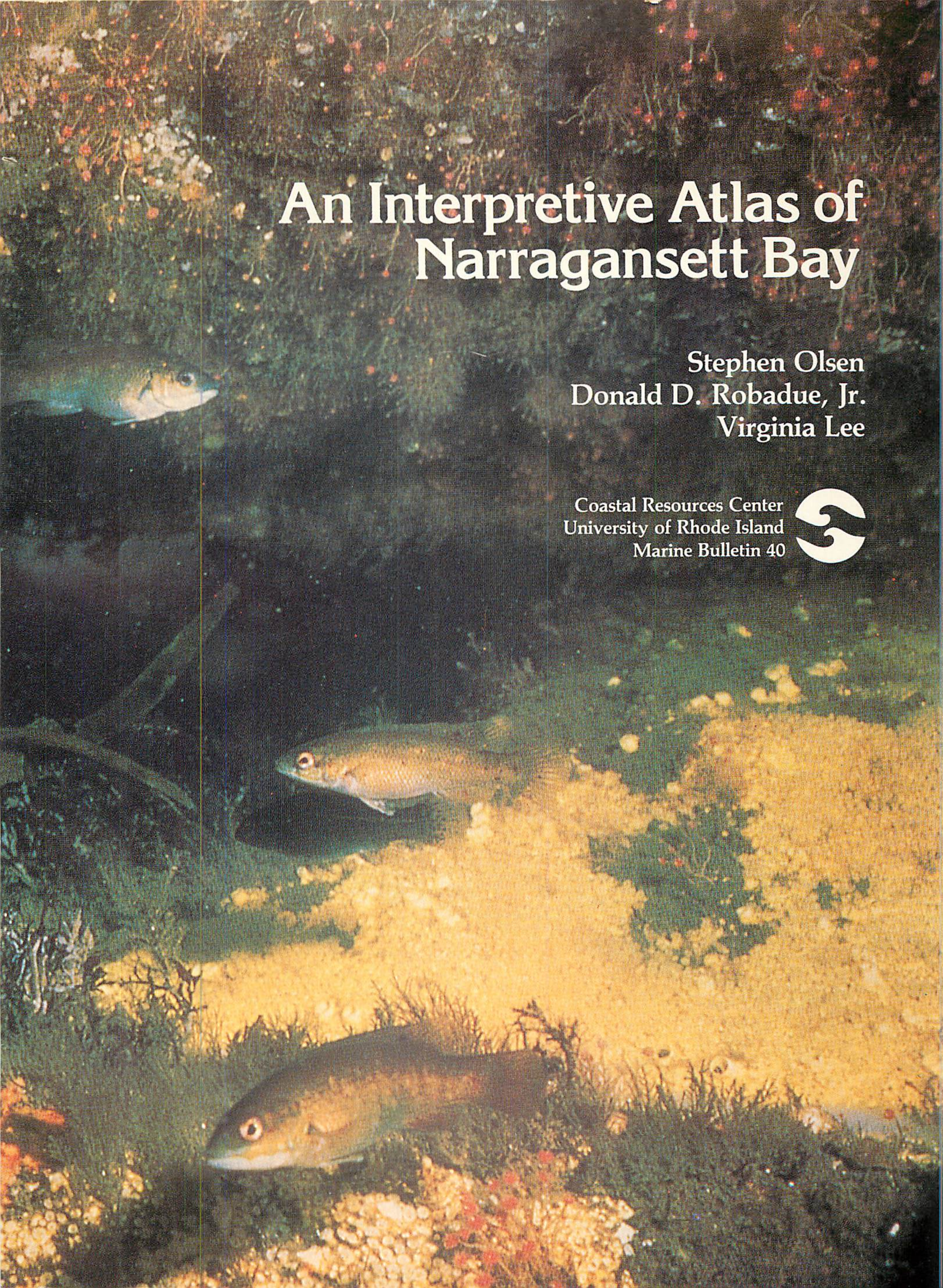

An Interpretive Atlas of Narragansett Bay

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Coastal Resources Center
University of Rhode Island
Marine Bulletin 40

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Contents

Cover photo by Wes Pratt.

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Preface

This book is an attempt to synthesize our present understanding of how Narragansett Bay functions as an ecosystem and to provide a sense of the changing historical role the Bay has played in the lives of Rhode Islanders. It is an outgrowth of the state's Coastal Management Program, and we hope that it will be useful to all those who are concerned with how we manage a bountiful and beautiful estuary that is the common heritage of all Rhode Islanders. Narragansett Bay is one of the world's most studied estuaries, and the reports, theses, scholarly articles, and books on various aspects of the Bay would fill floor-to-ceiling bookshelves in a large room. Relying heavily upon graphics, we tried to summarize what to us, as people who have spent many years working on the Rhode Island Coastal Resources Management Program, appeared to be the most interesting and useful information. In the text we attempted to present the salient points that have emerged from years of intensive research by many people as well as to give a sense of the trends and the major unknowns. This was not an easy task. Much of the fascinating detail and interpretation had to be left out, and our efforts to avoid the problems posed by using technical terminology often became a struggle. Simplification of such a quantity of information in terms that any layman can understand and appreciate proved far more difficult than we expected.

Our two principal themes, the ecology and the history of the Bay, cannot be woven into a complete and clear story because too many parts are missing or unknown. If we knew all the linkages between cause and effect in the Bay ecosystem and could comfortably predict the consequences of all the decisions that affect the Bay, the business of management would be far easier. But we do not. Furthermore, not only do we lack many of the important facts, but the values and priorities of society are constantly evolving. This is one reason why a sense of history is important.

When decisions are made that affect the Bay we must try to understand what is being given up, gained, or risked. Yet it is clear that many people who care passionately about the Bay are not familiar with how it functions as an ecosystem and are unaware of the inexorable process of change brought about by the explosion in human population in the past two hundred years. This high density of people will continue to alter the Bay's highly complex ecosystem. The future quality of the Bay will be determined by the concerns and desires of all Rhode Islanders. If we are to do the job of managing this resource well, we will be assisted by a common data base. We hope that this book will help fill that need and provide a better understanding of the context within which decisions affecting the Bay are made.

Acknowledgments

The beginnings of this book go back to the early 1970s, when much time and effort at the Coastal Resources Center were devoted to compiling information on Rhode Island's coastal and marine resources. Much of this work was included in the Rhode Island Coastal Resources Management Program, adopted in 1978, and the two-volume *Bay Bib: Rhode Island Marine Bibliography*. Numerous graduate students worked under the direction of Lynne Zeitlin-Hale to compile and organize this information, some of which appears in a different form in this volume.

Numerous faculty and staff at the University and various state agencies provided us with data for the various chapters and reviewed drafts of the text. We are particularly indebted to Robert McMaster, Jon Boothroyd, Malcolm Spaulding, Ted Smayda, Perry Jeffries, Scott Nixon, Saul Saila, Candace Oviatt, and Sheldon Pratt at the URI Graduate School of Oceanography. Sections touching on history and economics were reviewed by William Metz, Niels Rorholm, and Thomas Grigalunas. The staff at the Rhode Island Statewide Planning Program and Dick Sisson at the Department of Environmental Management were generous with their assistance. At the Coastal Resources Center, George Seavey provided early drafts for the chapters "Birds" and "Dredged Channels," and Clarkson Collins did the preliminary work on recreational boating. Debi Clarke typed and retyped innumerable drafts with her usual cheerfulness. Without the skills of Vicki Desjardins as editor and Larry Pearce as graphic designer par excellence we would never have made it. Finally, we owe a great thank you to the Rhode Island Coastal Management Program for funding the project.

Figure 1. Narragansett Bay

Chapter 1

Land Forms

The Glaciers

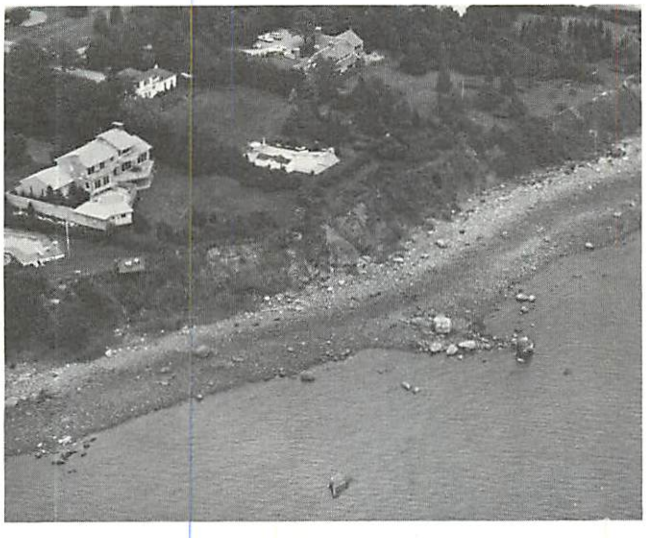
Glaciers have advanced and retreated across North America many times during the past 3 million years. We do not know what caused this movement of ice across the continent. One theory is that changes in the earth's orbit around the sun and the tilt of the axis caused dramatic shifts in the earth's climate. The time in which we live is one in a series of interglacial warm periods. The glaciers are in good part responsible for the present shape and character of the land, since the ice leveled hilltops and filled valleys with rocks, clay, and gravel.

The most recent of the great glaciers, the late Wisconsin ice sheet, bulldozed its way across southern New England some 18,000 years ago. It reached as far south as Long Island, Block Island, Marthas Vineyard, and Nantucket, which are all segments of a terminal moraine that marks the leading edge of the ice. When the glacier paused in its retreat, smaller recessional moraines were formed, one of which is the line of steep, low hills north of the salt ponds along the south shore of Rhode Island.

One of the legacies of the glaciers is the glacial drift that blankets the bedrock above most of the land and sea floor in this region. This drift, the unconsolidated layer of boulders, cobbles, gravel, sand, and clay that was moved and deposited by the ice sheet, is as much as 100 m (300 ft.) thick in channels scoured out by the ice and some 6 to 50 m (12 to 150 ft.) thick in most areas of Rhode Island and Block Island Sounds. In Narragansett Bay, the average depth of these glacial sediments is 50 m (150 ft.) (5).

Changing Sea Level

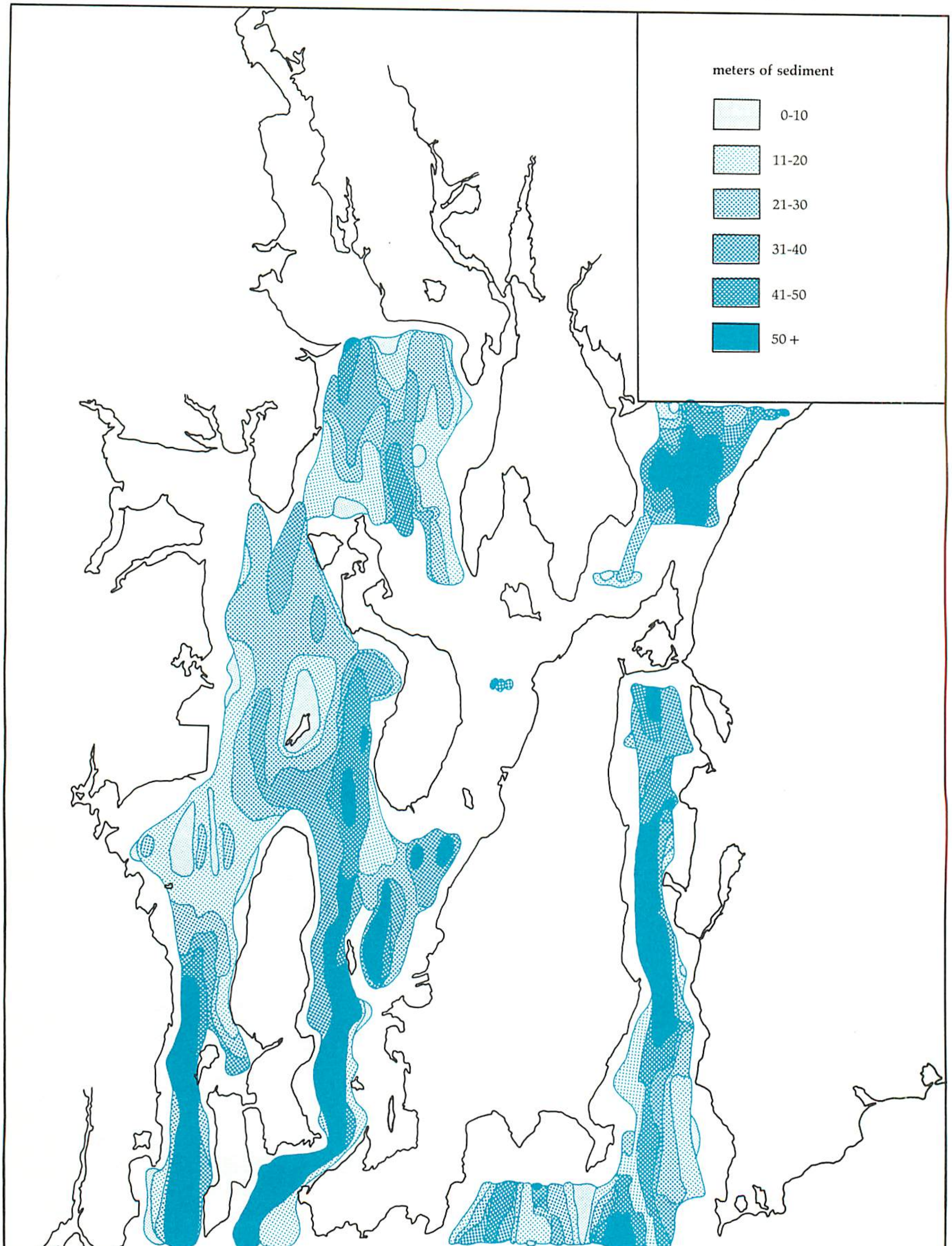
Glaciers have dramatic effects on sea level. When much of the earth's surface water was in the form of ice, the oceans were much smaller. During the era of the Wisconsin Glacier, the sea level in this region was about 100 m (300 ft.) lower than it is today (4). As the ice melted, sea level rose and the ocean advanced inland. Sea level at present is changing slowly along the Rhode Island shore, rising about 30 cm (1 ft.) each century (3). The present rise is due both to a slow increase in the volume of water in the ocean and to gradual sinking of the southern New England land mass. The present rate of rise in sea level may seem insignificant, but it should be kept in mind that much of our shoreline is low-lying and that a vertical rise of one foot may account for an inland advance of thirty or more feet. Some scientists fear that the increase in carbon dioxide in the world's atmosphere caused by the rapid burning of fossil fuels in this century may



A glacial outwash scarp and beach, Oakland Beach, Warwick. *Photo by Jon C. Boothroyd.*

A sand beach and small barrier spit fronting a salt marsh, Baker Creek, Warwick. *Photo by Jon C. Boothroyd.*

Figure 2. Thickness of sediments overlying bedrock. Future research will complete this data. *Adapted from Collins, 1978.*



cause a warming trend. This could melt more of the ice at the poles and rapidly accelerate the rise in sea level worldwide. Others argue that the carbon dioxide levels are not great enough or that it may only serve to forestall the period of climatic cooling that will precede the next era of glaciation.

Geologic Faults and Earthquakes

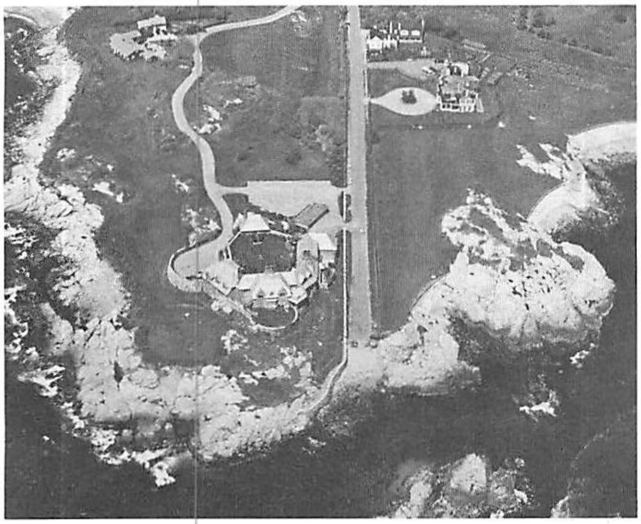
Narragansett Bay and much of Rhode Island lie in an ancient basin filled with soft sedimentary rocks. These sedimentary rocks and the older crystalline rocks that surround the basin are broken by fractures that developed long ago. If the bedrock moves along a fracture, it is called a fault. Movement along a fault is an earthquake. Geologists can recognize faults that lie exposed at the surface on land, but they must rely on anomalies in the pattern of magnetism in bedrock to identify subsea or subsurface faults.

Figure 3 shows the major surface faults and inferred subsurface and subsea faults in the Bay area. Southern New England is classified as a moderately active earthquake zone. No major quakes have been recorded since Colonial times, but several minor quakes, most of which line up with known faults, occur each year in Rhode Island. Knowledge of the location of faults is important when selecting sites for major facilities such as nuclear power plants and oil or gas tank farms.

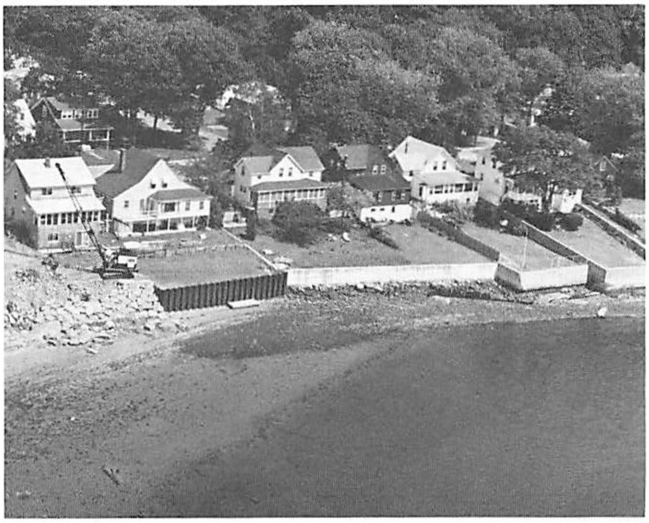
Topography and Sediments of the Bay

Narragansett Bay (excluding Mount Hope Bay) covers an area of 265 square kilometers (102 square miles) and is made up of three drowned valleys whose shape has changed little since the last glaciation. The deepest of the three valleys, the East Passage, provides deep-water access up to the south end of Prudence Island, making it one of the very few potential sites on the East Coast for a deep-water port where mammoth ships could dock or offshore drilling platforms could be fabricated.

Since the rivers and streams flowing into the Bay are small, the buildup on the Bay floor of sediments eroded from the land is slow. Over most of the Bay floor, glacial deposits are buried beneath up to 15 m (50 ft.) of "Recent" sediments, which have built up over the past 8,000 to 12,000 years (6). In general, sediments near the mouth of the Bay are more sandy than those in the upper Bay. Current velocities and patterns are the primary determinants of which sediments are deposited in specific areas and at what rate



A bedrock shoreline of hard granite, Lands End, Newport. *Photo by Jon C. Boothroyd.*



Various types of man-made shoreline, Bullock Neck, East Providence. *Photo by Jon C. Boothroyd.*

of accumulation. Fine-grained silts and clays build up in areas where current velocities are low, whereas sands and gravels are typical of more active areas. Protected waters, which are characteristic of harbors, accumulate sediments much more rapidly than exposed waters. It is not unusual for some stretches of navigation channels and many harbors to require dredging every 10 to 15 years if sufficient water depth is to be maintained for the passage of boats and vessels.

The Bay's Shoreline

A large variety of shoreline types are found along the edges of the Bay. Wide sandy beaches are found along the ocean shore at Bonnet Shores and between the southern headlands of Middletown, outside the boundaries of the Bay proper. There are a few sandy beaches in the Bay where longshore currents have built small barrier spits across shallow embayments and cuspate beaches such as Conimicut Point.

These low-lying land forms are flexible and may take on different shapes during a major hurricane. The most common shoreline in the Bay is a narrow beach of gravel, cobbles, and boulders backed by a scarp or bluff of unconsolidated glacial sediments. The scarp is often unvegetated. The most resistant shorelines are made of bedrock, of which two types are present. The shorelines of Beavertail and Common Fence Point are made of soft rock. Brenton Point is made of a hard granite and metamorphic rock that is by far the most resistant to erosion. Another category of shoreline is common in sheltered waters, where sediments are likely to accumulate. Here the salt marshes flourish and overlie the rock, sand, or silt. If undisturbed, salt marshes are capable of laying down peat composed of dead plant material that permits the living marsh to grow upward and keep pace with rising sea level. In some old and well-established marshes, the peat may be several meters thick.

A survey of the Bay's shoreline made in 1979 (1) revealed that along a quarter of the shoreline natural features have been replaced by man-made structures. Most of the construction on the shorelines that has taken place in the last two decades is an attempt at "erosion prevention," undertaken at great cost by private property owners. Unfortunately, many of the people who have built bulkheads or sheathed their shorefront with fitted stone do not realize that most of the erosion in the Bay takes place during major storms and hurricanes and that their structures will not withstand what geologists call a "high energy event." These same structures, however, are usually more elaborate than what is necessary to check the small-scale erosion that takes place between major storms.

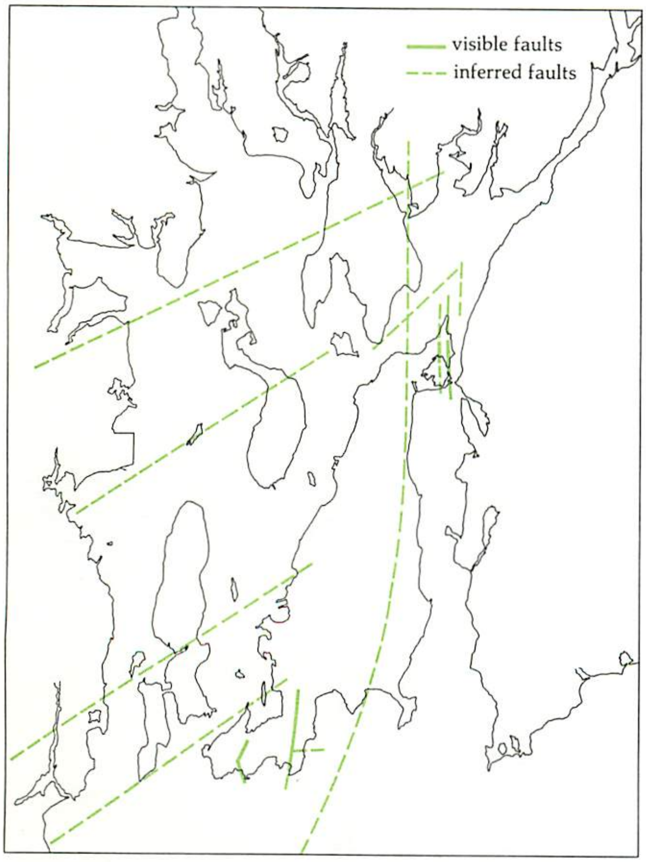


Figure 3. Visible and inferred geologic faults in the Bay area. Visible faults can be seen on the land surface; inferred faults below the surface on land and in the Bay are traced from magnetic anomalies. *Adapted from Collins, 1978, and Quinn, 1971.*

Figure 4. Bathymetry. *Adapted from Nautical Chart #13221, National Ocean Survey, NOAA.*

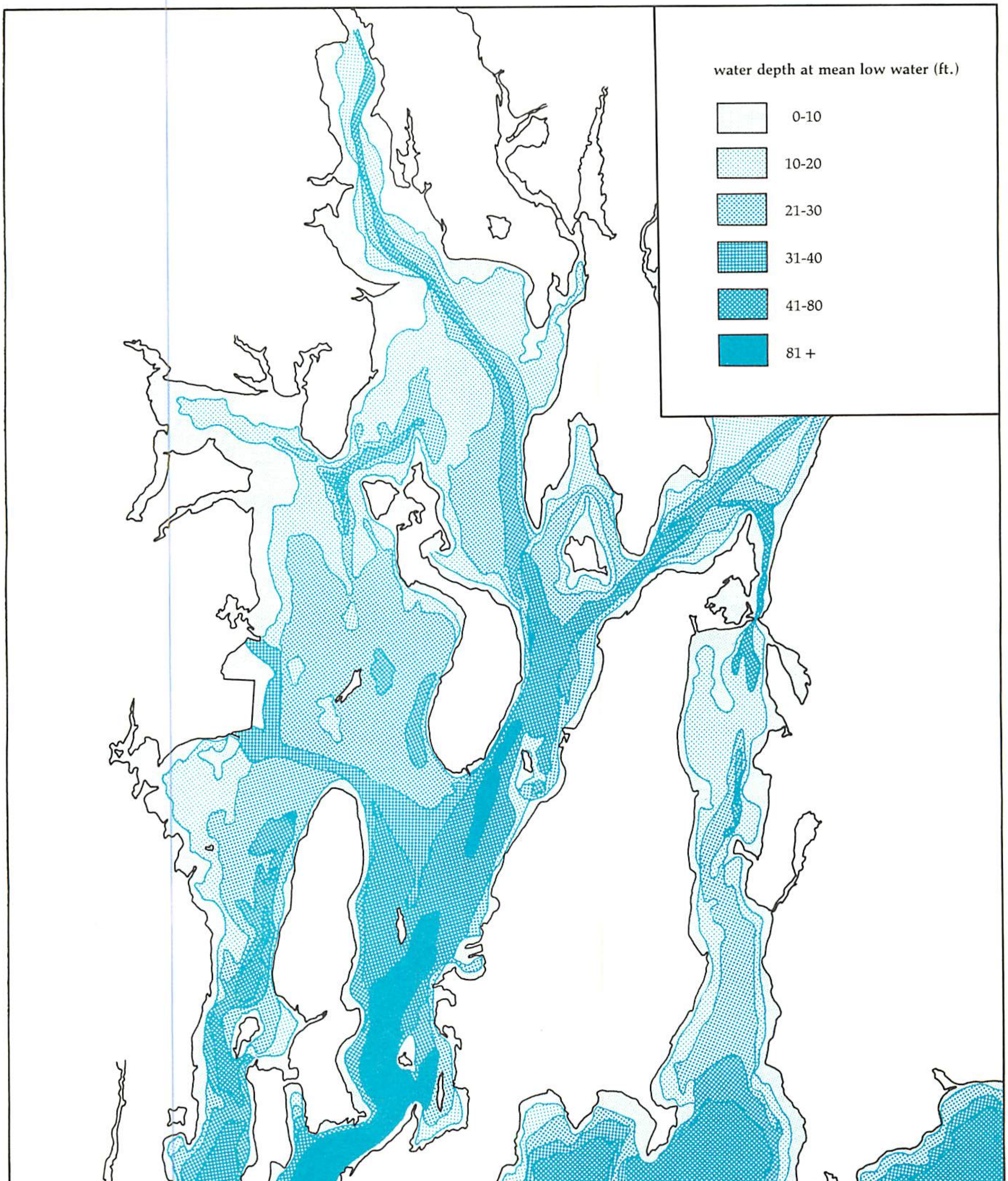


Figure 5. Principal surface sediment types. *Adapted from McMaster, 1960.*

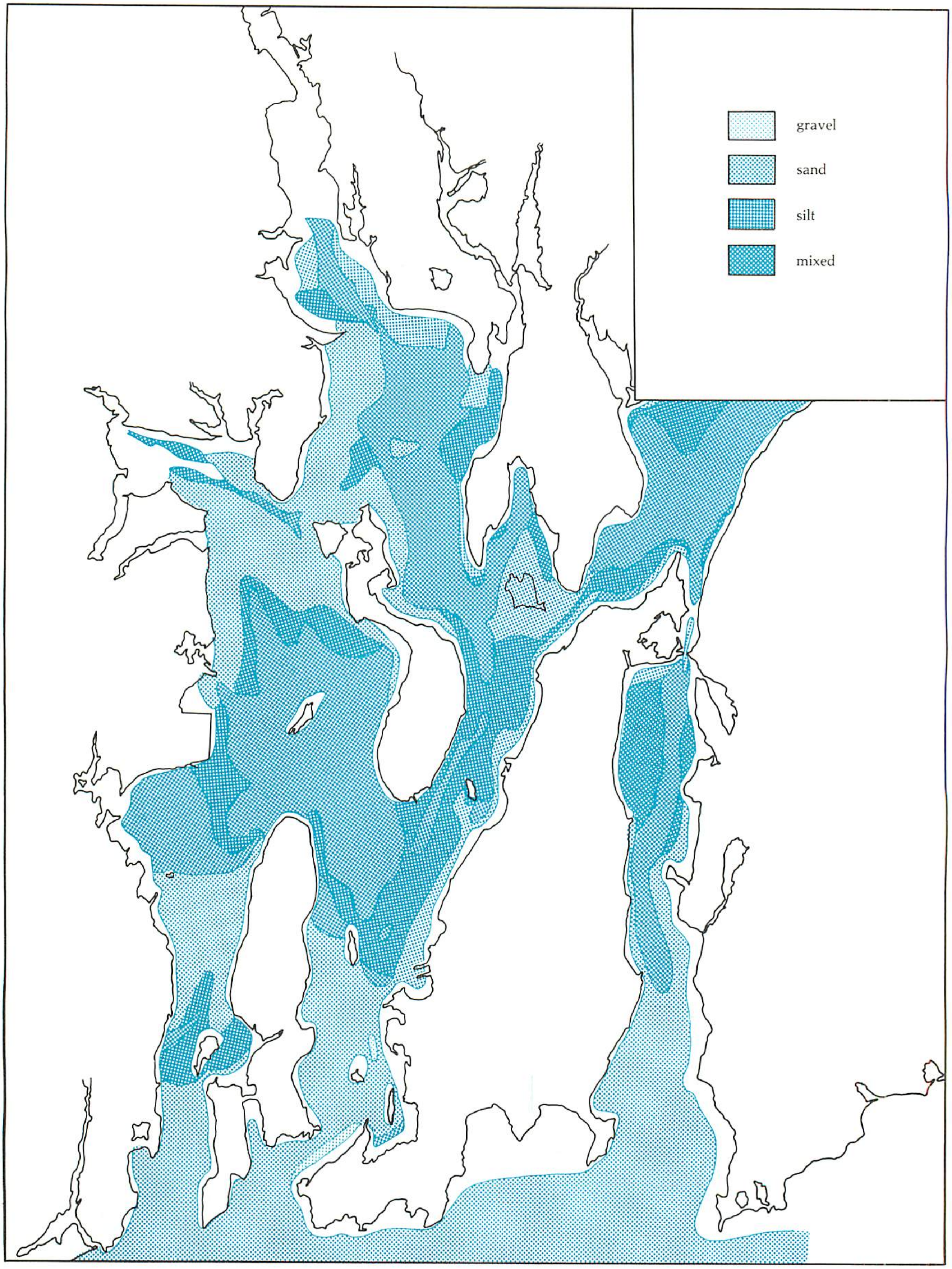


Figure 6. Shoreline types. *Adapted from Boothroyd and Al-Saud, 1978.*

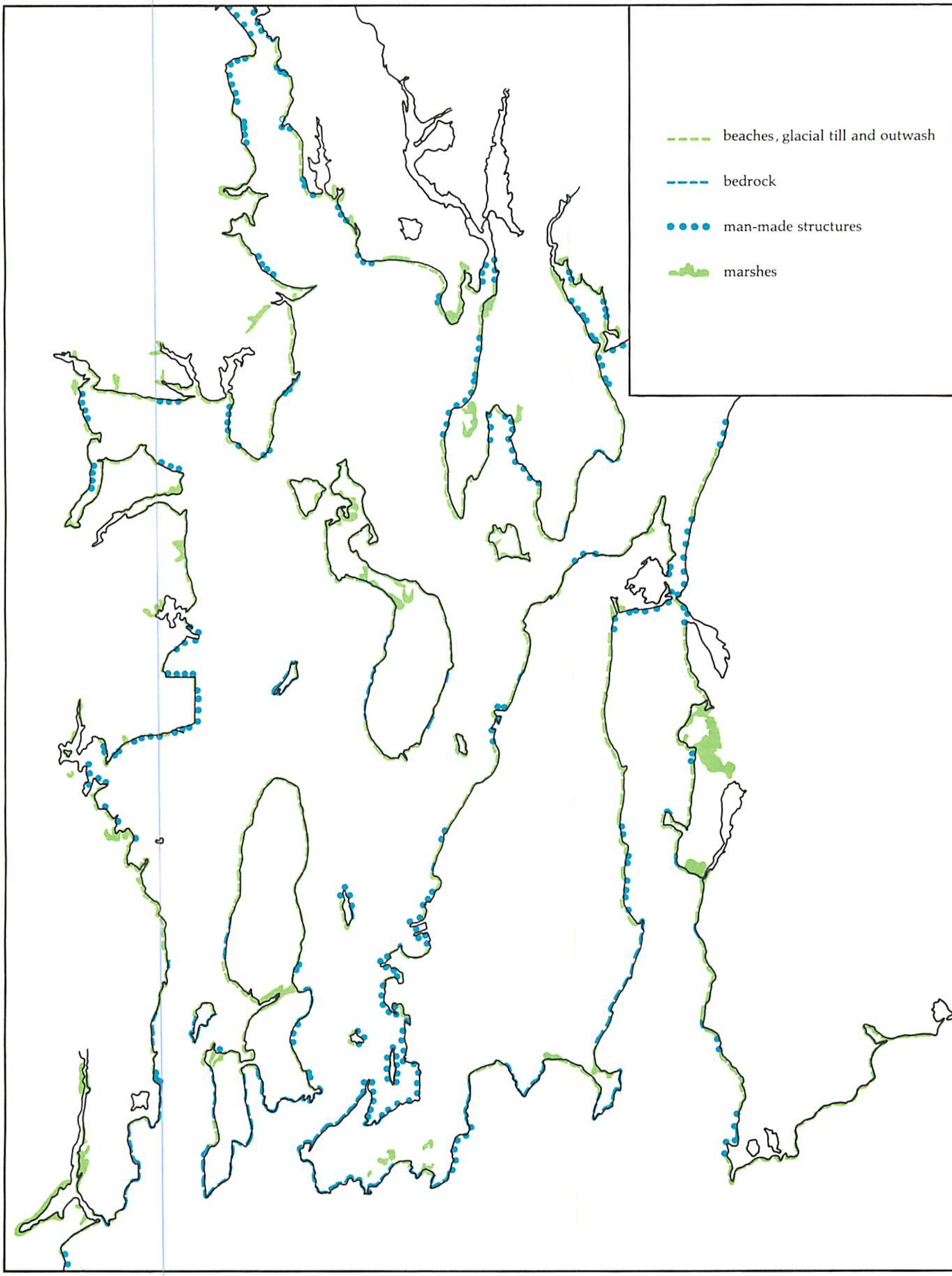


Figure 7. Coastal areas prone to flooding during major storms and hurricanes. *Adapted from Kraft, 1971, and McMaster, 1962.*

