and poor spatfal	Habitat restoration, disease monitoring, and resource management
No	Decreasing	Sedimentation, predation,disease and possibly harvest pressure	Habitat restoration, resource assessment and management
	Population increasing		None needed
	Unknown		Further research
Yes(oil), No (Freshwater)	Stable	Current management and existing capture methods	Continued management
Yes	Increasing	Good regional and local management	Continued management
Yes	Decreasing	Overharvesting in Gulf of Maine	Improve management and possible stocks enhancement
Yes	No trend, highly variable	Unknown	Continue stocks assessment
Yes	Some rivers up, other down	Unknown	Continue stocks assessment
Yes	Decreasing returns	Possibly overharvest or predation	Continue stocks assessment, and examine stocking program
Yes	Insufficient data	Unknown	Consistent stocks assessment
Yes	Stable		Periodic monitoring
Yes	Increasing since 1989	Increased resource protection, recent lack of disease outbreaks, restoration efforts	Continued protection, monitoring, restoration and mitigation
Yes	Increase in restored march acreage	Restoration of tidal flow and reduction in freshwater volume through stormwater management	Continued restoration and stormwater management
No	Possibly increasing	Possible local excess nutrients	Research and monitoring

Issue	Problem	Isolated Locations within NH estuaries	Throughout NH Estuaries	Impacts
Phytoplankton	Late summer blooms during low flow periods	Salmon Falls River	No	Low dissolved oxygen-Salmon Falls River
Freshwater Wetlands	Loss of wetland acreage (some local gains)		Yes	Loss of wetland habitat and function
Other Waterfowl	No		Yes	
Eagles	No		Yes	
Terns	Limited breeding in NH	Nearshore islands, coastal salt marshes	No	Lower seabird diversity
Ospreys	No	Great Bay	No	
Other Issues Shoreline Habitat	Loss of shoreline habitat acreage		Yes	Potential for decreased water quality, loss of habitat function
Upland Habitat	Loss of upland habitat acreage		Yes	Potential for decreased water quality, loss of habitat function
Conservation Lands	Acquisition of land and conservation easements for open space and habitat preservation		Yes	Protection/loss of habitat
Impervious Surfaces	Increased area of impervious surfaces		Yes	Water quality degradation, increased stormwater runoff volume and velocity, loss of habitat
Shipping	Potential for spills and discharges	Piscataqua River	No	Oil spills and ballast water contaminants
Boating	Potential for spills, discharges and habitat disruption		Yes	Illegal waste discharge, habitat destruction, other contaminants (debris, oil&gas)
Commercial fishing Finfish	Declining stocks		Throughout the Gulf of Maine	Tremendous economic impact and ecosystem alterations
Lobsters	Increasing Fishing effort		Yes	
Anadromous fish	Unknown		In all estuarine rivers	Restoration of spawning habitat and improved access to habitat
Dredging	Resuspension of potentially contaminated sediments; loss of eelgrass	Cocheco River Little Bay	No	Re-introduction of historical contaminants to the estuarine environment

Documented	Trend	Suspected/Documented Causes	Potential Solutions
Yes	Unchanged	Phosphorus in waste water treatment plant effluent (low flow periods) and stormwater runoff	Phosphorus removal and stormwater management
Yes	Decreasing acreage overall	Acreage decreasing due to road construction and residential and commercial development. Increased beaver population may create new wetland areas, often at expense of surrounding upland properties	Protection, mitigation
Yes	Increasing	Habitat protection, restoration and resource management	Continued protection, monitoring, resource management and habitat restoration
Yes	Variable, possibly increasing seasonal population	Species preservation and habitat protection	Continued preservation, protection and monitoring for environmental risk factors
Yes	Increasing	Breeding colony being re-established	Continued preservation, protection and re-colonization efforts
Yes	New nesting sites	Establishment of nesting platforms	Continued preservation, protection and monitoring for environmental risk factors
Yes	Acreage lost is Increasing (rate unclear)	Residential and commercial development, increase in impervious surfaces generating contaminated runoff	Establishment of riparian buffers, local zoning, various land protection and habitat restoration strategies, property owner education
Yes	Increasing	Residential and commercial development, increase in impervious surfaces generating contaminated runoff	Local zoning, various land protection and habitat restoration strategies, property owner education
Yes	Increasing	Growth, development and land use practices reducing habitat values and functions	Continued land purchases and conservation easements on local and regional levels
Yes	Increasing	Residential and commercial development, road construction	Local zoning, various land protection and habitat restoration strategies, property owner education
Yes	No trend	Result from accidents and operator error. Ballast water discharge is a routine function.	Improved accident prevention, oils spill response and potential treatment of ballast discharge
Unknown	Increasing/stable	Lack of facilities, boater ignorance of consequences of their actions	Education, pumpouts
Yes	Decreasing fish stocks	Overharvesting and habitat destruction	Comprehensive management strategies, stocks enhancement, potential for aquaculture
Yes	Stable	Current management and existing capture methods	Continued management
Yes	Increasing	Fish ladders, destruction of spawning habitat, and predation	Continued management, research and restoration activities
Yes	Unknown	Contaminant from historical and current sources buried in sediments	Research, continued dredge management

Table 5.2 *NHEP Priority Problems List: Documented Problems.*

Problem	Cause	Impact	Location Affected
CONTAMINANTS			
Elevated concentrations of microbial pathogens	Stormwater, CSO's, septics, WWTP's (bypasses,infiltration), boats and illegal connections	Shellfish bed closures Potential public health risk	Great Bay- Tidal rivers under all conditions systemwide in wet weather Hampton- Tidal creeks Tidal creeks under all conditions systemwide in wet weather
Elevated sediment and biota concentrations of trace metals (Cr, Pb, Hg)	Historical, municipal and industrial effluents, atmospheric deposition, Stormwater	No recent observations	Localized hotspots: Cocheco, Lamprey, Exeter rivers, PNS Systemwide means > regional means
Elevated concentration of PCB in lobster tissue	Unknown/historical discharges?	Consumption advisory	Systemwide and regional
Nutrient loading	WWTP's effluent exacerbated by low f.w. flow	Intense Plankton Blooms depressed oxygen	FW and isolated tidal portions of Cocheco and Salmon Falls rivers
LIVING RESOURCES			
Declines in oyster populations	Sedimentation, disease, loss of cultch, poor recruitment	Loss of valuable habitat Loss of ecosystem function Loss of harvesting opportunities	Systemwide
Decreased clam density, boom and bust fishery	Predation, harvest pressure, poor recruitment, mussel colonization, disease (?)	Loss of valuable habitat Loss of ecosystem function Loss of harvesting opportunities	Systemwide and regionwide
Declining flounder populations	Harvest pressure in Gulf of Maine Predation(?) by bass, cormorants	Loss of harvesting opportunities	Regionwide
Degraded saltmarshes	Reduced tidal flow, development	Change in vegetation	localized areas (identified by NRCS)
Declines in alewife returns	Unknown	loss of important forage species	Taylor River, Exeter River

NHEP Priority Problems List: Potential Problems. **TABLE 5.3**

Problem Contaminants	Cause	Potential Impact(s)	Locations Potentially Affected
Nutrient enrichment	WWTP's, stormwater and NPS (lawn fertilizer, septics)	Algal blooms, marcroalgal proliferation, low DO, eelgrass loss, decreased clarity	Tidal: Exeter/Squamscott* Lamprey (?) Impoundments in freshwater rivers
Toxic contamination	Dredging Cocheco River	redistribution of chromium & PAHs	Cocheco & Piscataqua rivers
Oil spills	Accidents	Lethal and sublethal affects	Piscataqua River and systemwide
Other Issues			
Increase in impervious surfaces	Development	Change in quantity and timing of delivery of stormwater Potential for increased contamination	Systemwide
Loss of riparian habitat	Development	Potential for increased contamination	Systemwide
Freshwater wetlands loss	Development	Potential for increased contamination Loss of flood control function	Systemwide
Changes in circulation patterns	Dredging	tidal flat erosion	Hampton Harbor (Seabrook)

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subject to chemical analysis. Whereas most samples had low to moderate concentrations of metals, DDT and PCBs, a high PCB concentration (>2.9 ppm) was found in one sample from Hampton Harbor (Figure 2.25), and a high concentration (>125 ppm) of vanadium was found in two samples from Rye Harbor. On the Maine side of Portsmouth Harbor, high concentrations of copper (>342 ppm), lead (>285 ppm), mercury (>3.0 ppm) and zinc (>436 ppm) were measured in numerous samples from the Portsmouth Naval Shipyard.

The estuarine chemistry of tin in its various inorganic and organic forms has been extensively studied (Weber et al., 1995). The studies have largely occurred in the Great Bay Estuary, providing information on the concentrations and dynamics of tin species in coastal New Hampshire. The estuarine chemistry of mercury has been the focus of more recent studies by the same group (Puk and Weber, 1994; Weber et al., 1998). Ongoing and pending studies are designed to determine atmospheric deposition, extensive spatial determinations of mercury concentrations in sediments, and elucidation of the biological cycling of mercury species in saltmarsh sediments in the Great Bay Estuary.

An assessment of fecal-borne microbial contaminants in sediments and water around the Portsmouth Naval Shipyard was made from September 1991 to June 1993 (Jones, 1994). The purpose was to use fecal-borne bacteria as evidence for the presence of sewage-borne waste materials, and to use such evidence to help establish the sources of the toxic contaminants found around the Shipyard. Measurements were made of *Clostridium perfringens* in water and in surface and subsurface sediments at 28 sites in the vicinity of the shipyard and in York Harbor from September 1991 through June 1993. *C. perfringens* concentrations were relatively low in water samples near the shipyard and site 23 in York Harbor had the consistently lowest levels of all sites. The highest levels of contamination in surface sediments and sediment cores were generally near Seavey Island, site 2 off New Castle and the Rt. 95 bridge, while lower levels of *C. perfringens* were apparent at sites in channels away from the Piscataqua River and in York Harbor. Sediment core profiles showed highly contaminated layers at some sites. Comparison of *C. perfringens* to lead and mercury concentrations showed similar trends in spatial distributions. The relationship between trace metal contaminants and the fecal-borne bacterial indicator suggests that some metals in sediments around the shipyard are probably associated with sewage effluent.

Besides microbial indicators of fecal contamination, there are numerous chemicals that are useful indicators of specific sources of nonpoint source pollution. Studies on the Portsmouth Naval Shipyard focused on a range of chemical markers and indicator compounds for sewage, atmospheric deposition, petroleum and runoff. Results suggested that sewage is a major source of heavy metals and toxic organic contaminants to the lower estuary, and other sources such as atmospheric deposition, urban runoff and petroleum spills also contribute contaminants (Bowen and Pruell, 1994).

Overall, the estuarine sediments of New Hampshire are contaminated with some trace metals and toxic organic compounds at relatively high levels. Most significant sources of contaminants are historical and similar or worse contaminated conditions have existed for over 20 years in some cases. The transport of contaminants with resuspended sediments throughout the Great Bay Estuary has been documented. Of course, transport of floating oil during significant spills is a well-documented example of contaminant transport. The potential for contamination even from remote sources, either naturally occurring or as a result of dredging and oil spills, is an ever-present threat. Prevention of further loading of contaminants where management is possible is thus an important concern. A coordinated monitoring program that includes periodic analysis of sediments is needed to determine temporal trends for sediment contaminants.

