THE ECOLOGY OF THE GREAT BAY ESTUARY, NEW HAMPSHIRE AND MAINE: AN ESTUARINE PROFILE AND BIBLIOGRAPHY

Edited by Fredrick T. Short
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This volume is dedicated to Dr. Galen E. Jones, former Director of the Jackson Estuarine Laboratory and retired Professor of Microbiology at the University of New Hampshire. Galen is a great supporter of marine and estuarine research and worked for years to establish the strong marine research program at the University of New Hampshire.

Cover Photograph is an aerial view of the Great Bay Estuary, with Dover Point and the Piscataqua River in the foreground, looking across Little Bay to Great Bay.

Drawings by Victor E. Young and Funi Burdick.

Photographs by Fredrick T. Short

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Preface

The preparation of The Ecology of The Great Bay Estuary, New Hampshire and Maine: An Estuarine Profile and Bibliography has been a combined effort involving many individuals and agencies. For all those involved, creating the Profile represented an opportunity to pull together the many sources of information concerning the Great Bay Estuary. Many of these sources were scientific, but we have supplemented the science with history, natural history, and social and political information. All of these approaches are valid frames of reference when considering the Estuary, its past, present, and future.

We have written the Estuarine Profile as a document to be read and understood by the concerned citizen, by monitoring groups and management agency personnel, as well as by scientists studying this or another estuarine system. Some of the material referenced is of course very technical, but the Profile itself should give an overview of the ecology of the Great Bay Estuary to anyone with the interest to read it. While the Profile may seem lengthy, and indeed we attempted to be thorough, one of the aims of the Profile is to outline what is not yet known about the Great Bay Estuary.

If the Profile has a bias beyond completeness of information, it is toward the long-term preservation of the Estuary as a natural resource for New Hampshire and Maine. Therefore, we set out management priorities for the Estuary, based on the scientific information available. And where information is lacking, we outline the research needed so that science can contribute to decision making about management issues within the Estuary in the future.

Direct funding for the project came from the U.S. Department of the Navy through the U.S. Environmental Protection Agency; from the National Estuarine Research Reserve Program, Sanctuaries and Reserves Division, NOAA, U.S. Department of Commerce, through the New Hampshire Fish and Game Department; and from the University of New Hampshire. Because of the magnitude of the project and the overlap with other ongoing research, some sections of the Estuarine Profile and its publication costs were funded under a separate grant from NOAA's Coastal Ocean Program.

The information presented in this document combines material from a profile of Great Bay prepared for New Hampshire Fish and Game Department (Short 1991) and a historical overview of the Great Bay Estuary prepared for the U.S. Navy (Short 1992). Some of the background material used in the document was obtained from the Great Bay Estuarine Research Reserve Management Plan (NHOSP 1989). The Bibliography presented here is updated from the original Research Bibliography of the Great Bay Estuary (Short and Tracy 1986) and the more recent Sea Grant publication (Penniman et al. 1989).

The Editor would like to thank all the contributing authors for their cooperation and comments on the entire document. Additionally, thanks to Heather Talbot for her patience and dedication in typing the manuscript, to Allison Currie and Sandy Weiss for research assistance on several chapters, to my wife Cathy Short for excellent suggestions and editing of the final document, and to John Nelson, Robert Croker, Linda Dietz, Jim Tayon, Kristin Wall, and Robert Johnston for their careful reviews of the manuscript.

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Introduction

The Great Bay Estuary is a complex embayment on the New Hampshire-Maine border that is composed of the Piscataqua River, Little Bay, and Great Bay. The Estuary is a tidally dominated system and the drainage confluence of seven major rivers, several small creeks and their tributaries, and ocean water from the Gulf of Maine (Fig. 0.1). In the following document, the term "Great Bay Estuary" and the word "Estuary" written with a capital "E", refer to the entire estuarine system: Great and Little Bays and the Piscataqua River, taken together. "Great Bay" refers only to the broad inner bay which begins at Furber Strait, the location of the Great Bay National Estuarine Research Reserve (Fig. 0.2).

Except for the Bellamy, all the major tributaries to the Great Bay Estuary carry treated sewage effluent into the Estuary, contributing bacteria and nutrients to estuarine waters. Since European settlement of the area, the Estuary has experienced a series of contamination loadings including massive sawdust input, fish waste, untreated sewage, and mill and tannery chemicals. Because of the strong tidal influence, with high tidal volume and rapid currents, much of the contamination released into the Estuary over the years has very quickly been flushed out of the system and is not seen by the casual observer.

Often today the Estuary is referred to as "pristine", and as "New Hampshire's hidden coastline". While it's true that the Great Bay Estuary is relatively unknown to many who live in or visit New Hampshire, it is not accurate to characterize its waters as pristine. Though not currently heavily contaminated, the Great Bay Estuary exhibits warning signals of its fragility: shellfishing closures, loss of eelgrass habitat, and increasing shoreline development all point to an uncertain future.

The Great Bay Estuary is a drowned river valley, with high tidal energy and characteristic deep channels with fringing mud flats. The Estuary formed during the most recent deglaciation of the area, approximately 14,500 years ago; when the ice retreated, the earth's crust remained pushed down and was flooded by the sea. Its total drainage area today is 2,409 km^2 (930 mi^2). Tidally induced and wind driven currents control circulation, mixing, resuspension of sediments, and strongly influence primary productivity. The main habitat types within the Estuary are eelgrass, mudflat, salt marsh, channel bottom, and rocky intertidal.

The Piscataqua River is an ocean-dominated system extending from the Gulf of Maine at Portsmouth Harbor and forming the border of New Hampshire and Maine to the fork of its tributaries, the Salmon Falls and Cocheco Rivers. The ecology of the Piscataqua River is influenced by the heavy industrial development at its mouth, where the city of Portsmouth and the Portsmouth Naval Shipyard are located, as well as by industrial development along the New Hampshire side of the river and residential development on the Maine side.

Little Bay, the central component of the Great Bay Estuary, begins at Dover Point and extends from the General Sullivan Bridge to Furber Strait. This narrow, deep-channeled Bay is flanked by mud flats and receives fresh water from

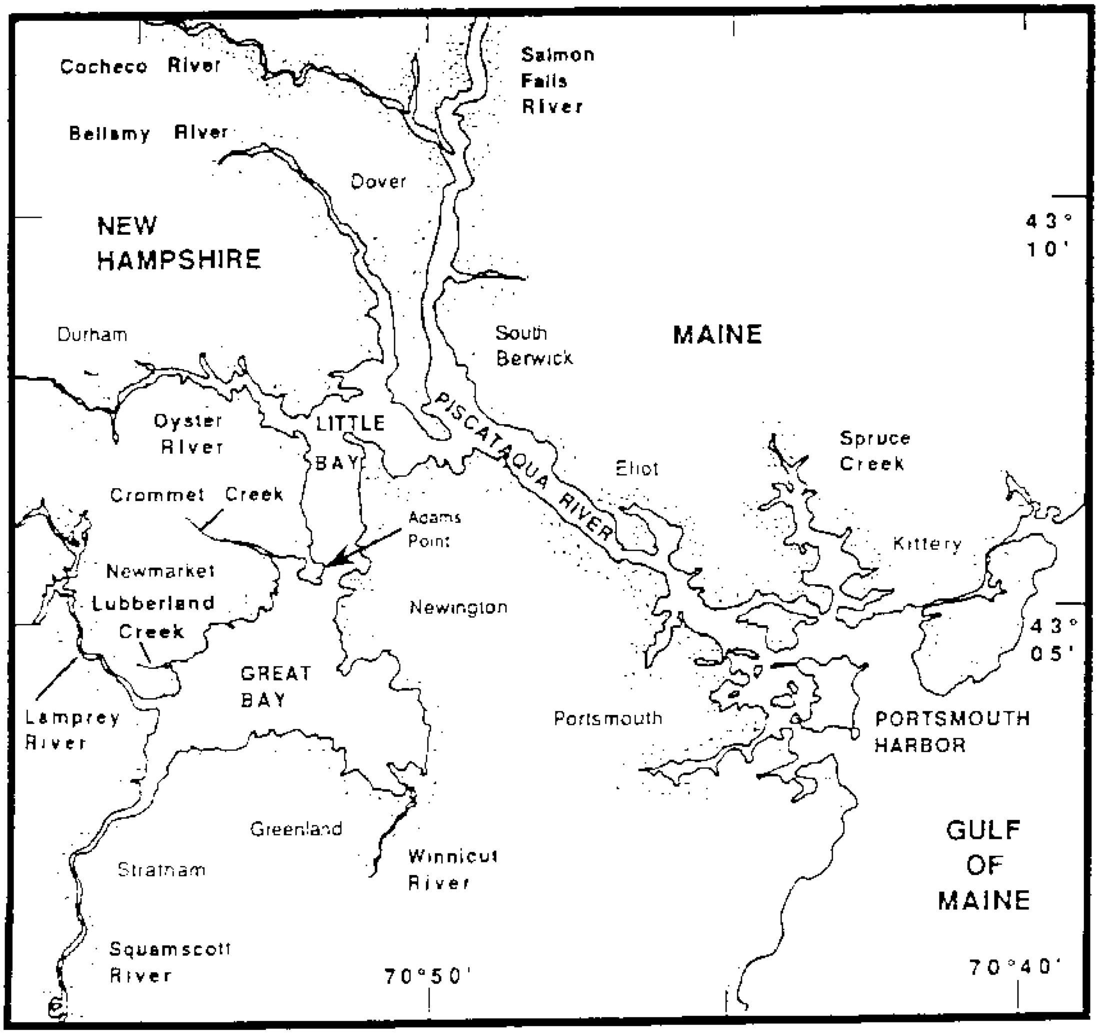


Fig. 0.1. Map of the Great Bay Estuary showing the important waterways and surrounding towns.

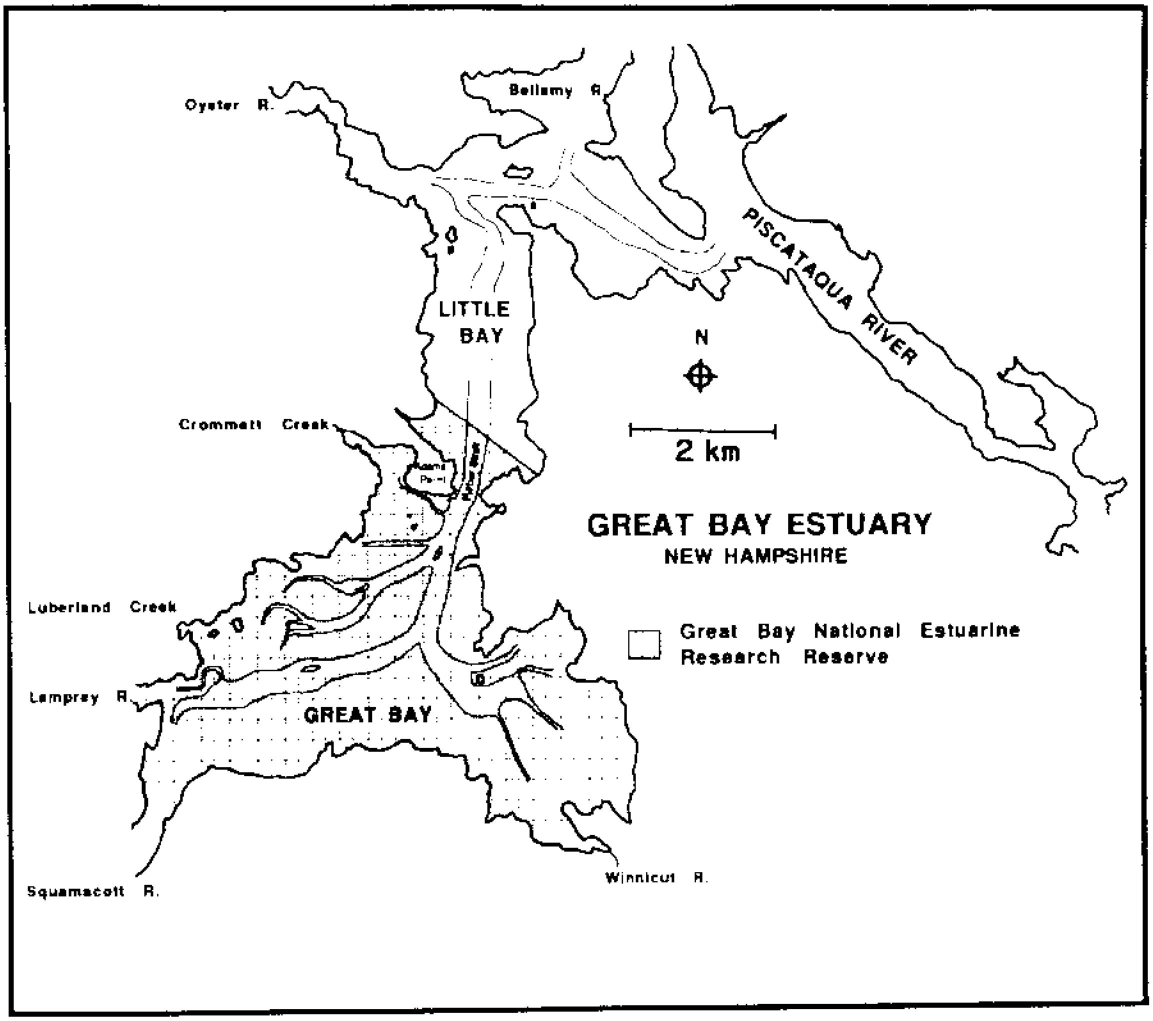


Fig. 0.2. Great Bay Estuary showing tidal channels as mapped in October 1989 (Short et al. 1991) and the waters of the Great Bay Estuarine Research Reserve.

the Oyster and Bellamy Rivers. The majority of Little Bay is rimmed by residential development with publicly owned lands at the mouth of the Oyster River and at Dover Point, Fox Point, and Adams Point.

Great Bay begins at Furber Strait, where a 13 meter deep channel extends nearly from shore to shore. The Squamscott and Lamprey Rivers are the major sources of fresh water entering Great Bay and contribute substantially to its nutrient loading and bacterial contamination. The Winnicut River, Crommet Creek, and Lubberland Creek also empty into Great Bay. Because of large private landholdings and the former Pease Air Force Base, Great Bay has the least developed shoreline of the three components of the Estuary. The shoreline of the decommissioned base has now become the Pease Wildlife Refuge, perpetuating the open space which contributes to the peaceful atmosphere of Great Bay, a winter habitat for bald eagles.

Great Bay itself is the location of the Great Bay National Estuarine Research Reserve, designated in October of 1989 to protect estuarine waters for research and education. The Research Reserve designation applies to Great Bay only. While many government agencies and special interest groups have some jurisdiction or concerns in the Great Bay Estuary, there is no single management or conservation organization with the charge to manage and preserve the character and natural resources of the Estuary as a whole.

The Great Bay Estuary is a resource of tremendous value to both New Hampshire and Maine. As open space, as a buffer for point and nonpoint source pollution, as wildlife habitat, as a recreational location, the Estuary has value beyond measure. Although some parts of the Estuary are quite undeveloped and even protected from future development, other parts are already heavily developed and showing signs of degradation. What will its future be? As a part of the discussion about the future of the Estuary, this document is intended to be a summary of what is known about the Great Bay Estuary to date.

Chapter 1: History of Human Activities and Today's Resource Values in the Great Bay Estuary

by F. Short and M. Webster

History

The earliest known inhabitants of the Great Bay Estuary region were Native Americans such as the Squamscott Tribe on the Lamprey River (George 1932) and other coastal tribes. The Piscataqua Tribe was one of at least twelve New Hampshire tribes of Iroquois or Algonquins (Hugo-Brunt 1957). These people were fishermen, hunters, and to a limited extent, farmers, and used the fish (alewives and pogies) and shellfish (oysters and clams) of the Estuary for food. The earliest-recorded white visitor to the Estuary was in 1603, although it is believed the region was used by Europeans for fishing throughout the 16th century (Hugo-Brunt 1957). Fishing and fur-trading were quite active in Newfoundland and the St. Lawrence Estuary throughout the 1500s, and probably extended south to the Piscataqua River region as well.

In 1603, the English captain Martin Pring explored the Isles of Shoals and the Piscataqua River, and within ten years, explorers Samuel de Champlain and John Smith had also visited the Piscataqua, noting ample supplies of lumber, game, and fish (Saltonstall 1968). It was the fishery resources that sustained the first settlement, called Pannaway, established in 1623 on 6,000 acres of what is now called Odiorne Point. Small boats were used for fishing, and salted fish were used for trade. Also in 1623, another Englishman named Edward Hilton established a trading post at Dover Point (Jackson 1944). Hilton had initially come to the New World in search of profit from mines and vineyards, but quickly realized that lumber and fish were the profitable resources of the region. Present day Hilton Park is named after Edward Hilton, founder of Dover.

Other establishments soon followed, including fishing communities at the Isles of Shoals and Strawberry Bank plantation (established as a land grant by John Mason) in 1631, and five fishyards in Kittery by mid-century. A sawmill and active beaver-trade center were established on the Salmon Falls River, near what is now South Berwick, Maine. Other sawmills were set up along the banks of the Estuary, especially on its tributaries, numbering about twenty by 1665 (Saltonstall 1968). By 1700, there were 90 sawmills along the Piscataqua River (Garvin 1971) supporting an active lumber trade.

Dried fish (e.g. salted alewives), lumber, and furs were exported from the New World in exchange for supplies such as compasses, canvas, and ropes (Saltonstall 1968). The waterways of the Estuary provided access to settlements on the tributaries and to the Native American tribes. Initially, contact between the Native American people and the settlers was peaceful, with trade of venison, corn, and furs for European goods such as iron tools, coats, guns, and bullets (Hugo-Brunt 1957). However, European disease, such as a 1633 epidemic that nearly exterminated the Piscataqua Tribe, and losses experienced in trying to defend their territory drove most of the Native Americans from the area. The Squamscott Tribe left the Lamprey in 1672, moving west to the Hudson River (George 1932). Soon after, between 1675 and 1713, struggles against the settlers nearly exterminated the remaining Native American population (Hugo-Brunt 1957).

Throughout the early 1700s, exploitation of the region's natural resources, fish, lumber, and furs, contributed to increased settlement and trade with the New World settlements further south, in Europe, and the West Indies (Gilmore and Ingmire 1989). Some land was cleared for farming but cultivation was solely for local use (Hugo-Brunt 1957).

The Great Bay Estuary was very rich in marine resources in the 17th and early 18th centuries. Oysters were plentiful, and clams were so abundant in the Bellamy River that they were used to feed hogs (Jackson 1944). Lobsters were also abundant in both Great and Little Bays. A variety of fish species inhabited the Estuary, and the most abundant were used as fertilizer for crops. Salted alewives were a major component of early commerce, and were traded to Boston (Saltonstall 1968) and the West Indies in exchange for rum, sugar, molasses, and salt (George 1932).

In 1708, the British council of Trade and Plantations received word from the New World that the Great Bay Estuary was "...furnished with great plenty of fish; such as cod and haddock, ...bass, shad, mackerell, herring, blew-fish, alewives, pollack, frost fish, perch, flounders, sturgeons, lumbs, ells, seals, salmon and many others, and all sorts of shell-fish, such as lobsters, crabs, cockles, clams, mussels, oysters, etc." (Jackson 1944). Salmon were abundant, especially in the Cocheco and Salmon Falls Rivers, and one Portsmouth merchant reported recovering 1,000 tons in one season during 1717 (Jackson 1944). He wrote to Ireland, his homeland at the time, advertising that there was need in the Piscataqua region for farmers and for fishermen who knew how to cure fish, and that there were opportunities to be very successful (Saltonstall 1968).

By about 1650 a profitable cod and mackerel fishery employed as many as 1,500 men at Shoals. The fishing industry grew, and made many plantation owners very wealthy through the first half of the 18th century (Saltonstall 1968, Singer 1986). Lists of exports from Portsmouth in 1746 and 1752 included cod, pickled fish, and sturgeon, traded for West Indies goods and pork, oats, guns, wheat, nails, tar, and pitch (Clark and Eastman 1974). Fish were also exported to Canada (Halifax), Spain and Portugal, and other coastal American cities (Saltonstall 1968).

Lumber was another important natural resource of the region, and white pine and oak surrounding the Estuary were exploited from the earliest settlements (George 1932). The first plantations set up sawmills and began shipbuilding, and lumber and shipbuilding activities continued as significant industries in New Hampshire throughout the two hundred years leading up to the Industrial Revolution. The first vessels were small boats constructed as early as the 1650s for local fishing use and the Boston lumber trade. Shipbuilding spread along the Bay's tributaries, in order to be as close as possible to the lumber sources and sawmills, such as those at Newmarket (George 1932), Exeter, and Kittery and Eliot, Maine (Saltonstall 1968).

The boats built at these yards were either small enough to be sailed downriver, or were taken downriver unfinished to Portsmouth to be outfitted (George 1932). Two naval vessels were built in Portsmouth in the 1690s. The shipbuilding industry grew very rapidly from 1700 to the 1750s, with increased settlement and trade in the region. Records from the early 1700s state that wharf areas in the towns of Exeter and Newmarket were crowded and needed to be monitored to be kept open (George 1932, Saltonstall 1968). Sawmills exhausting shoreline lumber supplies moved further inland to locate saw logs.

Besides lumber for the shipbuilding industry, exports of lumber included 150- to 200-foot tall, straight white pines for masts and spars, which supplied the English Navy until 1775. Planks, barrel staves, scaffolding and other building materials, and furniture were also produced and exported, contributing to the active trade between Portsmouth and the rest of the world (Hugo-Brunt 1957, Clark and Eastman 1974). Sawmills and shipyards eventually covered the banks of the Piscataqua River and all the Bay's tributaries, and the number and size of ships built increased. American ships were in demand abroad because they were cheaper to build than English ships (Saltonstall 1968). Between 1722 and 1727, 94 vessels with an average carrying capacity of 60 tons were built at dozens of shipyards along the Piscataqua River. The shipbuilding business provided a well-developed economic base for the coastal economy: carpenters, coopers, shipwrights and sailmakers set up business and thrived.

All trade dwindled during the years 1773-1783, due to the American Revolution, and fishing coastal waters became more dangerous. Shipbuilders were busy building war ships for the colonists. After the war, shipbuilding in and around Portsmouth continued, with a trend toward larger ships. In 1790, 20 vessels were built and launched from the Piscataqua River. Between 1800 and 1860, 575 sailing vessels were constructed near Portsmouth, averaging over 1,000 tons each (Jager and Jager 1983). More labor was required, and laborers from Canada, Ireland, and Germany came to Portsmouth, where they were housed in large boarding houses along the river. The size of ships being constructed limited how far inland they could be constructed, but the inland yards continued to contribute raw materials, smaller craft, and other lumber products.

Commerce, including fish exports, recovered and grew from 1783 until 1807, when a trade embargo limited foreign trade. Ironically, after the War of 1812, waged to protect the rights of American merchants, foreign trade from Portsmouth never fully recovered. Consequently, more of the labor force turned to fishing, especially cod and mackerel fisheries operating out of Portsmouth, New Castle, Kittery and Shoals. Most of the fish and fish oil were traded to the South, in exchange for tar, potatoes, apples, etc. One export list of 1812 lists 1989 quintals (hundredweight) of dried fish, and another record lists 81 fishing vessels based in Portsmouth in 1841 (Saltonstall 1968).

After the War of 1812, American shipbuilders and merchants sought to decrease any reliance on foreign trade, and trade along the coastal states resumed. Small coastal trading vessels and boats for local use were built. The shipbuilders enjoyed a brief period of renewed industry with the sailing clipper era of the 1840s to 1860s. However, after that period steam-powered vessels


Gundalow "Captain Edward H. Adams" at mooring in Adams Cove, Great Bay Estuary, New Hampshire.

replaced sailing vessels. Because of the size and weight of the new steel ships, and the cost of materials, Portsmouth shipyards were unable to compete and became less active (Hugo-Brunt 1957, Saltonstall 1968). Lumber continued to be exploited for other products, especially with the emergence of portable sawmills around 1880 and the change of the paper-making process to use small trees (Jager and Jager 1983).

An important vessel used during the 1800s, unique to the Great Bay area, was the gundalow, a commercial sailing rig used to transport hay, timber, etc. as well as people (NERBC 1980, NHOSP 1989). The gundalow was "heavy and broad bottomed", a "local craft ideally suited to the shoaly conditions of the rivers and Great Bay" (NHOSP 1989). The vessels travelled among the towns along the Piscataqua River and could sail to Boston if necessary but this would be a slow, dangerous trip which would depend on good weather (Adams 1976).

With the decline of shipbuilding, and the growth of the Industrial Revolution, the economic base of the Piscataqua region shifted to manufacture and industry. Manufacture of goods dated to the early 18th century, with textiles, bricks, iron, and later farm-goods produced along the Estuary and its tributaries and transported to Portsmouth for local use and export.

During the early 18th century the immigration of Scotch-Irish settlers brought to New Hampshire new knowledge of techniques for flax-raising, flax wheels, and making linen. Weaving communities were established, reviving what was until then a cottage industry (Little 1931). In 1751, a carding mill and dye house were set up on the Lamprey River at Newmarket, and in 1804, three cotton mills and a dam for power were built (George 1932). Newmarket became one of the most important textile producers in the northeast. Other mills were established, such as on the Salmon Falls River in South Berwick, and a canvas mill in Exeter (Saltonstall 1968). Dover had three mills on the Cocheco River, constructed in 1814 (Jackson 1944).

Most mills relied on water for power, with the exception of the mills in Dover, which ran on coal-powered steam engines. All the mills relied on a supply of cotton from the south and the waterways for imports of cotton and exports of finished products (George 1932). The flannel, linen, calico and other textiles of the New Hampshire mills were produced into the 20th century. Between 1850 and 1900, Newmarket alone produced 1,500,000 yards of cotton cloth (Winslow 1983). In 1850, Portsmouth had three mills, employing 275 men and 280 women, but they were combined into one mill by 1860. In 1880, the mill burned and was replaced at a different site. However, the new mill only employed twelve, and operated for less than ten years. After that the textile industry in Portsmouth ended with no one employed in textiles by 1900 (Sparhawk 1983). However, textiles were the leading manufactured item in New Hampshire, and the mills were productive until the Depression of the 1930s (Jager and Jager 1983).

Bricks were another important product from the shores of the Estuary. Lists of exports from 1752 to 1783 include hundreds of thousands of bricks, produced in brickyards such as those at Dover Point and Eliot, Maine (Adams 1976). Blue marine clay was taken from the shoreline and adjacent lands with clay deposits, using horse pulled plows. Quality bricks were produced at the Piscataqua brickyards, which remained very active to keep up with demands from Portsmouth and Boston. In 1888 alone, 15,000,000 bricks were exported (Adams 1976). In some parts of the Bay, large areas of clay were excavated, altering the shoreline.

Other excavating activity included mining bog ore from the marshes, swamps, and ponds. Sometime in the early 18th century an iron-works was established on the Lamprey River above Newmarket to process the bog ore (George 1932). The ore was dug up with an oyster rake, or with a pick and shovel if dry enough. The ore was 25% iron and was of inferior quality, suitable for cannonballs, anchors, and iron fixtures, but not for the iron fittings needed for shipbuilding. Iron was listed as an export to Boston as early as 1713 (Saltonstall 1968), but the iron-works was shut down when most of the sizable deposits were used up.

Tanneries were another industry that became established along the tributaries to the Bay. Hides were used for trade even before the first permanent settlements, but it is not known when chemical processing came into use. The chemical tanning process produces chrome sludge and acid solution wastes that were discharged into the waterways. The tanneries provided leather for shoes, saddles, and other products which were important industries in the region in the 19th century (Stone 1976, Winslow 1983).

These industries were followed by others as the population expanded and new industries developed. Various machine shops, leather manufactories, distilleries, foundries, breweries, etc. were established in Portsmouth and the region by the late 1800s (Sparhawk 1983). Three breweries (including the largest in the world around the turn of the century) existed in Portsmouth until Prohibition in 1918 (Sparhawk 1983). Shoe manufacture was important in Portsmouth until 1904, when competition from other areas forced the manufacturer to close. Machine shops and coal haulage increased with increased factories. Stone-cutters and masons, printers, rubber manufacturers, launderers, and even cigar-makers inhabited Portsmouth between the 1850s and 1910, contributing to the activity and commerce of the city (Sparhawk 1983). Railroads, bridges, and streetcars, constructed in the mid-1800s, decreased the reliance on water-transport and increased activity beyond the city limits.

Farming activity during the earliest settlement period was for local use only, but expanded to provide exportable animals and products. By 1750, beef, cattle, sheep, and oxen were being exported, mainly to Canada. English hay was imported and established on farmlands around the Bay, and eventually hay was exported as well. Lard and butter, bread and flour, corn, beans, and cider were also exported (Clark and Eastman 1974). Bridges, such as the Piscataqua Bridge constructed at Broad Cove by 1855 (Chesley 1984), provided more reliable, year-round access to Portsmouth than ferries. This increased the possibilities of trading farm goods.

Throughout the rise of industrialization, use of the fishery resources continued. With impacts from an increased population and its industry, fish populations started showing some decline between the mid-18th to early 19th centuries (Jackson 1944). Overfishing may have contributed to the decline, because there were no management strategies for the seemingly limitless resources. Weirs were commonly used for fishing in the tidal portions of the rivers, and resulted in the capture of many anadromous fish, which work back and forth with the tide to adjust to the salinity change as they migrate upriver. Weirs, nets, and drag seines were all used for fishing in the Bay, using non-selective methods that may have contributed to overfishing of some species of fish. The decline of the bass population by the early 1800s has been attributed to these indiscriminate fishing methods. One report from 1812 claims that "The Bass was formerly taken in great plenty in the river Piscataqua; but by the injudicious use of nets, in the winter, this fishery was almost destroyed" (Jackson 1944). A newspaper item from 1872 indicated that the remaining populations were still being harvested, with over 200 pounds captured in a weir on one tide (Adams 1976). Laws were passed to prevent further damage to overfished species, but not all the populations affected fully recovered. The construction of the cotton mills and dams on the tributaries in the 19th century further hindered salmon and shad. Salmon typically will not seek new breeding areas if their own are inaccessible, although shad will (Jackson 1944).

The pollution of the waterways by human activities probably also had an impact on the natural resources of the Estuary. Most of the information on pollution problems comes from various reports and news articles concerning public health. Wells dug to obtain water during the earliest settlement of Portsmouth became contaminated by human waste, which was often disposed of simply by allowing it to soak into the ground in "soak aways" (Hugo-Brunt 1957). In 1796, the Aqueduct Company constructed water pipes to transport spring water from a reservoir at the head of North Mill Pond to other areas of towns where well-water could no longer be used (Hugo-Brunt 1957). A Board of Health was formed in Portsmouth in 1799, composed of three Health Officers empowered to search for and order removal of "...all Nuisances, or other Causes injurious, or dangerous to the health of the inhabitants...created or occasioned by Stagnant waters, drains, common Sewers, slaughter houses, tan Yards, docks, necessaries, or any putrid Substances" (Estes and Goodman 1986). The Justice of the Peace could issue search warrants to the Health Officers and offenders could be fined or jailed.

These measures were in response to diseases such as yellow fever and tuberculosis that became epidemics due to crowded and unsanitary conditions in the towns. Epidemics of cholera, yellow fever, and small pox spread along the coast in the 1800s, and strict quarantine measures were taken against all incoming vessels. In 1802, a Portsmouth citizen declared that sanitary conditions in the town would have to improve to protect against epidemics. His report listed "Overflowing vaults, sewers, drains with garbage and filth in the streets, lanes, yards, cellars, &c.&c...[which] emit such nauseous smells as to poison the whole atmosphere" (Estes and Goodman 1986). Newspaper items throughout the 19th century include repeated warnings against pollution in the town, and of inspections. In 1805 it was noted that "...fishsellers have uncommonly neglected cleanliness in the market - they are to throw remains into water beyond the low tide mark" (Estes and Goodman 1986).

Fisheries, slaughterhouses, laundries, industries and manufacture yards, stables and pig yards, residential privies, and waste cellars all contributed to sanitation problems in the town. North and South Mill Ponds were especially polluted; in 1886 a sewer was built along a portion of North Mill Pond, and in 1894 along South Mill Pond, prior to building a hospital nearby. Sewers for the rest of the town were under construction in 1893, to remove sanitary waste to the Piscataqua River, after the death of 13 children was attributed to "imperfect sewage" (Estes and Goodman 1986). These early sewers were constructed of wooden pipes which decayed quickly, and typically had seals that leaked (Adams 1976).

Increased crowding brought even more laws concerned with sanitation, including microbial pollution standards for food and drink, and testing of water and ice supplies for chemical contaminants in 1891 (Estes and Goodman 1986). By the late 1800s, regulations were imposed on the keeping of animals in the downtown area, and piggeries were forbidden. Increased manufacturing activities and industrialization brought new sources of pollution as well. In 1900, the Portsmouth Medical Association complained about the "...overwhelming pollution of the South Mill pond and the foul odors arising from breweries, soap factories, etc.", and ordered that it be cleaned up (Estes and Goodman 1986).

Sanitation problems evident from reports on Portsmouth probably also occurred in every settlement around the Estuary as well. Other sources of pollutants originated in more rural areas from agricultural activities, mills and tanneries. The cotton mills used natural dyes from indigo, madder, walnut, pine, maple, hickory, sumac, etc. (Little 1931) which were quite strong, and the wastes were discharged directly into the river. There are records of factory workers dying from blood poisoning due to exposure to the potent dyes (Armstrong 1969), although little is known about the actual quantities of dyes used and discharged to the waterways. Tanneries also contributed to pollution along the tributaries of the Estuary, although it is not known when the first chemical processing began. Discharges of wastes from tanneries occurred as late as 1968 when 42,700 m^3 of chromate sludge was discharged from a Dover tannery into the Cocheco River.

Sawdust from the sawmills was a pollution problem from very early settlement days. The first sawmills were located on the waterways because they were run with water power, and the location allowed for easy export of the prepared products. For each 1,000 feet of lumber cut, approximately forty bushels of sawdust was produced, which was disposed of in the waterway. A visiting merchant noted in 1750 that salmon weren't returning to the Piscataqua as much as in the past because of sawdust from the sawmills choking the waterways (Jackson 1944). The sawdust destroyed spawning beds and young fry. A Fish and Game Commission report of 1889 declared that the mills were located "...so as to run the refuse into some stream to avoid the bother to take care of it" (Jager and Jager 1983). There are historical reports of sawdust literally coating broad areas of mudflats at low tide, especially in the upper reaches of the Piscataqua River (Jackson 1944). Portable sawmills operated along the tributaries of the Estuary as late as the 1950s.

The main concerns until our present century were for cleanliness in the towns, so cleaning up pollution simply meant getting pollutants to the river, where it was assumed they would pose no harm. Reports of the 18th and 19th century do not mention the water quality of the Estuary, but it does not appear to have been a major concern.

Despite increased pollution in the Estuary, fishing activity continued throughout the 19th century, including commercial alewives and smelt harvests. Newspaper clippings from that time provide some information on the fisheries industry (Adams 1976). Smelt catches included fish averaging 6 to 8 pounds. Large schools of pollack came up the Estuary, with individual fish over a foot in length. Up to 100 pounds of eels were harvested per day and sold to Boston in 1888. Oysters weighing as much as three pounds or more each were dredged using horses, harvested at 10 to 16 bushels per day. Through the early 20th century, eels, pollack, alewives, and smelt were harvested from the Estuary, and coastal fishing around the Shoals included catches of cod and haddock, with sunfish, swordfish, halibut, and sharks encountered as well.

A report on the status of marine resources in the Great Bay Estuary in 1944 (Jackson 1944) declared that shellfish populations were greatly diminished and that pollution limited the use of the shellfish beds that remained. Tidal flats along both banks of the upper Piscataqua River were closed due to pollution, including microbial contaminants and industrial pollutants such as sawdust. Clam populations had declined from previous levels, and oysters had declined presumably due to overharvesting and increased sedimentation in the Bay.

From the diverse list of species originally discovered living in the Estuary, smelt remained the most important commercial fish in 1944. Several fish species appeared to be gaining in numbers including striped bass, and eels were still caught in some places; shad, alewives and small amounts of white perch, cod, pollack, frost fish, herring and small flounders were also taken commercially from the Estuary. Occasionally, salmon, lumpfish, or sturgeon were caught in the Estuary. Cunner populations were showing decline. Lobster populations in the Bay had been successful, with modest harvesting, until World War I, when coastal lobstermen moved into the Bay. Jackson (1944), predicted that this intense harvesting could exhaust the supply. However, present commercial lobstering is conducted in the estuary and in the near shore area (depths of 100′ or less) within five miles of the shore (NOAA and NH Office of State Planning 1988).

In the mid 1940s industrial and sewage pollution were problems originating in population centers on the Salmon Falls, Cocheco, Lamprey and Exeter Rivers (only the Oyster River had no industry in 1944). Lower pH values in the Salmon Falls, Cocheco and Bellamy Rivers (average pH 7.3) in 1944 were hypothesized to be the result of increased industrial discharges on those rivers (average pH for the upper Piscataqua River, Little Bay and Oyster River was 7.9).

Sewage pollution was severe in the 1940s, due to discharges of untreated sewage. Results of an early 1940s year-long survey of microbial contamination were published in Jackson's report (1944). Average coliform bacteria counts are listed in Table 1.1. The values are based on 520 samples and over 4,000 cultures throughout the Estuary. The U.S. Public Health Service Standard for shellfishing at the time was 70 coliform bacteria per 100 ml water. Most samples exceeded that value.

Other activities affecting the Great Bay Estuary include dredging and filling. In 1905, a peninsula called Henderson's Point on Seavey Island was blasted to make the channel larger and aid navigation. Forty-six tons of dynamite were detonated to remove a ledge 400 feet long and 300 feet wide, to a depth of

Table 1.1. Fecal coliform bacteria for various sites in the Great Bay Estuary sampled in the early 1940s. Results are average coliform bacteria counts per 100 ml from a number of samples taken throughout an entire year (Jackson 1944).

Waterway	**Human Population**	**Estimated Number of Samples Cultured**	**Average Coliform per 100 ml**
Salmon Falls River	17,000	255	3,286
Cocheco River	31,800	454	10,634
Upper Piscataqua (to Dover Point)	unknown	200	767
Lower Piscataqua (Dover Point to Rte. 95 Bridge)	35,000	30	2,400
Bellamy River	3,000	559	1,573
Oyster River	3,500	766	803
Lamprey River	7,700	36	2,895
Exeter River	8,800	201	9,020
Lower Little Bay (Dover Point to Fox Point)	unknown	413	108
Upper Little Bay (Fox Point to Adams Point)	unknown	302	87
Great Bay (west of line from Weeks Point to Woodman Point)	unknown	747	144
Greenland Bay (east of above line)	unknown	405	120
Fabian Point to Pierce Point East	unknown	63	20

35 feet (McDonough 1978). Other dredging projects have been conducted to aid navigation, and to deepen nearshore areas for marinas and cargo terminals. Filling intertidal areas for development has also occurred, changing the shape of the shorelines and altering natural habitat areas.

Dredging and filling for development projects has come under increased scrutiny in recent years, in part due to impacts on marine habitats. However, population and industry continue to increase. The population and work force of New Hampshire expanded rapidly in the 1970s, ahead of national averages, with metal products and electronics replacing more indigenous industries. Portsmouth is a mix of restaurants and shops as well as commercial port activities. Along the Piscataqua River in Portsmouth there are two bulk cargo docks, a petroleum distribution facility, two electrical generating stations, a tugboat operation, the state fish pier and the New Hampshire State Port Authority cargo terminal (NOAA 1988). Upriver there are other petroleum terminals and a liquified petroleum gas facility.

Tourism is another major industry for the New Hampshire seacoast region, with impacts to the marine environment from increased population, insufficient septic facilities at summer residences, and boat traffic and associated impacts. Only one boat sanitary pump-out facility exists in the coastal region, and there is no effective enforcement program in existence to ensure its use (Kimball Chase and SRPC 1989).

Current use of the area within the Great Bay National Estuarine Research Reserve includes limited commercial and recreational fishing, clamming/oystering, bird hunting, bird watching and boating. In 1987, NOAA and the NH Office of State Planning estimated the value of the total oyster harvest to be 1.6 million dollars (NOAA and NH Office of State Planning 1987). This estimate was based on major oyster beds on Nannie Island, the mouth of the Lamprey River and Oyster, Bellamy and Piscataqua Rivers as well as minor beds throughout the estuary. Commercial fishing includes river herring, American eel and rainbow smelt with limited commercial lobstering in Little Bay (NOAA and NH Office of State Planning 1987). Important recreational species are striped bass, rainbow smelt, winter flounder, alewives and coho salmon.

Development along the shoreline of the Great Bay Estuary has been reserved for residential, agricultural or conservation purposes as determined by land use controls of the surrounding towns (NOAA and NH Office of State Planning 1987). Pressure to develop waterfront in Great Bay is less than in Little Bay because low tide brings mud flats and narrow channels. These limit boating and many people do not want to live next to the extensive mud flats (NOAA and NH Office of State Planning 1987).

Throughout its history the Great Bay Estuary has experienced heavy use from recreational as well as commercial activity. Since the first settlements, the Estuary has been an important fisheries resource; NOAA and the NH Office of State Planning (1988) go so far as to say "within [the New Hampshire] state jurisdiction every bit of inshore water is of vital importance to fisheries interests". Other industry has also been vital to the region ranging from early activities of the export of lumber as well as other natural resources and shipbuilding, to manufacturing following the Industrial Revolution to the current energy and petroleum facilities. Continued use and enjoyment of the Estuary will require monitoring of the human activity in the region and its effects on the Estuary.

Today's Scenic Resource Values

The scenic use of the Great Bay Estuary (Fig. 0.1) is enjoyed primarily by way of boating and a few public viewing points (e.g. Adams Point, Hilton Park and Prescott Park). Several large tour boats bring groups into the Estuary to see the fall foliage and scenic beauty. Fishermen, sportsmen, and boating enthusiasts frequent the Estuary year-round, enjoying its relatively undisturbed beauty and natural resources.

Great Bay can be viewed by car from a large section of Bay Road (Durham Point Road) along the western shore between Durham and Newmarket. Public access and other views of the Bay are available from Adams Point which has 1.4 miles of coastline on the Bay with hiking trails, a boat launching ramp, and a wildlife conservation area all owned by the State and managed by New Hampshire Fish and Game. Access is also available from a state-owned Great Bay National Estuarine Research Reserve visitor area at Depot Road in Stratham, as well as from the boat landing on the Squamscott River (Chapman's Landing) at the Route 108 bridge in Stratham. With the closure of Pease Air Force Base, it is anticipated that one or two additional public access sites will be defined at Woodman and Thomas Points on the Pease land. Additionally, a 1075 acre wildlife area is proposed within the former base which would continue to protect that part of the Great Bay shoreline.

Little Bay is nearly as inaccessible to public use as is Great Bay. Launching ramps for public boat access can be found at Adams Point and Cedar Point in Durham. Scenic views of Little Bay are available from the Bellamy Bridge and the General Sullivan Bridge and from rest areas along Route 4. Towns on Little Bay have resident access and recreation facilities on the Oyster River at Wagon Hill Farm in Durham, and Fox Point in Newington. Hilton Park in Dover provides a picnic ground on Little Bay, west of the General Sullivan Bridge.

The Piscataqua River is divided down the middle between the States of New Hampshire and Maine. The Maine side, to the north, has limited development, restricted primarily to residential use except for the U.S. Naval Shipyard Portsmouth. The New Hampshire side, to the south and down-estuary of Little Bay, is heavily industrialized. Nonetheless, the River and Portsmouth Harbor provide the attraction of water access and scenic views. Public boat access to the Piscataqua on the New Hampshire side is available at Hilton Park in Dover and at Pierce Island in Portsmouth. Town-maintained boat launch access in Maine is found on the Piscataqua River in Eliot and in Pepperel Cove in Kittery. Picnic and recreation areas are available at Hilton Park, Prescott Park, and Pierce Island. Several historic sites along the Piscataqua River also provide scenic access, including Fort Constitution in New Hampshire, and Fort McClary and Fort Foster in Maine.

Today's Recreational Resource Values

Recreational activities within the Great Bay Estuary are extensive and diverse. Boating activities include sailing, fishing, water skiing, rowing, and

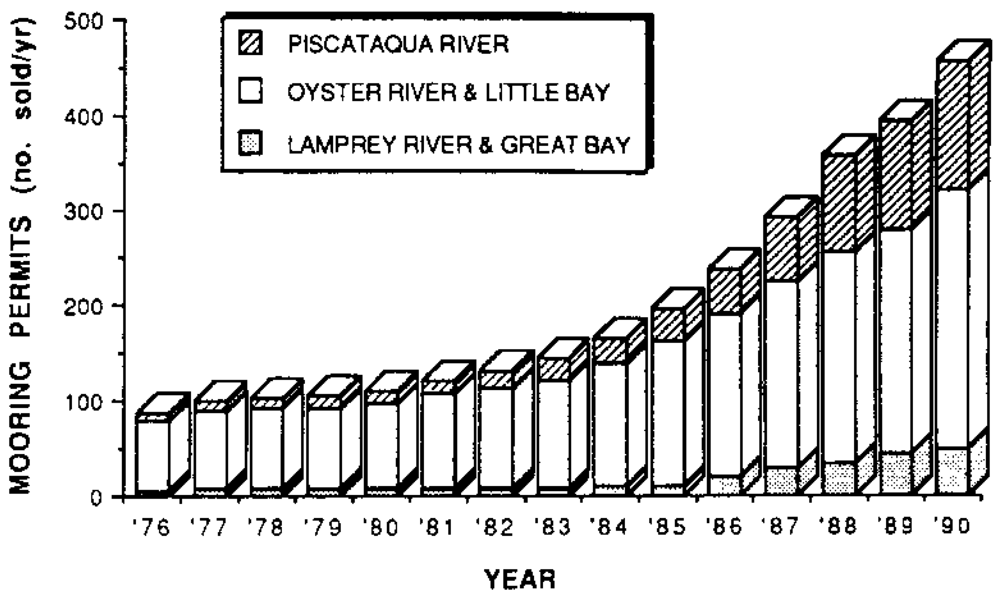


Figure 1.1. Annual mooring permits sold from 1976 to 1990 in the Great Bay Estuary (NH Port Authority 1991).

canoeing. The Estuary is experiencing a rapid increase in boating activity as evidenced by the number of mooring permits issued by the state of New Hampshire (Fig. 1.1). The low number of boats currently moored in Great Bay proper results primarily from the extensive mudflats limiting access to channels from the shore. Most marinas are located in Portsmouth Harbor, Little Bay, or in the rivers entering Great Bay.

Finfishing activity includes fishing for striped bass, bluefish, salmon, eels, tom cod, shad, smelt, river herring, and flounder. Such activities are not limited to boat access. Cast or bait fishing is done from the shore in many places and from the bridges crossing the Estuary. One of the major winter activities in Great and Little Bays is ice fishing for smelt which is done in the open and from bob houses. Ice fishing catches have increased over the last decade, while at the same time, smelt spawning activity has decreased in historic areas (Fig. 1.2), threatening the future of this recreational fishery. The smelt fishery in Great Bay occurs primarily in the Greenland Cove area and Lamprey-Squamscott River area from early January to March. From 1972 to 1977, the smelt fishery was evaluated in Great Bay with Greenland Cove being more productive than the Lamprey-Squamscott area (NAI 1978a).

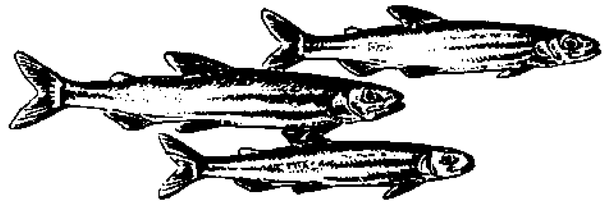
Shellfishing is an important recreation in the Great Bay Estuary, the harvest of the renowned Great Bay oysters being the predominant resource utilized (see Chapter 8). The bivalve fishery in the Estuary is currently closed to harvest except in Great Bay. Clamming activities for the soft-shell and razor clams on many beaches in Great Bay have become intensified because of the closure of clamming elsewhere in the state due to sewage pollution (see Chapter 10).

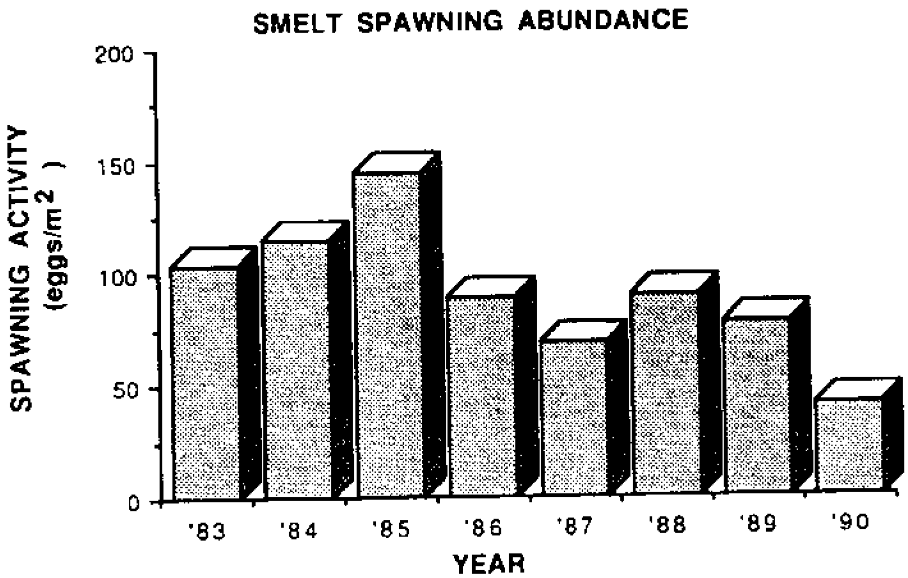
Another important recreational boating activity is the trapping of lobsters that occurs throughout the Estuary. Recreational lobster fishing is popular in the Portsmouth Harbor area on both the Maine and New Hampshire sides of the river.

Fishing activities in New Hampshire appear to be greater than ever, despite a reduction in fish stocks and decreased catches. For flounder taken in New Hampshire waters by rod and reel from bridges, piers and jetties (NHFG 1979-1989), the estimated catch has decreased dramatically during the 1980s (Fig. 1.3).

The NH Department of Fish and Game has pursued stocking and monitoring efforts on selected fish stocks in order to enhance recreational fisheries (NHFG 1989). The Coho salmon stocking program was begun in 1969 (Fig. 1.4). Salmon eggs were brought from the west coast and raised in a hatchery for 18 months. The smolt were released in the spring at a size of 10 fish/lb. The Coho program was an experimental research project to determine if the western fish could be introduced into eastern waters. The goal was to get a one percent return; this was obtained during two years only (Fig. 1.4). In 1989, the program changed the stock salmon species to Chinook because Coho eggs were no longer available. Additionally, an Atlantic salmon stocking program was begun.

The shad stocking program has the goal of reintroducing the species to the Great Bay Estuary. Their limited return in the past few years shows some sign of success for this stocking program. The stocking programs for salmon and shad (Fig. 1.4 and 1.5) have had limited effects on catch returns, but it is too early to judge the success of these efforts.





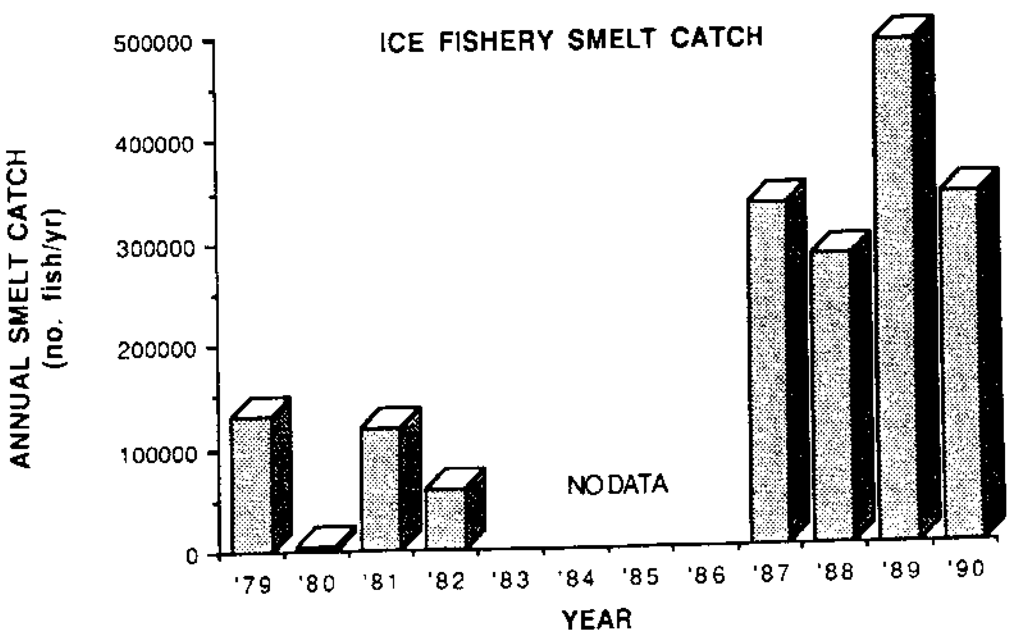


Fig. 1.2. Annual smelt spawning activity and estimated annual ice fishery smelt catch in the Great Bay Estuary (NHFG 1979-1990).

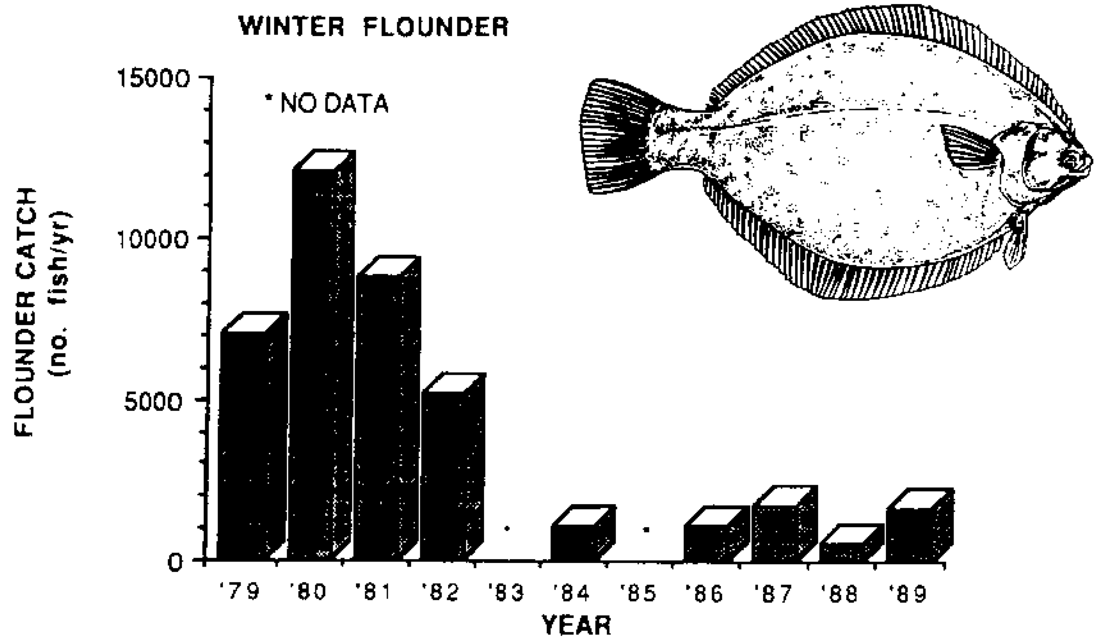
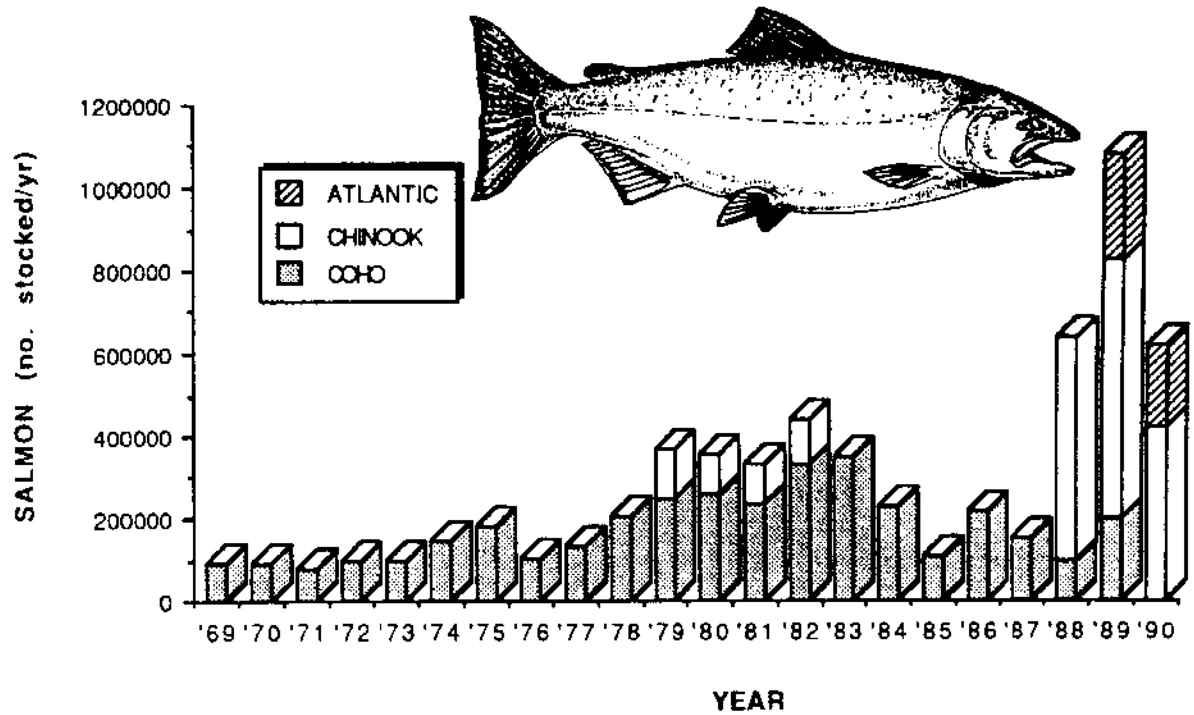


Fig. 1.3. Estimated annual flounder catch from bridges, piers, and jetties from 1979 to 1989, based on summer creel surveys (NHFG 1979-1989).