Chapter 2

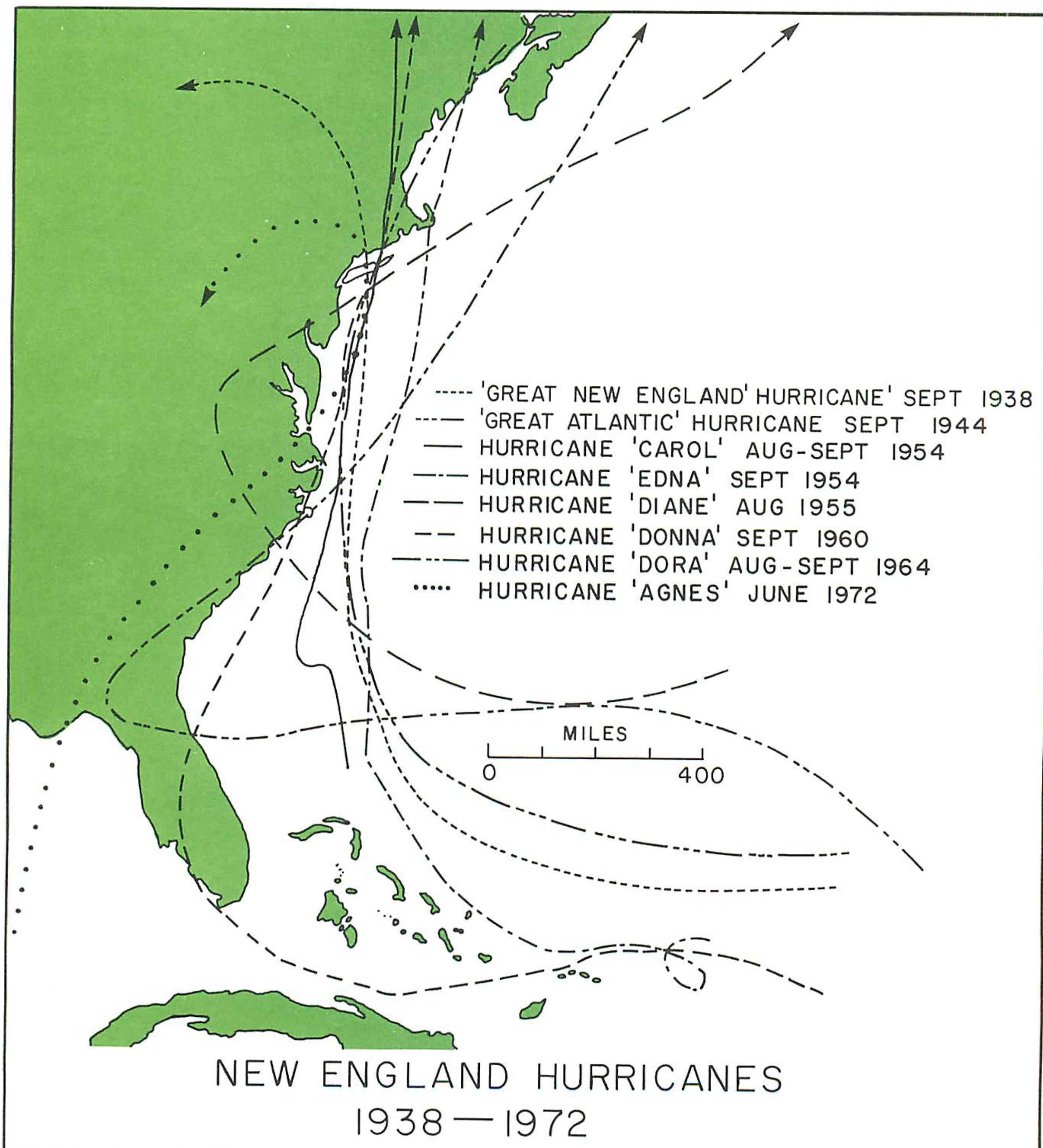
Storms, Hurricanes, and Flooding

The weather in New England is strongly influenced by subarctic air from the northwest in the winter and by tropical marine air from the southwest in the summer. Northeasterly gales are common throughout the year, and hurricanes occasionally come up the coast from the southeast. Historical records collected by the U.S. Army Corps of Engineers document that there were at least two hurricane floods in New England in the seventeenth century, three in the eighteenth century, ten in the nineteenth century, and eleven so far in the twentieth century (5). Hurricanes are therefore not freak events but important recurring phenomena.

The severity of the impact of a major storm or hurricane will depend on the direction from which the storm hits the coast, the state of the tide, and the storm's size and speed of advance. The most severe impacts occur when a storm strikes at high tide and when the wind is blowing across the ocean and forces a surge of water up onto the shore. The funnel-like shape of the Bay amplifies the height of a storm surge as it moves up the Bay, and therefore the highest flood levels in the state are seen along the Providence River. The Blizzard of 1978 did little damage to the state's south shore because it blew across the land and out to sea. Similar wind velocities from the southeast would have caused far more destruction. The state was not so fortunate when it was struck by the Great New England Hurricane of 1938 and Hurricane Carol in 1954. On both of these occasions, sustained winds of over 160 kph (100 mph) with gusts of 260 kph (160 mph) came from the southeast and struck at high tide. When the 1938 hurricane struck, Exchange Place in Providence was under ten feet of water in a matter of minutes. The storm surge piled water 4.8 m (15.6 ft.)

The Great September Gale of 1815. *Oil painting by John Russell Bartlett, from the Rhode Island Historical Society.*

Figure 8. Tracks of hurricanes that have struck the New England coast, 1938-72. *From Kraft, 1971.*



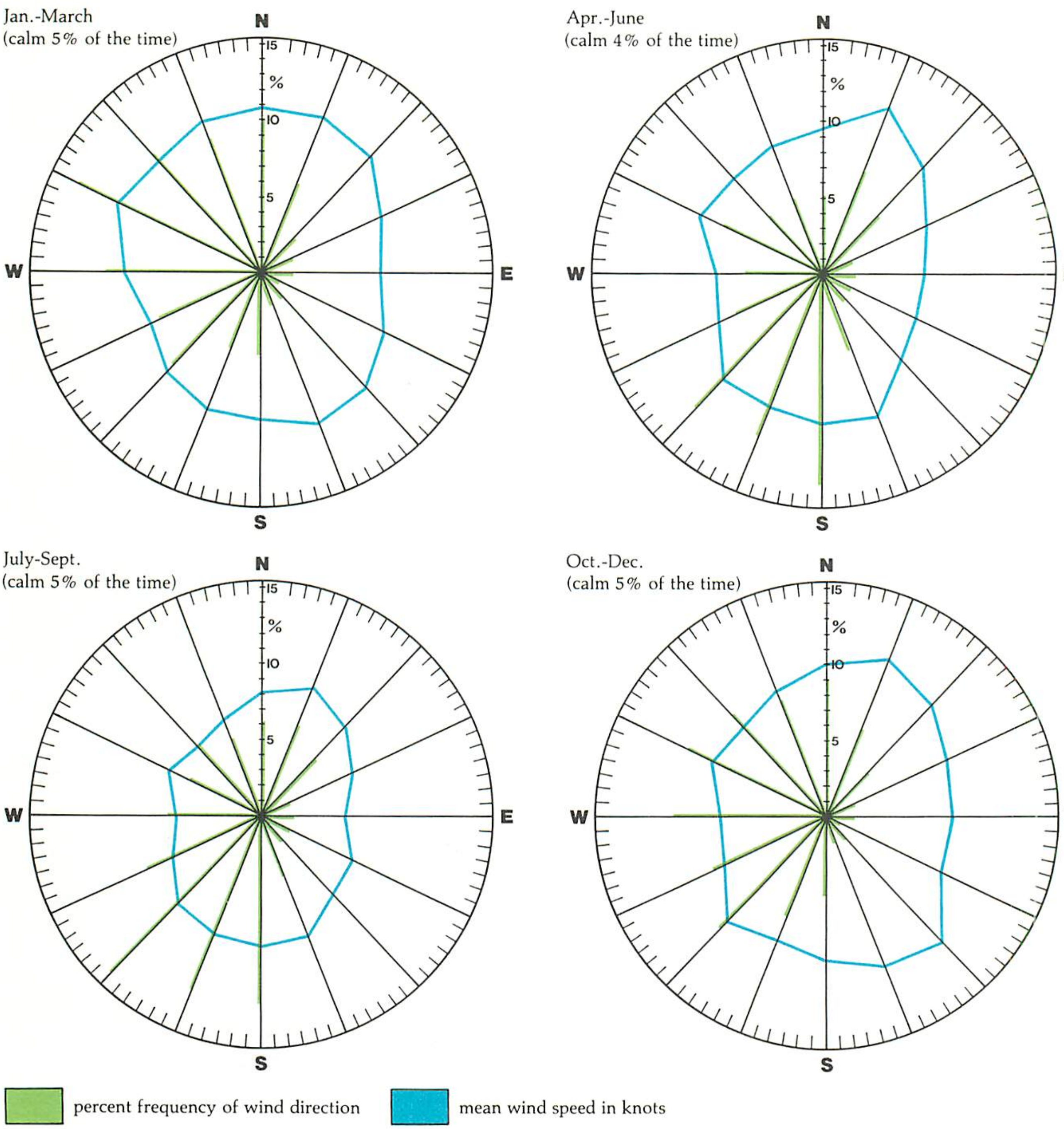
higher than mean sea level, and waves tossed oil barges into downtown streets. In all, some 92 km² (36 sq. mi.) of the state was flooded (6). Property damage was estimated at $125 million statewide, tens of thousands of trees were blown down, 2,000 houses were destroyed, and boats and docks were splintered into driftwood all along the coast. Because there was no warning of the approaching storm, people were caught totally unprepared. Two hundred and seven Rhode Islanders died. Sixteen years later, Hurricane Carol again submerged downtown Providence, this time under eight feet of water. Damage to the city of Providence alone was estimated at $40 million, and nearly 4,000 homes were destroyed (3). Because people were warned, there was no loss of life in 1954.

The Hurricane Barriers

The 1938 and 1954 hurricanes spurred the Army Corps of Engineers to undertake flood control projects all along the New England coast. One of their most ambitious projects was for Narragansett Bay. The Corps' plan called for construction of the Fox Point hurricane barrier to protect Providence and a line of

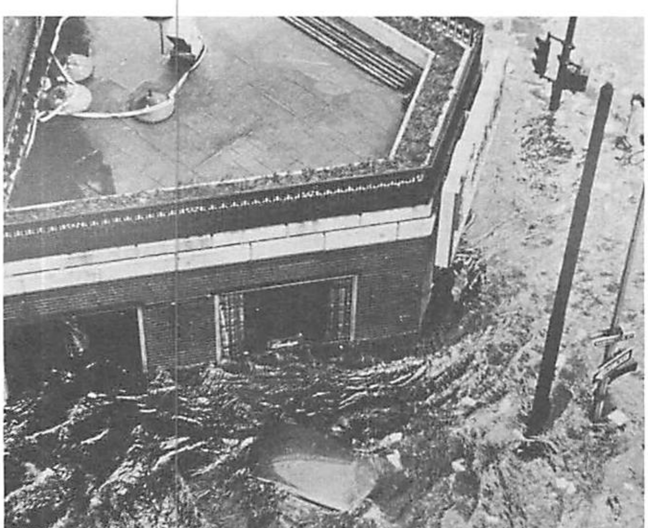
Aftermath of the 1938 hurricane, Conimicut Point, Warwick. *From the Providence Public Library, Rhode Island Collection.*

Figure 9. Seasonal wind speed and direction. Wind roses showing the average wind speed and direction for each season. Diagrams are averages of 26 years of data (1945-72). *Drafted from data compiled by U.S. Naval Weather Service, 1973.*



Note: Scale on radii is both percent frequency and speed in knots.

massive breakwaters across the entrances to the lower Bay and Mount Hope Bay. Construction of the Fox Point barrier was authorized in 1957. Work on the $16 million project began in 1961 and was completed in 1966, the federal government contributing two-thirds of the funding. The barrier consists of a concrete dam 700 feet long flanked by 2,200 feet of rock-faced earthen dikes. The dam has three 40-foot-wide gates, which in the event of a hurricane are closed to prevent flooding in the city. River water accumulating behind the dam is pushed over the barrier by pumps (4). The lower Bay barriers caused great controversy. The plan called for rock barriers across the West Passage at Bonnet Shores and between Castle Hill and Fort Wetherill on the East Passage. Both would have had an ungated opening for shipping and a series of sluice gates. The plan called for dikes at the head of the Sakonnet River, across Mackerel Cove Beach on Jamestown Island, on Bonnet Shores in Narragansett, and at Castle Hill in Newport. The estimated cost of the lower Bay project was $90 million, and damage from another hurricane the size of the one in 1938, without the barriers, was projected at $75 million (in 1956 dollars) (1). The cost of the lower Bay project and a number of environmental concerns combined to prevent the project from being built.



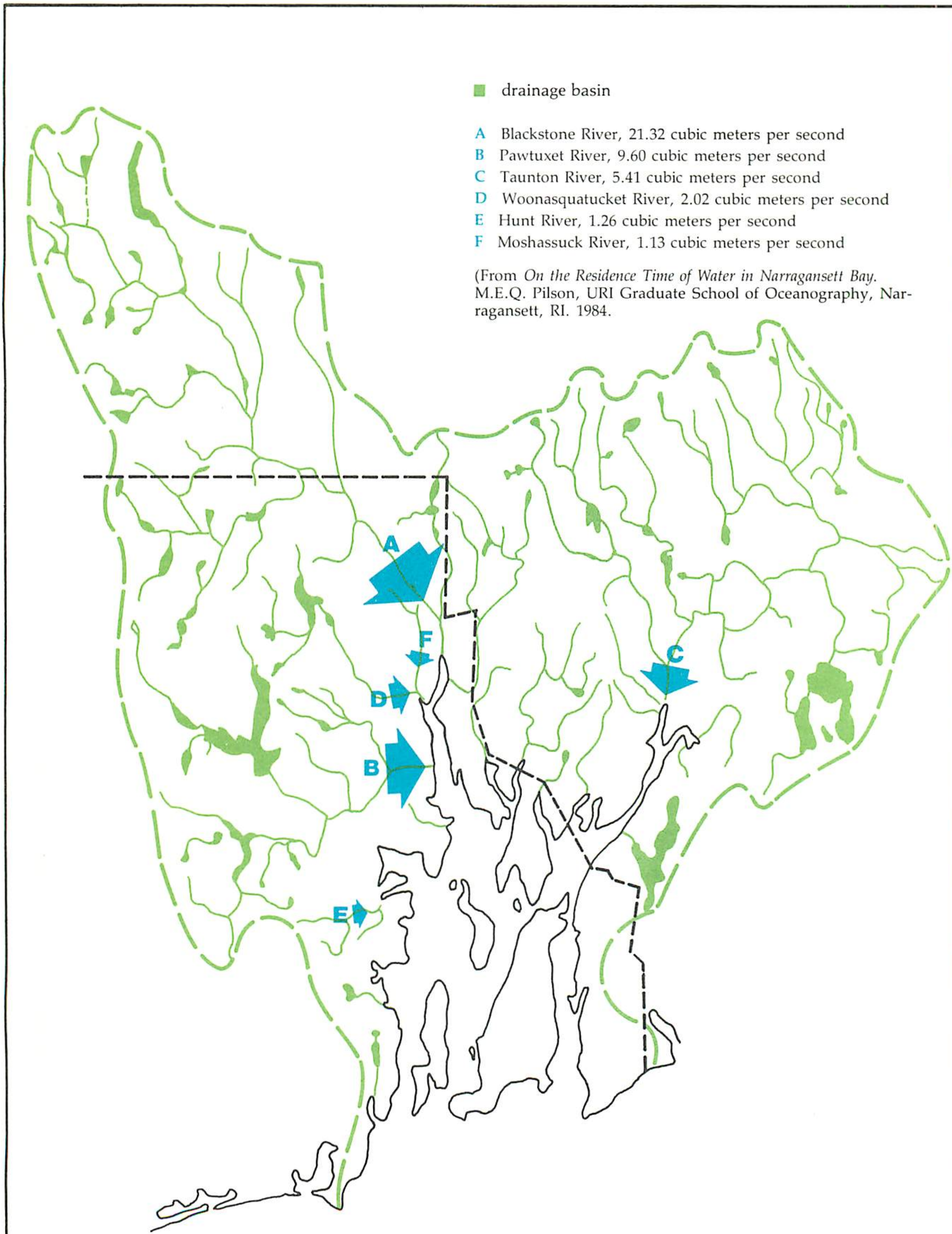
The 1954 hurricane floods the Biltmore Hotel in Providence. *From the Providence Public Library, Rhode Island Collection.*

National Flood Insurance

One of the arguments against the lower Bay hurricane barriers was that steps could be taken to direct building away from flood-prone areas and to provide insurance for property that might be damaged. Such programs have indeed been written and funded, but unfortunately they are a mixed blessing. The most important of this kind of legislation, the National Flood Insurance Program, which is subsidized by the federal government, was started in 1968 to provide insurance for most structures in flood-prone areas. The Flood Insurance Program has provided each community with maps showing expected flood elevations and risk zones, which are used in applying local building ordinances and for calculating insurance rates. All of Rhode Island's coastal communities presently receive the full limits of flood insurance coverage in return for flood management measures adopted by each community. New building in hazard areas must be elevated or "flood-proofed." However, the only places where building is not permitted is in the floodways of rivers and streams that are expected to overflow their banks and on sand dunes. There are no provisions for the dramatic erosion that usually accompanies a major hurricane. During the 1938 hurricane, several stretches of Bay shore were cut back 10 m (30 ft.) or more, but today houses again line shorelines where every structure was destroyed. Many argue that the Flood Insurance Program has encouraged building in hazardous areas. It is also known that the enforcement of the Program's construction requirements has been uneven at best.

It has been 26 years since Rhode Island felt the full force of a hurricane. Many sites where homes were washed away in 1938 and 1954 have been redeveloped. The next major hurricane that strikes at high tide with full-force winds blowing out of the southeast will again extract a great toll from Rhode Islanders. The only bright side is that weather forecasting is now sufficiently sophisticated to provide ample warning of an approaching storm. The losses should therefore be in property and not in lives.

Figure 10. The Narragansett Bay drainage basin and the average annual flows of principal rivers. *Drafted from data compiled by New England River Basins Commission, 1954.*



Chapter 3

The Waters of Narragansett Bay

In Narragansett Bay, fresh water from the land mixes with seawater to create a highly productive ecosystem known as an estuary. The classic definition of an estuary is "a semi-enclosed body of water that has free connection with the open sea and within which seawater is measurably diluted by fresh water derived from land drainage." The manner in which fresh and salt water mix within an estuary is complex. It is also extremely important, since water, life-sustaining nutrients, free-floating planktonic life, and pollutants all circulate and mix in the same manner. The key point to understanding estuarine circulation is that fresh water is less dense than seawater, and therefore tends to stay at the surface as it flows seaward while a compensating current of seawater flows up into the estuary along the bottom. In all estuaries there is a salinity gradient from fresh water at the head of the estuary to seawater at or near the mouth. Different communities of plants and animals have adapted to conditions along this gradient. The volume of fresh water flowing into an estuary, the shape of the estuary, and the effects of tides and the wind all determine the manner in which fresh water and seawater mix. The three principal types of mixing are shown in Figure 11. The lower two-thirds of Narragansett Bay is closest to the "well-mixed" (vertically homogeneous) condition, while highly stratified (unmixed) conditions predominate in the Providence River.

Sources of Fresh Water

Nearly 90 percent of the annual flow of fresh water into the Bay comes from rivers that empty into upper Narragansett Bay and Mount Hope Bay (7). These rivers, in turn, drain some 4,790 km^2 (1,849 sq. mi.) of land, most of which is in Massachusetts (4). The water flowing from these rivers has for some 200 years been polluted by industries and cities. Today the water quality is much improved, but the rivers still contribute a significant proportion of the pollutants as well as the life-supporting nutrients that flow into the estuary. Approximately 10 percent of the freshwater input to the Bay is provided by sewage and by rain falling directly onto the Bay's surface (5). The estimates of freshwater inputs given in Figure 12 do not account for all sources. There are no estimates for the volume of fresh water that enters the Bay by groundwater seepage, by way of small streams and creeks, or by sheet runoff during storms and thaws.

Figure 12 shows that the flow of fresh water has a distinct seasonality and that the pattern does not correspond to a relatively constant monthly rainfall within the drainage basin. The marked decrease during summer months in the volume of water flowing from rivers appears to be due to evaporation, the uptake of water by plants, and the penetration of rainwater into the ground to recharge underground freshwater supplies. In the winter, when most plants are dormant and the ground is frozen, rainwater rapidly runs off the land and into the rivers.

The movement of Bay water at any single place and time is the result of a complex combination of forces produced by the tides, winds, the gradients in salinity (illustrated in Figure 13), and gradients in temperature.

Tidal Circulation

To the casual observer, the most apparent currents in the Bay are tidal. These currents are caused by the gravitational forces of the sun and moon, which make the oceans oscillate in a rhythmical and predictable manner. Within approximately 12½ hours, the Bay's surface rises and falls 100 to 130 cm (3 to 4 ft.). These oscillations are marked by currents that commonly reach up to 77 cm/sec (1½ knots) at peak velocities midway between high and low water. Twice a month on a new and full moon, the positions of the sun and the moon are aligned to produce particularly strong effects known as spring tides, which are significantly higher and lower than normal tides. The first and last quarter of the moon produce very low-amplitude neap tides.

The character of the tidal currents at specific locations is governed by the topography of the area. Currents flow faster through constricted passages, and the tidal range is somewhat higher at the head of the Bay in Providence than at the mouth. Friction between the moving water and the Bay floor reduces the speed of currents near the bottom and close to shore. Thus, tidal currents at the surface in the middle of the East and West Passages may be 77 cm/sec (1½ knots) when currents along the bottom and close to shore are only 22 cm/sec (½ knot). Because high tide progresses up

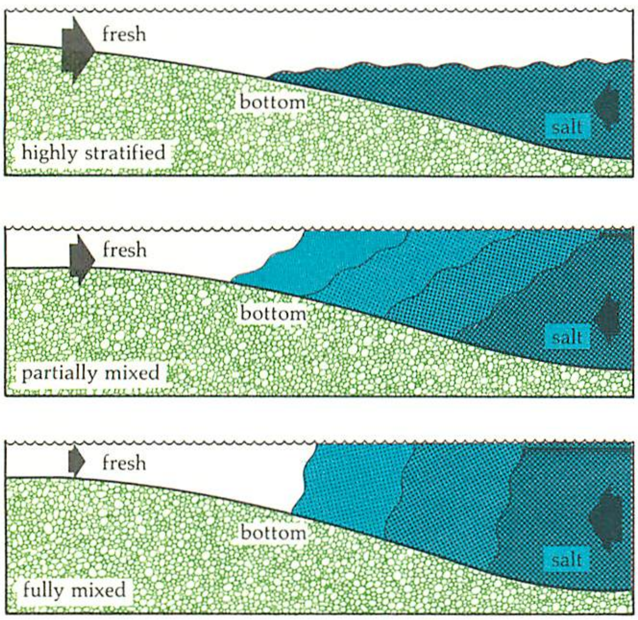


Figure 11. Schematic diagram of nontidal estuarine mixing patterns. Less saline surface water flows seaward and a compensating current of more saline ocean water flows up into the estuary along the bottom. Various amounts of mixing takes place along the boundary between the two layers. *From Lippson et al., 1979.*

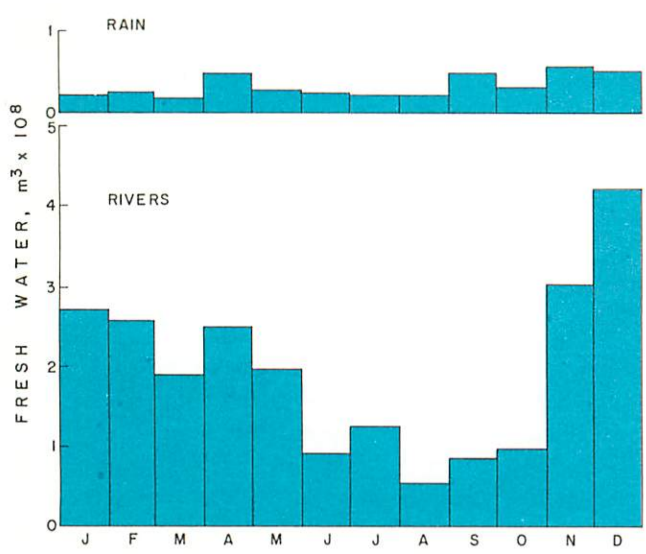


Figure 12. Monthly freshwater flows into the Bay from rivers and from rain falling directly on the Bay, 1972-73. *Drafted from data compiled by U.S. Geological Survey, 1977.*

the Bay as a wave, high tide is some 20 minutes later at Providence than at Newport (2).

	Mean Tidal Ranges	*Spring Tides*
Bay Mouth	1.1 m (3.5 ft.)	1.3 m (4.4 ft.)
Bay Head	1.4 m (4.6 ft.)	1.6 m (5.3 ft.)

It is important to remember that the tides slosh water back and forth. Upper Bay water is not flushed out into the Sound by a single outgoing tide. Indeed, an object floating in the Port of Providence, if we ignore the effects of wind, snags, and other hazards, would be carried on an average outgoing tide approximately eight miles, which is no further than Rocky Point (6). The same object or particle of water would reappear a short distance below its original position some 12 hours later, after the flow had reversed. The nontidal currents discussed next are responsible for gradually moving a particle of water down Bay and ultimately into the Sound.

Circulation Due to Salinity and Temperature Gradients

The currents that are most important to the exchange of fresh water from the land and seawater from the Sound are nontidal. The basic patterns of nontidal estuarine circulation are shown by Figure 11. The deeper offshore water is of a relatively constant salinity and temperature, whereas the surface layer is warmer than the bottom layer in the summer and colder in the winter. The salinity of the surface layer, although less than bottom water, varies seasonally. Surface water mixes with bottom water as it progresses down Bay and therefore becomes more saline. Nontidal currents in Narragansett Bay move slowly, at about 10 cm/sec ($\frac{1}{5}$ knot) (6).

The two-layered circulation pattern that is usually present in the upper Bay has profound consequences for the mixing and flushing of pollutants that flow from Central Falls, Pawtucket, Providence, and elsewhere into the Providence River. Due to the layered circulation, seawater from the Sound flows into the upper Bay, and polluted surface waters are carried seaward, thus rejuvenating what would otherwise be a sluggish and more polluted stretch of water. The situation is complicated by the forces of the wind which, it appears, at times reverse the expected flows. There are very few field data on the behavior of currents over a continuous series of tidal cycles in any locality, but a single 51-day record from a current meter placed on the bottom south of Conimicut Point (8) suggests that southeast winds flowing up the Bay prevent surface waters from flowing down Bay. This may cause a compensatory loss in the input of clean cold water from the Sounds. This situation may last as long as several weeks. Such temporary losses in the usual two-layered flow may prove to be associated with periods when the upper Bay suffers the worst consequences of pollution.

Nontidal currents gradually flush water out of the Bay into Rhode Island Sound. The common estimate of the time needed to transport a particle of water from the Port of Providence to the mouth of the Bay is 45 to 50 days (6).

Wind-driven Circulation

In Narragansett Bay, the winds play a highly variable but frequently dominant role in the movement of waters and the rate at which the Bay exchanges water with the Sound. Southerly winds pile water up at the head of the Bay; northerly winds move water out of the Bay into the Sound. Unlike the tides and the currents formed by temperature and salinity gradients, the winds can only be predicted in terms of general patterns. We can expect southwesterlies to dominate in the summer and northwesterlies in the winter. Average monthly wind speeds are usually highest in December and January. All presently available flushing time estimates for the entire Bay or specific sections are based largely on indirect measurements. It is well recognized by all those who have worked on the problem that the winds play a dominant role in determining the behavior of Bay waters. Since the winds are highly variable, all present estimates for flushing times and nontidal current patterns must be viewed with great caution. Since the actual patterns vary greatly as the winds change, the "real world" result may not be close to one predicted by a theoretical model, which does not include the effects of winds.