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APPENDIX A

Population and Population Density of Rockingham and Strafford County Towns

(NHOSP, 1997b)

Population by Towns: US Census and NH OSP Projections. **TABLE A-1**

Town	**Area (mi^2)**	**US Census 1990**	**OSP Est 1993**	**OSP Est 1995**	**OSP Est 2005**	**OSP Est 2015**
ROCKINGHAM COUNTY						
Exeter	19.5	12481	12500	11995	11943	12017
Greenland	13.6	2768	2863	2799	3085	3402
Hampton	13.5	12278	12466	11970	12028	12641
Hampton Fall	12.5	1503	1584	1424	1443	1529
New Castle	2.0	840	835	825	849	874
Newfields	7.3	888	964	800	736	749
Newington	12.1	990	700	675	736	812
Newmarket	13.8	7157	7308	7197	7952	8740
North Hampto	13.8	3637	3733	3274	2858	2903
Portsmouth	15.6	25925	22561	22766	24112	25033
Rye	14.0	4612	4590	4048	3396	3371
Seabrook	9.5	6503	6616	6547	7245	7959
Stratham	15.2	4955	5224	5873	8066	9395
Brentwood	16.8	2590	2677	2599	2858	3153
Candia	30.2	3557	3589	3599	3962	4370
Chester	26.0	2691	2812	2749	3113	3465
Danville	11.7	2534	2766	2974	4047	4713
Deerfield	51.9	3124	3194	3424	4273	4901
East Kingsto	9.9	1352	1458	1349	1500	1654
Epping	26.2	5162	5342	5548	6735	7616
Fremont	17.2	2576	2703	2599	2858	3153
Hampstead	14.4	6732	7056	7722	10216	11799
Kensington	11.8	1631	1631	1599	1698	1842
Kingston	20.8	5591	5651	5748	6594	7366
Newton	9.9	3473	3527	3524	3849	4245
Northwood	29.7	3124	3159	3299	3905	4370
Nottingham	48.1	2939	3001	3199	3934	4432
Raymond	29.3	8713	8925	9446	11999	13734
Sandown	14.3	4060	4228	4773	6566	7647
STRAFFORD COUNTY						
Dover	28.2	25042	25500	24324	24310	25767
Durham	25.5	11818	11515	11416	11303	11937
Madbury	14.0	1404	1456	1535	1853	2081
Rollinsford	7.7	2645	2681	2594	2647	2828
Barrington	49.1	6164	6406	6661	7954	8884
Farmington	37.4	5739	5810	5888	6480	7077
Lee	20.4	3729	3816	4374	5813	6679
Middleton	18.6	1183	1181	1334	1715	1956
Milton	34.7	3691	3758	4119	5122	5794
NewDurham	45.0	1974	1973	2266	2947	3364
Rochester	46.9	26630	26960	27078	29374	31948
Somersworth	10.3	11249	11370	10812	10935	10990
Strafford	52.0	2965	3083	3484	4639	5320

TABLE A-2 *Population Density By Towns: US Census and NH OSP Projections.*

Town	Area (mi²)	US Census 1990	OSP Est 1993	OSP Est 1995	OSP Est 2005	OSP Est 2015
ROCKINGHAM						
Exeter	19.50	640.05	641.0	615.13	612.46	616.26
Greenland	13.60	203.53	210.5	205.81	226.84	250.15
Hampton	13.50	909.48	923.4	886.67	890.96	936.37
HamptonFalls	12.50	120.24	126.7	113.92	115.44	122.32
NewCastle	2.00	420.00	417.5	412.50	424.50	437.00
Newfields	7.30	121.64	132.1	109.59	100.82	102.60
Newington	12.10	81.82	57.9	55.79	60.83	67.11
Newmarket	13.B0	518.62	529.6	521.52	576.23	633.33
NorthHampton	13.80	263.55	270.5	237.25	207.10	210.36
Portsmouth	15.60	1661.86	1446.2	1459.36	1545.64	1604.68
Rye	14.00	329.43	327.9	289.14	242.57	240.79
Seabrook	9.50	684.53	696.4	689.16	762.63	837.79
Stratham	15.20	325.99	343.7	386.38	530.66	618.09
Brentwood	16.80	154.17	159.3	154.70	170.12	187.68
Candia	30.20	117.78	118.8	119.17	131.19	144.70
Chester	26.00	103.50	108.2	105.73	119.73	133.27
Danville	11.70	216.58	236.4	254.19	345.90	402.82
Deerfield	51.90	60.19	61.5	65.97	82.33	94.43
EastKingston	9.90	136.57	147.3	136.26	151.52	167.07
Epping	26.20	197.02	203.9	211.76	257.06	290.69
Fremont	17.20	149.77	157.2	151.10	166.16	183.31
Hampstead	14.40	467.50	490.0	536.25	709.44	819.38
Kensington	11.80	138.22	138.2	135.51	143.90	156.10
Kingston	20.80	268.80	271.7	276.35	317.02	354.13
Newton	9.90	350.81	356.3	355.96	388.79	428.79
Northwood	29.70	105.19	106.4	111.08	131.48	147.14
Nottingham	48.10	61.10	62.4	66.51	81.79	92.14
Raymond	29.30	297.37	304.6	322.39	409.52	468.74
Salem	25.60	1005.70	1017.0	995.70	1018.13	1069.30
Sandown	14.30	283.92	295.7	333.78	459.16	534.76
STRAFFORD						
Dover	28.20	888.01	904.3	862.55	862.06	913.72
Durham	25.50	463.45	451.6	447.69	443.25	468.12
Madbury	14.00	100.29	104.0	109.64	132.36	148.64
Rollinsford	7.70	343.51	348.2	336.88	343.77	367.27
Barrington	49.10	125.54	130.5	135.66	162.00	180.94
Farmington	37.40	153.45	155.3	157.43	173.26	189.22
Lee	20.40	182.79	187.1	214.41	284.95	327.40
Middleton	18.60	63.60	63.5	71.72	92.20	105.16
Milton	34.70	106.37	108.3	118.70	147.61	166.97
NewDurham	45.00	43.87	43.8	50.36	65.49	74.76
Rochester	46.90	567.80	574.8	577.36	626.31	681.19
Somersworth	10.30	1092.14	1103.9	1049.71	1061.65	1066.99
Strafford	52.00	57.02	59.3	67.00	89.21	102.31

APPENDIX B

Drainage Area and Discharge of Tributaries to the Great Bay Estuary

Drainage area and discharge for rivers entering the Great Bay Estuary. From Short (1992). **TABLE B-1**

Rivers	**Drainage Area[a] (km^2)**	**Mean Discharge[b] cfs**	**Period of Record**
Lamprey	543	278	1934-77
Squamscott	331	163[c]	none
Winnicut	19	-	none
Oyster	78	19	1934-77
Bellamy	85	25[c]	none
Cocheco	472	242[c]	none
Salmon Falls	392	204	1968-78
Piscataqua	414	210[c]	none
Total	**2334**	**1141**	

[a] drainage areas from Brown and Arellano (1979)

[b] flow data from Normandeau Assoc., Inc. (1979)

[c] Calculated from a regression of mean discharge = 0.5617 x area - 22.62 (R2=0.998) based on data[a] from the Lamprey, Oyster and Salmon Falls Rivers.

APPENDIX C

Land Cover and Land Use Classification and Areas for the Great Bay and Hampton Harbor Estuary Watersheds

(Complex Systems Research Center/UNH, 1995)

Definitions of Land Cover and Land Use

Land cover data were developed from LANDSAT Thematic Mapper imagery, 1988 and 1990. For the purposes of the NEP nomination, some categories were collapsed for simplicity.

Forested	Land with tree cover, characterized by greater than 30 sq. feet/acre.
Wetland	Based on National Wetlands Inventory Criteria, and indicating the presence of hydric soils, hydrophytic vegetation, and evidence of hydrology.
Urban	Developed or built-up areas.
Agriculture	Lands that are actively farmed, or pastureland.
Disturbed	Land that has been altered to the extent that soil is exposed (e.g., gravel pits).
Cleared	Other classes of cleared lands, including clear cuts, orchards, etc
Water	Self explanatory.

Land use data was collected from a variety of sources including aerial photography interpretation, municipal tax records, and windshield surveys. Data sources were colleected in late 1980s and early 1990s.

Forested/Open (default)	Areas with no other uses present (default)
Single Family Residential	Areas of detached single family residences
Multi Family Residential	Areas of attached and detached multi-family residences, apartment complexes, etc.
Mobile Home	Areas of delineated groupings of homes in subdivisions. Scattered mobile homes are included in Single Family Residential.
Commercial/Mixed	Areas of retail and service establishments, as well as urban and non-urban areas where uses are too mixed to be mapped appropriately at the given scale. Also represents educational, administrative, and religious facilities, as well as cemeteries.
Industrial	Areas of manufacturing or non-retail commercial facilities.
Recreational	Public and private parks, recreational areas, playgrounds, ballfields, golf courses, sport facilities, and reserves.
Agriculture/Mining	Crop and pasture lands, dairy, and livestock facilities, as well as areas with active resource extraction (e.g., gravel pits).
Not Classified	Areas with no data available.

TABLE C-1

Watershed Land Cover for the Great Bay and Hampton/Seabrook estuaries (NH Portion)

	Great Bay Estuary		Hampton/Seabrook Estuary	
Category	Acres	% of Total	Acres	% of Total
Forested	296,070	66	10,094	40
Wetland	44,703	10	5,392	21
Urban	43,944	10	5,800	23
Agriculture	28,418	6	2,039	8
Disturbed	8,494	2	380	2
Cleared	9,240	2	400	2
Water	17,211	4	1,030	4

TABLE C-2

Watershed Land Use for the Great Bay and Hampton/Seabrook Estuaries (NH Portion)

	Great Bay Estuary		Hampton/Seabrook Estuary	
Category	Acres	% of Total	Acres	% of Total
Forested/Open (default)	271,080	57	19,341	77
Single Family Residential	47,474	10	2,798	11
Multi Family Residential	1,710	< 1	1,198	5
Mobile Home	1,693	< 1	167	< 1
Commercial/Mixed	11,345	2	1,130	4
Industrial	3,118	< 1	282	1
Recreational	12,216	3	128	< 1
Agriculture/Mining	17,243	4	89	< 1
Not Classified	96,958	20	—	—

Note: Total acreage values for land use categories may not correlate well with those of land cover categories due to differences in catetgory definitions and data collection methods. Land cover data is derived from LANDSAT Thematic Mapper imagery, while land use data is derived primarily from aerial photo interpretation, municipal tax records, and windshield surveys of areas actively used for some purpose (for example, “agriculture” is defined and was identified differently in the development of land use and land cover information; hence, total acreage values do not correlate well).