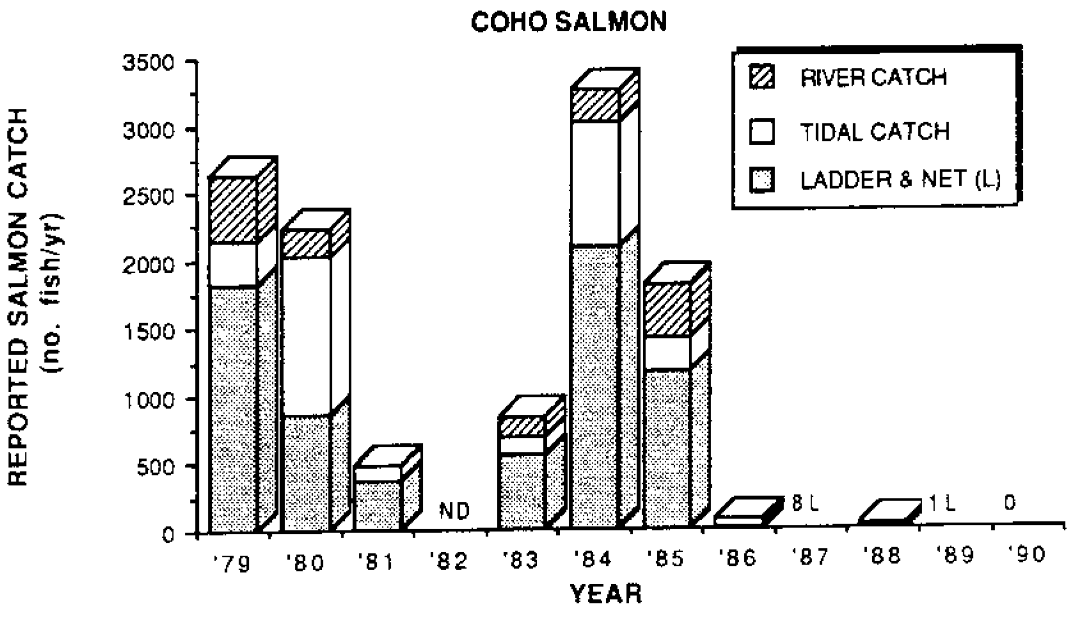
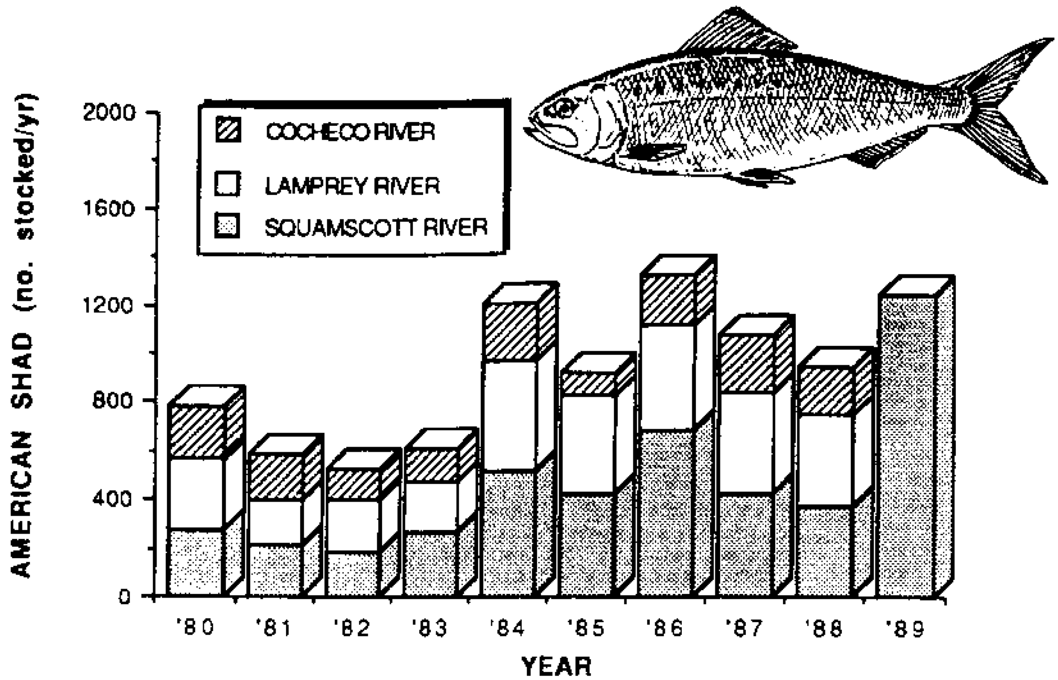


Fig. 1.4. Annual number of salmon stocked in the Great Bay Estuary and the annual reported returns of Coho salmon as river catch, tidal catch, and ladder/net captures from 1979 to 1990. ND indicates no data available (NHFG 1979-1990).



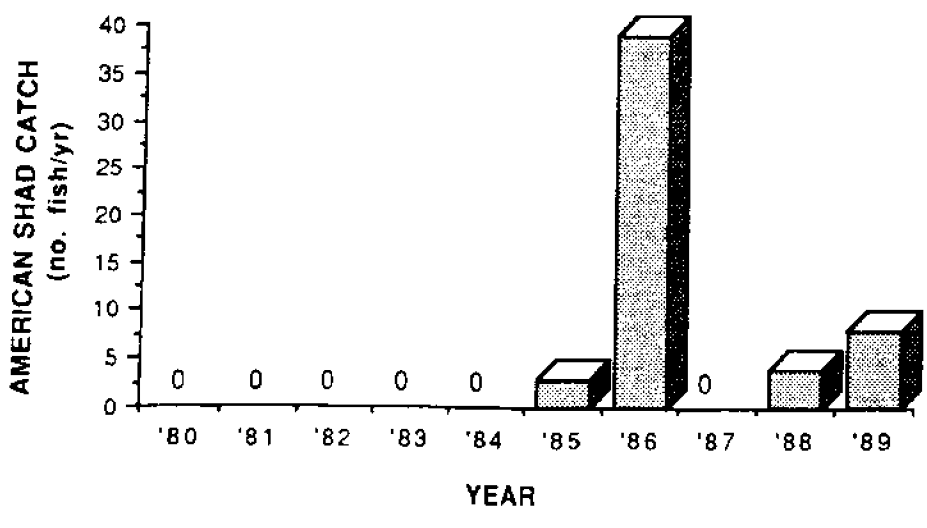


Fig. 1.5. Annual number of american shad stocked and the reported returns in the Great Bay Estuary form 1980 to 1989 (NHFG 1980-1989).

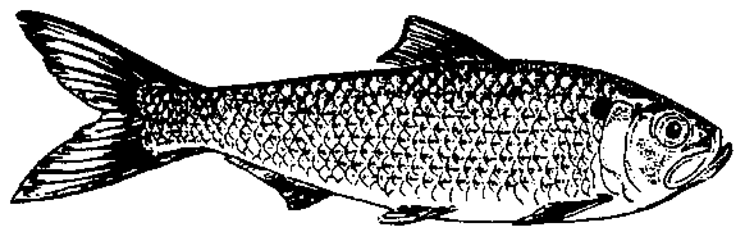
Waterfowl hunting during the fall and winter is a major recreational activity that is concentrated in Great Bay. Estimated total harvests of ducks and geese are believed to be quite small. Bird watching is increasing in popularity with a volunteer group now conducting bird counts for the Great Bay Estuarine Research Reserve. The return of eagles to the Estuary in the last few years has also stimulated interest. Swimming, although limited by the lack of sand beaches, is another important recreational activity. The shoreline of the Great Bay Estuary is also enjoyed by beach walkers and hikers negotiating their way just below the high tide line.

Today's Commercial Resource Values

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 is a center of shipping activities, including fuel oils, wire cable, cement, scrap metal and salt, and fishing activities which include lobster and finfish harvest from offshore and within the Estuary. A commercial aquaculture operation is flourishing within Spinney Creek on the Maine side of the Piscataqua. Additionally the Naval Shipyard Portsmouth, on Seavey Island in Portsmouth Harbor, uses the Estuary to provide submarine access to their repair facility and for shipping activities.

Commercial uses of Great Bay are few. Limited commercial lobstering is done within the main channel of Great Bay. Tour boats bring visitors to see the scenery and enjoy various vistas. There are no marinas in the Great Bay proper, although several small marinas are found within the tidal rivers in Exeter and Newmarket plus down-estuary in Little Bay. The harvest of bait fish occurs in some riverine areas but it is only documented on a volunteer basis. A river herring (alewife) fishery shows a decrease in reported commercial catch through the 1980s (NHFG 1989), despite the nearly continuous increase in spawning returns (Fig. 1.6).

Great Bay Estuary is affected by the disposal of diverse industrial and domestic wastes. Historically, many of the towns around the Estuary used water power from the rivers to operate mills and tanneries. The historic discharge of waste materials into the Estuary from industries was much greater than it is today. Today, treated sewage effluent (chlorinated and settled) is discharged from all the towns and cities surrounding the Estuary (Table 6.1). Industrial pollutants (heavy metals and organic sludge), in addition to sewage, are discharged into the Piscataqua River and other parts of the Estuary from Dover, Rochester, Newington, Portsmouth and other sites (Capuzzo and Anderson 1973, Lyons et al. 1982, Hines et al. 1984, Nelson 1986).



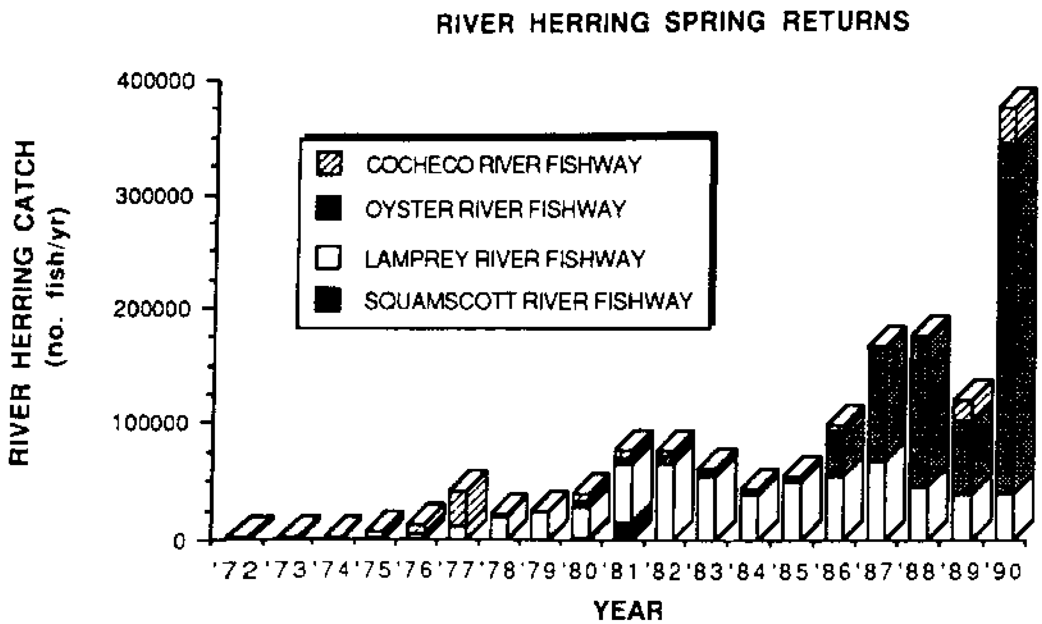


Fig. 1.6. Annual river herring catch in the Great Bay Estuary.

Chapter 2: Characterization of Estuarine Habitats
by F.T. Short, P.F. Sale, and J.A. Guy

Together, the physical and biological features of the Great Bay Estuary can be divided into five dominant habitats. All of these provide valuable structure which contributes to the overall function and productivity of the Estuary. The five habitats are presented in order of spatial dominance in Great Bay (Table 2.1), though the contributions of each habitat to the estuarine ecosystem are at present not completely known. In general, the major role and contribution of these habitats to Great Bay is defined by their contribution to secondary production both within the fish populations and within mammal and bird populations of the Bay area. There is no comparable assessment of habitat dominance currently available for Little Bay or the Piscataqua River. Such habitat evaluations are important for establishing management priorities in the lower Estuary. The distribution of saltmarsh in the entire Estuary is currently being mapped (Ward, per. com.), but the other habitat areas remain unknown. Despite the lack of quantitative data on habitat distribution in the lower Estuary, the following habitat characterizations are generally applicable.

Eelgrass Habitat

The eelgrass habitat provides the largest spatial habitat distribution within Great Bay. Eelgrass beds in the Estuary occur as large meadows and small contiguous beds forming intertidal and subtidal seagrass habitats. The eelgrass habitat is primarily characterized by the presence of the rooted marine angiosperm *Zostera marina* which is found extensively on muddy and sandy bottoms throughout shallow portions of the Bay (see Chapter 7). Eelgrass habitats elsewhere have been shown to function as breeding areas and nursery grounds for the reproduction of finfish and invertebrates (Thayer et al. 1984). Thus, they are a feeding area for many fish, invertebrates and birds. For example, geese and ducks frequent these habitats, feeding directly upon eelgrass, while wading birds and diving ducks are attracted by the many fish and other food sources. Eelgrass habitats provide a refuge for juvenile and small fish inhabiting the Estuary. As a result of this concentration of fish, other larger predatory fish such as striped bass (NAI 1979b) are attracted to eelgrass beds for feeding.

The structure of the eelgrass habitat, with floating leaves extending into the water column altering current circulation and flow patterns, provides a mechanism for entrapment of sediments and larval organisms suspended within the water column. Great Bay eelgrass habitats may also be important in recruitment of fish, shellfish and invertebrates (Thayer et al. 1984, Grizzle et al. in review). The use of seagrass habitats by juvenile winter flounder has been documented in a Cape Cod estuary (Saucerman 1989). Many species found within the eelgrass habitat are distinct from the species assemblage observed in the other major Great Bay Estuary habitats.

Table 2.1. Area of Great Bay and the component habitats of the Bay (Data for Great Bay and channel habitat from Fig. 0.2, eelgrass from Fig. 10.2, mudflat from Figs. 0.2 and 10.2, salt marsh, fucoid algae and shellfish from Nelson 1981a)

	Area (km^2)	Area (acres)	% Area
GREAT BAY	22.715	5613	-
Eelgrass Habitat	10.462	2585	46%
Mudflats (unvegetated) Habitat	4.864	1202	21%
Saltmarsh Habitat	4.112	1016	18%
Channel Habitat	3.278	810	14%
Fucoid algae	0.028	7	<1%
Shellfish (part of other habitats)			
scattered oyster beds	1.060	262	5%
major oyster beds	0.600	148	3%
major clam beds	0.302	74	1.3%
minor clam beds	0.082	20	<1%

Studies are currently underway to evaluate the importance of the eelgrass habitat to fish (Sale and Guy unpubl.) and lobster (Short unpubl.) populations in the Great Bay Estuary. Preliminary purse seine sampling has identified four numerically important juvenile species that utilize Great Bay eelgrass meadows - i.e. rainbow smelts, Atlantic silversides, nine-spined sticklebacks, and river herrings. Data from 1990 show that all four species are most abundant during late summer (Table 2.2). Silversides and sticklebacks are permanent residents of eelgrass habitats, while smelt and river herring spawn in fresh water and make use of the eelgrass beds during their larval and juvenile phase, en route to open waters.

Rainbow smelt are less transitory than river herring, utilizing the eelgrass beds for about five months per year. Measurements from 1989 and 1990 show the first smelt larvae of the year appearing within Great Bay eelgrass beds in June. They ranged in size from 7-25 mm total length (Sale and Guy unpubl.). Smelt utilize eelgrass habitat at a very young age and throughout much of their juvenile life; they leave the Bay sometime in October.

Atlantic silversides were most abundant within Great Bay as juveniles from August to October; they inhabit open beach areas at high tide and eelgrass beds at mid-low tide (Table 2.2). Their seasonal movement suggests that Atlantic silversides are important exporters of production and biomass from estuarine systems to deeper, offshore waters (see Chapter 8).

Spawning in the nine-spine stickleback takes place in early summer and is commonly associated with aquatic vegetation. Nests are built in the eelgrass and eggs are deposited and fertilized within them, followed by a period of parental care by the male (Wootton 1976). Sticklebacks were caught consistently in the eelgrass habitats within Great Bay.

The river herring is an important forage and commercial species in estuarine and marine ecosystems. Spawning in fresh water, river herring enter the Bay in emigration waves, consisting of large schools of juveniles moving down river. Adams (1990) reported a 97% emigration from the

Table 2.2. Finfish from two eelgrass beds in Great Bay, New Hampshire (Sale and Guy, unpubl.). Abundance (N), rank, percentage composition (%) and size range (mm) of species was collected from June to October 1990 using a 14m by 2m purse-seine of 1mm mesh. Percentage composition was derived using total catch for all months combined. For rank, the ten most abundant species were graded from highest to lowest each month, the most abundant species receiving ten points and the tenth most abundant species receiving one point. Each species score was then totalled over the four months sampled to produce a relative ranking from the most abundant (having the highest score = 1) to the least important (having the lowest score = 10).

SPECIES	COMMON NAME	BED 1				BED 2			
		N	Rank	%	Size	N	Rank	%	Size Range
		MARINE							
Alosa pseudoharengus	Alewife	177	2	5.01	42-121	149	4	2.44	39-110
Alosa sapidissima	American shad	1		<1.0	80				
Brevoortia tyrannus	Atlantic Menhaden					1		<1.0	53
Cyclopterus lumpus	Lumpfish	1	10	<1.0	12	1	10	<1.0	15
Tautogolabrus adspersus	Cunner	4	9	0.11	13-32	7	9	<1.0	16-27
Osmerus mordax	Rainbow smelt	1798	1	50.93	19-97	4474	2	73.19	22-90
Pomatomus saltatrix	Bluefish					1		<1.0	53
		ESTUARINE							
Menidia menidia	Atlantic silverside	1425	5	40.34	40-123	717	5	11.73	37-125
Microgadus tomcod	Atlantic tomcod	71	4	2.01	47-186	72	8	1.18	46-90
Apeltes quadracus	4-spine stickleback	4	8	0.11	21-48	104	3	1.70	22-52
Gasterosteus aculeatus	3-spine stickleback	3	7	<1.0	18-30	50	7	<1.0	12-47
Pungitius pungitius	9-spine stickleback	35	3	<1.0	24-53	499	1	8.16	9-58
Pseudopleuronectes americanus	Winter flounder	1		<1.0	77				
Syngnathidae fuscus	Northern pipefish	10	6	1.0	99-146	38	6	<1.0	35-197

Lamprey River into Great Bay over a 14 day period. Young-of-the-year river herring were caught sporadically in Great Bay eelgrass beds.

Mudflat Habitat

The second most extensive habitat within Great Bay is the unvegetated intertidal mudflat. This extensive low relief environment is an important contributor to the primary productivity of the Bay through the seasonally important benthic diatom production (Sickley 1989, Jaramillo per. com.). Mudflats are extremely important areas of benthic invertebrate production (see Chapter 8). The high densities of worms and bivalves often found in these mudflats are major attractants for predators.

The principal grazers on the mudflat infauna are birds, crabs, and fish. Wading birds of many species (Table 8.4) follow the falling tide to feed on clams and worms, while the intertidal flats are exposed. Conversely, fish and crabs move onto the flats at high tide to prey on some of the same invertebrates. One organism that has a major impact on the character and production of the mudflat environment is the horseshoe crab, *Limulus polyphemus*. Horseshoe crabs feed extensively in mudflat areas well up into the intertidal zone during high tide and then migrate into the subtidal zone during low tide, leaving pot marks and depressions on the intertidal mud surface (Jaramillo per. com.). Another species that extensively utilizes the mudflats within the Great Bay Estuary is the mudsnail, *Ilyanassa obsoleta*. Found in the tens of thousands on a mudflat, it feeds on the highly productive benthic diatom layer.

Salt Marsh Habitat

Salt marshes form the third most abundant estuarine habitat within Great Bay. Two types of salt marsh habitats are found within the Estuary (see Chapter 7). First, the typical New England salt marsh type (high marsh) is found primarily at the mouths of most of the rivers. Second, fringing salt marsh (low marsh, with occasional high marsh species) forms a discontinuous band of salt marsh vegetation around the periphery at approximately the bottom of the high tide line. Both of these marsh types are primarily composed of four salt marsh plant species *Spartina alterniflora* in the low marsh and in the high marsh *Spartina patens*, *Distichlis spicata* and *Juncus gerardii*.

The New England salt marshes, in particular tidal creeks and ditches that are found within the marsh systems, provide habitat for juvenile fish, feeding areas for birds, homes for numerous insect species, and a large supply of organic detritus that fluxes into the Estuary annually (Teal and Teal 1962). Salt marshes are also utilized by a number of terrestrial mammal species including deer, mink, otter, etc. Fringing salt marshes vary in width from 1-15 meters in different areas around Great and Little Bays (Josselyn 1978). They also provide a home for many species of invertebrates including numerous amphipods and snails.

The secondary production of fish in salt marsh habitats has been examined in a tidal creek situated within a large salt marsh meadow fringing the Squamscott River (Guy, Armstrong and Sale unpubl.). The hoop nets used blocked off an entire tidal creek in the marsh and captured all the fish that moved out of the salt marsh on the ebb tide. Young-of-year tomcod, white perch, river herring, silversides, smelt, mummichogs and the pumpkinseed were caught in June - October 1990. Estuarine species dominated the total catch, forming over 93% of total fish collected for all months. Three species, the common mummichog, the silverside

Table 2.3. Finfish from a salt marsh creek in Great Bay, New Hampshire (Sale and Guy, unpubl.). Abundance (N), rank, percentage composition (%) and size range (mm) of species was collected from May to November 1990 using a 5m long hoop net of 3mm mesh. Percentage composition was derived using total catch for all months combined. Species are ranked using relative importance.

SPECIES	COMMON NAME	N	RANK	%	SIZE RANGE
		MARINE			
Osmerus mordax	Rainbow smelt	473	3	3.80	32-103
Alosa pseudoharengus	Alewife	91	8	0.73	23-277
Clupea harengus harengus	Atlantic herring	7		<0.1	45-53
Brevoortia tyrannus	Atlantic menhaden	2		<0.1	42-47
Alosa aestivalis	Blueback herring	1		<0.1	64
Pomatomus saltatrix	Bluefish	4		<0.1	108-153
		ESTUARINE			
Fundulus heteroclitus	Common mummichog	9526	1	76.56	18-112
Menidia menidia	Atlantic silverside	738	5	5.93	24-93
Morone americanus	White perch	515	2	4.13	24-284
Pungitius pungitius	9-spine stickleback	357	6	2.87	19-61
Apeltes quadracus	4-spine stickleback	143	7	1.15	28-50
Gasterosteus aculeatus	3-spine stickleback	22		0.18	24-68
Anguilla rostrata	American eel	164	4	1.32	120-518
Microgadus tomcod	Atlantic tomcod	128	10	1.03	22-52
Liopsetta putnami	Smooth flounder	5		<0.1	10-114
Pseudopleuronectes americanus	Winter flounder	2		<0.1	41-95
Syngnathus fuscus	Northern pipefish	2		<0.1	185-206
Mugil cephalus	Mullet	1		<0.1	58
		FRESHWATER			
Lepomis gibbosus	Pumpkinseed	240	9	1.93	23-145
Lepomis macrochirus	Bluegill	6		<0.1	29-202
Micropterus salmoides	Largemouth bass	2		<0.1	220-224
Pomoxis nigromaculatus	Black crappie	1		<0.1	83
Notemigonus crysoleucas	Golden shiner	5		<0.1	48-120
Notropis cornutus	Common shiner	4		<0.1	41-58
Semotilus corporalis	Fallfish	3		<0.1	33-49

and white perch were the most numerically abundant (Table 2.3). Marine species, which included anadromous fish, smelt and alewives, represented a small part (4.64%) of the total catch (Table 2.3). The large numbers of mummichogs in the salt marsh may be a major food source for wading birds.

Channel Bottom and Subtidal Habitat

The fourth major habitat type is the channel bottom/subtidal habitat. Its importance is not well understood. The substrata varies from soft mud to hard sand to gravely cobble and rock in different locations. Several fish species, including winter and summer flounder, utilize these habitats as adults during some stages of the tidal cycle. Channel areas may provide refuge for fish and invertebrates that retreat from the eelgrass flats, tidal marshes and mudflats at low tide. Another major feature of shallow channel bottom and subtidal habitats is the extensive oyster beds which provide high production and a major recreational fishery within Great Bay (see Chapter 8). The characteristics and functional features of this habitat have received very little attention in past overall assessments of the Great Bay Estuary.

Rocky Intertidal Habitat

The fifth major habitat is the hard bottom rocky intertidal which occurs sporadically around the Bay fringing the shoreline and covering some extensive outcrops. The rocky shore habitat is dominated by two macroalgal species *Ascophyllum nodosum* and *Fucus vesiculosus*. *A. nodosum* is a long-lived species which dominates larger rock outcrops, while *F. vesiculosus* is short-lived and occupies less stable substrata. A major contribution of these seaweeds to the estuary is the release of algal reproductive structures (receptacles) and fragmented tissue into the estuarine detrital cycle (Josselyn and Mathieson 1978). For example, it is estimated that as much as 50% of *A. nodosum* biomass is released as reproductive material into the Estuary each spring (Josselyn 1978).

In addition to being important to the primary productivity of northern estuaries, fucoid algae provide structural complexity to intertidal habitats (Baardseth 1970). In muddy intertidal zones of northeastern estuaries, the limited stable substratum available for algal or invertebrate attachment makes valuable any surfaces that will support colonization. A variety of smaller seaweeds (e.g. *Pilayella littoralis* and *Ectocarpus siliculosus*) are epiphytic upon *Ascophyllum* (Mathieson and Hehre 1986). These small, filamentous seaweeds potentially contribute a substantial proportion of total annual intertidal primary production (Chock and Mathieson 1983). A variety of invertebrates also colonize intertidal fucoids (Hardwick-Witman and Mathieson 1983). The shade and cover provided by *Ascophyllum* fronds at low tide also protects smaller species from drying out rapidly.

Intertidal areas are known to be important habitat for crustaceans, anthropods, isopods and green crabs as well as a feeding area for predatory fish at high tide and a feeding area for some birds at low tide (Nelson 1981). Additionally, these habitats may be important breeding areas for the mud snail, *Ilyanassa obsoleta*.

The five major habitats described above contribute to the productivity of the Estuary and are crucial links in establishing the functional value of the Estuary in terms of its productivity and importance to commercial fisheries, water quality and overall environmental health. Quantitative evaluations of these habitats throughout the entire Estuary are crucial to understand their functional role in the estuarine system.

Chapter 3: The Estuarine Hydrosystem
by F.T. Short

The Watershed

The Great Bay Estuary extends inland from the mouth of the Piscataqua River between Kittery, Maine, and New Castle, New Hampshire (Fig. 3.1) 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.

Tidal flow restrictions occur at Fox Point in Little Bay and Dover Point where Little Bay meets the Piscataqua River. At Dover Point the channel is 430 m (0.27 mi) wide with a maximum depth of 10.5 m. Strong tidal currents often occur at Furber Strait where tidal waters from Great Bay pass through the restricted outlet between Adams Point and the eastern shore of the Bay. Great Bay, starting at Furber Strait, is a large, shallow, estuarine embayment. Great Bay has an average depth of 2.7 m with deeper channels extending to 17.7 m. Channels from the Lamprey and Squamscott River combine at the southwest end of the Bay and connect to the channel from the Winnicut River near the center of the Bay to form the main channel that continues into Little Bay. The Great Bay Estuary has a low tide volume of 166×10^6 m^3 and a high tide volume of 230×10^6 m^3 (Brown and Arellano 1979).

The water surface of Great Bay covers 23 km^2 (8.9 mi^2) at mean high water and 11 km^2 (4.2 mi^2) at mean low water (Turgeon 1976). Thus, greater than 50% of the areal surface of Great Bay is exposed as mud or eelgrass flat at low tide. Additionally, extensive intertidal salt marsh borders much of the mouth of the Squamscott and Winnicut Rivers, and Crommet and Lubberland Creeks. Several small islands (i.e. Nannie, Swan, Vols, and the Footman Islands) are found within the Bay.

The Great Bay Estuary derives its freshwater inflow from seven major rivers (Table 3.1). The Lamprey, Squamscott and Winnicut Rivers flow directly into Great Bay. The Bellamy and Oyster Rivers flow into Little Bay while the Salmon Falls and Cocheco Rivers combine to form the Piscataqua River and flow to the open coast. The flows from all seven rivers intermingle with tidal water sloshing into and out of the bays and rivers in response to tidal energy. The drainage basin for the Estuary (Fig. 3.2) is 2409 km^2 (930 mi^2). Two-thirds of the basin is located within New Hampshire; the remainder is in southern Maine (Reichard and Celikkol 1978). The estuarine tidal waters cover approximately 44 km^2 (17 mi^2), with a 160 km (100 mi) of shoreline.

River flow varies seasonally, the greatest volumes occurring as a result of spring runoff. However, the tidal component in the Estuary dominates over

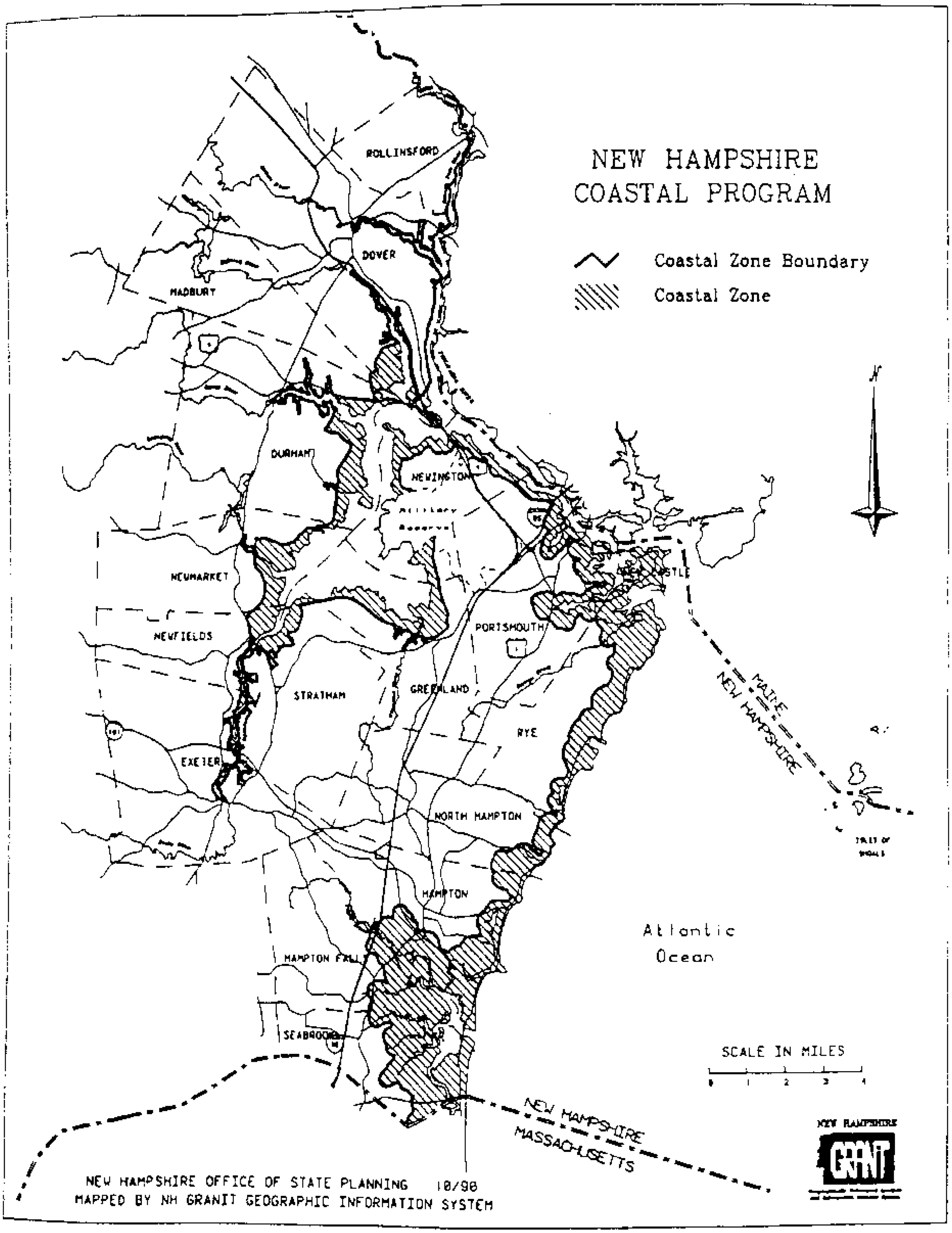


Fig. 3.1. New Hampshire Coastal Program as mapped in 1990 (NHOSP 1990).

Table 3.1. Drainage area and flow discharge for rivers entering the Great Bay Estuary

Rivers	Drainage Area[a] (km²)	Mean Discharge[b] cfs	cms	Period of Record
Lamprey	543	278	7.9	1934-77
Squamscott	331	163[c]	4.6	none
Winnicut	19	-	-	none
Oyster	78	19	0.5	1934-77
Bellamy	85	25[c]	0.7	none
Cocheco	472	242[c]	6.9	none
Salmon Falls	392	204	5.8	1968-78
Piscataqua	414	210[c]	5.9	none
Total	2334	1141	32.3	

[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 (R^2=0.998) based on data[a] from the Lamprey, Oyster and Salmon Falls Rivers.

freshwater influence throughout most of the year. Freshwater input typically represents only 2% or less of the tidal prism or volume (Reichard and Celikkol 1978, Brown and Arellano 1979), but the percentage varies seasonally. Stream flow entering the Great Bay Estuary is gauged at the Oyster, Lamprey, and Salmon Falls Rivers (NAI 1979b). Historical river flow data, together with the discharge area for each river, was used to calculate river flow estimates for the ungauged streams entering into the Estuary (Table 3.1). The calculations suggest that the average combined freshwater inflow is greater than 30 cubic meters/second (1141 cubic feet/second). Approximately 50% of the average annual precipitation 102 cm (40 inches) in the Great Bay Estuary drainage basin enters the Estuary as stream flow (NHWSPCC 1975).

Tidal Conditions

The Great Bay Estuary is a tidal system with the average tidal range varying 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. At the mouth near Portsmouth, the tide is 4 minutes behind the Portland tide chart. Moving up the Estuary to Dover Point, the tide is 1.5 hours behind Portland; while at Adams Point, it is 2 hours later and in the lower Squamscott River it is 2.5 hours behind (NOAA 1990).

Since freshwater inputs to the Great Bay Estuary are relatively low, tidal currents are more important to overall water movement than density-driven circulation patterns (Swift and Brown 1983). 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.

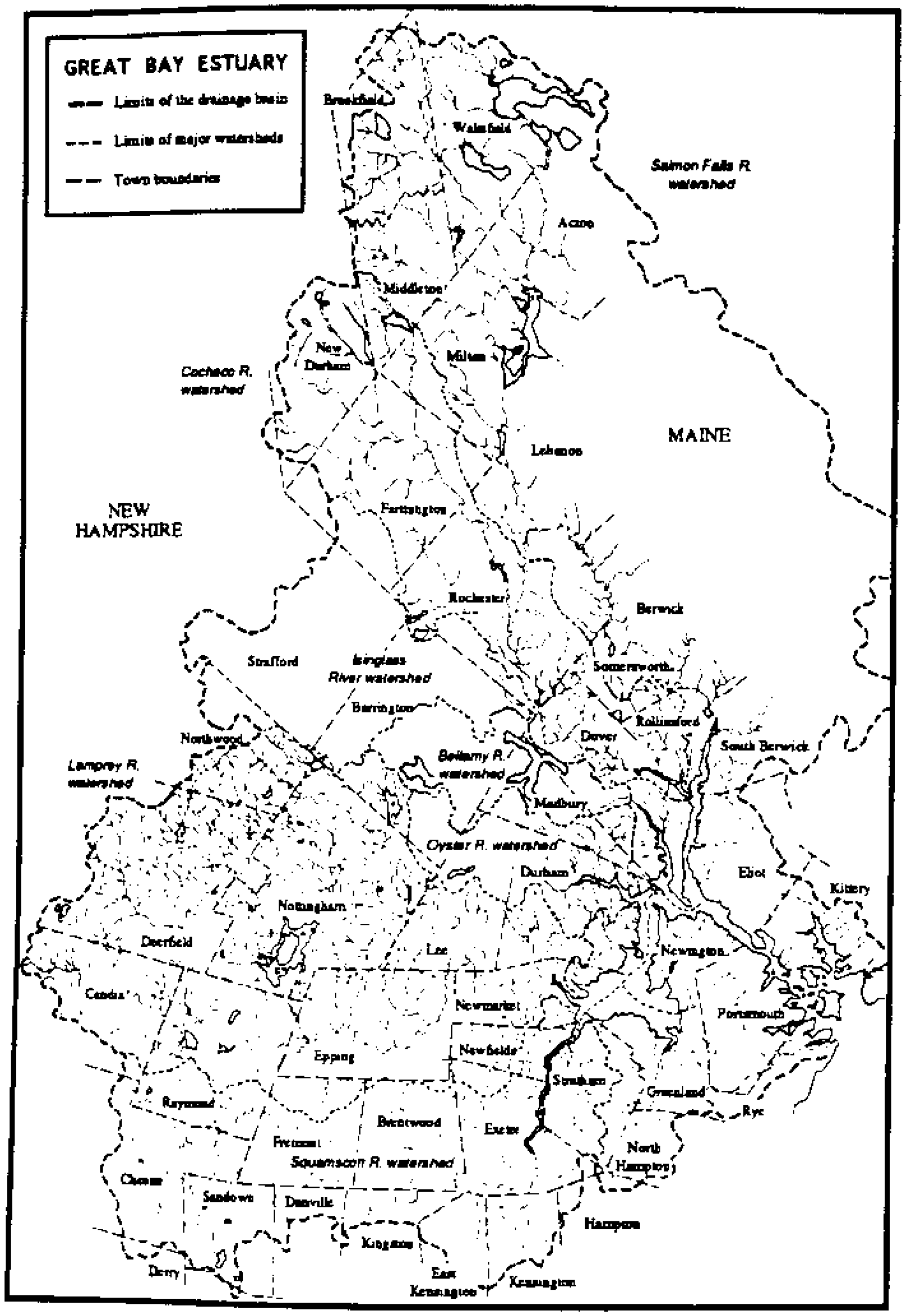


Fig. 3.2. Map of the Great Bay Estuary drainage basin, indicating the towns and watersheds of major rivers entering the Estuary (redrawn from NHWSPCC 1971). Details for tributies of some rivers were not available.

In 1929, the U.S. Coast and Geodesic survey published a compilation of tide and current data for Portsmouth Harbor, the Piscataqua River and its tributaries as far inland as the mouth of the Squamscott River at the head of Great Bay (Hoskinson and LeLacheur 1929). The report compiled data from discontinuous records between 1850 and 1926, and also included results of a complete survey of tide height, current speed, and current direction conducted in 1926. A continuous tide gauge was also installed at the Portsmouth Naval Shipyard at that time.

The 1926 tidal current survey included monitoring current speed, direction and tide phase for durations up to 5 days at 32 stations throughout the Estuary. Currents were measured using both current pole and log line techniques, and current meters. The final report included composite maps of current speeds and directions for each hour of the tide. The results of the 1926 survey indicated that ebb currents had greater speeds and durations than flood currents. At most stations maximum ebb currents occurred near the surface; for flood currents surface speeds were slightly depressed, with maxima occurring lower in the water column. Current speeds were lowest at two stations just outside the harbor, averaging 0.5 to 0.77 m/s, and increased to average maximum speeds of 1.5 to 2.3 m/s in the constricted channels of the Piscataqua River. Spring tide currents were as great as 2.5 to 3.1 m/s at some stations.

NOAA (1989) annual tidal current data confirm the average current speeds and tidal asymmetry (ebb currents greater than flood currents) reported from the 1926 survey. Tidal currents are greatest at Dover Point and in the lower reaches of Piscataqua River (1.5 to 2.0 m/s) and decrease within Little Bay to 0.75 m/s (NOAA 1990). The channel restriction at Furber Strait produces speeds of 1.0 m/s or greater at Adams Point; these tidal currents quickly decrease to 0.5 m/s within Great Bay (Reichard and Celikkol 1978). Ebb currents are typically greater, though not at all locations, and may be twice as fast as flood currents (NOAA 1989). An unpublished study by Shevenell in 1973 yielded similar speeds for a site east of Seavey Island, with maximum current velocities occurring during ebb tides, at or near the water surface.

A dye-dispersion test and current velocity measurements conducted over one tidal cycle in the Piscataqua River provided evidence that the main tidal flow was confined to a central channel in the river (Schmidt 1980, Trask and Brown 1980). While vertical mixing of dye occurred relatively quickly within the channel, lateral mixing to quieter waters near shore was minimal. Schmidt concluded that water and water-born contaminants would be flushed rapidly by tidal flow in the main channel, with only gradual mixing to and from near-shore "storage areas".

Swenson et al. (1977) measured tidal current profiles along cross-channel transects at six stations throughout the entire estuary. Measurements were made over a complete tidal cycle. Contour diagrams indicated that the strongest currents were confined to a central "core" in the flow at all stations, and especially for more restricted sites such as the Piscataqua River at Newington and Portsmouth. Maximum current speeds decreased from 1.80 m/s in the Piscataqua River to 0.60 m/s in mid-Great Bay. Contour diagrams showing the maximum flood and ebb current speeds for each station are shown in Figure 3.3.

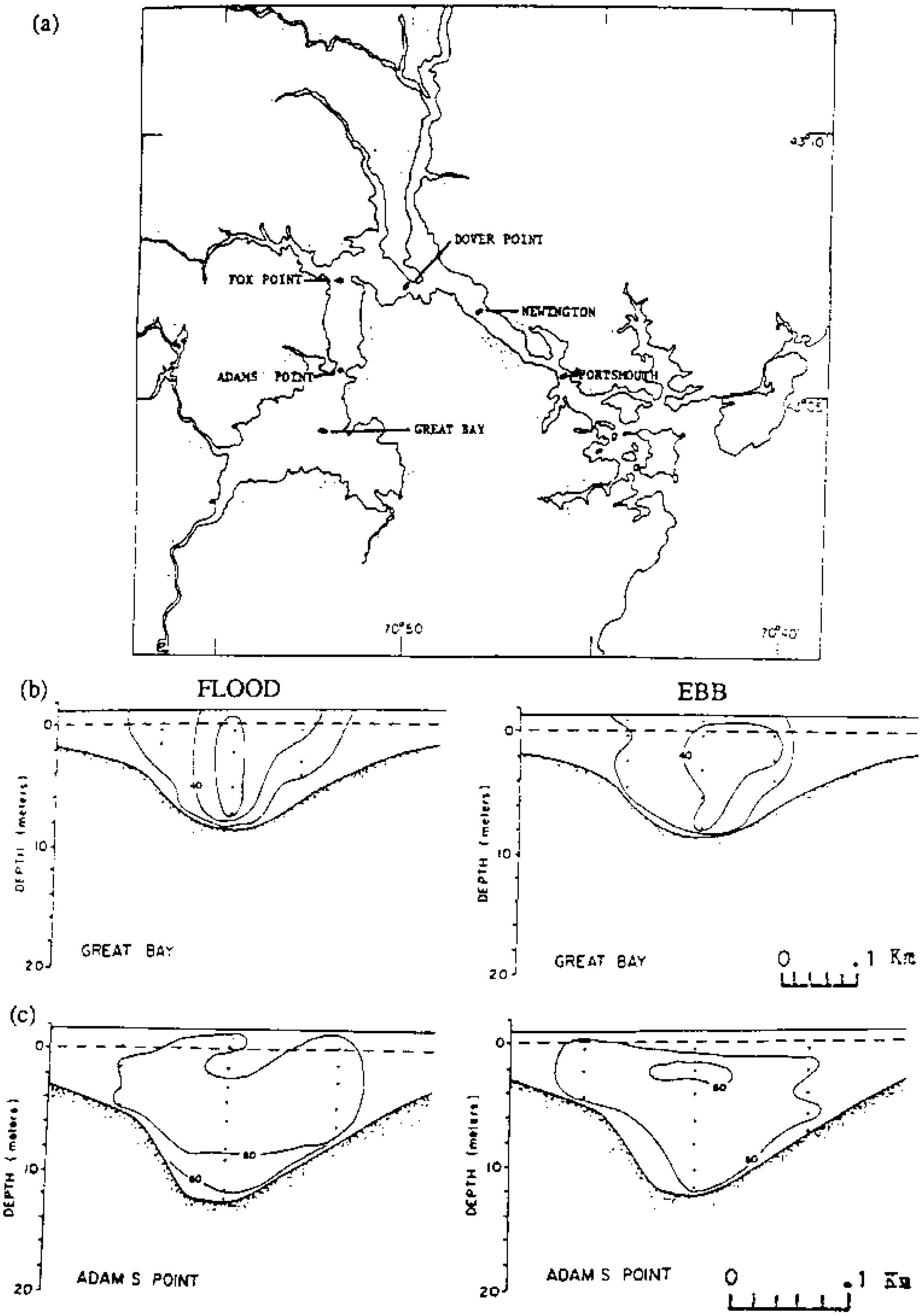
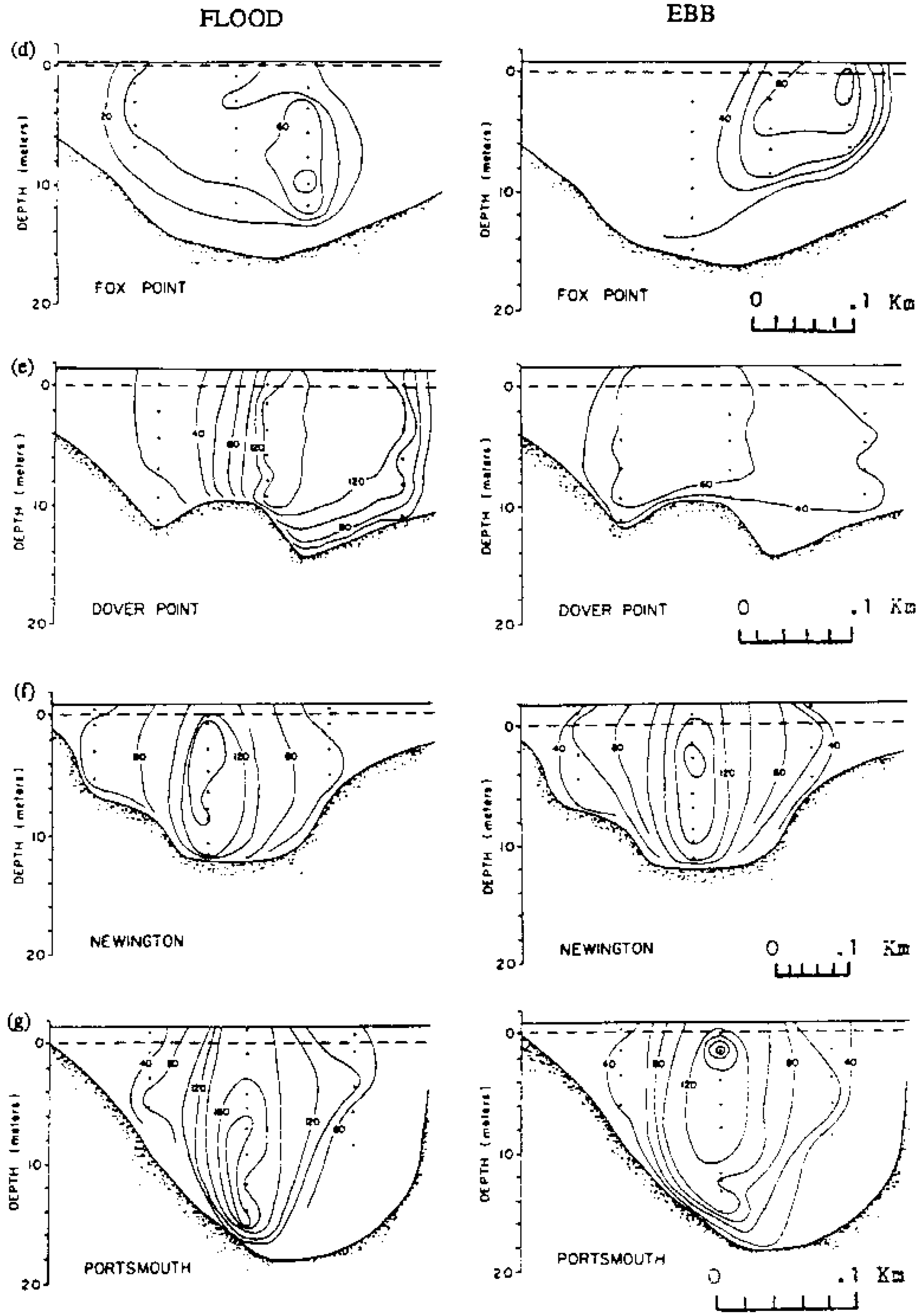


Fig. 3.3. Station location map (a) and contour plots of velocity (cm/s) from flood and ebb tide current measurements (b-g). Profiles with maximum current speed shown (From Swenson et al. 1977).

Fig. 3.3 continued



A study in the Piscataqua River focused on surface currents in areas near the shoreline as part of a study to determine the fate of spilled oil around five oil terminals in the Piscataqua River (Savage et al. 1982). Results of drifter studies for each site were presented in the report, indicating that areas near the shore may have lower current speeds with variable directions and even weak counter-currents.

Swift and Brown (1983) included tidal current measurements in a study to characterize bottom stress and tidal energy loss throughout the Estuary. Currents were measured at stations along a transect from the outer harbor to the mouth of the Squamscott River. Maximum current speeds were 0.5 m/s in Little and Great Bays, and ranged from 0.5 to 2.0 m/s at stations in the Piscataqua River. Comparisons among transects indicated that average current speeds were related to channel cross-sectional area, with greater current speeds in narrower channels. Swift and Brown also concluded that tidal amplitude and energy dissipation is greater in the lower, narrower portion of the Estuary. In Little and Great Bays, frictional dampening is less and the tide acts more like a standing wave. This accounts for the slight increase in amplitude in Great Bay, and for the less distinct differences in tide height and phase throughout Great Bay.

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). Independently, Turgeon (1976) estimated a travel flow time of four days for a particle to be transported a distance of 4 km through Little Bay. Several other studies described by EBASCO (1968) have either measured or calculated flushing rates for sites in the lower Piscataqua River, with a renewal rate of 258 m^3/s near Rollins Farm (dye dispersion study), 439 m^3/s at PSNH Newington Station and 498 m^3/s at PSNH Schiller Station (estimated from current speeds). These renewal rates correspond to flushing times from 3.3 to 6.3 tidal cycles, assuming no mixing occurs (Ebasco 1968). Other flushing rates for the entire lower Piscataqua River region range from 5.8 to 12 tidal cycles (Ridley and Ostericher 1960). Longer flushing rate estimates account for mixing of water masses within the system, and may therefore be more realistic.

Tides cause considerable fluctuations of water clarity, temperature, salinity and current speeds, and have a major impact on the channel bottom/subtidal, rocky intertidal and eelgrass habitats (Chapter 2). Tidal currents are extremely important in determining the character and productivity of the Great Bay Estuary. Shallow areas of the Estuary, especially in Great Bay, are also greatly affected by wind-wave conditions. Wind waves can also influence grain-size distributions and sediment transport throughout the Estuary. Waves that influence the bottom may resuspend sediments, increasing turbidity levels well above levels attributed to tidal currents alone (Anderson 1972). The current velocity induced by waves at the sediment surface can be greater than tidal current velocities; especially for shallow areas of the estuary where overall average tidal current strength is low. A study in Adams Cove, Great Bay, found spatial and seasonal differences in sediment transport that could be accounted for mainly by differences in wind wave activity (Webster 1991). Therefore, the effects of tidal currents throughout the Estuary may be modified by wind waves.

Chapter 4: Estuarine Geomorphology
by L.G. Ward

Geology

The Great Bay Estuary basin is eroded into a complex assemblage of metasedimentary, metavolcanic and plutonic rocks ranging in age from 345 to 600 million years old (Devonian to Ordovician geologic periods) (Notovny 1969). The bedrock which frequently outcrops along the shores of the Estuary has been divided into three geologic formations, the Kittery, the Eliot and the Rye. The Kittery and Eliot Formations meet along a north-south trending contact which extends under Great and Little Bays (Notovny 1969). The Kittery Formation forms the western shoreline of Great Bay and portions of the Piscataqua River and is composed of impure quartzite, slate, phyllite and schists. The rock outcrops found along much of the shoreline are highly jointed (fractured) in a criss-cross pattern, and produce highly irregular, angular rock fragments which often form small shingle beaches. The Eliot Formation forms the eastern shore of Little and Great Bays and portions of the upper Piscataqua River and is composed of argillaceous sediments which were metamorphosed into slate, phyllite and pyritic quartzite (Notovny 1969). The Rye Formation is found in the lower Piscataqua River area and is dominantly composed of metasedimentary and metavolcanic rocks.

The coastal region of New Hampshire has undergone extensive structural deformation largely associated with the Acadian orogeny that folded the crust into northeast-southwest trending anticlines (convex upward folds in the rocks) and synclines (concave downward) (Billings 1980). The axis of the Great Bay syncline coincides with the axis of Great Bay and Little Bay (Notovny 1969). The bedrock in the seacoast region is extensively jointed and has numerous faults. Most notable is the Portsmouth Fault that extends in a northeasterly-southwesterly direction, and is located just east of Great Bay (Notovny 1969).

Although the influence of the regional geology on the formation and present day characteristics of Great Bay is only speculative, the rock types and structures undoubtedly have a strong influence on the general geomorphology and sedimentology. For instance, Smith (1988) noted in his surficial mapping of the nearby York County, Maine quadrangle that the formation of many of the drainage streams and coastal embayments was structurally controlled. In addition, Birch (1984) speculated from geophysical evidence that the Piscataqua River lies in a northwest extension of a fault that is located on the inner continental shelf of New Hampshire. Therefore, the location of the Piscataqua River may be at least in part structurally controlled.

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.

During the Quaternary, the huge continental glaciers, which periodically advanced and retreated across New Hampshire, caused the earth's crust to be depressed due to the immense weight of the ice. Following ice removal, the crust rebounded as the weight of the glaciers was removed. During the most recent deglaciation, which probably started approximately 14,500 years ago (Birch 1990), the crust remained pushed down immediately following ice removal, causing flooding of the land by the sea. At this time sea level was approximate 50 meters higher than today. As the earth's crust rebounded, sea level dropped, reaching a depth on the order of 30 to 50 meters below present some 11,000 to 12,000 years ago (Birch 1990). However, the actual depth and time are disputed (Belknap et al. 1987a). From ~11,000 to ~12,000 years ago until ~2,000 to ~3,000 years ago, relative sea level rose rapidly until reaching within a meter or so of present conditions (Belknap et al. 1987b).

Since the retreat of the glacial ice from the Great Bay Estuary, it appears the Estuary has been flooded by the sea, subaerially exposed and inundated by the sea once again. This complicated sea level history has lead to a stratigraphic sequence which reflects a transgression-regression-transgression of the ocean. The recent geologic history and stratigraphy of these deposits has been described by Haug (1971) based on sediment cores and some subbottom seismic surveys. According to Haug (1976), the Holocene sedimentary deposits in the vicinity of Thomas Point to the Footman Islands reach a thickness of 14.5 meters at mid channel and lie on top of basement rocks composed of the Kittery and Eliot Formations or a thin layer of glacial tills. Haug (1976) described three sedimentary units in the Great Bay including: 1. a fine-grained, blue-gray marine clay (Presumpscot Formation) at the base (appearing approximately 12 m below mean low water), 2. overlain by a thin (0.5 m), organic rich layer (interpreted as a marsh deposit) and 3. capped by estuarine sediments. The marine clay or Presumpscot Formation was deposited immediately following ice retreat and inundation by the ocean. Following isoatatic rebound of the region, subaerial erosion of the Presumpscot Formation likely occurred. As eustatic sea level rose, the Great Bay was once again flooded by the sea, facilitating the deposition of marsh deposits. A radiocarbon date of one of the peat deposits gave an age of approximately 8,340 ± 200 years before present. Apparently, the marsh deposits were not able to keep pace with relative sea level rise and Great Bay evolved into a shallow estuary. Probably, Great Bay has existed as a wide, shallow estuary for the last 8,000 years, with up to 10 m of sandy silt with mud and sand lenses being deposited. Based on sediment thickness, Haug (1971) estimated the long term sedimentation rate at 0.1 cm/y. Leavitt (1980) reported a similar rate, also based on sediment thickness as determined from subbottom seismic records. More recent rates (last century) range from 0.2 to 0.4 cm/yr (Leavitt 1980).