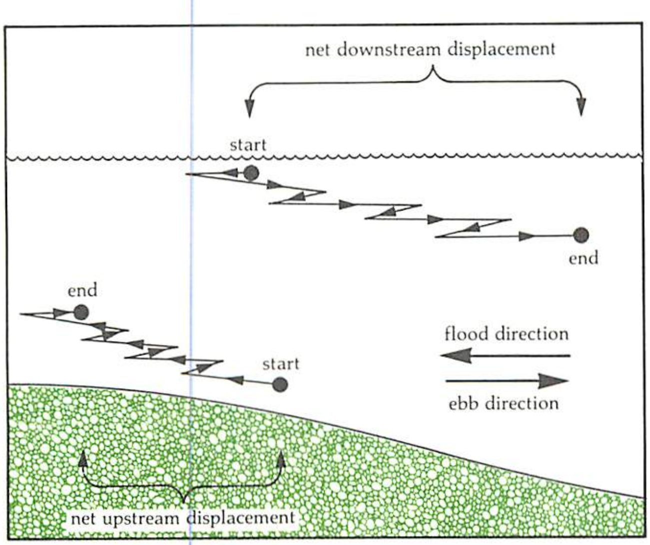
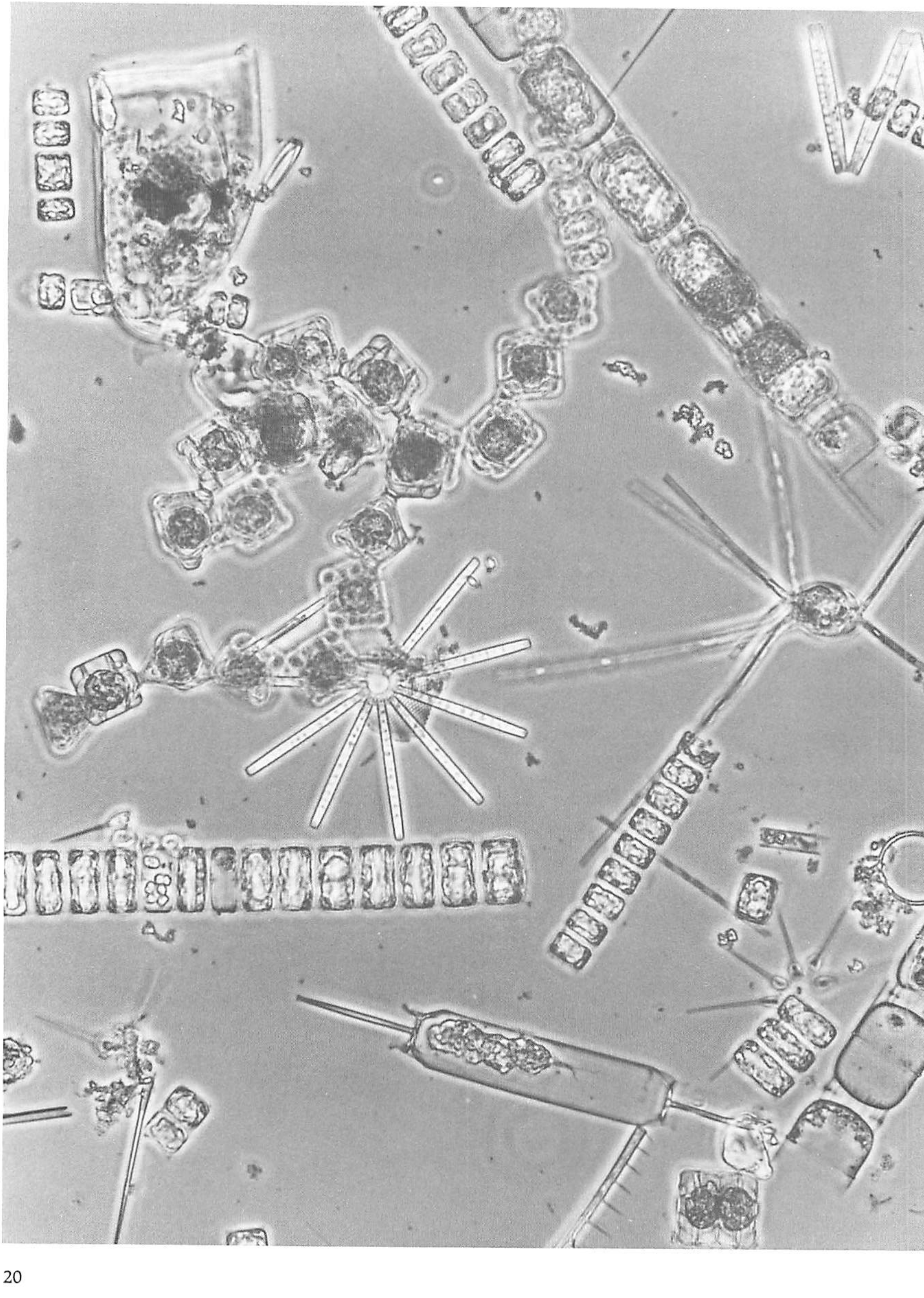


Figure 13. Movement of a particle of water in response to both tidal and nontidal currents in an estuary. *From Lippson et al., 1979.*

Narragansett Bay diatoms. *Photo by Paul W. Johnson and John McN. Sieburth.*



Chapter 4

The Plankton

The word "plankton" is derived from the Greek, meaning "that which is made to wander or drift." The plankton, which are the base of the food web, are composed of plants, called *phytoplankton*, animals, the *zooplankton*, and decomposers, the *bacterioplankton*. They float suspended in the water and drift with the currents. The phytoplankton in the Bay are all single-celled organisms that are not visible to the naked eye. Most of the 250 species that are present in the Bay fall into two broad categories: the *diatoms*, which have two glasslike shells made of silica that fit together like a pillbox, and the *flagellates*, which have one or more whiplike appendages that draw or propel them through the water. Half to three-quarters of the zooplankton in the Bay are tiny crustaceans called copepods which are planktonic all their lives. Many of the remaining zooplankton, however, are only temporary members of this community. These *meroplankton* are the eggs and larvae of nearly all species of fish and most benthic animals. In the Bay, the dominance of the copepods is interrupted for brief periods during the summer when meroplankton, primarily larval mollusks, crabs, shrimp, and fish, swarm in the water in huge numbers. Most of these temporary members of the zooplankton metamorphose into nonplanktonic juvenile forms after a few weeks.

An important but little understood category of plankton are the free-floating bacteria, known as bacterioplankton. Some drift in the water as individual cells or attached to small particles, but most bacterioplankton are gathered into free-floating clumps. The abundance of bacterioplankton fluctuates in cycles which appear to be correlated to the phytoplankton population. They may play an important role in remineralizing nutrients from decaying organic matter and serve as a food source for some very small animals.

The Annual Plankton Cycle

In Narragansett Bay the phytoplankton are by far the most important primary producers, synthesizing organic matter from carbon dioxide and inorganic nutrients with sunlight as the energy source. In shallower, less turbid estuaries, seaweeds and seagrasses may assume this role. The microscopic phytoplankton are far simpler structurally than larger plants, and their life cycle is short. Populations may double in a day and entire communities rise and fall each year. The ever-changing abundance and species composition of the Bay's phytoplankton follow a more or less regular annual pattern directly related to the abundance of nutrients, temperature, and the effects of grazing by zooplankton, benthic animals, and fish (Figure 14).

Winter/Spring. The cycle begins in the winter, when inorganic nutrients carried into the Bay by fresh water from the land combine with those produced by remineralization and accumulate to high levels. The phytoplankton do not respond immediately but wait until longer days and increased sunlight begin to warm the Bay's waters. Sometime between December and March, and beginning in the upper Bay and then moving progressively southward, the dramatic winter/spring plankton bloom fills the Bay's waters with myriads of

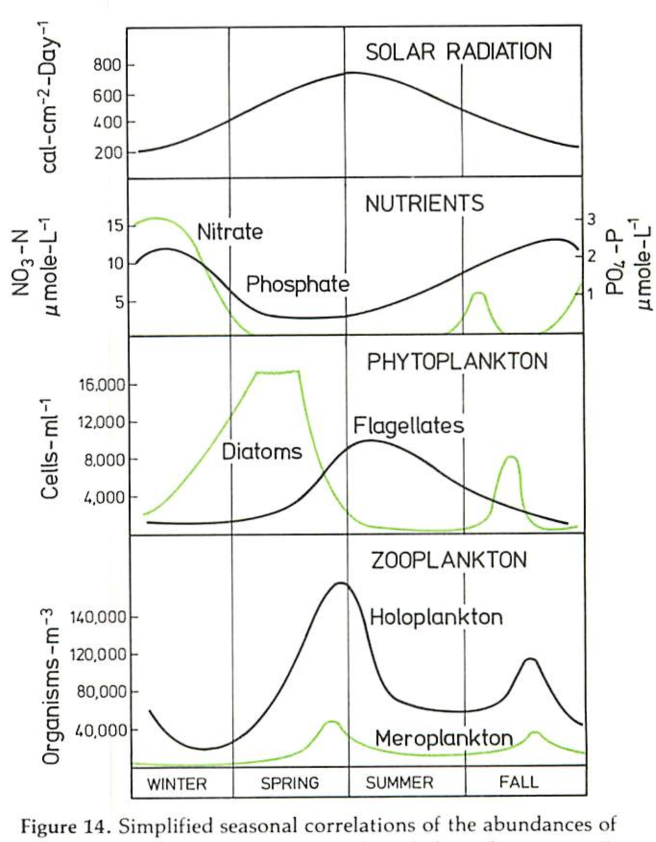


Figure 14. Simplified seasonal correlations of the abundances of phytoplankton and zooplankton with sunlight and nutrients. *From Jeffries, 1969.*

diatoms. A single drop of water will contain as many as 4,500 cells, each of which can divide several times a day (8). This explosion of growth soon becomes limited by a scarcity of nitrogen, and sometimes by the silica that diatoms require to manufacture their two external shells (4). As the diatoms decline in late spring, flagellates increase and produce a series of smaller phytoplankton blooms. Intensive research on the dynamics of the shift from diatoms to flagellates has revealed that the flagellates succeed for a variety of reasons. Flagellates are better able to utilize the organic nutrients released by animals and produced during the early stages of remineralization (3), and at least one flagellate species excretes into the water a substance that inhibits the growth of diatoms. The burgeoning population of copepods also takes its toll on the diatoms, since copepods are capable of consuming as much as five percent of the standing crop each day. Larger animals such as quahogs and menhaden also feed directly on the phytoplankton.

Summer. In early or mid-summer, the flagellates (phytoplankton) and the copepods (zooplankton) attain their peak abundances and then decline. Copepods attain densities of 150 per liter, but their distribution is very uneven. The subsequent decline of the flagellate phytoplankton and the copepods is due to heavy predation as well as to a growing scarcity in essential nutrients. As the waters of the Bay become warmer, the benthic community becomes active, and filter feeders such as clams, amphipods, and sponges consume large quantities of phytoplankton. In the water the copepods are joined by swarms of larval shellfish, crustaceans, and fish, all competing for both phytoplankton and zooplankton smaller than themselves. Adult copepods, which in the spring fed solely on phytoplankton, sometimes consume their own young. The huge schools of menhaden that visit the Bay during the summer feed by filtering plankton from the water and add yet another form of predation. Measurements of the abundance of both phytoplankton and zooplankton in waters through which a school has just passed show that the feeding of these fish decreases the abundance of the plankton (7). For the zooplankton, however, all predators are overshadowed by a voracious species of ctenophore, or comb jelly, a translucent jellylike animal about the size and shape of a walnut. The population of comb jellies grows rapidly in the upper Bay as temperatures rise in the early summer and then moves down Bay as the summer progresses. The population may reach impressive densities of 50 animals per cubic meter by late summer (5). Their effect on the entire zooplankton population can be devastating.

Fall/Winter. The comb jellies are in turn consumed by butterfish, which appear to play a significant role in the decline of comb jellies in the fall. In the late fall, with grazing pressure reduced and some nutrient remineralization having occurred, the diatoms may bloom again. This increase is smaller and far less

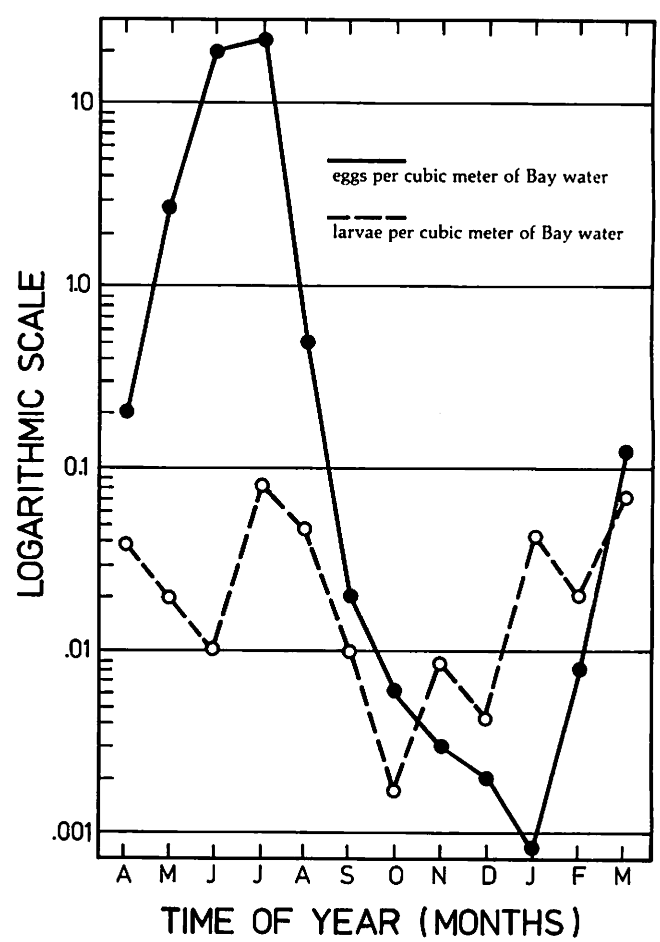


Figure 15. Seasonal abundances of fish eggs and larvae in 1957. Note the logarithmic scale; there are nearly 1,000 times more fish eggs than fish larvae during the summer. *From Herman, 1963.*

intense than the winter/spring bloom, but when it does occur it is followed by another brief pulse in the zooplankton population.

Variations in the Abundance and Distribution of Plankton

Researchers at the URI Graduate School of Oceanography have been intensively studying the plankton in the Bay since the early 1950s. Great volumes of data have been accumulated and many fascinating insights into the dynamics of this community have emerged. But we are still a very long way from being able to answer all the important questions the plankton pose. We know more about the phytoplankton than the zooplankton. The seasonal and spacial distribution of these microscopic plants, the relative importance of the various species, and the influence of temperature, salinity, and key nutrients are all generally understood. We can predict with some confidence the gross effects of pollution due to the nutrient enrichment brought by sewage and increased

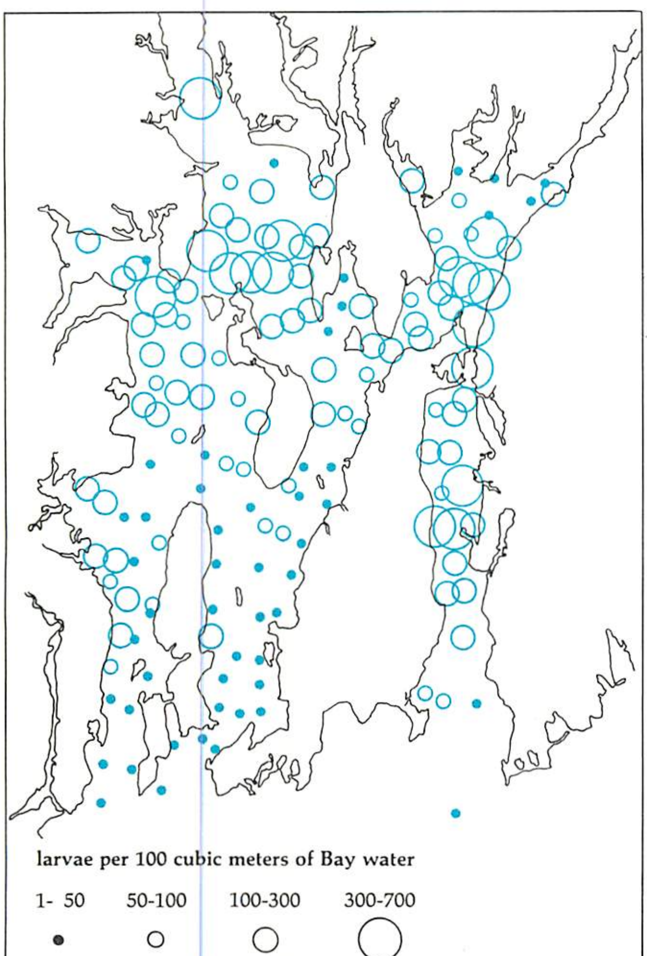


Figure 16. Distribution of winter flounder during their month of peak abundance (April) in the Bay in 1973. *Drafted from data compiled by Matthiessen, 1974.*

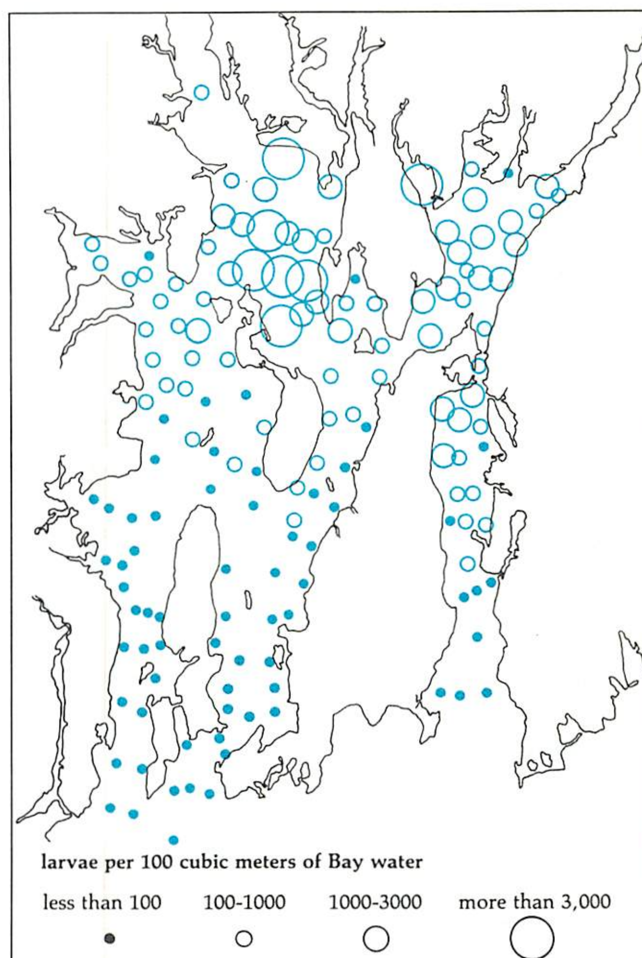
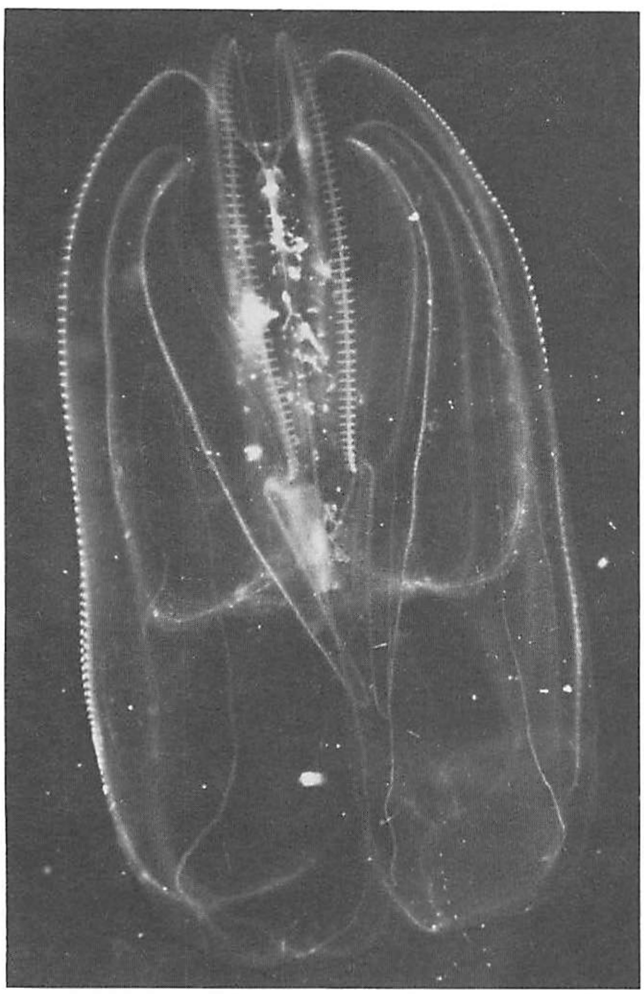


Figure 17. Distribution of menhaden larvae during their month of peak abundance (June) in the Bay in 1973. *Drafted from data compiled by Matthiessen, 1974.*

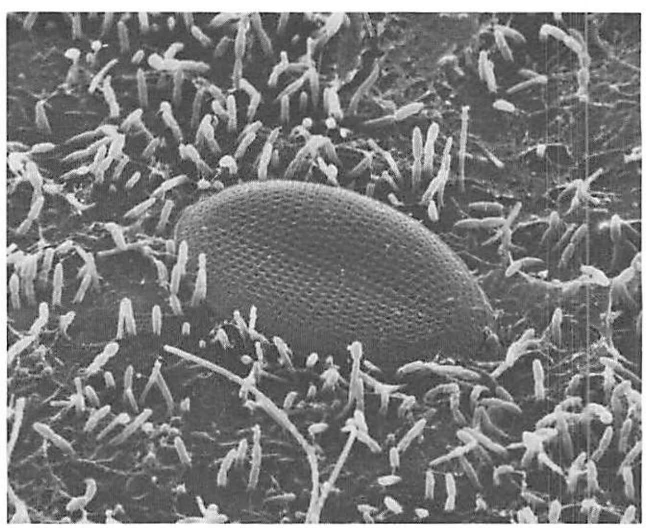
land runoff. But we do not know the final impact of the many pollutants that are of less obvious importance than nitrogen and phosphorus, nor do we understand the interactions among these pollutants. We also do not know how the various plankton species interact with one another. Above all, we do not know why there is so much variability from one year to another in the timing and size of blooms and in the species composition of the phytoplankton population.

There appear to be some strong trends in the changing character of the phytoplankton over the past 20 years, but why these take place and what they signify are questions that we cannot answer. The winter/spring bloom, for example, can start as early as November and as late as April. The summer bloom of the flagellates may occur anywhere between July and September and may last for a few weeks or two months. The abundance of the phytoplankton present in a bloom may vary by an order of magnitude — from 4.5 million cells per liter to 50 million cells per liter. According to Dr. Ted Smayda (9), who has been studying Bay phytoplankton for two decades, there is evidence that the total annual productivity of the phytoplankton is increasing. Regular monitoring at a sampling station in the upper West Passage shows that productivity has risen from approximately 300 to 500 grams of carbon per square meter of Bay surface per year. These data could indicate that the Bay is becoming progressively more polluted. On the other hand, such an increase may be due to a "natural" shift or a long-term cycle which may be related to temperature or a combination of more subtle factors. We simply do not know.

The effects of nutrient pollution on the phytoplankton in the upper Bay are obvious. The upper Bay is, on the average, three to four times more productive than the lower Bay. In any estuary we would expect a pattern like this, but in the Bay there is no doubt that pollution, most of which flows into



Comb jelly *(Mnemiopsis leidyi). Photo by Harold Wes Pratt.*



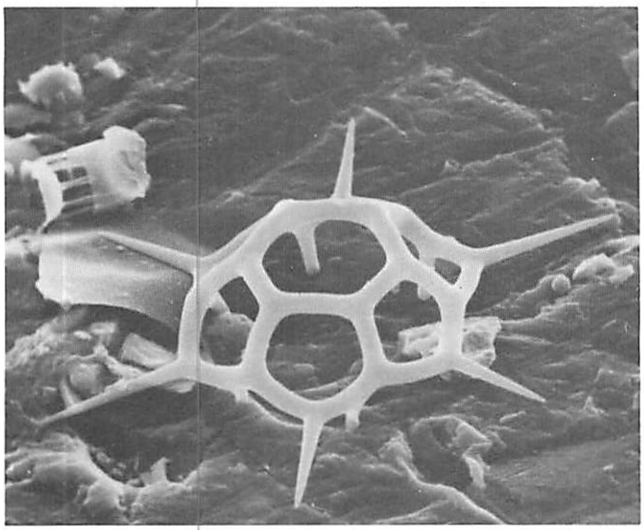
A diatom *(Cocconeis scutellum)* surrounded by filamentous bacteria. *Photo by Paul W. Johnson and John McN. Sieburth.*

the Providence River, is amplifying the natural variation. In the Providence River, the typical signs of eutrophic waters are all too evident. The abundance of nutrients gives rise to massive and erratic blooms of phytoplankton, and subsurface waters, particularly during the summer, frequently become anoxic (low in oxygen) and kill fish and sometimes shellfish. The density of phytoplankton in these highly enriched waters can be remarkable. Some 114 million cells per liter were recorded off Sabin Point in July 1978 (1).

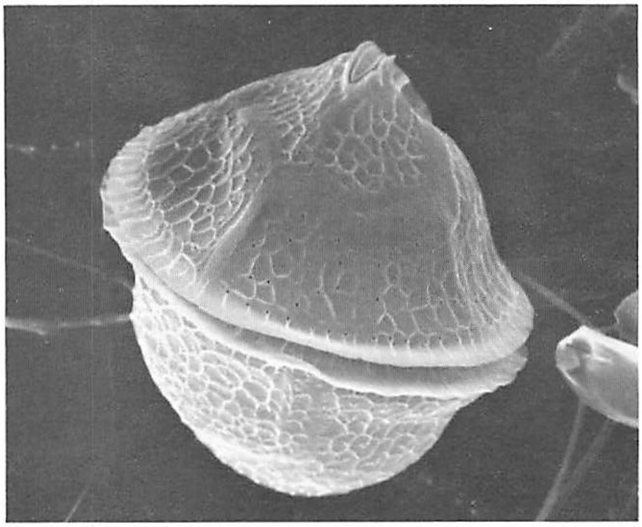
One kind of phytoplankton bloom makes headlines — the "red tide" that occasionally occurs in the Bay and more commonly elsewhere along the East Coast. It is caused by a massive bloom of several common flagellates that can give the water a reddish hue. When present in sufficient quantities in shellfish, people who consume the shellfish suffer from paralytic poisoning and in extreme cases may die. There is evidence that red tides are associated with polluted waters.

The zooplankton pose another series of problems. All research on these tiny animals is complicated by their extremely uneven distribution and by the difficulty of analyzing samples once they reach the laboratory. Their varying seasonality and abundance from one year to the next and shifts in the most abundant species in a given season, as with the phytoplankton, present a host of unanswered questions. The eggs and larvae of fish and benthic animals that make up the meroplankton are especially sensitive to a wide spectrum of pollutants.

The phytoplankton in Narragansett Bay are the base of the ecosystem's food web. Ultimately, the Bay's abundant quahog, shellfish, flounder, sport fish, and all the other animals that abound in the Bay may be traced back to the phytoplankton. The Bay's ecosystem has evolved to its present state over thousands of years, and it is a balanced and resilient system. However, when man adds nutrient-rich wastes to the Bay, he affects the very base of the system. The eutrophication of waters caused by overfertilization can have drastic and in some cases catastrophic consequences. The consequences of environmental pollution are apparent in the upper Bay, and there is clear evidence that a wide spectrum of pollutants are being dispersed and are accumulating further down the Bay (see Chapter 14). Experiments such as those being undertaken at the Marine Ecosystems Research Laboratory at the URI Bay Campus are important efforts to trace the effects and fates of individual pollutants as they cycle through miniature replicas of the Bay ecosystem. This work is providing important, and at times startling, insights into the less than obvious effects of human-caused changes to the Bay ecosystem.

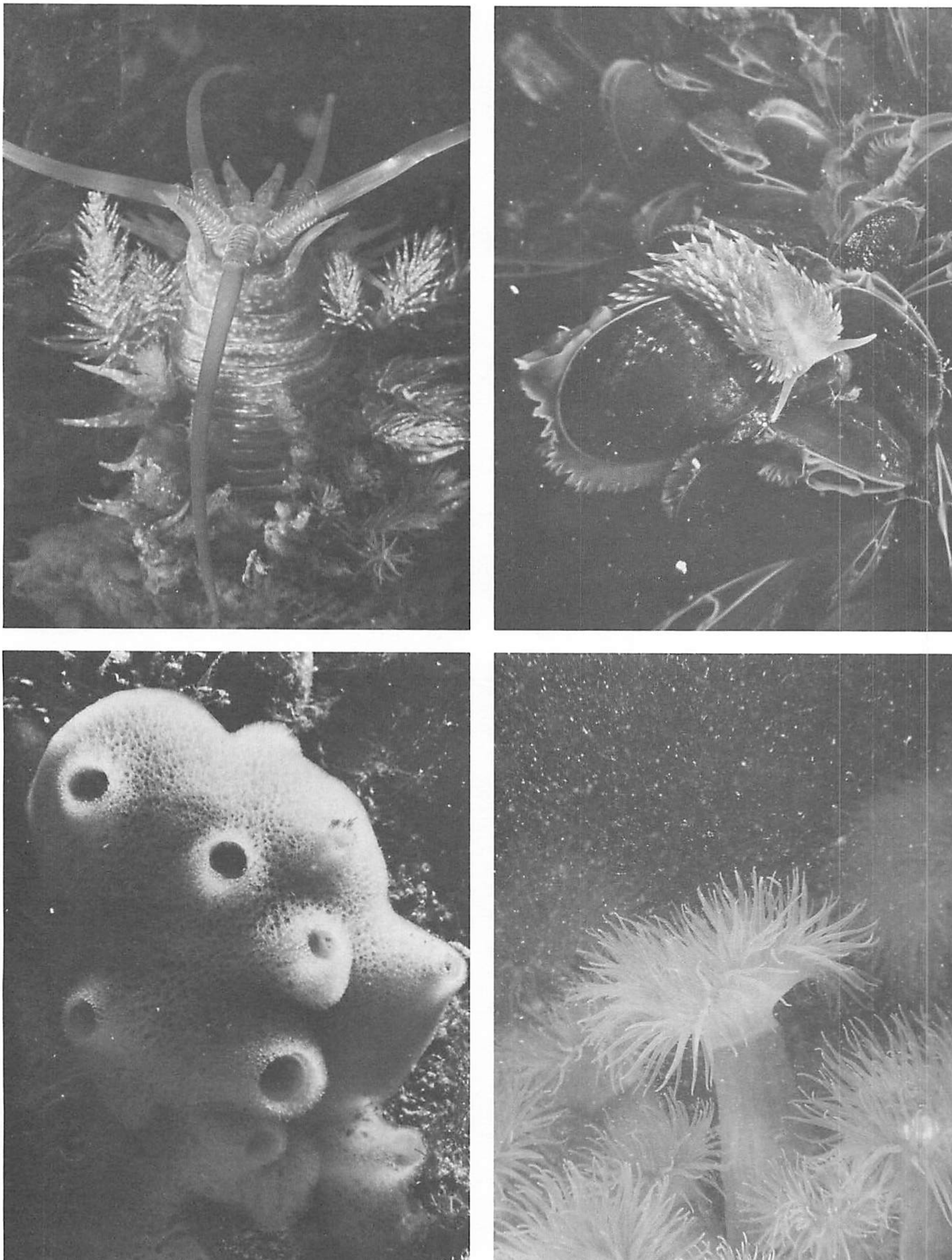


A flagellate *(Distephanus speculum). Photo by Paul Hargraves.*



This dinoflagellate *(Gonyaulax tamarensis)* when present in large numbers causes the feared red tide. *Photo by Paul Hargraves.*

Top left: A polychaete worm *(Diopatra cuprea)*. Top right: A sea slug *(Aeolidia papillosa)* on feeding blue mussels *(Mytilus edulis)*. Bottom left: A sponge *(Halichondria bowerbanki)*. Bottom right: Frilled anemones *(Metridium senile)*. Note the snowlike plankton in the background. *Photos by Harold Wes Pratt.*



Chapter 5

The Bottom Community

The organisms living on and in the bottom are known as the benthos. These include the worms and clams, which live in the bottom; a rich variety of tiny organisms that live between the grains of sediment; and species such as crabs, lobsters, and sponges, which live on the surface of the bottom. Two species of great importance to Rhode Islanders — quahogs and lobsters — are members of the benthos. Benthic organisms may be divided into two major groups according to their feeding habits: *filter feeders*, such as quahogs, draw their food out of the water, while *deposit feeders*, such as mud snails and shrimps, ingest or sift through the sediment and consume organic matter within it.

The benthic community in Narragansett Bay plays a critical role in the functioning of the ecosystem. Benthic filter feeders consume significant amounts of phytoplankton, and the Bay's high primary productivity may be attributable in good part to the recycling activity of the benthos. The benthos remineralize sufficient inorganic nutrients to support approximately one-quarter of the system's primary productivity (2). As might be expected, the release of nutrients by the benthos to overlying water follows a seasonal pattern, with the greatest rates of exchange occurring in the summer, when organisms are most active. It is believed that most of this recycling activity is carried out by microscopic organisms and not by the larger animals.

In any estuary one would expect to find a series of changing communities as one proceeds from a marine environment at the mouth of the estuary to a freshwater ecosystem at the head. One would expect to find the fewest species in the upper estuary, where widely fluctuating salinity makes survival impossible for all but a few highly adapted organisms. This theoretical pattern is borne out in Narragansett Bay. Although there has been no systematic survey to map and characterize the benthic communities throughout the Bay, enough work has been done to piece together general patterns (see Figure 19). In some places, the boundaries separating one community from another are well defined, but in others a gradation is seen over a wide transition zone. It is important to recognize that the groupings of organisms we are calling communities here may not all be as well integrated as some in more stable parts of the ocean. In coral reefs, for example, the various species present have evolved into a "superorganism" that has adjusted to its physical environment so as to make efficient use of the available space and energy. The communities in the lower and perhaps the mid-Bay may show such adaptation, but in the upper Bay rigorous physical conditions have not permitted the evolution of such well-balanced interrelationships.

The Lower Bay

Organisms adapted to true marine conditions live in the lower Bay and at depths of 40 feet or more in the mid-Bay, where temperatures are low and salinities high. Evidence of this are the bed of sea scallops off Gould Island, the ocean quahogs in the East Passage, and the populations of surf clams, another marine species, off Bonnet Shores in the West Passage and in the lower reaches of the Sakonnet River. In the lower reaches of the East and West Passages, much of the bottom is composed of empty oyster and quahog shells on which live large numbers of boat shells *(Crepidula fornicata)*. Compared to mid-Bay communities, this community is relatively unproductive of organisms that are of direct value to man. The shelly bottom prevents quahog larvae from gaining a foothold and there appears to be little fish food. There are, however, sizable beds of blue mussels.