APPENDIX D

Abundance and Value of New Hampshire Shellfish Resources

Abundance and Value of Shellfish Resources (N.H. Fish and Game)

TABLE D-1

	CLAMS			OYSTERS		
AREA	**Acres**	**Bushels of Adults**	**Value @ $100/bu**	**Acres**	**Bushels of Adults**	**Value @ $60/bu**
Hampton Harbor	242	19,400	$1,940,000	0	0	0
Little Harbor Area	400	1,600	$160,000	0	0	0
Great Bay Estuary & Tributaries	2575	8,700	$870,000	52	51,931	$3,115,860
TOTAL	3217	29,700	$2,970,000	52	51,931	$3,115,860

Estimated Great Bay Oyster Population Data

TABLE D-2

Bed Location	**Open/Closed Status**	**1981 Est. Acres**	**1993 Est. Acres**	**1981 Est. Bushels per Bed**	**1993 Est.Bushels per bed**
Nannie Island	Open	18.5	18.5	18,193	20,615
Adams Point	Open	2.0	5.1	1,794	8,358
SW Great Bay	Closed	9.8	no data	59,122	no data
Oyster River	Closed	7.4	6.0	12,062	10,038
Bellamy River	Closed	3.1	1.0	3,891	1,074
Piscataqua River	Closed	12.3	12.3	23,735	5,412

APPENDIX E

Finfish and Intertidal and Subtidal Infaunal Invertebrate Species in the Great Bay Estuary

TABLE E-1

Species list of finfish collected from Great Bay Estuary, New Hampshire. Collections were made by fyke, haul seines, trawls and gill nets from July 1980 to October 1981 (Nelson 1981).

Species	Common Name
MARINE	
Acipenseridae:	
Acipenser oxyrhynhus	Atlantic sturgeon
Ammodytidae:	
Ammodytes americanus	American sand lance
Bothidae:	
Scopthalmus aquosus	Windowpane
Clupeidae:	
Alosa aestivalis	Blueback herring
Alosa pseudoharengus	River herring(Alewife)
Alosa sapidissima	American shad
Brevoortia tyrannus	Atlantic menhaden
Clupea harengus harengus	Atlantic herring
Cottidae:	
Hemitripterus americanus	Sea raven
Cyclopteridae:	
Cyclopterus lumpus	Lumpfish
Gadidae:	
Gadus morhua	Atlantic cod
Pollachius virens	Pollock
Urophycis chuss	Red hake
Urophycis tenuis	White hake
Labridae:	
Tautogolabrus adspersus	Cunner
Osmeridae:	
Osmerus mordax	Rainbow smelt
Pholidae:	
Pholis gunnellus	Rock gunnel
Pomatomidae:	
Pomatomus saltatrix	Bluefish
Rajidae:	
Raja erinacea	Little skate
Raja ocellata	Winter skate
Salmonidae:	
Oncorhynchus kisutch	Coho salmon
Oncorhynchus tshawytscha	Chinook salmon
Salmo salar	Atlantic salmon
Serranidae:	
Centropristis striata	Black sea bass

Species	Common Name
ESTUARINE	
Anguillidae:	
Anguilla rostrata	American eel
Atherinidae:	
Menidia menidia	Atlantic silverside
Cottidae:	
Myoxocephalus aenaeus	Grubby
Cyprinodontidae:	
Fundulus heteroclitus	Common mummichog
Fundulus majalis	Striped mummichog
Gadidae:	
Microgadus tomcod	Atlantic tomcod
Gasterostidae:	
Apeltes quadracus	4-spine stickleback
Gasterosteus aculeatus	3-spine stickleback
Pungitius pungitius	9-spine stickleback
Percichthyidae:	
Morone americanus	White perch
Petromyzontidae:	
Petromyzon marinus	Sea lamprey
Pleuronectidae:	
Liopsetta putnami	Smooth flounder
Pseudopleuronectes americanus	Winter flounder
Syngnathidae:	
Syngnathidae fuscus	Northern pipefish
FRESHWATER	
Catastomidae:	
Catastomus commersoni	White sucker
Centrarchidae:	
Lepomis gibbosus	Pumpkinseed
Lepomis macrochirus	Bluegill
Micropterus dolomieui	Smallmouth bass
Micropterus salmoides	Largemouth bass
Cyprinidae:	
Notemigonus crysoleucas	Golden shiner
Notropis hudsonius	Spottail shiner
Semotilus corporalis	Fallfish
Esocidae:	
Esox niger	Chain pickerel
Ictaluridae:	
Ictalurus nebulosus	Brown bullhead
Percidae:	
Perca flavescens	Yellow perch
Salmonidae:	
Oncorhynchus mykiss	Rainbow trout
Salvelinus fontinalis	Brook trout

TABLE E-2 *Intertidal and subtidal infaunal invertebrate species collected (retained on a 0.5 mm screen) in the Great Bay Estuary, New Hampshire between June 1981 to May 1982 (Nelson 1982).*

	Intertidal	Subtidal
Phylum: RHYNCHOCOELA		
Nemertea spp.	x	x
Phylum: ANNELIDA		
Class: Polychaeta		
Aglaophamus circinata	x	x
Aglaophamus neotenus		x
Ampharete spp.	x	x
Aricidea catherinae	x	x
Capitella capitata	x	x
Chaetozone spp.	x	x
Clymenella torquata	x	x
Eteone heteropoda	x	x
Eteone longa		x
Eteone spp.	x	x
Exogone hebes	x	x
Fabricia sabella	x	x
Harmothoe spp.		x
Heteromastus filiformis	x	x
Hypaniola grayii		x
Lumbrineris tenuis	x	x
Nephtys paradoxa		x
Nephtys picta	x	x
Nephtys spp.		x
Nereis diversicolor	x	x
Nereis zonata	x	x
Nereis spp.	x	x
Paraonis fulgens	x	
Pholoe minuta	x	x
Phyllodoce maculata		x
Phyllodoce mucosa	x	x
Phyllodoce spp.	x	x
Polydora ligni		x
Polydora spp.		x
Praxillela gracilis	x	
Prionospio steenstrupi	x	x
Prionospio spp.		x
Pygospio elegans	x	x
Scolelepis squamatus	x	x
Scolelepis spp.	x	x
Spio spp.	x	x
Streblospio benedicti	x	x
Tharyx acutus		x
Class: Oligochaeta		
unidentified *Oligochaeta* spp.	x	x
Phylum: MOLLUSCA		
Class: Gastropoda		
Haminoea solitaria	x	x
Hydrobia minuta	x	x
Hydrobia spp.		x
Ilyanassa obsoleta	x	x
Littorina littorea	x	x
Lunatia heros	x	x
Lunatia spp.		x
Nassarius trivittatus		x
Odostomia spp.	x	x
Class: Bivalvia		
Cerastoderma pinnulatum		x
Crassostrea virginica	x	x
Ensis directus		x
Gemma gemma	x	x
Lysonia hyalina	x	x
Macoma balthica	x	x
Modiolus modiolus	x	x
Mulinia lateralis	x	x
Mya arenaria	x	x
Mytilus edulis	x	
Nucula tenuis		x
Nucula spp.		x
Solemya velum		x
Tellina agilis	x	x
Phylum: ARTHROPODA		
Class: Crustacea		
Ampelisca abdita/vadorum	x	x
Caprella spp.	x	x
Corophium spp.		x
Crangon septemspinosa	x	x
Cumacea spp.	x	x
Cyathura polita	x	x
Diastylis polita		x
Edotea triloba	x	x
Gammarus mucronatus	x	x
Gammarus spp.		x
Harpinia spp.	x	x
Leptognatha caeca		x
Leucon americanus	x	x
Leucon nasicoides	x	x
Microdeutopus gryllotalpa	x	x
Microdeutopus spp.	x	x
Oxyurostylis smithi	x	x
Photis macrocoxa	x	x
unidentified Copepoda spp.	x	x
unidentified Ostracoda spp.	x	x
Phylum: HEMICHORDATA		
Class: Enteropneusta		
Saccoglossus kowalevskii		x

APPENDIX F

Status and Trends for Overall Quality and Use Support for Water Quality in New Hampshire's Coastal Surface Waters: 1988-1996.

(NHDES, 1996b, 1994, 1992, 1990, 1988)

Status and trends for water quality in coastal surface waters from 1988 to 1996:
Overall quality and use support.

TABLE F-1

F= fully supporting all uses; P= partially supporting all uses; N= non-supporting all uses

FRESHWATER RIVERS AND STREAMS: **MILES**

	Coastal Basin				**Piscataqua River Basin**			
	F	P	N	Total	F	P	N	Total
1988	21	2	5	28	111	41	31	183
1990	24	4	0	28	83	45	55	183
1992	59	0	15	74	950	21	30	1001
1994	72	2	0	74	957	22	22	1001
1996	74	0	0	74	990	6	5	1001

TIDAL WATERS: SQUARE **MILES**

	Open Ocean				**Coastal Shoreline**				**Estuaries**			
	F	P	N	Total	F	P	N	Total	F	P	N	Total
1988	NA	NA	17.9	0.1	0	18	6.8	-	9.8	16.6		
1990	NA	NA	17.9	0.1	0	18	6.8	-	9.8	16.6		
1992	53.8	0	0.2	54	18	0	0	18	9.5	—	18.7	28.2
1994	53.8	0	0.2	54	18	0	0	18	9.5	—	18.7	28.2
1996	54	0	0	54	18	0	0	18	10.5*	0.4	17.3	28.2

*Area reflects individual use support for shellfish consumption only.

TABLE F-2 *Status and trends for water quality in coastal surface waters from 1988 to 1996: Overall quality and use support. (NHDES 1996b, 1994, 1992, 1990, 1988)*

F= fully supporting all uses; P= partially supporting all uses; N= non-supporting all uses

INDIVIDUAL USE IMPAIRMENT (SQ MILES)
SWIMMING*

	Open Ocean				**Coastal Shoreline**				**Estuaries**			
	F	P	N	Total	F	P	N	Total	F	P	N	Total
1988	ALL	—	—	ALL	17.9	0	0.1	18	ALL	—	—	ALL
1990	54	0	0	54	17.9	0	0.1	18	16.6	0	0	16.6
1992	53.8	0	0.2	54	18	0	0	18	16.6	0	0	16.6
1994	53.8	0	0.2	54	18	0	0	18	28.2	0	0	28.2
1996	54	0	0	54	18	0	0	18	28.2	0	0	28.2

AQUATIC LIFE SUPPORT

	Open Ocean				**Coastal Shoreline**				**Estuaries**			
	F	P	N	Total	F	P	N	Total	F	P	N	Total
1988	no data				no data				no data			
1990	no toxicity data				no toxicity data				no toxicity data			
1992	54	0	0	54	18	0	0	18	28.2	0	0	28.2
1994	54	0	0	54	18	0	0	18	27.8	0.4	0	28.2
1996	54	0	0	54	18	0	0	18	4.4	23.8	0	28.2

**Some temporary closures of swimming areas in coastal waters have occurred as a result of heavy bather use.*

APPENDIX G

Fecal Coliform Data for Great Bay, Little Harbor, Rye Harbor and Hampton Harbor: 1985-1996.

Annual geometric means for fecal indicator bacteria at the three sites at low and high tides: 1988-97. (Langan and Jones, 1997) **TABLE G-1**

BOLD values for fecal coliforms designate values >14/100 ml, the standard for approved shellfish waters.