Estuarine Geomorphology and Sedimentary Processes

The 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/yr, Hicks et al. 1983), tidal action, wave effects and biological processes.

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 Bay and Little Bay, resulting in the very shallow nature of these Bays. Consequently, the surface area of the bays changes dramatically from high to low tide (see Chapter 3).

The tidal marshes in the Great Bay Estuary and all the tributaries have been mapped utilizing color infrared transparencies and extensive ground truth work (Ward et al. 1991, Ward et al. 1992). The largest expenses of marshes are found in the Squamscott River, while the lower Piscataqua River has far fewer marshlands. Preliminary analyses of the tidal marshes indicate most marshes are estuarine tributary, estuarine embayment or fringing marshes (Ward et al. 1991).

The sources of sediments in 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 the fine-grained sediments is likely from freshwater tributaries. However, all of the associated rivers are now dammed, reducing this potential source.

Today, the shoreline is continuously modified by wave and tidal action, ice effects and man. Wave energy in the Estuary for the most part is very low, having minimal effects upon the coarse-grained beach sediments. However, 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.

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 effect 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.

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, Short et al. 1986). Thompson (1977) found that ice on a tidal flat near Adams Point contained 0.58 to 27.23 grams of sediment per liter of ice. According to Thompson (1977), 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.

Anderson (1983) summarized the seasonal physical and biological processes which occur in 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, as breakup causes erosion and resuspension events are common. During summer, biologic processes dominate and deposition is more common. Storm activity in fall as biologic processes slow causes increased tidal flat erosion.

In the lower estuary near Portsmouth Harbor or on the inner shelf, suspended sediment concentrations are much lower than in the Great Bay, Little Bay or tributaries (Squamscott, Bellamy, Cocheco, Salmon Falls or upper Piscataqua Rivers). Shevenell (1974) described the processes influencing the particulate matter distribution off the mouth of the Piscataqua River and inner shelf. The main sources of particulate matter in the coastal shelf waters 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 climatic changes (storms, high river discharges). Particulate matter 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. More recently, suspended sediment concentrations were measured over tidal cycles at several transects in the lower Estuary (mouth, Seavy Island, Dover Point), as well as along the salinity gradient from the mouth of the Piscataqua River to the entrance of the Squamscott River (Ward, unpublished data). Preliminary analyses of suspended sediment distributions indicated concentrations are low at the mouth of the Estuary, typically remaining below 4 mg/l during July, 1992. Suspended sediment concentrations were higher in the middle Estuary by Dover Point, periodically exceeding 10 mg/l (on the ebb tide). More complete analyses of the suspended sediment distribution in the lower Great Bay Estuary are forthcoming (Ward, in preparation, Portsmouth Naval Shipyard ongoing studies).

Adams Cove, a typical intertidal mudflat in the Great Bay Estuary.

Chapter 5: Estuarine Hydrochemistry
by F.T. Short

Temperature Environment

The Great Bay Estuary, including Great Bay, Little Bay, and the Piscataqua River, has both seasonal and diurnal temperature variations, exhibiting characteristics of many other New England estuaries. The seasonal patterns of surface water temperatures on the nearshore open coast of New Hampshire and within Great Bay illustrate the warming and cooling effect of the Estuary (Fig. 5.1). Typically, the maximum temperatures occur during mid-summer through the fall. The relative shallowness of Great Bay allows for rapid warming in the spring-summer and cooling in the fall-winter, with lowest temperatures occurring during January to March (Fig. 5.1).

Open coastal sites and the Piscataqua River have a narrower temperature range than inner estuarine sites. For example, surface water temperatures at the Isles of Shoals vary from 3.8° to 18.2°C, versus -1.0° to 19.0°C at Portsmouth Harbor, -2.0° to 24.1°C at Dover Point, -1.8° to 26.5°C at Adams Point, and -2.0° to 27°C within Great Bay proper (Norall and Mathieson 1976, NAI 1979a, Norall et al. 1982). Even greater variation (daily and seasonally) of temperatures is present within riverine habitats of the Great Bay Estuary. Daly and Mathieson (1979, 1981), Daly et al. (1979), Glibert (1976a), Loder et al. (1979), Norall and Mathieson (1976), Norall et al. (1982), and Silver and Brown (1979) present details regarding temperature and salinity variations within this area.

Overall, there is a pattern of greater variation, as well as increasing mean surface water temperatures, from the open coast to the inner estuary (Fig. 5.2). Ebb tide temperatures are usually higher than flood temperatures from April through September, when the Great Bay Estuary waters are warmer than the Gulf of Maine (NAI 1979a). In early autumn, estuarine and coastal water temperatures are nearly equal, so little tidal temperature variation is seen. However, by November, the Estuary's waters are colder than the Gulf of Maine and lower temperatures occur on the ebb.

Little vertical stratification of the water column is evident, due to high current flows in the Piscataqua River. The maximum vertical gradient is 2.5°C over 12 m depth in Portsmouth Harbor (NAI 1979b). Time series analysis of data from 1973 to 1982 showed a significant decrease (0.17°C/year) in mean water temperature (Loder et al. 1983a). Comparison of temperature monitoring between the mid-1970s and recent years (Loder et al. 1983b, Langan et al. 1990) shows a very similar seasonal pattern (Fig. 5.3).

The low temperatures, characteristic of winters in Great Bay, result in significant ice formation. An ice thickness of 0.3 meters or more is usually present from late December to March in parts of Great Bay and the major tidal rivers (except the Piscataqua) within the Great Bay Estuary. However, warm winters during 1988-90 have shown an absence of continuous ice cover in Great Bay. The

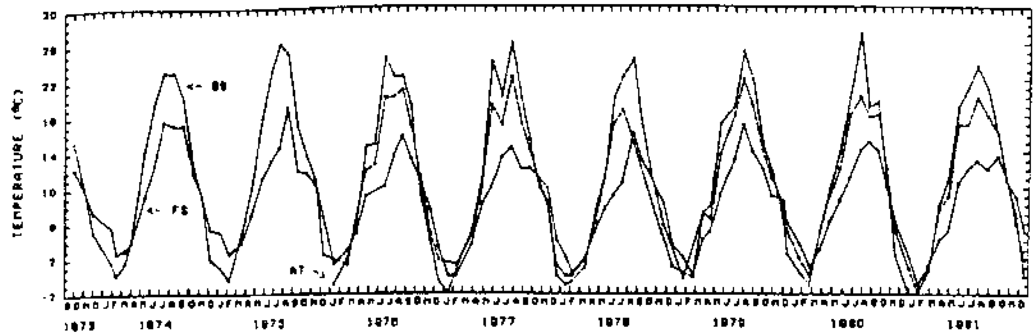
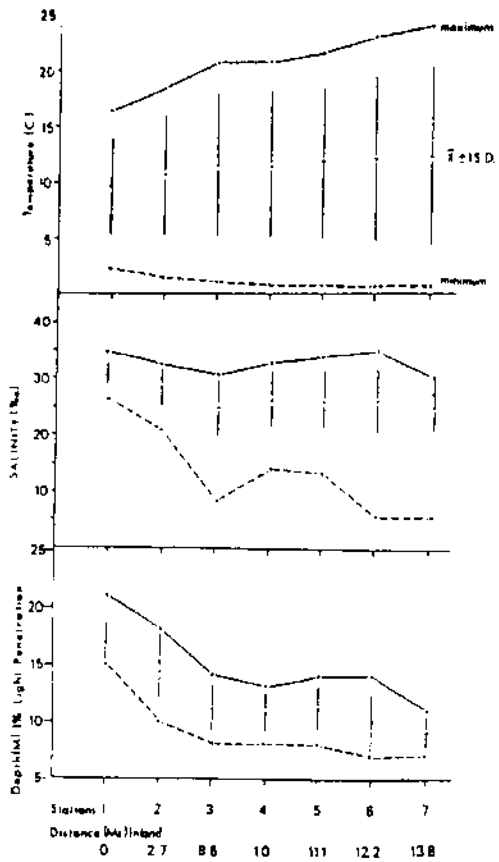


Fig. 5.1. Seasonal variation of surface water temperature on the nearshore open coast of New Hampshire at Fort Stark (FS) and within the Great Bay Estuary at Atlantic Terminal (AT) and Great Bay (GB) during 1973-1981 (Reproduced from Mathieson and Hehre 1986).



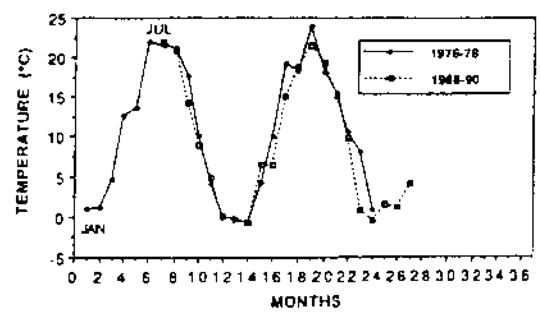


Fig. 5.3. Comparison of low tide water temperature for 1976-78 and 1988-90 off Adams Point at the mouth of Great Bay, New Hampshire (Data from Loder et al. 1983b and Langan et al. 1990; see also Table 5.1).

Fig. 5.2. Maximum, minimum, and mean values of surface water temperatures, salinities and 1% light penetration on the nearshore open coast of New Hampshire (Station 1 – New Castle) and within the Great Bay Estuary (Station 7 – Great Bay) during 1974-1978 (Reproduced from Mathieson and Hehre 1986).

scouring effects of ice are damaging to organisms growing on rocks, pier pilings and other solid substrata. Large sections of salt marsh and shallow eelgrass beds are torn loose by ice and rafted during periods of thaw (Hardwick-Witman 1985, Mathieson et al. 1982, Short et al. 1986). The destructive effect of ice disrupts many estuarine habitats, contributing to the export of plant materials from the Estuary.

Salinity Regime

Salinity within the Estuary is controlled by freshwater discharge into the Estuary and varies both seasonally and with stage of the tide. Distinctly different seasonal patterns of surface water salinities are evident between the nearshore open coast of New Hampshire and Great Bay (Fig. 5.4). Typically, the maximum salinities occur in the summer and fall, while the lowest salinities occur during January to early spring, during winter and spring thaws. As with temperature, greater variation of salinity occurs within Great Bay than in the more stable lower Estuary. For example, the surface water salinities at the Isles of Shoals range from 31-33 ppt, while greater variations are evident at Portsmouth Harbor (25-34 ppt), Dover Point (1-30 ppt), Adams Point (7-31 ppt), and within Great Bay proper (3-31 ppt) (Norall and Mathieson 1976, Norall et al. 1982). Overall, there is a pattern of increased salinity variation and a decrease in surface water salinities from the open coast of New Hampshire to the inner Estuary (Fig. 5.2).

The lowest measured annual salinities in the Piscataqua River range from 5 ppt in 1973 to 20 ppt in 1974 and 1976 (NAI 1979a). These low values are associated with major spring runoff events. During the remainder of the year, salinities are usually greater than 20 ppt throughout the Estuary. Maximum values, up to approximately 35 ppt, occur in late summer when freshwater runoff is minimal (Daly et al. 1979, NAI 1979a). Little salinity stratification has been seen, as turbulent flows facilitate mixing in the River (NAI 1979a).

Time series analyses of chemical and hydrographic trends within Great Bay Estuary during 1973 to 1982 showed significant changes in salinity only; salinity values (at Dover Point) rose an average of 0.34 ppt/year (Loder et al. 1983a). Comparison of mid-1970 salinity data (Loder et al. 1983a) with recent observations at Adams Point (Langan et al. 1990) shows similar seasonal variability (Fig. 5.5) but no long term trend of rising salinity.

Dissolved Oxygen

Dissolved oxygen values in the Great Bay Estuary typically range from 5.0 mg/l to 8.6 mg/l (Loder et al. 1983a). Monthly average dissolved oxygen values for the lower estuary range from 7.4 mg/l to 12.6 mg/l on the flood tide and from 7.2 mg/l to 12.8 mg/l on the ebb tide (NAI 1979a). Dissolved oxygen is high in the spring, averaging 11.3 mg/l, and decreases into the summer months. Little variation is noted in the Piscataqua River between surface and 10 m measurements, and values vary only slightly with tidal stage. Lowest values occur in late summer and early fall. No evidence of low dissolved oxygen bottom waters (hypoxia) or anoxia have been reported in the water column of the Great Bay Estuary.

Suspended Load

Generally, the highest suspended loads, composed of plankton and sediments, occur in the upper Estuary where the greatest tidal variation in turbidity is also measured (NAI 1979a). Seasonally, the highest suspended load

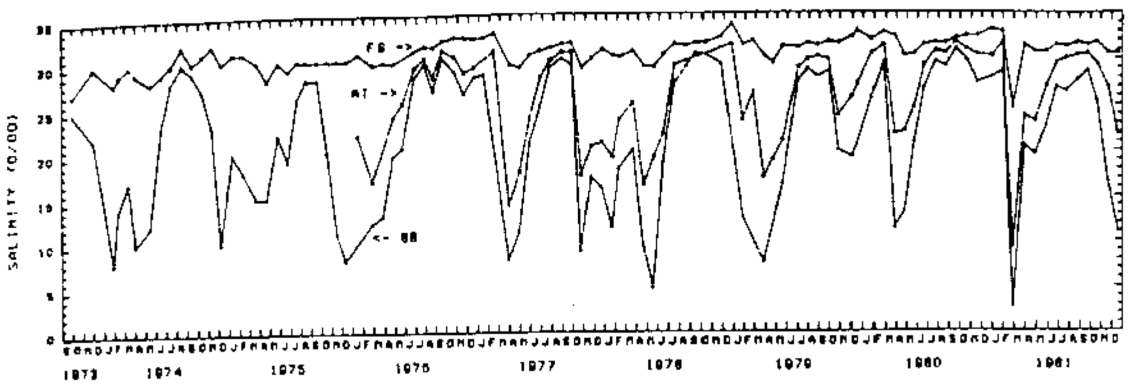


Fig. 5.4. Seasonal variation of surface water salinities on the nearshore open coast of New Hampshire at Fort Stark (FS) and within the Great Bay Estuary at Atlantic Terminal (AT) and Great Bay (GB) during 1973-1981 (Reproduced from Mathieson and Hehre 1986).

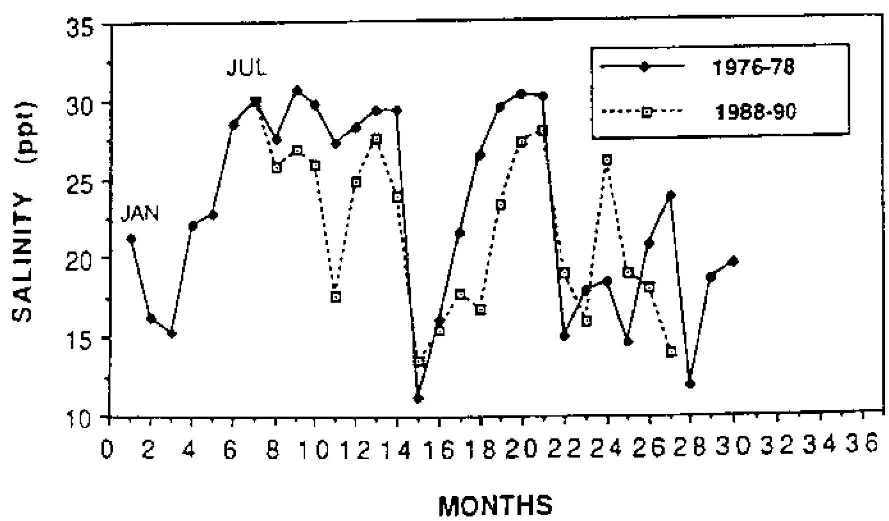


Fig. 5.5. Comparison of low tide water salinity for 1976-78 and 1988-90 off Adams Point at the mouth of Great Bay, New Hampshire (Data from Loder et al. 1983b and Langan et al. 1990; see also Table 5.1).

values occur during spring, followed by a decrease in the summer, followed typically by an increase again in fall and a decrease in winter. Variations in turbidity between the surface and 10 m measurements are minimal (NAI 1979a). Turbidity values are higher on the ebb tide than on the flood tide.

Total suspended solids historically averaged 11 mg/l for the period 1976-1978 (Table 5.1), with minimum values reaching nearly to 0 (clear water) at times during the fall and winter (Loder et al. 1983). Recent monitoring (1991-1992) shows nearly the same average total suspended solids (Ward unpubl.). Interestingly, the maximum suspended solids do not appear to be as high today as they were in the 1970s (Fig. 6.5). There has been a small increase in phytoplankton (see Chapter 7) which does not significantly affect suspended load.

Nutrient Characterization

A substantial record of chemical measurements in the Great Bay Estuary has been made during the last two decades. Intensive monitoring of water chemistry parameters was made for the eight year period from 1973 through 1981 (Loder et al. 1983a, b). Sporadic sampling of nutrient concentrations and continuous sampling of temperature and salinity has been made at the Jackson Estuarine Laboratory, Adams Point between 1984 and 1990 and more intensive monitoring of water characteristics and chemical nutrients were made at Furber Strait and in the Squamscott River starting in 1988 and continuing to the present (Langan et al. 1991). The compilation of these three data sets provides extensive nutrient and other chemical data for the Great Bay Estuary covering eighteen years. As yet, there has been no overall synthesis of this information. However, there has been some analysis of different aspects of the initial monitoring from 1973 through 1981, with a number of publications resulting from these early studies (see below).

Nutrients historically were generally highest during the winter months from December to March. Thereafter, a sharp decline occurred due to the spring phytoplankton bloom (Norall and Mathieson 1976). Intermediate levels were usually found during the summer, and then increased during the fall. A detailed tabulation of historic seasonal and spatial variations of nitrogen, phosphorus, and silica within the Great Bay Estuary and the adjacent open coast of New Hampshire is given by Norall and Mathieson (1976), and Norall et al. (1982). Additional nutrient data for the same area are summarized by Burns and Mathieson (1972b), Glibert (1976a), Loder and Glibert (1977, 1980), Daly et al. (1979), Daly and Mathieson (1979), Loder et al. (1979, 1983a, 1983b), Lyons et al. (1982), Mathieson and Burns (1975) and Mathieson and Tveter (1975).

Over the course of the regular monitoring program that ended in 1981, no significant changes in major nutrient concentrations were evident in the waters of the Great Bay Estuary (Loder et al. 1983a, b). However, some other water column characteristics did show interesting trends. These included, in the lower part of the Estuary, salinity showing a significant ($p < 0.05$) increase, temperature showing a significant ($p < 0.05$) increase throughout the Estuary and a slight increase in total phosphorus throughout the Estuary over that 9 year period. It is important to note that this long term monitoring study showed no significant increases in phosphate or any of the nitrogen species, even though there was ample documentation that nutrient loading to the Estuary had increased substantially over that period (Loder et al. 1983a). The primary cause of increased

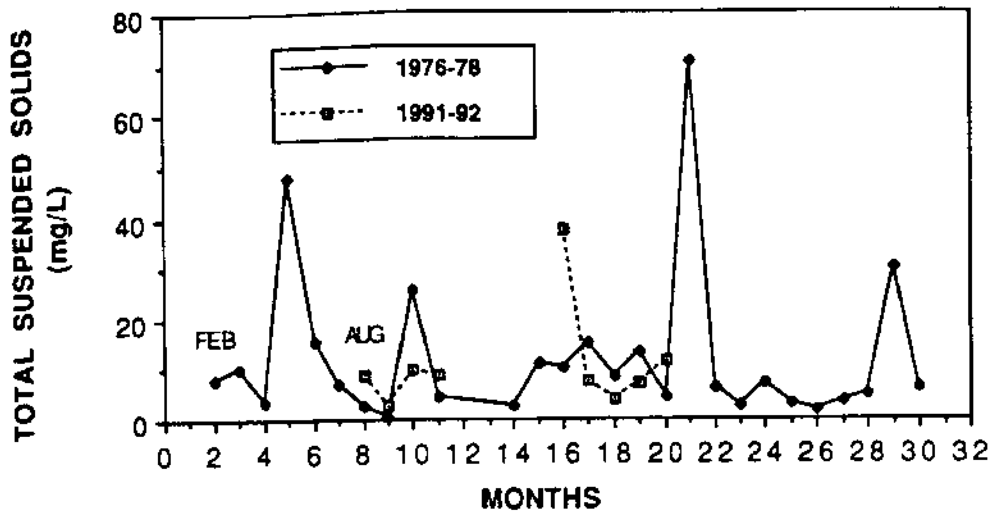


Fig. 5.6 Comparison of total suspended solids for 1976-78 and1991-92 during low tide off Adams Point at the mouth of Great Bay, New Hampshire (Data from Loder et al. 1983b and Ward unpublished; also see Table 5.1).

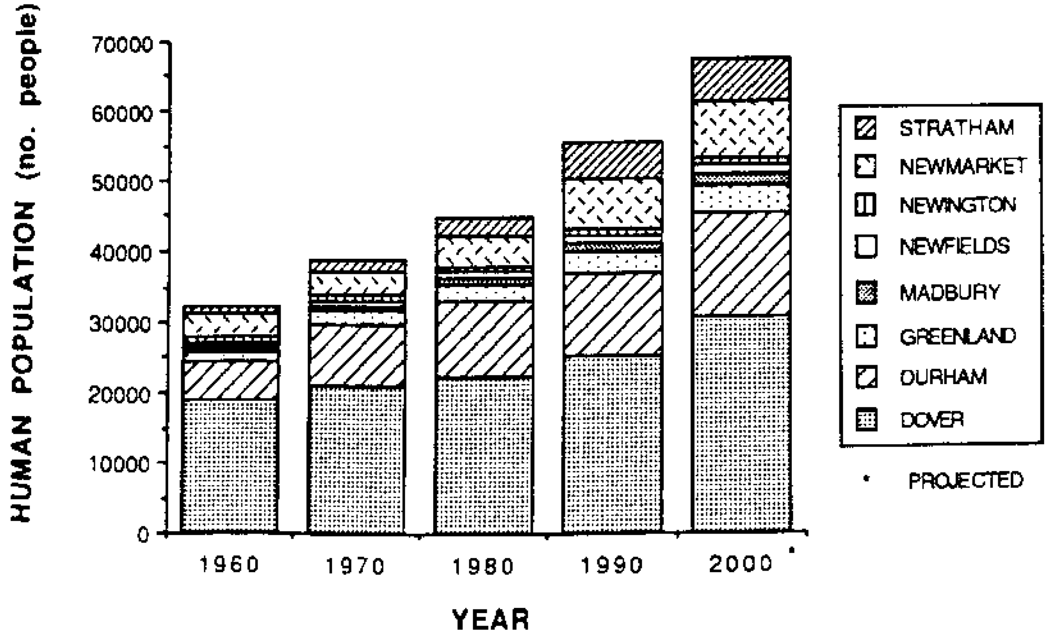


Fig. 5.7 Human population growth in some communities around the Great Bay Estuary from 1960 to 2000 (Rockingham County Planning Comm. 1991 and Strafford County Planning Comm. 1991).

loading was the construction of sewer lines for many of the towns on the tributaries entering Great Bay and the construction of wastewater treatment plants that discharge treated sewage to all the major rivers. These treatment plants establish point sources of nitrogen and phosphorus inputs into all of the major rivers entering the Estuary.

In addition to the construction of wastewater treatment plants on the rivers (Table 6.1), the population within the watershed for the Great Bay Estuary has increased substantially over the last two decades (Fig. 5.7). Thus, with increased nutrient loading to the system, why were no increased nutrient concentrations observed within the Bay? Three possible scenarios are suggested. First, nutrients may be rapidly flushed out of the estuarine system into the Gulf of Maine. The increase in loading would be passed through the system so quickly that elevated concentrations would not be detected. Given the relatively slow tidal exchange rate, this does not seem likely. Second, plants (i.e. primary producers) within the Estuary may be removing this excess nutrient loading and converting it to organic nutrients. Nutrients bound in plants are either recycled within the Estuary or exported as particulate organic matter. Additionally, an end result of this possible increased primary productivity is an increased secondary productivity within the Estuary and an export of fixed carbon and nutrients from the Estuary in the form of fish and bird migration or other removal of resources. Third, nutrients may be remineralized within the Estuary by microbial processes and lost to the atmosphere in the case of nitrogen or bound to sediment in the case of phosphorus.

Preliminary analysis of the more recent nutrient data (Short et al. in prep.) suggests that the average levels of some nutrients, particularly ammonium and phosphate, have increased slightly within the Bay, while others show no differences since the mid-1970s. The increase in average nutrient levels within Great Bay (Table 5.1) is not nearly as dramatic as the change in annual patterns observed (Fig. 5.8). Today, three major nutrients, ammonium, nitrate and phosphate, do not show the general seasonal cycle of high winter values and low spring-summer values that was seen in the 1970s. Beyond this loss of a periodic seasonal signal in the data, the minimum values observed for ammonium and nitrate are now as much as ten times the minimum values from the mid-1970s. Although maximum values have not increased and average values have remained about the same, this ten-fold increase in minimum ammonium and nitrate levels may be an early sign of real changes within the Estuary. The range in phosphate levels is similar for both periods but the seasonality appears different (Fig. 5.8).

Increases in nitrogen and phosphorus are believed to result from the continual increase in nutrient loading evident with increased human growth and development within the watershed of the Great Bay Estuary. The origins of these nutrients are both point and nonpoint sources.

Point sources of nutrients are primarily the large wastewater treatment plants on each of the main rivers entering the estuarine system and other direct discharges that are permitted within the watershed (Table 6.1). Nonpoint sources include a variety of inputs ranging from ground water discharge into the Bay, failed and leaking septic systems, run-off from developed areas including parking lots, golf courses, agricultural farms, boat activity, wildlife, and upland sources (Table 6.2). The extent of these mostly anthropogenic inputs into the Estuary

Table 5.1. Comparison of water column data at low tide in Furber Strait off Adams Point, Great Bay, New Hampshire. Comparisons include temperature, salinity, dissolved oxygen (DO), total suspended solids (TSS), percent organics (%ORG), ammonium (NH4), nitrate (NO3), phosphate (PO4), pH, chlorophyll *a* (CHLA), and phaeophyton (PHAEO). Mean = mean of all values, SD = standard deviation, and n = number of observations. Data for 1976-78 from Loder et al. 1983a; for 1988-90 from Langan et al. 1990; for TSS 1991-2 from L. Ward unpublished.

YEAR	TEMP °C	SAL ppt	DO (ml/L)	TSS mg/l	%ORG	[NH4] µm	[NO3] µm	[PO4] µm	pH	CHLA µg/l	PHAEO µg/l
1976-78											
Mean	11.87	23.23	6.58	10.93	-----	3.64	5.66	0.88	7.84	2.37	2.97
SD	8.20	6.53	1.20	15.19	-----	2.36	4.19	0.52	0.20	2.38	2.00
n	17	24	22	24	-----	24	23	23	21	23	21
1988-90											
Mean	9.84	21.21	6.86	10.87	24.00	4.01	5.20	0.89	7.57	2.82	3.44
SD	8.32	5.20	1.91	10.41	11.64	1.55	2.05	0.47	0.26	2.15	2.71
n	24	24	23	9	24	24	24	24	20	24	24

Table 5.2: Comparison of water column data at low tide from the Squamscott River. Comparisons include temperature, salinity, total suspended solids (TSS), percent organics (%ORG), ammonium (NH4), nitrate (NO3), nitrite (NO2), phosphate (PO4), chlorophyll *a* (CHLA) and phaeophyton (PHAEO). Mean = mean of all values, SD = standard deviation, and n = number of observations. Data for 1976-78 from Loder et al. 1983a; for 1988-90 from Langan et al. 1990.

YEAR	TEMP °C	SAL ppt	TSS mg/l	%ORG	[NH4] µm	[NO3] µm	[PO4] µm	CHLA µg/l	PHAEO µg/l
1976-78									
Mean	9.80	9.27	-----	-----	14.27	8.78	2.03	-----	-----
SD	9.36	8.48	-----	-----	13.64	5.03	1.31	-----	-----
n	22	23	-----	-----	15	19	23	-----	-----
1988-90									
Mean	11.04	2.31	46.20	21.55	6.25	6.93	1.06	9.77	8.69
SD	9.23	3.53	18.20	6.13	3.33	2.64	0.56	16.50	10.71
n	23	23	23	23	23	23	23	23	23

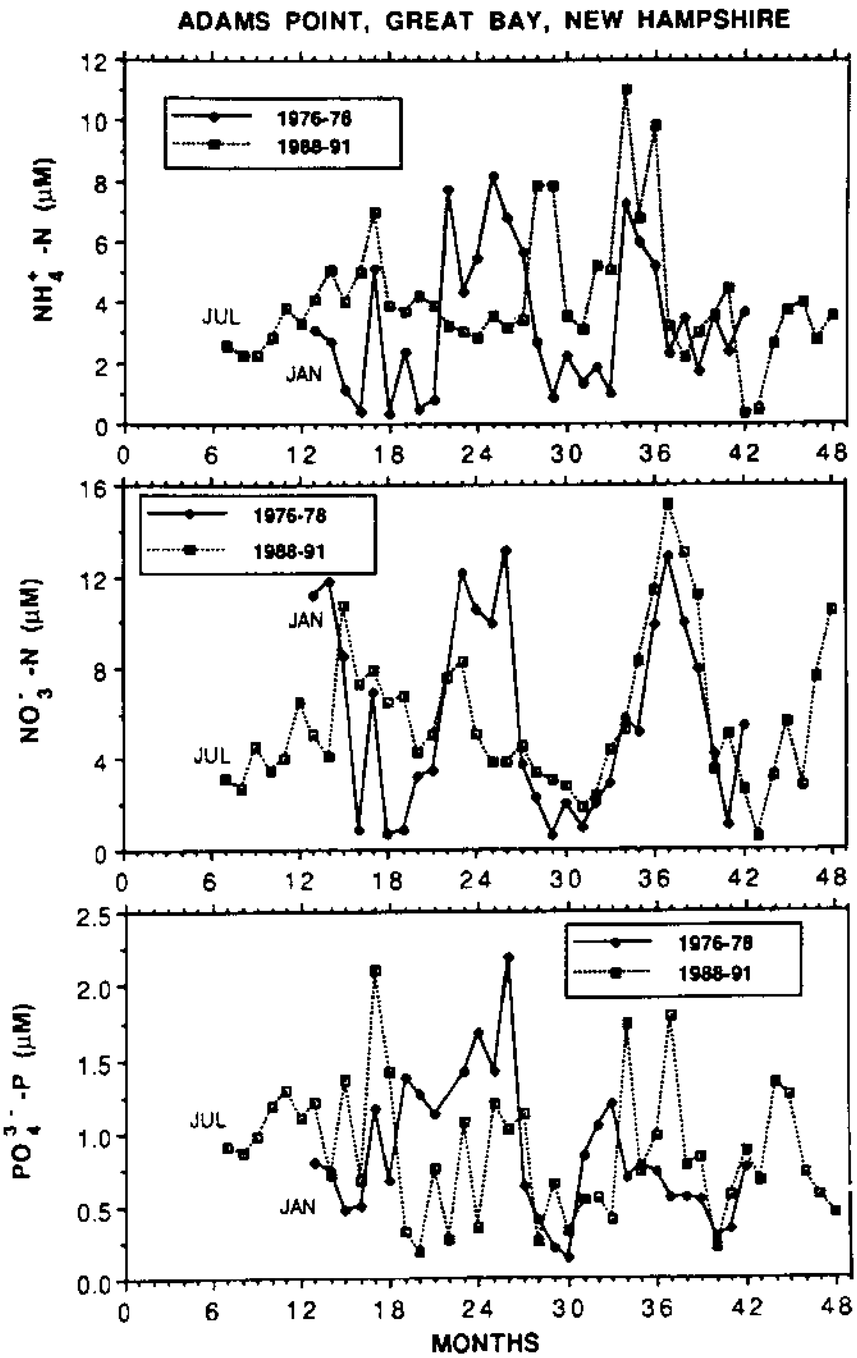


Fig. 5.8. Comparison of water column ammonium (NH_4^+), nitrate (NO_3^-), and phosphate (PO_4^{3-}) concentrations for 1976-78 and 1988-91 during low tide off Adams Point at the mouth of Great Bay (Data from Loder et al. 1983b and Langan et al. 1991; see also Table 5.1)

has been assessed by Loder et al. (1983) and Love (1984). They stated that the inputs of phosphorus into the system were greater than those from natural sources of regeneration, remineralization, and recycling processes, showing that human input was a major source of nutrients to Great Bay.

In addition to the upstream nutrient inputs to the Great Bay Estuary, a major source of nutrient loading comes from the mouth of the Estuary, where the discharge from the Portsmouth City wastewater treatment plant is located (Table 6.1). Besides this large volume of sewage entering from Portsmouth, additional small inputs to the Piscataqua River occur from Newington, Kittery (ME), Eliot (ME) and other small towns along the shore.

In order to evaluate the overall nutrient loading into the Great Bay Estuary from upstream, the nutrient levels in the tidal water of the Squamscott River are presented. The Great Bay Monitoring Program at the Jackson Estuarine Laboratory has evaluated water characteristics within the Squamscott River since 1988 (Langan et al. 1990). The recent Squamscott River data has been compiled and compared with nutrient data from the same location during 1976-78 (Loder et al. 1979).

Comparison of nutrient concentrations for the major nutrients in the water -- ammonium, nitrate and phosphate -- shows a decrease in average concentrations from the earlier to the later of these two time periods (Table 5.2). The reduction in nutrient concentrations is surprising since over that same time period population and development have increased within the Squamscott River watershed (Fig. 5.7 and 2.3, respectively). The suspected increased loading of nutrients from increased development and population does not appear to be reflected in the ambient nutrient concentration in the river. Since the volume of discharge has increased (Table 6.1), the reduction in nutrient levels may be a result of the improved treatment of effluent at the Exeter wastewater treatment facility after the 1989-90 upgrade.

A more detailed look at the patterns of nutrient abundance throughout the sampling periods (Fig. 5.9) again shows very little difference in nitrogen and a decrease in phosphate between the mid-1970s and the late 1980s. Unlike the increased level of minimum concentrations seen in Great Bay data (Fig. 5.8), a decrease in the maximum and minimum nutrient concentrations in the river is apparent for the two time periods. The decrease in nutrient inputs to the Great Bay from the Squamscott River suggests that the source of elevated nutrients in Great Bay (Fig. 5.8) came from elsewhere in the system, and may not be from increased riverine input.

pH

Hydrogen ion concentrations (pH) within the Great Bay Estuary are generally well buffered by seawater and average 7.8; little seasonal variability is evident. Average pH values for the lower estuary range from 7.2 to 8.0. The pH values are slightly higher on the flood tide (NAI 1979a). Values of pH do not vary greatly from year to year, but do exhibit some variability within each year (NAI 1979a). Winter and spring pH data for 1989 showed an extended period of much lower pH values compared to previous observations (Fig. 5.10). Such an anomalous prolonged depression in pH could have a major impact upon many organisms within the estuary. Whether this event was related to acid rain is unknown, but it is important to continue monitoring in order to watch for the recurrence of such conditions.

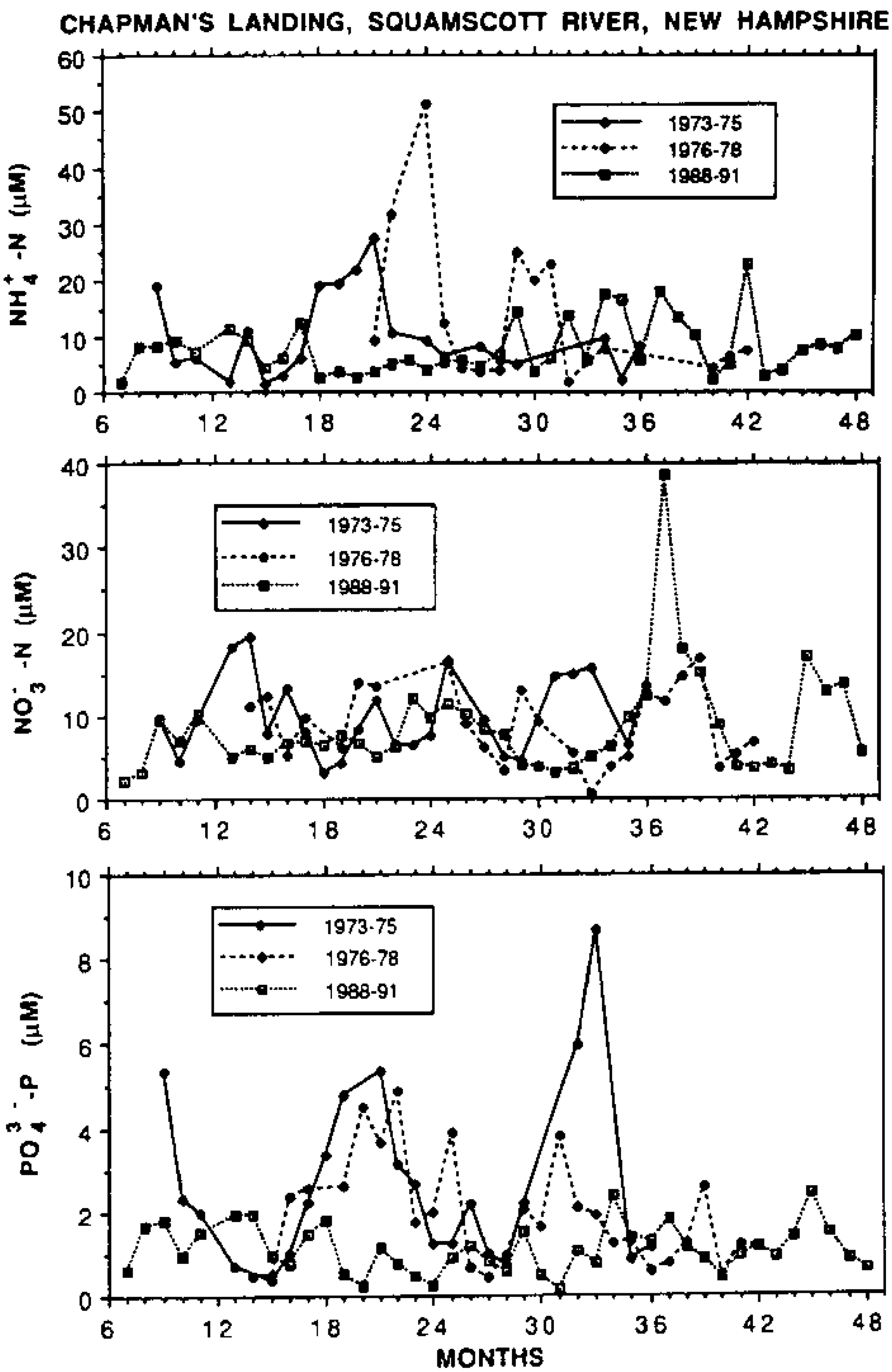


Fig. 5.9. Comparison of low tide water column ammonium (NH_4^+), nitrate (NO_3^-), and phosphate (PO_4^{3-}) concentrations for 1973-75, 1976-78, and 1988-91 in the Squamscott River (Data from Loder et al. 1983b and Langan et al. 1991; see also Table 5.2).

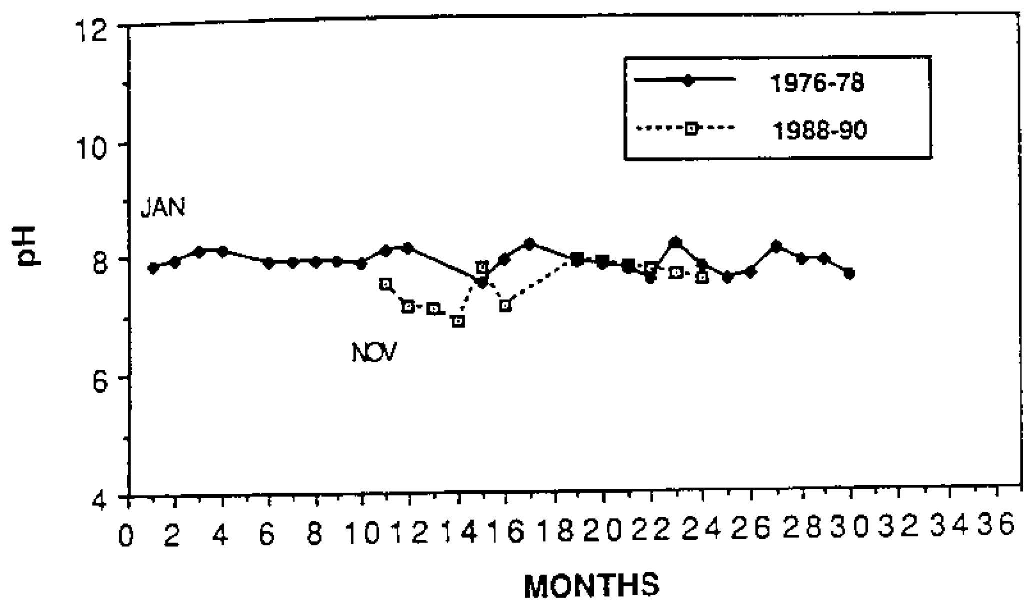


Fig. 5.10. Comparison of depth-averaged mean pH for 1976-78 and 1988-90 during low tide off Adams Point at the mouth of Great Bay, New Hampshire (Data from Loder et al. 1983b and Langan et al. 1990; see also Table 5.1).

Chapter 6: Pollution
by S.H. Jones, F.T. Short, and M. Webster

Pollution problems in the Great Bay Estuary have existed for centuries and have been the subject of study over the last forty years. Various types of pollution associated with a range of human activities have caused impacts on the estuarine biota. Heavy metals from tannery wastes, toxic organic compounds from petroleum processing activities, and microbial pathogens from sewage discharges, all have had significant impacts. Other natural processes influenced by human activities have contributed toxic substances which, in concert with anthropogenic substances, have exacerbated pollution problems in the Estuary. The current state of our knowledge about different types of pollutants and the problems they present to the Great Bay Estuary is outlined below.

Microbial Pathogens

Many diseases result from the fecal-oral route of disease transmission that is often associated with consumption of or contact with contaminated water or seafood. Humans pass the pathogenic bacteria, viruses, and parasites in feces, and chronic exposure to inadequately treated wastes can result in persistent contamination of water with these pathogens. The number of pathogens required for expression of diseases, especially viral diseases, can be as low as one microorganism. Thus, adequate treatment of sewage and other fecal wastes to prevent fecal material from contaminating surface waters, is a critical pollution issue. Sewage pollution is a major problem in coastal New Hampshire, and much public attention has recently been directed to the closing of shellfish beds because of prohibitive levels of fecal-borne microbial contaminants in the overlying waters of shellfish growing areas (See Chapter 10).

Most of the seven major rivers that empty into the Great Bay Estuary (Fig. 0.1) are also the receiving waters from municipal wastewater discharges for communities located on the rivers (Table 6.1). In addition, local municipalities have relied on combined sewage overflow (CSO) systems for collecting and discharging sanitary sewage and stormwater runoff into these rivers. Runoff water from farms and feedlots located along these rivers also flows into the rivers as a result of inadequate drainage and management practices. Improper discharge of fecal wastes from boats, leachate from landfills, other nonpoint urban runoff, and wildlife are other possible sources of microbial pollution. Thus, there are a variety of point and nonpoint sources of fecal-borne microbial pathogens that contaminate the Estuary. However, point sources remain the most prevalent source of pollution affecting most New Hampshire surface waters (Flanders 1990), including the Great Bay Estuary.

Historically, there has been a great deal of research in the Great Bay Estuary conducted by researchers at the Jackson Estuarine Laboratory and the Department of Microbiology at the University of New

Table 6.1. Wastewater volumes entering the Great Bay Estuary (Updated from Loder et al. 1983a)

Community Served[a]	Treatment Level	Mean Daily Flow on 10^6 gal/day Design	1973	1982	1990	Receiving Water	Start-Up Year
New Hampshire							
Dover	Secondary	4.40	1.62	1.93	2.85	Piscataqua R.	1991
Durham	Secondary	2.50	1.16[b]	0.83	1.02	Oyster R.	1981
Epping#	Secondary	0.27	0.10	0.11	0.14	Lamprey R.	1971
Exeter	Secondary	3.00	1.36	1.12	1.92	Squamscott R.	1990
Farmington	Secondary	0.35	----	0.32	0.25	Cocheco R.	1978
Newmarket	Secondary	0.85	0.31[b]	0.30	0.54	Lamprey R.	1971
Newington	Secondary	0.30	----	0.08	0.12	Piscataqua R.	1980
Pease AFB	Secondary	1.20	.08	0.72	0.72	Piscataqua R.	1953
Portsmouth (Pierce Island)	Advanced Primary	7.50	2.09[b]	5.60[b]	4.53[b]	Portsmouth Harbor	1992
Rochester#	Secondary	3.93	----	----	3.63	Cocheco R.	1986
Rollinsford#	Secondary	0.15	0.08	0.04	0.13	Salmon Falls R.	1967
Somersworth#	Secondary	2.40	1.02	1.47	1.23	Salmon Falls R.	1967
Small Volume Others#	Primary	0.20	----	0.06	0.13	Cocheco R.	1960s
Maine							
Berwick#	Secondary	0.60	0.48	0.80	0.73	Salmon Falls R.	1975
South Berwick	Primary	0.45	----	0.19	0.25	Salmon Falls R.	1965
Kittery	Secondary	1.22	0.61	0.65	1.29	Portsmouth Harbor	1970
TOTAL		**28.82**	**9.12**	**14.52**	**19.78**	**Cumulative Great Bay Estuary**	

[a]Communities labeled with a # indicate that effluent is discharged upstream of the dam defining head-of-tide.
[b]Primary Treatment

Hampshire on 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 (NHWSPCC 1960, 1965, 1971). 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 shown to be 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. The researchers concluded that these specific pathogens 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 Bay. The findings were early evidence that contributed to growing doubts about the adequacy of using total coliforms for classifying approved shellfish waters, especially when indicator levels are relatively low. The occurrence of the specific pathogens *Salmonella* sp. and enteric viruses was never demonstrated to be correlated with any reported incidence of disease caused by these microorganisms in surrounding communities.

Metcalf and Stiles (1968a) found that enteric viruses were discharged from sewage effluent pipes and disseminated throughout Great Bay. The viruses were rapidly taken up by oysters and retained for months within the 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 watershed, 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 soft shell clam and oyster harvest seasons in Great Bay, which span the cold autumn through spring months and are only closed during the warm summer months.

Recently studies have again been conducted at JEL to determine the incidence and concentrations of different bacterial pathogens and indicators in Bay water and shellfish, including total and fecal coliforms, *Escherichia coli*, and enterococci (Jones and Langan 1989, Jones 1990). One of the most striking trends determined from the studies is the consistent incidence of higher levels of indicators at Furber Strait at high tide than at low tide. The phenomenon has a couple of possible explanations. It is generally accepted that bacterial pollution should be highest in tidal waters at low tide, based on the assumption that the important pollution sources are from inflowing fresh water. There continues to be discharge of inadequately treated wastewater from sewage treatment facilities in Durham and Portsmouth (upgraded in 1992). Higher levels of contamination in flood tide waters at Adams Point may indicate that such downstream sources are more important than those of rivers entering directly into

Great Bay, where some wastewater facilities have been improved. Alternatively, biological and physical processes within Great Bay may cause removal of microbial contaminants from the water column, resulting in lower contamination levels within the Bay. Such processes would have greatest influence at low tide when the volume of water in Great Bay is minimal, and differences could be measured in the low tide outflow water at Furber Strait. The latter hypothesis is also consistent with a number of observations:

- the constancy of the classification, at least since 1960 (NHWSPCC 1960, Flanders 1990), of some portion of Great Bay as approved for shellfishing when all surrounding areas were typically closed, i.e., there were always higher levels of bacterial contaminants in the surrounding rivers and in Little Bay; and

- the trends in fecal contamination coming into Great Bay from the Squamscott River was the same before and after improvements to the Exeter wastewater treatment facility.

Scientists at JEL have hypothesized that processes such as filtration, sedimentation and absorption associated with eelgrass and shellfish beds may be reducing microbial contaminant levels in Great Bay. A study, currently underway at JEL will address this issue.

Preliminary evidence from monitoring bacterial indicators in the Squamscott River and at Furber Strait suggests that elevated levels of contaminants are associated with rainfall events of greater than 1.52 cm (0.6 inches) of rain during any 24 hour period (Jones and Langan 1989). A follow-up study during a period of low runoff, 1989-90, in the Squamscott River did not show the same relationship between contaminant concentrations and rainfall/runoff (Jones 1990).

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 and elsewhere. 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 (Margolin and Jones 1990, Margolin et al. 1990). Gene probe assays showed good agreement with traditional tissue culture methods. 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.

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. 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 from the Bay in more recent studies (Jones et al. 1991). 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). Such a discovery does not mean that *V. vulnificus* is a relatively new inhabitant of the Estuary. Rather, it was never looked for before, its incidence was transient, detection methods were difficult and erratic, or there was no incidence of disease to cause alarm. *V. vulnificus* has since been detected routinely in all of the tidal portions of the major tributaries where shellfishing is not permitted, and twice in the areas of Great Bay open to shellfishing (O'Neill et al. 1990, Jones et al. 1991). *V. vulnificus* has only been detected from July to October, and its incidence is positively correlated with salinity and temperature (O'Neill et al. 1990). A relatively high incidence of hemolysin-negative, or potentially avirulent, strains of *V. vulnificus* have been isolated from the Estuary (O'Neill et al. 1991).

Other studies have shown differential elimination of fecal-borne bacteria compared to vibrios from oysters in disinfected or minimally-contaminated water (Jones et al. 1991). Fecal coliforms and *E. coli* are easily eliminated from both relayed and depurated oysters. Pathogenic vibrios do not respond to depuration, while *V. vulnificus* can be eliminated from oysters relayed to water from Spinney Creek in Eliot, Maine, and waters near Furber Strait. The Estuary may be relatively unique in this way, having areas with minimal levels or no *V. vulnificus* where shellfish could be relayed to for purification. There has not been any epidemiological evidence of food poisoning or wound infections in the local communities associated with the incidence of either vibrio.

Point source pollution is generally recognized as the major source of microbial contaminants in the Great Bay Estuary, and action is being taken to eliminate the remaining major point sources of sewage contaminants (Flanders 1990). Strategies pursued have included increasing the efficiency and effectiveness of existing disinfection systems, eliminating CSOs in Portsmouth, and upgrading primary treatment facilities. Portsmouth, Dover, and Exeter have signed consent decrees with New Hampshire Department of Environmental Services (DES) that legally bind them to improve their wastewater treatment facilities, while Newmarket and Somersworth have made improvements without these decrees (NHDES 1990). New requirements for chlorine limits and testing have been incorporated into discharge permits for Dover, Durham, Exeter, Farmington, Newmarket, and Somersworth. The actions have cost $65,800,000 to date, of which $62,000,000 was funded by grants from DES via state and federal money. Wastewater discharges from facilities in Newington, Newfields, and from the Maine side of the estuarine system are also of concern (Table 6.1).

Sanitary surveys are now being conducted by communities to eliminate failed septic systems and other individual discharges. A state sanitary survey conducted in 1990 by DES was successful in eliminating some of the previously unidentified sources of sewage pollution in the Bellamy River.

Although point sources of fecal pollution have historically masked nonpoint sources of microbial contaminants in the Great Bay Estuary, nonpoint sources are now recognized as important sources of pollution. In the Piscataqua River watershed, all waters are classified as Class A (water supplies) or Class B (swimmable, fishable). However, the tidal portions of the major inflowing rivers to the Estuary do not meet these classifications and only a portion of Great and Little Bays is open to shellfish-harvesting. Most of these impairments are based on violations of the total coliform criteria necessary for the different designated uses (Flanders 1990). Onsite wastewater treatment systems (point sources) contribute to 40% of documented impairments, land disposal sites 20%, urban and highway runoff 13%, and other nonpoint sources, such as boats and commercial establishments, represent the major impairments of designated use. As point source contamination problems are reduced, information about nonpoint sources of pollutants will become increasingly important.

Some studies have been conducted to determine best management practices for controlling nonpoint source contamination of estuarine waters. The Durham Urban Runoff Program report (NHWSPCC 1983) showed stormwater runoff from urban areas was associated with violations of coliform standards for shellfish waters in the tidal portions of the Oyster River. Cleanup methods, including building swales to trap run off and vacuum cleaning parking lots, were effective techniques for reducing levels of bacterial indicators in the runoff. The most significant control of microbial contaminants resulted from impoundment of runoff waters in Mill Pond, just upstream of the tidal dam on the Oyster River. Control measures such as those found to be effective in this study could be extremely useful and relatively inexpensive strategies for reducing the microbial pollution of the Estuary and its tributaries.

In the New Hampshire Water Quality Report to Congress (Flanders 1990), a summary of nonattainment segments of rivers and bays within the Piscataqua River watershed revealed 161 km (100 miles) of the 295 km (183 miles) of rivers and 914 km^2 (353 mi^2) of assessed waters violated water quality standards because of point and nonpoint source pollution. A total of 18.5 km (11.5 miles) were upgraded since 1986-87, while 47.6 km (29.6 miles) were downgraded. Another report (USEPA/NOAA 1987) cited the percentage of surface waters affected by nonpoint and point source pollution in limiting shellfish harvesting. That is, 11% of the harvest waters were affected by urban runoff, 37% by agriculture and feedlots, 37% by forestry activities and wildlife, 15% by onsite sewage disposal systems, 93% by municipal wastewater treatment facilities, and 8% by other straight pipe discharges.

The overall trend of increasing pollutant levels is a cause of great and immediate concern for the Bay. Point source sewage discharge into the watershed is by far the greatest source of fecal contamination to the Bay.

Nutrient Loading

The discharge of nitrogen and phosphorus, a process called nutrient loading, into the Great Bay Estuary is an aspect of pollution that requires consideration. All of the seven major rivers entering into the Great Bay Estuary have sewage treatment plants that discharge nutrients into the rivers and then into the Estuary (Table 6.1). In addition, the city of Portsmouth, the towns of Eliot, Kittery and Newington (including sewage from Pease Wastewater Treatment Plant) all discharge various degrees of treated sewage effluent into the Piscataqua River. The combination of nutrients entering into the Great Bay Estuary from all these sources constitutes the point source nutrient load to the system.

With increased population growth over the last couple of decades, the loading of nitrogen and phosphorus into the Estuary from point source discharges has increased in direct relationship to increased wastewater volume discharge (Table 6.1). Counterbalancing some of this nutrient loading has been the upgrade in treatment facilities, evidenced in lower nutrient levels in the Squamscott River after improvements in the Exeter wastewater treatment plant (see Chapter 5 and below). In addition to increased point source discharges, the increase in land development within the watershed of Great Bay (Fig. 10.3) suggests an additional increase in nonpoint source pollution into the Estuary (Table 6.2). As seen in other estuaries (Nixon and Pilson 1983, Kemp et al. 1983), increased loading of nitrogen and phosphorus into an estuarine system is the primary cause of coastal eutrophication.

Eutrophication, or the summation of all biological effects of increased nutrient discharge, is the number one problem threatening the health of estuaries in the United States. In 1988, NOAA's Strategic Assessment Branch, OAD/NOS calculated nutrient loading rates for all of the major estuaries on the East Coast of the U.S. (NOAA 1989). The findings, based on land use estimates and the physical structure of the estuary, show Great Bay Estuary to be a moderately loaded estuary. Such results suggest that conditions within Great Bay are better than many estuaries along the East Coast, but give no indication of how rapidly these conditions are changing.

The analysis of the Great Bay Estuary nutrient characteristics by the Strategic Assessment Branch of NOAA suggests that nonpoint source pollution is a greater source of nitrogen and phosphorus to the Estuary than point source discharge. Estimates of nitrogen loadings to the Great Bay Estuary, 21.9×10^4 kg (242 tons) /year from point source pollution and 35.7×10^4 kg (394 tons) /year from nonpoint source pollution, are similar to data from EPA (Table 6.2). The NOAA report suggests that point source pollution provides a greater load of phosphorus to the Estuary with 14.6×10^4 kg (161 tons) /year discharged versus 39.0×10^3 kg (43 tons) /year from nonpoint source pollution.

Using these loading rates, the rates of riverine discharge into the Great Bay Estuary and the flushing time of the Estuary, the NOAA report gave a prediction for expected nutrient concentrations within the Estuary water column. Their estimate was 7 μM (micromoles/liter) of total nitrogen and 1 μM of total phosphorus. Analysis of actual nutrient data (Chapter 5) shows that the average concentrations of inorganic nitrogen and phosphorus within Great Bay proper are 10 μM and 0.9 μM respectively (Short et al. in prep.). It should be noted that the NOAA estimate of nutrient loading used to calculate estuarine nutrient concentrations was based totally on inputs and flushing time for the entire Estuary and did not include any biological removal of nitrogen and phosphorus. By contrast, average values for nutrient concentrations within Great Bay itself are based upon recent direct measurements. The nutrient concentrations measured in Great Bay include, or are the net result of, inputs minus removals by eelgrass, seaweed, phytoplankton, other primary producers and bacteria. The results drawn from the Strategic Assessment Branch evaluation of Great Bay Estuary nutrient status suggest that the nitrogen-to-phosphorus ratio for the Estuary is 7 to 1 (normal ratio is 16 to 1), leading them to suggest that nitrogen remains the primary limiting nutrient to plant growth within the Great Bay Estuary (NOAA 1989).