The Central Bay

Two clearly different communities extend over much of this area. In areas of deep water, where sediments are soft and salinities high, a deposit-feeding community flourishes which is dominated by two species of small clams, *Yoldia limatula* and *Nucula annulata*, and a worm that attains a length of 8 cm (3 in.), *Nephtys incisca.* This community is widespread on soft bottom in Buzzards Bay and Long Island Sound, and is also found at the bottom of dredged channels. The deposit-feeding organisms constantly rework the top few centimeters as they sift organic matter from between the sediment grains and excrete it in packets called pseudofeces. This produces a soft, pelletized surface. Since the pellets clog the feeding mechanisms of filter feeders, they are largely excluded. Currents occasionally sweep these nutrient-rich pellets into suspension, thus enriching the water. Average densities of 7,000 to 9,000 individuals per square meter have been recorded for this community, with an ap-

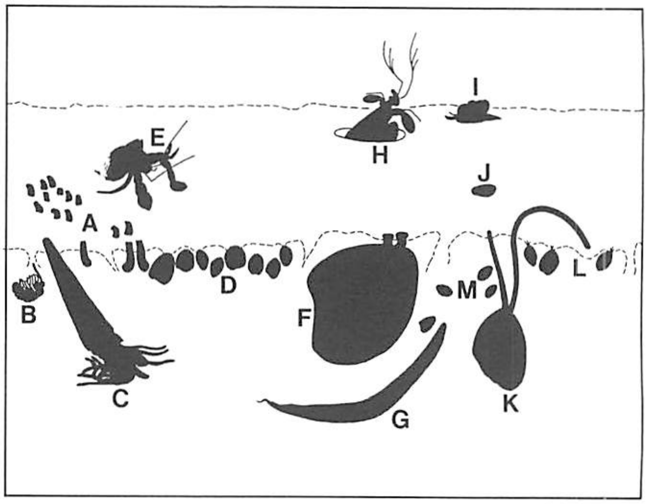
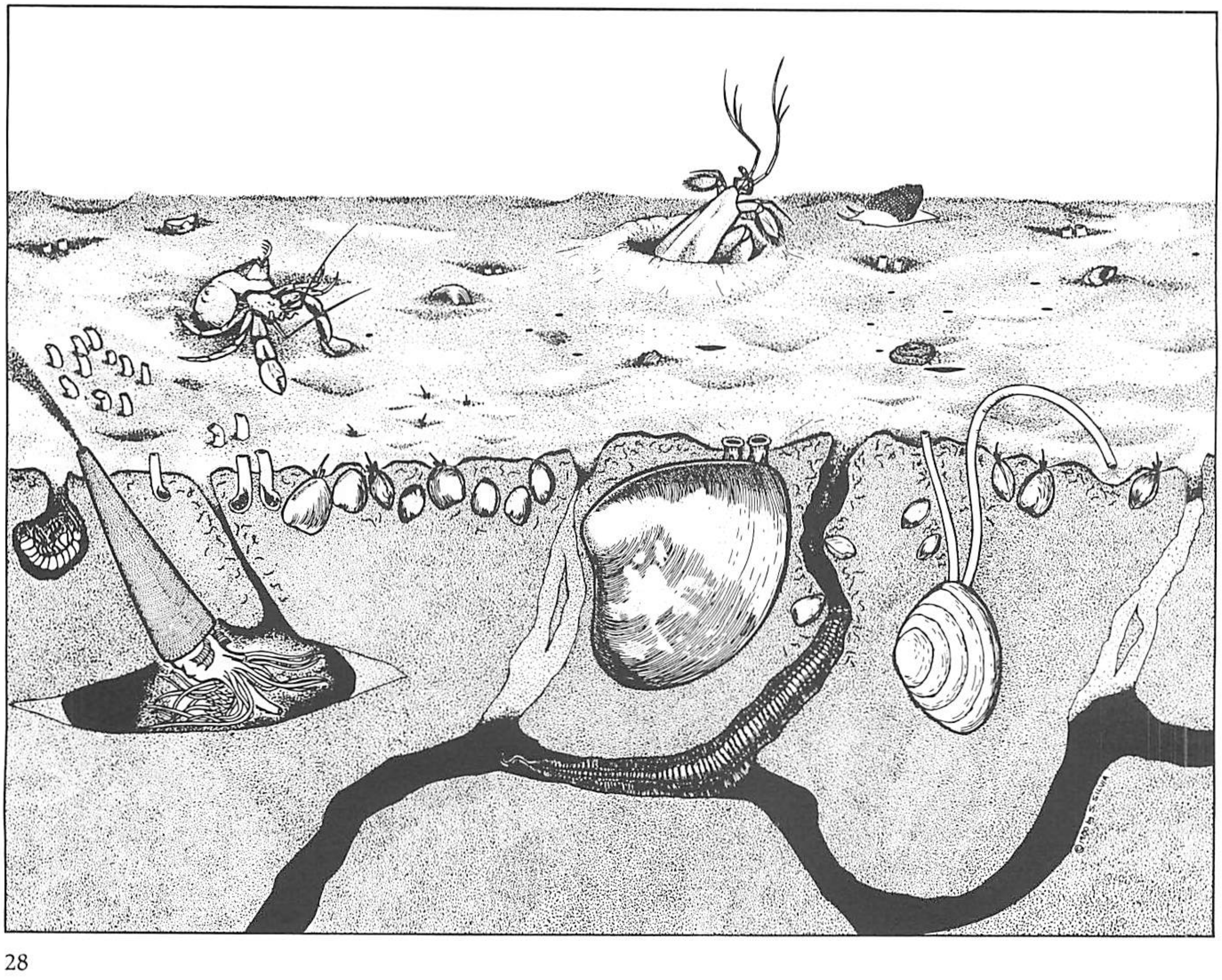


Figure 18. A benthic community. Illustration by Steven P. Silvia. (A) Tube-dwelling amphipods, *Ampelisca.* (B) Benthic amphipod in filter-feeding position, *Leptocheirus pinguis.* (C) Ice cream cone worm, *Pectinaria gouldii.* (D) Coot clams, *Mulinia lateralis.* (E) Hermit crab, *Pagurus longicarpus.* (F) Quahog, *Mercenaria mercenaria.* (G) Shimmy worm, *Nephtys incisa.* (H) Mantis shrimp, *Squilla empusa.* (I) Mud snail, *Ilyanassa trivittatas.* (J) Worm casting. (K) Macoma clam, *Macoma balthica.* (L) Nematodes. (M) Nut clams, *Nucula proxima.*



proximate standing crop of 8 grams per square meter (1). Both species of clams are slow-growing, and it is believed that this community provides a low yield to man in the form of fish, although winter flounder can maintain themselves by feeding on the worms. Because they are filter feeders, quahogs are not common in these areas. Another species of clam, *Pitar morhuana*, which looks like a small quahog but is inedible, has adapted to soft bottoms and is often present.

The second principal community typical of the central Bay is dominated by small tube-dwelling amphipod crustaceans of the genus *Ampelisca*. Their gray-brown parchmentlike tubes extend several centimeters into the bottom and up to one centimeter above it. As many as 30,000 per square meter frequently carpet the bottom with a dense mat that may produce a biomass of up to 29 grams per square meter (1). *Ampelisca* communities are usually found on sandy or silt/sand sediments at shallower depths than the *Yoldia, Nucula, Nephtys* community. The *Ampelisca* community is typical of much of Greenwich Bay and the shallows that extend from there down to Quonset Point. This community is probably widespread throughout much of Mount Hope Bay. The *Ampelisca* community is typically rich in quahogs, and the *Ampelisca* themselves are an important food source for fish — particularly winter flounder. Since this crustacean reproduces twice a year, their young are available to fish throughout the summer. Amphipods are known to be particularly sensitive to hydrocarbon pollution and to general organic pollution. Such pollutants are discharged in large volumes into the upper Bay and may have resulted in a reduction of this highly productive and valuable community type.

The Upper Bay

A line drawn between Conimicut and Nayatt Points delineates both the southern boundary of severely polluted waters and the northern edge of central Bay benthic communities. The dredged channel, however, permits an extension of cool, clean seawater along the bottom a short way up into this area. In the upper Bay, the stresses of fluctuating salinity typical of the upper reaches of an estuary are compounded by the effects of severe water pollution. In its original condition, this area had an average depth of 3 to 5 m (10 to 15 ft.) and was rich in oysters, quahogs, and soft-shelled clams. Today quahogs are abundant in the lower Providence River below Gaspee Point and soft-shelled clams are also present further up the river. Another small clam *(Mulinia lateralis)* is present in dense beds. *Mulinia* are short-lived, and beds may disappear as rapidly as they developed. They are typical of stressed environments and are sometimes viewed as an indicator of pollution. *Mulinia* are also abundant in Mount Hope Bay. *Mulinia* are known as "coot clams" and are probably an important source of food for sea ducks such as scaup. Burrowing and tube-building worms, which tolerate fluctuating salinity and low oxygen levels and are regarded as pollution indicators, dominate the soft bottom prevalent in much of the Providence River.

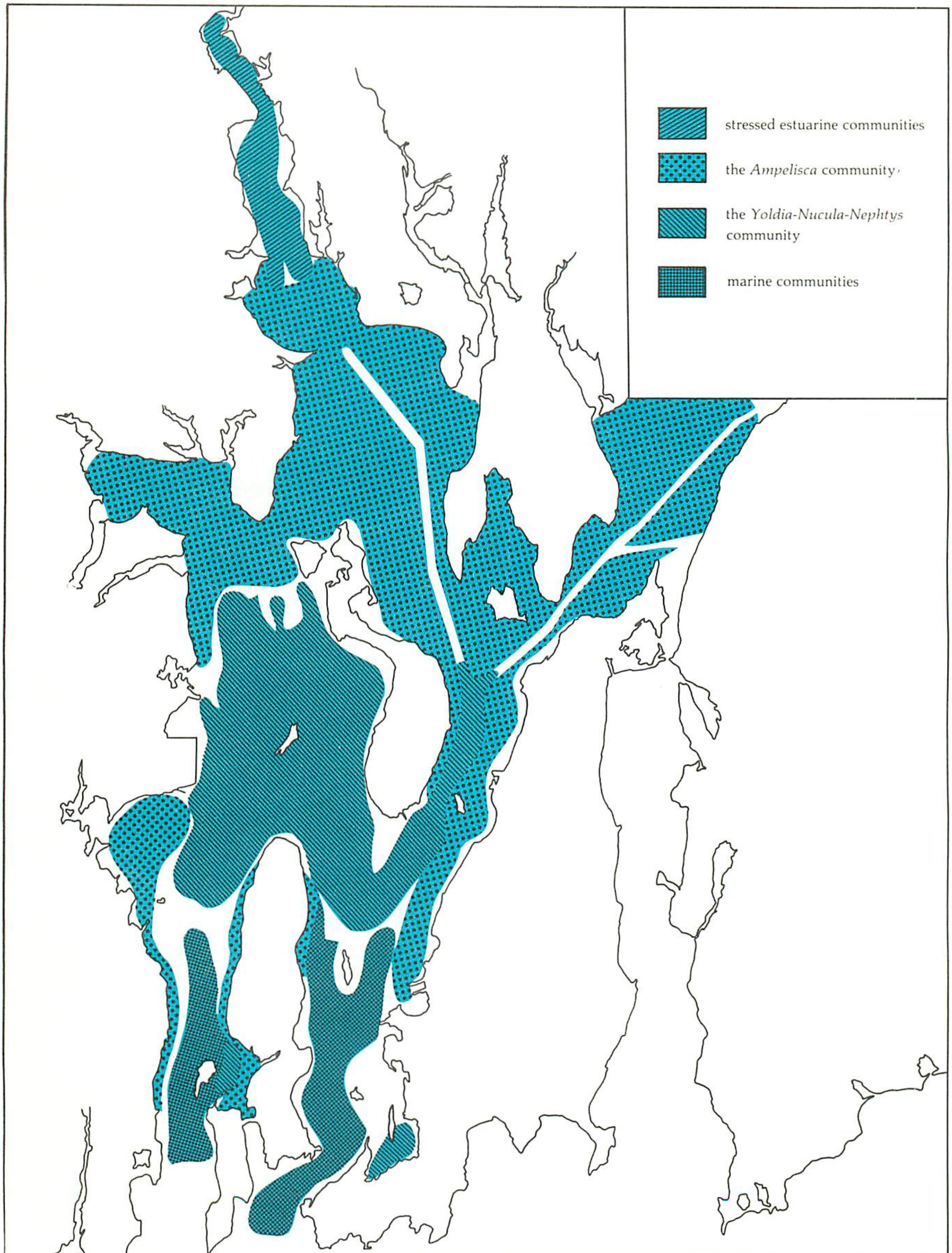
In Providence Harbor, the bottom of the dredged channel and ship berths is almost lifeless. A thin black soup, low in oxygen, overlies the bottom. In those parts of the port that have not been dredged, the remnants of the original benthos may be found as scattered individuals. Soft-shelled clams, *Mulinia*, mud snails, and small tube-building worms survive below the low-water mark, and the hardy ribbed mussel abounds in the salt marshes that fringe the shore in areas that have not been bulkheaded.

The Bay Quahog

Of great interest to most Rhode Islanders is the famous quahog. Quahogs are the most abundant benthic animal of their size in Narragansett Bay. In recent years, the total Rhode Island harvest ranged from 5 million pounds of meats in 1955 to 2 million pounds in 1978, the great majority of which are taken from the Bay.

Quahogs do not characterize a distinct community type such as those just described but are distributed throughout the Bay, from the low-tide mark to depths of up to 18 m (50 ft.) in a wide range of sediments. Some of the potentially most productive areas in the Providence River are closed to fishing because of pollution. Quahogs have a clumped distribution, and their abundance from one small area to another varies widely. Quahogs are most abundant in fine sediments, but the presence of some coarse constituents is also important. Thus, quahogs are more abundant in mud

Figure 19. Distribution of major benthic communities. *Compiled by Sheldon D. Pratt, Graduate School of Oceanography, URI.*



containing sand, shell, and small rocks than in mud without these constituents. Quahogs are least abundant in clayey sediments (3). Quahogs spawn in the summer when temperatures rise above 20 °C (68 °F) and become sexually mature in their second summer. It is thought that medium-sized cherrystone quahogs are the most prolific spawners.

The growth rate of quahogs varies as much as threefold from one location to another, depending on temperature, sediment type, and food abundance. The growing season is from May through October, with half the annual growth occurring before mid-July. Growth is generally fastest in coarse sediments and declines with increasing silt/clay constituents in the bottom (4). It is believed that fine sediments clog the quahogs' filtering apparatus and make feeding less efficient. Growth is most rapid in young quahogs:

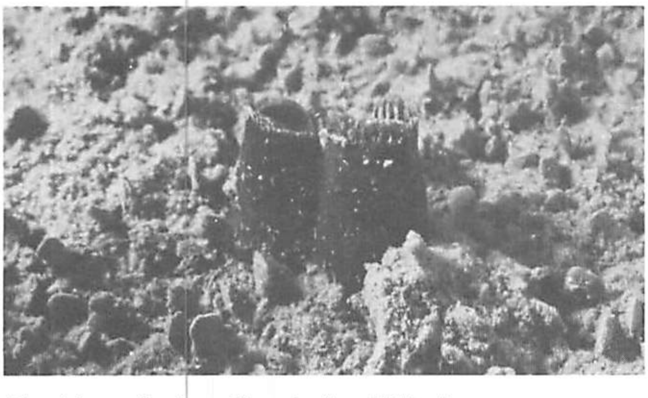
Age (years)	1	2	3	4	5	8	12
Size (inches)	1.0	1.8	2.3	2.8	3.1	3.6	3.9

When the soft parts of a quahog have attained their full development and the shell is no longer increasing in length, the rim of the shell begins to thicken and the quahog becomes a "blunt." This happens at no specific age or size. Quahogs feed primarily on phytoplankton, especially small diatoms.

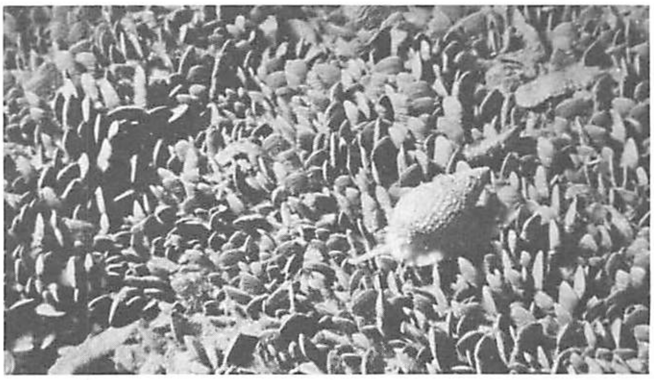
Great efforts have been expended by several researchers to estimate the size and distribution of the quahog population in the Bay. It has proved very difficult to obtain good estimates because the shellfish are so unevenly distributed. One sample may yield nothing, while another a few feet away may yield many. Another problem is that, in underfished beds particularly, quahogs may be buried in the bottom several layers deep.

Water pollution continues to take a heavy toll in the reduced numbers of quahogs available for harvesting. The primary criterion used in closing areas to shellfishing is the abundance of fecal coliforms in the water; these are an indicator of sewage and the pathogenic bacteria and viruses it may contain. A shellfish depuration plant is capable of killing harmful microorganisms that might be found within the shellfish, but none have been built in the Bay area. Unfortunately, pathogenic microorganisms are only one aspect of the pollution in the upper Bay. There are signs that Providence River quahogs are not healthy and may be dying off in at least some areas. Several researchers are concerned that they may be accumulating significant levels of petroleum or heavy metals, which are not removed by the usual depuration methods.

Another man-made change to the Bay is seen in some localized areas in the form of siltation and the substitution of soft muddy sediments where a firmer substrate once existed. This is caused by poor land management practices and land clearing. The bottoms of dredged channels are typically also very soft and accumulate fine sediments. In all areas where very soft bottom types are formed, we may expect to see a decline in original quahog populations and an increase in the abundance of the inedible clam *Pitar*. This is particularly evident where deep-dredged channels have cut across areas of sandy bottom.



The siphons of a clam. *Photo by Harold Wes Pratt.*



A snail *(Nassarius)* on an *Ampelisca* community. *Photo by Harold Wes Pratt.*

Top: A scup swimming over a bed of mussels. Bottom: A winter flounder. *Photos by Harold Wes Pratt.*

Chapter 6

Finfish

If we could somehow see into the Bay and observe the movements of fish, we would see that populations of different species move in and out of the Bay following well-established seasonal patterns. These migratory movements, although different for each species, provide for distinct summer and winter populations of finfish. The migrations are related primarily to temperature, and the major shifts between winter and summer populations take place when the water temperature is about 10°C (18°F).

Fish are divided into two broad categories — the bottom-dwelling species, such as flounder and cod, and the pelagic species, which feed in the water, such as menhaden and bluefish. Squid are a pelagic species, but they are mollusks, therefore shellfish, and not fish at all. However, since the behavior of squid is so close to that of the finfish, they are included in this section.

All Rhode Islanders are well aware that there are fish in the Bay and that they are frequently plentiful. Estimating the abundance of the various fish populations, however, is a thorny scientific problem that illustrates some of the difficulties encountered in all branches of marine biology. The usual method of collecting bottom fish is to catch them by dragging an otter trawl behind a boat. The trawl sweeps along the bottom and scoops up the fish lying in its path. Any fisherman will quickly point out that it isn't that simple. Fast-swimming fish can avoid the net, and the fishing efficiency of a trawl and the area covered during a tow are difficult to standardize. When fish population surveys are made, great care is taken to standardize individual trawling operations, but the differences between replicate samples still remains high. When the size of a population in an area is estimated, a series of standardized trawls are taken at randomly selected sites. Pelagic fish are only partially sampled with a bottom trawl. In the Bay, estimates for squid have been made using a modified "balloon" trawl, which lifts off the bottom and will not catch many bottom fish, and menhaden populations are estimated by aircraft pilots who can see the schools and guide fishermen to them. The only way that we can estimate bluefish and striped bass populations is by extrapolating from commercial and recreational catches and from studies elsewhere based on the recapture of tagged fish. One of the problems is that the various methods are not comparable, and some important populations do not get sampled at all. In the Bay, for example, we know that there are sizable populations of anchovies, but since these are caught neither by bottom or squid trawls, nor by menhaden and sport fishermen, we know virtually nothing about them.

Narragansett Bay is visited each year by a great many species of fish because it lies along the boundary between southern and northern populations. Thus, herring from Georges Bank may visit the Bay at the end of their southward midwinter migrations, and species such as scup and occasional exotic tropical strays brought up by the Gulf Stream make their appearance during the summer. In all, over 100 species may appear in any given year, about half of which are occasional visitors.

The Distribution and Abundance of Bottom Fish

A year-long, Bay-wide survey (excluding Mount Hope Bay and the Sakonnet River) of bottom fish made in 1972 (5) yielded an annual minimum estimate of 117 individuals, or 28.5 pounds, per acre. This translates into a standing crop of 1.9 million pounds of bottom fish. (The margin of error gives a range of 0.8 to 2.9 million pounds.) This is comparable to other estimates made using similar sampling techniques in New England estuaries and offshore fishing grounds. This Bay-wide survey showed that despite the constant movement of species in and out of the Bay the total biomass of bottom fish is remarkably steady. In Long Island Sound, the seasonal fluctuations in total bottom fish biomass vary 20 to 50 fold, but in the Bay only a fourfold shift is seen, with a maximum in the fall and the minimum in the spring. Ten species dominate the bottom fish population and account for 91 percent of all catches. Among these, winter flounder is by far the most common (36 percent of the total catch), and another flounder, the sand dab, is second most abundant. Both winter flounder and sand dabs are present at all seasons. The dominant species succeed each other, so that the peak abundance of two species rarely coincides and competition for the same food sources is thus minimized. The Bay-wide survey showed that the upper Bay harbors fewer species and a smaller biomass than the lower Bay. Deep water appeared to contain the highest biomass and, with the exception of the early fall, a lower diversity of species.

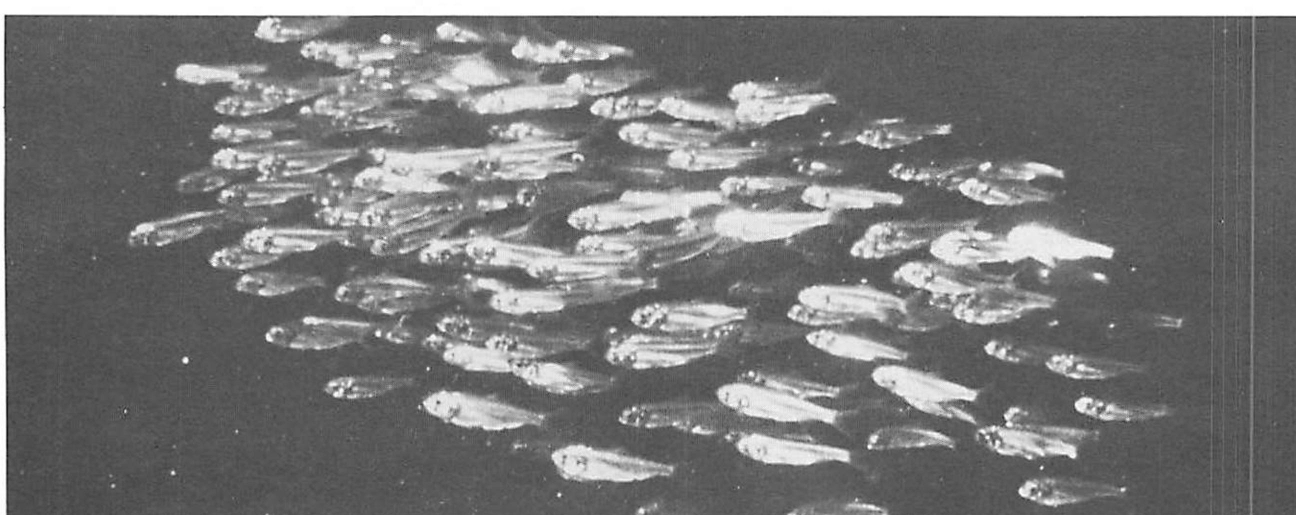
Winter Flounder. The winter, or blackback, flounder is the dominant bottom fish in the Bay. The population is also a Rhode Island resource, since the species makes only small migrations to the Sound. Figure 21 shows peaks in the Bay population in the spring and fall, when both juveniles and adults are found throughout the Bay and can be sampled with trawls. In spring, as temperatures rise, adults move into deeper, cooler waters in the Sound and juveniles venture out of harbors and shallow embayments into the Bay itself. In the fall, the adults move up Bay and the juveniles return to the shallows. Winter flounder begin spawning in their third year, when they are 19 to 24 cm (7½ to 9½ in.) long. The eggs are laid on the bottom in shallow water in the late winter and early spring. Winter flounder feed on benthic worms and crustaceans and "graze" on the siphons of shellfish. A seven-year record of the abundance of bottom fish at a station in the West Passage provides a rare insight into the long-term fluctuations in the abundance of winter flounder and shows that their abundance in the Bay declined by 78 percent between 1968 and 1972 (2). This decline is correlated to a very small long-term change in the water temperature. It seems unlikely that a very small temperature change could affect the population directly, but it may become magnified through complex and little understood predator/prey relationships.

Unlike the winter flounder, most of the commercially important species of bottom fish make seasonal migrations of several hundreds of miles. Fluke and butterfish spend the winter in very deep water far offshore at the edge of the continental shelf. Whiting and pollack make similar journeys and are offshore in the summer. Of the most abundant species, only the sand dab is not migratory.

Pelagic Fish

There are fewer species of pelagic fish than of bottom fish in the Bay, but they make up for this by their numbers and their importance to fishermen. All the pelagic species are highly seasonal, with anchovies and sea herring appearing in the winter, and menhaden, squid, bluefish, and striped bass in the summer. When schools of menhaden are present, their biomass may be far greater than that of the bottom fish. Population estimates for the Bay are for as much as 16 million pounds of menhaden and 2 million pounds of bluefish and stripers (3).

Menhaden. These oily, herringlike fish migrate up and down the East Coast from Florida to Maine. There are periods of several years when no menhaden appear



A school of menhaden. *Photo by Harold Wes Pratt.*

in the Bay. When they do come, they are usually abundant and are caught in large numbers. In recent years, the annual commercial Bay catch has ranged from 15 to 23 million pounds. Adult menhaden arrive in April, but since they do not form schools until May, they are not noticeable. During the summer, large schools move in and out of the Bay and are most abundant in the upper Bay. Menhaden move south as water temperatures cool in the fall.

Larval and juvenile menhaden are carnivorous and, like other fish, snap up individual prey. The adults, however, are grazers and feed by filtering volumes of water through their gills and retaining the larger plankton on sievelike gill rakers. When schools of adults are present in the Bay, their impact on the zooplankton, including the larvae of many important fish and crustaceans, can be devastating. A single fish can sweep clear 30 liters (8 gallons) of water a minute! The effect on the phytoplankton is less severe, since 80 percent of the phytoplankton are too small to be retained by the gill rakers (1). Individual schools of menhaden frequently number 200,000 pounds. In 1976, an abundant year, an estimated 50 million pounds of menhaden moved in and out of the Bay during the summer. Some 80 percent of this population was harvested by commercial fishing vessels (3). Since menhaden, when present, are the favorite food of striped bass and bluefish, the commercial menhaden fishery has caused a storm of protest from sport fishermen. It appears, however, that even when menhaden populations are too low to support a commercial fishery there are enough to feed the blues and stripers. It must be remembered that bluefish and bass feed on whatever is available, and are present in the Bay during those

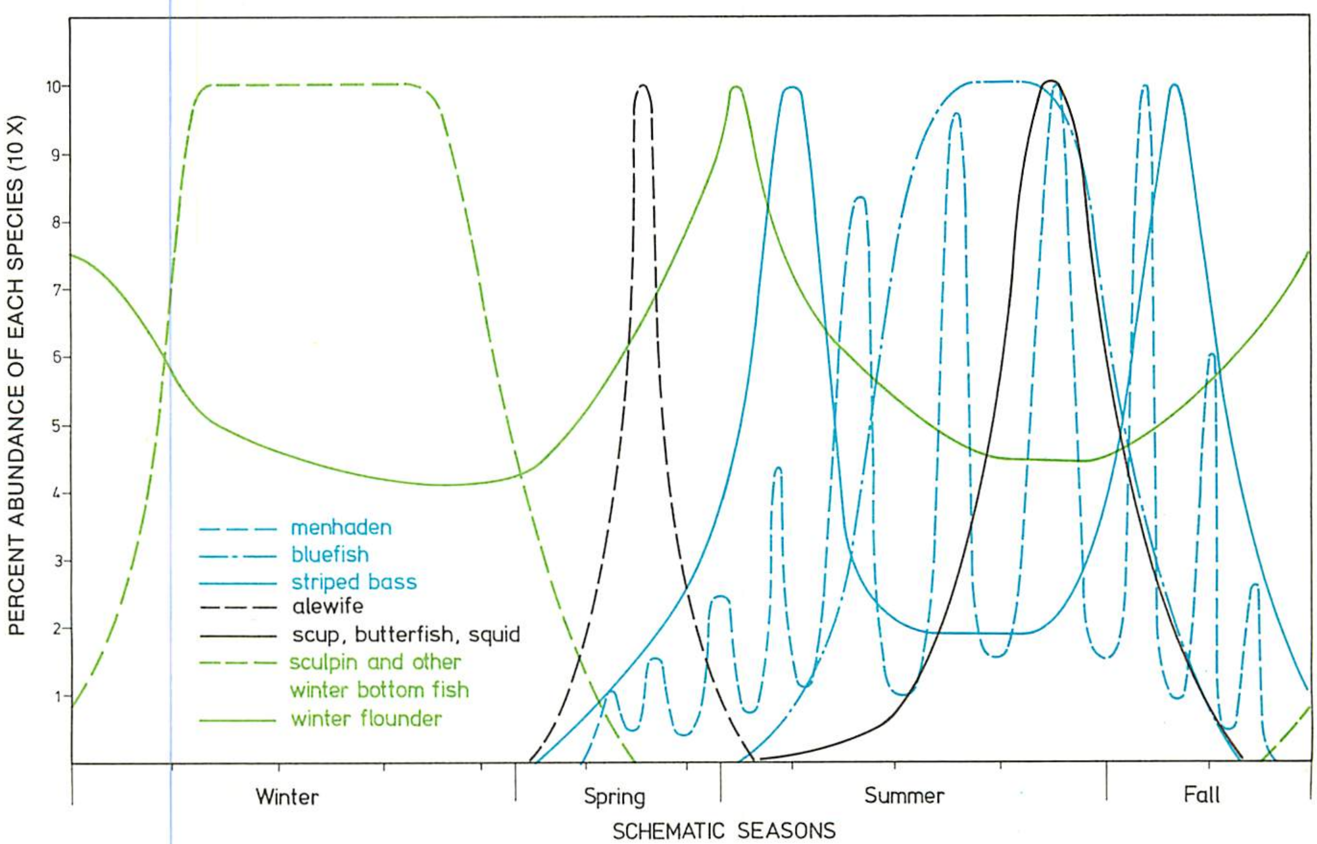


Figure 20. Schematic showing the seasonality of major fish species in the Bay.

periods when no menhaden are present for several years at a stretch.