ADAMS POINT

	Fecal Coliforms		*E. coli*		Enterococci		*C. perfringens*	
Year	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
1988-89	**29**	**15**	5	4	2	1		
1989-90	**33**	**16**	**16**	10	7	4		
1990-91	**23**	**17**	**15**	13	5	6		
1991-92	**26**	13	10	10	11	10	**21**	**23**
1992-93	12	11	11	9	2	2	9	12
1993-94	10	6	8	5	3	3	4	4
1994-95	7	6	4	3	3	2	4	6
1995-96	**21**	**17**	**16**	14	6	6	7	6
1996-97	**14**	13	11	10	4	4	5	7
Overall mean	**17**	12	10	8	4	4	6	8

SQUAMSCOTT RIVER

	Fecal Coliforms		*E. coli*		Enterococci		*C. perfringens*	
Year	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
1988-89	**53**	**362**	13	**42**	6	**29**		
1989-90	**44**	**234**	**24**	**137**	12	**60**		
1990-91	**20**	**190**	**15**	**142**	6	**18**		
1991-92	**24**	**148**	**19**	**81**	**14**	**48**	**44**	**73**
1992-93	**23**	**90**	**19**	**71**	3	**18**	**25**	**35**
1993-94	12	**61**	10	**54**	5	**27**	10	**22**
1994-95	12	**42**	6	**20**	5	**18**	4	**18**
1995-96	**51**	**128**	**28**	**104**	13	**56**	**16**	**15**
1996-97	**25**	**91**	**20**	**60**	5	**25**	13	**16**
Overall mean	25	**118**	**16**	**71**	7	**30**	14	**23**

LAMPREY RIVER

	Fecal Coliforms		*E.coli*		Enterococci		*C. perfringens*	
Year	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
1991-92	**114**	**214**	**101**	**191**	5	12	11	**17**
1992-93	**237**	**379**	**222**	**394**	**25**	**29**	8	**18**
1993-94	**100**	**225**	**90**	**178**	**22**	**33**	4	12
1994-95	**61**	**133**	**55**	**133**	**26**	13	4	7
1995-96	**268**	**588**	**195**	**497**	**86**	**169**	12	**17**
1996-97	**85**	**78**	**64**	**62**	14	**30**	7	8
Overall mean	**123**	**204**	**104**	**182**	**25**	**31**	7	11

TABLE G-2. *Fecal coliform concentrations (per 100 ml) at sites in Little Harbor: 1988-1996 (NHDHHS).*

FC/100 ML

Year	**T1**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**T13**	**T14**	**LH2**	**WC1**
1988	7.1	109	8.5		28.2	156	77.3	24.5			
1989	10.9	129	16.7		67.1	234	460	33			
1990	16.4	84	31		57.8	128	196	14.5			
1991	40.1	541	76.2		67.6	167	199	190			
1992	21.8	14.1	20.5		35.1	53.9	30.9	10.7			
1993	6.9	4.2	18.6		14	7.3	18.9	11.7			
1994	6	3.9	12.1		16.1	11.3	53	7.4			
1995	2.6	3.3	7.5	49.8	5.4	7.7	8.4	2.6	10.1	2.8	56.4
1996	2.3	16.2	4.7	11.1	50.3	6.9	17.4	4.2	7.3	7	12.5
Overall average	8.3	28.7	14.1	23.5	29.3	38.2	64.4	13.7	8.6	5	26.6
Last 30 average	4.3	5.5	9.4	23.5	17.3	13.3	23.1	13.7	8.6	5	26.6

NUMBER OF SAMPLES

Year	**T1**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**T13**	**T14**	**LH2**	**WC1**
1988	11	10	11		9	10	9	11			
1989	9	9	9		9	9	9	9			
1990	4	4	4		4	4	4	2			
1991	7	7	6		6	7	6	4			
1992	6	5	6		6	6	7	3			
1993	8	8	7		8	8	8	7			
1994	8	7	7		8	7	8	6			
1995	5	5	5	4	5	5	5	5	4	4	3
1996	8	8	9	7	2	4	3	10	10	7	3
Total samples	66	63	64	11	57	60	59	57	14	11	6

PERCENTAGE OF SAMPLES >43/100 ML

Year	**T1**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**T13**	**T14**	**LH2**	**WC1**
1988	9	70	27		44	80	78	45			
1989	22	89	22		67	89	89	44			
1990	25	75	50		50	100	100	0			
1991	71	86	83		67	86	100	100			
1992	17	20	17		50	50	29	33			
1993	13	0	29		13	0	25	14			
1994	13	14	14		38	29	50	0			
1995	0	0	0	50	0	20	20	0	25	0	67
1996	0	38	0	0	50	0	0	10	20	14	33
Overall average	18	46	25	18	42	53	58	28	21	9	50
Last 30 average	7	13	10	18	30	23	10	10	21	9	50

Fecal coliform concentrations (per 100 ml) at sites in Rye Harbor: 1985-1996 (NHDHHS). **TABLE G-3**

FECAL COLIFORMS/100 ML

Year	RH1	RH2	RH3	RH4
1985	276	25	48	
1986	51	6	4	6
1987	118	15	46	23
1988	53	13	3	7
1989	20	5	5	9
1990	18	12	6	9
1991	32	10	5	4
1992	7	5	6	10
1993	28	15	5	21
1994	17	13	5	20
1995	10	6	2	4
1996	3	6	2	4
Geometric mean	**29**	**10**	**10**	**11**
Last 30 geo.mean	**13.6**	**9.3**	**3.6**	**10.9**

NUMBER OF SAMPLES

Year	RH1	RH2	RH3	RH4
1985	2	2	2	
1986	11	11	4	7
1987	17	16	6	15
1988	7	8	6	7
1989	8	8	6	8
1990	3	3	3	3
1991	6	6	6	6
1992	6	6	6	6
1993	9	9	6	9
1994	7	7	7	6
1995	4	4	4	4
1996	7	8	7	8
Total	**87**	**88**	**63**	**79**

FRACTION OF SAMPLES > 43/100 ML

Year	RH1	RH2	RH3	RH4
1985	1	0.5	1	
1986	0.55	0.18	0	0.14
1987	0.59	0.13	0.5	0.27
1988	0.57	0.25	0	0.14
1989	0.5	0.13	0	0.13
1990	0.33	0.33	0.33	0.33
1991	0.5	0.17	0.17	0
1992	0.17	0.17	0.17	0.17
1993	0.44	0.33	0	0.33
1994	0.14	0.14	0.14	0.33
1995	0.25	0	0	0
1996	0.14	0	0	0.13
Average	**0.44**	**0.17**	**0.14**	**0.19**
Average	**0.23**	**0.13**	**0.07**	**0.23**

TABLE G-4 *Fecal coliform concentrations at sites in Hampton Harbor: 1985-1996 (NHDHHS).*

FECAL COLIFORMS/100 ML

Year	HH 1A	HH 2B	HH 5B	HH 5C	HH 10	HH 11	HH 12	HH 17	HH 18	HH 19
1988	24	26	27				9			
1989	10	14	17				5			
1990	16	51	15				7			
1991	38	18	28				21			
1992	14	27	13				8			
1993	16	11	15	10	12	8	11	13	11	9
1994	13	16	8	16	13	16	15	17	7	20
1995	9	9	8	7	6	5	6	8	3	7
1996	4	9	13	19	16	11	7	7	6	14
Overall average	15	13	13	10	11	10	10	12	6	12
Last 30 average	12	11	11	10	9	8	8	8	4	11

NUMBER OF SAMPLES

Year	HH 1A	HH 2B	HH 5B	HH 5C	HH 10	HH 11	HH 12	HH 17	HH 18	HH 19
1988	11	8	9				10			
1989	7	1	1				8			
1990	4	2	2				4			
1991	6	5	5				6			
1992	5	4	3				4			
1993	37	44	35	15	45	15	36	45	16	19
1994	26	36	10	11	34	29	34	29	29	28
1995	9	25	25	24	17	17	17	17	25	17
1996	3	10	10	10	10	10	10	10	10	10
Total samples	108	135	100	60	106	71	129	101	80	74

PERCENTAGE OF SAMPLES > 43FC/100 ML

Year	HH 1A	HH 2B	HH 5B	HH 5C	HH 10	HH 11	HH 12	HH 17	HH 18	HH 19
1988	45	38	33				10			
1989	14	0	0				13			
1990	25	50	50				25			
1991	67	40	60				50			
1992	40	25	33				0			
1993	35	20	29	13	16	0	22	20	25	16
1994	19	25	0	27	18	34	26	28	7	43
1995	11	4	8	4	0	12	0	12	4	12
1996	0	10	30	20	10	20	30	20	10	20
Overall average	30	20	23	13	13	20	20	21	10	26
Last 30 average	20	7	17	10	7	17	17	17	7	27

APPENDIX H

Tissue Concentrations of Toxic Contaminants in Bivalve Shellfish, Lobsters, Winter Flounder, and Marine Plants

TABLE H-1

*Trace metal contaminant concentrations (dry weight) in marine plant tissues at sites in New Hampshire and southern Maine.**

Species **Site**	**Ag**	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
Zostera marina: leaves									
Clark Cove	0.70	1.21	1.51	2.05	12.70	0.02	3.07	2.72	78.6
Sullivan Pt.	0.83	1.52	1.62	1.74	11.20	0.02	1.73	1.88	85.7
Dry docks	0.47	1.20	1.09	1.23	23.10	0.02	1.31	2.72	64.9
Back Channel	0.63	1.17	1.03	1.50	13.80	0.02	1.41	2.25	66.4
Jamaica Cove	0.73	1.54	1.05	2.89	17.00	0.02	1.79	3.78	71.1
Piscataqua R.	0.70	1.01	1.22	0.92	15.00	0.01	1.58	1.27	67.0
York Harbor	0.19	1.03	1.78	0.85	8.13	0.01	1.24	0.99	47.9
Average	**0.68**	**1.28**	**1.25**	**1.72**	**15.80**	**0.02**	**1.82**	**2.44**	**72.3**
Zostera marina: roots									
Clark Cove	0.58	2.76	0.53	7.57	8.45	0.05	2.38	5.96	43.6
Sullivan Pt.	0.76	6.62	0.61	7.55	12.00	0.04	3.43	10.90	72.9
Dry docks	0.80	5.84	0.43	9.37	20.80	0.04	3.16	9.05	48.4
Back Channel	0.61	4.90	0.49	12.40	29.40	0.05	3.60	19.70	67.4
Jamaica Cove	0.64	3.00	0.58	11.60	18.60	0.06	3.13	11.10	61.9
Piscataqua R.	0.54	3.76	0.56	6.56	12.00	0.03	2.84	8.48	46.3
York Harbor	0.19	1.72	0.63	2.46	8.70	0.01	1.31	2.48	27.7
Average	**0.66**	**4.48**	**0.53**	**9.18**	**16.90**	**0.05**	**3.09**	**10.87**	**56.8**
Spartina alterniflora									
Clark Cove	0.26	1.20	0.04	1.97	1.91	0.02	0.80	1.12	36.1
Sullivan Pt.	0.24	1.20	0.03	1.47	2.06	0.01	0.54	0.71	34.0
Back Channel	0.24	1.20	0.08	2.76	2.54	0.02	0.86	1.73	40.9
Jamaica Cove	0.14	1.20	0.08	1.44	3.23	0.01	0.68	0.63	18.9
Piscataqua R.	0.17	1.20	0.04	1.89	1.84	0.01	0.41	0.73	32.9
Spruce Creek	0.26	1.20	0.15	2.36	1.22	0.01	0.85	0.87	23.8
York Harbor	0.12	1.20	0.10	2.82	1.27	0.01	1.50	1.27	23.6
Average	**0.22**	**1.20**	**0.07**	**1.98**	**2.13**	**0.01**	**0.69**	**0.97**	**31.1**
Spartina patens									
Clark Cove	0.10	1.20	0.03	0.87	1.84	0.02	0.52	0.59	20.6
Sullivan Pt.	0.09	1.20	0.05	1.54	2.97	0.01	0.59	0.97	25.3
Back Channel	0.15	1.20	0.11	2.50	3.56	0.01	1.11	2.11	47.7
Piscataqua R.	0.22	1.20	0.16	3.52	3.70	0.02	1.75	4.08	22.1
Spruce Creek	0.14	1.20	0.13	2.88	2.03	0.02	0.95	1.18	20.1
York Harbor	0.11	1.20	0.14	1.06	1.89	0.02	0.59	0.54	11.1
Average	**0.14**	**1.20**	**0.10**	**2.26**	**2.82**	**0.02**	**0.98**	**1.79**	**27.7**
Ascophyllum nodosum									
Clark Cove	0.15	14.7	0.33	0.84	10.6	0.04	1.7	1.50	
Sullivan Pt.	0.65	2.1	0.78	0.63	31.4	0.03	3./	0.60	
Storage yard	1.02	17.2	0.55	0.47	26.1	0.06	2.7	6.90	116.0
Dry docks	0.33	15.2	0.37	0.76	10.1	0.03	1.1	1.03	63.9
Jamaica Cove	0.32	26.8	0.70	0.97	6.30	0.04		1.70	53.1
York Harbor	0.07	5.7	0.27	0.40	1.89	0.01	0.59	0.05	37.6
Average	**0.49**	**15.2**	**0.55**	**0.73**	**16.90**	**0.04**	**1.83**	**2.35**	**77.7**