Although the average concentrations of nitrogen and phosphorus in Great Bay are not significantly different now than thirteen years ago (Table 5.1), there has been a dramatic change in the range of nitrogen concentrations. Today, the minimum nitrogen concentrations are an order of magnitude higher than the minimum values observed in the mid 1970s. Recent elevated nutrient concentrations in the Bay suggest that a

Table 6.2. Annual total nutrient discharge into Great Bay Estuary (USEPA 1988)

Nonpoint Source	N(10^4 kg)	N (tons)	P(10^4 kg)	P (tons)
Agriculture	15.06	166	0.64	7
Urban	20.59	227	3.26	36
Forest	0.36	4	0	0
Total	36.01	397	3.90	43
Point Source				
Wastewater treatment	20.86	230	13.88	153
Industry	1.18	13	0.63	7
Total	22.04	243	14.51	160
Total Charge	58.05	640	18.41	203

change in nutrient loading may have occurred over the past decade. The occurrence of no change in average nitrogen concentration or range of concentrations within the Squamscott River suggests that it is not the source of increased nitrogen loading (Table 5.2). The downstream contamination source for fecal coliforms in Great Bay (see Chapter 10) suggests the wastewater treatment plants may also be responsible for the increased minimum nitrogen and phosphorus concentrations observed. Data on the nutrient status of Great Bay need to be examined in greater detail in order to evaluate management priorities for limiting nutrient load into the Estuary as well as for improving overall estuarine water quality.

Another explanation for elevated minimum nutrient levels observed in Great Bay is the loss of eelgrass in the Bay due to the wasting disease (see Chapter 10). The loss of eelgrass biomass from the Bay dramatically decreases nitrogen uptake rates from the water column and results in elevated concentrations of nitrogen in the ebb tide waters of the Bay. However, some of this loss in nutrient uptake is made up by increases in macroalgal populations in the Bay, evidenced by large populations of the seaweed, *Ulva lactuca*, in areas that were formerly eelgrass habitats (Short per. obs.).

The evaluation of nitrogen inputs by NOAA (1989) suggests that nonpoint source pollution (Table 6.2) has made a greater contribution to nitrogen loading in the Bay than point source. If this is true, major management activity will be required to identify sources of nonpoint pollution and take steps to immediately remove these nutrient sources. In fact, the Great Bay Hydrologic Unit was developed by the Soil Conservation Service, Agricultural Stabilization and Conservation Service, Rockingham and Strafford County Conservation District, University of New Hampshire Cooperative Extension and New Hampshire Office of Water Supply and Pollution Control Division to establish goals for reducing nonpoint source inputs of nutrients and other pollutants into Great Bay watershed (Tables 6.3, 6.4). As soon as the magnitude of nonpoint and point source pollution has been identified, it will be important to establish priorities for dealing with both sources of nutrient loading.

Heavy Metals and Toxic Organic Compounds

Substantial industrial and domestic wastes enter the Great Bay Estuary via its tributaries and from sources located directly on its shores. Heavy metals are part of these wastes, originating from sewage treatment plants, tanneries, foundries, military facilities, and metal plating operations. Armstrong (1974) measured concentrations of copper, zinc, chromium, lead, and cadmium in the sediments of the Estuary, and found elevated levels of copper, zinc and chromium but was only able to detect cadmium at one site in the Cocheco River (Table 6.5). Capuzzo (1974) focused on chromium, and Nelson (1986) measured mercury and nickel in addition to copper, zinc, lead, and chromium in sediments and oysters (Table 6.5). In general, levels of various metals were higher in the sediments of the tributaries of the Great Bay Estuary than in Great and Little Bays (Armstrong 1974, Capuzzo 1974, Nelson 1986). Most metals also occur in greater concentrations in the tributaries than in the Piscataqua River, with the exception of mercury. High levels of mercury in the Piscataqua River sediments may be due to the use of mercury steam at the Schiller

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Table 6.3. Factors contributing to nonpoint source pollution into Great Bay Estuary

Agriculture (United States Soil Conservation Service et al. 1990, NHDES 1989)

- manure application exceeding prescribed agronomic rates
- manure application on frozen or sloping ground
- liquid runoff from stored manure
- faulty calibration of manure spreaders
- unknown manure nutrient levels
- lack of complete nutrient management plans for landowners
- erosion
- close proximity of many crop production fields to water courses
- conventional cultivation/tillage techniques with low residue crops

Urban (Strafford County, NH Conservation District 1990)

- seepage of septic effluent into ground water
- leachate from stump dumps
- leachate from active/abandoned landfills
- subsurface disposal
- hazardous waste disposal
- urban (sewer, storm, and surface) runoff
- drainage pipe outfalls
- freshwater inflow from culverts into tidal marshes
- erosion and sedimentation from construction sites
- discharges from boats
- mosquito control activities

Electric Station between 1950 and 1968 (Nelson 1986).

The presence of a considerable industrial input of chromium was apparent from the studies of Armstrong (1974) and Capuzzo (1974). One source was a leather processing plant in Dover which used a chrome tanning process from 1940 to 1976. Approximately 18,200 kg of dichromate salt were discharged in 1968 by the tannery into the Cocheco River in Dover (Capuzzo 1974). Chromium concentrations in sediments were found to decrease with distance downstream from the tannery outfall, and chromium concentrations further downstream in the Piscataqua River also decreased along a downstream gradient (Nelson 1986). Capuzzo and Anderson (1973) used the elevated chromium accumulations from 1940 to 1969 to estimate the sedimentation rate for Great Bay. The estimated sedimentation rates, 0.16 to 0.78 cm per year, are comparable to accretion rates determined for other estuaries by different methods (Capuzzo and Anderson 1973).

Fine-grained sediments found in tidal flats were associated with higher levels of chromium and nickel (Armstrong 1974, Nelson 1986), especially in areas of Great Bay where current velocities are relatively low. Nelson (1986) suggested that low metals may be taken up by the extensive eelgrass beds in Great Bay. Metals taken up by eelgrass could be translocated into the sediments or transported throughout the Estuary by tidal currents as the leaves die and break off. The reduction of chromium concentrations in Little and Great Bays during the time between the Armstrong (1974) study and the Nelson (1986) study may reflect burial of older chromium-contaminated sediments with newer, less contaminated deposits. In comparison to other coastal areas of the northeastern Atlantic Coast, metals in Great Bay Estuary sediments are near the middle of the range, falling above Canadian sites and lower than heavily industrialized areas near New York (Nelson 1986).

Contaminants in Sediment, Soil, Surface Water, and Ground Water

Sediment samples from a variety of sites on the Piscataqua River have been analyzed for contaminants for federal and private dredging projects. The results show relatively clean sediments, with heavy metal concentrations from low to moderate at most sites, based on the Maine Classification of Dredged Materials standards (Table 6.6). Since New Hampshire has no written standards for

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Table 6.4. Nonpoint source water pollution reduction plan for the Great Bay hydrologic unit (United States Soil Conservation Service et al. 1990)

Objectives:

1. Reduce nonpoint source water pollution from agricultural land, i.e. nutrients, manures, pesticides, and soil erosion.

2. Reduce nonpoint source water pollution from forest land, i.e. nutrients, soil erosion, and pesticides.

3. Reduce nonpoint source water pollution from urban, suburban, and non-agricultural and forest land uses.

Table 6.5 (page 1 of 3)
ORGANIC COMPOUNDS DETECTED IN PHYSICAL MEDIA OF THE ESTUARY

Location	Sampling Year	Media	Concentration (in ppb) Petroleum Hydrocarbons	PCBs	Volatile Organics	Semi-volatile Organics	Pesticides
Great Bay Estuary							
Pierce Point (10)	1987	Sediment		(10)		480 ◊	
Three Rivers Point (10)	1987	Sediment		(10)		10,000 ◊	
Piscataqua River							
Badger's Island - north side (3)	1988	Sediment	340,000	(200)			
Badger's Island - northwest side (6)	1989	Sediment		(10)-21		(20)-741 ◊	(20)
Badger's Island - northwest side (7)	1989	Sediment		(100)		(200)-1500 ◊	(50)
Badger's Island - west side (2)	1984	Sediment		(500)	(5) Δ		
Badger's Island - west side (5)	1988	Sediment		(0.0)			
Badger's Island - west side (2)	1984	SW		(10)	(0.01) Δ		
Badger's Island - south side (4) (just east of Rte. 1 Bridge)	1987	Sediment		(300)-(600)			
Clark Island Embayment (2)	1984	Sediment		(500)-5,820	(5)-11 Δ		
Clark Island Embayment (2)	1984	SW		(10)	(0.01) Δ		
Four Tree Island (2)	1984	Sediment		(500)			
Piscataqua River - off Prescott Park (4)	1988	Sediment	1,200,000-1,500,000	(50)			
PSNH Schiller Station Wharf (9)	1990	Sediment	(60,000)	(1,000)			
Salamander Point (2)	1984	Sediment		(500)			
Seavey Island (1)	1976	Sediment		(10)-4,036 *		(50)-1,020 --	(50)-530 †
Spruce Creek							
Walts Fluid Air in Kittery, ME (8)	1988	Sediment			≤ 3,578,000	≤ 88,840	
Walts Fluid Air in Kittery, ME (8)	1988	Soil			≤ 86,468	≤ 800	
Walts Fluid Air in Kittery, ME (8)	1988	GW			≤ 353		
Pepperrell Cove							
Pepperrell Cove (2)	1984	Sediment		(500)	(5) Δ		
Pepperrell Cove (2)	1984	SW		(10)	(0.01) Δ		

SW = Surface water.
GW = Ground water.
( ) = Indicates limit of detection
* = Aroclor 1254 only.

† = DDT only.
Δ = Methyl Ethyl Ketone, Methylene Chloride, or Trichloroethylene.
-- = Phenol only.
◊ = PAHs only

References:

(1) Parsons, Brinckerhoff, Quade and Douglas, Inc. and Normandeau Associates 1978
(2) Louriero Engineering Assoc. and YWC 1986
(3) U.S. Army Corps of Engineers 1988b
(4) U.S. Army Corps of Engineers 1988a
(5) TGG Environmental 1988
(6) U.S. Army Corps of Engineers 1989
(7) ME DEP 1989
(8) CE Environmental 1990
(9) U.S. Army Corps of Engineers 1990
(10) Isaza et al 1989

Table 6.5 (page 2 of 3)
INORGANIC COMPOUNDS DETECTED IN PHYSICAL MEDIA OF THE ESTUARY

Location	Sampling Year	Media	As	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn
			Concentration (in ppm)								
Great Bay Estuary											
Pierce Point (15)	1987	Sediment		0.96	100			0.77		40	
Tributaries, bays, head of Piscataqua R. (14)	1971-72	Sediment			19.8-831	6.3-201					35.3-336
Cocheco River (13)	1972	Sediment			9-221						
Mouth of Cocheco River (13)	1972	Sediment			8-72						
Salmon Falls River (13)	1972	Sediment			7-77						
Three Rivers Point (15)	1987	Sediment		1	140			0.48		43	
Piscataqua River											
Badger's Island - west side (2)	1984	Sediment		(0.05)	14.5-17.5				15.2-19.5	22.5-67.5	
Badger's Island - west side (7)	1988	Sediment	8.1-20.2	0.8-1.2	14.8-18.6	6.1-10.9		(0.5)	8.9-27.2	17.4-19.8	21.9-23.3
Badger's Island - west side (2)	1984	S W		0.07	0.04				0.23	0.38	
Badger's Island - northwest side (9)	1989	Sediment	4.3-30	2.1-7.7	19-193	18-38		(0.2)-0.63	11-22	25-130	44-130
Badger's Island - northwest side (8)	1979	Sediment	(0.3)-(0.5)	1-2	18-92	8-34		(0.2)	copy unreadable	10-60	24-42
Badger's Island - northwest side (8)	1989	Sediment	1.81-10	2.2-21.3	22-193	12-38		0.186-0.84	11-22	29-130	44-130
Badger's Island - north side (4)	1988	Sediment	8	(0.5)	33	20		0.05	30	110	62
Badger's Island - south side (5)	1987	Sediment	19	(0.6)	59	10		0.1	32	11	33
(just east of the Rt. 1 Bridge)											
Clark Island Embayment (2)	1984	Sediment		(0.05)	12.7-145 *				9.6-952.4	4.4-625	
Clark Island Embayment (2)	1984	S W		0.04-0.05	0.04-0.04				0.13-0.17	0.44-0.46	
Four Tree Island (2)	1984	Sediment		(0.05)	16.5				23.8	7.5	
Jamaica Island - north side (10)	1987	Sediment		(0.05)-0.23	35-103	49-61	12,000-22,400	0.35-0.51	17-21	65-79	123-135
Noble's Island (3)	1981	Sediment			58-157	19-30		0.00064-0.00145	19-28	43.7-60.5	70-121
Piscataqua R. just south of Cocheco R. (13)	1972	Sediment			8-56						
Piscataqua R. between Cocheco and Little Bay (13)	1972	Sediment			17-44						
Piscataqua R. just north of Little Bay (13)	1972	Sediment			10-56						
Piscataqua R. at Little Bay (13)	1972	Sediment			14-47						
Piscataqua R. off Prescott Park (5)	1988	Sediment	1.8-2.7	1.0-1.2	23-30	78-120		0.68-2.1	12-14	170-170	160-210
Piscataqua R. at Spinney Creek (10)	1987	Sediment			25-30	5.0-8.0	8,100-13,600	0.09-0.17	8.1-14	14-22	34-42
Portsmouth Naval Shipyard (6)	1988	Sediment		0.06-0.24	7.4-27.2				16-46	5.6-13.1	
PSNH Schiller Station Wharf (12)	1990	Sediment	11-20	0.8-2.5	29-150	17-46		(0.02)-(0.03)	37-90	5-6	39-82
Salamander Point (2)	1984	Sediment		(0.05)	12.2				17.2	62.5	
Seavey Island (1)	1976	Sediment		6-10	18-438	20-4100		0.01-5.5		50-7,000	40-17,200
Seavey Island - DMSO (2)	1984	Soil		(0.25)-37.61	9.8-203				9.5-15,800	4.8-192,022	
Seavey Island - DMSO (2)	1984	Soil		(0.05)	20.8-41.3				37.3-87.5	32.5-293	
Seavey Island - DMSO (2)	1984	S W		(0.004)-0.06	(0.02)-0.05				(0.02)-0.26	(0.04)-0.46	
Seavey Island - northwest side (2)	1984	Soil		(0.05)	14.2				25	80.1	
Seavey Island - southwest side (10)	1987	Sediment		(0.05)-0.07	21-26	13-38	7,300-9,000	0.12-0.13	8.3-8.8	24-35	81-84
Spruce Creek											
Spruce Creek (10)	1987	Sediment		(0.05)-0.15	53-95	15-24	13,000-21,000	0.035-0.41	9.8-17	26-51	58-105
Watts Fluid Air in Kittery, ME (11)	1988	Sediment			24-57,000					N D-3,000	
Watts Fluid Air in Kittery, ME (11)	1988	G W			0.035 **				0.035 **	0.014 **	
Pepperrell Cove											
Pepperrell Cove (2)	1984	Sediment		(0.05)	23				20	<0.5	
Pepperrell Cove and Phillip Island (10)	1987	Sediment		0.12-0.19	97-149	27-48	21,900-27,600	0.38-0.71	18-25	45-89	97-134
Pepperrell Cove (2)	1984	S W		0.07	0.04				0.19	0.28	

N D = Not Detected.
S W = Surface water.
G W = Ground water.

( ) = Indicates limit of detection.
J = Estimated value.

* = One sample had an unusually high result equal to 67,247 ppm.
** = Indicates average of sample values.

References:
(1) Parsons, Brinckerhoff, Quade, and Douglas, Inc. and Normandeau Associates 1978
(2) Louriero Engineering Assoc. and YWC 1986
(3) Nelson 1986
(4) U.S. Army Corps of Engineers 1988b
(5) U.S. Army Corps of Engineers 1988a
(6) ME DHS 1988
(7) TGG Environmental 1988
(8) U.S. Army Corps of Engineers 1989
(9) ME DEP 1989
(10) ME DEP 1991
(11) CE Environmental 1990
(12) U.S. Army Corps of Engineers 1990
(13) Capuzzo and Anderson 1973
(14) Armstrong et al. 1976 (Armstrong 1974)
(15) Isaza et al. 1989

Table 6.5 (page 3 of 3)
ORGANIC AND INORGANIC COMPOUNDS DETECTED IN BIOTA OF THE ESTUARY

Location	Sampling Year	Sampling Media	PAHs	PCBs	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn
			Concentration (Organics in ppb, Inorganics in ppm)									
Great Bay Estuary												
Bellamy River (7)	1987	Clams	(100)	37	0.12	1.7			0.045		1.8	
East Seafood Co. (7)	1987	Mussels	250	58	0.41	0.72	2.3		(0.03)	1.2	0.9	18
Fox Point (7)	1987	Clams	4,700	19	0.19	1.4			(0.03)		1.5	
Fox Point (7)	1987	Mussels	11,000	44	0.56	0.71	1.6		(0.03)	1	0.84	13
Hilton State Park (7)	1987	Clams	5,700	17	0.15	1.3			(0.03)		2	
Hilton State Park (7)	1987	Mussels	220	59	0.43	0.63	1.7		(0.03)	0.71	0.87	15
Lamprey River (7)	1987	Mussels	780	60	0.5	8.5	2.4		(0.03)	2.5	4.5	23
Nannie Island (7)	1987	Clams	3,300	31	(0.05)	0.9			(0.03)		0.84	
Nannie Island (7)	1987	Mussels	1,900	92	0.33	1.2	1.6		(0.03)	0.58	1.3	13
Pierce Point (7)	1987	Clams	(100)	34	0.21	4			(0.03)		5.4	
Three Rivers Point (7)	1987	Clams	510	19	0.2	2.2			(0.03)		1.8	
Piscataqua River												
Atlantic Heights (7)	1987	Mussels	570	24	0.32	0.71	1.5		(0.03)	(0.3)	1.3	27
Badger's Island (7)	1987	Mussels	340	19	0.36	0.54	1.4		(0.03)	(0.3)	0.81	27
Badger's Island - west side (3)	1984	Mussels			(0.5)-1.9	(2.5)-2.4				(2.5)-2.2	3.8-60.3	
Badger's Island - west side (3)	1984	Lobster meat		510	(0.5)	(2.5)				(0.5)	101	
Badger's Island - west side (3)	1984	Algae		(100)	9.0	18.3				51.6	58.4	
Clark Island (7)	1987	Mussels	240	18	0.35	0.6	1.1		(0.03)	(0.3)	0.87	25
Clark Island Embayment (3)	1984	Mussels		230-780	(0.5)	(2.5)-15.1				(2.5)-13.3	23-76.7	
Clark Island Embayment (3)	1984	Lobster meat		140-8800	(0.5)	(2.5)				(0.5)	(1.0)	
Clark Island Embayment (3)	1984	Algae		(100)	12.7-29.4	8.87-46.6				23.7-228	66.5-169	
Fort Point (7)	1987	Mussels	(100)	19	0.32	0.81	1.5		(0.03)	(0.3)	1.5	30
Four Tree Island (3)	1984	Mussels			(0.5)-1.6	(2.5)-5.8				(2.5)-4.4	10-117	
Four Tree Island (3)	1984	Algae		(100)	7.1	10.6				2.5	35.5	
Four Tree Island (7)	1987	Mussels	2,300	270	0.31	1.3	1.7		(0.03)	(0.3)	1.2	22
Goat Island (7)	1987	Mussels	680	40	0.35	1.1	1.4		(0.03)	(0.3)	1.3	23
Jamaica Island (7)	1987	Mussels	670	22	0.29	0.68	1.2		(0.03)	(0.3)	1.4	19
Pierce's Island (7)	1987	Mussels	390	19	0.41	1.1	1.2		(0.03)	(0.3)	(0.5)	34
Pierce's Island (7)	1987	Lobster meat	(100)-2,800	(10)-80	(0.05)	0.2-0.3	8.1-15		(0.03)-0.11	(0.3)	(0.5)	20-32
Pierce's Island (7)	1987	Lobster - viscera	4,600-19,000	370-11,000	1.4-2.0	0.3-0.34	28-72		(0.03)-0.1	0.3-0.6	(0.5)	17-24
Piscataqua River, 95 to Rt. 1 bridges (5)	1987	Mussels			3	4.8	13	420	0.74	2.2	5.9	100
Piscataqua River, Kittery (6)	1986	Lobster meat									(0.01)-0.79	
Portsmouth Naval Shipyard (4)	1988	Mussels		15.20-99.35 *	(0.05)-1.07	1.5-4.0				(2.0)	(0.30)-7.5	
Portsmouth Naval Shipyard (4)	1988	Lobster meat		32.87-117.9 *	(0.05)-0.21	(0.20)-12.4				(2.0)	(0.30)-6.7	
Portsmouth Naval Shipyard (4)	1988	Lobster - Hepatopancreas			0.36-3.77	(0.20)-1.40				(2.0)	(0.30)	
Seavey Island - DMSO (3)	1984	Mussels			(0.5)-3.8	(2.5)-3.8				(2.5)-856	1.8-349	
Seavey Island - DMSO (3)	1984	Lobster meat			(0.5)	(2.5)				(0.5)	(1.0)	
Seavey Island - DMSO (3)	1984	Algae			4.5-8.5	6.3-10.7				17.2-21.6	35.5-99.4	
Seavey Island - north side (5)	1987	Mussels			2.4	3.8	8.9	430	0.58	2.2	12	150
White Island, Outer Harbor (5)	1987	Mussels			2	1.8	8.5	140	0.45	2.2	2.6	100
Spinney Creek												
Spinney Creek (1)	1977	Oysters			1.8	20	96				20	5000
Spinney Creek (2)	1985	Clams			0.14-0.18	0.38-0.61	1.92-2.11	43.34-45.63		0.55-0.83	0.25-0.38	16.51-17.02
Spruce Creek												
Spruce Creek (2)	1985	Clams			0.11-0.13	0.92-1.12	2.33-2.63	147-149		0.36-0.61	0.36-0.44	16.88-17.30
Spruce Creek (5)	1987	Mussels			1.5	2.6	7.9	270	0.39	1.3	5.9	110
Pepperrell Cove												
Pepperrell Cove (3)	1984	Mussels			(0.5)-2.3	(2.5)-2.6				(2.5)-2.5	4.9-165	
Pepperrell Cove (5)	1987	Mussels			2.5	3.9	9.1	390	0.57	2.3	11	110
Pepperrell Cove (3)	1984	Lobster meat		5,810*	(0.5)	(2.5)				(0.5)	(1.0)	
Pepperrell Cove (3)	1984	Algae		(100)	5.7	9.5				21	28.4	

( ) = Indicates limit of detection. * = Aroclor 1254 only

References:
(1) EPA 1978
(2) FDA 1985
(3) Lourlero Eng. Assoc. and YWC 1986
(4) ME DHS 1988
(5) ME DEP 1991
(6) Sherburne 1989
(7) Isaza et al. 1989

Table 6.6. Acceptable Levels of Contaminants

Classification of Dredged Material for the State of Maine. (USACE 1989).

Constituent	Low: Class I	Moderate: Class II	High: Class III
Oil and Grease (%)	< 0.25	0.25 - 1.2	> 1.2
Volatile Solids (%)	< 4.5	4.5 - 15.3	> 15.3
Silt/Clay (%)	< 60	60 - 90	> 90
Metals (ppm)			
Mercury	< 0.5	0.5 - 3.0	> 3.0
Lead	< 83	83 - 285	>285
Zinc	<135	135 - 436	>436
Arsenic	< 7	7 - 22	> 22
Cadmium	< 3	3 - 15.5	> 15.5
Chromium	<112	112 - 513	>563
Copper	< 83	83 - 342	>342
Nickel	< 36	36 - 92	> 92
Other (ppm)			
PCB			> 2.7
DDT			> 0.2

New Jersey ECRA Values and Proposed Federal Action Levels (McLaren/Hart 1991a).

	NJ ECRA	Action Level
Organics (ppb)		
Petroleum hydrocarbons	100,000	--
PCBs	1,000-5,000	90
Pesticides	--	--
Semivolatile organics	10,000	--
Volatile organics	1,000	--
Inorganics (ppm)		
Arsenic	20	80
Cadmium	3	40
Chromium	100	400
Copper	170	--
Iron	--	--
Mercury	1	20
Nickel	1000	2000
Lead	250-1000	--
Zinc	350	--

dredged material, Maine classification levels are used in most reports for the Piscataqua River. Other sediment and soil values used for comparison are from the New Jersey Environmental Cleanup Responsibility Act (ECRA) and proposed Federal Action Levels (Table 6.6).

As a reference, the Maine Classification of Dredged Material is presented here, dividing dredged material into Classes I, II and III for determination of disposal sites. Class I material is coarse-grained sediment with contaminant levels less than the mean value for all samples taken by the Army Corps of Engineers in the Gulf of Maine tidal system. Class I material can be used for habitat creation projects and beach nourishment. It is suitable for open-water disposal and as a cap for more contaminated sediments at ocean disposal sites, and can be used as cover for sanitary landfills. Class II material may have contaminant levels greater than the mean, but less than two standard deviations above the mean, of all Gulf of Maine samples. Contamination is considered moderately high, and such sediments can be used for the same uses as Class I material with the exception of beach nourishment. Class III sediments are fine-grained and/or have abnormally high levels (greater than two standard deviations above the mean of all Gulf of Maine samples) of two or more contaminants. Bioassay and bioaccumulation tests may be required to determine if ocean disposal is appropriate, and if so Class III materials must be capped. Class III material is treated as sludge for land disposal and must be handled in accordance with solid waste disposal guidelines.

This classification scheme is used to determine suitability of use or disposal of dredged materials. Since classification levels are based on Gulf of Maine tidal system averages, they provide a useful reference for comparing contaminant levels from different sites in the Estuary (Table 6.5).

In 1972, two sediment samples were analyzed from Outer Cutts Cove in the Piscataqua River, just north of the Route I-95 bridge (NAI 1987). PCBs, oil and grease, and heavy metal concentrations were all low. The volatile solids concentration in one sample was moderate (9.6%). Samples taken from the intertidal zone at the west end of Badger's Island in 1988 (Table 6.5) had no detectable volatile solids or PCBs, a low percentage of oil and grease, and low or moderate levels of heavy metals by State of Maine Dredged Materials Classification standards (Table 6.6) (TGG Environmental 1988). Sediment samples taken from the channel west of Badger's Island in 1979 and again in 1989 show similar results, with low or "background" levels of pesticides, PCBs, PAHs, oil and grease, and most metals (Table 6.5) (USACE 1989). However, the heavy metals chromium, lead, arsenic and mercury increased in concentration in some samples from low to moderate levels (according to the Maine Classification of Dredged Material) and cadmium increased from low to high levels in the time between 1979 and 1989.

Several sites in the Piscataqua River showed only low to moderate levels of metals in samples taken in 1987-90 (Table 6.5). Sites include the north (USACE 1988b) and south (USACE 1988a) sides of Badger's Island, the bank of the Piscataqua River off Prescott Park (USACE 1988a), as well as the bank of the Piscataqua River at the PSNH Schiller Station Wharf (USACE 1990). Metals classified as moderate in concentration from samples around Badger's Island included arsenic and lead, and petroleum hydrocarbons detected on the north side of Badger's Island exceeded NJ ECRA limits. Levels of volatile solids were moderate at the site near Prescott Park while copper, lead and zinc were also detected at moderate levels and petroleum hydrocarbons were elevated above NJ ECRA limits. Arsenic, nickel and chromium occurred at moderate levels in the sediments near PSNH Schiller Station Wharf with arsenic and chromium also exceeding NJ ECRA values.

Sediment samples were collected by the Maine Department of Environmental Protection (DEP) at several locations in Portsmouth Harbor in 1987, in conjunction with testing blue mussels for contaminants. Sediments from several sites in Spruce Creek, and from the Piscataqua River near Spinney Creek had low levels of heavy metals (Table 6.5) (MEDEP 1991). Concentrations in sediments from the south side of Seavey Island, adjacent to Berth 4 of the Portsmouth Naval Shipyard, were also low in heavy metal concentrations. Sediment samples from the north side of Jamaica Island had moderate levels of mercury and zinc, and chromium exceeded NJ ECRA values. Pepperrell Cove showed higher concentrations of heavy metals than most other sites, including moderate levels of chromium, mercury and lead.

Evidence indicates that heavy metal concentrations in the Piscataqua River sediments have increased over the past decade. Samples taken from different locations in the same general area, e.g. around Badger's Island, may yield different results. This may be due to location with respect to the contaminant source, but is probably also due in part to transport and settlement patterns.

Potential metal contamination in the lower Estuary includes transport from the upper Estuary and direct contamination from municipal and industrial discharges, as well as the Portsmouth Naval Shipyard from activities prior to 1976 when its industrial waste outfalls were terminated. A list of permitted industrial discharges and their locations is given in Table 6.7. The locations of those on the lower Piscataqua River are shown in Figure 6.1. Industrial discharge permits are issued by the EPA and include standard conditions that may require monitoring flow, total suspended solids, pH and temperature. Additional requirements may include monitoring for heavy metals, toxic organics, and oil and grease. Copper and iron may be monitored as indicators of all heavy metals. Oil and grease limits are typically set to a daily maximum of 20 mg/l and to a monthly average of 15 mg/l. Sanitary waste may be monitored for biological oxygen demand (B.O.D.), dissolved oxygen, ammonia and nitrogen, total and fecal coliform bacteria, and residual chlorine or iron (if treated with ferrous sulphate). A list of municipal wastewater treatment plants discharging to the Great Bay Estuary and its tributaries is given in Table 6.1. Elevated levels of contaminants could be attributed to industrial discharges (Table 6.7), municipal wastewater discharges, or surface runoff from other sources.

Other sites of possible contamination affecting the Piscataqua River are discussed below. The levels of contaminants in soils, marine sediments, and surface and/or ground waters at these and other sites are considerably higher than background levels detected throughout the Estuary. Migration of contaminants within the Estuary needs to be addressed (see Chapter 10).

1.) The Kittery Wastewater Treatment Plant (WTP) has an outfall in the Piscataqua River just upriver from Seavey Island. Effluent is not tested for heavy metals but sludge is. A review of heavy metals test results for sludge over the past

Table 6.7. List of permitted discharges to the Great Bay Estuary and its tidal tributaries not including wastewater treatment facilities (Table 6.1). (Source EPA-NPDES files)

Name	Waterway	Discharge	Permit Conditions for Contaminants
Portsmouth Naval Shipyard Seavey Island	Piscataqua River	Storm-water runoff; non-contact cooling water; oil spill containment area runoff	Oil/grease limits Permit pending
Bow Street Associates Limited Partnership	Piscataqua River	Floor sump	Oil/grease limits
National Gypsum Co.	Piscataqua River	Storm-water runoff	Permit pending
Northeast Petroleum Terminal	Piscataqua River	Oil terminal waste	Permit pending
PSNH - Schiller Station	Piscataqua River	Non-contact cooling water; boiler, heat and yard drains; drains and overflows; wastewater treatment plant effluent	Oil/grease limits
C.H. Sprague & Son Co.	Piscataqua River	Oil terminal waste	——
Mobile Oil terminal	Piscataqua River	Not specified	Oil/grease limits
Simplex Wire & Cable Co.	Piscataqua River	Storm-water runoff; non-contact cooling water	Standard
Great Bay Fish Co.	Piscataqua River	Storm-water runoff; non-contact cooling water; seafood processing wastewater	Oil/grease limits; B.O.D.
Defense Fuel (New England Tank Industries)	Piscataqua River	Oil terminal waste; lagoon outlet discharge	Oil/grease limits
C.H. Sprague - Newington	Piscataqua River at Pickering Brook	Storm-water runoff	Oil/grease limits
PSNH - Newington Station	Piscataqua River	Storm-water and floor drains; non-contact cooling water	Monitor Fe, Cu, Pb; oil/grease limits; Fe, Cl for sanitary waste
Clarostat Manufacturing Co. Dover, NH; electroplating facility	Cocheco River (tidal)	Non-contact cooling water; hot water, copper, silver, soap and acid rinses	Monitor Cu, Pb, Ni, Ag, Zn; total toxic organics, cyanide
Davidson Rubber Co. Dover, NH	Knox Marsh Brook to Bellamy River	Storm-water runoff; non-contact cooling water	Oil/grease limits
Heidelberg-Harris (Harris Graphics) Dover, NH	Cocheco River	Non-contact cooling water	Standard
Tillotson Rubber Co. Rochester, NH	Tributary to Cocheco River	Non-contact cooling water	Pending
Spaulding Fibre Co. N. Rochester, NH	Salmon Falls River	Non-contact cooling water; boiler blowout	Standard
Kane-Gonic Brick Corp. Gonic, NH	Cocheco River	Storm-water runoff; process wastewater	Oil/grease limits, aluminum
Essex International Corp. Newmarket, NH	Lamprey River	Non-contact cooling water	Standard

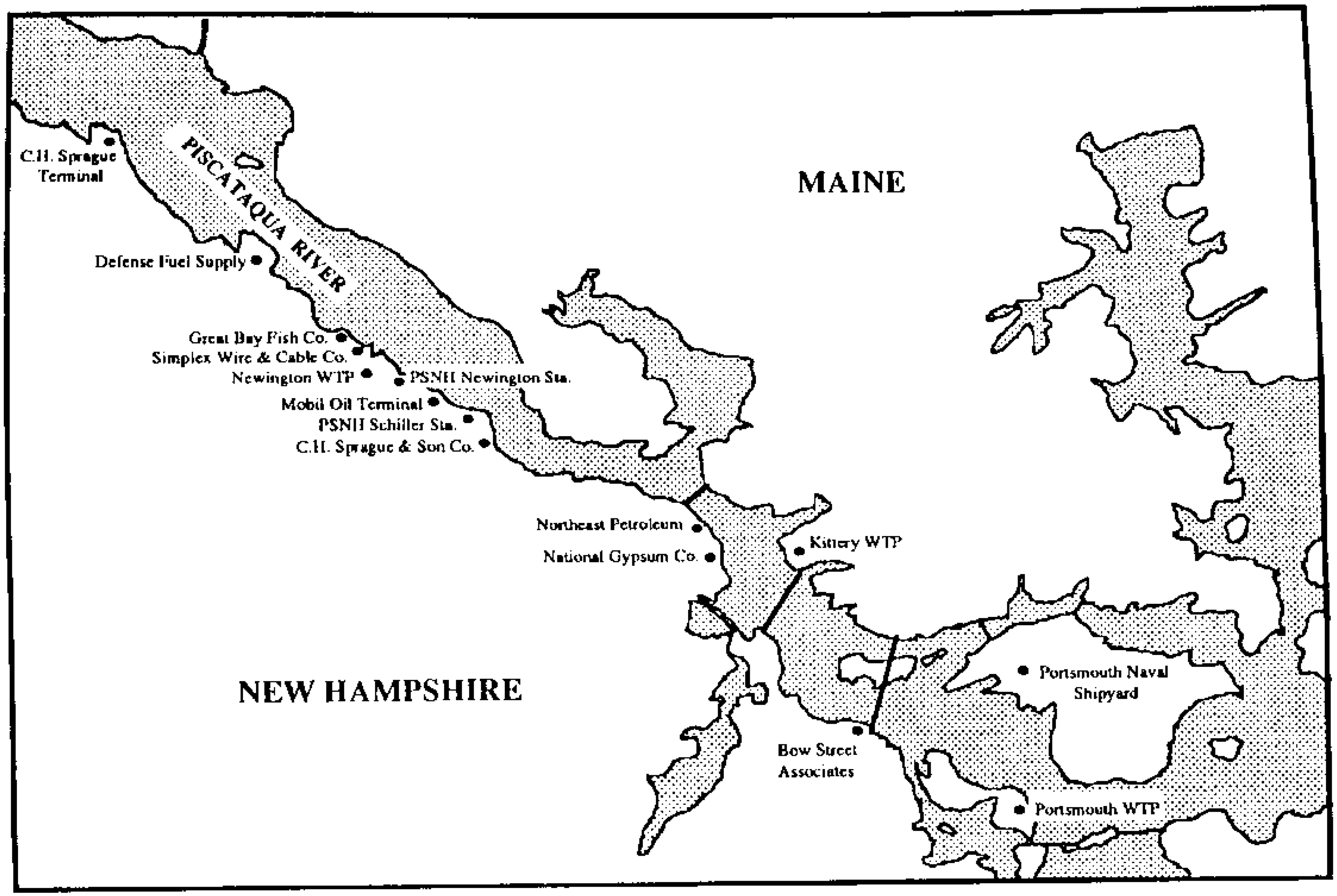


Fig. 6.1. Permitted discharges to the lower Piscataqua River and Portsmouth Harbor, compiled from EPA NPDES permit files for New Hampshire.

two years indicated consistently high levels of copper and zinc, and moderate levels of cadmium, nickel and lead (Kittery Sewer Department 1990, unpublished lab results). The sludge is applied to land areas as fertilizer, and so does not affect the Estuary directly. A potential source of these heavy metals is pretreated waste from the Portsmouth Naval Shipyard (PNS) that is discharged to the Kittery WTP. Sewer effluent from PNS accounts for over 40% of Kittery WTP volume. However, a review of monthly test results from PNS demonstrate that they are not routinely discharging heavy metals at levels above the intended treatment specifications. On a few occasions, levels of aluminum, copper, nickel, and zinc were discharged slightly above their specification limits but should not account for the high levels of heavy metal in the Kittery WTP sludge.

2.) Another source of pollutants to the Kittery WTP and the Piscataqua River is from the Watts FluidAir RCRA Corrective Action Permit site in Kittery. Watts FluidAir was an industrial manufacturing plant which operated from 1970 to 1991 conducting painting, degreasing, chromating and other industrial operations that produced contaminated wastes. Waste waters were discharged through several outfalls directly into wetlands and an unnamed stream on the site which discharges into the north branch of Wilson Creek, which in turn flows into Spruce Creek. In 1983, it was determined that untreated process water was being discharged directly from the plant outfalls, and a waste water treatment system was installed. The system was ineffective and as of 1987, waste water was trucked to the Kittery WTP for treatment.

In 1988, site investigations were conducted to determine contamination levels in soils, ground water and surface water. Elevated levels of volatile organics and heavy metals were detected in wetland soils adjacent to two of the outfalls, and elevated levels of volatile and semi-volatile organic compounds were detected in soils and ground water beneath the plant extending in a plume across the property (C-E Environmental 1990). An additional contaminated groundwater plume was detected with a source at the leach field. A list of contaminants detected in sediments, ground water and surface water at the site is given in Table 6.8. Levels of contaminants from the site closure plan can be seen in Table 6.5 (C-E Environmental 1990). Groundwater investigations determined that ground water on the site discharges to surface waters to the southwest, or toward Wilson Creek. Therefore, contamination in ground water and wetlands on the site provides a possible source of contamination to Wilson Creek and Spruce Creek. Sampling was conducted in Wilson Creek and Spruce Creek as part of the Watts FluidAir investigations, and indicated that no contaminants were detectable at harmful levels below the tidal limit. Although harmful levels were not detected, it is impossible to determine whether or not background levels of contaminants may have increased in Wilson Creek or Spruce Creek due to migration from the Watts FluidAir site. Continued migration of the ground water plume or surface drainage transport of contaminants does pose a potential threat to the tidal areas.

The remediation plan for the site includes pumping contaminated ground water and discharging it to the Kittery WTP for treatment, removing contaminated stream and wetland soils for hazardous waste disposal, and restoring the stream and wetland areas. This work is currently scheduled for 1992. If contaminants are completely removed and

Table 6.8. Contaminants detected at elevated levels in soils, ground water and surface water at the Watts FluidAir site, Kittery, Maine. NF denotes not found. (From C-E Environmental 1990).

Matrix	Volatile Organic Compounds	Semi - Volatile Organics	Heavy Metals
Sediment	Vinyl Chloride 1,1-, 1,2-Dichloroethane MEK (2-Butanone) 1,1,1-Trichloroethane Carbon Tetrachloride Trichloroethene Tetrachlorethene 4-Methyl-2-Pentanone Total Xylenes 1,1,2-Trichloroethene Toluene Acetone 2-Hexanone	Acenaphthene, Fluorene, Anthracene, Chrysene Phenanthrene Fluoranthene, Pyrene Benzo (a) Anthracene Dibenzofuran Dibenzo a anthracene Benzo (b) Fluoranthene Indeno (1,2,3-cd) pyrene Benzo (g,h,i) perylene Bis (2-ethylhexyl) phthalate	Cr Cu Pb Ni Zn
Ground Water	1,1,1 Trichloroethane Trichloroethene MEK (2-Butanone) 1,1-, 1,2-Dichloroethene 1,1-, 1,2-Dichloroethane 1,1,2 Trichloroethane Toluene Tetrachloroethene	Two found but not listed.	Cr Cu Pb Ni Zn
Surface Water	MEK (2-Butanone)	NF	Cr Cu Pb Zn

adequate erosion control and runoff collection procedures are used during restoration, there should be no further risk to the Estuary from the site.

3.) Additional potential contamination to the Estuary includes surface drainage from contaminated sites at Pease Air Force Base, now designated Pease International Tradeport, which was declared an EPA Superfund site in February, 1990. The former base occupied a large area in Newington and Portsmouth, bordering on Great Bay with surface drainage to the Piscataqua River, from the 1950s to 1991. As of 1991, the base was closed, and current base activity is limited to Air National Guard use plus new development. A variety of activities at the Air Force Base produced hazardous materials, many of which were disposed of by burning, dumping or burial in tanks in landfills on the base. A records search conducted by CH2M Hill (1984) identified 16 sites on the base with a history of hazardous materials dumping or spills

(Figure 6.2). A summary of the activity at each site is given in Table 6.9. All sites are within close proximity to Great Bay or the Piscataqua River by surface drainage, and within close proximity to domestic wells on the base. Site investigations between 1987 and 1990 indicated that various sites had elevated levels of hazardous contaminants in soils, ground water and surface water. Heavy metals, pesticides, and volatile organics were found at concentrations above federal action levels, state standards, and base-wide background levels (Roy F. Weston 1990). The contaminants with elevated concentrations in either soils, ground water or surface water at each site are listed in Table 6.9.

The industrial shop/parking apron at Pease (Site 15, Figure 6.2) has a history of discharges and spills; this includes industrial waste effluents discharged directly to Great Bay and drainages to the Piscataqua River in storm drains from the late 1950's to 1974, when oil/water separators were installed (CH2M Hill 1984). Waste oils and fuels, solvents, including trichloroethene (TCE), and other materials were also discharged to the storm drain or dumped directly onto the ground or in nearby drainages. Underground waste TCE tanks were used from 1955 to 1965, and leaks contaminated water in a nearby well (detected in 1977). Numerous fuel spills have also occurred, resulting in fuel-saturated soils around the site.

Surface waters receiving drainage from contaminated sites on Pease were tested for sediment and water contamination (Table 6.10). Sediments from several of the surface waters on the base showed elevated levels of oil and grease and heavy metals (cadmium and lead). Water samples from three creeks and Peverly Pond showed elevated levels of contaminants, including copper, iron, volatile organics, and oil and grease. Flagstone Brook had elevated levels of iron, arsenic and lead, volatile organics, DDT, phenol and cyanide. In addition, marine organisms from the mouth of McIntyre Brook, including oysters, ribbed mussels and soft-shelled clams, have been collected for contaminant analyses. These samples and detailed soil, ground water and surface water studies currently being conducted should help define real and potential risks to the Estuary from the base (Roy F. Weston 1990 and unpublished). Under the EPA Superfund designation, investigation and clean-up of contaminated sites at Pease are now under way.

4.) Activities at the Portsmouth Naval Shipyard on Seavey Island have provided several sources for marine contamination (Roy F. Weston 1983). Sediment samples taken at berth sites at the shipyard in 1978 showed high levels of a variety of contaminants resulting from the discharge of industrial wastes at the sites (Table 6.5) (Parsons and NAI 1978) . Over 82,571 m^3 of marine sediments were dredged in 1978 to deepen these berth areas and deposited at the southeast end of Seavey Island. The material was deposited on an existing landfill that covered a former intertidal area between the two islands. The landfill had been used from 1945 to 1978 as a dumpsite for hazardous and non-hazardous wastes (Table 6.11). Dredge spoils from the berth sites were contained by a clay barrier and a clay cap (Parsons and NAI 1978). The status of the undredged material at the berth locations is unknown.

More recent investigations determined that marine sediments on the face of the landfill and in the Clark Island embayment had elevated levels of chromium (Table 6.5) (Loureiro Engineering Associates, Inc. and YWC, Inc. 1986). In addition, lead concentrations were elevated along the face of the landfill and in the area.

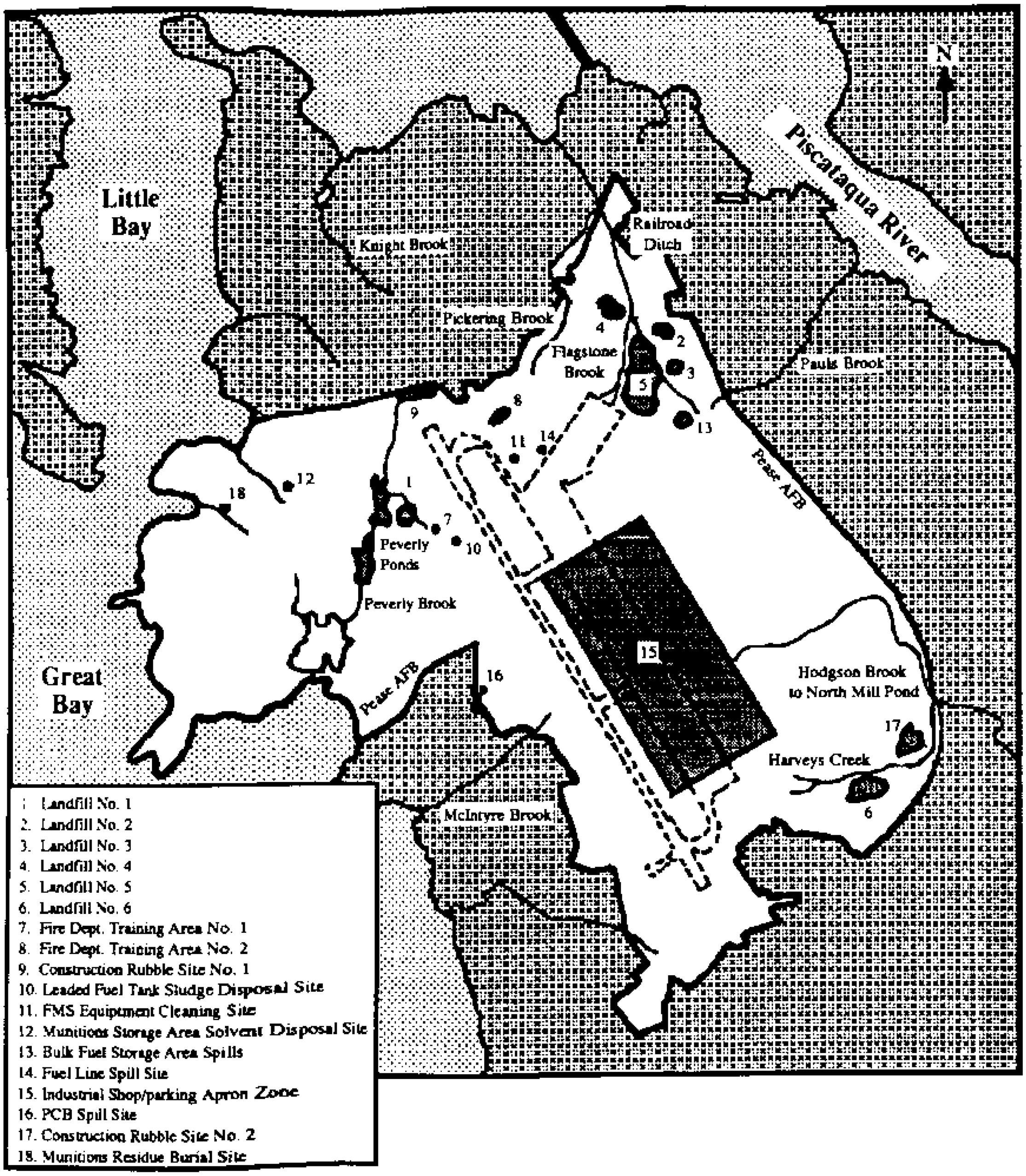


Fig. 6.2. Hazardous material discharge and spill sites at Pease Air Force Base, New Hampshire. (Modified from CH2M Hill 1984 and Roy F. Weston 1990).

Table 6.9. List of hazardous materials sites at Pease Air Force Base, Portsmouth, NH, and contaminants found to be above background levels (and/or above Federal Action Levels or state standards) in soils, ground water, and surface water. NF denotes not found. (From Roy F. Weston 1990).

Site Number	Activity	Dates	Waterway	Hazardous Materials	Contaminants
1	Landfill	1953-1961	<100' to Peverly Pond to Great Bay	Waste oils, paints, solvents, thinners, strippers, pesticide containers, Cd-plating waste solutions in drums, TCE	Fe, Mn, As, 4-Methylphenol
2-5	Landfills	1960-1972 1974-1975	Railway ditch to Pauls Brook; Flagstone Brook to Piscataqua River	Waste oils, paints, solvents, thinners, strippers, pesticide containers, industrial waste sludge, TCE	Cd, Cu, Hg, Pb, Fe Toluene, tetrachloroethene
6	Landfill	1972-1974	Harveys Creek to Hodgson Brook to North Mill Pond	Waste oils, paints, solvents, thinners, strippers, pesticide containers	Fe, As, Benzene, toluene, ethylbenzene, xylenes, vinyl chloride, phenol, methyl phenols,
7,8	Fire Dept. Training Areas	1955-1984	Peverly Ponds to Great Bay; 750' to Pickering Brook to Flagstone Brook to Pisc. R.	Percolation of waste oils, solvents and fuel discharged directly at sites up to one week prior to burns	Toluene, ethylbenzene, xylenes, chlorobenzene, naphthalene, isophorone, phenanthrene
9	Construction Rubble Disposal	late 1950's to 1984	400' to Peverly Brook to Great Bay	Waste solvents, TCE	Trichloroethene

Table 6.9 (continued)

10	Leaded Fuel Tank Disposal	late 1950's to mid 1970's	Peverly Ponds to Great Bay	Residual fuel and fuel sludge, rust and sandblasting material	Fe, Mn, Pb, xylenes, Benzenes, phenols, chloroethenes, toluene
11, 12	Cleaning, Storage Area	intermittent use, 1950's to 1980	Storm drains and surface runoff to Flagstone Brook to Piscataqua River; unnamed stream to Great Bay	Waste solvents, thinners, TCE	Toluene
13, 14	Fuel Storage and Fuel Line	1950's to 1984	Storm drains to Pauls Brook and surface runoff to Piscataqua	Fuel oil spills and leaks	NF
15	Industrial Shop, Aircraft Parking and Refueling	1950's to 1984	Storm drains and surface runoff to Great Bay; Newfields Ditch and Harveys Creek to Hodgson Brook; McIntyre Bk.	Hydraulic fluid, diesel and JP-4 fuel spills, solvents and waste oil spills, TCE	Fe, Mn, As, xylene, benzenes, toluene, tri-, tetra-, and dichloroethene, vinyl chloride, chloroform, phenol, methyl phenols, trichlorophenol, methyl flouromethane
16	PCB Spill Site	1983	Surface runoff to Great Bay	35 Gal of transformer oil with 500,000 ppb PCB, most contained	Spilled oil and contaminated soils stored in drums
17, 18	Construction Rubble Disposal and Munitions Residue Burial	not listed	Harveys Creek to Hodgson Brook to North Mill Pond; surface drainage to Great Bay	no record of hazardous materials	Xylenes

Table 6.10. Contaminants above background levels (and/or above Federal Action Levels and state standards) in sediment and water samples from surface water bodies on Pease Air Force Base. NF denotes not found. (From Roy F. Weston 1990).

Surface Water	Volatile Organics	Semi-Volatile Organics	Pesticides	Metals	Cyanide
Newfields Ditch	Benzenes, toluene, xylenes	Methyl phenols, nitrophenol	DDD, DDT	As, Be, Cd, Cu, Fe, Mn, Ni, Th, V, Zn	Present
Harveys Creek	NF	Pyrene	DDD, DDT, DDE, Lindane	As, Cd, Fe, Pb, Mn, Ni, Zn	Present
McIntyre Brook	Trichloroethene	Phenanthrene, anthracene, chrysene, benzo (k) fluoranthene, bis (2-ethylhexyl) phthalate	NF	As, Ba, Be, Co, Fe, Hg, Mo, Ni, Tl, V, Zn	NF
Pauls Brook	NF	NF	Chlordane	Mn, V, Zn	NF
Peverly Brook	NF	Di-n-butyl phthalate Phenanthrene, acenaphthene, fluorene	DDD, DDE, DDT		NF
Flagstone Brook	1, 2-Dichloroethene	Chrysene	DDD, DDE, DDT	Sb, As, Co, Fe, Pb, Mn, Ni, Tl, V, Zn	NF

between the landfill and the pier in the cove, and nickel concentrations were high in marine sediments along the edge of the landfill. Concentrations of heavy metals were all low at control stations in the vicinity of Seavey Island (Pepperrell Cove, west side of Badgers Island, Four Tree Island, and Salamander Point).

Algae samples (*Fucus vesiculosus*) collected from the embayment had elevated levels of chromium, cadmium, lead, and nickel, and mussels showed elevated levels of nickel and PCBs (Table 6.5) (Loureiro Engineering Associates, Inc. and YWC, Inc. 1986). Lead concentrations were elevated in all mussel samples collected, but the maximum concentrations occurred at the control stations at Pepperrell Cove and Four Tree Island.

The high concentrations of heavy metals in marine sediments and organisms along the face of the Jamaica Island landfill indicate that they may be associated with contaminants at the landfill site. Additional assessments are currently underway to determine if the landfill is now contributing contaminants to the embayment (Munns et al. 1992). Possibly, the contaminants in the cove are from industrial discharges to the waterway either currently or in the past (e.g. industrial discharges from the Shipyard up to 1975), or they are associated with dredging and disposal activities conducted at the berth areas and landfill site in 1978 (Loureiro Engineering Associates, Inc. and YWC, Inc. 1986). A detailed investigation of contaminants in soils and ground water at the landfill is

Table 6.11. Hazardous Materials Reportedly Disposed of at Jamaica Island Landfill, Portsmouth Naval Shipyard. (Adapted from Roy F. Weston 1983).

Substance	Estimated Quantity	Time Period	Comments
Plating Sludges			
Chrome	5,000-10,000 pounds	1945-1972	Sludges were mixed in with normal refuse and were disposed of directly into the landfill. Exact location unknown
Lead	5,000-10,000 pounds	1945-1972	
Cadmium	5,000-10,000 pounds	1945-1972	
Asbestos insulation	Several thousand pounds	1945-1960	Exact location unknown
Volatile organics TCE, methylene chloride, toluene, MEK	20,000 gallons	1955-1975	Drums were taken to the landfill where wastes were drained out directly onto the ground.
Acetylene and chlorine gas cylinders	100-200 cylinders	1955	Unconfirmed
Contaminated dredge spoils containing:		1978	Total spoils deposited was 82,571 m^3 cubic yards. Small amounts of PCB's and mercury were also found in dredge spoils. Dredge material came from sediments at Berths 6, 11, and 13.
Chromium	5,000 pounds		
Lead	20,000 pounds		
Waste paints and solvents	500,000 gallons	1945-1965	Probably disposed of in whole 55 gallon drums.
Spent sandblasting grit	5,000 tons/year	1945-1975	Disposed throughout the site.
Mercury-contaminated wastes in concrete vaults	6 4-ft diameter vaults at each of 2 sites	1973-1975	No record of release

currently being conducted (McLaren/Hart 1991b).

Additional potential marine contamination at the Portsmouth Naval Shipyard exists at a 2-acre storage yard along the southeast corner of Seavey Island, Defense Reutilization and Marketing Office (DRMO). An assessment of soil, surface water and marine organism contamination was conducted in 1986 (Loureiro Engineering Associates, Inc. and YWC, Inc. 1986). Scrap metal, motors, paper wastes, and lead and nickel-cadmium batteries were stored in this area and have resulted in high levels of some contaminants in the soil. Battery cells were seen littered along the embankment and in the river. Soil profiles suggested that contamination was greatest in the upper few feet of soil in the storage yard, but had infiltrated deeper into the saturated zone. Potential contamination to the river was identified as wind transport of soil, as runoff, and as ground water/tidal exchange. Chromium levels were moderate in some soil samples directly at the storage yard. Nickel occurred at moderate to high levels in most samples and cadmium and lead concentrations were high according to Maine Classification for Dredged Materials.

No marine sediments were tested along the edge of the storage yard, but seawater, surface water runoff, and marine organisms were tested (Table 6.5) (Loureiro Engineering Associates, Inc. and YWC, Inc. 1986). Seawater tested along the embayment was low in concentrations of all metals tested with the exception of lead in one sample. Seawater samples at the DRMO were high with respect to state health standards for lead concentrations and nickel concentrations. Organisms tested included mussels, which showed elevated levels of lead at three stations and nickel at one station. These values are much higher than samples from other sites in the harbor. Algae samples (*Fucus vesiculosus*) collected adjacent to the storage yard had elevated levels of lead at one station.