Bluefish and Striped Bass. Like other abundant species, bluefish and striped bass do not overlap their periods of greatest abundance. Stripers usually arrive in May, are most abundant in June, and leave as the bluefish appear in midsummer. The adult bluefish leave in the early fall as the bass return for another short stay. Juvenile, "snapper" blues that were spawned offshore earlier in the year are abundant in the fall, but they too leave as the waters cool. Bluefish have historically shown wide variations in abundance and have recently been extremely numerous. Most of the striped bass that appear in the Bay are females and their abundance has been declining in recent years. Sport fishermen harvest a large segment of the striper and bluefish populations that come into the Bay each summer. In

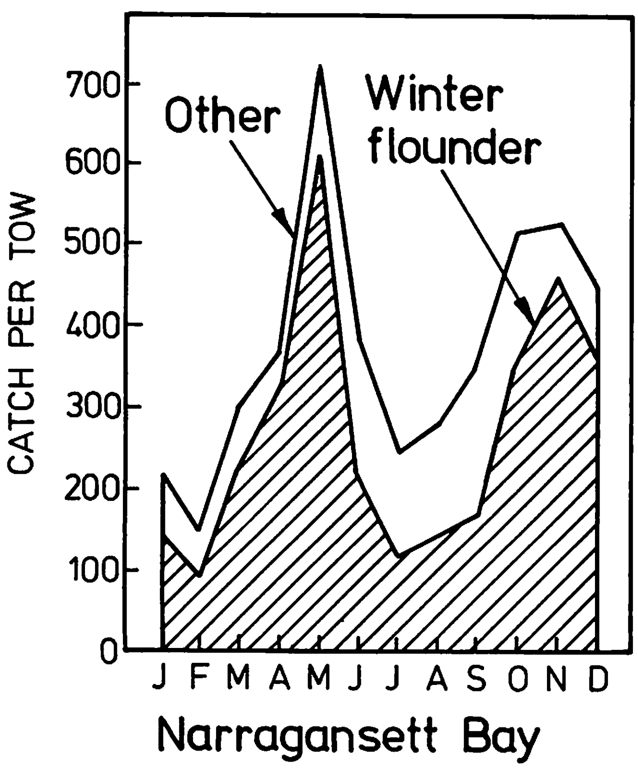


Figure 21. Average catch per tow of winter flounder and other bottom fish at a single sampling station in the lower West Passage during 1969. *From Jeffries and Johnson, 1974.*

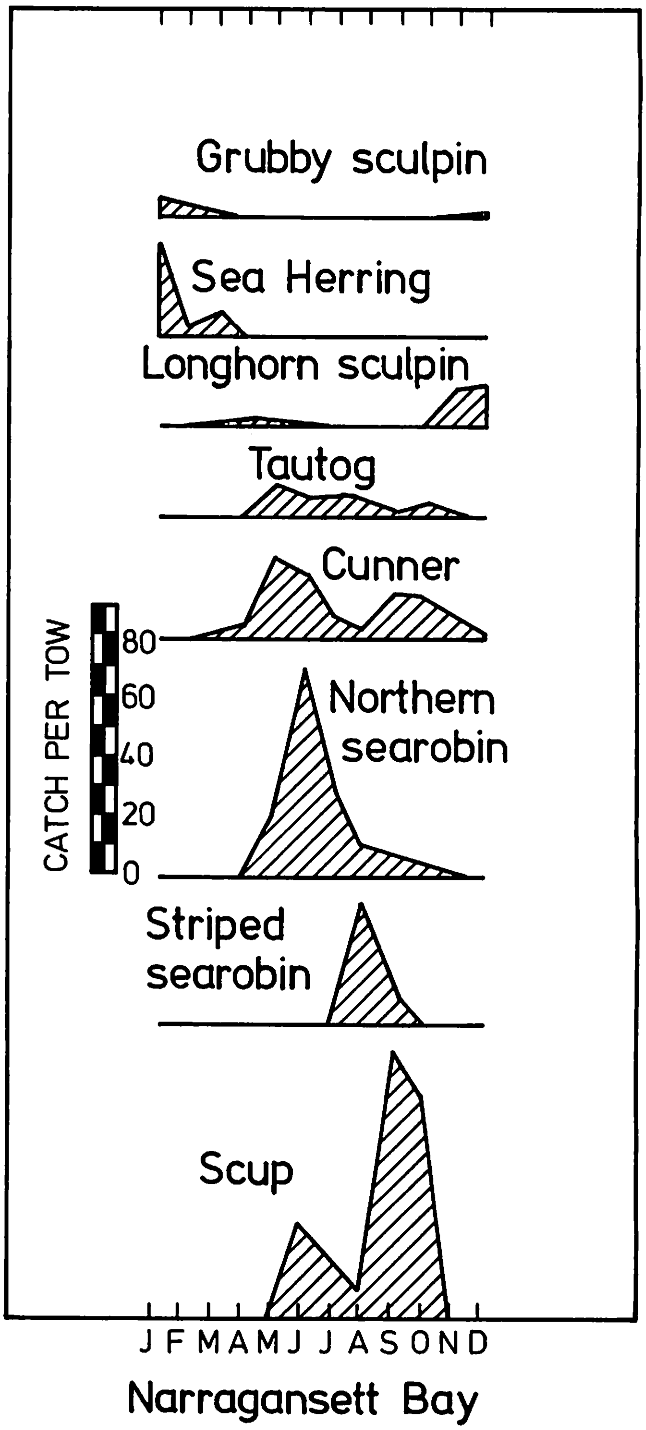


Figure 22. Average catch per tow of bottom species of secondary importance at a single sampling station in the lower West Passage during 1969. *From Jeffries and Johnson, 1974.*

1976 it was estimated that 26 percent of the stripers and 65 percent of the bluefish that entered the Bay were caught (3). More than half of each catch was taken by a dozen highly effective fishermen!

Alewives. These herringlike fish used to be very abundant seasonally in Narragansett Bay. Adult fish migrate from offshore in the spring into freshwater streams, where they spawn. The dams built on almost every stream and river flowing into the Bay as the state industrialized blocked these migrations and decimated the population. The Rhode Island alewife catch in 1880 was 3 million pounds, but today only a few vestigial populations survive. According to a 1974 survey, there were runs of 500 fish or more in the Annaquatucket River (North Kingstown), Brickyard Pond (Barrington), and Nonquit Pond (Tiverton). The two largest runs in the state were outside the Bay area. The Department of Environmental Management has tried to re-establish alewife populations by building fish ladders around dams and re-introducing spawning fish. Rhode Island populations, however, remain very small.

The Bay as a Finfish Habitat

Like any estuary, Narragansett Bay is a valuable feeding and spawning ground for many species. Its high primary productivity and rich benthos provide abundant and diverse food. Its sheltered, shallow embayments are the nurseries for the eggs and larvae of many fish species. Our understanding of the Bay's finfish populations beyond such generalities, however, is not great. The life histories of the major commercial and sport species are fairly well known, but we do not understand why the abundance of a particular species shows wide variation independent of fishing pressure. It remains difficult to explain why some year classes of fish are far more successful than others. We have great problems trying to separate natural cycles from fishing pressure, and at any given time our estimates of the abundance of a species are rough approximations with a low statistical accuracy. The relationships among species have only recently become the subject of substantial research, but, again, we are hampered by the absence of good ecological models for the major environments.

Seasonality of Regularly Occurring Fishes in the Narragansett Bay Area (Adapted from Jeffries and Johnson, 1974)

More Common in Winter

Atlantic (sea) herring, *Clupea harengus harengus*
Atlantic cod, *Gadus morhua*
Blackback flounder, *Pseudopleuronectes americanus*
Grubby (shorthorn) sculpin, *Myoxocephalus aeneus*
Longhorn sculpin, *Myoxocephalus octodecemspinosus*
Ocean pout, *Macrozoarces americanus*
Sea raven, *Hemitripterus americanus*
Silver hake, *Merluccius billinearis*
Striped anchovy, *Anchoa hepsetus*
Rainbow smelt, *Osmerus mordax*
Tomcod, *Microgadus tomcod*
White hake, *Urophycis tenuis*

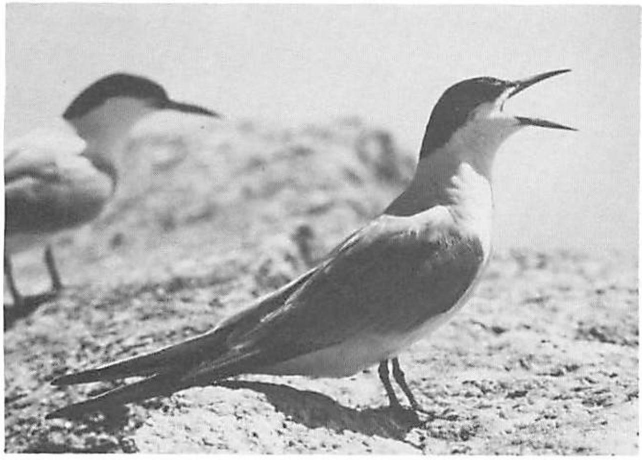
More Common in Summer

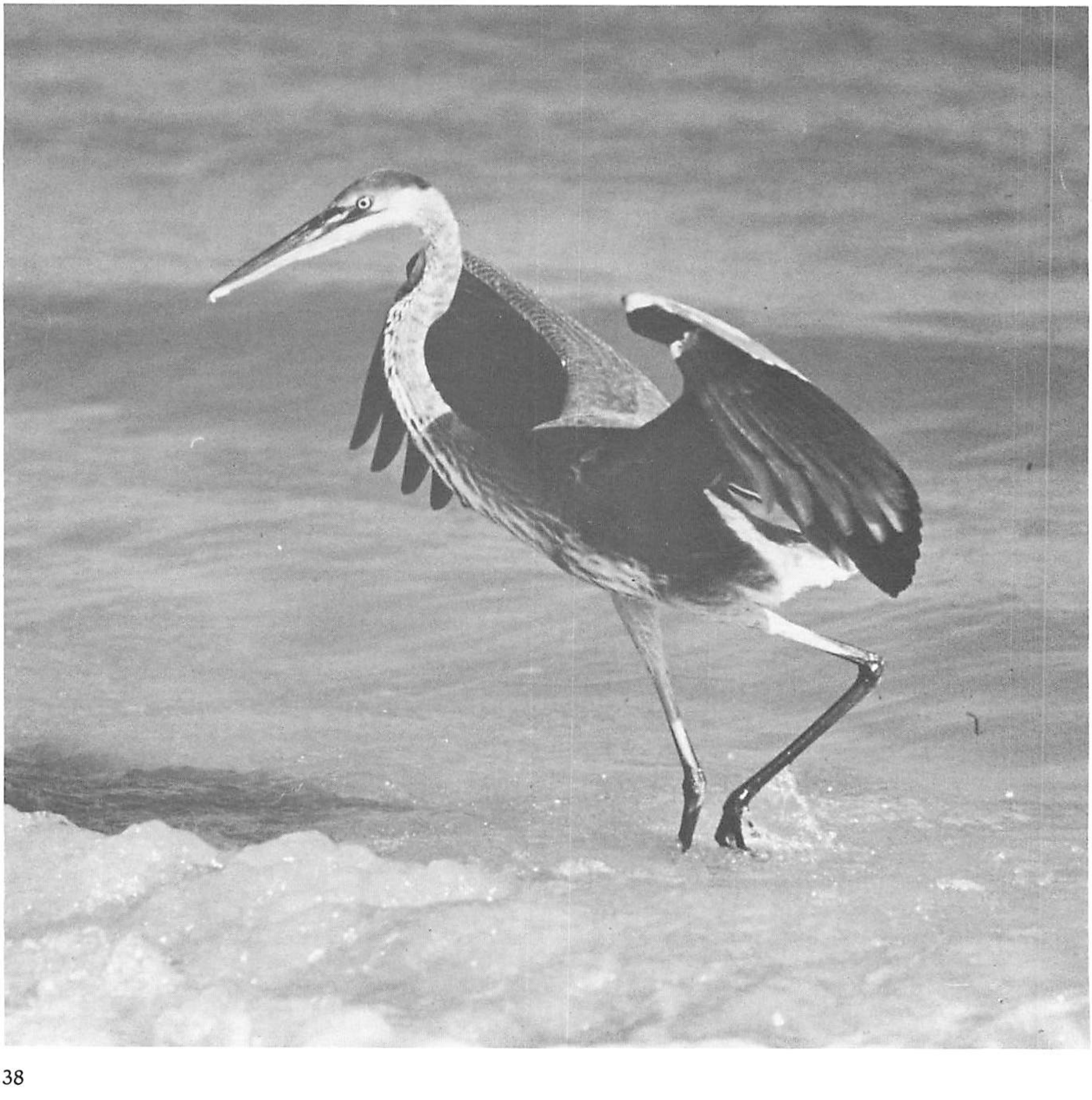
Alewife, *Alosa pseudoharengus*
Atlantic mackerel, *Scomber scombrus*
Bluefish, *Pomatomus saltatrix*
Butterfish, *Poronotus triacanthus*
Cunner, *Tautogolabrus adspersus*
Fourspot flounder, *Paralichthys oblongus*
Fluke, *Paralichthys dentatus*
Gray triggerfish, *Balistes capriscus*
Menhaden, *Brevoortia tyrannus*
Northern kingfish (king whiting), *Menticirrhus saxatilis*
Northern searobin, *Prionotus carolinus*
Northern puffer, *Sphaeroides maculatus*
Pollack, *Pollachius virens*
Red hake, *Urophycis chuss*
Scup, *Stenotomus chrysops*
Smooth dogfish, *Mustelus canis*
Spiny dogfish, *Squalus acanthias*
Spotted hake, *Urophycis regius*
Squid, *Loligo pealii*
Squirrel (red) hake, *Urophycis chuss*
Striped bass, *Morone saxatilis*
Striped searobin, *Prionotus martis*
Summer flounder, *Paralichthys dentatus*
Tautog, *Tautoga onitis*
Weakfish, *Cynoscion regalis*
Whiting, *Merluccius bilinearis*

No Distinct Seasonality

American eel, *Anguilla rostrata*
Blueback herring, *Alosa aestivalis*
Common searobin, *Priorotus carolinus*
Goosefish, *Lophius americanus*
Little skate, *Raja binerinacea*
Sand dab, *Scophthalmus aquosus*
Toadfish, *Opsanus tau*

Top left: Common tern. *Photo by Prentice Stout.* Top right: Black-crowned night heron. *From the Audubon Society of Rhode Island.* Bottom: Great blue heron. *Photo by Prentice Stout.*





Chapter 7

Birds

Well over 350 species of birds have been observed on or around Narragansett Bay (1). Although there are only some 40 year-round resident species, many more either nest here during the summer months or pass through twice yearly on their way to and from breeding grounds in Canada and the Arctic. Narragansett Bay is an important wintering ground for thousands of ducks and other waterbirds. Rhode Island's location along the Atlantic Flyway is the major reason for its abundant and varied bird population, but also important is the high diversity of habitat types that the state offers within a small area. These include various uplands, including forests, shrub lands, and agricultural lands, many fresh water ponds, and the Bay with its wetlands, mud flats, tidal creeks, and sheltered coves.

The birds of Narragansett Bay can be placed into six general groups: the gulls and terns, the long-legged waders, waterfowl, small shorebirds, raptores, and the perching birds of the uplands (2).

The Birds and Their Habitats

Gulls and Terns. The ubiquitous herring gull and the great black-backed gull are permanent year-round residents of Narragansett Bay. They nest on isolated islands and rock outcrops and scavenge from local dumps and fishing boats. These two species are joined by as many as eight others during various seasons, making "seagulls" the dominant birds along our coastline. Terns, which can be seen in Rhode Island from April to October, also nest in colonies around the Bay and feed on small fish and crustaceans. Their nesting sites include those beaches and rocky outcrops where they can outcompete the gulls for space and avoid predation by rats, dogs, cats, and man. The least tern, the smallest of the two most common species, has recently suffered a dramatic decline in the Bay due to losses in its nesting areas. In a few years, it may no longer be seen on the Bay. Herring gulls, in contrast, have become extremely numerous, because they have adapted to feeding on garbage at landfills. Herring gulls did not nest in Rhode Island before 1937 (4), but since then they have displaced terns from many of their former rookeries.

Long-legged Waders. Herons, egrets, and other long-legged wading birds are common inhabitants of salt marshes and tidal flats throughout Narragansett Bay. Many of these birds, particularly egrets, were very scarce at the turn of the century because they were hunted for their feathers. They have made a strong recovery and are now plentiful and increasing. When nesting, these birds choose isolated islands covered with trees or shrubs close enough to tidal flats for them to fly there for food. Small fish, crabs, insects, clams, and snails are common foods. Narragansett Bay boasts of two major breeding colonies: Hope Island, which recently became the largest heron rookery in New England, and Gould Island. These birds are highly migratory and are present around the Bay only during the late spring and through the summer. Two species are relative newcomers to Rhode Island, the glossy ibis and the cattle egret. Both are now becoming common and nest in rookeries with other waders.

Waterfowl. Waterfowl are a major aesthetic and recreational resource of the Bay. They include more than 20 species of surface-feeding (dabbling) ducks, diving ducks, geese, and swans. While only small numbers and a few species nest here, winter finds many thousands of ducks congregating in large "rafts," particularly in the upper Bay off Gaspee and Conimicut Points. Mallards and black ducks are the most common year-round waterfowl residents of the Bay. A few breed in small coves, inlets, and marshes. Other nesting species in Rhode Island are the Canada goose and the mute swan. The swan, a species brought to Long Island from Europe in the 1930s, has increased greatly in abundance, and now nests in many coastal ponds along the Bay and south shore. The Canada goose, now relatively common throughout the year, becomes a dominant fixture along our coast in the fall and winter. The remaining waterfowl species are primarily nonresident birds which frequent our coast, often in considerable numbers, during the winter months. Baldpate, canvasback, goldeneye, scaup, and bufflehead can be particularly plentiful.

The feeding habits of waterfowl vary greatly from area to area and according to season. The food eaten varies with the age and species of waterfowl and with availability. Availability in turn is affected by icing, hunting pressure, agricultural practices and other human activities, flooding, and annual variations in plant production. Common foods for waterfowl include eelgrass, seaweeds, pondweeds, insects, crustaceans, and agricultural crops such as corn and rye grass. Waterfowl in Rhode Island also consume considerable quantities of barberry and greenbriar berries.

The Bay is host to large numbers of waterfowl, particularly during the late fall and winter months, when birds from breeding areas to the north and west utilize the open coastal waters for feeding and resting. Utilization of the upper Bay area near Conimicut, Gaspee, and Nayatt Points as well as the nearby ponds and embayments can be especially heavy when free of ice for species such as scaup, black, mallard, widgeon, canvasback, and goldeneye. Scaup (or bluebill) is usually the dominant species, with rafts of 20,000 birds or more occasionally observed. In the lower Bay's less protected waters, some scaup and goldeneye are also observed with mergansers, scoters, and, on rarer occasions, the eider duck. The small bufflehead is also common on the sheltered lower Bay waters, such as Jamestown's Sheffield Cove.

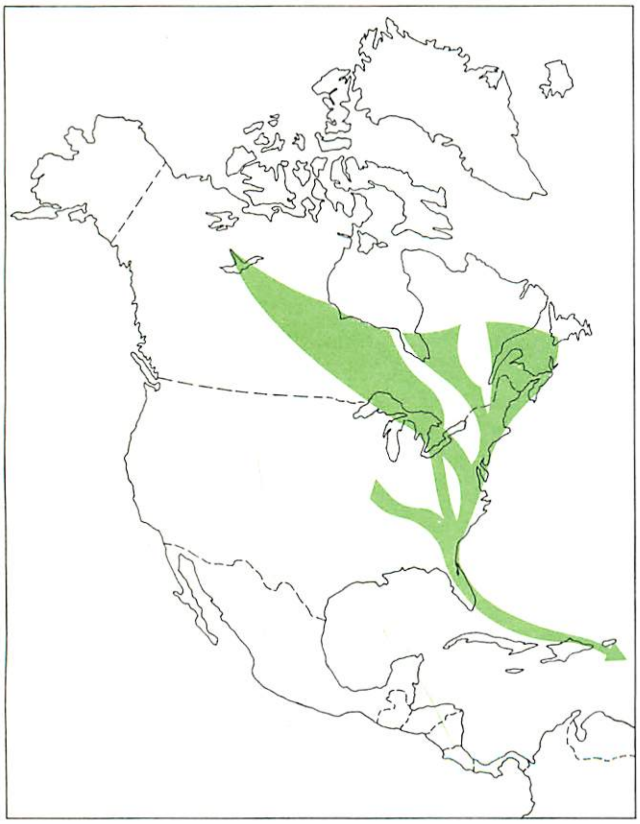


Figure 23. The East Coast flyway. *Adapted from Gusey, 1976.*

Small Shorebirds. More than 30 species of sandpipers, plovers, and other shorebirds inhabit Narragansett Bay's tidal flats, beaches, and marshes. Except for three or four species, all are migrants, seen only in the spring and late summer or early fall. Because of plumage changes, some species look entirely different during the fall migration than they did on the route north. Since most of these birds tend to travel in small flocks from site to site, any one species is likely to be present in considerable numbers one day and be gone the next. These birds are most common along shallow mud flats, particularly at low tide, where they feed on insects and their larvae, small worms, mollusks, and crustacea. Only small amounts of plant material are eaten, mostly in the form of seeds. The purple sandpiper is unique among these birds in its habits, staying close to rocky shorelines and remaining through the New England winters. When better weather approaches in May and June, this bird leaves for the far north.

Perching Birds. The last major group of birds found along the Bay and its islands are the passerine or perching birds. These birds are more widely distributed than the foregoing groups because they do not require a direct association with the marine or wetland environment. Most are found in uplands throughout Rhode Island. They are significant as a group around the Bay because the variety of habitats along the shore attracts large numbers of these birds during their migration and the nesting season.

Raptores. The sixth category of birds, the raptores, or birds of prey, are a small and less common group. They include a few species of owls and hawks. Those most likely to be seen along the shores of the Bay are marsh hawks, American kestrels (which are small falcons that feed largely on insects), and ospreys. The osprey, or fish hawk, used to nest in considerable numbers around the Bay, but the population went into a steep decline in the last decade, due, many think, to the widespread use of pesticides. It now appears to be making a slow recovery. The red-tailed and broad-winged hawks may also occasionally be seen on the uplands bordering the Bay. The owls are largely nocturnal and therefore rarely seen. They can be observed on rare occasions in undeveloped land areas such as Sachuest Point, Beavertail, or Prudence Island. The short-eared owl is a day hunter and can sometimes be observed along beaches and sand dunes.

Ecologic and Economic Significance of Bird Populations

The birds found in and around Narragansett Bay are of considerable ecological and economic significance. Enormous numbers of insects and their larvae are consumed daily along the water's edge, primarily by the perching birds. The small shorebirds and wading birds also prey on insects, but to a lesser degree. Songbirds and many of the small shorebirds consume considerable quantities of berries and other fruits of shrubs and herbaceous plants. Because of this, the seeds of these plants are scattered over wide areas to revegetate barren or disturbed areas and to distribute plant species.

Although it is nearly impossible to quantify the importance of these birds, it is recognized that a healthy and diverse bird population adds greatly to the aesthetic resources of our coastline. It is hard to imagine any waterfront area in Rhode Island without a substantial bird population. Birds are enjoyed by legions of bird watchers, an activity which is growing in importance as a recreational and educational pursuit.

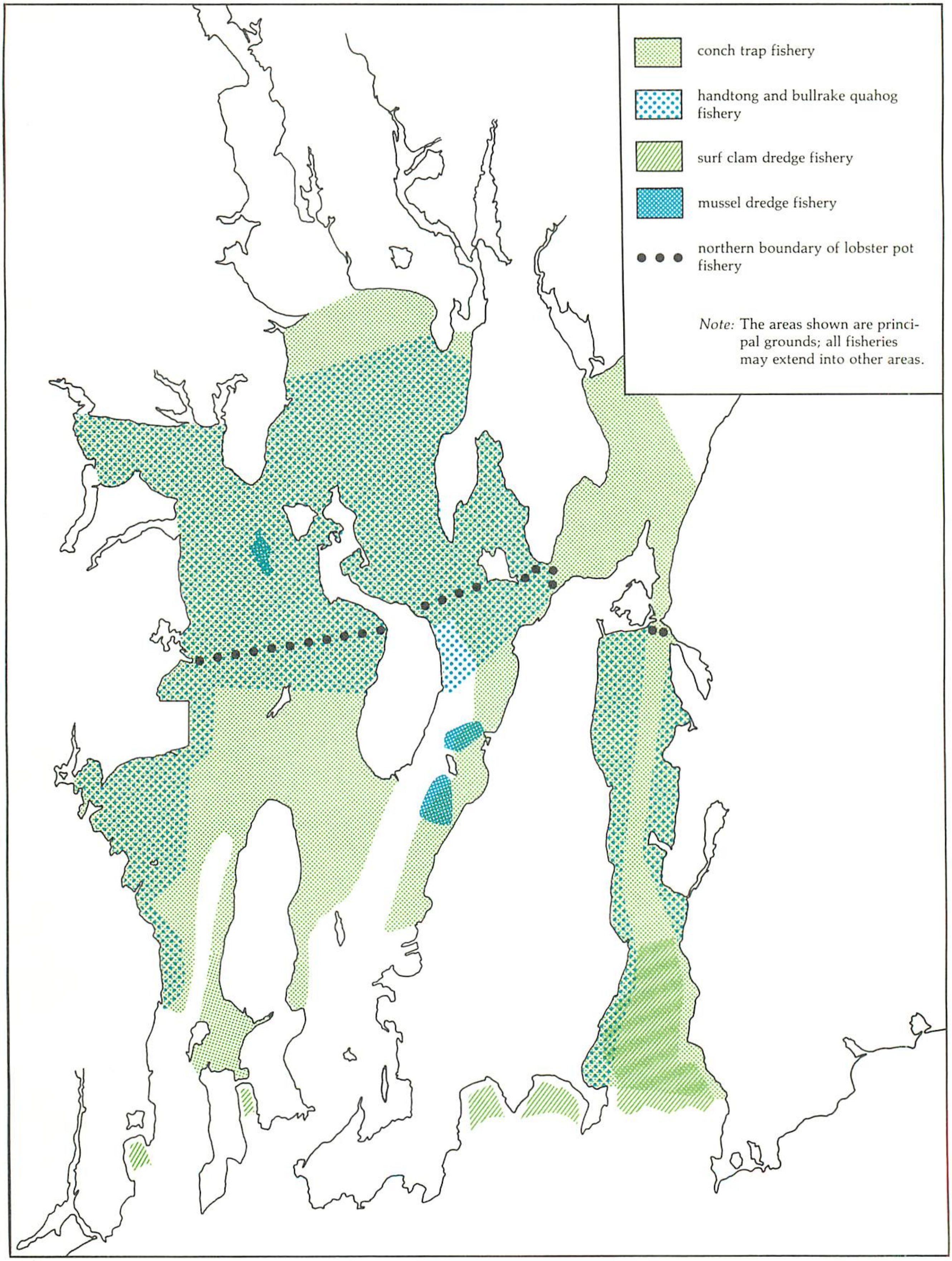
For the hunter, the large waterfowl population provides an important source of sport, with considerable benefits to the state in tax receipts from arms and ammunition sales. Approximately 35 percent of the Rhode Island scaup harvest and 10 percent of both the black duck and the mallard harvest is taken each year from the upper Bay. The abundance of ducks varies considerably from year to year. Data published by the U.S. Fish and Wildlife Service (3) for the years 1963-74 list an average annual harvest of 2,000 scaup and 3,200 black ducks for Rhode Island. The approximate average yearly yield from the upper Bay may therefore have been some 1,000 black ducks and scaup during this period.

Management of the Bay's bird population takes several forms. Some state-owned or private lands containing species nesting areas, such as Hope and Gould Islands, are off-limits to unsupervised human intrusion during the breeding season. Such areas permit especially vulnerable species to fledge their young with minimal harassment.

The annual bag limits for waterfowl are based largely on periodic waterfowl surveys during the fall and winter months. Bag limits for individual species and the use of license and arms revenues for salt marsh protection and management area acquisition have gone far to sustain both resident and migratory species. Habitat protection, however, is more significant than regulatory controls in assuring the protection of species which have direct economic or recreational value. This includes small shorebirds and wading birds in particular. Birds will continue to flourish around and on Narragansett Bay if we continue to provide them with a diverse and clean environment and pockets of wilderness where they can breed without disruption from man.

Purple sandpipers. *Photo by Prentice Stout.*

Figure 24. Principal grounds for commercial shellfisheries.



Chapter 8

Fisheries

There are no consistent long-term records of the fish and shellfish that have been harvested from Narragansett Bay. The annual statistics on the fish and shellfish landed in Rhode Island by commercial fishermen date back several decades but do not differentiate between catches from the Bay and elsewhere. There are very few data for the catches of sport fishermen. The patchwork of information that we do have, however, shows that many important species of fish and shellfish in Narragansett Bay and other coastal waters were far more abundant in the past than they are today. Reports from the Colonial period mention the large numbers of lobsters that could be picked up at low tide, and huge schools of cod, menhaden, bluefish, scup, squid, butterfish, and other fish that seasonally came close alongshore and could be easily caught in very large numbers with beach seines. There are reports, arguable "fish tales," of farmers coming to Narragansett Pier and catching, with hook and line, a two-ton winter supply of cod in a single day from one skiff. We know there were prolific beds of oysters as well as an abundance of soft-shelled clams, scallops, and quahogs in the Bay. The Seekonk River was a prime public oyster bed until the mid-1800s (2). Alewives and smelt were seasonally abundant, and there were at least some salmon and sturgeon. It appears that each time we saw a major advance in the efficiency of fishing gear, there was a decline in the abundance of fish available to inshore fishermen. Nearshore fish populations have thus declined in a manner similar to the waterfowl and mammals which once abounded in greater numbers than they do today.

The Three Major Periods of Finfisheries

Rhode Island finfisheries, of which Bay fisheries form a part, show three distinct historical periods (6). The colonists caught large numbers of fish by hook and line from skiffs and with seine nets that were set out from small boats to encircle schools of fish as they passed near shore. Along the south shore of Rhode Island, and no doubt also in the Bay, seined fish were taken away by the cartload to be used as manure on fields.

The wharf of the Tallman and Mack Trap Company in Newport in 1900. *From the Providence Public Library, Rhode Island Collection.*

The second period is characterized by floating and staked fish traps, which came into use in the latter half of the last century. These nets were highly efficient and intercepted schools of fish as they passed along the shore. The traditional hook and line and seine fishermen complained bitterly that the traps drastically reduced the abundance of fish and drove them out of business. Congressional investigations in the 1870s supported these claims, but measures taken at the time to curb the New England trap fishery proved largely ineffective. In 1910, nearly 400 fish traps were in use in Rhode Island, many of them in Narragansett Bay (3). Concern that fish traps were decimating important stocks finally led to severe restrictions on where and when they could be used. Today traps are prohibited in the Bay, and only a few floating traps are operated off the ocean shore and in the Sakonnet River. During this same period, anadromous fish populations declined sharply because dams and the pollution in rivers and streams prevented migrating fish from reaching their freshwater spawning grounds.

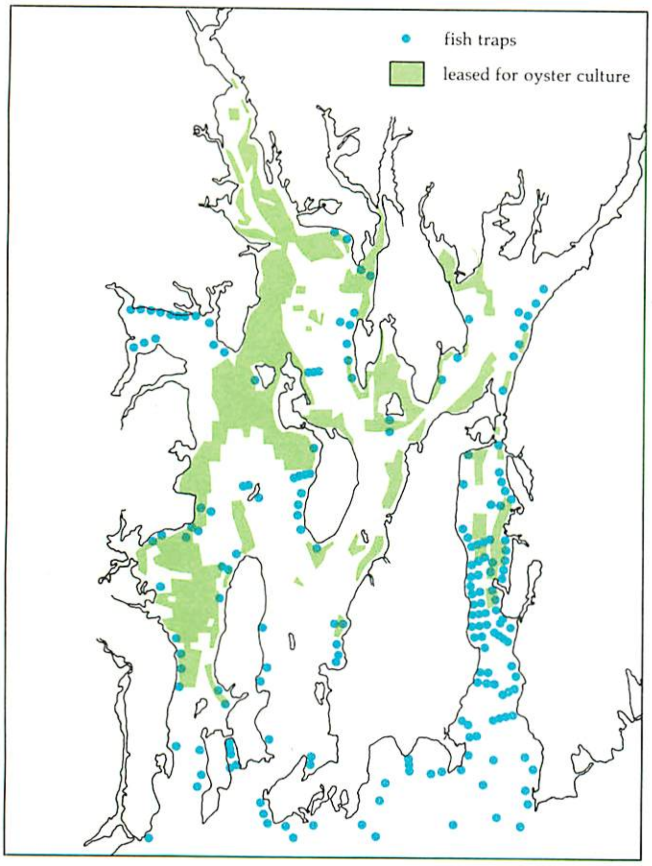


Figure 25. Locations of fish traps in 1910 and grounds leased for oyster culture in 1914. *Adapted from Alexander, 1966, and Holmsen, 1973.*

In the 1930s, trawlers began to work in Rhode Island waters, and this marked the start of a third period. Trawlers (locally known as "draggers") tow a funnel-shaped net over the seabed. The decline of the trap fishery coincided with the rise of this new fishery, which concentrated on bottom fish and operated in the Sounds and beyond. Trawlers can pursue their prey and operate in all but the worst weather. They proved to be highly effective and brought rapid declines in the near-shore abundance of bottom-dwelling species. The most recent shift in fisheries came in the 1960s, when large foreign fleets of trawlers began an onslaught on New England's fish stocks on offshore grounds. That fishery peaked in 1973, and helped lead to passage of the 200-mile fishing limit and the mandate for strict and comprehensive fishery management that is now, with great difficulty, beginning to develop regulations over all fisheries.

Bay Finfisheries Today

Today the finfisheries in Narragansett Bay are dominated by recreational fishermen who use a hook and line to catch two important gamefish, striped bass and bluefish, and various bottom fish of which winter flounder make up the largest part. The gamefish are taken primarily from boats and only during the summer and early fall, when these species are present. Bottom fish are taken all year and from almost any place where a fisherman can get a line into the water. A recent three-year study of marine recreational fishing in Rhode Island (4) provides us for the first time with detailed information on the size and nature of this sport. Preliminary data for 1978 show that sport fishermen took a large harvest from the Bay, which included the following:

	Total Bay Catch (thousands of pounds)
Winter flounder	373
Striped bass	492
Bluefish	1,286

According to these data, nearly all (98 percent) of the striped bass were taken in the upper Bay, while 63 percent of the bluefish and 71 percent of the winter flounder were caught in the lower Bay. The lower Bay is defined here as the waters south of a line drawn from Warwick Point to the north end of Prudence Island and across to Colt State Park.