*From NCCOSC, 1997

TABLE H-2 *Tissue Contaminants in blue mussels at sites on or near the New Hampshire coast: 1982-1997.*

Numbers in **BOLD** exceed the USFDA (1993) alert level for lead (11.5 µg/g dry weight). No other contaminant concentrations exceeded published USFDA alert levels or action limits.

Site Location Study*, year**, site #		METALS (µg/g; dry weight) (wet weights converted assuming 15% DW)											ORGANICS: (ng/g)		
NEW HAMPSHIRE		**Ag**	**Al**	**As**	**Cd**	**Cr**	**Cu**	**Fe**	**Hg†**	**Ni**	**Pb**	**Zn**	**PCBs**	**PAHs**	**Chlr. pest.**
USFDA Action Levels for Shellfish				*25*	*87*			*6.7*	*533*	*11.5*			*13000*		*33000*
Hampton Harbor, NH															
1993	GOMC (1997a)	0.05	94		2.1	1.6	6.4	274	0.46	1.4	2.4	123	10	71	4.2
1995	GOMC (1997c)	0.05			1.7	2.0	8.6	363	0.38	1.3	2.7	143			
1996	GOMC (1997d)	0.11	185		1.5	1.4	7.9	293	0.50	1.1	2.3	115	24	107	5.5
Rye Harbor, NH															
1994	GOMC (1997b)	0.10	125		1.4	1.5	6.5	280	0.61	1.4	2.1	90	5	71	3.5
1997	GOMC (1998)	0.06	180		1.5	2.1	7.0	313	0.64	1.7	2.3	117	12	69	12.0
Witch Creek, NH															
Rye	Isaza et al. (1989)				1.9	3.1	14.0		<0.2	2.5	6.7	100	260	14000	
	Isaza et al. (1989)				2.2	4.1	10.7		<0.2	<2.0	5.1	153	113	667	
Little Harbor, NH															
New Castle 1991	GOMC (1992)	0.90			2.7	9.0	45.5	330	0.50	4.2	5.2	270	16	<DL	ND
1992	GOMC (1994)	0.06	343		1.6	4.2		543	0.50	3.1	4.2	217	48	174	15.1
1995	GOMC (1997a)	0.05			2.2	2.7	8.8	510	0.69	1.7	6.5	155			
Fort Point, NH															
New Castle	Isaza et al. (1989)				2.1	5.4	10.0		<0.2	<2.0	10.0	200.0	127	<667	
1991; #2	Johnston et al. (1994)	0.51	154	7.5	1.1	2.7	6.9	419	0.22	1.7	4.5	103			
Goat I., NH															
Portsmouth	Isaza et al. (1989)				2.3	7.3	9.3		<0.2	<2.0	8.7	153	267	4530	
Shapleigh I., NH															
Back Channel 1991	GOMC (1992)	0.08			1.8	8.0	30.5	513	0.40	3.4	5.0	130	28	<DL	ND
Portsmouth 1992	GOMC (1994)	0.08	370		2.2	4.5		750	0.67	2.7	5.6	167	74	378	17.9
1991; #11	Johnston et al. (1994)	0.15	273	7.3	1.7	4.1	7.8	680	0.27	1.6	9.2	119			
Pierce’s I., NH															
Portsmouth	Isaza et al. (1989)				2.7	7.3	8.0		<0.2	<2.0	<3.3	227	127	2600	
1991; #14	Johnston et al. (1994)	0.13	302	10.7	1.5	3.8	5.8	579	0.72	1.7	5.7	89			

Site Location Study*, year**, site #	METALS (µg/g; dry weight) (wet weights converted assuming 15% DW)											ORGANICS: (ng/g)		
NEW HAMPSHIRE	**Ag**	**Al**	**As**	**Cd**	**Cr**	**Cu**	**Fe**	**Hg†**	**Ni**	**Pb**	**Zn**	**PCBs**	**PAHs**	**Chlr. pest.**
USFDA Action Levels for Shellfish			*25*	*87*			*6.7*	*533*	*11.5*			*13000*		*33000*
Four Tree I., NH														
Portsmouth Isaza et al. (1989)				2.1	8.7	11.3		<0.2	<2.0	8.0	147	180	15300	
Rt. 1 bridge, NH														
1991; #15 Johnston et al. (1994)	0.67	131	12.5	1.3	2.2	6.9	362	0.14	1.5	3.5	81			
Atlantic Heights, NH														
Portsmouth Isaza et al. (1989)				2.1	4.7	10.0		<0.2	<2.0	8.7	180	160	3800	
East Seafood Co., NH														
Newington Isaza et al. (1989)				2.7	4.8	15.3		<0.2	8.0	6.0	120	387	1670	
1991; #24 Johnston et al. (1994)	2.20	581	9.3	1.9	6.2	9.1	1070	0.50	2.7	5.8	134			
Piscataqua River, NH														
Dover, 1991; #26Johnston et al. (1994)	2.80	508	11.1	4.3	8.6	11.4	1190	0.20	3.1	5.9	125			
Piscataqua River (PSNH)/Little Bay, NH														
1991-93; #24-28NCCOSC (1997)	1.43		10.14	3.17	6.29	10.29		0.42	3.05	5.39	125	1646	145	46.9
Dover Point, NH														
Hilton State ParkIsaza et al. (1989)				2.9	4.2	11.3		<0.2	4.7	5.8	100	393	1470	
Dover 1994 GOMC (1997b)	0.10	238		3.1	3.1	7.9	455	0.83	1.7	3.4	145	26	187	10.4
July, 1996 GOMC (1997d)												66	658	2.2
October, 1996 GOMC (1997d)												46	298	4.6
1997 GOMC (1998)	0.06	233		1.8	2.5	6.7	325	0.70	1.4	1.9	110	49	266	20.2
General Sullivan Br., NH														
1991; #27 Johnston et al. (1994)	1.20	193	8.0	2.5	5.1	8.2	489	0.46	2.6	5.8	140			
Bellamy R., NH														
mouth; 1991; #28Johnston et al. (1994)	1.90	388	13.5	2.0	4.4	8.5	638	0.29	1.9	2.8	142			
Fox Point, NH														
Newington Isaza et al. (1989)				3.7	4.7	10.7		<0.2	6.7	5.6	87	293	73300	
1996 GOMC (1997d)												78	1355	7.6
Nannie I., NH														
Great Bay Isaza et al. (1989)				2.2	8.0	10.7		<0.2	3.9	8.7	87	613	12700	

Site Location Study*, year**, site #	METALS (µg/g; dry weight) (wet weights converted assuming 15% DW)											ORGANICS: (ng/g)		
NEW HAMPSHIRE	**Ag**	**Al**	**As**	**Cd**	**Cr**	**Cu**	**Fe**	**Hg†**	**Ni**	**Pb**	**Zn**	**PCBs**	**PAHs**	**Chlr. pest.**
USFDA Action Levels for Shellfish			*25*	*87*			*6.7*	*533*	*11.5*			*13000*		*33000*
Lamprey R., NH														
Newmarket Isaza et al. (1989)				3.3	57.0	16.0		<0.2	16.7	30.0	153	400	5200	
NEW HAMPSHIRE &MAINE														
Portsmouth Hrbr, mouth-Rt.1 br. (1993) 1,2,11,14,16,170-73NCCOSC (1997)		0.19		10.31	1.64	4.25	8.25	0.44	2.09	6.09	98	745	72	26.9
MAINE														
Mast Cove, ME														
1991; #25 Johnston et al. (1994)	1.20	305	6.5	2.0	3.8	7.0	655	0.35	2.0	3.9	120			
Piscataqua R., ME														
I-95 to power line MEDEP (1993)				3.0	4.8	13.0		0.74	2.2	5.9	100			
Rt. 1 bridge, ME														
1991; #16 Johnston et al. (1994)	0.10	294	5.7	1.7	3.8	7.1	679	0.30	2.3	6.6	117			
Badger I., ME														
Kittery Isaza et al. (1989)				2.4	3.6	9.3		<0.2	<2.0	5.4	180	127	2270	
1991; #17 Johnston et al. (1994)	0.85	316	5.1	1.1	3.3	6.4	626	0.28	2.0	5.2	93			
Back Channel, ME														
E. bridge #32Gilfillan et al. (1985)	0.64			2.5	4.6	8.3		-		26.6	105			
1991; #18 Johnston et al. (1994)	0.06	223	8.0	1.9	3.5	6.1	648	0.39	1.4	10.9	98			
1993; #18,167-169NCCOSC (1997)	0.23		10.14	2.08	4.09	12.04		0.44	1.93	13.14	113	849	80	34.2
W. bridge; east endMEDEP (1993)	-			2.4	3.8	8.9		0.58		12.0	150			
Back Channel, MEW. bridge; east end														
#5 Gilfillan et al. (1985)	0.51			2.5	5.5	7.8				7.2	90			
#31 Gilfillan et al. (1985)	0.70			2.4	4.2	8.4				5.9	80			
Jamaica I., ME														
Kittery Isaza et al. (1989)				1.9	4.5	8.0		<0.2	<2.0	9.3	127	147	4470	
1991; #19 Johnston et al. (1994)	0.09	245	7.6	2.1	3.8	5.8	635	0.68	2.0	6.2	91			
1993;#19,164-66NCCOSC (1997)	0.25		9.63	2.22	4.64	14.68		1.1	2.67	32.37	123	732	79	33.3
Clark Cove, ME														
1991; #3 Johnston et al. (1994)	0.08	203	13.2	1.9	3.0	5.5	434	0.44	1.6	5.2	92			
1991; #4 Johnston et al. (1994)	0.61	348	10.5	0.1	4.0	7.6	617	0.22	1.4	10.3	130			
1991; #5 Johnston et al. (1994)	0.06	231	7.4	2.2	4.2	5.8	476	0.44	1.9	10.8	109			
1991; #6 Johnston et al. (1994)	1.2	237	8.8	1.9	3.7	8.4	573	0.16	1.8	9	132			