The cadmium, chromium, and lead concentrations in algae samples from the Clark Island embayment and adjacent to the storage yard (Loureiro Engineering Associates, Inc. and YWC, Inc. 1986) were higher than levels detected in two relatively clean estuaries in Massachusetts, the Ipswich River and Essex River estuaries (Beskenis and Duerring 1991). The concentrations were also greater than those in algae samples from Buzzards Bay, which were detected at maximum concentrations of 2.4 ppm for cadmium, 8.7 ppm for chromium, and 25.1 ppm for lead (nickel was not analyzed for Buzzards Bay algae samples) (Beskenis and Duerring 1991). Results of the 1986 survey indicated that contaminants at the storage yard were continuing to migrate to the marine environment adjacent to the storage yard by wind transport, surface runoff, and potentially through ground water/tidal exchange at depth in the soil (Loureiro Engineering Associates, Inc. and YWC, Inc. 1986). Interim remedial measures have been taken to control runoff from a number of Solid Waste Management Units (Table 6.12 and Fig. 6.3) prior to formulating a permanent remediation plan. Final corrective measures are being determined under a RCRA Corrective Action Permit.

A research and monitoring project is being sponsored by the Navy to provide a framework for assessing the ecological risk of PNS operations to the Estuary. The ecological risk assessment framework consists of quantitatively estimating the likelihood of adverse ecological effects resulting from exposure to hazardous waste releases at the shipyard. The project, initiated in August 1991, involves a detailed assessment of the existing environmental quality in the lower Great Bay Estuary to determine if contamination from the shipyard can be linked to measurable environmental impacts. The effect of shipyard contaminants on the

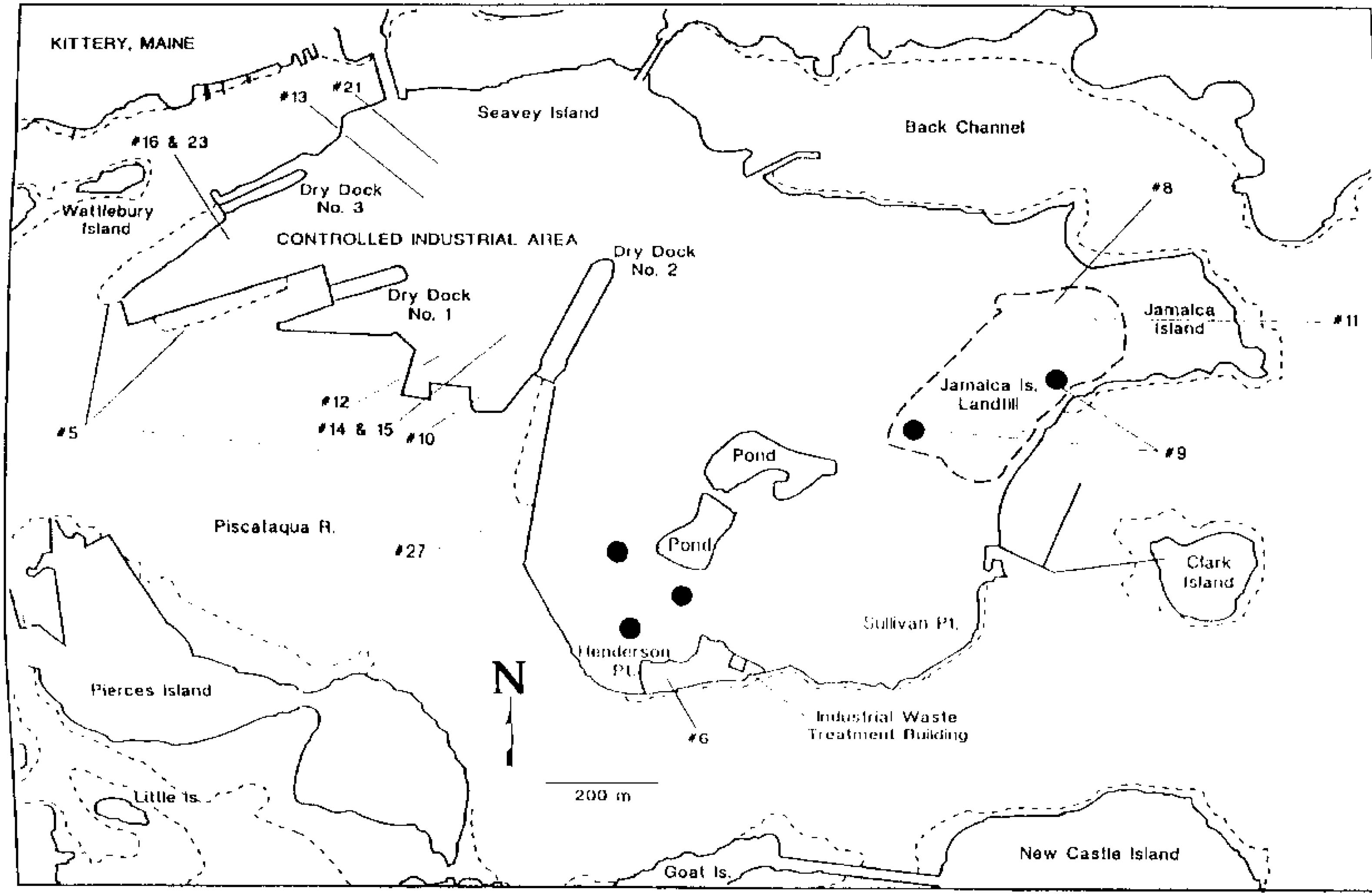


Fig. 6.3. Portsmouth Naval Shipyard Solid Waste Management Units (SWMUs) located on Seavey Island in the Piscataqua River (see Table 6.12).

Table 6.12. Solid Waste Management Units on the Portsmouth Naval Shipyard (see Fig. 6.3) that are currently being investigated and corrected, as needed, under the EPA RCRA Investigation (Fred C. Hart Associates, Inc. 1989, McLaren/Hart 1991b, and J. Tayon PNS per. com).

Units	Description	Status	**Hazardous Materials**
Industrial Waste Outfall (SWMU #5)	Liquid discharge (3 sites)	1945-75 Ceased	Heavy metals, PCBs, cyanide, phenol, oils and grease
DRMO Storage Yard (SWMU #6)	Refuse storage with runoff to river (2 acres)	~1959 to present	Lead, chromium, nickle-cadmium, oil and grease
Jamaica Island Landfill (SWMU #8)	Fill over mudflat hazardous waste (25 acres)	1945-78	Heavy metals, PCBs, cynide, asbestos, oil, volatile organics, contaminated dredge spoil, etc.
Mercury Burial Sites (SWMU #9)	Concrete containers sealed and buried	1973-75 no record of release	Mercury
Battery Acid Underground Tank (SWMU #10)	Spent battery acid	1974-1984 Tank pulled after leak in 1984 9680 gal capacity	Lead, sulfuric acid
2 Waste Oil Tanks (SWMU #11)	Used lubricating oil degreasers in steel tank	7,500 gal capacity Pulled 6/89	PCBs, heavy metals, volatile organics
Boiler Blowdown Tank (SWMU #12)	Heated water	3,800 gal capacity 1974 to present	None
2 Rinse Water Tanks (SWMU #13 & 16)	Unspecified rinse water	695 and 750 gal capacities 1974 to 1991 (removed)	Heavy metals, cyanide
Acid/Alkaline Drain Tank (SWMU #21)	Spent cleaning solutions	695 gal capacity 1974 to 1991 (removed)	Heavy metals, cyanide, hydrocarbons
Chemical Cleaning Facility Tank (SWMU #23)	Spent cleaning solutions	2,270 gal capacity 1978 to 1991 (removed)	Heavy metals, cyanide
Aboveground Oil/Water Tanks (SWMU #26)	Waste oil	Dockside dumpsters at berths	Hydrocarbons
Fuel pipeline (SWMU #27)	Fuel oil	Ruptured 1978 pipeline and soil (removed)	Hydrocarbons, PAHs

Estuary is being determined by comparing measures of contamination and biological impact made at sites in the immediate vicinity of PNS with similar measures made at reference sites in the Estuary. The information developed from the study will provide a context for evaluating ecological risks from shipyard operations (USEPA-ERLN and MESO-NOSC 1991, Johnston and Nixon 1992, and Munns et al. 1992).

5.) The city of Portsmouth Wastewater Treatment Plant (PWTP) has been in operation since 1964 (all of the information following was obtained from PWTP Manager Dick McCann). The plant originally received waste from 14 pumping stations in Rye and Portsmouth with an average processing capacity of 1.5 million gal/day. In 1977, the wastewater volumes increased, so a temporary 2 million gal/day bypass was built pumping directly into the Piscataqua River. Construction on a PWTP upgrade was begun in January 1990 and by February 1992 a plant designed for advanced primary treatment of 4.8 million gal/day was completed. When necessary, the plant can process 7.5 million gal/day with 100% treatment and up to 22 million gal/day with partial treatment.

The advanced primary treatment process first sends waste though settling basins where solids are separated. The sludge is removed and dried somewhat so that it can be sent to Waste Management, Inc. in Rochester, NH. The liquid is sent through a filter to remove any remaining solids and chlorinated before being pumped out into the Piscataqua River. According to Dick McCann, after receiving advanced primary treatment the outflow could actually meet secondary treatment standards.

The input to the PWTP is mostly from household waste. Industrial input to the plant constitutes under 100,000 gallons of the 4 million gallons received daily. Four million gal/day is discharged into the Piscataqua River at a site 122 meters (400 feet) north of Pierce Island at a depth of 20 meters (65 feet). The liquid is discharged continuously into the river at a constant rate. Recent sampling of PWTP sludge, which is sent to Rochester for further treatment, found levels of pesticides, metals and other chemicals to be less than detection limits for most of the chemicals tested. The liquid discharged into the Piscataqua River is sampled every day for bacteria, coliforms, suspended solids and pH. Outflow is tested for metals one to four times a year or whenever new permits take effect; however, metals are usually not detected. Sampling of the outflow also reveals no biological oxygen demand or coliform bacteria.

Contamination of Biological Resources

Pollutants are a concern in estuarine systems primarily because of uptake by marine organisms and transfer through the food web. Pollutants may stress marine ecosystems, affecting individual organisms (metabolic and reproductive changes, mortality) and the species composition of communities (Parsons et al. 1984). Ecological risk assessments may be conducted if the potential for contamination exists at a site. An ecological risk assessment includes assessments of the contaminants present, their potential exposure to the environment and organisms, the toxicity associated with exposure, and adverse effects to individual organisms and the community (McLaren/Hart 1991b). The effect of pollutants on marine organisms is typically assessed with controlled experiments to evaluate chronic and acute lethal limits.

Mercury, lead, and chromium were measured in oysters, *Crassostrea virginica*, collected from Nannie Island in Great Bay, and the Oyster, Bellamy, and Piscataqua Rivers in the Great Bay Estuary (Table 6.5) (Nelson 1986). No mercury was detected, while chromium levels were significantly (statistical test $p < 0.05$) higher in oysters from the Piscataqua River than from the other sites. A comparison of metal concentrations in overlying waters to oysters indicated lead biomagnification on the order of 3 to 12 times at the different sites. Lyons et al. (1982) compared oyster tissue concentrations to levels of chromium in the freshwater portions of the rivers entering Great Bay Estuary and reported biomagnification of chromium to be 56 to 355 times. Lead and chromium concentrations from these studies indicate no toxicity hazard associated with consumption of Great Bay oysters. Oysters were also analyzed in Spinney Creek in 1977 (Table 6.5) (USEPA 1978) where elevated (above background) levels of cadmium, chromium, copper, lead and zinc were found.

In a recent study, clams (*Mya arenaria*), mussels (*Mytilus edulis*), and lobsters (*Homarus americanus*) from 17 locations in the Great Bay Estuary were analyzed for heavy metals (cadmium, chromium, copper, lead, mercury, nickel, and zinc), PCBs and PAHs (Isaza et al. 1989). Lead was found to exceed the National Shellfish Sanitation Program Alert level of 5.0 ppm in clams. Lobsters collected at Pierce Island displayed elevated levels of PCBs (Table 6.5) in their viscera. No consumption advisory was announced based on risk assessments and because levels of contaminants in the lobsters' musculature were low and very similar to most other Northeast coastal areas. Within Great Bay, levels of chromium in mussels collected from near the mouth of the Lamprey River were 6.5 times greater than average levels in other Great Bay mussels.

Mussels were also collected for analysis of heavy metals in Portsmouth Harbor in 1987 (Table 6.5) (ME DEP 1991) where average or below average concentrations were found when compared to other industrialized areas (Nelson 1986). Comparisons between the Portsmouth Harbor sites sampled by the Maine DEP indicated that Pepperrell Cove mussels had higher concentrations of lead and iron, and mussels north of Jamaica Island had higher concentrations of lead, iron and zinc than other sites in the harbor. Maximum mercury and copper concentrations in this study occurred in mussels near the Route I-95 bridge. Cadmium and chromium concentrations in mussels adjacent to the Portsmouth Naval Shipyard storage yard (Loureiro Engineering Associates, Inc. and YWC, Inc. 1986) were only slightly higher than the concentrations from other Portsmouth Harbor sites reported by the Maine DEP. However, nickel and lead concentrations adjacent to the storage (DRMO) yard (Loureiro Engineering Associates, Inc. and YWC, Inc. 1986) were much higher than concentrations for the rest of the harbor (ME DEP 1991).

An earlier study conducted by the FDA (FDA 1985) compared levels of heavy metals in molluscs at nine locations along the coast of Maine. *Mercenaria mercenaria* from Spinney Creek, and *Mya arenaria* from Spruce Creek showed average to below average levels of all metals except zinc when compared to the other Maine stations.

The Maine Department of Marine Resources conducted a study of lead in lobsters from ten locations in Maine in 1986 (Sherburne 1989). Lead in 5 out of 10 lobsters (claw muscle) from the Piscataqua River at Kittery was below the detection limit of 0.01 ppm, (Table 6.5). The mean lead concentration for Piscataqua River lobsters was the second highest for all ten locations in Maine, which ranged from <0.02 - 0.25 ppm. These results are not directly comparable to the Great Bay Estuary survey (Isaza et al. 1989), because the lead detection limits were different, based on different methods used. However, all the 1989 survey lead concentrations were below 0.5 ppm, including those in Portsmouth Harbor and the lower Piscataqua River, and two Piscataqua River samples from the 1986 Maine survey had concentrations above 0.5 ppm.

Contaminants from industrial and municipal discharges and spills throughout the entire watershed have the potential of reaching the Estuary and entering the food chain. Although overall contaminant levels for most sites in the Estuary were average or below average when compared to other industrialized areas, elevated levels of some contaminants in marine organisms indicate that inputs to the system may be too high. The presence of several highly contaminated sites directly on or near the Estuary (Pease Air Force Base, Portsmouth Naval Shipyard, Watts FluidAir site) show the lack of concern for environmental degradation in former years. However, all three sites are in the process of cleanup or planning for environmental restoration in the near future under USEPA guidelines. Similar sites may exist, undiscovered as yet, especially in association with small industries and businesses along the tributaries of the Estuary. Control over use, discharge and monitoring of hazardous materials and wastewater has begun but needs to be increased to ensure that harmful contaminants do not enter the Estuary (see Chapter 10).

Non-point source pollution can contribute to overall contaminant levels in the Estuary, and hence to increased concentrations in marine organisms. A study conducted by the New Hampshire Water Supply and Pollution Control Commission (NHWSPCC 1983) evaluated water quality effects in streams from storm-related runoff from rural and urban sites. The results indicated that rain events caused increased concentrations of the heavy metals iron, lead, nickel, zinc and copper. Concentrations approached and occasionally exceeded toxic limits for organisms in the receiving waters. Lead, nickel and zinc concentrations in runoff from paved areas were high, especially with longer durations of dry weather between storm events. The range of nickel concentrations exceeded EPA National Pollution Discharge Elimination System limits, and the range of lead concentrations approached, but did not exceed, these limits. With the conversion to unleaded gasoline, lead contributions from paved areas and roads is probably less than it was in former years. Because of the increased concentrations due to runoff found in this study, cumulative impacts of pollution from several non-point sources may be important in causing contamination in the Great Bay Estuary and need further assessment.

Oil

Oil has had a major effect on the Great Bay Estuary for decades. There are over 3 million barrels' worth of bulk oil and fuel storage in Newington alone, representing a major volume of stored petroleum products. These facilities are continually refilled by tanker delivery through Portsmouth Harbor and the Piscataqua (Tom Morgan, Newington Town Planner). A review of oil spills and impacts was compiled in the mid-1970s to assess the potential impact of locating an oil refinery on Great Bay (UNH 1974). The effects of oil spills on marine organisms has also been evaluated

(Reynolds 1971, Isaza et al. 1989), and additional work has been done on oil related compounds (see below). Hydrocarbons, compounds containing only carbon and hydrogen, are the primary constituents of oil, usually exceeding 75%. Other constituents of oil consist of organic compounds containing sulfur, oxygen, nitrogen or trace metals.

Hydrocarbons occur in various structural forms including branched and straight chained alkanes, aromatics and polycyclic aromatics (Blumer 1969). Alkanes are the lightest fraction of oil and are common ingredients in gasoline. Aromatics are, as their name implies, odor-producing and include such compounds as benzene and toluene. Polycyclic aromatic hydrocarbons (PAHs) are fused aromatic ring compounds such as naphthalene, a compound with the characteristic odor of moth balls. PAHs are characterized by high boiling points and slow decay rates (Blumer 1969).

The characteristics of spilled oil are altered by evaporation, dissolution, and microbial and chemical oxidation. Since the varying constituents of oil are affected at different rates by these weathering forces, the relative composition and therefore biological effects of the spilled oil also varies.

Oil can enter sediments by several means. One is by floating ashore and penetrating intertidal sediments; this contamination can gradually move into subtidal sediments. Oil can also enter subtidal sediments directly by sinking and penetrating underlying sediments. Once within sediments oil degrades slowly and may be present for many years.

Oil contamination within the Great Bay Estuary was evident at all 24 locations sampled by Nelson in 1982. Highest levels were evident in areas with sand/silt sediment composition, while lesser quantities and types of compounds were observed in more porous sandy sediments. Increased oil content and types were more evident within subtidal sediment samples than within intertidal samples. Oil content appeared highest at locations near industrial terminals and at sites of previous known oil spills.

PAH bioaccumulation within aquatic vertebrates does not appear to be a common process (except on a short term basis) since PAHs are absorbed and eliminated rapidly by most vertebrates (Callahan et al. 1979). However, some invertebrates, particularly bivalve molluscs, have difficulties eliminating PAHs. Bjørseth (1978) and Lee et al. (1972) observed extensive bioaccumulation of PAHs by mussels. Biotransformation by benthic organisms and biodegradation are slow in aquatic systems, even though the latter is an important process in chronically affected systems (Callahan et al. 1979).

Total PAH in clams and mussels within the Great Bay Estuary range from below the detection limit to levels higher than those reported for other New England locations (Isaza et al. 1989). Mussels from Fox Point have PAH levels 7.5 times (4.0 standard deviations) greater than the average values for Great Bay Estuary. The 11.0 ppm PAH level at Fox Point may be indicative of a significant source of PAHs at that location. The mean PAH levels of 1.45 ppm in mussels and 2.82 ppm in clams are higher than respective levels from other locations in the United States (Isaza et al. 1989). Similarly, PAH levels in clams from 4 of 7 sampling locations greatly exceeded the mean value for the three other Great Bay Estuary locations (Isaza et al. 1989). Sediment concentrations are similar to those found in other New England locations, except for the heavily polluted

Charles River in Massachusetts. The levels of PAH in the hepatopancreas of lobsters from Great Bay Estuary were higher than those reported in other New England locations, though the lobster musculature was not higher.

PAH levels were substantially higher in clams collected from sites surrounding Pease Air Force Base (3.3-5.7 ppm, Nannie Island, Fox Point, and Hilton State Park) and in mussels at Fox Point (11.00 ppm) than at other collection sites further from the Base where clams ranged from 0.10 (the biodetection limit or BDL) to 0.51 and mussels ranged from 0.10 (BDL) to 2.30 (Isaza et al. 1989). Lobsters from Pierce Island also had elevated levels of PAHs in their viscera (4.60-19.00 ppm). Guerin and Jones (1988a, 1988b) found bacteria in sediments from Great Bay Estuary to be capable of degrading phenanthrene, one of the PAHs found in shellfish in the Estuary. A 1985 study by the New Hampshire Division of Public Health Services reported no detectable levels of PCBs, PAHs, or pesticides of Great Bay oysters (see Isaza et al. 1989).

Tin and Organotin Compounds

Inorganic tin, which is not very toxic, is naturally present in the Great Bay Estuary. However, methyltin and butyltin compounds are of environmental concern because they are more toxic, more mobile, and more easily bioaccumulated than inorganic tin. Butyltin and methyltin compounds occur in sediments, plants, and water of the Great Bay Estuary (Weber et al. 1988, Grovhoug et al. 1987). Methyltin compounds, including mono-, di- and trimethyltin (MeSn), are probably the result of methylation of inorganic tin by estuarine plants and microorganisms including the seaweed *Enteromorpha* spp. (Donard et al. 1987) and bacterium *Pseudomonas fluorescens* (Jones et al. 1989). Butyltin compounds originate from marine anti-fouling paints applied to ship hulls, but their general use has been discontinued.

Concentrations of MeSn in the water and biota of the Great Bay Estuary vary considerably with the sample site and type. Butyltin compounds and MeSn were measured in oysters (Han and Weber 1988), seaweed (Donard et al. 1987), and eelgrass (Francois and Weber 1988, Francois et al. 1989). In almost all samples, oysters, eelgrass, and seaweeds bioconcentrated organotin compounds from surrounding water. Typical organotin concentrations were 0.01 to 0.2 ng/g in water and 1 to 50 ng/g dry wt in various biota (Weber et al. 1988). By contrast, concentrations of MeSn in leaves of *Spartina alterniflora* range from 470 ng/g (spring) to 4 ng/g (autumn) (Weber, Billings, and Falke, unpublished results). Observations that MeSn is a high fraction of total tin in water (up to 80%) and in biota (often greater than 90%) are an important clue to the mode of formation and fate of MeSn in all compartments of the Great Bay ecosystem and indicate their importance in the estuarine biogeochemical tin cycle. High MeSn concentrations in *S. alterniflora* and sediment/pore water indicate potential sites for methylation and demethylation reactions.

Chapter 7: Estuarine Primary Producers
by F.T. Short and A.C. Mathieson

The major contributors to estuarine primary production are the hundreds of plant species that grow in and around the Great Bay Estuary. All of these primary producers use sunlight to produce oxygen and organic matter through the process of photosynthesis. The rate of primary production for each plant species is determined by the characteristics of that species, local environmental conditions and the amount of available light reaching the plant. Primary production is the major source of organic matter to the estuary. Produced material accumulates as living biomass and upon death enters the detrital cycle within the system or is devoured directly by numerous species of estuarine consumers (see Chapter 8).

Phytoplankton

Phytoplankton are a major component of primary production within estuaries. Little data is available concerning phytoplankton species composition, abundances, or production within the Great Bay Estuary. The best data available for the Estuary was collected during 1970 to 1978 as part of a baseline study for the Newington Electric Power Generating Station; measurements of phytoplankton populations (Table 7.1) were made in Great Bay and on the Piscataqua River (NAI 1971-1980). The phytoplankton community was dominated by diatoms, primarily *Chaetoceros* spp. and *Skeletonema costatum*, with seasonal occurrence of *Rhizosolenia* spp. and *Asterionella glacialis*, and the dinoflagellates *Ceratium longipes*, *C. tripos* and *Peridinium depressum* (NAI 1979a). Phytoplankton cell densities generally ranged from 20 to 5000 cells per liter.

Some of the phytoplankton in Great Bay are pennate diatoms (e.g. *Navicula* spp. and *Fragilaria* spp.) that have been suspended in the water column by the currents that also resuspend benthic sediments (Donovan 1974). *Denotula confervacea* was a major component of the winter-spring Bay phytoplankton and dominated over *Thalassiosira* spp. in areas of lower salinity (Donovan 1974). *D. confervacea* was infrequent at the coastal stations in the Estuary (Donovan 1974).

Phytoplankton primary production in the Estuary is generally greatest during April to July, declining through August and September with a slight increase in October (NAI 1978a, b). The average annual phytoplankton production for the Estuary during 1977-78 was greater in Great Bay (14 mg $C/m^3/h$ on ebb tide) than at more coastal stations. Chlorophyll *a* values were similarly distributed, with 6 mg/m^3 occurring in the surface ebb tide sample for Great Bay (NAI 1978a, b). Within the middle and upper estuary during 1973-1981, chlorophyll *a* concentrations varied from 1 to 14 mg/m^3, with an average of 5 mg/m^3 (Loder et al. 1983a).

Comparison of 1976-78 chlorophyll *a* and phaeophyton data (Loder et al. 1983a) with recent values (Langan et al. 1990) shows an absence of a "typical" April-May phytoplankton bloom (Fig. 7.1). Historic reports state that this spring

Table 7.1. Phytoplankton species collected during 1977 by net and whole water sampling within the Great Bay Estuary (modified from NAI 1978).

Class: BACILLARIOPHYCEAE

Order: CENTRALES
- *Actinoptychus undulatus*
- *Biddulphia alternans*
- *Biddulphia aurita*
- *Ceratulina bergoni*
- *Chaetoceros affinis*
- *Chaetoceros atlanticus*
- *Chaetoceros brevis*
- *Chaetoceros compressus*
- *Chaetoceros concavicornis*
- *Chaetoceros danicus*
- *Chaetoceros debilis*
- *Chaetoceros decipiens*
- *Chaetoceros diadema*
- *Chaetoceros furcellatus*
- *Chaetoceros laciniosus*
- *Chaetoceros lauderi*
- *Chaetoceros lorenzianus*
- *Chaetoceros lorenzianus* f. *forceps*
- *Chaetoceros similis*
- *Chaetoceros socialis*
- *Chaetoceros teres*
- *Chaetoceros* spp.
- *Corethron hysterix*
- *Coscinodiscus* spp.
- *Ditylum brightwellii*
- *Detonula confervacea*
- *Detonula* sp.
- *Eucampia zoodiacus*
- *Guinardia flaccida*
- *Leptocylindrus danicus*
- *Lithodesmium undulatum*
- *Melosira moniliformis*
- *Melosira nummuloides*
- *Paralia sulcata*
- *Porosira glacialis*
- *Rhizosolenia alata*
- *Rhizosolenia delicatula*
- *Skeletonema costatum*
- *Thalassiosira nordenskioldii*
- *Thalassiosira rotula*
- *Thalassiosira* spp.

Order: PENNALES
- *Amphora* spp.
- *Asterionella formosa*
- *Asterionella glacialis*
- *Bacillaria paxillifer*
- *Campylodiscus echeneis*
- *Climacosphenia moniligera*
- *Cocconeis scutellum*
- *Cylindrotheca closterium*
- *Fragilaria oceanica*
- *Fragilaria* spp.
- *Grammatophora marina*
- *Gyrosigma balticum*
- *Gyrosigma fasciola*
- *Gyrosigma/Pleurosigma* spp.
- *Isthmia nervosa*
- *Licomophora abbreviata*
- *Licomophora flabellata*
- *Navicula crucigera*
- *Navicula* spp.
- *Nitzschia delicatissima*
- *Nitzschia longissima*
- *Nitzschia paradoxa*
- *Nitzschia seriata*
- *Rhabdonema arcuatum*
- *Rhabdonema adriaticum*
- *Surirella* spp.
- *Thalassionema nitzschioides*
- unspecified Pennales

Class: CHRYSOPHYCEAE

Order: OCHROMONADALES
- *Dinobryon* spp.
- *Olisthodiscus luteus*

Order: DICTYOCHALES
- *Dictyocha fibula*
- *Distephanus speculum*
- *Ebria tripartita*

Class: DINOPHYCEAE

Order: GYMNODINIALES
- *Amphidinium crassum*
- *Gymnodinium* spp.

Order: PROROCENTRALES
- *Prorocentrum micans*
- *Prorocentrum triestinum*

Order: PERIDINIALES
- *Ceratium furca*
- *Ceratium fusus*
- *Ceratium horridum*
- *Ceratium longipes*
- *Ceratium minutum*
- *Ceratium* spp.
- *Ceratium tripos*
- *Peridinium conicum*
- *Peridinium depressum*
- *Peridinium trochoideum*
- *Peridinium* spp.

Order: DINOPHYSIALES
- *Dinophysis norvegica*

Class: HAPTOPHYCEAE

Order: PRYMNESIALES
- *Phaeocystis pouchetti*

Class: CRYPTOPHYTA

Order: CRYPTOMONADALES
- *Chroomonas* spp.

Class: CHLOROPHYCEAE

Order: ZYGNEMATALES
- *Staurastrum paradoxa*

Class: CYANOPHYCEAE

Order: CHROOCOCCALES
- *Agmenellum* sp.

Order: OSCILLATORIALES
- *Arthrospira subsalsa*

Class: EUGLENOPHYCEAE

Order: EUGLENALES
- *Eutreptia* spp.
- *Eutreptiella* spp.

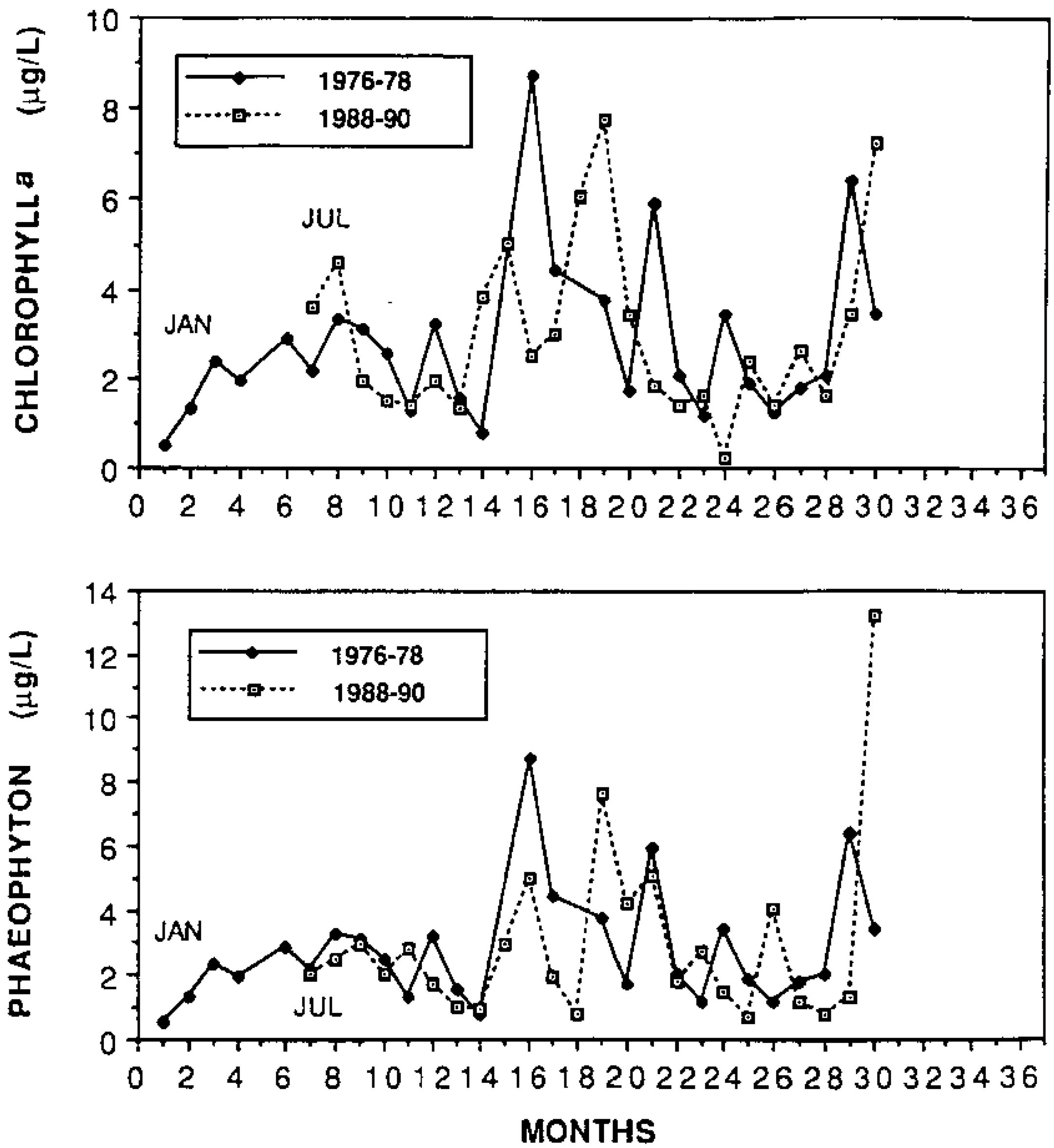


Fig. 7.1 Comparison of chlorophyll and phaeophyton concentrations for 1976-78 and 1988-90 during low tide off Adams Point at the mouth of Great Bay, New Hampshire (Data from Loder et al. 1983b and Langan et al. 1990; see also Table 5.1).

bloom is frequent, but a large degree of variability is apparent in the data. The peak chlorophyll *a* values observed in data from recent years occurred much later, in June or July. Currently, a project is underway at JEL that will examine the timing and magnitude of the spring bloom in greater detail.

Eelgrass

Eelgrass, *Zostera marina*, is a submerged marine flowering plant that is rooted within the sediments of coastal and estuarine waters, contributing significantly to the health and productivity of these areas. Eelgrass is known and appreciated by shellfish enthusiasts, fishermen, and duck hunters because of its important role in the life cycle of scallops, crabs, finfish, geese, and ducks. Eelgrass and the ecosystem it fosters are an important component of the Great Bay Estuary, covering 10 km^2 (3.9 mi^2 or 2500 acres), almost half the area of bottom in Great Bay alone.

Eelgrass communities are valuable sediment traps and help stabilize bottom sediments (Thayer et al. 1975). Their leaves form a three-dimensional baffle in the water, thus acting as dampers and reducing water motion. Eelgrass meadows act as a filter of estuarine waters, removing both suspended sediments and dissolved nutrients (Jackson 1944, Short and Short 1984). Suspended materials carried by currents move into eelgrass beds and are rapidly settled to the bottom. Polluting levels of nutrients entering the Estuary from coastal development are taken up by eelgrass leaves for their growth (see review by Short 1987). However, in the Great Bay Estuary and elsewhere, too many nutrients from wastewater effluent and fertilizers can produce algal blooms that shade and destroy eelgrass ecosystems. For these reasons, eelgrass health is both a factor in and an indicator of the overall health of bays and estuaries.

The three-dimensional structure of an eelgrass bed provides breeding and nursery areas for young finfish and shellfish, such as flounder, scallops, and crabs (Thayer et al. 1984). The dense underwater meadows provide a vertical substratum, or place of attachment, in the water column as well as a haven from predators. In addition, birds such as Canada geese, brant geese, and ducks consume the leaves and seeds of eelgrass as a principal food source.

In the normal life cycle of eelgrass, many of the leaves break away from the base of the shoots, especially in the fall. Some float away, carried by the currents; others fall to the bottom where they decompose (Phillips 1984). Detritivores begin to break down the leaves into smaller particles, which are consumed by bacteria and fungi. In this detrital process many invertebrates also consume the decaying eelgrass. The adult and larval forms of these invertebrates become food for larger life forms such as fish and crabs.

A catastrophic decline of eelgrass in the early 1930s (Rasmussen 1977), subsequently known as the wasting disease, killed over 90% of the North Atlantic eelgrass population (Milne and Milne 1951). As a result, scallops, clams, crabs, and many fish species suffered from the loss of protective habitat and from the sedimentation and erosion that occurred because eelgrass no longer anchored the bottom sediments. The effects of eelgrass loss in Great Bay, the increased suspended sediments, and the changes in the Bay habitats after the 1930s decline were described by Jackson (1944) and were the basis of the review by Milne and Milne (1951).

In most areas along the North Atlantic coast including the Great Bay Estuary, eelgrass recovered from the wasting disease by the 1960s, although in some locations the eelgrass never grew back (Thayer et al. 1984). Now a new outbreak of the disease, discovered first in the Great Bay Estuary and now found on both sides of the Atlantic, is threatening eelgrass populations again (Short et al. 1986). The symptoms of the current disease are similar to those in the 1930s. First, pinhead-sized black dots appear on the leaves (Short et al. 1988). The dots spread, forming large black stripes and patches. Eventually the whole leaf blackens, dies, and sinks or breaks off and floats away. The causal agent of the wasting disease has recently been identified as a marine slime mold, *Labyrinthula zosterae* (see Chapter 10). The recurrence of the disease was first noticed in 1984 in the Great Bay Estuary (Short et al. 1986) and has continued during recent years (Fig. 10.2). Now diseased plants have been found from Nova Scotia to North Carolina, on the west coast of the United States, on the coast of Europe (Short et al. 1988), and Japan (Short et al. in press).

Besides the wasting disease, another major factor that limits the production and survival of eelgrass in coastal areas is pollution resulting in decreased water clarity. Decreased water clarity reduces the amount of light reaching eelgrass and therefore reduces eelgrass growth (Dennison 1987). Of the two main factors contributing to water clarity reduction, suspended sediments shade or smother the plants directly while nutrient loading shades the plants by promoting planktonic and macroalgal growth.

The causes for the many recently reported declines of eelgrass along the East Coast are varied and include: the wasting disease (Short et al. 1987, Short 1988, Short et al. 1988), reduced water quality from coastal eutrophication (Orth and Moore 1983 and 1988, Kemp et al. 1983, Twilley et al. 1985), and intensive phytoplankton blooms (Dennison et al. 1989).

Eelgrass abundance in the Great Bay has been monitored seasonally in a number of studies through the 1970s and 1980s. Monthly samples of eelgrass abundance were monitored in 1972 by Riggs and Fralick (1975), in 1980-81 by Nelson (1981, 1982), and in 1986-90 by Short, Jones and Burdick (1991). The results of all these studies (Fig. 7.2) show the same seasonal pattern of abundance with low biomass occurring during the winter and rapid biomass increase during the spring and early summer. Maximum biomass, 250 g dry wt/m^2, occurs in late July or August. Such a pattern of abundance appears typical for eelgrass at this latitude (Short et al. 1989). Detailed analyses of seagrass populations in the Great Bay Estuary are presented in a recent summary report for the National Estuarine Research Reserve Program (Short et al. 1992) and in an ongoing investigation of the Portsmouth Naval Shipyard (Munns et al. 1992).

Seaweed

The Great Bay Estuary is typical of northern New England estuaries in having a wide diversity of seaweed species. The dominant species within the Estuary are the substantial intertidal populations of the fucoid macroalgae, *Ascophyllum nodosum* and *Fucus vesiculosus*, covering an area of 0.011 km^2 (0.010 mi^2 or 7 acres) within Great Bay alone, growing on the shingle cobble and granitic outcrops.

A total of 219 seaweed species are known in New Hampshire marine and estuarine waters, including the Isles of Shoals (Mathieson and Hehre 1986,

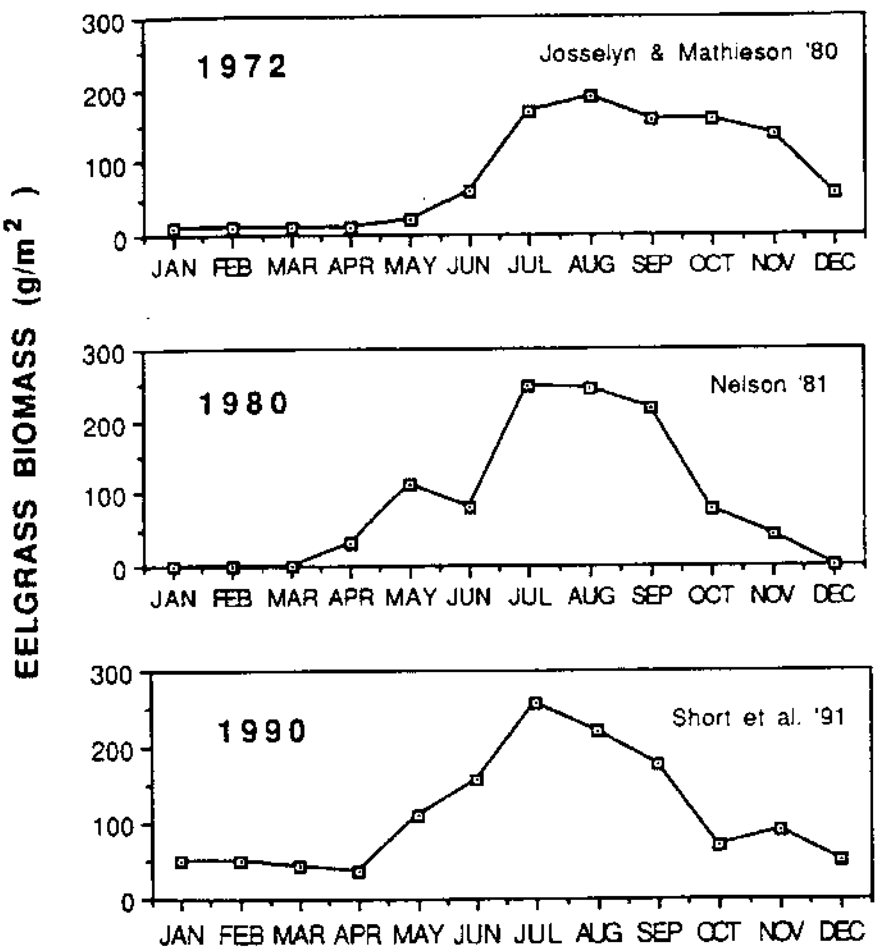


Fig. 7.2 Comparison of eelgrass biomass in Great Bay for 1972, 1980 and 1990. Data source for each year is indicated on the respective graph.

Mathieson and Penniman 1991). Of this total, 169 taxa (77.2% of total) are recorded within the Great Bay Estuary, including 45 Chlorophyceae, 46 Phaeophyceae and 78 Rhodophyceae (Table 7.2). A "typical" estuarine reduction pattern occurs from the Piscataqua River (144 taxa, 85.2% total estuarine) to Little Bay (132 taxa, 89.1% total estuarine) and Great Bay proper (90 taxa, 53.3% total estuarine). Each of the seven tidal rivers entering the Great Bay Estuary has a relatively reduced flora, ranging from only 4 taxa within the Winnicut River to 49 taxa in the Oyster River.

Within the Great Bay Estuary, two basic distributional patterns have been identified (Mathieson and Penniman 1991):

- Cosmopolitan - present in both estuarine and open coastal environments
- Estuarine - restricted to estuarine environments

Most species (i.e. 85% or 144 taxa) exhibit cosmopolitan distributional patterns of varying degrees - i.e. 66 Rhodophyceae, 41 Phaeophyceae and 39 Chlorophyceae. Twenty-five taxa (15%) are restricted to estuarine habitats - i.e. 13 Rhodophyceae, 6 Phaeophyceae and 6 Chlorophyceae. Six of the latter only occur within riverine habitats near the headwaters of tidal tributaries - i.e. *Mougeotia, Oedogonium, Spirogyra* and *Stigeoclonium* species, plus *Audouinella violacea* and *Sacheria fucina*.

Of the 169 total taxa within the Great Bay Estuary, 83 species are interpreted as annuals (49.1%), 2 (1.2%) as aseasonal annuals or pseudoperennials, and 84 (49.7%) as perennials (Table 7.2). Overall, the green algae exhibit the highest number of annuals (38 taxa, 84.4%), while the browns are intermediate (23 taxa, 50%) and the reds the lowest (25 taxa, 32.1%).

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 be 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 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).

Ascophyllum nodosum, rockweed, reaches maximum development in Great Bay because it is intolerant of extreme wave exposure and prefers the sheltered shoreline. Throughout the Estuary, the percent cover of *Ascophyllum* varies from 0 to 97.8% within the mid-intertidal zone (Nelson 1981a). The standing crop of fucoids throughout the Estuary has a range of 0-5,474 g dry wt/m^2 (average 2,073 g dry wt/m^2) (Nelson 1982). Maximum seasonal growth of *Ascophyllum* occurs during spring and fall in the Great Bay Estuary (Mathieson et al. 1976). *Ascophyllum* plants may be quite long-lived in some areas, persisting for 15 years (Baardseth 1970). Within Great Bay *Ascophyllum* can be heavily pruned annually by ice, losing up to one-half its standing crop (Mathieson et al. 1982). The

TABLE 7.2. Summary of seaweed species composition from ten Great Bay Estuarine areas (modified from Mathieson and Penniman 1991).

	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 7.2 (continued)

PHAEOPHYTA	Piscataqua R.	Little Bay	Great Bay	Bellamy R.	Cocheco R.	Lamprey R.	Oyster R.	Salmon Falls	Squamscott R.	Winnicut R.	Longevity*
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	

Table 7.2 (continued)

RHODOPHYTA	Piscataqua R.	Little Bay	Great Bay	Bellamy R.	Cocheco R.	Lamprey R.	Oyster R.	Salmon Falls	Squamscott R.	Winnicut R.	Longevity*
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 7.2 (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	

distal tips of fronds freeze into ice cover and are then torn free when ice-out occurs (Mathieson et al. 1982). Fragments of *Ascophyllum* torn loose by ice-pruning may enter the detrital cycle or they may lodge amongst *Spartina alterniflora* culms and grow, forming the unattached ecad *scorpioides* of *Ascophyllum nodosum* (Chock and Mathieson 1983). In certain areas of Great Bay, the biomass of the ecad *scorpioides* within the upper intertidal can reach 896 g dry wt/m^2 (Chock and Mathieson 1983).

Ascophyllum produces an abundance of reproductive cells over an annual cycle (Baardseth 1970). Lateral shoots, termed receptacles, bear the gametes that are released during March-May within the Great Bay Estuary (Mathieson et al. 1976) and may equal the standing biomass of vegetative plant material (Josselyn 1978, Josselyn and Mathieson 1978, 1980). Intertidal seaweeds such as *Ascophyllum* and *Fucus*, release large quantities of dissolved organic matter into the Estuary.

On stable rocky substrata, within the low intertidal to upper subtidal zone, Irish moss, *Chondrus crispus*, forms significant communities. Even so, the most abundant subtidal macroalga within Great Bay is *Gracilaria tikvahiae* (Penniman et al. 1986). The primary occurrence of *G. tikvahiae* in Great Bay (e.g. Footman Islands, Thomas Point, and Nannie Island) is limited by a lack of stable subtidal substrata in the euphotic zone. *G. tikvahiae*, as well as other subtidal seaweeds, grow attached to oyster shells, small rocks, discarded bottles and sunken logs.

The growth of *G. tikvahiae* may reach 10%/day during the summer; overall its growth is primarily limited by water temperature and light, while dissolved nutrients (i.e. nitrogen and phosphorus) do not appear to limit production (Penniman 1983, Penniman and Mathieson 1987). In contrast to the detailed studies of intertidal macrophytes at Cedar Point, Little Bay (Chock and Mathieson 1983), no quantitative studies have been conducted to determine standing crops of subtidal seaweeds throughout Great Bay.

In recent years, other subtidal seaweeds have appeared to dominate seaweed populations in part of the Great Bay Estuary. *Ulva lactua* and *Enteromorpha* spp. are found in large abundance often intermixed with or attached to eelgrass or overgrowing oyster beds. The proliferation of these nuisance seaweeds is often an indicator of coastal eutrophication (Lewis 1964, Harlin and Thorne-Miller 1981, and Short et al. 1991).

Salt Marsh

Salt marshes are an important component of the Great Bay Estuary, forming continuous meadows and fringing areas around the shoreline. Approximately 4.1 km^2 (1.6 mi^2 or 1000 acres) of salt marsh surround Great Bay. Within Great Bay, extensive salt marshes are found along the Squamscott 1.6 km^2 (0.6 mi^2 or 400 acres) and Winnicut Rivers, and Lubberland and Crommett Creeks.

Salt marshes in the Great Bay Estuary are dominated by *Spartina alterniflora* (cord grass) and *Spartina patens* (salt hay). Both species are perennial grasses, annually producing large amounts of organic matter that are exported from the marshes into the detrital food web or deposited within the marshes, contributing to the underlying marsh peat (Nixon 1982, Teal and Teal 1962). The "New England salt marsh", typical of salt marshes in the Estuary, is dominated by monospecific stands of *S. alterniflora* in the low marsh and monospecific stands of *S. patens* in the high marsh. The ecology of these two species in the Great Bay Estuary has had only limited study in the past.

The other primary high salt marsh species in the Great Bay Estuary include *Juncus gerardii*, and *Distichlis spicata*. A variety of other plant species also occur in the Great Bay Estuary salt marshes (Table 7.3) appearing as a mosaic of plant zones. Furthermore, several species found within the Estuary salt marshes are classified as rare or endangered by the state of New Hampshire (e.g. *Iva frutescens*).

In the mid '70s, the seasonality of leaf production in *S. alterniflora* was monitored at Cedar Point in Little Bay (Chock 1975). The data show the seasonal maximum biomass, 630 g dry wt/m^2, occurring in August (Fig. 7.3). Flower production of *S. alterniflora* begins in July and continues into October, after which the main vegetative stalks begin to die, the entire above ground plant biomass dies off, and enters the detrital cycle, either being exported from the Bay or decomposing within the estuarine system. Much research has dealt with efforts to restore *S. alterniflora* in areas where it has been destroyed or introduce it into new areas as part of mitigation efforts (see Chapter 10).

The annual production of *S. patens* was assessed during the mid 1980s. Stem density and standing biomass was measured in the Squamscott River north of Chapman's Landing at the time of seasonal maximum standing crop (Fig. 7.4). The biomass measured at this site was extremely high compared to other sites in northern Massachusetts, on the New Hampshire coast, and at the Wells Estuarine Research Reserve in southern Maine (Short 1988). This biomass of 820 g dry wt/m^2 was almost 20% higher than any other sites measured. On the same samples, the measurement of stem density was 6600 stems/m^2 similar to other sites measured in New Hampshire and slightly less than those measured in the Parker River Marsh in Massachusetts (Fig. 7.5).

The marshes surrounding the Great Bay Estuary are subject to extreme environmental variation. The large tidal amplitude in the region enhances the export of marsh grass from the marshes to the Estuary. Annual ice scouring of the intertidal marsh surface removes most the remaining marsh grass during the high spring tides in late winter. Ice cover and freezing activity in intertidal salt marsh dislodge portions of the surface peat. Whole sections of marsh with intact intertidal communities are rafted into lower intertidal or subtidal areas that are often too deep for them to survive (Hardwick-Witman 1985). Ice-rafted marsh segments that are deposited within the intertidal zone are a potential means of salt marsh propagation within the Great Bay (Hardwick-Witman 1985, 1986).

Breeding et al. (1974) described the numerous soil types of coastal New Hampshire salt marshes. Marshes bordering streams on the Squamscott River and Crommett and Lubberland Creeks in Great Bay, as well as the other rivers in the Estuary, are generally sulfihemist. Fringing marshes, which are common around the Estuary, also have sulfihemist soils of varying thicknesses; these overlay a variety of substrata (i.e. mud, sand or bedrock). The sulfihemist soil type has slow internal drainage, a very high water table, and contains large amounts of organic matter and sulfidic minerals. Studies of gas flux from the Squamscott River marsh demonstrates that sulfur gas is a major emission from this marsh system (Chapter 9).

Clearly, the salt marshes of the Great Bay Estuary are a productive part of the estuarine environment. A project to map the salt marsh of the Great Bay Estuary is currently underway through funding from NH Coastal Zone Management Program (Ward per. com.). Other studies within the Great Bay Estuary have shown the

Table 7.3. Major plant species occurring within New Hampshire salt marshes (modified from Breeding et al. 1974).

Acnida cannabina	Water hemp
Aster subulatus	Annual salt marsh aster
Aster tenuifolius	Perennial salt marsh aster
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

Table 7.3 (continued)

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	Fresh water 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

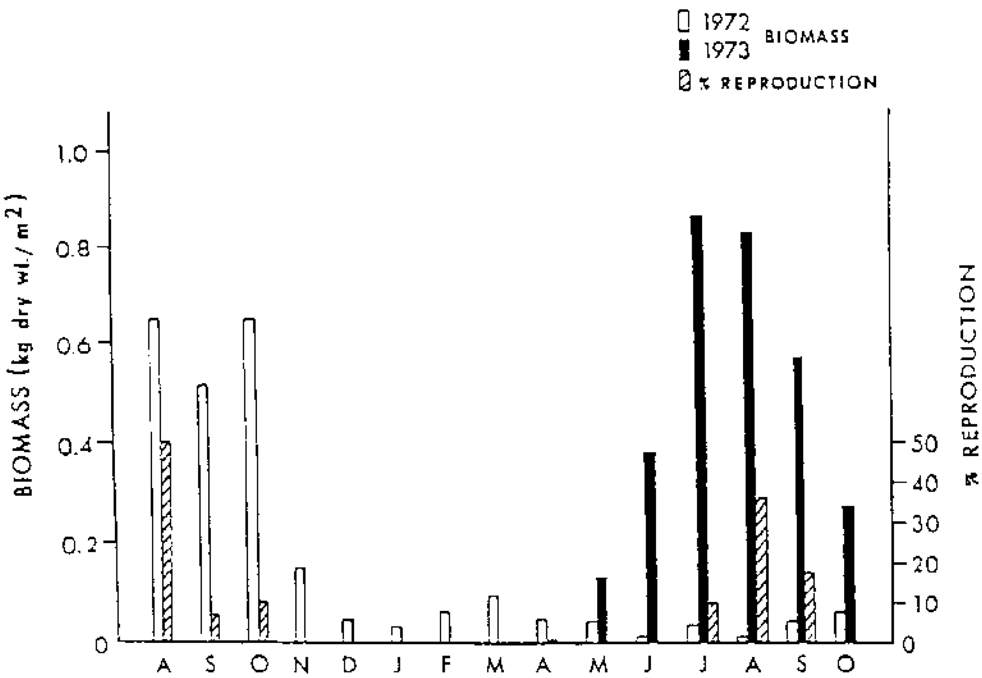


Fig. 7.3. Seasonal comparison of *Spartina alterniflora* biomass and percent reproduction in 1972-73 for Cedar Point, Great Bay Estuary, NH (Chock 1975).

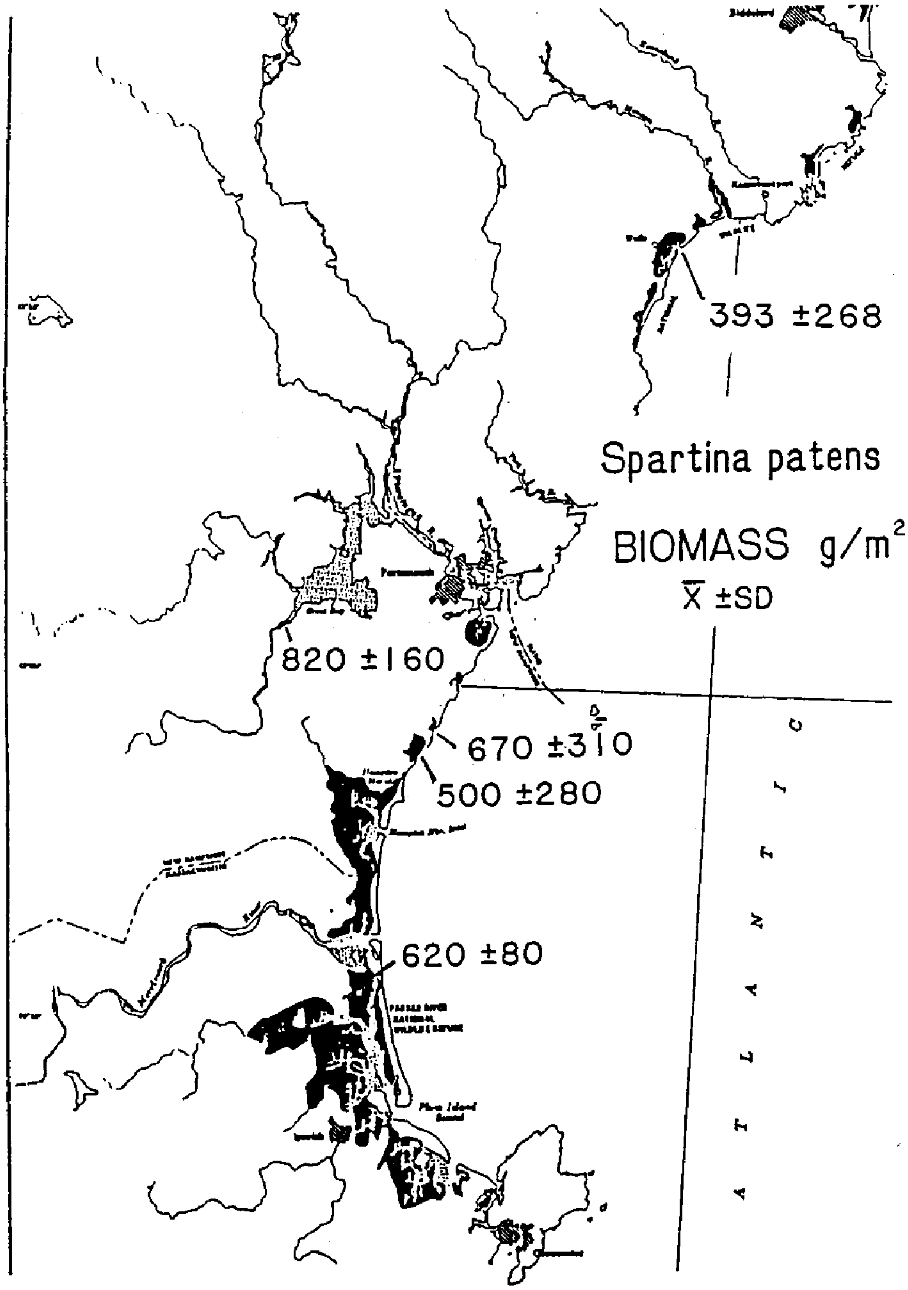


Fig. 7.4. Seasonal maximum biomass (g dry wt/m2) for *Spartina patens* along the northern New England coast (Short 1986).