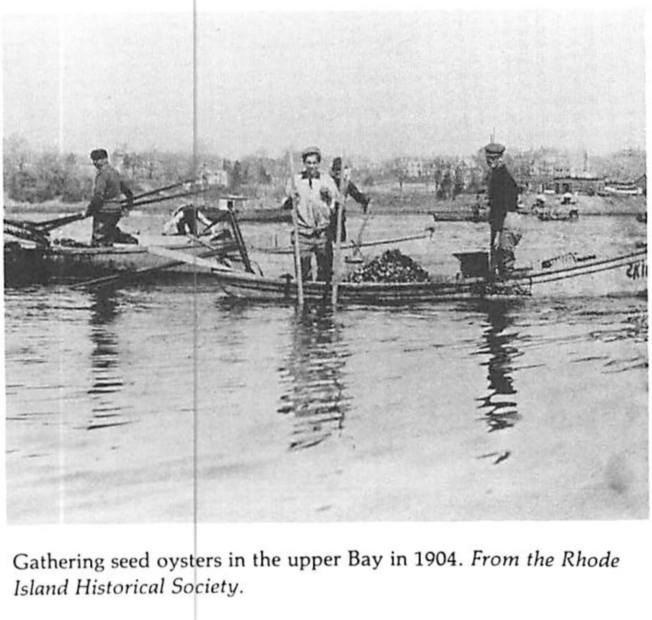
Commercial finfisheries in the Bay today include those fish sold by sport fishermen, the catches of approximately six small trawlers that fish in the lower Bay and the Sound, and the large-volume but low-value catches of menhaden taken by purse seiners (most of these are from out of state). The menhaden boats surround individual schools with a wall of netting that is then closed, or pursed, at the bottom and drawn into the vessel. It is not possible to estimate from available data what portion of the Rhode Island commercial bottom fish catch is taken in the Bay. We may assume, however, that nearly all the menhaden landed were harvested in the Bay. In recent years, menhaden catches have ranged from 15 to 23 million pounds (5).

Shellfisheries

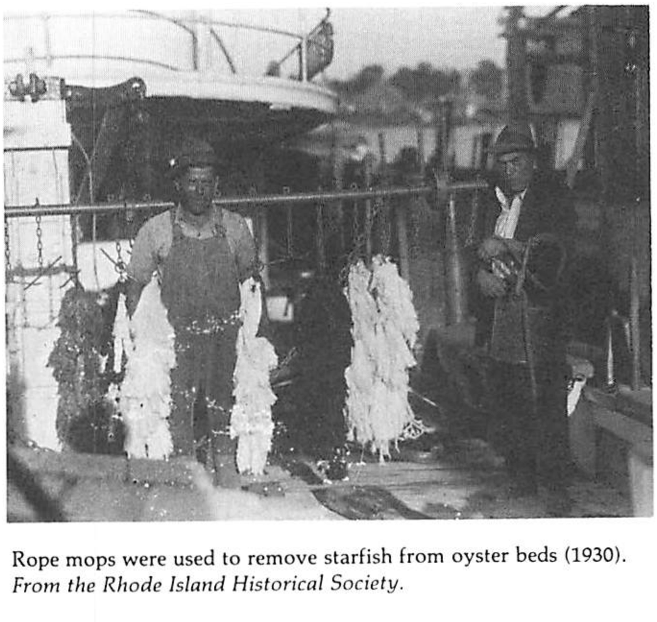
The native Indian population that lived around the Bay when the colonists arrived relied upon intertidal shellfish as a major source of food. The colonists also exploited these resources, often with a profligacy that angered the Indians. Farmers, for example, fattened herds of hogs on the abundant beds of soft-shelled clams in the upper Bay.

During the second period in finfisheries (when fish traps prevailed), native oyster populations declined, but a large and lucrative oyster culture industry based on imported seed flourished in the Bay. By 1910, some 20,000 acres of the Bay bottom were leased to private growers, the industry employed nearly 1,500 people, and 15.3 million pounds of oysters were harvested (1). Narragansett Bay oysters commanded top prices and had the reputation of being better flavored than oysters grown anywhere else. The industry went into a rapid decline in the 1930s, and the last oyster dealer went out of business in 1957. Many reasons were given for the loss of this industry, including pollution, overfishing (which ruined estuarine populations that were the source of oyster seed for the growers), damage to the beds by hurricanes, and poaching.

Bay scallops were also once abundant in the Bay. In 1880, 20,000 gallons of meat were shipped from Rhode Island to New York City, and most of these were probably harvested in the Bay (2). Scallops were still abundant in the 1940s and early 1950s, but then they disappeared. One of the richest areas for scalloping was Greenwich Bay.

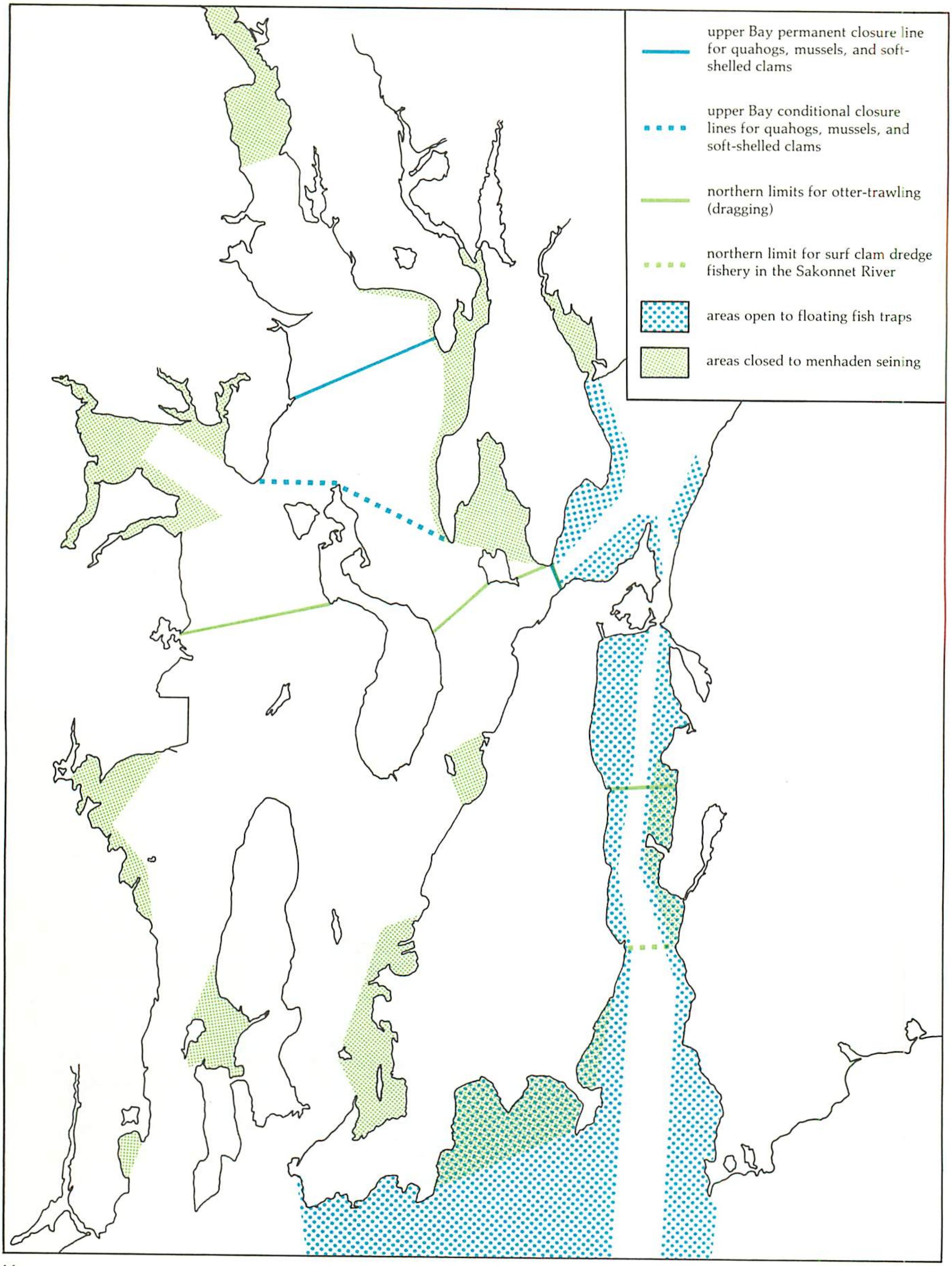


Gathering seed oysters in the upper Bay in 1904. *From the Rhode Island Historical Society.*



Rope mops were used to remove starfish from oyster beds (1930). *From the Rhode Island Historical Society.*

Figure 26. Open and closed areas established by regulation for various fisheries. Also see Figure 39 for water quality classifications; all areas classified as SB or SC are closed to harvesting of quahogs, mussels, and soft-shelled clams.



As the oysters in the Bay declined, quahogs became the basis of an increasingly important fishery. These clams are very abundant and gave rise to two distinct fisheries. Dredge boats harvest quahogs very efficiently by dragging a metal dredge that digs into the bottom. The second method relies on the muscles and skills of individual fishermen working in small skiffs who harvest the quahogs with tongs or a bullrake. The handles of bullrakes may be as long as 70 feet and can work beds 50 feet below the surface. In the 1950s, bitter disputes broke out between the dredgers and the handrakers. The handrakers argued that a few dredgers could put hundreds of handrakers out of business and would decimate the quahog population. In the end, the handrakers won, and today dredgers are only occasionally permitted to fish, and then only in areas determined to be of no great value to handrakers. The quahog fishery peaked at 5 million pounds in 1955. The more recent harvests (over 2 million pounds, worth $4.3 million at the dock, in 1978) provide employment to some 500 full-time fishermen and nearly 2,000 part-time commercial fishermen (5).

The quahog fishery is severely threatened by pollution. Many of the most prolific beds are off-limits, and the Bay above Conimicut and Nayatt Points is permanently closed to shellfishing. It is estimated by the Department of Environmental Management that some 38 percent of the quahog population is in this permanently closed area (7). The conditional shellfish area between Conimicut Point and the north end of Prudence Island contains 25 percent of the population but is closed to shellfishing after rainfall or when the Providence sewage treatment plant is not functioning. The conditional area was closed 75 percent of the time in 1978, and was permanently closed in 1979 when the treatment plant broke down completely.

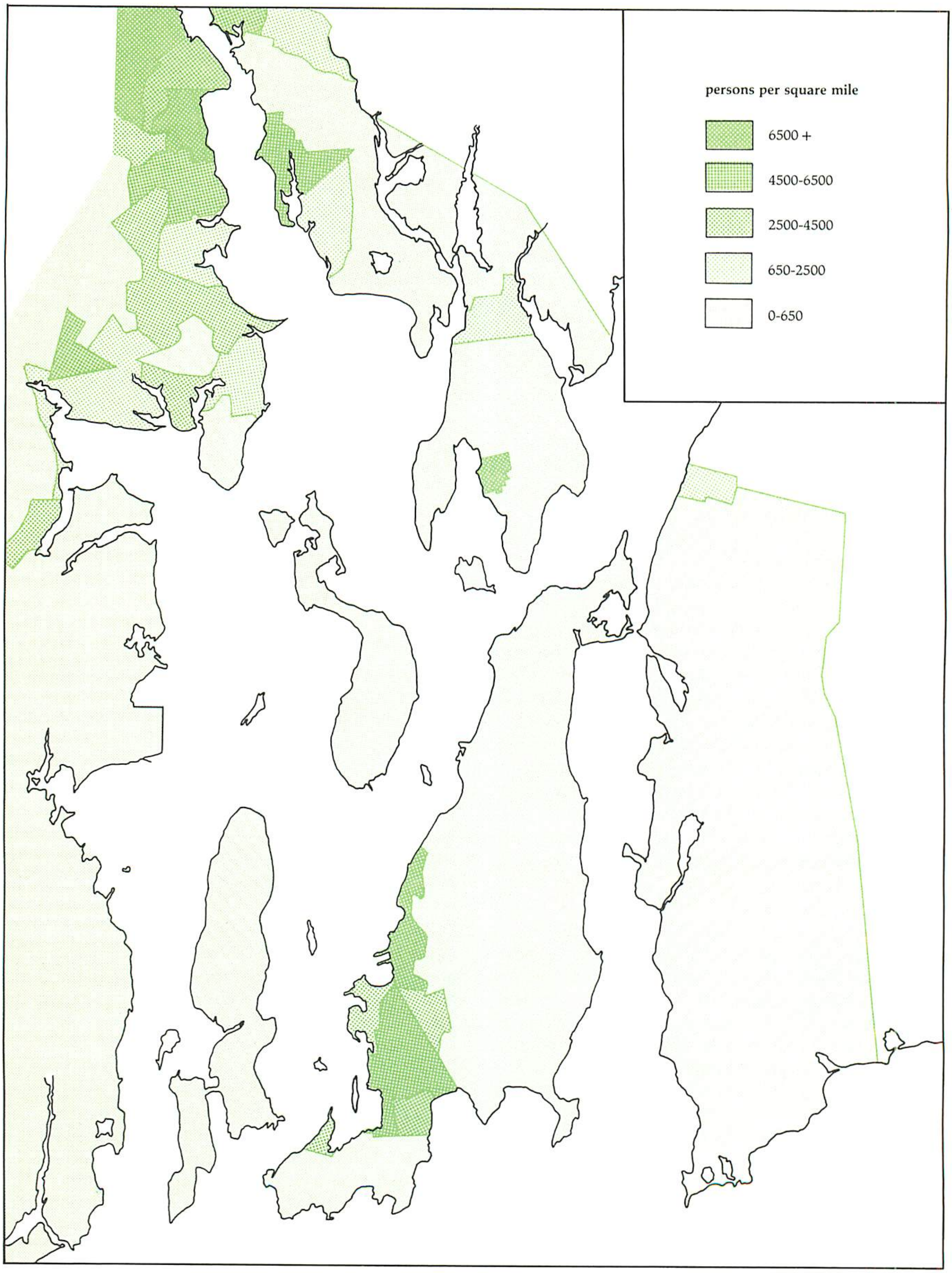
Soft-shelled clams, conchs, and mussels also support fisheries in the Bay. Softshells are dug from intertidal beds by recreational, and some commercial, fishermen. Conchs are caught in wooden traps, primarily in the spring and fall, and the annual harvest in 1978 was 170,000 pounds of meats, worth $140,000 at dockside (5). Blue mussels are harvested intertidally by recreational fishermen, and a large bed in deep water near Dyer Island in the East Passage supports a small dredge fishery.

Lobsters have not always been as prized as they are today. Colonists referred to them as "that relative of the cockroach" and fed them to hogs. An inshore fishery, using wooden traps, grew in the late 1800s and peaked in Rhode Island in 1924, when nearly 2 million pounds were taken, largely in Narragansett Bay. Rhode Island catches declined to a low of 0.1 million pounds in 1952 and increased only when fishermen ventured offshore (6). Lobsters attain sexual maturity between their fifth and seventh year, which is approximately when they reach the size of a legal "chicken lobster." In recent years, after great argument, the minimum legal size was slightly increased. This should improve the minimum weight of the smallest lobsters harvested and, more important, may significantly increase the number of juveniles produced each year. The lobster population in the Bay is heavily fished as it moves into the Sounds in the spring and returns up Bay in the fall.

The Future

If the pollution of the upper Bay is curtailed, we may see a gradual expansion of the quahog fishery into some of the Bay's most productive beds. If water quality does not improve, and if standards imposed by the Department of Health become more stringent, the fishery may be forced further down Bay and suffer another major decline. Advances in the technology of aquaculture may bring a return of leased grounds and the rearing of cultured shellfish. The Bay, however, is crowded with users, and fishermen, at least at present, are strongly opposed to the leasing of any areas of the Bay to aquaculturists. In 1978, however, a small area in the East Passage near Melville was leased to a mussel-growing company, and interest in aquaculture is growing. Passage of the Fishery Conservation and Management Act in 1976 has eliminated much of the foreign fishing within 200 miles of the coast and brought fisheries management controls over all stocks. The result should be a recovery among severely overfished stocks, and this, combined with a chronic shortage of fuel, may bring a revival in near-shore fisheries. It is certainly likely that more fishing vessels will use the Bay as a port. The most productive finfishing grounds, however, will remain offshore, in the Sounds and beyond.

Figure 27. Population density in Bay cities and towns in 1970. *Drafted from data compiled by R.I. Statewide Planning Program,* State Land Use Policies and Plan, *1975.*



Chapter 9

Land Use in Bayfront Towns

The Garden of New England

When Giovanni da Verrazano sailed into Narragansett Bay in the summer of 1524, he was delighted by a setting "as pleasant as I can possibly describe" populated by a gentle and physically beautiful people that cultivated a variety of crops on fields extending well inland from the shore. These fields, according to the enthusiastic explorer, were "open and free of any obstacles or trees and so fertile any kind of seed would produce crops." The Indians spent their summers along the Bay shore, where they harvested the plentiful fish and shellfish and grew their crops. In the fall, they moved inland, where densely wooded and more hilly country provided protection from the weather and supplemented their supplies with fresh game.

When the first English settlers arrived in 1636, some seven to eight thousand Indians lived on both sides of the Bay, but by the end of the century most of the native population had been killed, or displaced and replaced by a similar number of settlers (3). The settlers were farmers, fishermen, and sailors. They began to clear the state of most of its woodland, turning it into pasture and cropland. The number of farms grew rapidly, and by 1765 Rhode Island was the most densely populated colony, with 45 people per square mile (3). The best lands were divided into large plantations, with much of the labor provided by native Indian and African slaves. The climate, the gentle rolling country, and the soils were ideal for livestock, and large numbers of sheep, cattle, and horses were raised. The famous Narragansett Pacer, a superb saddle horse, is one legacy of the state's prosperous agricultural past. The shore, visible from innumerable inland vantage points when the countryside was grass rather than woodland, played a crucial role in agriculture: seaweed was an important form of fertilizer, and it was hauled to fields ten or more miles inland in huge quantities. Farmers would blanket their fields with six to eight inches of seaweed and then till it into the ground. Many of today's roads leading directly inland from the shore were seaweed-hauling trails, along which passed thousands of loads drawn first by oxen and later by somewhat quicker horses. Some claim that the horse replaced the ox as the principal source of power on Rhode Island farms because they could haul seaweed faster and gave their owner an edge over competitors.

In 1850, 80 percent of the state was cropland or pasture (1). The number of farms peaked at 26,000 in 1880, but the subsequent decline was rapid. Better farmland to the west and rapid industrialization led to the abandoning of the more marginal farms and then, in this century, to a wholesale exodus. In the 1930s, ordinances were passed that prohibited the burning of pastureland to control the growth of brush. The results have been dramatic, and today unkept, frequently scraggly woodland covers the former pastures and fields, hiding the rolling open countryside and blocking out the state's once famous long views to the ocean. By 1974, there were only 600 farms left in the state, and a mere 6 percent of the land was used for raising crops (3). Two-thirds of the land that had previously been farmed or grazed was woodland or residential housing. As the 1980s begin, there are signs that we may see some return to agriculture but, it appears, on a very small scale. Much of the best farmland, which is flat, well drained, and stone-free, has been eaten up by developers, since these same characteristics make the land convenient sites for any kind of construction.

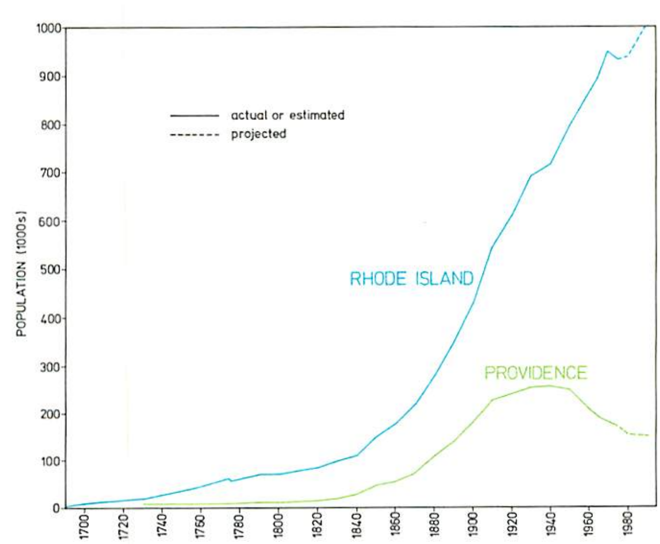


Figure 28. Actual and projected population trends in Rhode Island and Providence, 1665-1990. *Drafted from data compiled by McLoughlin, 1978; U.S. Bureau of Census, 1978;* Journal-Bulletin, *1979.*

Industrialization

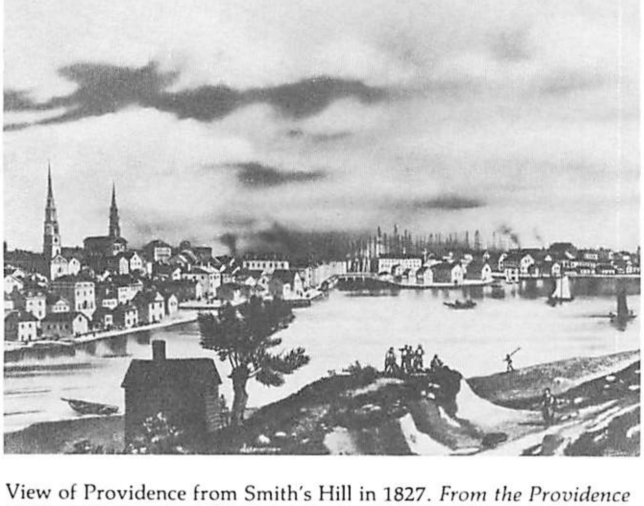
During its first 150 years, Rhode Island was the garden of New England. The prosperous merchants of Newport and the many shipbuilders that flourished around the Bay did little to alter the pastoral beauty of the countryside. But in the 1790s the merchants shifted their investment capital from shipping to the manufacturing of cotton and woolen textiles, and the state quickly became the center of America's Industrial Revolution as one large mill after another was built and better technology was quickly adopted and put into use. Samuel Slater built the first rural mill village, at Slatersville, in 1805 (3). The first mills were powered by waterwheels, and the hundreds of dams built to provide the necessary head of water brought about the demise of the Bay's anadromous fish populations and created a great number of mill ponds and lakes. By the 1830s, steam engines were replacing waterwheels, and factories became concentrated in rapidly growing cities in the northern portion of the state. By 1900, 40 percent of the entire population lived in Providence.

Industrialization not only changed the landscape; it also led to the pollution of rivers and streams. The practice of dumping all wastes into the nearest stream caused a severe cholera epidemic in Providence in 1854. That same year, the Moshassuck Canal, which flows into the Providence River, was described in one report as "foul smelling with hogs, dogs and cats [floating] in the water and large quantities of gas arising from decaying substances" (8). Wool and cotton mills, tanneries, and other industries dumped tremendous amounts of wastes into the Bay. An 1895 report to the General Assembly estimated that these industries dumped 6 million gallons of manufacturing refuse and 50,000 pounds of grease into the Providence River each day.

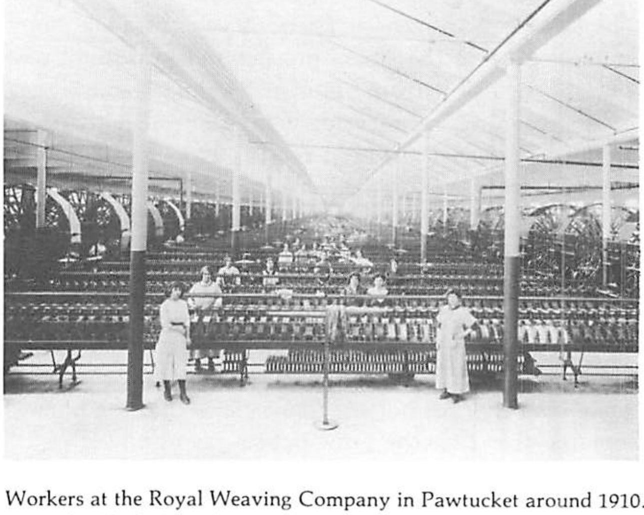
The mills required laborers, and in the late 1800s the state's growth in population outstripped that of any other New England state. Large numbers of immigrants, many of them sailing directly to Providence from Europe, provided a plentiful source of cheap labor and accepted the increasingly unpleasant conditions in Rhode Island's mills and factories. The explosive growth of the state's population, although it was centered in the northern part of the state, brought changes to the agricultural lands around the Bay. Summer colonies for the middle class, such as those at Oakland Beach and Conimicut, sprang up, and long stretches of the Bay shoreline began to take on an increasingly urban appearance.

Suburbanization and the Decline of Cities

By World War II, Rhode Island had been a leader in many of the forces that had shaped the nation, in-



View of Providence from Smith's Hill in 1827. *From the Providence Public Library, Rhode Island Collection.*



Workers at the Royal Weaving Company in Pawtucket around 1910. *From the Rhode Island Historical Society.*

Figure 29. Population change in Bay cities and towns, 1960-70. *Drafted from data compiled by R.I. Statewide Planning Program*, State of Rhode Island Selected Population and Area Data by Census Tract, *1975.*

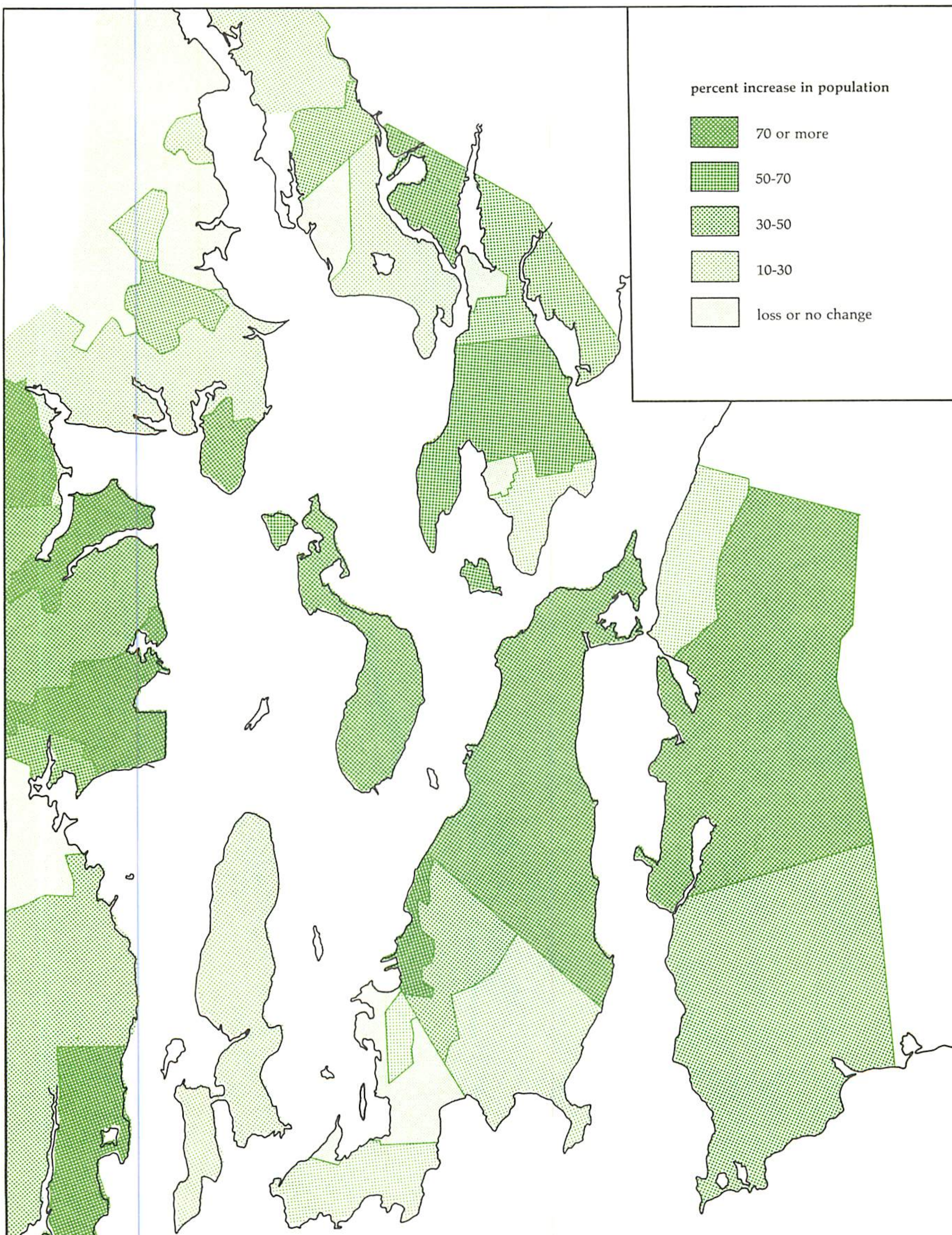
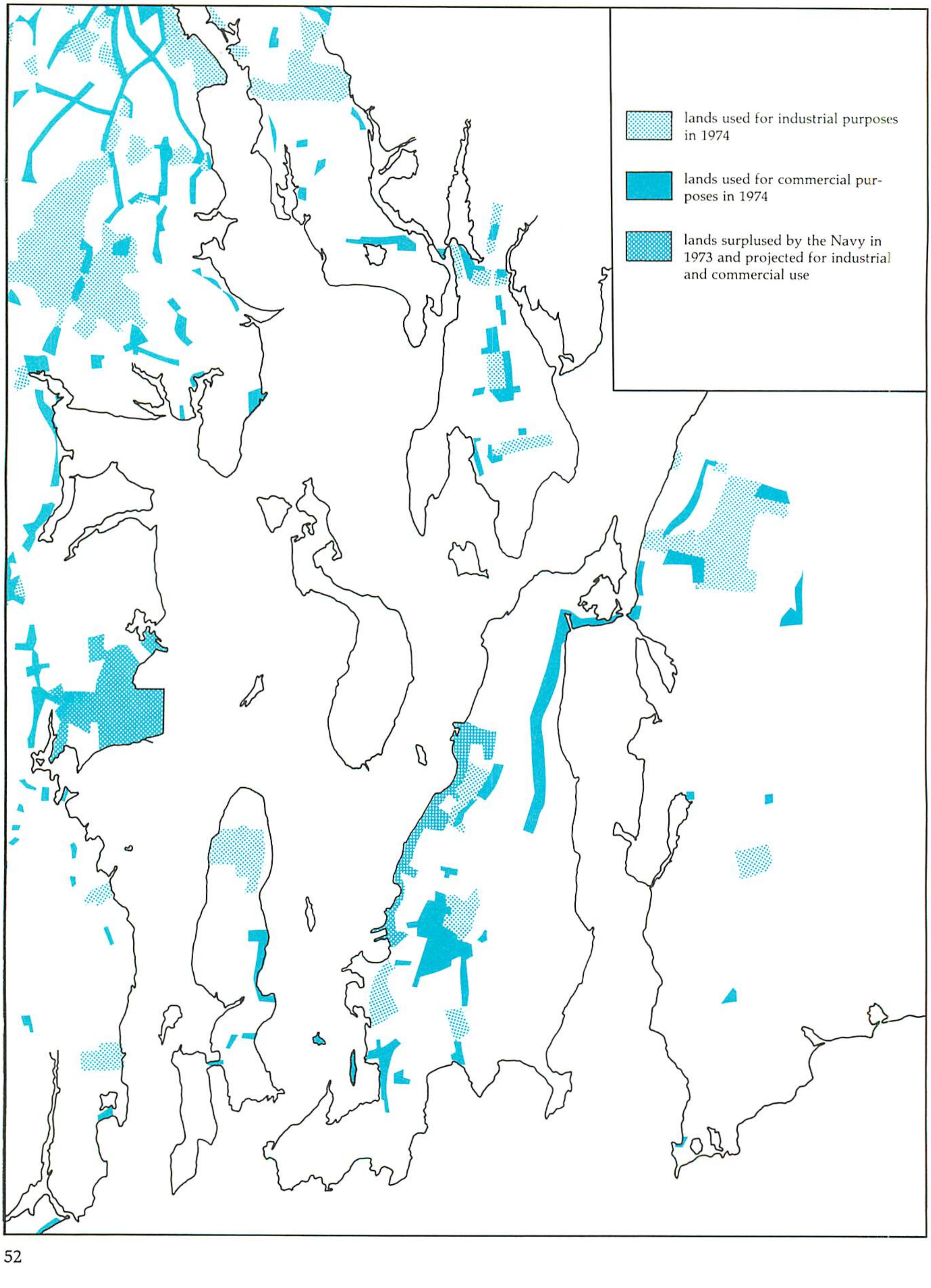


Figure 30. Industrial and commercial lands in Bay cities and towns. *Data for industrial and commercial lands from R.I. Statewide Planning Program, 1979. Data for Navy surplus lands from R.I. Governor's Office, 1974.*



cluding foreign trade, large automated factories, the adaptation of steam power to industrial processes, and the rapid growth of industrial cities. The Providence sewage treatment plant was, in 1900, a showpiece and the ultimate for such technology. The first Providence railroad station was also the biggest and best of its time. In the 1940s, Rhode Island was again the leader in an important national trend — the decline of the big cities. During that decade, the Providence metropolitan area lost population, and by the 1960 census it had been joined by Pawtucket, Central Falls, Woonsocket, Bristol, and a host of other urban areas across the nation. The reasons for this trend included the collapse of the New England textile industry as businesses moved to southern states, a sharp decline in immigration, and a large-scale migration of people out of cities to the suburbs. Rhode Island's population, after a long period of rapid and uninterrupted growth, had suddenly begun to level off by the 1970 census.