Site Location Study*, year**, site #	METALS (µg/g; dry weight) (wet weights converted assuming 15% DW)											ORGANICS: (ng/g)		
MAINE	**Ag**	**Al**	**As**	**Cd**	**Cr**	**Cu**	**Fe**	**Hg†**	**Ni**	**Pb**	**Zn**	**PCBs**	**PAHs**	**Chlr. pest.**
USFDA Action Levels for Shellfish			*25*	*87*			*6.7*	*533*	*11.5*			*13000*		*33000*
Clark Cove, ME (*continued*)														
1991; #7 Johnston et al. (1994)	0.85	294	6.3	1.6	3.4	7.5	627	0.24	2.4	10.7	107			
1991; #8 Johnston et al. (1994)	2.70	203	6.9	1.9	4.0	8.4	526	0.18	3.1	12.3	119			
1991; #161Johnston et al. (1994)	0.37			2.5	18.4	10.4	1110	0.45	9.0	7.5	97	61	680	
1991; #185Johnston et al. (1994)	0.06	189		1.7	6.0	7.8	596	0.32	3.0	5.0	100			
1993;3-#8,161-63NCCOSC (1997)	0.45		11.34	2.03	4.23	9.59		0.5	2.28	7.8	107	771	93	36.5
1993 GOMC (1997a)	0.28	187		2.4	3.3	7.5	535	0.74	2.6	5.4	126	70	154	11.1
1994 GOMC (1997b)	0.10	163		1.5	2.0	7.5	373	0.61	1.3	4.5	96	67	154	12.5
1995 GOMC (1997c)	0.12			1.8	3.3	9.9	535	0.56	1.7	6.1	135			
1996 GOMC (1997d)	0.10	335		1.7	2.9	8.2	518	0.86	1.4	5.1	113	38	203	7.3
1997 GOMC (1998)	0.06	428		1.6	3.0	7.0	610	0.66	1.9	5.1	125	37	147	15.3
Clark I., ME														
Kittery Isaza et al. (1989)				2.3	4.0	7.3		<0.2	<2.0	5.8	167	120	1600	
Sullivan Pt., ME														
Seavey I. #15Gilfillan et al. (1985)	0.50			3.6	5.7	7.4		-		8.1	90			
1991; #9 Johnston et al. (1994)	0.08	154	6.0	1.8	3.2	5.7	377	0.34	1.5	7.2	105			
1993;#9,159,160NCCOSC (1997)	0.19		8.76	1.97	3.23	7.55		0.32	1.63	7.27	98	949	70	51.8
Henderson Pt., ME														
Seavey I. #16Gilfillan et al. (1985)	0.60			2.9	6.0	8.2		-		5.4	81			
1991; #10AJohnston et al. (1994)	0.04	76.9	5.1	1.9	2.3	6.2	209	0.13	1.5	26	122			
1993;10.5,156-158NCCOSC (1997)	0.21		6.75	1.86	3.81	15.66		0.3	2.44	75.96	111	725	125	35.9
Dry Dock/Seavey I., ME														
1991; #10 Johnston et al. (1994)	0.03	522	8.4	2.0	3.4	8.1	497	0.97	1.4	13.5	222			
1991; #12AJohnston et al. (1994)	0.15	330	6.9	2.5	3.8	9.0	825	0.41	2.2	9.6	121			
1991; #12 Johnston et al. (1994)	0.07	280	6.5	3.1	3.5	32.3	536	0.45	2.3	11.0	105			
1993; #10,12,17,NCCOSC (1997) 151-155	0.34		8.3	2.22	3.94	12.14		0.48	2.2	8.08	107	2540	84	27.1
Spruce Creek, ME														
upstream #26AGilfillan et al. (1985)	0.68			2.5	5.3	7.1		-		6.9	85			
1991; #21 Johnston et al. (1994)	0.12	650	7.9	9.3	5.8	7.4	1300		2.1	6.4	125			
MEDEP (1993)	-			1.5	2.6	7.9		0.39		5.9	110			
Spruce Creek, ME														
downstream #20Johnston et al. (1994)	2.60	452	7.6	1.5	4.4	7.9	820	0.26	2.1	6.7	134			
1993; #20, 21 NCCOSC (1997)	1.36		7.75	5.4	5.1	7.65		0.26	2.1	6.55	130	821	103	34.6

Site Location Study*, year**, site #	METALS (µg/g; dry weight) (wet weights converted assuming 15% DW)											ORGANICS: (ng/g)		
MAINE	**Ag**	**Al**	**As**	**Cd**	**Cr**	**Cu**	**Fe**	**Hg†**	**Ni**	**Pb**	**Zn**	**PCBs**	**PAHs**	**Chlr. pest.**
USFDA Action Levels for Shellfish				*25*	*87*			*6.7*	*533*	*11.5*		*13000*		*33000*
Pepperill Cove, ME														
Kittery MEDEP (1993)				2.5	3.9	9.1		0.57	2.3	11.0	110			
1991; #1 Johnston et al. (1994)	0.17	317	8.4	1.4	3.8	5.8	600	0.43	1.7	6.2	96			
Fort Foster, ME														
west end; #30CGilfillan et al. (1985)	0.55			2.2	7.3	7.4				4.2	80			
Fort Foster, ME														
east end; #RPGilfillan et al. (1985)	0.62			2.6	5.6	6.8				3.7	89			
Horn I., ME														
Kittery #HIGilfillan et al. (1985)	0.58			2.6	3.5	6.8				3.5	88			
White I., ME														
Kittery #WIGilfillan et al. (1985)	0.65			2.6	3.3	6.1				4.0	85			
Wood I., ME														
Kittery #WOODGilfillan et al. (1985)	0.66			3.5	5.4	8.3				5.8	93			
Brave Boat Harbor, ME														
York & Kittery MEDEP (1993)														
1993; #175Johnston et al. (1994)	0.87	ND		3.5		8.1	840	0.21		1.8	111	3	168	ND
1993; #186Johnston et al. (1994)	0.18	94		1.5	4.3	5.7	725	0.18	2.8	1.7	67	ND	ND	ND
1993 GOMC (1997a)	0.20	177		2.8	3.1	7.1	469	0.71	3.0	3.5	118	ND	ND	ND
1996 GOMC (1997d)	0.30	290		1.7	1.5	6.6	353	0.42	1.5	1.8	110	ND	ND	0.6
York Harbor, ME														
upstream #22Johnston et al. (1994)	0.07	197	3.9	1.4	2.0	6.0	341	0.11	1.0	1.9	89			
1991; #23 Johnston et al. (1994)	0.11	176	5.7	1.4	1.9	6.5	385	0.31	1.2	1.9	83			
1993; 22,23,123NCCOSC (1997)	0.17		7.31	1.49	1.87	7.5		0.23	1.08	2.06	83	481	39	19.8
Saco River, ME														
river mouth MEDEP (1993)														
1994 GOMC (1997b)	0.10	103		1.6	1.6	6.3	288	0.56	1.1	2.5	86	13	49	5.6
MASSACHUSETTS														
Merrimack River, MA														
mouth 1993 GOMC (1997a)	0.14	49		2.8	2.6	6.5	393	1.08	1.5	4.8	113	44	162	6.8

*Refer to bibliography for study citations. PNS samples include all results from 1991 (Johnston et al., 1994) and 1993 (NCCOSC, 1997).

**Dates for GOMC and PNS studies are sample dates. Sample dates for Gilfillan et al. are 1982 & 1983; MEDEP are 1988-1992; Isaza are 1987.

†Some GOMC Hg results are suspiciously high.

TABLE H-3 *Trace metal and toxic organic contaminant concentrations (dry weight) in oysters, soft-shelled clams and ribbed mussels at sites in New Hampshire and southern Maine.*

Species **Site, Date**	**Information source**	**Ag** μg/g	**As** μg/g	**Cd** μg/g	**Cr** μg/g	**Cu** μg/g	**Hg** μg/g	**Ni** μg/g	**Pb** μg/g	**Zn** μg/g		**totPAH** ng/g	**totPCB** ng/g	**totDDx** ng/g
Crassostrea virginica														
Nannie I, 1986	Nelson, 1986				3.5				4.9					
Piscataqua River	Nelson, 1986				4.5				4.6					
Bellamy River	Nelson, 1986				2.25				3.7					
Oyster River	Nelson, 1986				2.7				3.8					
Nannie I. 1992	Langan & Jones, 1995		7.4		2		1.1		1			564		
Nannie I. 1994	Langan & Jones, 1995		7.2		1		0.68		1			442		
Fabian Pt 1992	Langan & Jones, 1995		8		3.9		1.3		2			490		
Fabian Pt 1994	Langan & Jones, 1995		7.6		2		1		2			461		
Pierce Pt. 1992	Langan & Jones, 1995		6.4		2		0.95		1			648		
Pierce Pt. 1994	Langan & Jones, 1995		4.1		1.5		0.54		1			285		
MacIntyre Bk 1991	Weston, 1992*		5.58			114	0.7		2.3	3767				
Adams Point 1991	Weston, 1992		4.33			171	0.8		5.16	5283				
Fox Point, 1996	Chase et al., 1997											1145	116	39
Upper GBE, 1991-93	NCCOSC 1997	12.5	10.1	4.41	2.94	266	0.28	3.27	1.75	6004		985	227	110
Upper Pisc. R., 1991	Johnston et al. 1994	17.6	4.3	6.8	2.6	257	0.2	2.7	0.85	5080			203	88.4
Boston Harbor, 1991	Johnston et al. 1994	19.9	8.8	3.7	3.8	208	0.17	4.1	1.3	5830			214	159
Adams Point, 1991	Johnston et al. 1994	12.3	5.8	3.5	3.1	187	0.07	2.7	1.1	4620			189	126
Nannie I., 1991	Johnston et al. 1994	22.6	5	4.3	2.2	301	0.19	3	0.61	7100			246	109
Average		**16.98**	**6.51**	**4.5**	**2.7**	**214.9**	**0.6**	**3.154**	**2.2**	**5383.4**	**627.5**	**199.2**	**105.2**	
Mya arenaria														
Nannie I., 1987	Isaza et al., 1989			0.3	6.0		<0.2		5.6			22000	207	
Pierce Point	Isaza et al., 1989			1.4	26.7		<0.2		36			<0.67	227	
Fox Point	Isaza et al., 1989			1.3	9.3		<0.2		10			31333	127	
Bellamy River	Isaza et al., 1989			0.8	11.3		0.29		12			<0.67	247	
Hilton State Park	Isaza et al., 1989			1.0	8.7		<0.2		13.3			38000	113	
Three Rivers Point	Isaza et al., 1989			1.3	14.7		<0.2		12			3400	127	
Witch Creek	Isaza et al., 1989			0.3	8.0		<0.2		8.7			35333	<66.7	
Seabrook	Isaza et al., 1989			1.4	4.3	15.3	0.3	9.3	8	80			80	
MacIntyre Bk 1991	Weston, 1992		20.6			11.3	0.4		12.5	59.4				
Average			**20.6**	**1.0**	**11.1**	**13.3**	**04.**	**9.3**	**13.1**	**69.7**			**26013.3**	**161.0**
Geukensia demissus														
MacIntyre Bk 1991	Weston, 1992		5.87			6.7	0.7		2.4	34.7				
Adams Point 1991	Weston, 1992		4.87			7.3	0.6		2	43.3				
Average			**5.37**			**7**	**0.6**		**2.2**	**39**				
USFDA Action Levels for Shellfish				*25*	*87*		*6.7*	*533*	*11.5*				*13000*	*33000*

* Weston (1992), Nelson (1992) and Isaza et al. (1989) results based on wet weight. Data shown assume 12% (oysters),15% (mussels) and 16% (clams) dry weight.