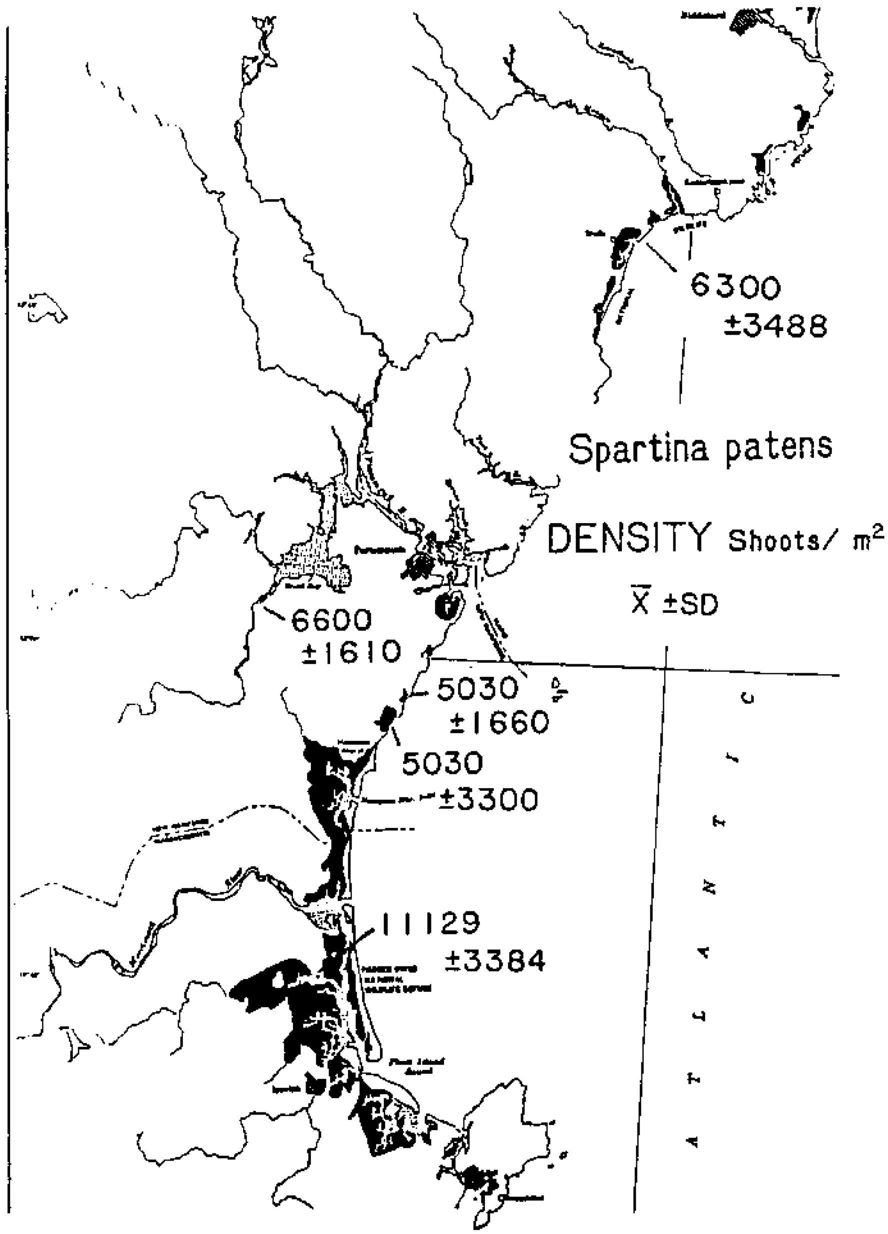


Fig. 7.5. Shoot density (shoots/m2) for *Spartina patens* along the northern New England coast (Short 1986).

importance of salt marshes in biogeochemical processes (see Chapter 9) and in the uptake and cooperation of methylated tin compounds (see Chapter 6). The importance of salt marsh habitats within the Great Bay Estuary, including the value of these systems as fisheries habitat, is described in Chapter 2.

Benthic Microalgae

Another important microalgal component of the estuarine flora are diatoms and other microscopic algae occurring on mudflats. These microalgae may contribute a substantial portion of total estuarine primary production. Recently, two masters theses have included an assessment of the benthic microalgal biomass in their studies of intertidal sediment stability (Sickley 1989 and Webster 1991). These geologically based studies provide the first quantitative evidence for benthic diatom abundance in Great Bay. Seasonal chlorophyll *a* data from Adams Cove shows a bimodal annual pattern of diatom abundance (Fig. 7.6). A spring diatom bloom occurs in March-April (Webster 1991) and a second bloom begins in late July and lasts through October (Fig. 7.6). The chlorophyll *a* content for the two studies ranged from 8-24 mg/l (Sickley 1989 and Webster 1991).

The diatom layer on the sediment surface was found to be related to a reduction in sediment resuspension (Fig. 7.6) with the benthic algal population binding the sediment surface together (Sickley 1989). Reduction in the binding of sediments was associated with the grazing and disturbing activity of both mud snails and horseshoe crabs on the mudflat (Sickley 1989). No clear relationship was found between benthic diatom abundance and grain size or total organic carbon (Fig. 7.6).

Upland

The uplands surrounding the Great Bay Estuary have both deciduous and coniferous forests. The most common tree species includes white pine, red oak, red pine, hemlock, red maple, gray birch, and quaking aspen. A more complete listing of the common upland vascular plants found within Strafford County, N.H., is presented in Table 7.4.

The plants comprising the upland which surrounds the Great Bay Estuary form a valuable buffer that protects the estuarine ecology in several ways. Research on riverine systems has shown clearly that an intact buffer zone or riparian zone along a river system has a significant role in maintaining the water quality, wildlife value, aesthetic beauty and riverine health (Jones 1986). Similarly, the buffer zone around an estuary provides the same functions.

In particular, for the Great Bay Estuary, these buffer zones are important in trapping nutrients and sediments that would otherwise wash into the Estuary contributing to the reduction in water quality. These zones also provide shelter and habitat for animals and birds that frequent the Estuary and utilize estuarine resources. In addition to these values, the upland also provides large amounts of organic matter to the Estuary, adding fuel to the detrital food chain. These materials include leaf fall and other dead plant material. Overall, the upland buffer is critical to the continued maintenance of a healthy Estuary and is an important consideration in regulating shoreline development.

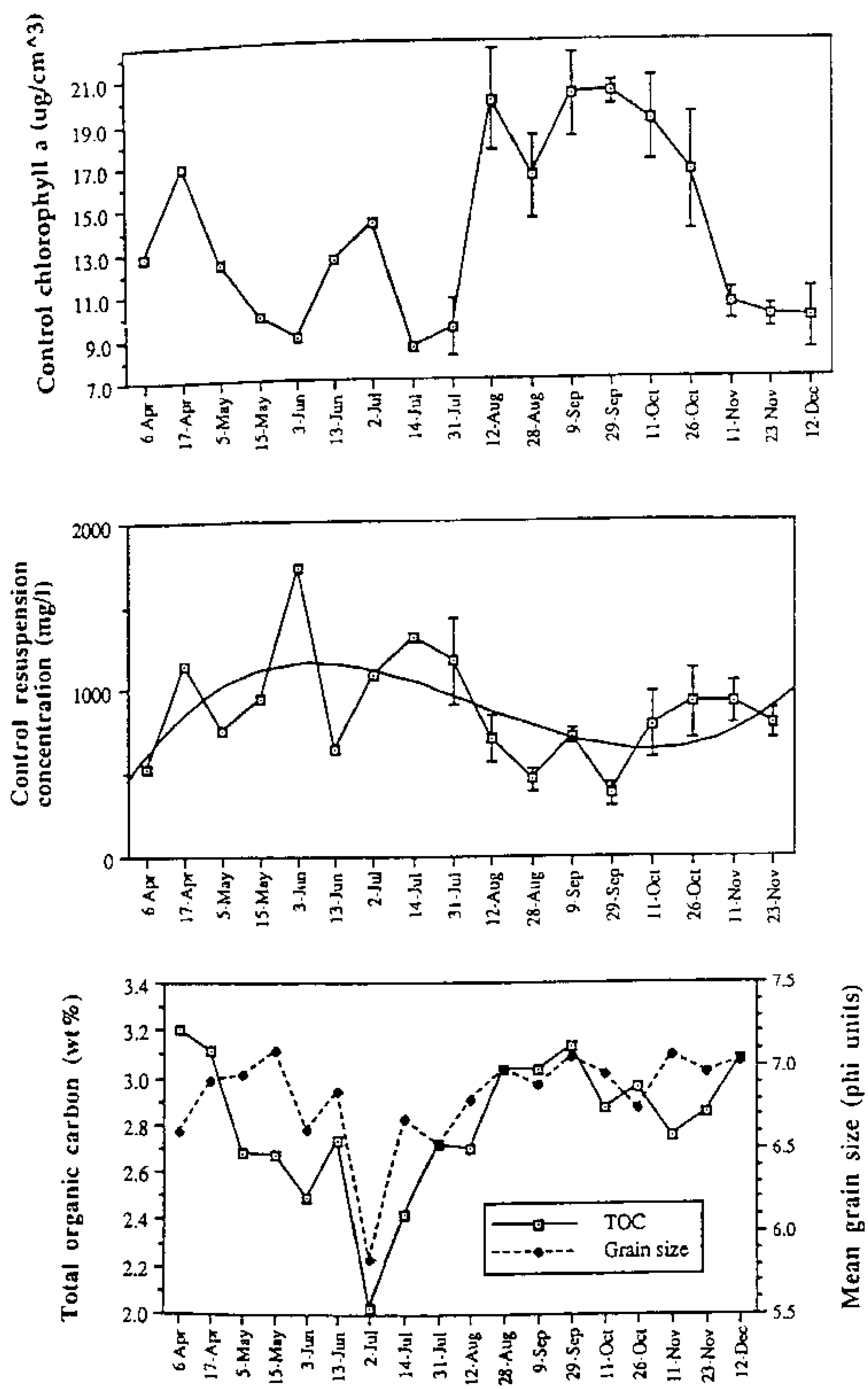


Fig. 7.6. Seasonal comparison of chlorophyll a, resuspension concentration, total organic carbon, and mean grain size in 1988 for the mudflat at Adams Cove, Great Bay Estuary, NH (Sickley 1989).

Table 7.4. Common upland overstory and understory vascular plant species in Strafford County, N.H. by habitat (modified from Hodgdon 1932 in Texas Instruments, Inc. 1974). A specific list for the upland area within the Reserve boundaries is not presently available.

DRY UPLAND FOREST

Primary overstory species

Acer rubrum	Red maple
Betula alleghaniensis	Yellow birch
Betula lenta	Sweet birch
Betula papyrifera	Paper birch
Betula populifolia	Gray birch
Carya ovalis	Sweet pignut
Carya ovata	Shagbark hickory
Fagus grandifolia	American beech
Fraxinus americana	White ash
Picea glauca	White spruce
Picea rubens	Red spruce
Pinus resinosa	Red pine
Pinus strobus	White pine
Populus tremuloides	Quaking aspen
Pyrus malus	Apple
Quercus alba	White oak
Quercus rubra	Red oak
Quercus velutin	Black oak
Salix alba	White willow
Sassafras albidum	White sassafras
Tsuga canadensis	Hemlock

Primary understory species

Aralia nudicaulis	Wild sarparilla
Berberis vulgaris	Common barberry
Castanea dentata	Chestnut
Comptonia peregrina	Sweet-fern
Dennstaedtia punctilobula	Hay-scented fern
Gaultheria procumbens	Teaberry
Hamamelis virginiana	Witch hazel
Juniperus communis	Common juniper
Kalmia angustifolia	Sheep laurel
Lycopodium complanatum	Trailing evergreen
Myrica pensylvanica	Bayberry
Prunus pensylvanica	Pin cherry
Prunus virginiana	Choke cherry
Pteridium aquilinum	Bracken fern
Quercus ilicifolia	Scrub oak
Rubus pubescens	Dwarf raspberry
Toxicodendron radicans	Poison ivy
Vaccinium angustifolium	Lowbush blueberry
Viburnum acerifolium	Maple-leaved viburnum

WET-LOWLAND FOREST

Primary overstory species

Acer rubrum	Red maple
Betula alleghaniensis	Yellow birch
Betula lenta	Sweet birch

Betula papyrifera	Paper birch
Carpinus caroliniana	American hornbeam
Chamaecyparis thyoides	Atlantic white cedar
Nyssa sylvatica	Blackgum
Picea mariana	Black spruce
Salix alba	White willow
Salix nigra	Black willow
Tsuga canadensis	Hemlock
Ulmus americana	American elm

Primary understory species

Alnus rugosa	Speckled alder
Cornus amomum	Silky dogwood
Cypripedium sp.	Lady slipper
Gaultheria procumbens	Teaberry
Ilex verticillata	Swamp winterberry
Kalmia angustifolia	Sheep laurel
Lycopodium obscurum	Ground pine
Mitchella repens	Partridge berry
Osmunda cinnamomea	Cinnamon fern
Polytrichum commune	Hairy cap moss
Rosa sp.	Rose
Smilax rotundifolia	Common greenbrier
Vaccinium corymbosum	Highbush blueberry
Viburnum alnifolium	Dockmackie
Viburnum cassinoides	Wild raisin
Viburnum recognitum	Arrow-wood
Vitis sp.	Grape

OPEN AND OVERGROWN FIELDS

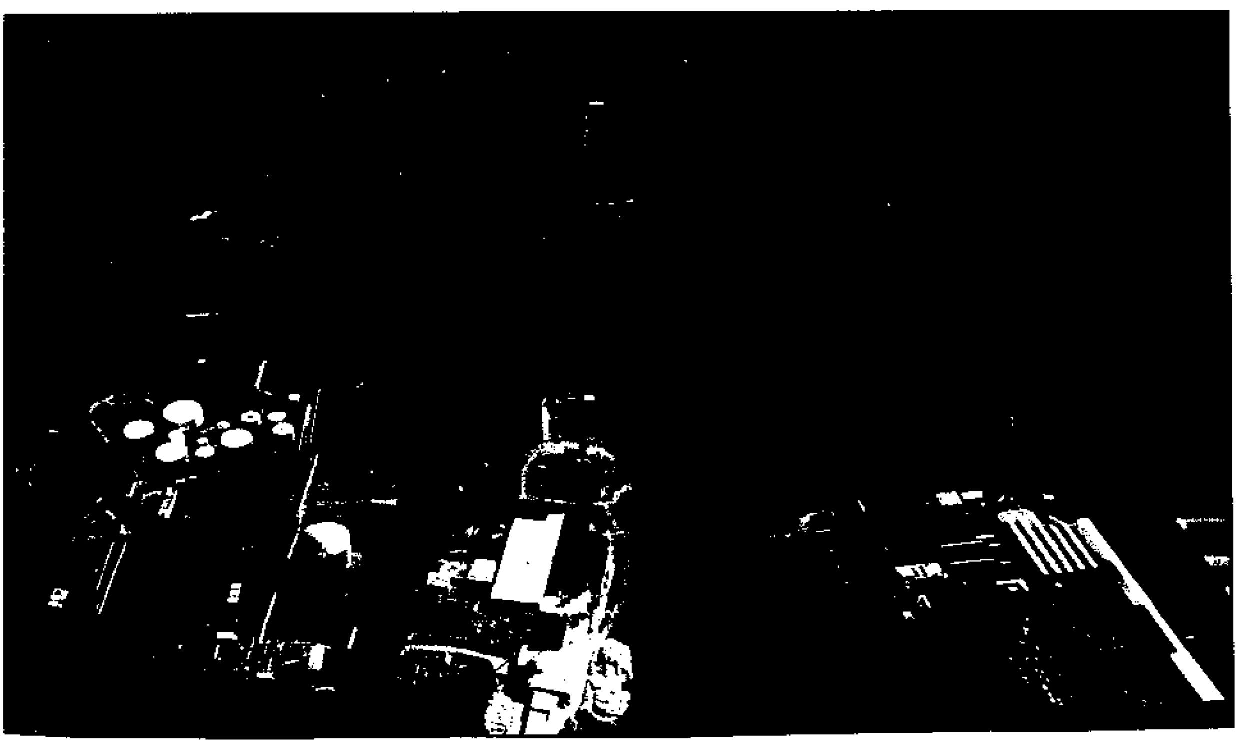
Overstory species

Betula populifolia	Gray birch
Juniperus communis	Common juniper
Juniperus virginiana	Red cedar
Prunus serotina	Black cherry
Prunus virginiana	Choke cherry
Viburnum sp.	Viburnum
Rhus typhina	Staghorn sumac

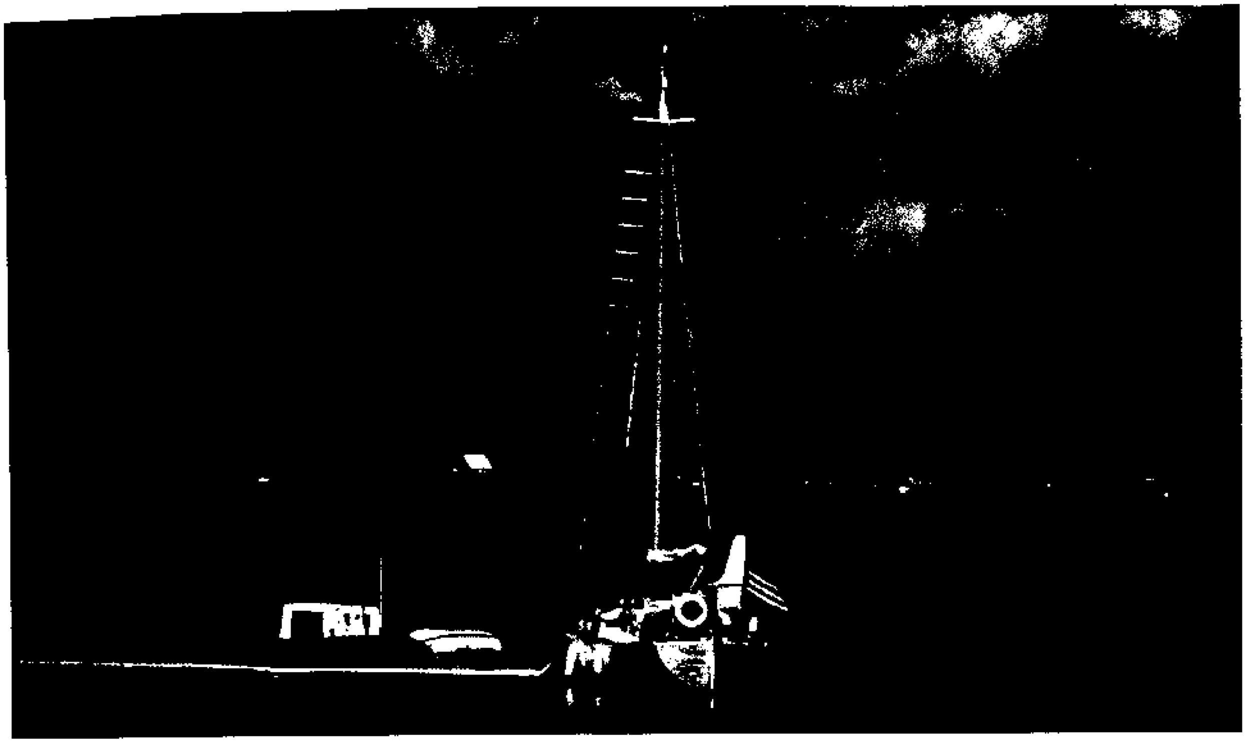
Ground cover species

Achillea millefolium	Common yarrow
Amaranthus retroflexus	Amaranth
Ambrosia artemisiifolia	Common ragweed
Aster sp.	Aster
Dactylis glomerata	Orchard grass
Daucus carota	Queen Anne's lace
Festuca rubra	Red fescue
Oxalis corniculata	Creeping lady's sorrel
Phalaris arundinacea	Reed canary grass
Phleum pratense	Common timothy
Poa pratensis	Kentucky bluegrass
Solidago sp.	Goldenrod
Spiraea latifolia	Meadow sweet
Trifolium pratense	Red clover

Aerial view of the Great Bay Estuary from offshore, showing Portsmouth Harbor and the Piscataqua River with Portsmouth Naval Shipyard *(center)*, Kittery, Maine (*right*), and Portsmouth, New Hampshire *(top, center)*.



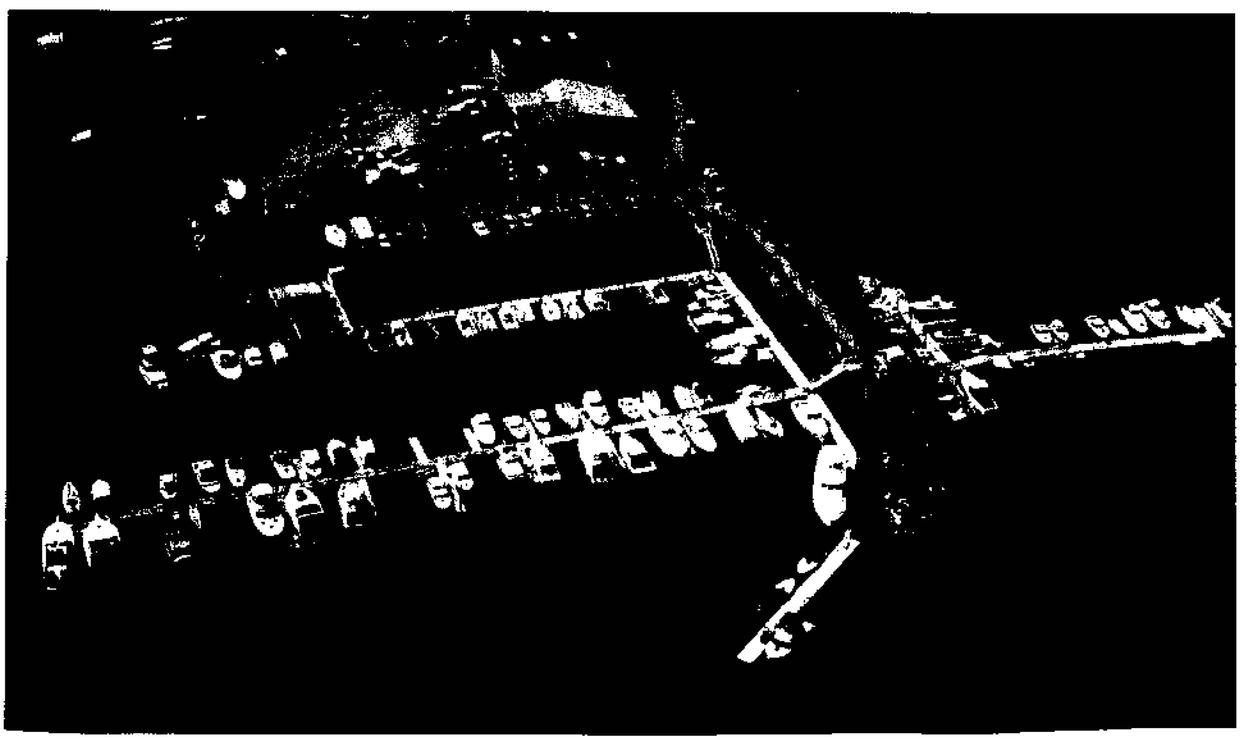
Aerial view of the Piscataqua River showing industrial development on the New Hampshire side *(foreground)* and residential development on the Maine side.



Recreational boating on the Great Bay Estuary.

Canada geese feeding on eelgrass in Great Bay.

Juvenile lobster foraging within the protection of a shallow eelgrass meadow in Portsmouth Harbor.



Aerial view of Great Bay Marina on Little Bay. Recent expansion of the marina is indicative of increased boating activity in the Estuary.

Aerial view of Adams Point at the juncture of Great and Little Bays, showing the Adams Point Wildlife Management Area and the Jackson Estuarine Laboratory.

Aerial view of the Squamscott River near the Route 108 bridge in Stratham, NH. The extensive salt marshes along the river are part of the Great Bay National Estuarine Research Reserve.

Chapter 8: Estuarine Consumers
by P.F. Sale, J.A. Guy, R. Langan and F.T. Short

Zooplankton

The population size of zooplankton in the Great Bay Estuary varies widely from 1000 to 10,000 individuals/m^3 (NAI 1976). Seasonally their abundance increases throughout the spring, peaking in early summer and declining sharply in later summer. Overall 32 zooplankton taxa were collected within the Great Bay Estuary (Table 8.1), less than at outer estuarine sites (NAI 1976). Throughout the Estuary, holoplankton, which spend their entire lives in the zooplankton community, accounted for 73% of the taxa. The dominant 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 (5%) and cirriped 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). Mollusk larvae are most abundant during June and July with a second peak in abundance during September. Prosobranch veliger numbers were greatest during June and July and were most abundant within Great Bay. Up to 25 veligers/liter may occur within Great Bay, with *Ilyanassa obsoleta* predominant (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 midestuary. Larval populations were most dense and species composition most varied during February to July as well as September through November, periods 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

Table 8.1. Zooplankton species collected from the Great Bay Estuary, New Hampshire during 1979 (NAI 1980).

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

water column on flood tides and downward movement during ebb tides promoted retention of larvae within Great Bay (Turgeon 1976) and other parts of the inner Estuary. Larvae of warm water species, such as *Geukensia demissa*, *Molgula manhattensis* and *Balanus improvisus*, were infrequently detected during 1970 to 1973 (Turgeon 1976).

Fishes

During the early 1800's, pollution and excessive sedimentation due to the rapid development of the seacoast region, adversely affected most commercial and recreational fishing stocks in the Great Bay Estuary (Jackson 1922, 1944, Warfel et al. 1942, Krochmal 1949). Nonetheless, many fisheries have re-established themselves since 1900. Today the Estuary supports, among its 52 species of fish (Table 8.2), populations of commercially and recreationally important resident and migratory species, including smelt (*Osmerus mordax*), winter flounder (*Pseudopleuronectes americanus*), smooth flounder (*Liopsetta putnami*), and striped bass (*Morone saxatilis*). Important forage species such as Atlantic silversides (*Menidia menidia*), river herring, also called alewives (*Alosa pseudoharengus*), blue backed herring (*A. aestivalis*), and common mummichog (*Fundulus heteroclitus*) are also present (Nelson 1981). Coho, and more recently chinook and Atlantic salmon, have been stocked (see Chapter 1) for the last fifteen years by New Hampshire Fish and Game (Stolte 1974, Nelson per. com.).

Of these 52 species, smelt supports a major winter sport ice fishery. In addition, the two species of flounder account for 14% of the total recreational catch of Great Bay during the warmer months (NHFG 1988). River herring, which breed in fresh water, and Atlantic silversides, which lay their eggs in vegetated habitats of Great Bay, are of principal importance because they are major forage for larger recreationally important species such as bluefish (*Pomatomus saltatrix*) and striped bass.

Table 8.2. 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
Mugilidae:	
Mugil cephalus	Mullet
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

Table 8.2 (continued)

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

Striped bass tracked with sonic tags in the Piscataqua River have been observed to meander through shallow eelgrass beds, feeding on Atlantic silversides, juvenile alewives, juvenile Atlantic herring, mysids, and sand shrimp (NAI 1979b). Both striped bass and bluefish transport estuarine production into coastal regions when they leave the Estuary each year. The common mummichog is another very abundant small forage species found in vegetated estuarine habitats (see Chapter 2). It is non-migratory and is prey to numerous recreational fish species.

Work completed in the Great Bay Estuary provides an excellent database on the species of fish using the Estuary, the life stages present, and the times of year they are found (NAI 1971-80, Nelson 1981, Sale and Guy unpublished, Howell and Armstrong unpublished). However, little information exists on their abundance and differential use of estuarine habitats (see Chapter 2). At present, inadequate data are available to decide whether the estuary plays a major or a minor role in supplying fish to coastal stocks. In addition, little is known about fish movement through the Estuary, or responses of fish to various estuarine habitats. Much more information is available in comparable estuarine areas further south on the Atlantic coast where a considerable research effort has been made (references in Adams 1976a, b, Orth and Heck 1980, Thayer et al. 1984, Olney and Boehlert 1988, Sogard et al. 1989a, b, c). It is likely that processes and roles in the strongly seasonal estuaries of the Gulf of Maine differ in significant ways from those in more southern estuaries where primary production is not strongly seasonal and where ice scour has little if any impact on vegetated aquatic habitats.

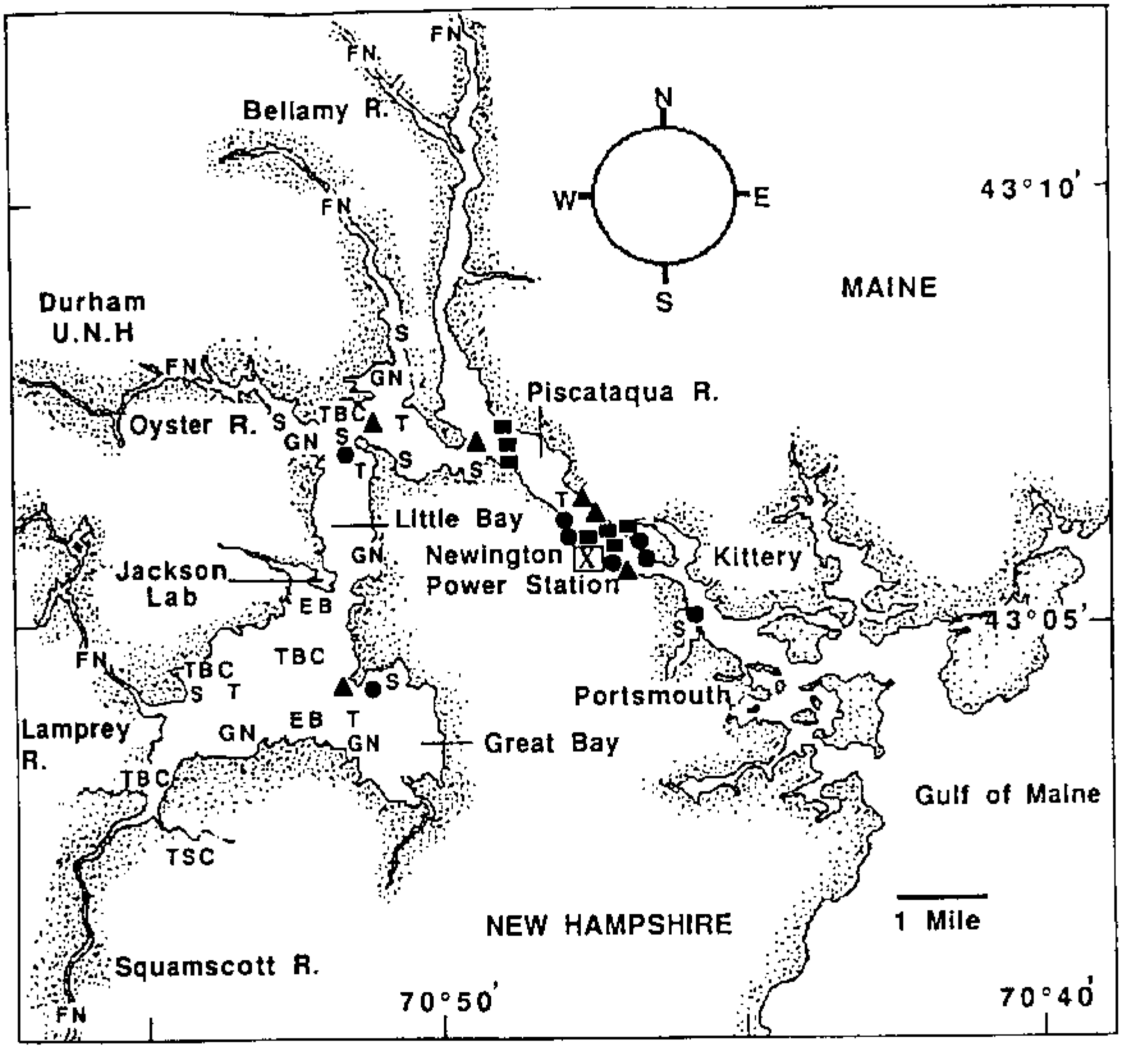
Monitoring studies of fish populations within the Great Bay Estuary were conducted in the 1970s for the Public Service Company of New Hampshire by Normandeau Associates Inc. (NAI 1971-1980) in order to determine possible effects on estuarine communities from the construction and operation of the Newington Power Generating Station. The power plant, which began operation in June 1974, is located on the Piscataqua River in Newington, approximately 5 miles upriver from Portsmouth Harbor. The station uses river water for cooling purposes and warm water is subsequently returned to the river.

NAI's monitoring studies utilized beach seining, otter trawling, sonic tracking, creel censuses, trap netting and larval tows to determine the distribution and abundance of finfish and ichthyoplankton routinely at various sites in the vicinity of the power station as well as within Great Bay (Fig. 8.1). The reports represent the longest temporal database of any fish study in the Great Bay Estuary. The information is somewhat limited for Great Bay proper as most effort was applied to the downstream part of the Estuary. Relevant information is therefore confined to isolated seining, trawling and creel census sites. Data summarized below are based on:

1) Duplicate 30 m seine hauls (13 mm mesh body and 6.5 mm mesh bag) taken monthly from April to November, 1971-1977 from the eastern side of Woodman Point (Fig. 8.1) (summarized in NAI 1980)

2) Duplicate 5.5 m otter trawls (32 mm mesh) every other month from April to November, 1971-1976, mid-channel off Woodman Point (summarized in NAI 1978)

3) Creel census data supplied by the Great Bay Striped Bass Club, 1971-1977 (summarized in NAI 1978).



NORMANDEAU ASSOCIATES INC. 1971-1980

- ● Seining -- 8 sites.
- ▲ Trawling -- 6 sites.
- ■ Ichthyoplankton -- 7 sites

NELSON 1981

FN	Fyke nets -- 6 sites.
S	Seines -- 8 sites.
GN	Gill nets -- 5 sites.
T	Trawls -- 5 sites.

HOWELL AND ARMSTRONG 1990-1991

TBC	Trawls and benthic cores -- 4 sites.

SALE AND GUY 1989-1990

EB	Eelgrass beds -- 2 sites.
TSC	Tidal saltmarsh creek -- 1 site.

Fig. 8.1. Map showing sampling locations for past and ongoing finfish surveys within the Great Bay Estuary.

Dominant resident species collected during the NAI monitoring in the shallow waters of Great Bay at Nannie Island and off Fox Point in Little Bay included the Atlantic silverside, common mummichog, winter and smooth flounder, stickleback, tomcod and grubby. Commercially and/or recreationally important anadromous species included rainbow smelt and river herring. The Atlantic silverside was the most abundant species captured by seine, often forming over 50% of the total catch by numbers.

At the deeper trawled site in Great Bay, eleven species were collected during the six years of monitoring. Of these, only four species were consistently abundant: winter flounder, pipefish (present in all collections), smelt, and grubbies (present in all but one collection). Abundances of fish in samples were low (<15 individuals), with smelt being the most abundant numerically.

An inventory of natural resources of the Great Bay Estuary was prepared by New Hampshire Fish and Game Department and the NH Office of State Planning in 1980-81 to provide a baseline of information on the flora, fauna, and physical environment (Nelson 1981, 1982). Sites were selected to sample areas historically impacted by oil spills and those that could be impacted in the future. Fish were collected using beach seines, gill nets, and trawls from July 1980 to October 1981 (Fig 8.1). With selected species, data are presented for each collecting method as follows: 1) total catch per site; 2) total numbers per month; 3) monthly mean and range of total lengths. For total numbers of fish collected by each gear type see Nelson (1981, Appendix 3.0). Gear and locations were of four kinds:

1) Thirty meter seines (13 mm mesh body and 6.5 mm mesh bag), fished monthly, except for 3 winter months, between September 1980 and August 1981 at Herods Cove, Moody Point, Fox Point, Oyster River, Bellamy River, and Cutts Cove.

2) Gill nets (13, 19, 32, 38, and 102 mm mesh) 38 m long and 2 m deep were fished monthly December 1980 and April to October 1981 at two Great Bay sites, Welch Cove and at the mouths of the Oyster River and the Bellamy River in Little Bay.

3) Replicate 5 minute trawls of 12 m shrimp trinets (38 mm mesh) were taken monthly from April to October 1981 at two mid-channel sites in Great Bay, two in Little Bay, and one in the Piscataqua River upstream of the Newington Power Station.

4) Fyke net samples were collected below the dams of the six major rivers entering the Estuary.

Dominant species in shallow sites were the mummichog, Atlantic silverside, and stickleback, although river herring, rainbow smelt and smooth and winter flounder also occurred. In deeper waters, smelt and winter flounder were most abundant; northern pipefish, windowpane flounder and little skate also occurred.

A number of other reports deal with the development of anadromous fish resources in coastal waters of New Hampshire (Goodrum 1941, NHFG 1979a, b). Yearly spawning runs were monitored for river herring and smelt in tributaries draining into Great Bay (Fig. 1.2 and 1.4). Spring spawning success for smelt, which was evaluated through egg deposition indices, provides information on the status of individual stocks (Fig. 1.2).

Thirteen master's theses and three doctoral dissertations provide information on the following species: smooth and winter flounders (Laszlo 1972, Burn 1978, Burke 1982 and Moroz 1985), smelt (Krochmal 1949, Skerry 1952, Tomashevski 1952, and Grout 1983), river and blueback herring (Lamb 1980 and Langan 1980), striped bass and white perch (Staples 1946), largemouth bass and golden shiners (Dupee 1977), coho salmon (Deegan 1979), the American eel (Hickman 1953) and white suckers (Muzzall 1978). Topics include histology, parasitism, chromosomal studies, morphology, food habits, age and growth, sex determination and reproduction. The most recent master's thesis, which was completed in 1990, documented the timing of juvenile river herring seaward migration within the Lamprey River (Adams 1990).

Prior to 1950 little published information existed on the fishes of the Great Bay Estuary (Jackson 1922, Warfel et al. 1942). More recent publications have dealt with the introduction of Coho salmon into coastal waters of New Hampshire (Stolte 1974), induced chromosome variation and growth in winter flounder (Hoornbeek and Burke 1981, Hoornbeek et al. 1982) and hermaphroditism in smelt (Grout 1983).

A number of studies are currently assessing larval and juvenile fish ecology within nursery habitats of the Great Bay Estuary. Eelgrass and salt marsh are, in area, the major vegetated shallow water habitats (Chapter 2) within Great Bay (Riggs and Fralick 1975, Chock and Mathieson 1976 and 1983, Short et al. 1986). There is accumulating evidence that such vegetated habitats support greater densities and/or greater diversities of small fish than adjacent unvegetated sites (Kikuchi 1966, Thayer et al. 1975, Orth and Heck 1980, Weinstein and Brooks 1983, Stoner 1983, Bell and Pollard 1989, Heck et al. 1989, Thayer and Chester 1989, and Heck and Thoman 1984). Preliminary sampling in Great Bay suggests that eelgrass beds and salt marsh creeks are of major importance to postlarvae, particularly juveniles of a wide range of fish species (Sale and Guy unpubl., see also Chapter 2). Numerically most abundant are rainbow smelt, Atlantic silverside, nine-spined stickleback, river herring, white perch, and common mummichog (Tables 2.2 and 2.3). While information exists on diets of each of these species, there is little information on rates of production, or ecological role within the estuarine system. Short descriptions of the ecology of some of the major species follow.

Adult smelt appear in estuaries during early autumn, then overwinter until stream temperatures rise sufficiently in spring for them to enter fresh water and spawn. They return to salt water immediately after spawning to spend the summer either in the Estuary or the adjacent open ocean. Smelt larvae, 5 mm in length when hatched, are carried passively downstream into the Estuary. Survival is aided by tolerance of larvae to high salinities, 18-22 ppt (Johnston and Cheverie 1988). Fry may be 20-40 mm long in a few months and 51 mm long by August (Scott and Crossman 1973). Bigelow and Schroeder (1953) reported growths of 44 mm to 63 mm in length for smelt during the first summer and autumn. It is still unclear at what age smelt leave the Estuary for the sea. However, Bigelow and Schroeder (1953) reported catching smelt late in October on a coastal beach. The fish will return to the Estuary to spawn as mature 2-3 year olds. During studies between 1979 and 1990, young-of-the-year smelt first appeared in Great Bay eelgrass beds in June and were collected through October (NAI 1979, Nelson 1981a, Sale and Guy unpubl.). Juveniles were caught in tidal creeks in early May.

Atlantic silversides are a short lived species reaching high abundance in a variety of estuarine habitats. During spring, summer and fall they are often the most abundant fish encountered within tidal creeks and the shore zone of salt marshes (Richards and Castagna 1970, Briggs 1975, Anderson et al. 1977, Hillman et al. 1977). Silversides were collected in a variety of habitats, unvegetated intertidal and eelgrass beds, and with a variety of gear, beach and purse-seines in the Great Bay Estuary (NAI 1979, Nelson 1981, 1982, Sale and Guy unpubl.). They were most abundant as juveniles from August to October in both of these habitats, especially in open beach areas at high tide and within eelgrass beds at mid-low tide (Table 2.2). Silversides were also caught as young-of-the-year in tidal creeks beginning in July. The majority of estuarine populations during these months are juveniles and year 1 adults, reaching sexual maturity within that year. Silversides have a lunar-related spawning cycle that usually occurs at a new or full moon in early spring; peak spawning occurs at approximately 14 to 15 day intervals (Middaugh et al. 1981). Juvenile silversides range in size from 20 mm to 98 mm total length by November (Conover and Ross 1982). Conover and Murawski (1982) reported that silversides less than one year old migrate offshore during late fall and experience very high overwintering mortalities (99%). Few if any fish survive to age 2; most die after spawning or during their second winter of life. This essentially annual life cycle suggests that Atlantic silversides are important exporters of secondary production and biomass from estuarine systems to deeper, offshore waters, as well as being important forage species within estuaries (Conover and Ross 1982).

Spawning by the nine-spine stickleback takes place in early summer and is commonly associated with benthic vegetation. Nests are built in the eelgrass where eggs are deposited and fertilized. This is followed by a period of parental care by males (Wootton 1976). After hatching, growth is rapid with larvae reaching a length of about 15 mm in 14 days. Maximum life span is 3 to 3.5 years, with juveniles reaching a total length of 45 mm in the first year (Scott and Scott 1988). Sticklebacks were caught consistently in eelgrass and unvegetated intertidal with scattered pockets of rockweed within the Great Bay Estuary (NAI 1979, Nelson 1981, 1982, Sale and Guy unpubl.). Sticklebacks were also present in tidal creeks.

The river herring (alewife) and blue back herring are important forage and commercial species in estuarine and marine ecosystems. River herring predominate in Great Bay. Throughout New England herring has had a long history of commercial exploitation. It is an important source of fish meal for animal food and bait for the lobster fishery (Mullen et al. 1986). Ecologically, river herring appear to be important energy links between zooplankton and predatory fish. Spawning occurs in fresh water from April to July within the North Atlantic region; the onset and peak of river herring spawning precedes by 2 to 3 weeks those of blueback herring. Downstream movement of adult river herring after spawning is apparently triggered by an increase in water flow, suggesting that emigration is a rheotactic response (Huber 1978). Transformation from larval to juvenile stage is usually complete when these fishes are about 20 mm total length (Mullen et al. 1986).

During their first year, larvae and juvenile river herring remain in or near areas where they spawned for several weeks before emigrating (as juveniles) to estuarine and coastal areas in their first year. Emigration "waves", consisting of large schools of juvenile river herring, are triggered by heavy rainfall (Cooper 1961), high water levels (Kissil 1974) and sharp drops in water temperature (Richkus 1975). The waves occurring between mid-June and mid-October can last two to three days, regardless of the duration of environmental changes (Adams 1990). Richkus (1975) reported that about 70% of the juveniles completed emigration from a Rhode Island drainage in only a few days, while Adams (1990) reported a 97% emigration from the Lamprey River into Great Bay over a 14 day period. Such patterns would explain the large catches of young-of-the-year during August within Great Bay eelgrass beds (Nelson 1981, 1982, Sale and Guy unpubl.). By contrast, smaller numbers of juveniles were caught in tidal creeks during July.

White perch is a major sports fish in Maine and New Hampshire, while further south significant commercial harvests are made from Massachusettts to North Carolina (Stanley and Danie 1983). Such fish are ubiquitous in estuarine and freshwater ecosystems; they exhibit semi-anadromous migrations within tidal water and spawning runs within lakes and ponds. Spawning usually occurs in fresh water, but it can also occur in brackish water. Once fertilized the eggs attach immediately to substrata or adhere to each other and drift freely downstream where incubation is semi-pelagic. Newly hatched larvae, which may be 3-4 mm long in 2 weeks (Hardy 1978), either swim vertically or sink, resulting in downstream drift in rivers or planktonic drift in estuaries and lakes (Wang and Kernehan 1979). Juveniles inhabit the inshore zones of estuaries and creeks for up to one year, until 20-30 mm in length, but may move downstream to beach and shoal areas during daylight. In fall, with decreasing temperatures, juveniles return to brackish waters to overwinter in tidal creeks and tributaries (Wang and Kernehan 1979). White perch were common in tidal creeks but not in eelgrass beds.

Mummichogs are not important commercial or recreational fish. However, because of their high abundances they are likely to be important in marsh food chains. Studies elsewhere have shown that mummichogs densities can be as high as six per square meter (Abraham 1985). Mummichogs mature in their second year; eggs are deposited in the high marsh on spring tides where they incubate in the air until the next spring tide. Juveniles remain in ponds and ditches on the marsh for 6-8 weeks. Fewer than 8% of fish complete two growing seasons (Kneib and Stiven 1978). Mummichogs were the most abundant species caught in salt marsh creeks of Great Bay Estuary, comprising over 50% of total catch each month (Sale and Guy unpubl.). Juveniles first appeared in June and were consistently caught in large numbers into November. Mummichogs were caught in eelgrass beds but were not abundant.

A research assessment of the effect of different estuarine habitats on the feeding ecology of winter and smooth flounders is currently underway by New Hampshire Fish and Game and the UNH Zoology Department. The program was designed to provide descriptions of four different estuarine habitats, emphasizing the role of faunal benthic organisms and community types relative to their importance to the feeding ecology of juvenile and adult flounder (H. Howell and M. Armstrong unpubl.).

The distributions and relative densities of the flounders at three sites (Fig. 8.1), are being sampled with a 5 m otter trawl of 25 mm mesh body and a 6 mm cod-end liner. Stomach contents (by species and size class) are being identified to the lowest taxon possible; sizes and wet weights of prey items are also being determined. Additionally, five replicate benthic cores are being taken from each site/month in order to characterize the benthic communities where flounder are feeding.

Benthic Invertebrates

Several environmental conditions are important in influencing invertebrate populations within the Great Bay Estuary, including water depth, substrata, temperature and salinity. Of these, tidally regulated depth creates a division between intertidal and subtidal populations (Table 8.3). Substratum type (i.e. mud/sand versus rock) is another major determinant of species composition. Rock and shingle substrata are populated by epibenthic organisms, while mud and sand have both epibenthic and infaunal components.

The Great Bay Estuary has an abundance of benthic invertebrates, primarily comprised of polychaetes (45% by number), crustaceans (26%), bivalves (15%), and gastropods (11%) (Nelson 1981, 1982). 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). In a subsequent investigation (Nelson 1982), a total of only 67 intertidal and 82 subtidal species were found in sampling 16 stations (Table 8.3). Both studies were based upon organisms retained by a 0.5 mm screen. During 1980-1981 samples were collected monthly, while during 1981-1982 sampling was bimonthly. The decreased frequency of sampling may explain the lower species numbers observed in the later investigation. Differences in core size and mesh size used to collect and sieve benthic samples can also affect results, influencing comparisons between different studies (Green 1979).

Intertidal Invertebrates

In studies of invertebrates (>1 mm size) found in the muddy intertidal environment throughout most of the Great Bay Estuary, the most common species were *Macoma balthica*, *Mya arenaria*, *Nephtys caeca* and *Nereis virens*. *Clymenella torquata*, *Gemma gemma* and *Scoloplos* spp. were occasionally found in abundance (NAI 1973). By contrast, the species found in greatest numbers on the rocky shore were *Littorina littorea*, *Mytilus edulis* and *Semibalanus balanoides*. The more coastal species *Semibalanus*, *Macoma*, *Mytilus*, and *Littorina* occur in low numbers within Great Bay, being replaced by *Crassostrea virginica*, *Geukensia demissa* and *Mulinia lateralis*.

The population structure of the intertidal fauna within Great Bay is also distinct from more coastal sites (NAI 1976). The small bivalve, *Gemma gemma*, is the most abundant intertidal infaunal organism in Great Bay (e.g. 103,000 individuals/m^2), while *Hydrobia minuta* is the most abundant gastropod.

In a recent study by R. Grizzle and colleagues (unpublished), it was also found that oligochaetes, gastropods, (*Hydrobia totteni*), bivalve mollusks, (*Gemma gemma*), and polychaetes (*Scolecolepides viridis*), were abundant within soft, muddy substrata of Great Bay and its tributaries. Sandy subtidal areas showed slightly higher species diversity with 400 species/m^2; densities of 21,033 to 26,391 individuals/m^2 were recorded. Oligochaetes and *G. gemma*, dominated within samples from sandy substrate.

A recent benthic survey in Adams Cove of Great Bay quantified the intertidal community (>0.5 mm in size) at two stations during each season (Webster 1991). The communities at both stations consisted mainly of annelids, 65 to 90%

Table 8.3. 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

Table 8.3 (continued)

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

of all individuals, but mollusks and crustaceans accounted for up to 35% of all individuals for some samples. Dominant annelids included *Streblospio benedicti*, *Heteromastus filiformis*, *Nereis deversiocolor* and oligochaetes. The dominant crustacean was the cumacean *Leucon americanus* and bivalves included *Macoma balthica*, *Gemma gemma* and juvenile *Mytilus edulis*. In spring and summer, the mud snail, *Ilyanassa obsoleta*, was very common, grazing on the mud surface. Total abundance ranged from 5,099 to 18,129 individuals/m^2, with *H. filiformis* the most abundant, 493 to 3,673/m^2. *M. balthica* ranged from 0 to 877/m^2, and mud snails ranged from 0 to 89/m^2. Most species showed greater abundance at a higher elevation in the intertidal zone, except for the mobile mud snails.

In general, the benthic community at intertidal sites in the Piscataqua River has greater percentages of annelids and lower percentages of crustaceans and mollusks than sites in Great Bay. A study by NAI (1980) at a site near a sewage outfall just upriver from Cutts Cove indicated a community of 44% annelids, 26% molluscs and 28% crustaceans for the period 1978-1979. However, samples collected more recently in outer Cutts Cove (NAI 1987, Kimball Chase 1990) showed communities made up of 82.5% and 60% annelids, virtually no crustaceans and 17.5% and 37% molluscs.

The dominant species reported in studies from the Piscataqua River include *Streblospio benedicti*, *Scoloplos sp.*, oligochaetes, and *Nereis* species (NAI 1980, NAI 1987, Kimball Chase 1990), and *Pygospio elegans* (NAI 1980). Total numbers of taxa reported for Cutts Cove were 20 taxa (averaging 11 per station) for outer Cutts Cove and 33 taxa (averaging 7.6 per station) for inner Cutts Cove (Kimball Chase 1990). Therefore species richness may be less than values reported for Great Bay (Nelson 1981). However, data for the Piscataqua River are mainly from one-time samplings, and do not reflect the total range of values that may occur over an entire year. Comparisons to monitoring data, especially from different years, should be made with caution because changes in abundance can be great from month to month (Nelson 1982).

Total abundances reported for the Piscataqua River are comparable to values from recent data in Great Bay (Grizzle unpublished, Webster 1991). NAI (1987) reported a range of 500 to 16,500 individuals/m^2 for outer Cutts Cove, and Kimball Chase (1990) reported 8,334 to 64,742 individuals/m^2 for inner and outer Cutts Cove. Recent Piscataqua River and Great Bay abundance values are less than those reported by N.H. Fish and Game (Nelson 1982) for similar sites in 1980 and 1981. In 1980, abundance values for several seasons ranged from 38,359 to 82,051 individuals/m^2 for a site near Rollins Farm on the Piscataqua River, and maximum values for four Great Bay stations ranged from 26,538 to 156,153 individuals/m^2. Total abundances for the Piscataqua River stations for 1978-1979 ranged from 12,820 to 106,410 individuals/m^2 (NAI 1980). Comparisons to the earlier data suggest that species richness and the dominant species have remained about the same, but that total abundance may be less than samples collected between 1978-1982. Monthly monitoring data would provide more information than the one-time samples collected recently.

Several additional samples were collected in the Piscataqua River system at North Mill Pond (Kimball Chase 1990). Samples from inner North Mill Pond indicated species richness, dominants and abundances similar to Cutts Cove samples. One sample from outer North Mill Pond indicated very shallow soft-substratum (approximately 15 cm deep) underlain by clay. The community was similar in abundance to North Mill Pond and Cutts Cove, with 36,347 individuals/m^2, but consisted mainly of the annelid *Streblospio benedicti* and oligochaetes.

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*.

Subtidal Invertebrates

N.H. Fish and Game Department (NHFG) studies found that subtidal soft sediment (> 0.5 mm size) communities within the Great Bay Estuary primarily contained the polychaetes *Streblospio benedicti* and *Heteromastus filiformis* plus the amphipods *Ampelisca abdita* and *A. vadorum* (Nelson 1981a, 1982). *Streblospio* and *Heteromastus* densities were greatest during the summer; *Ampelisca* is at a minimum at that time. Maximum abundance of *Heteromastus* within the Estuary was 2970 individuals/m^2 (Nelson 1982). Soft-shell clams, *Mya arenaria*, are found throughout the Estuary, with maximum densities of 820 individuals/m^2 (Nelson 1981).

Ongoing monitoring being conducted monthly by NHFG (1989-1991) includes four sites at the mouths of tributaries to Great Bay, and one site in Great Bay, but no sites in the Piscataqua River. This information is still being analyzed.

1978-1979 monitoring of 3 subtidal stations in the Piscataqua River (NAI 1980) yielded a total of 100 subtidal taxa, with abundances ranging from 25,640 to 83,333 individuals/m^2. Oligochaetes, *Streblospio benedicti, Exogene hebes, Mytilidae*, spat, and *Aricidea caterinae* were most abundant.

Large beds of the Eastern oysters, *Crassostrea virginica*, occur within the Great Bay Estuary. The highest densities of oysters (203 individuals/m^2) occur within the southwest part of Great Bay, while the largest beds are located near Nannie Island and within the upper Piscataqua River (Fig. 8.2). All beds with the exception of Nannie Island and a small bed at Adams Point are currently closed to harvesting due to bacterial pollution (See Chapter 10). Size frequency analysis of oysters for all areas studied during 1981-1982 show normal distributions (Nelson 1982). However, a 1990 study by S. Jones and R. Langan (unpublished) found that the size distribution of oysters within the Piscataqua River was skewed towards larger adults with few small individuals present (Fig. 8.3). The same study also showed that spatfall was highly variable both temporally and spatially.

As described above for several seaweed species (see Chapter 7), 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

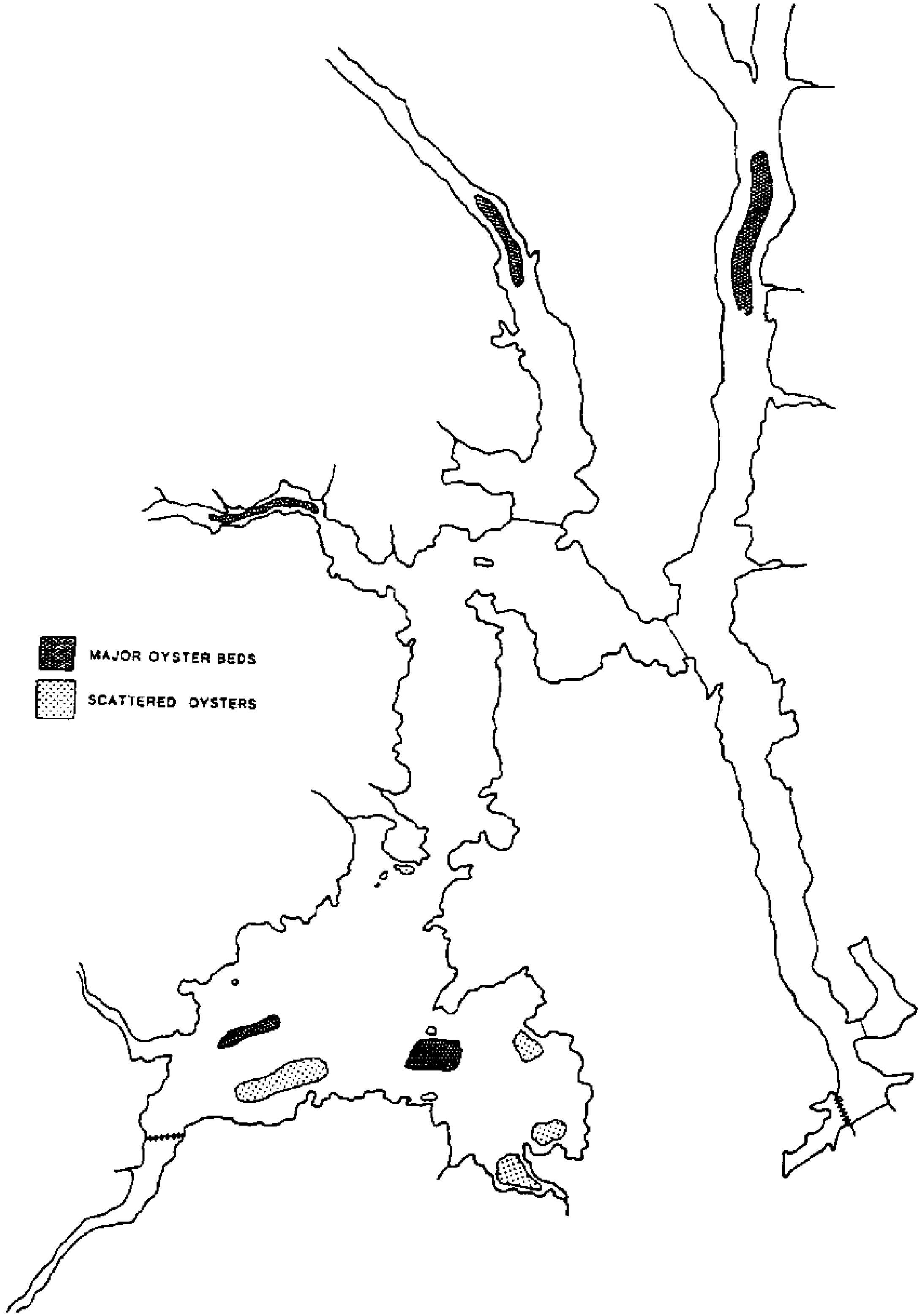


Fig. 8.2. Location of oyster concentrations in the Great Bay Estuary (Reproduced from Nelson 1982).