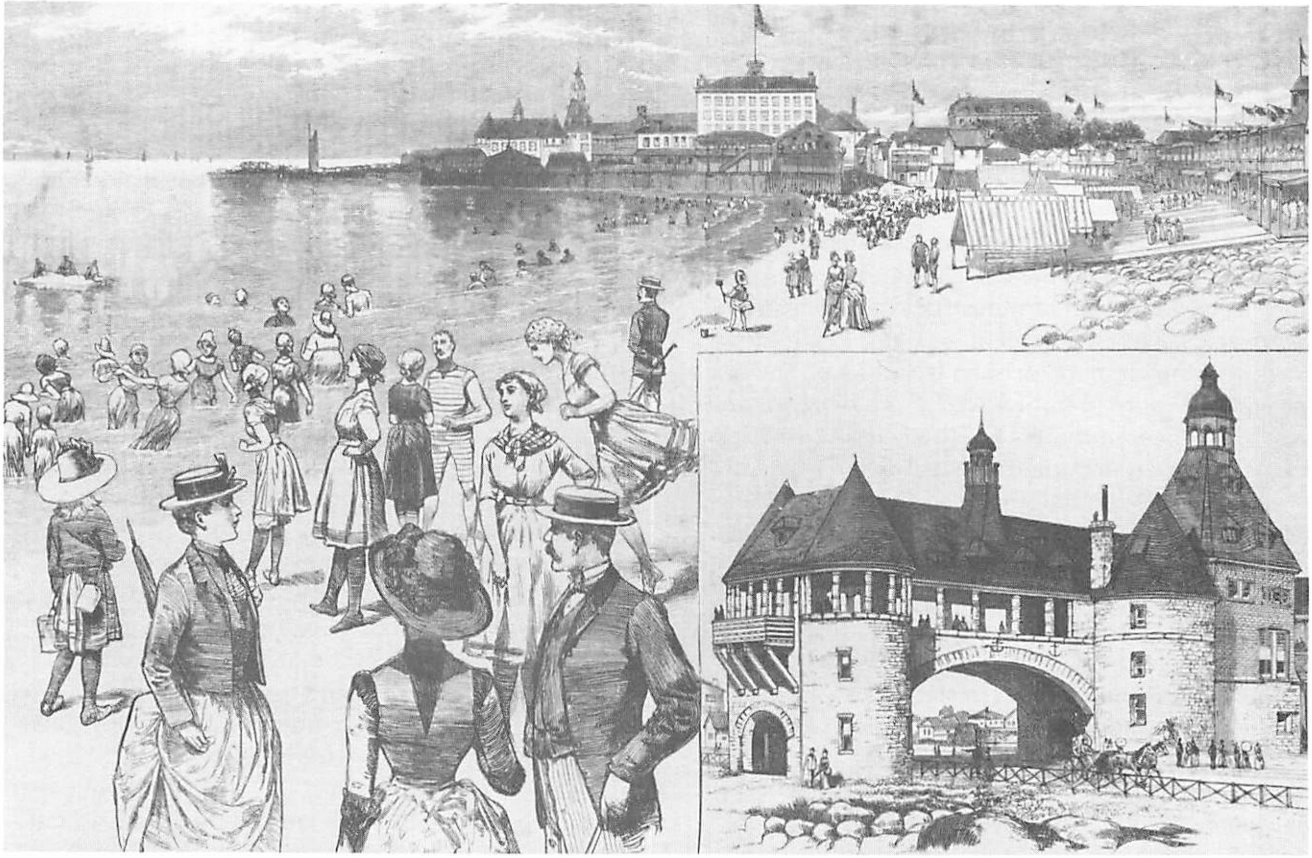
The slowdown in population growth was not apparent along much of the Bay, however, because so many people were moving out of the city to formerly rural communities along both sides of the Bay. In the three decades following World War II, the Bay's shoreline changed in appearance more than it had in the previous 200 years. Former villages spawled into large bedroom communities, and large expanses of upper and mid-Bay farmlands became urban. These trends continue today as shoreline residential development in towns such as Narragansett, South Kingstown, and Jamestown continues to grow at a rate that far exceeds construction elsewhere in the state.

The costs of suburbanization are great. The very large sums that had already been invested to provide water, sewage, roads, fire protection, schools, and other services in the cities have to be repeated. Meanwhile, the urban areas suffer losses in tax revenues, which are essential to maintaining the services they already have. The results are all too obvious. The Providence sewage treatment plant breaks down after years of neglect. There is less and less money available for costly but important goals for urban environmental quality and recreational outlets. Once beautiful rural lands become transformed by rapid, often poorly conceived development, and pollution problems of every variety proliferate.

We may now be seeing the peak in the suburbanization movement. In 1975, the state's Statewide Planning Program projected that urban lands would increase from 19 percent of the state in 1960 to 29 percent in 1990 (5). But by 1979 there were already nearly 200,000 fewer people in the state than projected and residential areas had grown at two-thirds the expected rate. High energy costs and a less expansive economy may amplify these trends dramatically and we may see a new era in the 1980s.

Although the rapid shoreline development seen all along the Bay in the past three decades may be slowing down, the changes that have already taken place present a host of problems that will remain with us for years to come. One response has been "environmental legislation" and the proliferation of plans and regulations over almost every activity. Here again, Rhode Island has been a leader. In 1971, the legislature passed a comprehensive bill which created the Rhode Island Coastal Resources Management Council (CRMC) and provided it with broad powers both to plan for the future use of the shoreline and tidal waters and to regulate activities in these areas through permitting procedures. Any person who wishes to build along the shore or put in a dock or discharge something into coastal waters must obtain a CRMC permit. The CRMC, however, cannot stop residential sprawl or address the crucial but elusive aesthetic issues that accompany major alterations to the environment. Rhode Islanders, therefore, through the CRMC and other such bodies, can make alterations by following the right procedures for such changes, but the central "control panel" over such trends as suburbanization and the decline of the cities remains beyond our reach.

Top: Engraving from *Leslie's Weekly*, July 30, 1887. *From the Rhode Island Historical Society.* Bottom: A traditional Rhode Island clambake. *From the Providence Public Library, Rhode Island Collection.*



Chapter 10

The Bay as a Playground

Before the Civil War, Newport was a resort for Southern aristocrats fleeing the summer heat and malaria. After 1865, Newport became a world-famous playground for millionaires and the Bay became a resort that catered to all classes. Jamestown was for those who wished to hide away. Wickford, and Narragansett Pier with its casinos, were favored by the sporty crowd. For the less affluent, the Bay's many coves and beaches became the place to spend a summer vacation or a day off from work. Large amusement parks, restaurants specializing in shore dinners, and many large hotels were built, and cottages dotted the shoreline. While Newport and, to a lesser degree, Narragansett Pier and Jamestown catered to an affluent and exclusive clientele, the upper Bay's amusement parks rivaled Coney Island. Crescent Park, Rocky Point, Bullocks Point, Oakland Beach, and Fields Point featured dining rooms that served vast numbers of shore dinners and lured crowds with roller coasters, carrousels, and other amusements. These attractions were linked by a flotilla of excursion boats, and regular passenger service brought in crowds from Boston and New York.

Newport, however, was in a class by itself. In the late 1880s, it became "the most palatial, extravagant, and expensive summer resort the world had seen since the days of the Roman Empire. Here the big businessman was king and Aquidneck his country seat" (4). During the 1890s, the Vanderbilts and other families of the American aristocracy built sumptuous "cottages" modeled on a strange variety of European castles and manors. Legions of master craftsmen were imported from Italy to build these edifices, and many millions were spent on the furnishings alone. Alistair Cooke gives us a sense of Newport in its heyday in his book *America* (2).

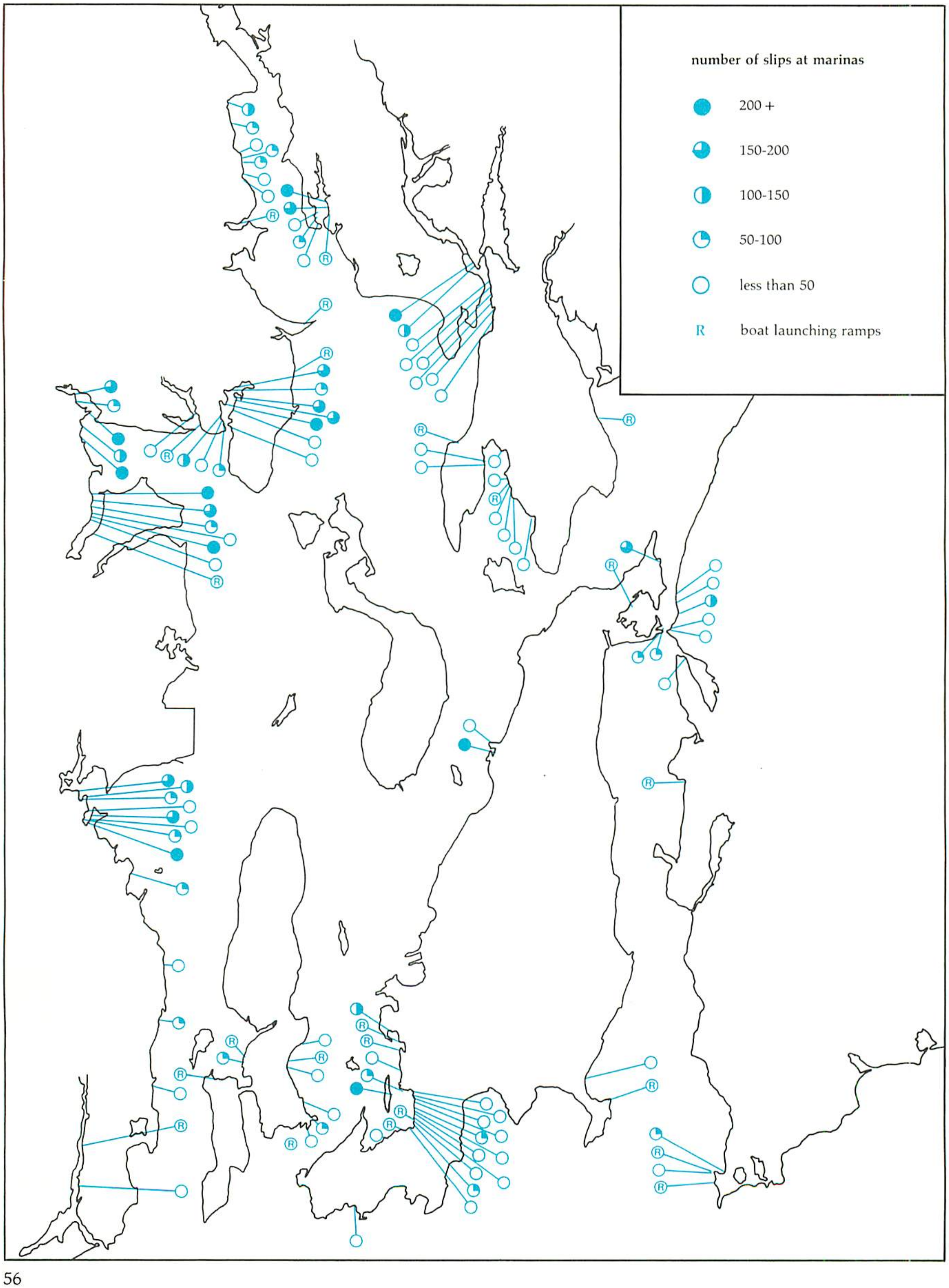
> The colony's houses were opened for only about seven weeks in the summer, but during that time the inmates packed a royal lifetime in formal picnics and luncheons, in dinners and polo and yachting and fancy-dress balls. It could cost up to $200,000 to throw a fancy-dress ball. There was one lady who set aside each summer $10,000 for what she would later itemize as "mistakes in my clothes." When the brother-in-law of Czar Nicholas II went to Newport, he confessed he had never even imagined such luxury. He had certainly never seen horses bedded down on linen sheets embossed with the family monogram. It was unlikely, too, that he had ever seen a man fling a Persian carpet on his lawn and order an army of gardeners to reproduce the intricacies of the pattern and colors in a mosaic of flower beds. There was a dinner at which the centerpiece was a long, thin sandbox implanted with tiny pails and shovels of sterling silver. The guests were invited on a given signal to dig for favors — for rubies, sapphires, and diamonds.

The social life of Newport was orchestrated by the wives of the millionaires. The men usually only appeared on the weekends and commuted to and from New York on luxury passenger boats that made the trip overnight. Many were avid sailors and they helped support a flowering in the craft of yacht building. The Herreshoff family of Bristol began to design and build magnificent yachts in the 1840s, and were turning out one world champion after another from 1893 well into this century. The Herreshoffs in fact designed every winner of the America's Cup race from 1893 to 1937, and many smaller but equally beautiful and superbly designed craft graced the Bay during this period (4).

The Newport extravaganza came to a sudden end with the 1929 Wall Street crash. The resort business had already peaked in the last decades of the 1800s, and the steamboating era declined soon thereafter. In the early years of this century, the excursion trade was carrying some one and a quarter million passengers annually, but by World War II the ferries had been completely replaced first by a network of trolley lines and later by the automobile. The final blow to both the resorts and the excursion boats was the 1938 hurricane, which leveled many of the remaining resorts and extensively damaged the piers where the boats took on passengers. The resort hotels lost most of their business when day trips by automobile replaced vacations at a resort as a predominant form of recreation.

During the 1960s and 1970s, we witnessed another era in pleasure-seeking on the Bay. Complementing the family house in the suburbs and the family car was the family-owned boat. The explosive growth in the number of boats has brought a proliferation of marinas along the shore. Today, there are virtually no sites left in the lower and mid-Bay where a new major marina can be built, and there is as yet no sign of a slackening in the growth of the recreational fleet. In the summer of 1979 there were an estimated 13,000 recreational craft at slips and moorings in Rhode Island waters (1). Marinas and yacht clubs in the Bay provided 80 percent of the state's slips and moorings used by the larger

Figure 31. Marinas and Public Boat Launching Ramps, 1979. *From Collins and Sedgwick, 1979.*



craft. The overcrowding at marinas is today causing a trend toward boats that can be brought to the water on a trailer and stored in the owner's driveway.

About 60 percent of the recreational fleet in 1979 were power boats, and half of these were used primarily for fishing (1). The rapid rise in the cost and availability of fuel may soon curtail this form of boating, and as the Bay Islands Park becomes a reality, we may again see a return to passenger boats, enabling large numbers of people to enjoy the Bay and move from one part of the park to another. We may even see ferries being used by commuters. This return to excursion boats may have been signaled by the launching of the *Bay Queen* in 1978. This 450-passenger boat can land passengers on a beach from a ramp in the bow and can therefore put visitors on islands that do not have a landing pier. The *Queen* has had no lack of business since she was launched.

The many summer cottages and hotels that were built during the last century are today only a memory.

The Silver Springs Dining Hall in East Providence. This was a regular stop for excursion steamers. *From the Providence Public Library, Rhode Island Collection.*

The cottages have been converted to year-round houses and in many instances have given rise to crowded, ticky-tacky residential neighborhoods. All but a few of the great hotels are gone. Rocky Point is still an amusement park and still serves quantities of shore dinners, but the pier is in disrepair and the old zest has gone. Waterfront real estate is now so expensive that, with the exception of a few neighborhoods in the upper Bay, none but the very rich can afford it. Most of the state's marinas were built when the land was cheap, particularly the sheltered marshy land most suitable for a marina in the days when nobody worried about filling and dredging. Today many marina operators find themselves running an economically marginal business on exorbitantly valuable real estate. The result may be that we will see a decline in marinas and even more competition for the services they provide.

The top value of all waterfront land for residential development and the rapid suburbanization of communities around the once rural lower and mid-Bay has brought radical changes to the appearance of the Bay. Much of the shore is still beautiful. But if the trends of the last three decades continue until the remaining fields, woodlands, and estates are transformed into house plots, then the Bay might suddenly lose its charm and perhaps the major reason for living near the Bay will be destroyed. We need only look at southern Long Island for a sense of how great a change we might see.

The Bay Islands Park

Perhaps one of the most important results of the Navy's pullout in 1973 was that it declared its extensive holdings on many of the Bay's islands as excess property. Fortifications, ammunition storage depots, and other facilities had radically altered these holdings from their natural condition, but the fact that they were Navy-owned protected them from the suburbanization that so altered other Bay shorelands in the years following World War II. Excessed lands that are dedicated to public recreation may be obtained from the federal government at no charge. This spurred the preparation of a detailed plan for a Bay Islands Park in

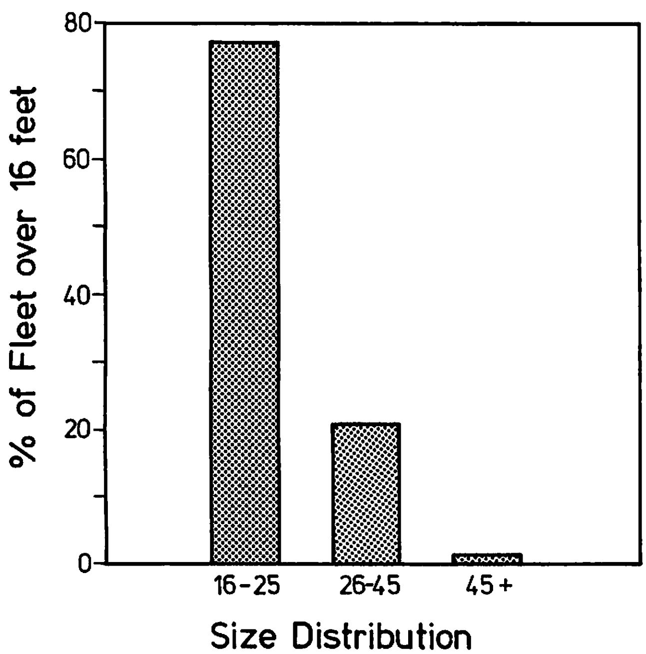


Figure 32. Rhode Island's recreational boat fleet by size class in 1979, excluding those under 16 feet. *From Collins and Sedgwick, 1979.*

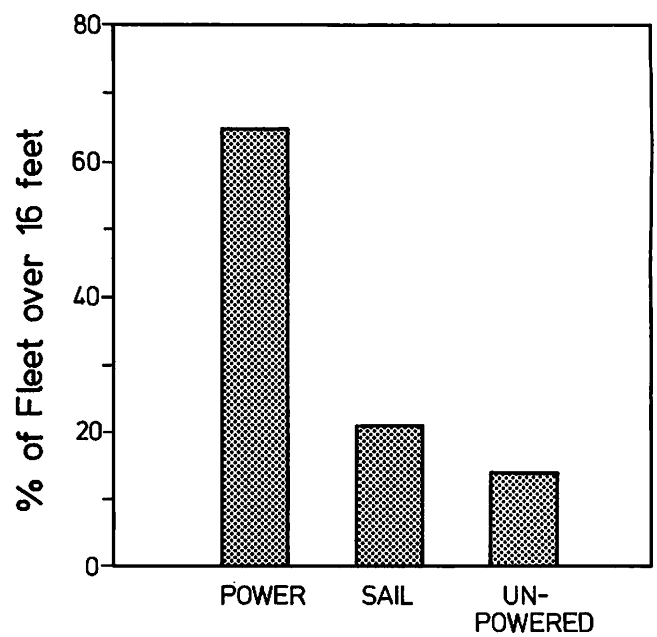
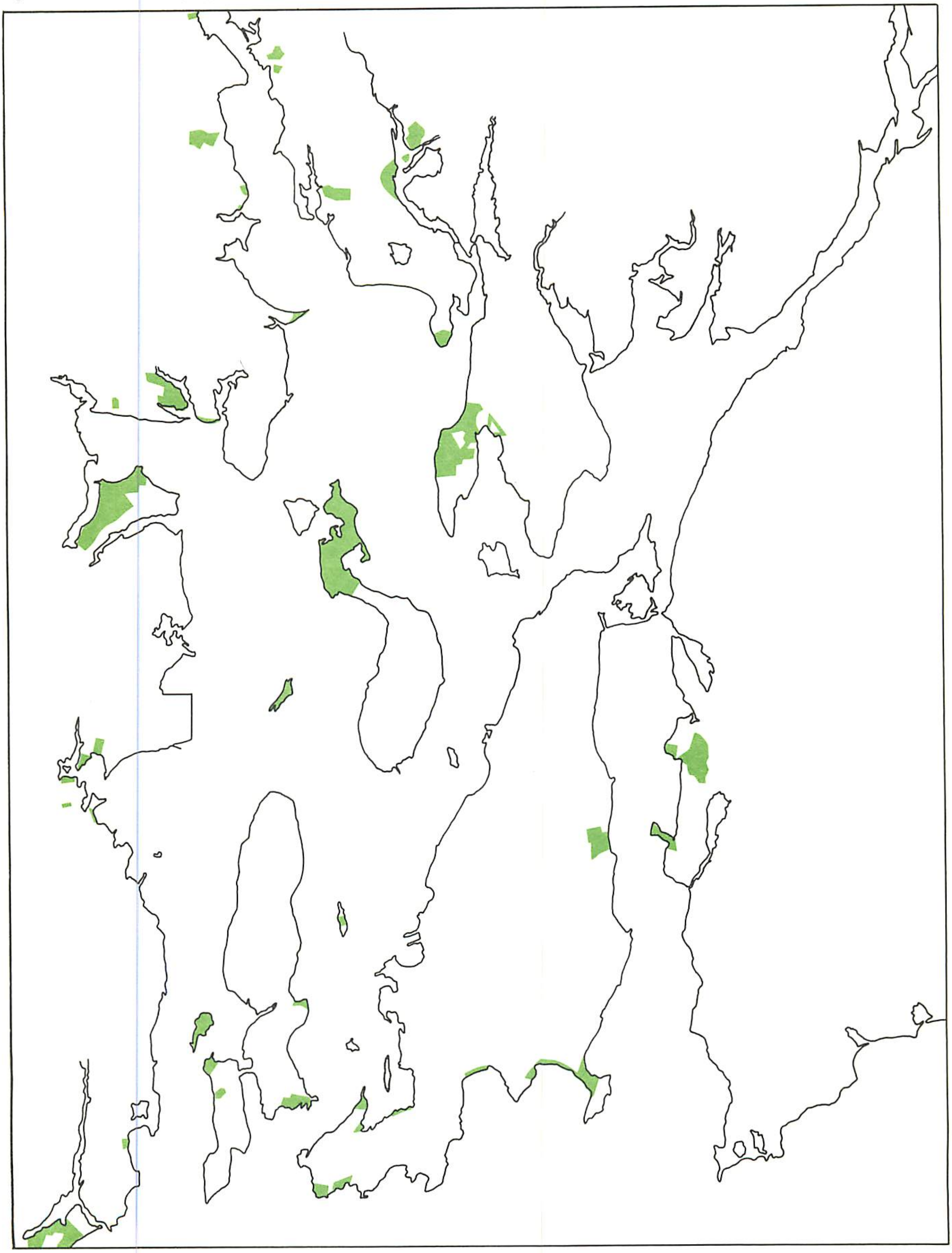


Figure 33. Rhode Island's recreational boat fleet by power source, excluding those under 16 feet. *From Collins and Sedgwick, 1979.*

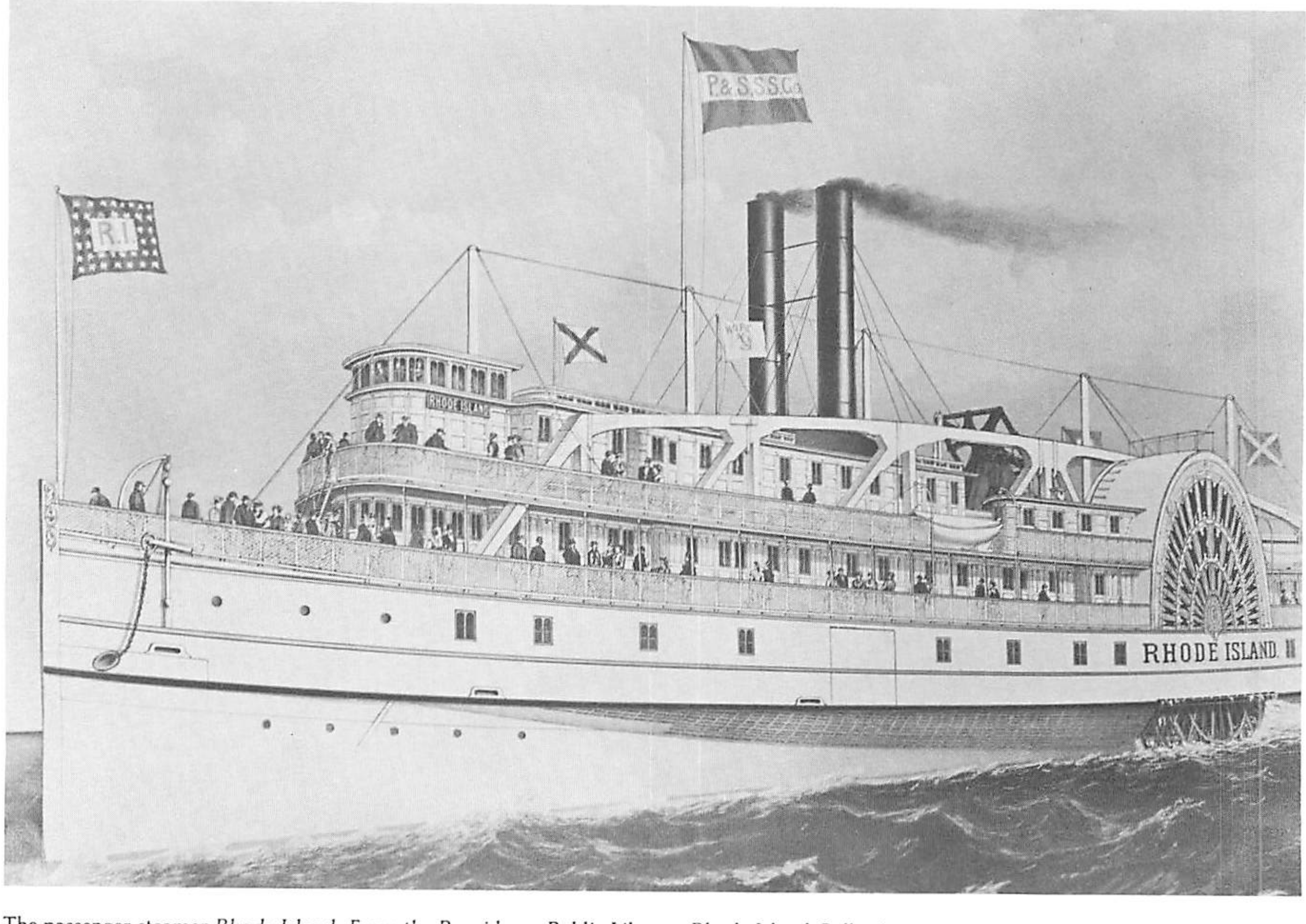
Figure 34. State and municipal parks and conservation areas on the Bay shore. *From R.I. Statewide Planning Program, 1976.*



1975 (3). The plan called for the creation of a park comprising the north and south ends of Prudence Island, Patience Island, Hope Island, and Dutch Island, and integrating them with sizable oceanfront parks in the lower Bay at Beavertail, Fort Wetherill, and Fort Adams. The scale of the concept and the contribution such a park would make to the future quality of the Bay excited great interest and wide support.

By early 1980, the state had worked through most of the details for transferring island property from the federal government. The Nature Conservancy had engineered the purchase by the state of North Prudence and of Patience, a total of 1,661 acres of exceptionally beautiful and unspoiled lands that had been privately owned. Much had been accomplished in converting Fort Adams, Fort Wetherill, Beavertail, and Brenton Point into parks. As presently envisioned by the Department of Environmental Management, the lower Bay segments of the park will support large numbers of visitors. The mid-Bay segments will retain their natural qualities. Visitors to North Prudence and Patience Island will be carefully controlled to avoid damage to their fragile and beautiful natural qualities, and few people will land on Hope Island. It is now likely that the Islands Park will be further enhanced by declaring Patience, North Prudence, and the surrounding waters as a national estuarine sanctuary for research and recreation.

An essential element of the Bay Islands Park is a good transportation system. The mid-Bay segments



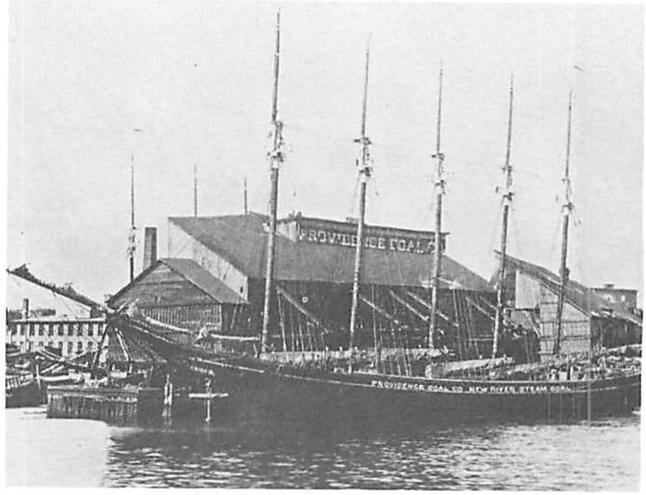
The passenger steamer *Rhode Island. From the Providence Public Library, Rhode Island Collection.*

and Dutch Island are only accessible by boat, and getting there should be half the fun. The Department of Environmental Management believes that an adequate transportation system can be built around existing ferries. Present plans call for using the summer ferry between Providence and Block Island to move people between Providence, South Prudence, and Newport. South Prudence, with its large pier, extensive paved roads, and buildings, will be the hub of the park, with a broad range of activities including, perhaps, a swimming beach and a trail for the handicapped. A bus will transport controlled numbers of people to North Prudence. Patience, which is ideal for school group camping, will be reached by rerouting a regularly scheduled ferry or by chartered boat. Access to the islands from the mid-Bay region could be provided by a regular service running between Allens Harbor in North Kingstown, South Prudence, and Melville. Another, smaller boat could ply between Dutch Island and West Ferry on Jamestown. The *Bay Queen*, which presently cruises the Bay during the summer months, is expected to stop at South Prudence and will provide an important addition to the daily service of the Block Island ferry.

Many Rhode Islanders are unaware of the beauty of the Bay and its islands. With a Bay Islands Park, all the state's population will be able to enjoy these islands. If they are properly managed, they will retain their natural character.

Easton's Beach, Newport. *From the Providence Public Library, Rhode Island Collection.*

Top left: The Providence River looking south around 1890. Top right: A coal schooner at the Providence Coal Company in 1912. *Both photos from the Rhode Island Historical Society.* Bottom: The Providence River looking north. *From the Providence Public Library, Rhode Island Collection.*



Chapter 11

Shipping

During Colonial times, maritime commerce was the driving force behind the Rhode Island economy. Narragansett Bay offered excellent harbors, and it was strategically placed for international commerce and within reach of the region's richest fishing grounds. Seagoing offered a wealth of opportunities for energetic, ambitious, and frequently ruthless colonists. Newport was the undisputed center for all shipping, and several smaller ports in the Bay flourished beside her. In 1769, Newport boasted a fleet of 200 vessels in foreign trade, 300 to 400 coasters, and many whalers (1). There was a regular packet service to London, and the port reaped the benefits of the lucrative triangle trade, which exchanged rum for slaves and gold in Africa, traded the slaves for sugar in the West Indies, and returned home with huge profits and raw materials for Newport's 22 distilleries. All these activities were choked off by almost three years of the British occupation of Newport during the Revolutionary War, and the once-booming seaport never recovered its position of maritime pre-eminence after the British left.

By 1790, Providence had replaced Newport as the state's major port. It had a productive hinterland and a core of energetic businessmen who put their money in trading ships that were pioneers in the China trade and active in all the major ports of Europe. This second boom in Bay shipping was short-lived, however. Major European markets were disrupted first by the French Revolution, then by the Napoleonic Wars and a series of embargoes. The Barbary pirates preyed heavily on American ships, while Rhode Island's own activities in privateering and slave trading declined. The Narragansett Bay shipbuilding trade went into rapid decline early in the century, and by 1830 international trade had all but disappeared from Narragansett Bay. This is reflected in the import duties collected in Providence on foreign goods, which totaled $400,000 in 1804 but had fallen to $100,000 in 1830. Export duties fell from $1.5 million in 1804 to a miserable $10,000 by 1860 (2).

During the 1830s, Rhode Island's major firms shifted their assets away from shipping and into textile manufacturing, which grew rapidly once water-powered mills were supplemented by steam-powered mills. The shift in the Rhode Island economic base is described as follows by McLoughlin in his book *Rhode Island*.

> Rhode Island was turning away from the sea, after two centuries. Home markets replaced foreign markets. Shipbuilding almost disappeared. Seaports like Newport, Bristol, Warren, Wickford, and Westerly faded into quaint backwater towns, while inland farming communities sprouted enormous wooden and brick factory complexes along their rivers. Crowded, smoky cities in the northern half of the state became the center of enterprise, prosperity, and power, while Aquidneck, South County, and the eastern shore — except at Fall River — stagnated.