TABLE H-4. *Trace metal and toxic organic contaminant concentrations (dry weight) in lobsters* (Homarus americanus) *and winter flounder* (Pleuronectes americanus) *at sites in New Hampshire, Maine and off-shore areas.*

Tissue type **Site**	**Information source**	**Ag**	**As**	**Cd**	**Cr**	**Cu**	**Hg/ methylHg**	**Ni**	**Pb**	**Zn**	**PAHs total**	**PCBs total**	**DDT and metabolites**
LOBSTERS		µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	ng/g	ng/g	ng/g
Juveniles-tail + claw													
Clark Cove	NCCOSC (1997)	0.50	5.1	0.01	0.12	18.1	0.88	0.15	0.05	84	135	18.0	3.16
Sullivan Pt.	NCCOSC (1997)	0.74	4.83	0.01	0.21	30.5	0.96/0.15	0.19	0.06	119	168	11.3	2.67
Dry docks	NCCOSC (1997)	0.46	4.35	0.01	0.21		2.39/4.61	0.22	0.05	117	485	63.5	11.40
Jamaica Cove	NCCOSC (1997)	0.60	6.72	0.03	0.24	25.3	0.73	0.29	0.06	123	161	11.8	2.01
Isles of Shoals	NCCOSC (1997)	0.60	10.54	0.01	0.25	23.6	0.39	0.22	0.05	99	52	15.0	3.57
Juveniles-hepatopancreas													
Clark Cove	NCCOSC (1997)	1.07	12.17	7.06	0.29	150.0	0.21/0.13	0.58	0.08	79	2685	1017.0	498.00
Sullivan Pt.	NCCOSC (1997)	1.44	12.33	8.05	0.25	151.0	0.22/0.08	1.00	0.07	102	3596	848.0	398.00
Dry docks	NCCOSC (1997)	2.72	9.67	5.72	0.48		0.31	0.87	0.10	119	8371	1429.0	554.00
Jamaica Cove	NCCOSC (1997)	1.27	14.65	6.71	0.40	148.0	0.24	0.91	0.12	90	4007	877.0	326.00
Isles of Shoals	NCCOSC (1997)	0.54	12.77	11.68	0.34	83.6	0.17	1.81	0.19	71	225	814.0	426.00
Sublegal adults-tail + claw													
Portsmouth Hbr.	NCCOSC (1997)	0.54	10.07	0	0.24	26.2	1.01	0.18	0.04	115	72	19.0	3.36
Isles of Shoals	NCCOSC (1997)	0.70	13.73	0.01	0.36	23.3	0.51	0.31	0.06	115	48	33.0	7.08
Sublegal adults-hepatopancreas													
Portsmouth Hbr.	NCCOSC (1997)	3.01	12.09	5.16	0.36	112.0	0.22/0.07	0.52	0.17	59	3495	1130.0	553.00
Isles of Shoals	NCCOSC (1997)	2.26	19.64	15.37	0.38	257.0	0.18	1.32	0.09	74	675	1587.0	779.00
Adults-tail + claw													
Portsmouth Hbr.	NCCOSC (1997)	0.25	7.60	0.01	0.26	15.3	0.51/0.28	0.19	0.05	100	111	18.9	4.76
Isles of Shoals	NCCOSC (1997)	0.50	19.09	0.01	0.18	22.2	0.74/0.97	0.18	0.08	104	209	17.2	3.28
Brave Boat Hrbr	Sowles et al. (1996)	0.80	24.00	0.26	1.02	50.0	0.72		0.70	140	82		
ME reference sites	*Sowles et al. (1996)*	*1.10*	*21.00*	*0.18*	*0.59*	*42.0*	*0.43*		*1.30*	*178*	*135*		
Adults-hepatopancreas													
Portsmouth Hbr.	Johnston et al. (1994)	1.02	13.06	13.48	0.41	542.0	0.35/0.12	0.56	0.38	66	1504	1362.0	812.00
Isles of Shoals	Johnston et al. (1994)	0.46	17.52	12.89	0.22	173.0	0.2/0.11	2.00	0.32	70	332	1093.0	508.00
Brave Boat Hrbr	Sowles et al. (1996)	5.10	24.00	21.00	0.37	380.0	0.29		0.53	62			
ME reference sites	*Sowles et al. (1996)*	*3.85*	*19.00*	*15.00*	*0.33*	*195.0*	*0.20*		*0.70*	*48*			

Tissue type Site	Information source	Ag	As	Cd	Cr	Cu	Hg/ methylHg	Ni	Pb	Zn	PAHs total	PCBs total	DDT and metabolites
Mixed adult/juvenile-tail + claw													
Portsmouth Hbr.	Johnston et al. (1994)	0.68	12.93	0.04	0.74	25.7	1.3	0.53	0.41	81	2267	32.8	7.3
York Harbor	Johnston et al. (1994)											27.8	7.34
Mixed adult/juvenile-hepatopancreas													
Portsmouth Hbr.	NCCOSC (1997)	1.44	19.73	13.18	0.58	256	0.22	1.28	0.34	74.5	4111	1466	667
York Harbor	NCCOSC (1997)											1181	791
Adults-muscle													
Pierces I.	Isaza et al., 1989 (assume 21.7% dry weight)			<0.23	0.92-1.38	37-69	0.14-0.51	<1.4	<2.3	92-147	<.5-12900	<0.05-66400	
Adults-viscera													
Pierces I.	Isaza et al., 1989 (assume 21.7% dry weight)			6.5-9.2	1.4-1.6	129-332	<0.14-0.46	1.4-2.8	<2.3	78-111	21200-87600	1705-50700	
Adults (cooked)-meat													
Little Bay	Schwalbe and Juchatz (1991)											<300	<20
Adults (cooked)-tomalley													
Little Bay	Schwalbe and Juchatz (1991)											490	70
US FDA Action Levels for Shellfish				*25*	*87*		*6.7*	*533*	*12*		*13000*	*33000*	
WINTER FLOUNDER													
Flesh													
Portsmouth Hbr.	NCCOSC (1997)	0.008	5.75	0.010	0.23	0.27	0.21/0.25	0.18	0.06	16.4	17.2	51.5	6.61
Portsmouth Hbr.	Johnston et al. (1994)	0.034	6.41	0.040	0.73	3.58	0.10	0.65	0.37	38.4	518	87.4	24.8
Gulf of Maine	NCCOSC (1997)	0.004	31.1	0.010	0.28	0.28	0.4/0.23	0.30	0.08	12.3	18.9	67.6	11
Tork Harbor	Johnston et al. (1994)											26.3	5.38
Liver													
Portsmouth Hbr.	NCCOSC (1997)	0.464	3.37	0.16	0.27	15.3	0.13/0.05	0.58	0.28	89.4	59.6	938	163
Portsmouth Hbr.	Johnston et al. (1994)	0.66	2.10	0.09	0.40	22.0		0.53	0.24	114	531	838	192
Gulf of Maine	NCCOSC (1997)	7.63	25.6	3.64	0.40	84.2	0.3/0.12	3.63	2.82	131	54.8	787	180
York Harbor	Johnston et al. (1994)											658	175

APPENDIX I

Zooplankton Species in the Great Bay Estuary

Zooplankton species collected from the Great Bay Estuary, New Hampshire during 1979 (NAI 1980). **TABLE I-1**

- Holoplankton
  - *Acartia hudsonica*
  - *Acartia* spp. copepodites
  - *Calanus finmarchicus* copepodites
  - Copepod nauplii, undifferentiated
  - *Eurytemora* spp. copepodites
  - *Evadne* spp.
  - *Microsetella norvegica*
  - *Oithona* spp. nauplii
  - *Oithona* spp. copepodites
  - *Podon* spp.
  - *Pseudocalanus* spp. copepodites
  - *Pseudocalanus*/*Calanus* nauplii
  - Rotifera
  - Tintinnida
- Meroplankton
  - *Anomia* spp. veligers
  - Bivalve umbone veligers, undifferentiated
  - Bivalve straight-hinge veligers
  - Cirripedia cyprids
  - Cirripedia nauplii
  - Gastropoda veligers
  - *Hiatella* spp. veligers
  - *Modiolus modiolus* veligers
  - *Mytilus edulis* veligers
  - Polychaete larvae
  - Polychaete eggs
- Tychoplankton
  - Foraminifera
  - Harpacticoida

APPENDIX J

Species of Seaweeds and Plants Occurring in New Hampshire Salt Marshes

Summary of seaweed species composition from ten Great Bay estuarine areas (modified from Mathieson and Penniman 1991).

TABLE J-1

	Piscataqua R.	Little Bay	Great Bay	Bellamy R.	Cocheco R.	Lamprey R.	Oyster R.	Salmon Falls	Squamscott R.	Winnicut R.	Longevity*
CHLOROPHYTA											
Acrochaete repens	x**										A
Blidingia minima	x	x	x	x	x	x	x	x	x	x	AA
Bryopsis plumosa	x	x	x	x	x						A
Capsosiphon fulvescens	x	x	x				x	x			A
Chaetomorpha aerea	x										P
Chaetomorpha brachygona	x	x	x								A
Chaetomorpha linum	x	x	x			x			x		P
Chaetomorpha melagonium	x	x									P
Chaetomorpha picquotiana	x	x	x								P
Cladophora albida		x	x								AA
Cladophora pygmaea	x	x	x								P
Cladophora sericea	x	x	x	x	x	x	x	x	x	x	AA/PP
Codiolum gregarium	x	x**									A
Codiolum pusillum		x**									A
Enteromorpha clathrata	x	x	x	x	x	x	x		x		A
Enteromorpha compressa	x	x	x				x	x			AA
Enteromorpha flexuosa ssp. *flexuosa*							x				A
Enteromorpha flexuosa ssp. *paradoxa*	x	x	x	x	x		x	x	x		A
Enteromorpha intestinalis	x	x	x	x	x	x	x	x	x		AA
Enteromorpha linza	x	x	x	x	x		x				AA
Enteromorpha prolifera	x	x	x	x	x	x	x	x	x	x	AA
Enteromorpha torta	x	x									A
Entocladia viridis		x	x								AA
Kornmannia leptoderma	x	x									A
Microspora pachyderma		x**	x				x		x		A
Monostroma grevillei	x	x	x								A
Monostroma pulchrum	x	x									A
Mougeotia sp.							x				A
Oedogonium sp.							x				A
Percursaria percursa	x	x									AA
Prasiola stipitata	x										AA
Pseudendoclonium submarium	x									AA	
Rhizoclonium riparium	x	x	x	x	x	x	x	x	x	x	AA
Rhizoclonium tortuosum	x	x	x	x			x				AA
Spirogyra sp.							x				A
Spongomorpha arcta	x	x									A
Spongomorpha spinescens	x	x									A
Stigeoclonium sp.						x			x		A
Ulothrix flacca	x	x	x	x	x	x	x	x	x		A
Ulothrix speciosa	x	x									A
Ulva lactuca	x	x	x	x	x	x	x	x	x		A/PP
Ulvaria obscura	x	x	x	x			x		x		A
Ulvaria oxysperma	x	x	x	x	x	x	x	x	x		A
Urospora penicilliformis	x	x	x								A
Urospora wormskioldii	x	x									A
Total Chlorophyta Taxa	35	37	25	14	12	11	20	11	14	4	