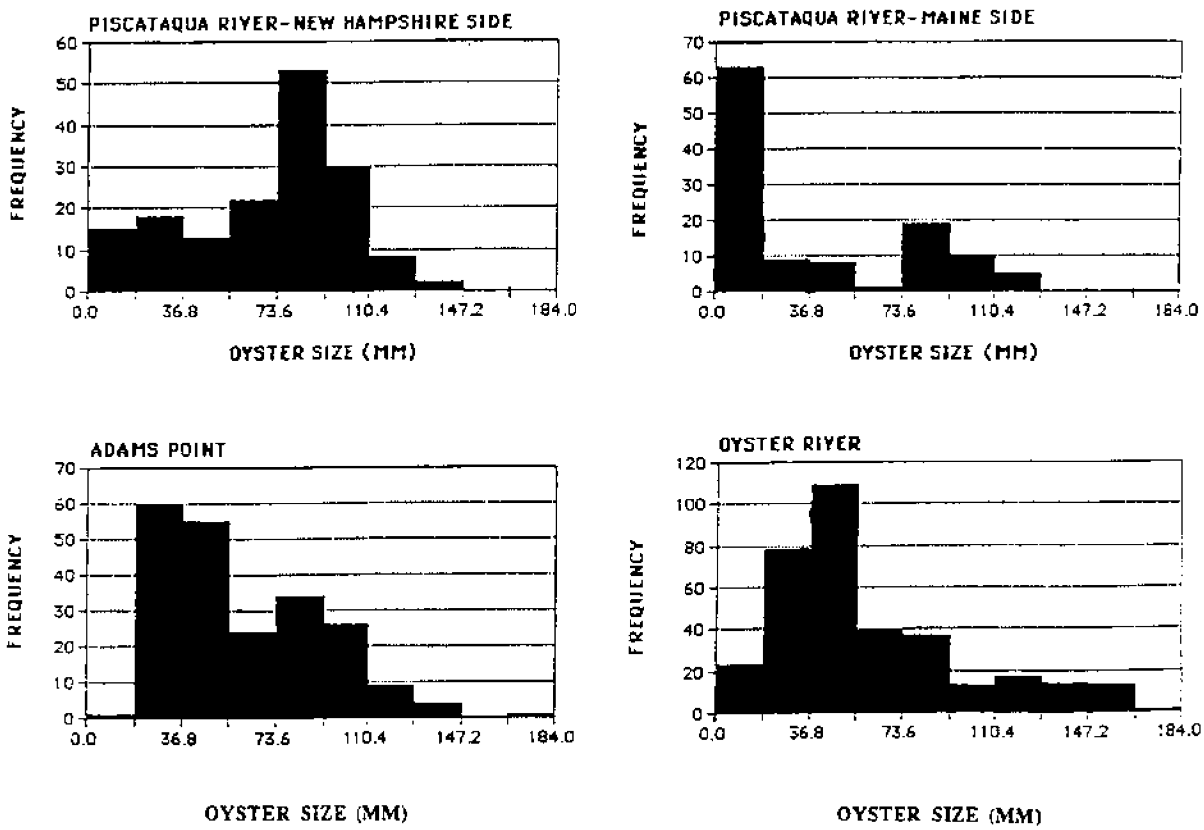


Fig. 8.3 Comparison of oyster size frequency distribution in the Piscataqua River, Oyster River, and off Adams Point in Great Bay, New Hampshire (Langan, unpubl. data)

populations from a warmer period 10,000 to 6,000 yr B.P. (*sensu* Bousfield and Thomas 1975). On the other hand, some of these disjunct species may represent recent human introductions (Jackson 1944).

To assess the extent of larval settlement in the Great Bay Estuary, a study on the colonization of artificial substrata was conducted by Normandeau Associates, Inc. (1972-1978). During 1972, fouling panels at Adams Point were settled by colonial diatoms, especially *Melosira moniliformis*; a spionid polychaete, *Polydora ligni*; amphipods, especially *Corophium* sp., *Amphithoe* sp., *Jassa falcata*, *Coremapus versiculatus* and *Hemiaegina minuta*, as well as the coelenterate *Tubularia crocea* (Table 8.3). Marked seasonal succession was observed (NAI 1978a, 1978b). *Balanus* sp. and *Mytilus edulis* were rare on fouling panels at Adams Point but abundant in the outer Estuary (NAI 1973).

Within the Estuary commercial fishing for lobsters (*Homarus americanus*) and rock crabs (*Cancer irroratus*) occurs, as well as recreational fishing for oysters (*Crassostrea virginica*). Historically a fishery for soft-shell and razor clams existed in Great Bay (Jackson 1944) but harvesting is now limited (Fig. 10.1) due to reduced clam densities and closures of beds due to red tide and bacterial pollution (see Chapters 6 and 10).

Birds

A diverse bird population occurs within the Great Bay Estuary and throughout southeastern New Hampshire. In surveys by the N.H. Fish and Game Department (Nelson 1982) as well as observation by Dr. Arthur Borror of UNH, 110 species (excluding upland birds) are known to use the Estuary (Table 8.4). The highest numbers of species occurred during April and September, coincident with spring and fall migrations. Ice cover during the winter severely restricts the areas utilized by birds in Great Bay and the rivers. Mean monthly abundances for all species combined varied from 322 in June to 3,319 during March (Nelson 1982). The most common species include: herring gulls, American black ducks, double-crested cormorants, great blue herons, and American crows. In addition, abundant overwintering migrants include: Canada geese, greater scaups, buffleheads, common goldeneyes, mallards, and red-breasted mergansers. Functionally, the bird groups observed within the Great Bay Estuary may be divided into six categories: seabirds, waterfowl and diving birds, shore birds, wading birds, estuarine predators and salt marsh birds. (Table 8.4).

Seabirds (i.e. cormorants and gulls) are year-round residents of the Estuary. Herring gulls and great black-backed gulls are common within the Estuary. In 1982, herring gulls had a maximum mean monthly abundance of 432 during September; most likely the numbers have increased since then with the general expansion of seagull populations throughout New England. The common tern occurs within the Great Bay Estuary during later spring and summer. In the past, terns nested on Nannie Island and the Footman Islands within Great Bay (Nelson 1981a). Double-crested cormorants are common during April to November.

Waterfowl are most abundant in the Estuary during the fall and winter months, but in recent years the numbers of birds has dropped dramatically (Fig. 8.4). The highest abundance of black ducks occurs from August (maximum abundance 895) through March. Large numbers (>900) of Canada geese occur during the winter. Eelgrass (*Zostera*

Table 8.4. Bird species of the Great Bay Estuary, New Hampshire (from NHFG 1981 and amended by A.C. Borror March 1991). A checklist of birds for Great Bay has recently been established by the Great Bay National Estuarine Research Reserve, which includes additional listings of upland birds.

Seabirds	
Great black-backed gull	*Larus marinus*
Herring gull	*Larus argentatus*
Ring-billed gull	*Larus delawarensis*
Bonaparte's gull	*Larus philadelphia*
Common tern	*Sterna hirundo*
Great cormorant	*Phalacrocorax carbo*
Double-crested cormorant	*Phalacrocorax auritus*
Laughing Gull	*Larus ridibuadus*
Iceland Gull	*Larus glaucoides*
Glaucous Gull	*Larus hyperboreus*
Manx Shearwater	*Puffinus puffinus*
Dovekie	*Plautus alle*
Thick-billed Murre	*Uria lomeria* (after storms)
Caspian tern	*Hydroprogne caspia*
Forster's tern	*Sterna forsteri*
Waterfowl and diving birds	
Mute swan	*Cygnus olor*
Canada goose	*Branta canadensis*
Snow goose	*Chen caerulescens*
Brant	*Branta bernicla*
Mallard	*Anas platyrhynchos*
American black duck	*Anas rubripes*
Common pintail	*Anas acuta*
American widgeon	*Anas americana*
Blue-winged teal	*Anas discors*
Green-winged teal	*Anas crecca*
Wood duck	*Aix sponsa*
Canvasback	*Aythya valisineria*
Greater scaup	*Aythya marila*
Lesser scaup	*Aythya affinis* (very rare, 1991)
Ring-necked duck	*Aythya collaris*
Common goldeneye	*Bucephala clangula*
Barrow's goldeneye	*Bucephala islandica* (very rare, 1991)
Bufflehead	*Bucephala albeola*
Oldsquaw	*Clangula hyemalis*
Black scoter	*Melanitta nigra*
Surf scoter	*Melanitta perspicillata*
Redhead	*Aythya amprilana*
White-winged scoter	*Melanitta deglandi*
Surf scoter	*Melanitta perspicillata*
Common merganser	*Mergus merganser*

Table 8.4 (continued)

Red-breasted merganser	*Mergus serrator*
Hooded merganser	*Lophodytes cucullatus*
Common loon	*Gavia immer*
Northern pintail	*Anas acuta*
Northern shoveler	*Spatula clypeata*
Gadwall	*Anas strepera*
Ruddy duck	*Oxyura jamaicensis*
Red-throated loon	*Gavia stellata*
Horned grebe	*Podiceps auritus*
Pied-billed grebe	*Podilymbus podiceps*
Red-necked grebe	*Podiceps grisegena*
Wading birds	
Least bittern	*Lxobrychus exilis*
American bittern	*Botaurus lentiginosus*
Glossy ibis	*Plegadis falcinellus*
Great egret	*Casmerodius albus*
Snowy egret	*Egretta thula*
Great blue heron	*Ardea herodias*
Green-backed heron	*Butorides striatus*
Black-crowned night heron	*Nycticorax nycticorax*
Little blue heron	*Florida caerulea*
Cattle egret	*Bubulcus ibis*
Yellow-crowned night heron	*Nyctanassa violacea*
Shore birds	
Black-bellied plover	*Pluvialis squatarola*
Killdeer	*Charadrius vociferus*
Solitary sandpiper	*Tringa solitaria*
Spotted sandpiper	*Actitis macularia*
Greater yellowlegs	*Tringa melanoleuca*
Lesser yellowlegs	*Tringa flavipes*
Dowitcher	*Limnodromus* spp.
Ruddy turnstone	*Arenaria interpres*
Pectoral sandpiper	*Calidris melanotos*
Dunlin	*Calidris alpina*
Sanderling	*Calidris alba*
Least sandpiper	*Calidris minutilla*
Semipalmated sandpiper	*Calidris pusilla*
Semipalmated plover	*Charadrius semipalmatus*
Lesser golden plover	*Plurialis dominica*
Upland sandpiper	*Bartramia longicauda*
Whimbrel	*Numenius phaeopus*
Red knot	*Calidns canutus*
Western sandpiper	*Ereunetes mauri*
White-rumped sandpiper	*Erolia fuscicollis*
Baird's sandpiper	*Erolia bairdii*

Table 8.4 (continued)

Stilt Sandpiper	*Micropalama himantopus*
Buff-breasted sandpiper	*Tryngites subruficollis*
Short-billed dowicher	*Limnodromus griseus*
Common snipe	*Capella gallinago*
American woodcock	*Philohela minor*
Wilson's phalarope	*Steganopus tricolor*
Rednecked phalarope	*Phalaropus fulicanus*
Estuary birds of prey	
Common snipe	*Capella gallinago*
Belted kingfisher	*Megaceryle alcyon*
Northern harrier	*Circus cyaneus*
Red-tailed hawk	*Buteo jamaicensis*
Bald eagle	*Haliaeetus leucocephalus*
Osprey	*Pandion haliaetus*
Peregrine falcon	*Falco pereginnus*
Great Horned Owl	*Babo virginianus*
Salt marsh birds	
Virginia Rail	*Rallus limicola*
Red-winged Blackbird	*Agelains phoeniceus*
Sharp-tailed Sparrow	*Ammospiza candacuta*
American Kestrel	*Falco sparverius*
Cooper's hawk	*Accipiter cooperii*
Turkey vulture	*Cathartes aura*
Sharp-shinned hawk	*Accipiter stnatus*
Northern goshawk	*Accipiter gentilis*
Red-shouldered hawk	*Buteo lineatus*
Broad-winged hawk	*Buteo platypterus*
Rough-legged hawk	*Buteo lagopus*
Merlin (pigeon hawk)	*Falco columbarius*

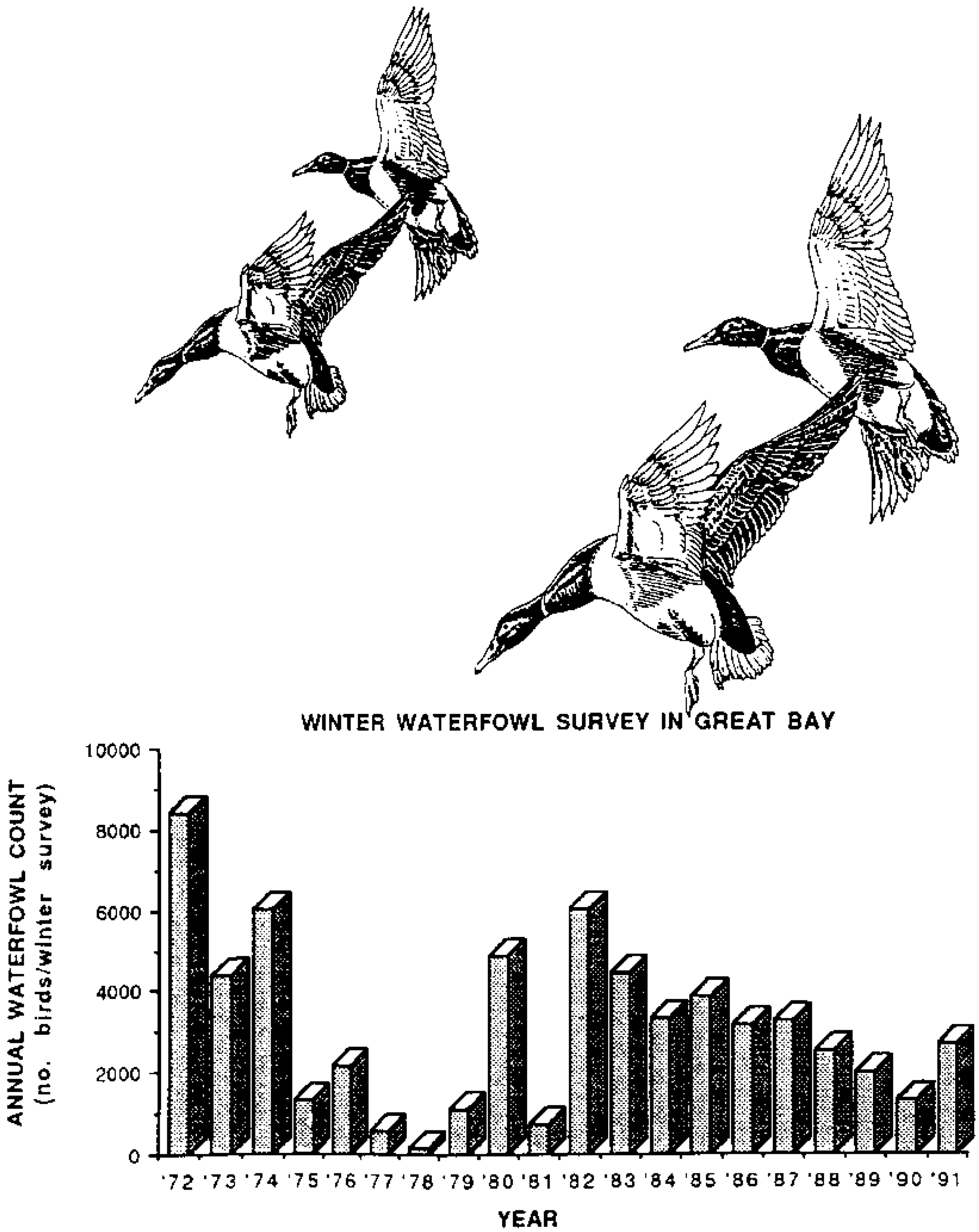


Fig. 8.4. Annual count of waterfowl wintering in Great Bay from 1972 to 1991 (NHFG 1991).

marina) and some green seaweeds, e.g. *Ulva lactuca*, provide a major source of food for overwintering ducks and geese (Short per. obs.). The long-term records of wintering black ducks and Canada geese populations shows a strong loss of both species, despite a large year to year variation due to weather and ice conditions (Fig. 8.5).

The great blue heron is the most prominent wading bird, occurring primarily from April to October. Other wading species include snowy egrets, green-backed herons, black-crowned night herons, glossy ibis, greater and lesser yellowlegs, and least sandpipers. Upland sandpipers are a rare species, even though they still nest on the Pease Air Force Base land.

Common terrestrial species utilizing the estuary are the American crow (*Corvus brachyrhynchos*) and the belted kingfisher (*Megaceryle alcyon*). Adams Point also has a large population of ruffed grouse (*Bonasa umbellus*) (Texas Instruments, Inc. 1974).

Several endangered and threatened bird species, including bald eagles, common terns, upland sand pipers, and common loons utilize part of the 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 (Audubon Society of NH per. com.). During recent winters up to fifteen eagles have occupied this wintering area simultaneously during early December through March (Table 8.5). Ospreys, common loons and pied-billed grebes forage in the Estuary during migration; one osprey pair nested on Great Bay in 1990.

Mammals

Harbor seals (*Phoca vitulina*) are frequently observed in winter and spring throughout the Great Bay Estuary, particularly at a rock ledge near the mouth of the Oyster River (NAI 1974b, Nelson 1982). In Great Bay, seals are seen in the channel at Furber Strait, on the rock ledge outcrop off Adams Point, and up the rivers, where they have been observed hauled out on the ice eating eels (Short per. com.).

Terrestrial mammals that utilize the Great Bay Estuary include raccoons (*Procyon loton*), white-tail deer (*Odocoileus viginianus*), red fox (*Vulpes vulpes*), woodchuck (*Mormota morax*), muskrats (*Ondlatra zihethicus*), chipmunks (*Tomias striatus*), grey squirrels (*Sciurus carolinensis*), cottontail rabbits (*Sylvilagus floridanus*), mink (*Mustela vison*), otter (*Lutra canadensis*) and beaver (*Caston canadensis*). Whitetail deer are very common in Durham and on Adams Point with several over-wintering yards present in the area (Texas Instruments, Inc. 1974).

Analysis of the New Hampshire Fish and Game records of mammals harvested for the towns in the Great Bay watershed suggest important trends in populations of various species over time. For example, harvesting of white-tailed deer in the region has showed a steady increase since the reduced deer population sizes of the early 1960s (Fig. 8.6). Sustained increased harvests reflect increased population size, probably resulting from improved management practices. The overall pattern of increase is not evident in some towns like Newington where deer harvests have dropped from 15.4 to 5.6% of the regional deer harvest, reflecting Newington's extensive commercial development.

The trapping of fur bearing animals also provides an indication of population size that may reflect indirect human impacts (Fig. 8.7). The relatively

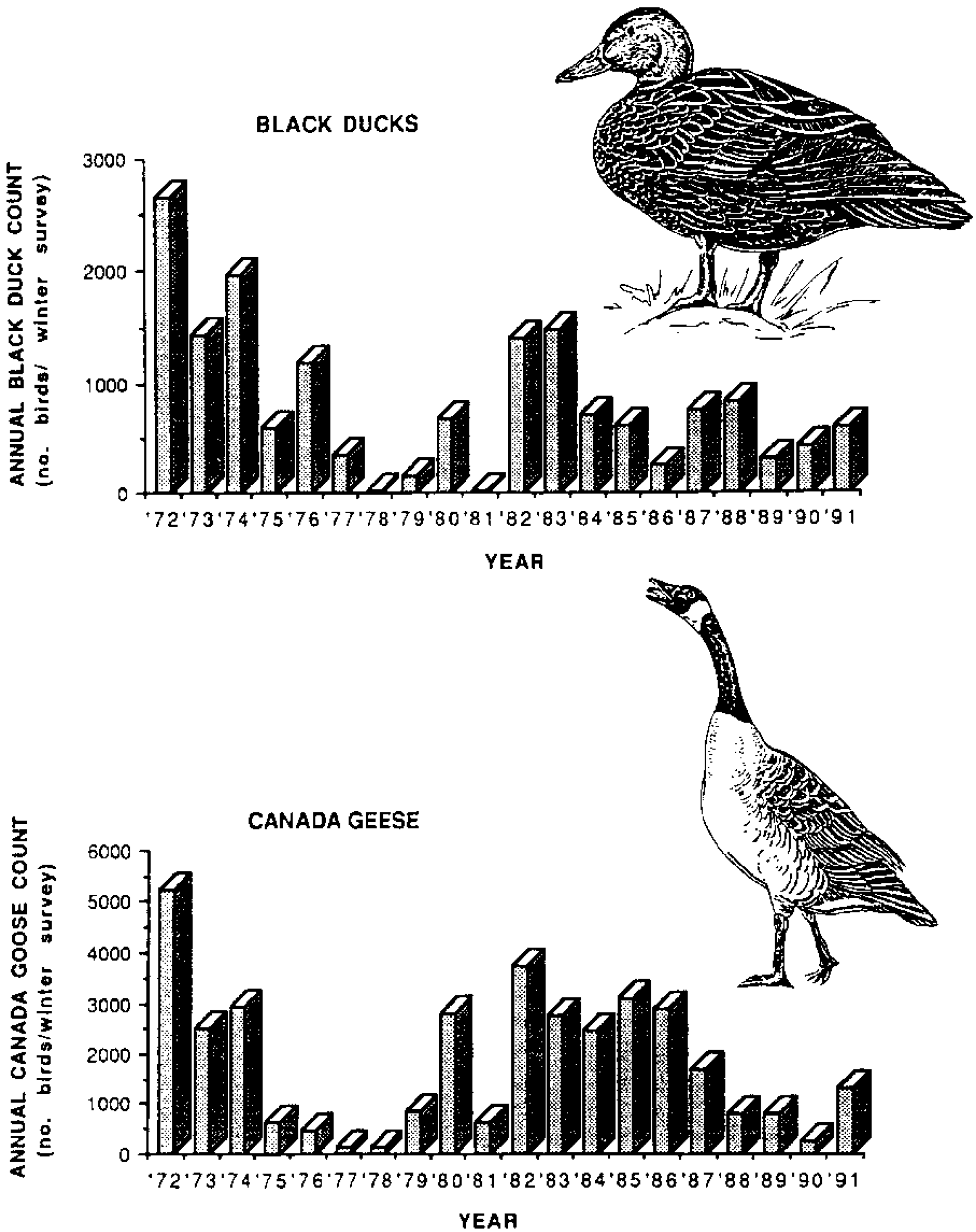


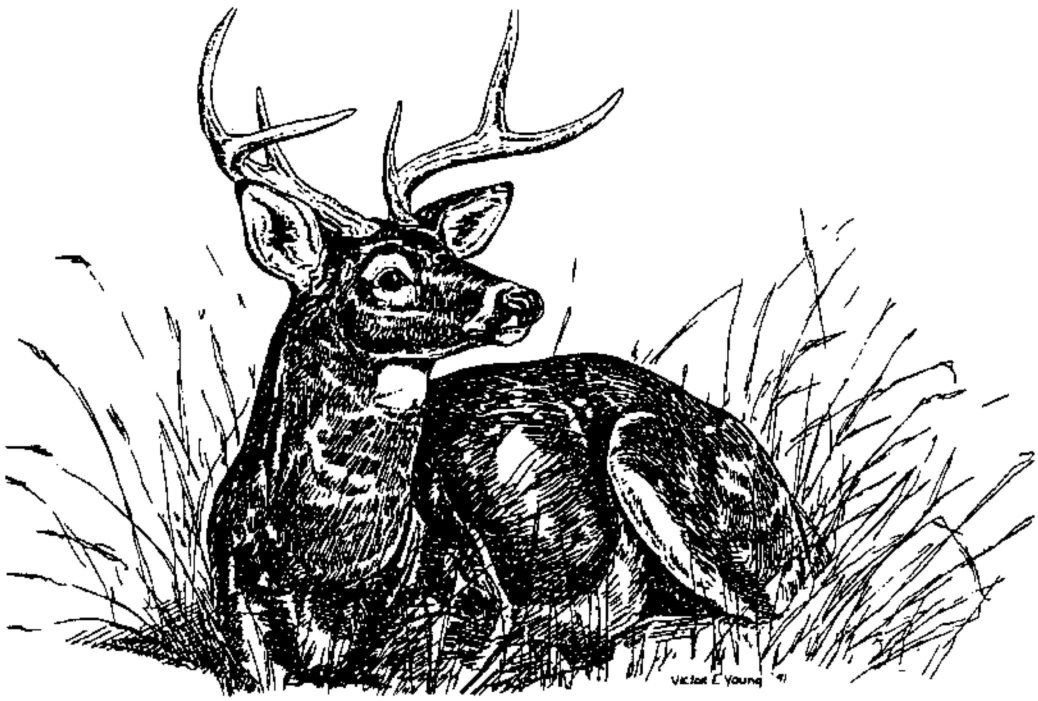
Fig. 8.5. Annual count of black ducks and Canada geese in Great Bay from 1972 to 1991 (NHFG 1991).

Table 8.5. Wintering bald eagle populations in Great Bay, New Hampshire 1982-1990 (Audubon Society of New Hampshire).

Year	Minimum Eagles Documented	Eagle Use Days	Period of Eagle Document
1982-83	4	61	30 Nov - 24 Feb
1983-84	7	79	25 Dec - 2 Mar
1984-85	8	146	22 Nov - 24 Mar
1985-86	9	151	23 Dec - 21 Mar
1986-87	9	172	14 Dec - 15 Mar
1987-88	15	187	1 Dec - 12 Mar
1988-89	11	239	10 Dec - 28 Mar
1989-90	12	220	7 Dec - 12 Mar

uniform harvest of beaver demonstrates the adaptable nature of this species which creates its own habitat by damming streams and flooding lowlands. Other animals like raccoon and fisher appear to have adapted to living with increased human populations and both have increased in population over the past twenty years. Fox populations increased from the seventies through the mid 1980s. Subsequently, they have decreased perhaps because of the appearance and rapid expansion of coyotes in this area.

Populations of muskrat, mink and otter have decreased recently (Fig. 8.7). The declines in these species may be associated with the heavy losses of wetlands, shoreline development along streams and rivers, and the overall decrease in open space. Although these harvest data are not the best indicators of mammal populations, they suggest that major changes in wildlife have occurred, particularly over the past five years.



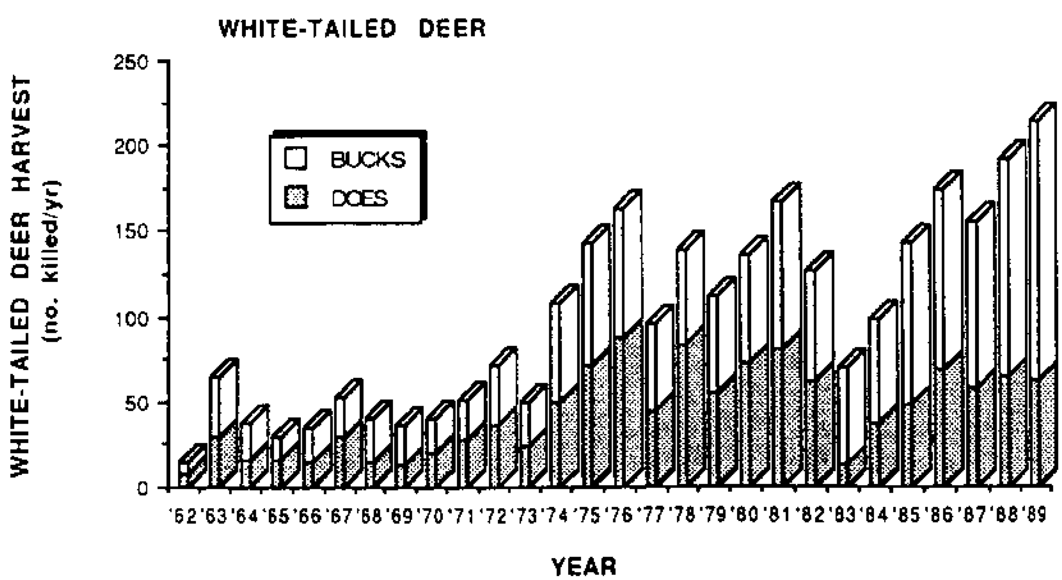


Fig. 8.6. Annual harvest of white-tailed deer in Great Bay communities from 1962 to 1989 (NHFG 1991).

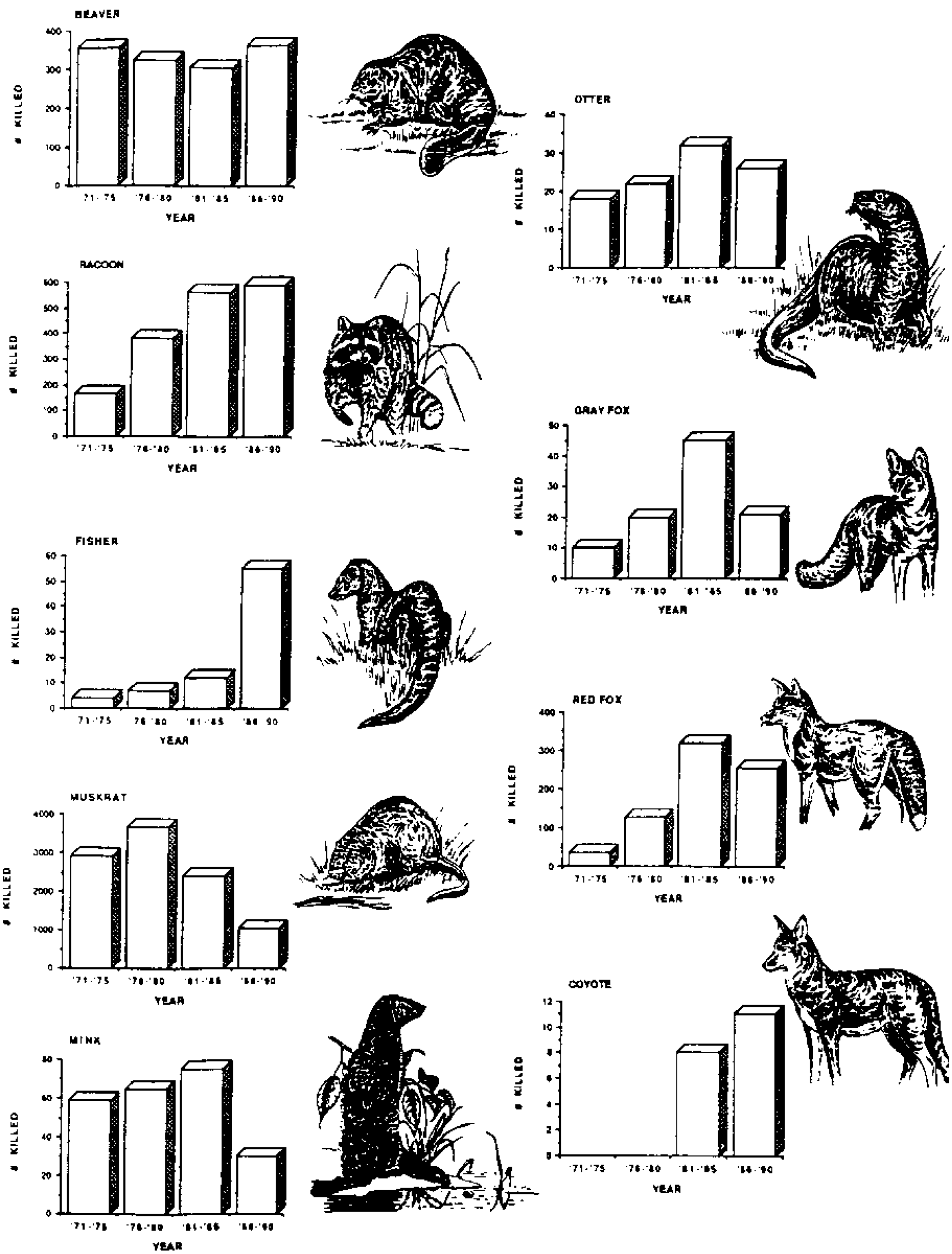
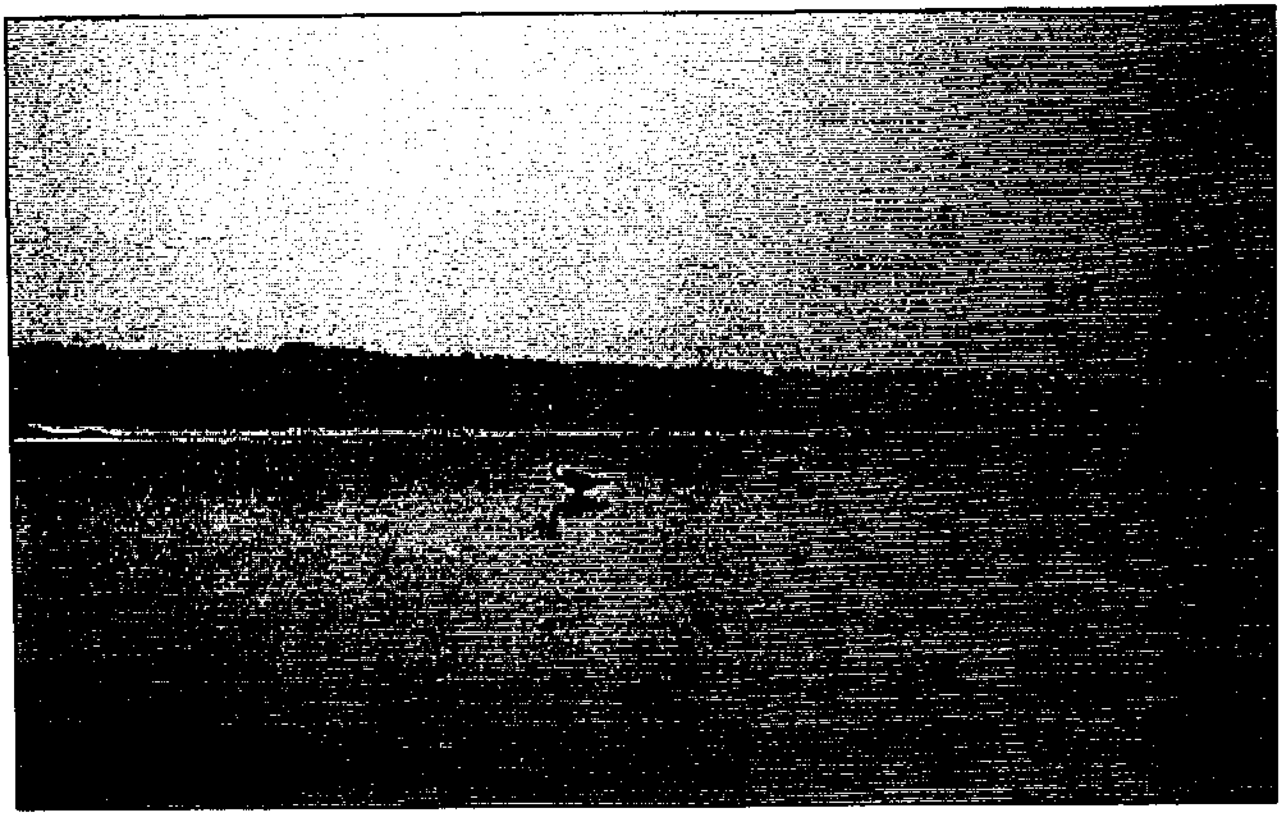


Fig. 8.7. Average annual mammal harvest from trapping in communities surrounding Great Bay from 1971 to 1990 (NHFG 1991).



Wading birds, like these great blue herons, line up along tidal channels to feed on fish and shrimp that leave the eelgrass meadows at low tide.

Chapter 9: Biogeochemical Processes
by S.H. Jones and F.T. Short

Biogeochemical processes are the main mechanism by which organic matter, produced in the estuary or entering the estuary, is broken down and remineralized as part of the estuarine detrital cycle. Organic matter is decomposed by microbial activity occurring both within the water column and within the sediments. Biogeochemical processes are important because through the processes of decomposition and mineralization, nutrients, organic matter, and microorganisms themselves become reprocessed and recycled within an estuary, vastly increasing overall productivity.

Environments like the Great Bay Estuary are sites of significant microbially-driven biogeochemical activities. The speciation and mobilization of sulfur, iron, and other elements can change rapidly as microbial metabolism causes cycling of these compounds. The key driving force for these transformations is the activity of sulfate-reducing bacteria in sediments and salt marsh rhizospheres (Hines et al. 1989), which is dependent on the availability of readily metabolizable organic matter. Lyons and Gaudette (1979) reported that differences in the nature and quantity of organic matter were responsible for observed differences in sulfate reduction rates in sediments from different areas within the Estuary. Sulfate reduction rates were low in sediments of the Piscataqua River because the organic matter was mostly recalcitrant terrestrial plant remains. Organic matter in sediments from near Footman Island is mostly composed of the remains of microalgae and eelgrass, which are more readily degraded, thus supporting higher rates of sulfate reduction than Piscataqua River sediments.

Iron is an abundant and chemically-reactive metal that is subject to extremely rapid cycling within estuarine sediments (Hines et al. 1982, Hines et al. 1984). Elevated levels of dissolved iron in Great Bay sediment pore water during spring were associated with the formation of strong organic matter-iron complexes (Lyons et al. 1979). Tugel et al. (1986) showed that iron reduction in sediment enrichment cultures was the result of enzymatic activity, even in the presence of sulfide. As sediment temperatures warmed in spring, heterotrophic activity and dissolved iron concentrations increased, while dissolved organic matter decreased (Hines et al. 1982). Further warming was accompanied by increases in sulfate reduction and dissolved organic matter, then a dramatic increase in dissolved iron with the onset of bioturbation activities. The speciation and mobilization of other elements are also affected by the springtime transition period and iron cycling in Great Bay (Hines et al. 1984). Manganese and molybdenum varied temporally with iron throughout 1978 within Great Bay sediments, while copper behaved chemically like iron only during spring. Hines et al. (1985) showed wide seasonal variations in rates of sulfate reduction and iron mobility within Great Bay sediments; these patterns also differed from year to year. The above described bacterial activities are important from an ecological standpoint, as well as having potentially profound influences upon the speciation and mobilities of heavy metal pollutants within sediments.

The natural cycling of nitrogen, phosphorus and silicon in estuarine sediments is also microbially mediated. During anaerobic degradation of organic matter, nitrogen is remineralized to ammonium, while phosphorus is remineralized to orthophosphate in association with sulfate reduction processes. Ammonium is released into the sediment pore water where it either absorbs to sediments, diffuses up into the oxidized surface sediments, or is removed by the uptake of rooted plants (Short 1987). The cycling of phosphorus is more complex. In addition to the same dynamics of ammonium, phosphate is immobilized during iron cycling (Fenchel and Blackburn 1979). The rate of nutrient remineralization in estuarine sediments is strongly influenced by organic content, temperature, and redox state of the sediments.

Recycling of nutrients in oxidized sediments is also microbially regulated. Nitrate and nitrite are formed through nitrification; nitrous and nitric oxides or di-nitrogen gases are formed through denitrification of nitrate, and gaseous nitrogen forms are removed via nitrogen fixation and diffusion into the overlying water. Phosphate removal in oxidized sediments is primarily by plant uptake or diffusion into the water. The benthic flux of C, N, P and Si from the sediments of Great Bay have been quantified (Lyons et al. 1982).

Animals living within the sedimentary environments of Great Bay have a considerable influence on reduction and oxidation reactions (Hines et al. 1991). The differences in seasonal variations of sediment chemistry demonstrated by Hines et al. (1985) were largely attributed to differences in infaunal bioturbation activities. For example, low dissolved iron concentrations during the summer of 1978 were probably caused by the absence of bioturbation, due to extremely severe winter conditions during 1978. Rates of sulfate reduction were 4.5 times more rapid at the Jackson Estuarine Laboratory (JEL) bioturbated site than at the non-bioturbated Squamscott and Lamprey Rivers site (Hines and Jones 1985). Infaunal bioturbation activities caused enhanced anaerobic microbial activity, continuous and rapid cycling of iron and sulfur, net removal of organic matter, and increased rates of nutrient cycling at the JEL site. Sediments subject to bioturbation were dominated by the capitellid polychaete *Heteromastus filiformis* and the tellinid bivalve *Macoma balthica* (Hines et al. 1984), which can turn over the top 10-15 cm of the sediments at this site several times each summer (Hines et al. 1991). Thus, seasonal differences in sediment pore water chemistry are related to differences in the incidence and rates of infaunal bioturbation.

In general, infaunal activity in Great Bay sediments increases in June, accompanied by increases in sulfate reduction rates and dissolved iron concentrations and a decrease in sulfide concentrations (Hines and Jones 1985, Hines et al. 1985, Hines et al. 1991). The sulfide is kept low because of precipitation with reduced iron, which is replenished throughout sediments with bioturbation activities. Transport of reduced FeS to sediment surfaces with infaunal fecal deposits results in oxidation of the iron upon contact with the oxygenated overlying water. The oxidized iron is reworked into sediments where it is again reduced to produce ferrous iron at rates that exceed sulfide production. The result is low sulfide concentrations and relatively elevated concentrations of dissolved iron.

Vascular plants also play key roles in mediating the redox potential and associated chemical reactions in sediments of the Great Bay Estuary. There is a close relationship between plant growth stage and sediment microbial activity in both eelgrass beds (Short 1987) and salt marshes (Hines et al. 1989, Morrison and Hines 1990).

Rates of ammonium and phosphate regeneration in the sediments of eelgrass beds in the Great Bay Estuary are extremely rapid (Short, Burdick, and Jones 1991). Analysis of eelgrass growth and nutrient requirements have shown that rapid rates of nitrogen mineralization are necessary to maintain high eelgrass production (Short 1987). The production of eelgrass leaves, which eventually become detritus on the sediment surface, and the turnover of root and rhizome material in the sediments, provide organic matter to fuel sulfate reduction and mineralization of nutrients. Photosynthetic oxygen production by eelgrass leaves is transported into the sediments via roots and can influence the oxidation state of the sediments (Smith et al. 1988). These microbial activities in the sediments stimulate plant growth.

In salt marshes, dissolved organic material from *Spartina patens* and tall and short *Spartina alterniflora* supply energy for enhanced sulfate reduction, especially during vegetative growth of tall *S. alterniflora* (Hines et al. 1989). Aboveground growth of plants begins in June and elongation ends in early August when flowering occurs (Chock 1975). Sulfate reduction is most active during elongation, with four-fold decreases in sulfate reduction observed upon the onset of flowering of *S. alterniflora*. Sulfate reduction and the dissolution and precipitation of iron within these sediments was dependent on variations in gas diffusion and water availability caused by plant productivity, water transport, tides, and rainfall events.

Waterlogged areas such as salt marshes are significant sources of sulfur gases, such as hydrogen sulfide, dimethyl sulfide, carbon sulfide, and dimethyl disulfide, all metabolites of biological activities (Hines et al. 1991). In the salt marshes of the Squamscott River, fluxes of dimethyl sulfide and methane thiol were greater from stands of *S. alterniflora* than from stands of *S. patens* (Morrison and Hines 1990). This was related to the greater amount of emergent biomass and the osmoregulatory compound, dimethylsulfonioproprionate, in *S. alterniflora*. A net efflux of carbonyl sulfide was measured in stands of *S. patens*, while a net uptake was measured in stands of *S. alterniflora*. Emissions of methane thiol and carbonyl sulfide were much lower than dimethyl sulfide emissions. Such sulfur gas emissions to the atmosphere are important as part of the global sulfur cycle and because of their potential impact on global climate.

Thus, the reprocessing and recycling of primary and secondary production within the Estuary, through the processes of biogeochemical activity, contribute to estuarine productivity through export to offshore waters and the global environment. These biogeochemical processes are the unseen machine that completes the cycle of life and death in the Estuary initiated by the primary producers and consumers.

House construction sites on Great Bay. The land is cleared of vegetation to the water's edge and houses are being built near the water with no shoreline buffer to protect the water quality.

Chapter 10: Great Bay Estuary Management Issues
by F.T. Short, S.H. Jones, P.F. Sale and P. Wellenberger

A number of specific as well as interactive management issues are of immediate concern when considering the health of the Great Bay Estuary. We have selected five primary issues which we consider critical. The issues are presented without prioritization, which can only be done after broad-based input from researchers, user groups, and governmental agencies associated with the Great Bay Estuary. The primary issues are the closure of shellfishing beds, the rapid rate of shoreline development, the loss of eelgrass habitat, a decrease in water clarity, and the need to investigate the potential impact of hazardous wastes and contaminants entering estuarine waters. The issues are of both immediate and long-range concern, and they should be addressed in the early stages of monitoring and research activities of the Great Bay Estuarine Research Reserve System. Until an estuary-wide management program can be developed and implemented, management activities for the remainder of the Estuary will fall to the towns and the two states involved, as well as the federal government. This chapter also discusses the issues of wetlands loss, habitat restoration, and mitigation for replacing resources destroyed by development. Finally, the management goals for Great Bay are presented and discussed in terms of research priorities, education objectives and management action.

Microbial Pollution and Shellfish Closures

The Great Bay Estuary has abundant shellfish resources that can be found in the tidal rivers as well as in Little and Great Bays (Nelson 1982). In New Hampshire, the limited shellfish resources are harvested only for recreational use because commercial shellfishing is not allowed. The shellfish that are of primary interest include oysters (*Crassostrea virginica*), mussels (*Mytilus edulis*), razor clams (*Ensis directus*) and softshell clams (*Mya arenaria*), with the major interest in oysters. State and federal laws set water quality standards that determine whether shellfish can be harvested from given areas. To help prevent disease in consumers of raw shellfish, water quality standards use certain types of bacteria and their concentrations as indices of fecal contamination. A problem occurs when estuarine water overlying potential shellfish harvest sites becomes polluted with fecal material and contaminates shellfish. Shellfishing in these areas is then prohibited, resulting in limited public access to shellfish resources.

The sewage contamination issue has recently received a great deal of public attention in New Hampshire, with the closing of clam and oyster beds in much of the Great Bay Estuary and the closing of the clam flats in Rye and Hampton/Seabrook Harbors. In response, the reopening of shellfish beds has emerged as a priority for New Hampshire regulatory agencies (Flanders 1989, 1990). In 1985, 71%, (9,000 of 12,599 acres) of classified shellfish waters in the Great Bay Estuary were closed to shellfishing

(USEPA/NOAA 1987). Based on 1988 sampling, 72% of shellfish waters in the Estuary were closed (NHDES 1989).

The coastal and estuarine waters of New Hampshire, as well as much of the rest of the country's coastal waters, have been contaminated with fecal material for as long as people have lived in the region. It has only been in this century that knowledge of the connection between human fecal pollution and disease incidence in the shellfish-consuming public has generated enough concern to induce governmental agencies at local, state, and federal levels to mitigate sources of pollution or to close shellfish beds where contamination persists. In New Hampshire, many communities built sewage treatment facilities from 1950 to 1970. However, during this time and thereafter the population of coastal New Hampshire increased at a tremendous rate (Fig. 5.7). The result of this population growth is that wastewater treatment facilities built 20 years ago are too small to adequately treat the volumes of wastewater generated by the communities that they serve. The discharge of this inadequately-treated sewage into the Estuary is the cause of shellfishing closures. The N.H. Department of Environmental Services and coastal communities are beginning to take steps to abate pollution which may eventually enable reopening of shellfish beds (NHDES 1990).

Classifying shellfish areas as approved for harvesting implies that the water is clean enough so that people will not become sick if they eat *raw* shellfish; shellfish contaminated with very high numbers of microbial pathogens can be eaten if properly cooked and not cause disease. Thus, continued fecal-borne pollution poses the greatest hazard to those that choose to eat raw shellfish harvested from the Estuary. The symptoms that are most commonly associated with consumption of raw shellfish are low-grade diarrhea and fever that last only a short time, and many such disease instances stemming from shellfish consumption are not reported. However, certain viruses and bacteria that may be associated with fecal pollution can cause more serious diseases, and it is the responsibility of the State to continuously monitor water quality to assure that classified areas meet appropriate water quality criteria.

The State of New Hampshire monitors the shellfish growing waters of New Hampshire at a number of sites, including some within the Great Bay Estuary. Water samples are collected each month at low tide and analyzed for total coliforms. The total coliform test is the oldest accepted bacterial indicator of fecal contamination for water quality assessment, but is now generally regarded as a poor indicator of fecal pollution (Grimes 1987). Other indicators such as the enterococci have been shown to be superior to total coliforms as indicators of the risk of gastrointestinal disease from exposure to contaminated water (US EPA 1986). The New Hampshire Department of Environmental Services is presently seeking a legislative change of the total coliform standard to another acceptable indicator (Flanders 1990).

There are no flawless indicators; using bacteria as indicators of viruses does not work, and no indicators correlate with the presence of indigenous bacterial pathogens, such as *Vibrio vulnificus* and *V. parahaemolyticus*, that are found in Great Bay (O'Neill et al. 1990, Jones et al. 1991). Eventually, the development of rapid, easy, and inexpensive methods based on molecular biological techniques for the detection of specific bacterial and viral pathogens will replace the use of indicators.

The closing of shellfish growing areas in the Great Bay Estuary has a variety of impacts on the shellfish resources of the region. For oyster beds that are closed, the lack of harvesting activities permits continued growth of the oysters to larger sizes. The lack of harvest activities may result in crowding of the oysters. Disturbance from harvesting may in some cases be good for an oyster bed, knocking silt off shellfish and turning shells over and allowing for additional spat settlement surfaces. Another possible impact of closing some areas and leaving smaller and smaller areas open to harvesting is that intensified harvesting in the open areas may eventually deplete these resources. The closing of the Seabrook/Hampton and Rye Harbor clam flats has resulted in an overall reduction of shellfishing activities (Fig. 10.1) but may increase harvest pressures on the Great Bay oysters and clams.

A large portion of the contamination problem within Great Bay may be derived from downstream sources originating from the Durham, Dover or other sewage plants that discharge improperly treated effluent into the Estuary. On the flood tide, this material is rapidly carried into the central part of Great Bay where it contributes substantially to fecal coliform contamination (see Chapter 6). The problem of fecal contamination within the Estuary goes hand in hand with problems of runoff and nutrient loading that also are of major concerns, contributing to eelgrass decline and decreased water clarity.

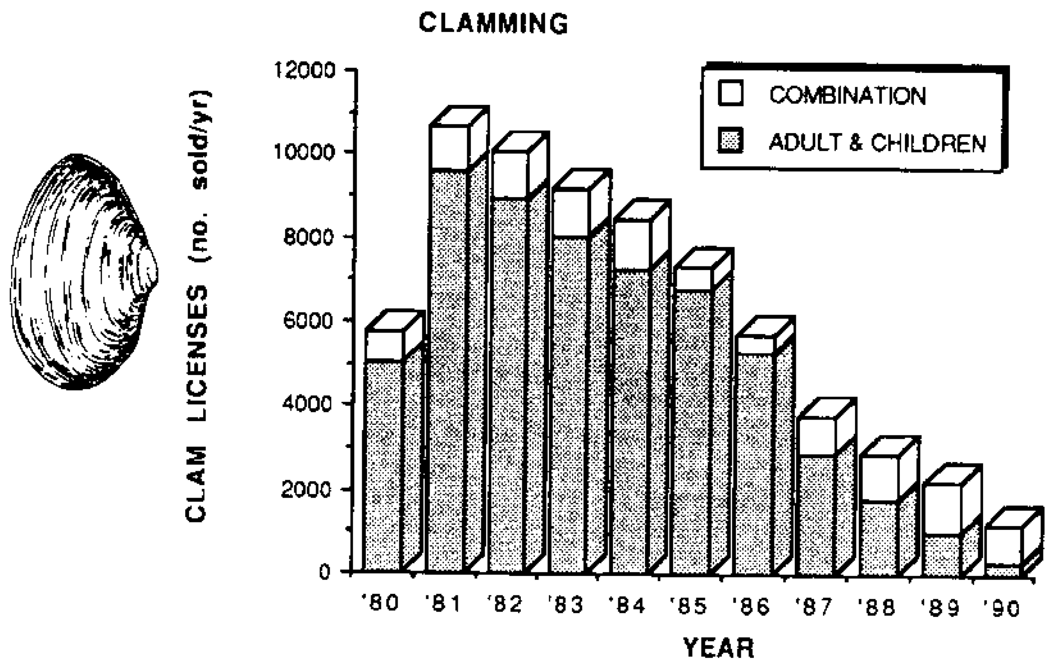
Shoreline Development

Rapid shoreline development is a major problem within estuarine areas throughout New England and the U.S. (Culliton et al. 1990). Ultimately, the major concerns are what degree of development should be allowed and what amount of shoreline should be protected in order to preserve the character of an estuarine environment. The model we need to consider is the same one utilized in determining buffer strips along rivers or riparian zones (100 m setback). That is, what setbacks are necessary in order to maintain water quality within an estuary? In addition, what setbacks are necessary to keep the systems functioning with healthy animal and bird populations?

Land and shoreline ownership around the Great Bay Estuary and throughout its tidal waters is predominantly private, with some lands protected or in governmental ownership (Table 10.1 and Table 10.2). Overall, the amount of protected shoreline is small (Table 10.2).

The issue of shoreline development is particularly crucial to the Great Bay Estuary as previously it has been minimal due to private and public ownership of large blocks of land. Today, few towns around the Estuary have adequate protection for shorelines or wetlands (Table 10.3). The pressure for shoreline development within the Estuary can only increase. The issue of shoreline protection is also complicated by the large number of town and governmental bodies involved. The closure of Pease Air Force Base and the fate of the eastern shoreline of Great Bay is of major concern (Schultz 1991). Shoreline protection is a major priority for the Great Bay Estuarine Research Reserve.

The loss of the upland buffer around the Estuary as a result of development will greatly threaten the long term health and productivity of the Estuary. From research on the riparian zone along river systems (Jones 1986), we know that this vegetated buffer is critical. Our knowledge of the value of a vegetated buffer along estuarine shore is not as well established and remains an area where research is needed. The rate of loss



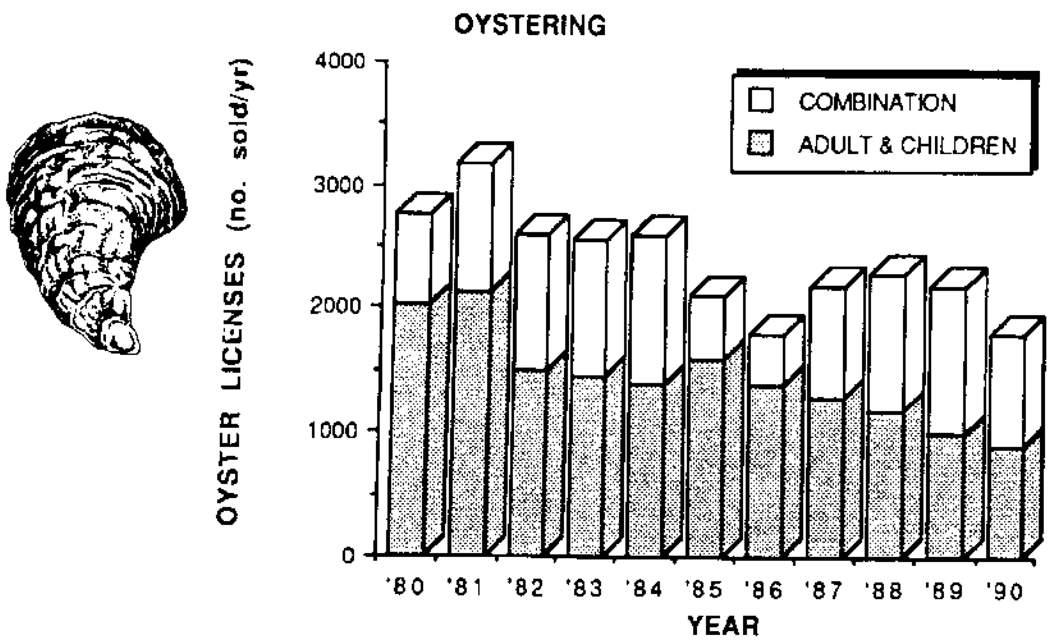


Fig. 10.1. Annual clam and oyster recreational/harvest permits sold as combination licenses and adult plus juvenile licenses between 1980 and 1990 in the Great Bay Estuary (NHFG 1980-1990).