* = Longevity designations (A = annual, AA = aseasonal annual, P = perennial, PP = pseudoperennial) ** = Only found in culture

TABLE J-1 *Summary of seaweed species composition (continued)*

	Piscataqua R.	Little Bay	Great Bay	Bellamy R.	Cocheco R.	Lamprey R.	Oyster R.	Salmon Falls	Squamscott R.	Winnicut R.	Longevity*
PHAEOPHYTA											
Agarum cribrosum	x										P
Ascophyllum nodosum	x	x	x	x	x	x	x	x	x		P
Ascophyllum nodosum ecad *scorpioides*	x	x	x	x			x				P
Chorda filum	x	x									A
Chorda tomentosa	x	x									A
Chordaria flagelliformis	x	x									A
Delamarea attenuata	x										A
Desmarestia aculeata	x										P
Desmarestia viridis	x										A
Desmotrichum undulatum	x										A
Dictyosiphon foeniculaceus	x										A
Ectocarpus fasciculatus	x										A
Ectocarpus siliculosus	x	x	x	x	x		x				A
Elachista fucicola	x	x		x							P
Fucus distichus ssp. *distichus*	x										P
Fucus distichus ssp. *edentatus*		x									P
Fucus distichus ssp. *evanescens*	x	x	x				x				P
Fucus spiralis	x	x	x								P
Fucus vesiculosus	x										P
Fucus vesiculosus var. *spiralis*	x	x	x	x	x	x	x	x	x		P
Giffordia granulosa	x	x									A
Giffordia sandriana	x	x									A
Isthmoplea sphaerophora	x	x**									A
Laminaria digitata	x	x									P
Laminaria longicruris	x	x									P
Laminaria saccharina	x	x	x								P
Myrionema corunnae		x									A
Myrionema strangulans		x	x	x							A
Petalonia fascia	x	x	x	x			x				A
Petalonia zosterifolia		x									A
Petroderma maculiforme	x	x	x								P
Pilayella littoralis	x	x	x	x	x	x	x				A
Pseudolithoderma extensum	x	x	x								P
Punctaria latifolia	x	x									A
Ralfsia bornetii	x	x	x								P(?)
Ralfsia clavata	x	x	x								P(?)
Ralfsia fungiformis	x										P
Ralfsia verrucosa	x	x	x								P
Scytosiphon lomentaria var. *complanatus*		x									A
Scytosiphon lomentaria var. *lomentaria*	x	x	x				x				A
Sorocarpus micromorus		x									A
Sphacelaria cirrosa	x	x	x								P
Spongonema tomentosum		x									P(?)
Stictyosiphon griffithsianus	x	x									A
Ulonema rhizophorum	x	x									A
Total Phaeophyta Taxa	38	35	18	7	4	3	8	2	2	0	

	Piscataqua R.	Little Bay	Great Bay	Bellamy R.	Cocheco R.	Lamprey R.	Oyster R.	Salmon Falls	Squamscott R.	Winnicut R.	Longevity*
RHODOPHYTA											
Ahnfeltia plicata	x	x	x								P
Antithamnion cruciatum	x	x	x				x				A
Antithamnionella floccosa	x	x	x								AA
Audouinella membranacea	x	x	x								P(?)
Audouinella purpurea	x	x									P
Audouinella secundata	x	x	x				x				AA
Audouinella violacea			x			x	x				A
Bangia atropurpurea	x	x					x				A
Bonnemaisonia hamifera	x	x	x								P
Callithamnion byssoides		x	x								A
Callithamnion hookeri	x	x									A
Callithamnion tetragonum	x	x	x	x	x	x	x		x		P
Callocolax neglectus	x										P(?)
Callophyllis cristata	x										P
Ceramium deslongchampii var. *hooperi*	x		x								P(?)
Ceramium elegans			x								A
Ceramium rubrum	x	x	x	x	x	x	x		x		P
Ceramium strictum	x	x	x	x	x	x	x	x	x		A
Chondria baileyana	x	x	x	x		x	x				A
Chondrus crispus	x	x	x	x	x		x		x		P
Choreocolax polysiphoniae	x										P
Clathromorphum circumscriptum	x	x	x							P	
Corallina officinalis	x										P
Cruoriopsis ensis	x										P(?)
Cystoclonium purpureum var. *cirrhosum*	x	x	x								P
Cystoclonium purpureum forma *stellatum*	x										P
Dasya baillouviana	x	x	x	x	x	x	x	x	x		A
Dermatolithon pustulatum	x	x	x								P
Dumontia contorta	x	x	x								A
Erythrotrichia carnea	x	x	x					x			A
Fimbrifolium dichotomum	x										P
Fosliella lejolisii	x	x	x								P
Gloiosiphonia capillaris		x									A
Goniotrichum alsidii	x	x	x								A
Gracilaria tikvahiae	x	x	x	x		x	x		x		P
Gymnogongrus crenulatus	x	x	x						x		P
Hildenbrandia rubra	x	x	x			x	x				P
Leptophytum laeve	x										P
Lithophyllum corallinae	x										P
Lithothamniom glaciale	x										P
Lomentaria baileyana	x		x	x		x					A
Lomentaria clavellosa	x	x	x								P(?)
Lomentaria orcadensis	x	x									P
Mastocarpus stellatus	x	x									P
Membranoptera alata	x										P
Palmaria palmata	x	x	x	x							P
Petrocelis cruenta	x	x									P
Peyssonnelia rosenvingii	x	x	x								P
Phycodrys rubens	x	x									P

TABLE J-1 *Summary of seaweed species composition (continued)*

	Piscataqua R.	Little Bay	Great Bay	Bellamy R.	Cocheco R.	Lamprey R.	Oyster R.	Salmon Falls	Squamscott R.	Winnicut R.	Longevity*
Phyllophora pseudoceranoides	x	x	x								P
Phyllophora truncata	x	x	x								P
Phymatolithon laevigatum	x	x									P
Phymatolithon lenormandii	x	x									P
Polyides rotundus	x	x	x								P
Polysiphonia denudata	x	x	x	x	x	x	x		x		A
Polysiphonia elongata	x	x	x	x	x	x	x		x		P
Polysiphonia flexicaulis	x	x		x							P
Polysiphonia harveyi	x	x	x	x	x	x	x		x		A
Polysiphonia lanosa	x	x									P
Polysiphonia nigra	x	x	x	x	x		x				P(?)
Polysiphonia nigrescens	x	x	x	x		x					P
Polysiphonia novae-angliae		x									P(?)
Polysiphonia subtilissima	x	x	x		x	x	x	x	x		P
Polysiphonia urceolata	x	x									P
Porphyra leucosticta	x	x									A
Porphyra linearis		x									A
Porphyra miniata	x	x	x								A
Porphyra umbilicalis	x	x	x	x			x		x		A
Porphyra umbilicalis forma *epiphytica*	x	x	x								A
Porphyrodiscus simulans	x										P(?)
Pterothamnion plumula	x	x	x								AA
Ptilota serrata	x										P
Rhodomela confervoides	x	x									P
Rhodophysema elegans	x	x	x								P
Rhodophysema georgii	x	x									P(?)
Sacheria fucina			x	x		x	x		x		P
Scagelia corallina	x		x								AA
Trailliella intricata	x										P
Total Rhodophyta Taxa	71	60	47	17	10	15	21	3	14	0	
Grand Total Seaweed Taxa	144	132	90	38	26	29	49	16	30	4	

Major plant species occurring within New Hampshire salt marshes (modified from Breeding et al. 1974). **TABLE J-2**

Acnida cannabina	Water hemp
Aster subulatus	Salt marsh aster (annual)
Aster tenuifolius	Salt marsh aster (Perennial)
Atriplex glabriuscula	Orach
Atriplex patula	Orach
Bassia hirsuta	Hairy smotherweed
Carex scoparia	Sedge
Carex hormathodes	Marsh straw sedge
Cladium mariscoides	Twig rush
Distichlis spicata	Spike grass
Eleocharis halophila	Salt marsh spike-rush
Eleocharis parvula	Dwarf spike-rush
Eleocharis smallii	Small's spike-rush
Elymus virginicus	Virginia rye grass
Euphorbia polygonifolia	Seaside spurge
Gerardia maritima	Seaside gerardia
Glaux maritima	Sea milkwort
Hordeum jubatum	Squirrel-tail grass
Iva frutescens	Marsh elder
Juncus balticus	Baltic rush
Juncus canadensis	Canadian rush
Juncus gerardii	Black grass
Lathyrus japonicus	Beach pea
Limonium nashii	Sea lavender
Lythrum salicaria	Purple loosestrife
Myrica pensylvanica	Northern bayberry
Panicum virgatum	Switchgrass
Phragmites australis	Common reed
Plantago maritima	Seaside plantain
Polygonum aviculare	Knotweed
Polygonum ramosissimum	Bushy knotweed
Potamogeton pectinatus	Sago pondweed
Prunus maritima	Beach plum
Puccinellia maritima	Seashore alkali grass
Puccinellia paupercula	Alkali grass
Quercus alba	White oak
Quercus bicolor	Swamp white oak
Ranunculus cymbalaria	Seaside crowfoot
Rosa rugosa	Rugosa rose
Rosa virginiana	Low rose
Ruppia maritima	Widgeon grass
Sanguisorba canadensis	Canadian burnet
Salicornia bigelovii	Dwarf glasswort
Salicornia europaea	Common glasswort
Salicornia virginica	Perennial glasswort
Scirpus americanus	Three-square bulrush
Scirpus acutus	Hard-stemmed bulrush
Scirpus atrovirens	Bulrush
Scirpus cyperinus	Wool grass
Scirpus maritimus	Salt marsh bulrush
Scirpus paludosus	Bayonet-grass
Scirpus robustus	Salt marsh bulrush
Scirpus validus	Soft-stemmed bulrush
Smilax rotundifolia	Common greenbrier
Solidago sempervirens	Seaside goldenrod
Spartina alterniflora	Salt water cord grass
Spartina patens	Salt meadow grass
Spartina pectinata	Freshwater cord grass
Spergularia canadensis	Common sand spurrey
Spergularia marina	Salt marsh sand spurrey
Suaeda linearis	Sea blite
Suaeda maritima	Sea blite
Suaeda richii	Sea blite
Toxicodendron radicans	Poison ivy
Triglochin maritima	Seaside arrow grass
Typha angustifolia	Narrow-leaved cattail
Typha latifolia	Broad-leaved cattail
Zannichellia palustris	Horned pondweed
Zostera marina	Eelgrass