Table 10.1. Acreage and approximate water frontage (WF) of properties owned in the Piscataqua River, Little Bay, and Great Bay tidal waters.**

WATERBODY	OWNER	ACRES	APPROX. WF(meters)
Piscataqua River Watershed:			
Cocheco R.	City of Dover	7.7	1523
	Private	561.5	12931
Piscataqua R.	U.S. Government	------	171
	State of Maine	9.3	232*
	State of New Hampshire	28.9	2085
	Town of Kittery, ME	4	576
	City of Dover	3.5	49
	City of Portsmouth	15	945
	Town of Newington	119	3136
	Private	1969.1	74688*
Salmon Falls R.	State of Maine	135	1260*
	Town of South Berwick, ME	7.4	439
	Private	478.1+	10268+*
Total		3338.54+	108303+
Little Bay Watershed:			
Bellamy R.	State of New Hampshire	313.4	2859*
	City of Dover	18.4	183+*
	Private	322.8+	8865*
Little Bay	State of New Hampshire	2.4	1008
	Town of Newington	119	3136
	Private	623.5+	14249
Oyster R.	Town of Durham	112	2769+*
	Private	956.5	7588*
Total		2368+	40657+
Great Bay Watershed:			
Brackett Br.	Private	105	1412
Crommet C.	State of New Hampshire	118	763*
	Private	429.5	10450
Foss Br.	Town of Greenland	3.7	195
	Private	99.2	1660
Great Bay	US Government	300	7729
	State of New Hampshire	131	1832+*
	Town of Greenland	9.9	264
	Private	1913.5	24507
Lamprey R.	Town of Newmarket	4.4	336
	State of New Hampshire	0.8	92
	Private	146.6	3399
Lubberland C.	State of New Hampshire	30	916*
	Private	275.8	18400
Pickering Br.	Private	263.1	2715
Shaw Br.	Private	44.7	1573
Squamscott R.	State of New Hampshire	159.5	2779*
	Town of Exeter	132.9	3840
	Town of Newfields	21.6	275
	Town of Stratham	7.9	794
	Private	2271.3	44515*
Unnamed Br.	Private	98.6	1725
Winnicut R.	State of New Hampshire	25	388*
	Private	348.7	4920*
Total		6940.5	135479+

* See Table 10.2 for protected land

** Sources: Strafford County, NH, Conservation District 1990; Hallett, A. 1990; NH Office of State Planning, personal communication, February 1990; Towns of Kittery, Eliot, and South Berwick, personal communication, February 1990; Rockingham County Conservation District, personal communication, March 1990; Tax Assessment Offices of Durham, Dover, Eliot, Greenland, Kittery, Madbury, Newfields, Newington, Newmarket, Portsmouth, Rollinsford, South Berwick, and Stratham.

Table 10.2. Acreage and approximate water frontage (WF) for conservation easement (CE) holders, land trusts (LT), and fee simple (FS) owners in the Great Bay Estuary*.

WATERBODY	ACRES	APPROX. WF(meters)	TYPE	HOLDER/OWNER
Piscataqua River Watershed:				
Piscataqua R.	9.2	153	FS	State of ME-Park & Landing
	1.1	97	FS	Society Pres. New England Antiquities
	.3	54	FS	Nat'l Soc. Colonial Dames
Salmon Falls R.	135	1252	FS	State of ME-State Park
	35	366	FS	Society Prot. New England Antiquities
	12	122	CE	Subdiv. homeowners
	29	672	CE	Strafford County Conservation District
	39	977	CE	Unknown
	47	916	CE	Strafford Rivers Con.
Total	307.7	4609		
Little Bay Watershed:				
Bellamy R.	14	183	CE	City of Dover
	287	1893	CE/FS	NH Fish & Game Dept.
	19	916	FS	NH Audubon
Oyster R.	2.5	92	CE	Durham Conservation Commission
	120.5	1573	LT	Land Trusts
Total	443.0	4657		
Great Bay Watershed:				
Crommet C.	118	763	CE	NH Fish & Game Dept.
Great Bay	131		FS	State of NH
Lubberland C.	30	916	CE	NH Fish & Game Dept.
Squamscott R.	159.5	2779	CE	NH Fish & Game Dept.
	52	------	CE	Rockingham County Conservation District
Wilcox Pt.	27.5		FS	NH Fish & Game Dept.
	9.67	841	CE	NH Fish & Game Dept.
Winnicut R.	25	388	CE	NH Fish & Game Dept.
	154	------	CE	Rockingham County Conservation District
Total	669.5	4846+		

* Sources: Strafford County, NH, Conservation District 1990; Hallett, A. 1990; NH Office of State Planning, personal communication, February 1990; Towns of Kittery, Eliot, and South Berwick, personal communication, February 1990; Rockingham County Conservation District, personal communication, March 1990; Tax Assessment Offices of Durham, Dover, Eliot, Greenland, Kittery, Madbury, Newfields, Newington, Newmarket, Portsmouth, Rollinsford, South Berwick, and Stratham.

Table 10.3. Land protection ordinances within the Great Bay watershed. Summary overview of town ordinances currently in effect regarding shoreline development setback distance and regulations for building on flood plains, on wetlands, and in aquifer areas.

TOWN	SHORELINE[1] SETBACK (FEET)	FLOODPLAIN	WETLAND[2]	AQUIFER
New Hampshire				
Dover	100'	Yes	Yes	Yes
Durham	50'	Yes	Yes	No
Exeter	300'/150'	Yes	Yes	Yes
Greenland	None	Yes	No	Yes
Madbury	300'	Yes	Yes	Pending
Newfields	150'/100'	Yes	No	Yes
Newington	None	No	Yes	No
Newmarket	125'	No	Yes	Yes
Portsmouth	None[3]	Yes	Pending	No
Rollinsford	250'	Yes	Yes	Yes
Stratham	150'/100'	Yes	Yes	No
Maine				
Eliot	75'/100'[4]	Yes	No	No
Kittery	75'/ MHW + 100'[5]	Yes	Pending	Yes
S. Berwick	100'	Yes	Yes	Yes

[1] First number represents large bodies of water, second perennial streams; tidal marshes can be included in either.
[2] All except Portsmouth are based upon soil type-poorly drained and very poorly drained.
[3] 100' on Sagamore Creek tidal marsh
[4] 75' for structures, 100' for septic systems
[5] 75' for non-tidal shores, mean high water plus 100' for tidal areas

of this estuarine edge is rapidly increasing and needs to be addressed.

Eelgrass Habitat Loss

Eelgrass, *Zostera marina*, is an important component of the estuarine environment (Short et al. 1986). Production from eelgrass enters the estuarine/nearshore detrital food web. In addition, eelgrass leaves serve to slow water flow and enhance sediment deposition; its root systems further stabilize sediments. Eelgrass beds also increase structural diversity of the Estuary by providing substrata for algal and invertebrate attachment, as well as protection from predators for juvenile fish and invertebrates. Eelgrass was previously widely distributed throughout the Great Bay Estuary (Nelson 1982, Short et al. 1986).

The problems of eelgrass dieoff and loss of its associated habitat are of major concern for fisheries, waterfowl populations, and the overall health of the Great Bay Estuary. The dramatic loss of eelgrass from the epidemic wasting disease within the Great Bay Estuary (Fig. 10.2) during the last twelve years (Nelson 1982a, Short et al. 1986 and 1991) is changing the character and functional relationships of organisms within the Estuary.

As with the 1930s' wasting disease, eelgrass growing in high salinity waters is most susceptible, while plants in lower salinity riverine sites are more resistant to infection (Milne and Milne 1951, Short et al. 1987). A marine slime mold (*Labyrinthula zosterae*), which was suspected but never proven to be the cause of the 1930s wasting disease, has now been shown to be the causal organism responsible for the present outbreak (Short et al. 1987, Muehlstein et al. 1988 and 1991). Localized die-offs have also occurred along the East Coast of the United States, including upper Casco Bay (Maine), Stage Harbor (Massachusetts) and the Niantic River (Connecticut). If conditions of salinity and temperature are right, *Labyrinthula* may transfer easily from plant to plant within dense eelgrass meadows. Detrital eelgrass leaves and ocean currents also spread the disease. *Labyrinthula* and the wasting disease symptoms are now found throughout most eelgrass populations on the East Coast. Whether the current outbreak of the wasting disease proves as serious to the Estuary as that of the 1930s (Jackson 1944) remains to be seen.

The dieoff of as much as 80% of the eelgrass population within Great Bay during each year of the late 1980s was followed by only a partial recovery from seed germination the following spring. The persistence of available eelgrass habitats within the Bay has decreased in recent years (Fig. 10.2). In the last two years there have been signs of a recovery of eelgrass in Great Bay and throughout the Estuary. However, the dieoff of eelgrass from the wasting disease has been exacerbated by problems of decreased water clarity resulting from nutrient loading and sedimentation resuspension within the Estuary (Short et al. 1991). It remains to be seen if recent increases in eelgrass abundance constitute the beginning of a recovery or are reflections of interannual variation.

Although the wasting disease is currently causing serious loss of eelgrass, the long-term survival and success of eelgrass in our coastal waters will depend largely on estuarine water quality. The situation is at the point where estuarine management is necessary to insure the survival of eelgrass and the ecosystem it supports. Factors that are currently decreasing water quality need to be addressed and corrected in order to create a coastal environment that will sustain healthy eelgrass, not to mention other marine organisms.

Water Clarity Problems

Decreased water clarity is a major concern to the health and productivity of the Great Bay Estuary. Problems of decreased water clarity result from large

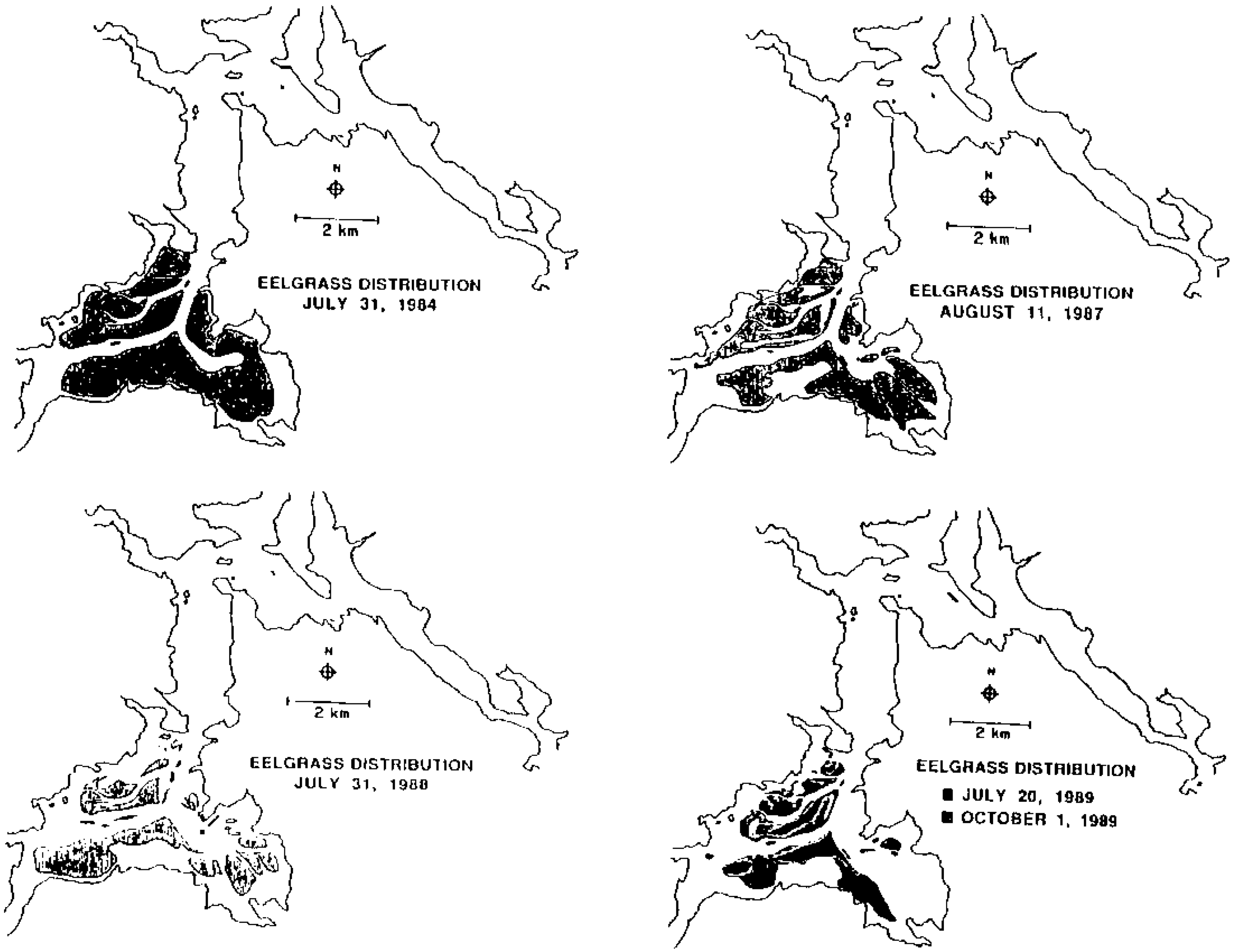


Fig. 10.2. Changes in eelgrass distribution in Great Bay between 1984 and 1989 (Short et al. 1991).

amounts of suspended materials that reduce light penetration into the water, thereby limiting the primary production of key plants, including eelgrass, macroalgae, phytoplankton, and benthic microflora.

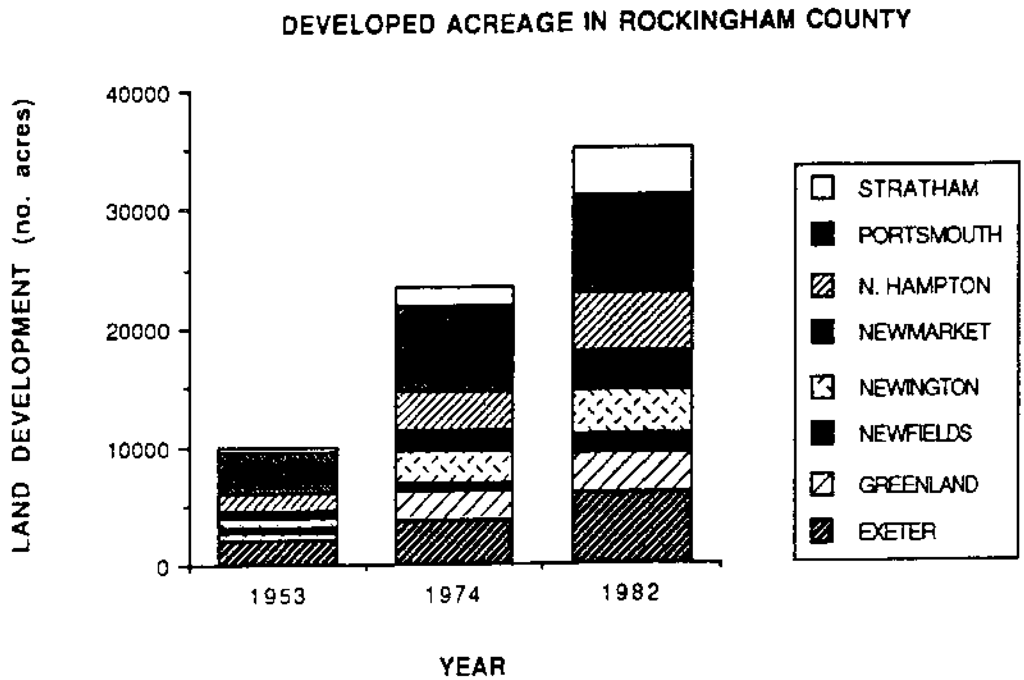
The causes of reduced water clarity in estuarine waters are three-fold: (1) sediment inputs and resuspension that increase turbidity within the water column; (2) nutrient loading from both point and nonpoint sources of nutrient pollution, stimulating phytoplankton growth which reduces light penetration; and (3) decline of eelgrass reduces the filtering capacity of the ecosystem. The problem of reduced water clarity limits the primary productivity of benthic plants. The same conditions also contribute to the dieoff of eelgrass by enhancing the wasting disease problem (see above). Suspended sediments result primarily from upland run-off, tidal currents, wind mixing, boat traffic, and clam digging in Great Bay. Sand, silt, and clay from human disturbance in upland areas wash into streams that carry suspended materials into the Estuary. Residential and commercial development as well as rapid rates of clearing and building within the watershed (Fig. 10.3) also contribute suspended sediments. The ultimate effect of suspended sediments in an estuary is decreased light, which causes reduction in benthic plant growth, sometimes to the point of elimination (Short et al. 1989).

Nutrient loading results from effluents that reach the Estuary from wastewater treatment plants, inadequate septic systems, boat discharge of human and fish wastes, and storm drain run-off carrying animal waste and fertilizers from lawns and farms. Additionally, it has been shown that even successfully functioning septic systems in coastal areas with sandy soils transmit nutrients through ground water directly into estuarine waters (Nixon and Pilson 1983). Nutrient loading is a particular problem in embayments with reduced tidal flushing. Ultimately, the primary cause of nutrient loading to an estuary is increased population density. The ultimate impact of eutrophication on eelgrass communities is the loss or degradation of the plants themselves, shifting the community of primary producers away from eelgrass dominance (Short et al. 1991). Under conditions of elevated nutrient loading phytoplankton may become so abundant that eelgrass and other algal populations are effectively shaded. Experiments with eelgrass have shown that reduction in light decreases growth, promotes a reduction in plant density and ultimately can eliminate an eelgrass population altogether (Short et al. 1991).

Environmental factors affecting water clarity, such as nutrient loading from both nonpoint and point sources, should be decreased. Other factors, such as the problem of suspended sediments, require research to separate out the inputs of new sediments into the Estuary from rivers and uplands from resuspended sediments within the Estuary.

Investigation Of Hazardous Waste And Contaminants

Currently, investigations are underway of the possibility of hazardous wastes and contaminants entering into estuarine waters at former the Pease Air Force Base, the Portsmouth Naval Shipyard, and the Watts FluidAir site. These and other potential sources of contamination to the Estuary pose both human and ecological health risks of concern. The clean-up and environmental restoration of these past hazardous waste disposal sites is currently underway through USEPA-CERCLA (Comprehensive Environmental Response Compensation and Liability Act) or RCRA (Resource Conservation and Recovery Act) programs. Laws and requirements for remediation of such hazardous waste disposal sites have been reviewed for similar problems in Rhode Island (Johnston and Nixon 1992).



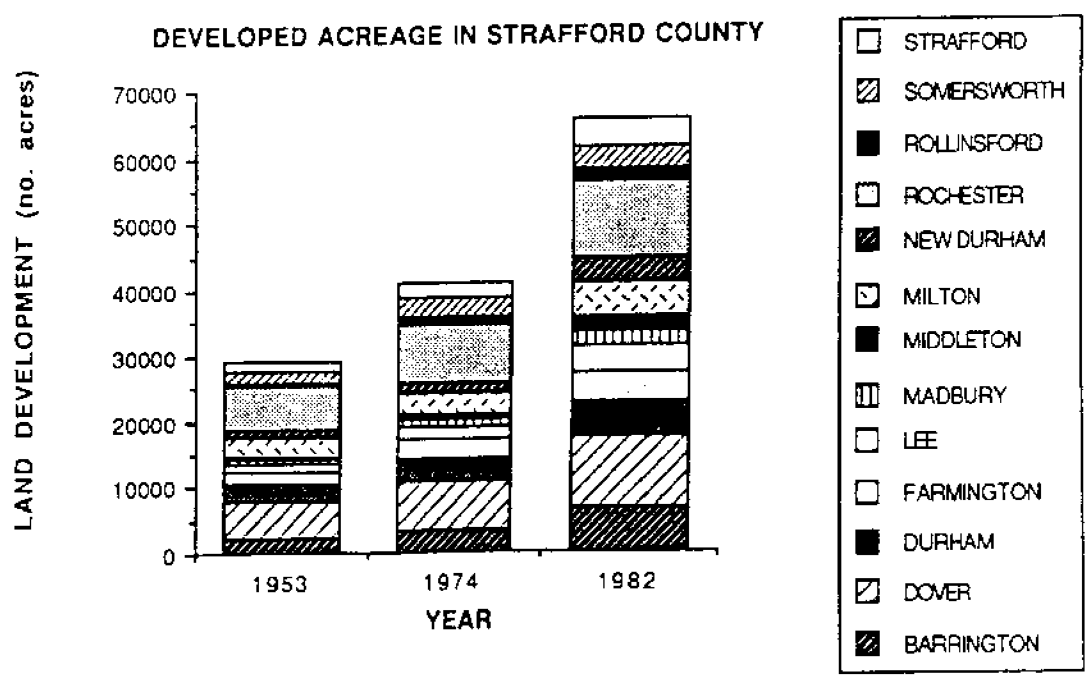


Fig. 10.3. Comparison of developed areage of the towns in Rockingham and Strafford counties (Befort et al. 1987).

The U.S. Navy is currently investigating the level of contaminants in the Great Bay Estuary and their ecological and human health risk (USEPA-ERLN and MESO-NOSC 1991). This study will provide an ecological framework to assess the potential impact of hazardous waste releases from the Portsmouth Naval Shipyard. Through this ecological study, conducted in part by scientists at the Jackson Estuarine Laboratory, UNH, a comprehensive baseline of the ecological conditions in the Estuary will be developed. This baseline will allow monitoring and research activities to determine the long term health and stability of the Estuary.

As described throughout this document (Chapters 1 and 6), the Great Bay Estuary has been the recipient of numerous unquantified levels of substances, many of which may contribute to health risks. The current discharge of contaminants into the Estuary is not well monitored and the possibility of hazardous waste discharge from as yet unidentified small business or industrial sources poses a potential threat.

Mitigation and Restoration

The loss of wetlands in estuarine areas has been recognized as a major issue threatening the maintenance of healthy environments. Wetlands loss includes the erosion and destruction of salt marsh, seagrass and other estuarine habitat through processes that directly impact these environments. Degradation of estuarine wetlands results from activities like filling and dredging, two impacts that directly and indirectly change the environmental quality to a point that these habitats can no longer persist. Due to the character of salt marsh and seagrass habitats, human-induced losses may be very slow to recover. In fact, in many cases reestablishment of these habitats is not possible without active human intervention through restoration efforts (Kusler and Kentula 1990).

Nationally, efforts are being made to restore marsh and seagrass habitats and guidelines are being established to evaluate methods for such restorations (Kusler and Kentula 1990). In New Hampshire, these efforts have also begun (see below). Much of the impact on wetland habitat results from human activities within the coastal zone. However, it has become recognized recently that some human development may occur even in some areas where wetlands exist. In response to this realization, the concept of wetlands mitigation has evolved.

Mitigation is the replacement of one wetland system, being destroyed for development purposes, with a newly created wetland system. The questions that come about in considering mitigation are: What constitutes equal value for destroying a wetland area? Is it just the replacement of acres of vegetation type or must the functional value of that habitat be considered? The functional value of a habitat includes sufficient area to provide a comparable value for wildlife, water fowl, and ecosystem function. The difficult aspects of these concepts are still being researched and scientifically examined (Pacific Estuarine Research Laboratory 1990).

The concept of mitigation is being relied upon extensively in order to attain President Bush's proclamation of "no net wetlands loss". It is the general consensus of at least some federal agencies, that "no net wetlands loss" means no overall loss of functional value in wetlands if wetlands must be destroyed for development purposes. However, the overwhelming opinion is that conservation of existing wetland habitats is far better than mitigation.

The recent proposed expansion by the New Hampshire Port Authority has brought to the Great Bay Estuary the issue of mitigation for estuarine areas impacted. The proposed development includes an area of Estuary to be filled for the construction of new docking facilities. The elimination of certain wetland areas is proposed with compensating mitigation in another area of the Estuary. The mitigation plan involves the reestablishment of wetlands in areas where they were destroyed in the last century and the overall improvement in health of a nearby tidal creek.

Restoration of Eelgrass

Over the last decade, dramatic declines of eelgrass, *Zostera marina*, have been documented in the Great Bay Estuary (Short et al. 1986, Short et al. 1991). Such losses have resulted from the recurrence of the "wasting disease" and eutrophication. As a result, several methods for artificial restoration of eelgrass beds by direct transplanting have been undertaken within Great Bay (Carlson and Short 1991).

Transplanting techniques were tested in June and July of 1990 in Great Bay. Methods included planting both adult plants and individual seedlings, anchoring multiple adult plants with a metal staple, and inserting plugs of plants in peat pots into holes in the sediment. A total of 885 units were planted in the three plots with an overall success rate of 77.5% after four months (success defined as planting unit survival and expansion). Transplanting with staples had the greatest success rate of 97.6%. Transplanting individual shoots demonstrated rapid vegetative expansion over the four month study period. The average expansion area of individual seedlings was $0.36/m^2$, while for adult plants with shoots the mean area was $0.48/m^2$. The plants in peat pots never expanded from the initial pot (Carlson and Short 1991).

Salt Marsh Restoration

Continued decline in the standing crop of various *Spartina alterniflora* beds throughout the Estuary in the early 1980s led to a consideration of restoration efforts. The feasibility of transplanting in areas where preexisting marshes had disappeared or suffered considerable reduction in size was addressed (Nelson et al. 1983).

Five transplant sites representing different soil types were chosen on intertidal mudflats or peat beds (Nelson et al. 1983). Plugs of *S. alterniflora* were selected from nearby marshes and planted at each site during May 1983. Stem density at three sites decreased until all transplants were washed from the substrate. The two remaining sites exhibited rapid growth through August, followed by a slight decline in September and increased shoot development in the fall. Such a pattern is typical of natural marshes in Little Bay (Chock 1975).

Grain size evaluation suggests increased transplant success in highly organic substrata having protection from wave action and strong tidal currents. Plant survival in more exposed areas was greater with larger grain sizes. Restoration efforts for salt marsh as well as for eelgrass have been initiated in the Great Bay Estuary and have the potential as valuable tools for management.

Great Bay Estuary Management

A management program for the Great Bay has been established under the auspices of the Great Bay National Estuarine Research Reserve, part of the Sanctuaries and Reserves Division of NOAA, US Department of Commerce. On the state level, the program is a component of the Marine Fisheries division of the New Hampshire Fish and Game Department. Management of several key land areas of Great Bay is conducted by the Great Bay Estuarine Research Reserve Manager. As a non-regulatory program, the primary management goal is to preserve the estuarine resources of Great Bay in order to maintain and improve the condition of this part of the Estuary for the purposes of research and education.

The jurisdiction of the Reserve Program is restricted to the bounds of the Great Bay Estuarine Research Reserve. Although the manager can provide valuable information to questions of an environmental nature within Little Bay and the Piscataqua River, as well as elsewhere in the watershed, he/she does not have oversight for the entire estuarine system. Management of the coastal natural resources comes under the authority of the Marine Fisheries Division of the New Hampshire Fish and Game Department for New Hampshire and under the Maine Department of Environmental Protection for the east half of the Piscataqua River. The Great Bay Research Reserve program through its role with Fish and Game has input regarding activities outside the Reserve boundary. Other agencies such as the New Hampshire Department of Environmental Services and New Hampshire Port Authority also have regulatory authority over management of various aspects of estuarine activities (i.e. boating, sewage discharge).

Unlike Great Bay, which has the Great Bay Estuarine Research Reserve as an oversight management organization, there is no organization for the management of Little Bay, the Piscataqua River, or the Estuary as a whole. For Little Bay, fisheries and natural resources are under the jurisdiction of the New Hampshire Fish and Game Department. Currently Little Bay has no other oversight organization monitoring research or other activities going on within that portion of the Estuary. The New Hampshire Department of Environmental Services, through its Wetlands Board, approves dredge and fill operations as well as installation of docks, piers and other structures within the waters of this area. The Department of Water Supply and Pollution Control regulates release of waste water and industrial discharge into the Estuary, while the Department of Transportation maintains authority over parks and state owned facilities around the that portion of the Bay. Additionally, the towns bordering Little Bay regulate setback and zoning activities independently for each community. The absence of any oversight organization or linkage between departments and governmental agencies precludes effective management of this portion of the estuarine system.

Because the Piscataqua River and its watershed is split between the states of New Hampshire and Maine, management of the Piscataqua River portion of the Great Bay Estuary is more complicated and potentially more difficult. The relatively undeveloped north side of the Piscataqua is under the regulation of Maine, while the heavily developed south side of the river is under New Hampshire jurisdiction. Additionally, a large island in the lower Piscataqua River is owned by the U.S. Navy, and the site of the Portsmouth Naval Shipyard is subject to its own regulatory authorities. Like Little Bay, the New Hampshire side of the Piscataqua River falls within the jurisdiction of a number of state agencies without any oversight management in place. The Maine side of the Piscataqua River is under the jurisdiction of the Maine Department of Environmental Protection and the Maine Office of State Planning as well as local regulatory control. Activities at the Portsmouth Naval Shipyard that affect the Estuary are regulated through the U.S. Environmental Protection Agency and adhere to environmental regulations of the State of Maine. The Portsmouth Naval Shipyard is currently undertaking an ecological assessment of the Great Bay Estuary in order to determine if there are any adverse effects to the Estuary from previous activities within Seavey Island where the Shipyard is located.

Unfortunately, as of this writing, there is no single estuarine management organization looking out for the health and welfare of the entire Great Bay Estuary and its natural resources. The formation of such an organization should be a high priority in order to insure the health and survival of this highly productive estuarine environment. Such an organization could be constituted through combined efforts of the State of New Hampshire, the State of Maine and the U.S. Navy.

In an effort to follow the status of water quality characteristics and ecological health of some of the Great Bay Estuary, the University of New Hampshire Jackson Estuarine Laboratory currently maintains a long term monitoring program for the Estuary. The upper-Estuary portion of this monitoring study is funded by NOAA through the National Estuarine Research Reserve Program while the monitoring in the Piscataqua River in Portsmouth Harbor is funded by the U.S. Navy. Additionally, a citizens' monitoring group called Great Bay Watch is monitoring a number of stations around the Estuary and the NH Office of State Planning is monitoring one station in Portsmouth Harbor. All these monitoring programs, coordinated through the Jackson Estuarine Laboratory, provide the bare minimum of environmental data necessary to monitor the status of environmental health in the Great Bay Estuary.

In conjunction with the regulatory State agencies, the Research Reserve has established management guidelines that encourage the preservation of the environmental health of Great Bay. To this end, we have identified a series of management and research priorities (Tables 10.4 and 10.5) to provide needed information for the successful management of the Bay and to answer fundamental questions about the productivity and importance of estuarine habitats. The research priorities (Table 10.5) are based on information about Great Bay that is presented in this document and on an in depth look at the management issues that are of highest priority within Great Bay. The ranking of research priorities was established based on the spring 1991 information of current conditions in Great Bay. It is understood that the priorities will change with time and in response to regulation and to management's implementation of corrective action. The background and bases for each of the research priorities are outlined in the previous chapters of this document. A similar analysis and prioritization of management issues is needed for the Great Bay Estuary as a whole.

Education

In addition to sponsoring and coordinating research within the Reserve, the manager is responsible for developing an education program. The primary educational responsibility of the Reserve is to educate the public, governmental agencies, and private interest groups as to the value of the Estuary and need to maintain a healthy productive estuarine environment.

For decades, the Great Bay Estuary and surrounding lands have been utilized as an educational focus for a limited group of students and the public. While area teachers and conservation minded groups have viewed the Estuary as an ideal informal classroom, organized public programs have also utilized the Estuary for education.

The University's Jackson Estuarine Laboratory is located on the tip of Adam's Point, affording a perfect location for ongoing research on Great Bay as well as for educational programs. Each semester, students enrolled in numerous classes come to the Lab to learn about Great Bay. In addition, many departments of the University, including the division of Continuing Education, conduct cruises of Great Bay from the Lab.

During the 1980s, the UNH Sea Grant Marine Extension Program was the primary source of education programs for the general public. The SEATREK program, a series of marine-related topics offered to the public, has included tours of the Jackson Lab since 1978. The tour guides for the program are the UNH Marine Docents,

Table 10.4. Specific Management Priorities for Great Bay.

Priorities	Problem	Method of Implementation
Maintain a healthy estuary.	Impact of human activity.	Continue a long-term monitoring program. Research and management efforts as listed below.
Decrease point source pollution.	Contaminated shellfish beds. Poor water quality.	Identify the source and fate of pollutants. Upgrade wastewater treatment plants to secondary treatment.
Decrease nonpoint source pollution.	Poor water clarity. Contaminated shellfish beds.	Identify sources of pollution. Implement corrective action.
Decrease nutrient loading.	Poor water clarity.	Upgrade wastewater treatment plants to tertiary treatment or alternate methods of treatment.
Reduce shoreline development.	Loss of riparian margin. Estuarine degradation and nonpoint source pollution. Negative aesthetic impact.	GBNERR staff will work to educate towns around the Bay to upgrade local zoning regulation. Press for implementation of existing regulations. Establish a shore watch program to identify violators.
Reestablish eelgrass and salt marsh habitats in the estuary.	Habitat loss due to pollution, wasting disease, and development.	Transplant eelgrass and salt marsh grasses into areas where habitat have been lost.
Conserve existing habitats in the face of development.	Loss of wetlands and estuarine areas. Decrease in estuarine productivity.	Educate local, state and federal agencies of habitat value. GBNERR staff will testify in public hearings on development proposals. Fund research programs to clarify the value of habitat types in Great Bay.

Table 10.5. Research Priorities for Great Bay.

Priorities	Problem	Method of Implementation
Determine the pollution sources in Great Bay.	Contamination of shellfish beds. Poor water quality.	Research on the fate of point source pollution discharges within estuary. Research to identify sources of nonpoint source discharge and fate in the estuary. Research to identify other sinks for contaminants within the estuary including fecal material, nutrients, heavy metals, and toxic organics. Research on the ways nutrient loading change the estuarine ecology.
Determine the importance of resuspended sediments versus sediment loading on the Bay.	Shoreline development. Loss of eelgrass. Poor water quality.	Research on the source and fate of suspended sediments in the Bay.
Restore eelgrass habitats.	Loss due to pollution and wasting disease.	Research to develop methods to transplant eelgrass in a cost effective way.
Improve recreational fishing and shellfishing in Great Bay.	Decline in the catch of many species.	Research the habitats critical for fish recruitment and growth. Identify the size and age distribution of oysters in the Bay.

specially trained volunteers from the community, who present lectures and slide shows on the estuary.

More recent programs offered by Sea Grant include the Great Bay Living Lab, the Math and Marine Science Program, and the Great Bay Watch. The Living Lab is a pilot program (funded by NOAA) teaching estuarine issues to junior and senior high school students. The Docents are again involved in working with the teachers. The Math and Marine Science Program, funded by the National Science Foundation, is a summer program for 10th graders from Maine and New Hampshire. It brings students together to study statistics, computer technology, and the estuarine and marine environment. The Great Bay Watch (funded by NOAA) is a volunteer citizen water quality monitoring effort where local residents are involved in sampling various physical and chemical parameters at ten sites around the Estuary.

In recent years, numerous local conservation groups have expressed greater interest in using the Great Bay for educational programs. The Audubon Society of New Hampshire has been monitoring winter use of the Bay by bald eagles since 1982 using local volunteers. Now through the efforts of the Seacoast chapter of Audubon, they offer field trips and bird walks around the Estuary.

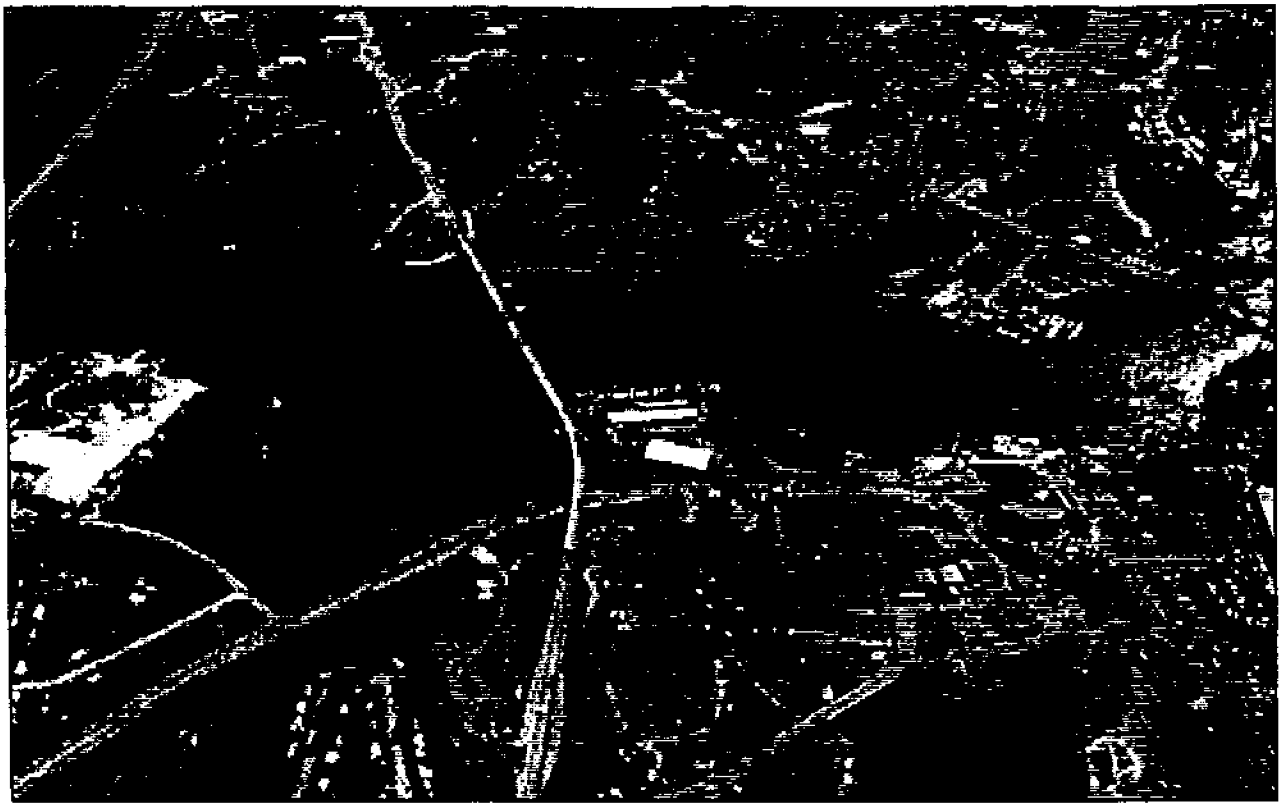
The Great Bay Estuarine System Conservation Trust is a private, non-profit organization whose purpose is "to conserve the land and water resources of Great Bay". In addition to being a primary force behind the formation of the Reserve, the Trust sponsors talks and workshops related to the protection of the Estuary. Each spring, they sponsor a clean-up of Adam's Point.

One group interested in tying together the past history of the Great Bay region with the present state of the Estuary is the Piscataqua Gundalow Project. The Gundalow Project evolved as a support group for the construction of a reproduction gundalow, once the dominant sailing vessel used on the Bay. The group now sponsors public programs in communities around Great Bay on the region's history and the importance of protecting the Estuary.

Now the focus of education is The Great Bay National Estuarine Research Reserve. As outlined in the Great Bay Research Reserve Management Plan, the goals of the Reserve's educational programs are two fold: to make available a range of opportunities for the public and government agencies to learn about the Great Bay estuarine system and the need for its wise use and management and to identify educational needs, gather the information, and develop the educational tools, and finally to disseminate this information to the public and to government agencies which have decision-making authority over Great Bay and other coastal resources. The pursuit of these goals has led to the establishment of a series of education priorities for the Research Reserve (Table 10.6) which are discussed in The Management Plan.

Table 10.6. Education Priorities for the Great Bay Estuarine Research Reserve.

Priorities	Audience	Method of Implementation
Establish information clearinghouse/resources file at visitor/education site.	General public/education interests/government agencies.	Continue to improve interagency communication and information exchange through Reserve's advisory committee.
Develop a variety of promotional materials including: • brochures • regular news releases in local papers • a Reserve newsletter • interpretive posters • slide presentations	General public especially landowners, fishermen, developers, local officials.	Work in cooperation with information personnel in Fish and Game, UNH, etc.
Encourage and expand current programs.	Nonschool youth leaders, UNH (students, docents, researchers), private organizations, government agencies.	Develop Memorandum of Agreement's where appropriate (i.e. Sea Grant).
Conduct informal "neighborhood" forums on how Reserve's land acquisition program works.	Bay area land owners, interested citizens, and town officials.	Reserve staff with assistance of Landowners, Great Bay Trust and Trust for NH Lands.
Develop a series of evening programs and/or day-long conferences for the public on topics including negotiating impacts of development.	Users of estuary, local/state officials, realtors and developers, Bay area and other NH residents.	Reserve staff with assistance of Coastal Program and representatives of advisory committee to "host" series.
Develop educational programs, designed primarily for teachers' training, which take participants out to various sites.	High school teachers.	Reserve staff in cooperation with other groups/organizations; Jackson Estuarine Lab or other appropriate researchers to help develop a series of presentations.
Develop educational programs for young people.	Area high school students.	Implement "researcher-in-the-schools" program, as follow-up, invite qualified students to assist researcher.
Provide a historical overview of the region's development, especially the interaction of people and resources.	General Public/No Specific Audience	Exhibits, i.e. the gundalow exhibit, and cooperative efforts with Society for the Preservation of New England Antiquities.



Aerial view of the Piscataqua River with the Port of New Hampshire *(center)*, Portsmouth, New Hampshire *(lower right)*, and Portsmouth Naval Shipyard *(upper right)*.

Chapter 11: Summary and Synthesis
by F.T. Short

Summary

The Estuarine Profile is a compendium of all current and historical information available to describe the character of the estuarine environment and the pressures facing the Great Bay Estuary. The analysis of the Great Bay Estuary begins with a historical overview and an assessment of the direct resource values that exist for the entire estuary (see Chapter 1). These include, but are not limited to, assessments of the scenic uses of the Estuary which provide great value to residents in the Bay area as well as the greater population of New Hampshire and southern Maine. Additionally, in part it is the scenic qualities of the Estuary which draw tourism to this region.

Direct resource values also include both recreational and commercial utilization of the Estuary. The mechanisms by which some of these resource values are maintained and enhanced is discussed. In monetary value, the resources of the Great Bay Estuary are priceless. Its resources, both physical dynamics and biological productivity, contribute immeasurably to the economy of the northeast and to the values we maintain as important in New Hampshire and Maine. At a minimum, it should be clear from this document that the resources of the Great Bay Estuary are important to the states and nation, and deserve to be protected and enhanced in a manner that will maintain the health of the overall environment.

The maintenance of resource values within a natural environment under extreme pressures from human intervention requires direct management. This document discusses some specific management issues that require attention (see Chapter 10). Additionally, it discusses the research needed to provide a scientific basis for some of these management goals.

The primary environmental issues in the Great Bay Estuary have been outlined. All require management action. The first, microbial pollution and shellfish closures, is a primary concern to recreational shellfishing in the Estuary and to the safe and continued utilization of our estuarine waters for recreation. Understanding the dynamics of pollution contaminants entering the Estuary and designing mechanisms for dealing with those problems are a major priority. In this regard, research is beginning at the Jackson Estuarine Laboratory to look at the fate of bacterial contaminants entering Great Bay and to determine the primary mechanisms responsible for removal of these contaminants. It is hoped that management activities can concentrate on enhancing these removal mechanisms as well as the long term, expensive, and inevitable job of eliminating contaminants from point and nonpoint sources around the Estuary.

Another management issue within the Great Bay Estuary is the loss of eelgrass habitat. The dramatic decline in abundance of this single plant species threatens to change the structure, character and productivity of the Great Bay Estuary. It may impact the success of fisheries, the migration of waterfowl, the circulation of tidal currents and the distribution of sediments. Loss of eelgrass may have secondary impacts that go beyond the Estuary itself. Efforts to restore eelgrass beds within the Great Bay Estuary are currently underway. Researchers at the Jackson Estuarine Laboratory are evaluating the feasibility of replanting and reestablishing beds that have been lost in order to maintain viable habitat.

A third management issue is water clarity problems in the Estuary. As described in detail under the chapter on estuarine hydrochemistry (see Chapter 5), the water quality characteristics of Great Bay have decreased dramatically over the last ten to fifteen years. Doubling of the total suspended load and increases in the minimum concentration of ammonium and nitrate observed in the Estuary are clear indicators that the dynamics of the water column conditions have changed from what they were in the past. The changes are alarming and strongly suggest the need for research to more clearly identify the source of these increases.

The reduction in water clarity in the Estuary contributes to the loss of eelgrass, the loss of benthic diatom production, the decrease of phytoplankton populations and reduction in the distribution of macroalgal species. Additional research is needed to better understand these impacts and management controls are needed to eliminate them.

Another management issue of increasing importance to the Great Bay Estuary is the restoration or mitigation of lost wetlands within the Estuary. Human development within the watershed of the Estuary leads to a rapid degradation of many wetlands areas and the loss of productivity in these systems. Efforts are now being undertaken to restore these lost wetland habitats and establish methods by which developers can mitigate for lost wetlands through the restoration of existing wetlands or creation of new wetland areas.

Finally, a major management issue is the establishment of clear management guidelines, with priorities, for maintaining environmental health in the Great Bay Estuary. Recommended management activities for Great Bay were set forth in the Great Bay Estuarine Research Reserve Management Plan (NHOSP 1989). As the Estuarine Research Reserve program grows, these issues need to be clarified and new priorities established by a collective assessment among scientists, managers, state officials, and the general public. Further, the identification of clear management issues and approaches for the entire Great Bay Estuary is critically needed to insure that the quality and resources of the Great Bay Estuary will be maintained in the future.

The Great Bay Estuarine Profile describes in detail the estuarine hydrosystem, identifies the watershed supplying fresh water into this environment, and describes the magnitude of sea water entering the system (see Chapter 3). In describing the estuarine hydrosystem, the tidal conditions in the Estuary are outlined and information is provided for the reader to understand how the dynamics of tidal activities interact with the dynamics of riverine flow.

The chapter on estuarine geomorphology (see Chapter 4) describes the geological history of the Great Bay Estuary, the sources of the fine sediment material found in the Estuary, and the effects of tidal conditions and other environmental factors on the distribution of sediments. The estuarine morphology is described, as well as aspects of estuarine sedimentation.

Much of the biological activity occurring within the Great Bay Estuary is dependent on the characteristics of the hydrochemical system. A detailed assessment of the chemical and physical structure of the Great Bay Estuary has been outlined (see Chapter 5). This information includes description of the temperature environment, salinity regime, levels of dissolved oxygen, the hydrogen ion concentration (pH), concentrations of suspended load and the nutrient characteristics of the Estuary. In many cases throughout this discussion, contrast has been drawn between data collected during the mid 1970s on nutrient and physical characteristics and data being collected today on these same characteristics through our ongoing monitoring program at the Jackson Estuarine Laboratory. The comparison, as mentioned above, points out some major changes in the character of the Estuary and suggests problems of degradation and eutrophication occurring within the Estuary. Additionally, this information demonstrates clearly the importance of longterm monitoring in keeping track of the health and productivity of the estuarine system.

One of the major problems facing the Great Bay Estuary, as well as other estuaries along the coastal United States, is pollution (see Chapter 6). The major management issues involving pollution related problems (Chapter 10) include microbial contamination of shellfish and reduction in water clarity due to nutrient loading (Chapter 5) and potential risks to human health from toxic contamination (Chapter 6). A history of microbial contamination within the Great Bay Estuary is presented, including aspects of viral and bacterial contamination. Wastewater treatment discharge and non-point source runoff are the primary sources of these contaminants.

Nutrient loading to the Estuary is another major pollution problem resulting from many of the same point and non-point sources discharges. The increase in human population and in land development within the watershed of the Great Bay Estuary appear to be the primary causes of increased nutrient loading to the Estuary. The observed increases in base level nutrient concentrations may in fact derive from increased nutrient loading (see Chapter 5).

Other pollutants in the Estuary include current and historic discharges of heavy metals, PCBs, PAHs, and other organic compounds into the estuarine watershed or the Estuary itself. Potential sources for these metal and organic contaminants historically are the tanneries and mills which were found on all the major rivers surrounding the Great Bay Estuary and more recently, from activities associated with the Pease Air Force Base, the Portsmouth Naval Shipyard and other industrial facilities. Additionally, other contaminants from non-point sources may provide contamination in the Estuary.

The assessment of biological organisms within the Estuary has revealed a wealth of information describing primary producers (Chapter 7) and major consumers (Chapter 8). The chapters are primarily descriptive reviews of the organisms found within the Great Bay Estuary along with limited discussion of their ecological significance. Each chapter provides as complete a list as possible of species found within the Estuary and, where possible, some assessment of the organism's abundance or contribution to the Estuary.

The discussion of primary producers includes information on populations of phytoplankton, eelgrass, seaweeds, salt marsh plants, benthic microflora, and upland plants (Chapter 7). In many cases, there are varying degrees and types of information on the plant populations which reflect the current level of knowledge regarding these species and species assemblages.

The discussion of estuarine consumers describes the limited knowledge available on zooplankton and invertebrate populations and much more substantial information on fishes and fish ecology in the Estuary (Chapter 8). Additionally, data on bird and mammal populations within the Estuary and the surrounding watershed have been included.

The discussion of biogeochemical processes (Chapter 9) within the Great Bay Estuary focuses primarily on research that has been done directly within the Estuary and does not attempt to provide a review of all known estuarine biogeochemical processes. As a result, Chapter 9 presents a synthesis of what is known about microbially mediated biogeochemical cycles within Great Bay only and discusses to a limited extent the importance of these processes.

The functional value of various parts of the Great Bay Estuary is determined by the physical characteristics and biological structure found within the Estuary. The combination of these conditions establishes specific habitats within the Bay that can be characterized according to aspects of their biological or physical structure. For this discussion, five such habitat characterizations have been described (see Chapter 2). These habitats within Great Bay are, in order of spatial dominance, eelgrass, unvegetated mudflat, salt marsh, channel bottom/submerged flat, and rocky intertidal. All of these components of Great Bay are important ecological features that provide a unique environment for certain species of plants, invertebrates, fish and other organisms. For the Piscataqua River and Little Bay, the spatially predominant habitat is the channel bottom characteristic of the riverine nature of the waters.

The ranking of these habitats by value is impossible since they all have unique characteristics that provide necessary contributions to the estuarine system. For example, the eelgrass and salt marsh habitats both provide valuable resources for fish. However, the fish species utilizing these two habitats for reproduction or nursery areas are often different and contribute differently to the overall secondary productivity of the Estuary (see Chapter 2 and 8). As yet, the value and contribution of many of these habitats, such as the mudflat environment, and the channel bottom/submerged flat are virtually unknown and are areas in need of research. In the eelgrass and salt marsh habitats, research has begun to identify secondary productivity associated with these areas and to define the trophic connections and interactions between fishes and invertebrates within these systems. However, this is only the beginning in the process of understanding the value of these plant dominated systems in the overall productivity of the Estuary. More research is needed on the contributions to secondary production and in the export of material from the Estuary through organic losses, fish migration and faunal migrations.

The rocky intertidal habitat is another area with little information on its ecological importance. A great deal is known about the composition and distribution of algal species and major invertebrates within these areas. The importance of these areas in the feeding of wading birds at low tide and in the foraging behavior of fishes at high tide has not been investigated.

The characterization of these five habitats is the first step in identifying areas of substantial resource value. The identifications provide the opportunity to subdivide the estuarine system into parts that can be studied, evaluated, and protected as distinct ecological units, as well as, important integral parts of the estuary.

Under current conditions, the lack of shoreline protection in some towns will accelerate the rate of build-up within the shoreline zone. Beyond this, and perhaps more importantly, the signs of eutrophication of the Estuary are being seen in changes in water quality. It is these signs of environmental degradation that pose the greatest immediate threat to sustaining estuarine productivity and health. The hope and intent of this Estuarine Profile is to provide the background information and conceptual framework from which useful management regulations can be established and enforced in order to protect and restore this valuable coastal resource (Chapter 10).

Synthesis

Within the Great Bay Estuary, Great Bay is frequently described as a pristine area. Hidden in the backwaters of coastal New Hampshire and unknown even to many residents of the State, on first view the description "pristine" seems justified. Great Bay has relatively little development along its shoreline and the landscape viewed from the Bay is forested upland extending from the rocky shore or salt marsh to the hill tops. The lack of docks along the shoreline and the scattering of boats moored in the tidal waters additionally give the perception of an untouched environment. The obvious presence of ducks, geese, blue herons, osprey, and eagles clearly encourage this pristine perception. In fact, it's only when one peers beneath the surface and into the structure of the ecosystem that the polluted character of Great Bay becomes evident.

The levels of pollution in the entire Great Bay Estuary are acutely apparent to the several hundred individuals in the State who attempt recreational shellfishing. Examination of any map of shellfish closures for coastal New Hampshire clearly illustrates that only a small portion of Great Bay is regularly open for the harvest of shellfish. The reason for the extensive closure areas in the Great Bay Estuary is sewage contamination. Sewage loading into the Estuary is the major problem causing the degradation of the estuarine system. It not only contributes to the high concentrations of fecal contaminants but also to the excessive loading of nitrogen and phosphorus into the Estuary.

Fecal contamination in the Great Bay Estuary is derived primarily from the discharge of improperly or inadequately treated human waste products. Such material enters Great Bay through river input from the Exeter wastewater treatment plant on the Squamscott River and the Newmarket wastewater treatment plant on the Lamprey River or from non-point source discharge. Additionally, substantial concentrations of sewage effluent enter Little Bay and the Piscataqua River from the Durham wastewater treatment plant, and plants in Dover, Newington, Kittery, Portsmouth, etc. The volume of discharge from these point sources has increased steadily within the Estuary watershed in direct response to increasing human population in the area. It is the point source discharge from all of these wastewater treatment facilities that has elevated the contaminant level within the Estuary to the point that very few areas are suitable for the harvest of shellfish.

The other problem caused by increased wastewater discharge into the Estuary is the excessive nutrient loading that accompanies this discharge. The resolution of the nutrient loading problem in the Great Bay Estuary will be partly corrected if problems of point source fecal contamination are eliminated. Fecal and nutrient pollution are closely connected. Although tertiary wastewater treatment is necessary if large amounts of nutrients are to be removed from discharge water, primary and secondary treatment are somewhat helpful in decreasing the nutrient load. Such a decrease in loading was seen following the upgrading of the Exeter treatment plant in 1990 with the observed reduction in nutrient concentrations in the Squamscott River.

The problems of nonpoint source pollution in the Great Bay Estuary are another major concern in the contribution of nutrient and microbial loading to the Estuary. The extent and magnitude of the nonpoint source pollution problem are yet to be determined and should be a high priority for research efforts within the watershed. Once nonpoint source discharge problems have been identified, steps need to be taken at the governmental level to reduce their impact to the Estuary.

Other important management issues in the Great Bay Estuary are a result of the problems of wastewater discharge and eutrophication. The loss of eelgrass, a result of the eelgrass wasting disease, and its inability to grow back and reinhabit many places in the Estuary because of eutrophication, is a problem that results from stress within the estuarine environment. Such stresses will be decreased by reduction in wastewater discharge and decreased nutrient loading to the Estuary, though the reestablishment of eelgrass habitats may take active restoration efforts.

The problem of reduced water clarity in the Estuary is, in large part, a result of the nutrient loading problem. However, reduction in water clarity in the Estuary is exacerbated by suspended solids in the water column. The component of suspended solids that is not composed of phytoplankton is a combination of sedimentary material, both organic and inorganic, that enters the Estuary through the rivers and runoff or is resuspended within the Estuary.

The earlier eight year monitoring program (1973-81) showed no significant change in most water column characteristics. However, recent monitoring does demonstrate significant changes in the overall water quality of the Great Bay Estuary. These changes should be viewed as a red flag to towns, cities, state and federal agencies, and the public at large that the estuarine system is degrading and management action is needed immediately.

The problem of determining the level of toxic contamination in the Great bay Estuary from past hazardous waste disposal sites or contaminant discharge within the watershed is an important issue that is currently being addressed by the U.S. Navy, the USEPA, and the University of New Hampshire. The potential threat to ecological and human health from these types of organic and inorganic contaminants makes this management issue a high priority (Chapter 10).

The first priority for management of the Great Bay Estuary must be to reduce the level of the point source discharge of both sewage contaminants and nutrients from wastewater treatment facilities. Once the point source discharges from wastewater treatment facilities are all upgraded to secondary treatment, the bacterial contamination problem in the Estuary will be reduced and the level of nutrient input will be decreased to some extent. Going beyond secondary treatment to remove inorganic nutrients from wastewater discharge is also important but a lower priority than removal of bacterial contaminants and reduction in nonpoint source discharge.

As a second priority, management of the Estuary must identify the nonpoint sources of pollution into the Estuary and employ techniques for their elimination. Of paramount importance is the realization that the Great Bay Estuary is not a pristine estuarine system that will function to absorb whatever human activities are imposed upon it. We are now at a juncture where the preservation and management of estuarine resources is imperative.

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