The remaining decades of the last century saw shipping relegated to a small coastal trade bringing in coal, lumber, and raw cotton and taking out textiles. The pace picked up again with the advent of steamboats at the end of the century. The steamers moved passengers on luxurious liners between New York and Boston, and maintained regular freight services to several Southern ports. By World War II, the steamboats too were gone.

In the years since World War II, the Bay's cargoes have been almost entirely petroleum imports. The major port remains Providence. Imports other than oil are today dominated by foreign-made cars and by lumber. Exports are small indeed, and consist primarily of scrap metal. Approximately one-quarter of all the goods brought into the state are carried on ships. In 1977, 12.5 million tons of cargo came into the Bay, and 4.8 million tons, nearly all of it petroleum, went to Fall River. Of the 7.7 million tons that went to Providence, 88 percent was petroleum and half of this was trucked out of state to cities and towns throughout southeastern New England. Oil imports at Providence peaked in 1973, just before the Arab oil embargo, and have declined slowly since then (3). The Port of Providence is the fourth-largest port in New England (following Portland, Boston, and New Haven), and its dependence on petroleum for most of its business is similar to other secondary ports in the region.

Most of the petroleum brought in by tankers is discharged to tank farms along the East Providence shore. On the west side of the river, the Providence Municipal Wharf and a number of privately operated piers handle a variety of imports. At the 143-acre Municipal Wharf, automobiles, lumber, and other assorted imports are discharged, and scrap metal is loaded for export. The wharfage leased from the city by various corporations handle petroleum, propane, asphalt, cement, chemicals, and other products. In all,

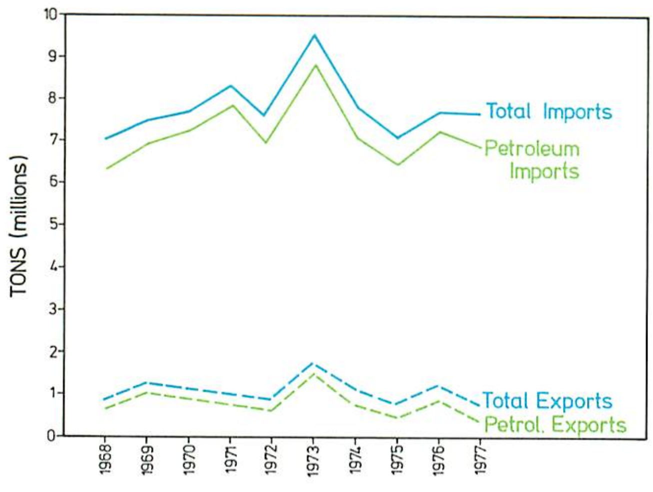


Figure 35. Maritime trade at the Port of Providence, 1968-77. *Drafted from data compiled by Alexander, 1966, and U.S. Army Corps of Engineers, 1977.*

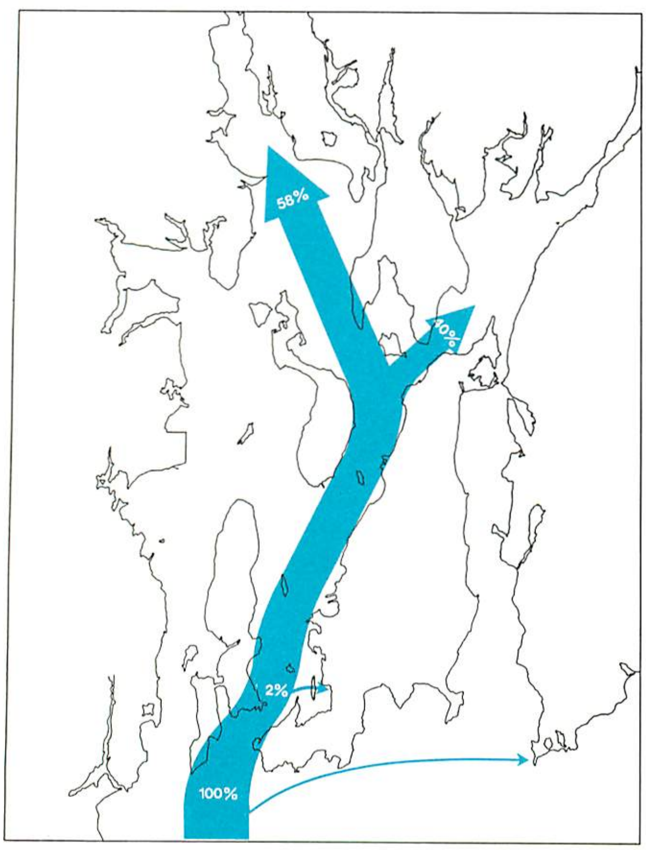


Figure 36. The flow of shipped imports in the Bay in 1977. *Drafted from data compiled by U.S. Army Corps of Engineers, 1977.*

the port facilities on both sides of the Providence River total some 635 acres, of which 85 percent is devoted to petroleum handling and storage.

The future of the Port of Providence may possibly include major expansion of its nonpetroleum cargoes. Container ships began to unload at the Providence Municipal Wharf in 1979, and the trend in nonpetroleum imports over the past several years has been one of steady growth. On the East Providence side, there is an ambitious plan to build a 46-acre wharf at Wilkes Barre Pier by filling in shoal water. The facility would be linked by the Providence and Worcester Railroad to markets in the Midwest, which could be reached without going through Boston or New York City. If the dredge material disposal problem can be solved and a host of other deterrents that face any major project are worked out, it is possible that the Port of Providence may attract large cargoes in the future.

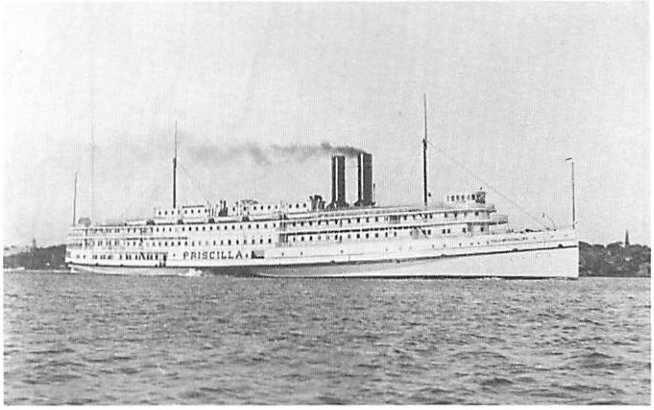
Another cluster of shipping piers used primarily for handling petroleum forms the Tiverton Shipping Area near the boundary between the East Passage and Mount Hope Bay. Cargoes handled there are a small fraction of those handled at Providence. A restricted turning basin and channel depths of 34 feet restrict vessels to sizes smaller than those that can land at Providence.

In the lower and mid-Bay, major port facilities built during World War II were declared surplus by the Navy in 1973. These are briefly described in Chapter 13. By the end of 1979, the two piers at Davisville had been leased to companies that service offshore oil- and gas-drilling operations. Operations have thus far been small compared to what they might be if drilling was underway on Georges Bank off Cape Cod as well as in the Baltimore Canyon off the coast in New Jersey. A major find in either or both areas could bring a large fleet of supply boats to Davisville and the use of up to 780 acres for laydown yards, pipecoating, and steel fabrication plants on ex-Navy property near the piers. To the south of Davisville lies a huge pier that was built to service aircraft carriers. A few lobster boats tie up in the lee of this wood-piling, concrete-surfaced structure, but no new major uses of the facility are foreseen.

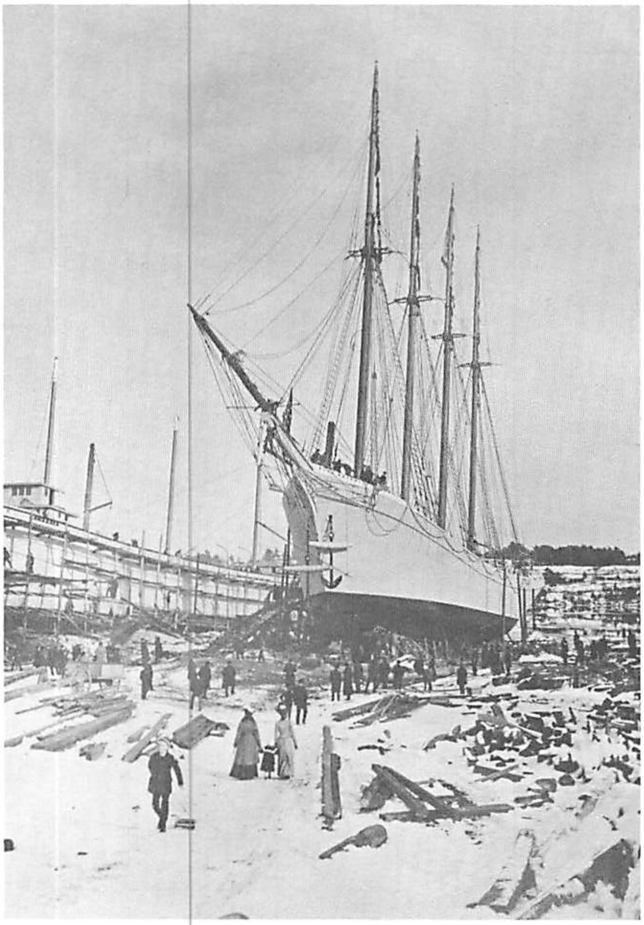
On the east side of the Bay, major ex-Navy facilities stretch along six miles of shoreline. Coddington Cove, once the home of the Atlantic Destroyer

Fleet, is being redeveloped as a shipyard and for various activities related to fisheries. One of the two large piers has been retained by the Navy. Further up the Bay is the Melville fuel pier. This may someday become a fishing port.

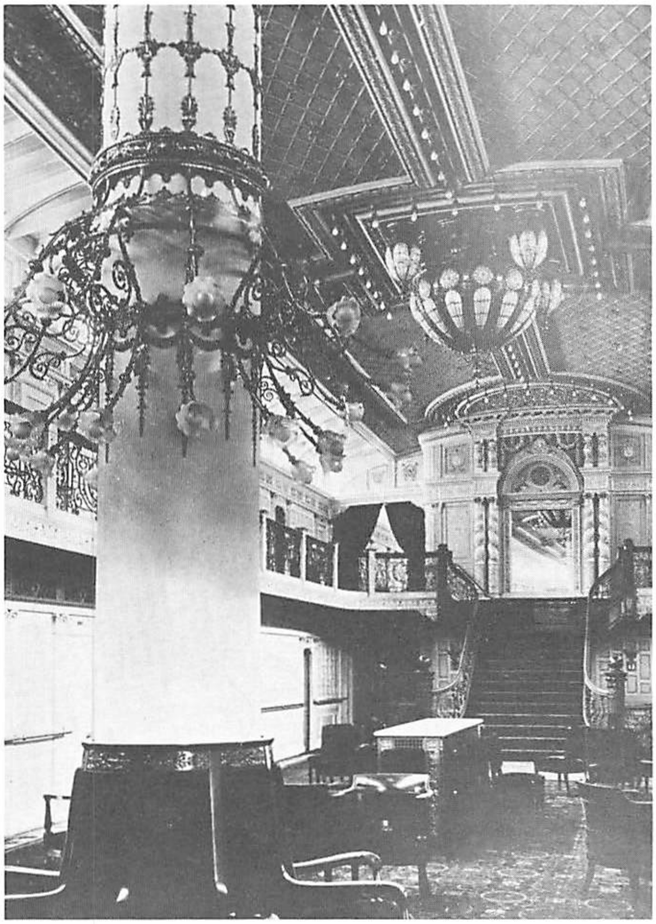
As we enter the decade of the eighties there is some evidence of a revival in commercial shipping traffic in the Bay. The flow of petroleum will probably decline as the era of energy shortages proceeds, but mixed cargoes may increase. The facilities built by the Navy may again be active, this time with small fishing vessels and, possibly, with a twenty- to thirty-year burst of oil-drilling activity offshore.



The S.S. *Priscilla. From the Providence Public Library, Rhode Island Collection.*

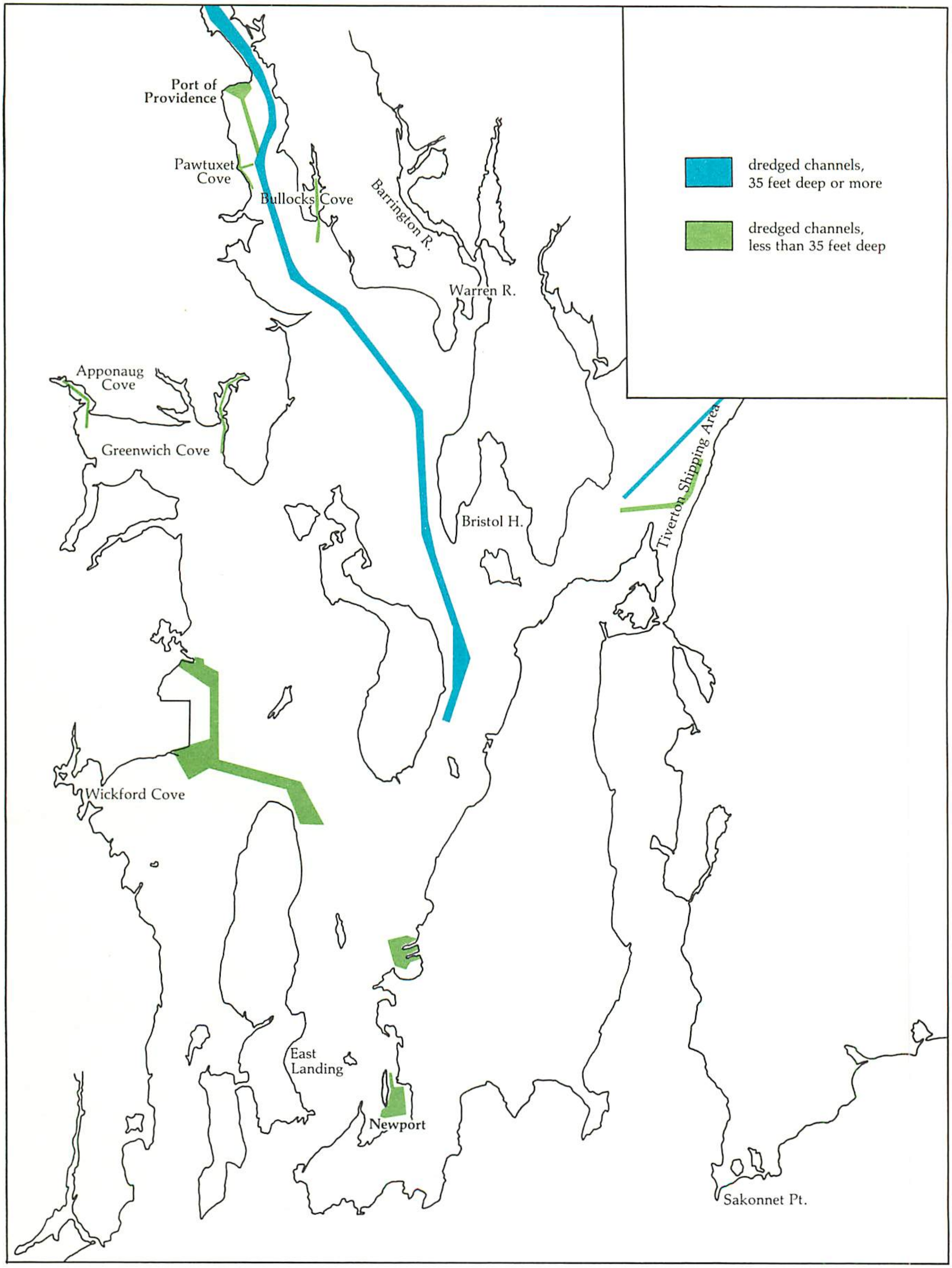


This schooner, the *Hope Sherwood,* was launched in Providence in 1903. *From the Providence Public Library, Rhode Island Collection.*



The interior of the S.S. *Priscilla* of the Fall River Line. *From the Providence Public Library, Rhode Island Collection.*

Figure 37. Dredged ports and channels. *From Seavey and Pratt, 1979.*



Chapter 12

Dredged Channels

The Bay's harbors at Providence, Newport, Quonset, Davisville, and Fall River would all be unusable by anything more than small craft if it were not for a long history of dredging channels, turning basins, and berths. Some 80 percent of today's marinas and small boat basins have also required dredging to make them operable, but the scale of these projects is tiny compared to the commercial shipping projects. Virtually all major dredging projects have been undertaken by the Army Corps of Engineers and paid for in large part by the federal government. In all, some 20 to 25 million cubic yards of bottom material have been dredged out of Narragansett Bay and Mount Hope Bay. This is enough to fill three lines of bumper-to-bumper dump trucks stretching from here to the West Coast.

Two massive navigation channel projects, both of which were undertaken after World War II, overshadow all other Corps dredging projects in the Bay area. These two projects alone required the removal of nearly 15 million cubic yards of sediment to create a 35-foot channel across Mount Hope Bay to Fall River and a 40-foot channel from the southeast side of Prudence Island up to Providence (2). For the Corps, however, this was merely another step in a process spanning more than a century. In 1852, the Corps began by constructing a nine-foot-deep channel in the Providence River in order to extend dockage for vessels up into the head of the harbor. In 1913, the channel between Fox Point and Bullocks Point was deepened to 25 feet, and in 1937 it was dug down to 35 feet and extended to Popasquash Neck. The final and biggest phase of the work was authorized in 1965 and completed in 1971. This created the present 40-foot channel that extends down Bay from the harbor a distance of 17 miles (1). Despite all this work, most piers in the Port of Providence cannot handle vessels with a draft of more than 35 feet. The volumes of sediment that need to be removed at the piers and wharfs are small, but they are highly polluted and the rising environmental concerns of the past decade have made it extremely difficult, if not impossible, to find disposal sites that are acceptable to all parties.

The Corps completed the present 35-foot channel across Mount Hope Bay to Fall River in 1957. The Corps has been authorized to deepen the channel to 40 feet, but here too the lack of a disposal site is preventing any action.

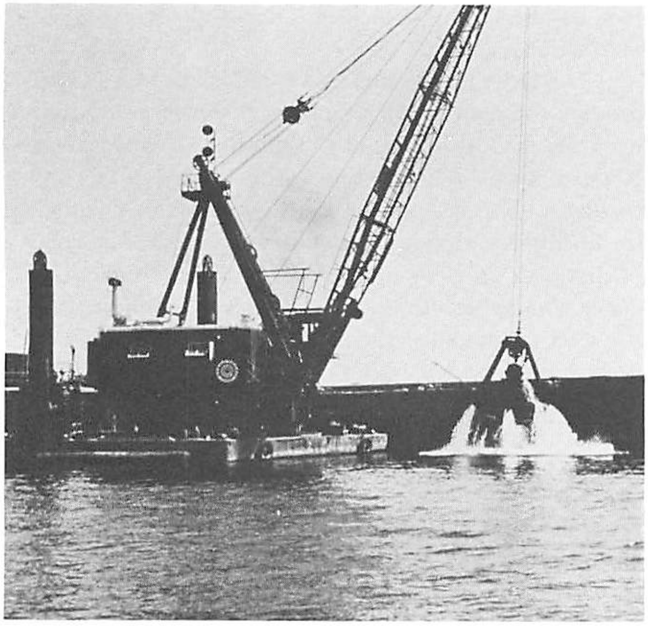
The federal government, when it approves Corps projects for commercial shipping channels and harbors, provides most if not all of the funding. It will provide 50 percent of the funds for approved projects for recreational boating, and more if the harbor or channel is for both recreational and commercial craft. The costs of dredging are considerable. Deepening the Providence channel to 40 feet cost some $19.4 million, and the 1979 estimate for the pending Fall River channel project calls for $36 million if necessary improvements in the harbor itself are also undertaken (3). Hauling away the spoils is a major expense and costs rise rapidly as the distance to the disposal site increases.

Recently Completed and Pending Dredging Projects in Narragansett Bay and Mount Hope Bay

		Millions of Cubic Yards
Completed		
Army Corps (1949-77)		
Providence shipping channel and harbor		10.9
Fall River channel and harbor		1.9
Other Narragansett Bay projects		0.9
Private Projects (1974-78)		
Narragansett Bay		0.07
	Total	13.77
Projects Pending in 1978		
Army Corps		
Narragansett Bay		0.6
Mount Hope Bay and Fall River		2
Private Projects		
Narragansett Bay		1
	Total	3.6

The Spoils Disposal Problem

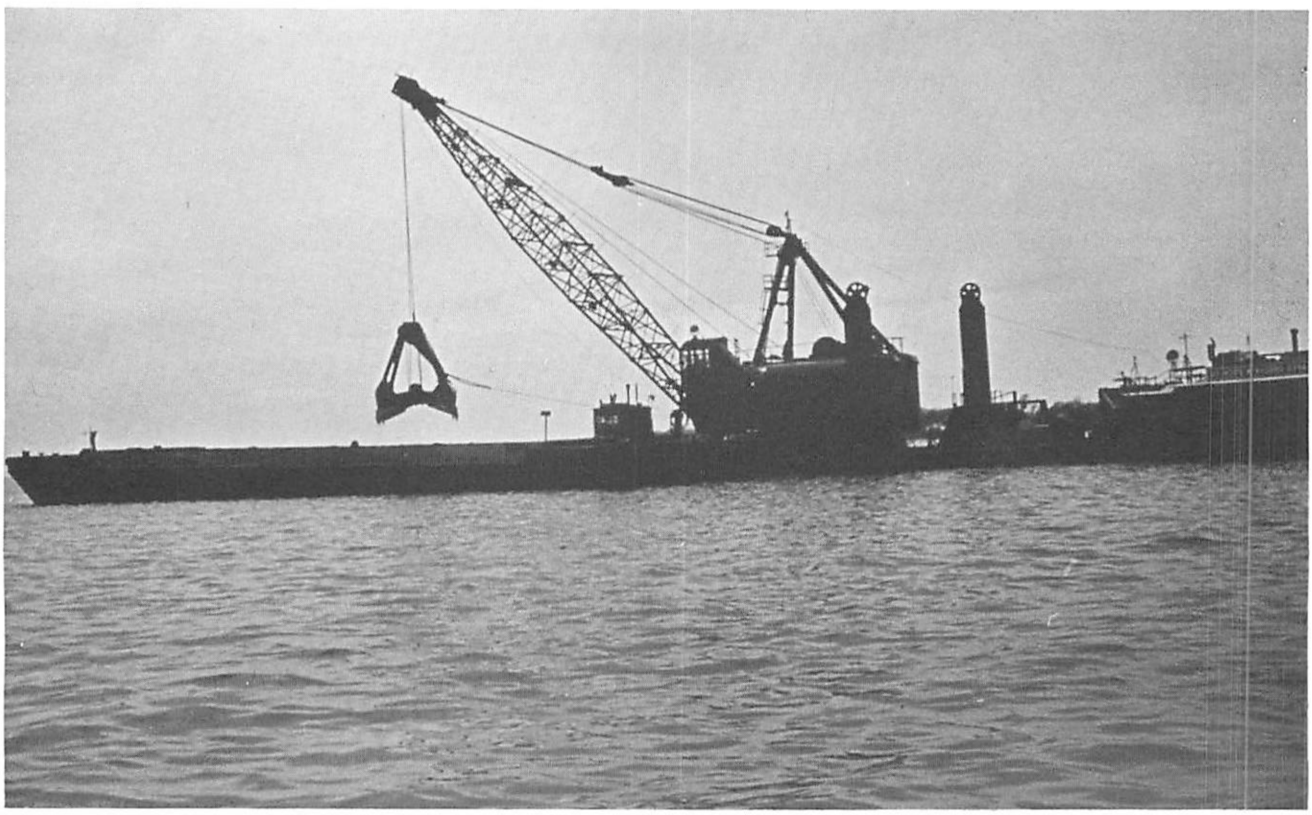
Before the 1960s nobody worried very much about where dredge spoils were dumped. Convenience and expense were the primary considerations, and millions of cubic yards were pumped onto salt marshes, low-lying shorelines, and behind bulkheads, or loaded into barges and dumped in deep water within the Bay. Bulkheading and filling has radically changed the shape and character of the upper Providence River shoreline and other waterfronts around the Bay. By the early 1960s, many of the state's salt marshes had been destroyed, largely because of dredging and filling



operations, since salt marshes and harbors compete for the same protected waters. The last recorded dumping of spoils on a Rhode Island salt marsh by the Corps took place in 1963. Land made from dredge spoils includes sizable portions of the Quonset Airport, Fields Point in Providence, and Common Fence Point in Tiverton.

Deep water off the southern end of Prudence Island received some 1.5 million cubic yards of dredge spoils between 1949 and 1966 (2). The spoils created by dredging channels and turning basins at Quonset and Davisville which were not used for creating land were piled up near the Davisville channel in a mound that rises some ten feet above the original bottom and is 2,500 feet across.

Deepening the Providence River shipping channel to 40 feet produced 10 million cubic yards of spoils. The disposal site selected for this huge volume of material was a square-mile site in Rhode Island Sound

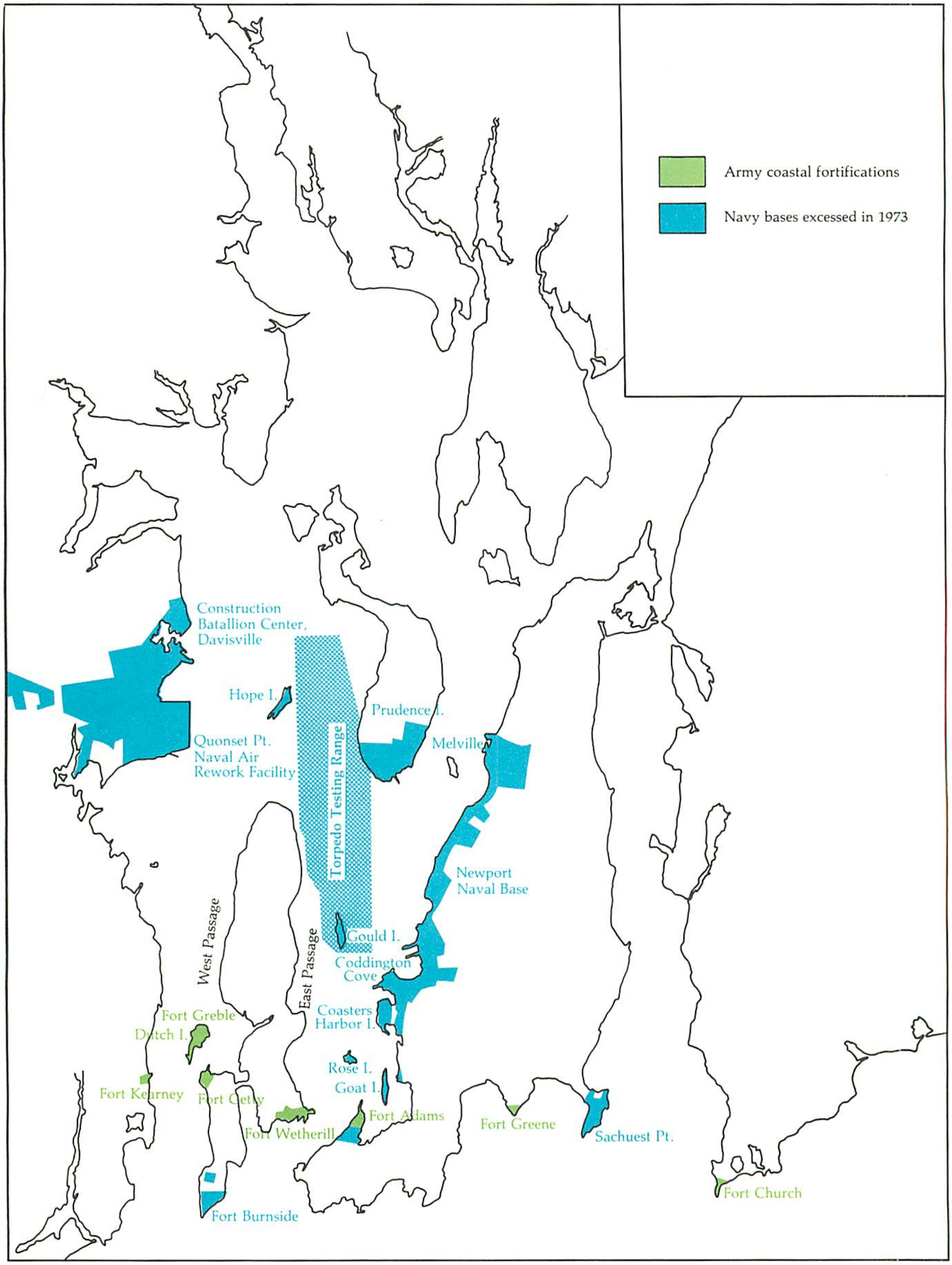


Loading a barge with dredge spoils. *Photos by Sheldon Pratt.*

near Brenton Reef. More by luck than by design, the dredging began in Providence and proceeded down Bay. The result was that the most polluted sediments, which lay in the harbor, were buried at the dump site by cleaner material from the lower reaches of the channel. Water depths at the dump site were 100 feet, and by the end of the project the spoils formed an irregular mound some 18 feet high and a half mile to a mile in diameter. The project brought a rising storm of protest from fishermen and environmentalists. The floating fish trap fishermen became convinced that water turbidity caused by the dumping caused migrating schools of scup to veer off from their usual migratory route and bypass their fish traps. In 1971, the fishermen brought suit against the Corps, and no spoils have been dumped at Brenton Reef, or anywhere else in the Sound, since then. Today the spoils mound has slumped and eroded to 16 feet from its original 18 feet. Both the mound itself and the neighboring bottom have been extensively studied and no evidence has been found to suggest that significant amounts of spoils or pollutants are moving away from the mound. The site has become a good lobster pot ground, and the increase in lobster pots and the obstruction caused by the mound itself have pre-empted some of the trawling that used to take place in the area.

Nine years after the dumping at Brenton Reef stopped, no solution has been found for a new or better way to dispose of spoils, and nearly all dredging in the Bay remains at a standstill. A solution must be found, since natural sedimentation makes it necessary to routinely dredge most harbors and channels to maintain their navigability. No easy solutions will be forthcoming. The sediments that accumulate in harbors, particularly in the upper reaches of the Bay, are contaminated with a host of heavy metals, man-made chemical compounds, and other potentially serious pollutants. Yet channels and berths in the Providence River should be maintenance-dredged every six to eight years. On-land disposal presents, if anything, worse problems than the removal of sediments to an underwater or shoreline site, because the pollutants are likely to migrate and enter groundwater as the spoils dry out. When left in the marine environment, the pollutants seem to stay put, and if buried beneath clean spoils, they should be out of reach of most forms of life. Small volumes of spoils can be used for building man-made salt marshes or, if they are of the proper grain size, for building beaches. In other parts of the country, islands have been built with spoils. Spar Island, in Mount Hope Bay, has already been expanded with spoils, and may be a good site for a sizable island. The expense of building an island, however, involves more than simply dumping the spoils in the Sound, and the Corps is reluctant to abandon the less expensive alternative. Meanwhile, existing harbors and marinas get shallower, and new projects remain on the drawing board.

Figure 38. Navy bases and coastal fortifications. *From Parkman, 1978, and R.I. Statewide Planning Program, 1970.*



Chapter 13

The Military Presence in Narragansett Bay

The lower Bay's shoreline has been dramatically affected by the construction of elaborate coastal defenses and by its use as a major base for naval operations. Beginning in 1776 and continuing well into this century, fortifications were constructed, maintained, expanded, and abandoned as weaponry and political circumstances changed. By 1940, the latest of the gun emplacements and forts around the Bay had all become obsolete. The Navy became a dominant presence in the Bay in World War II, but it withdrew most of its activities in 1973.

Coastal Fortifications

The Revolutionary War proved that Rhode Island was vulnerable to invasion. The British occupied Newport Harbor for almost three years, causing the evacuation of half the colonists from Aquidneck Island, and blocking all maritime trade. During the 150 years that followed the Revolution, the Army Corps of Engineers constructed, refitted, and expanded gun emplacements at nearly a dozen locations around the mouth of Narragansett Bay. The first forts were placed at points where channels were close to shore, making it nearly impossible for an enemy ship to enter the Bay. Early in the nineteenth century, the Bay was classified as a vital access to the Post Road, which connected New York City to Boston. Coastal defenses were considered essential for preventing an invading force from gaining control of this important highway, and Fort Adams became the center of military activity around the Bay during this period. Following the Civil War, there was little interest in maintaining or improving shore defenses until the release of the Endicott Report in 1886. The report documented the need for national defenses and spurred the construction of several new forts.*

All the Bay's defenses became outdated by advances in military technology in the First World War. At the outbreak of the Second World War, long-range artillery were installed at batteries on Sachuest Point and near Point Judith which provided the Bay with the most powerful coastal defenses in the region. However, the rapid development of amphibious landing tactics on open beaches, airpower, and missile technology made the concept of harbor artillery defenses obsolete, and these most recent defenses were abandoned soon after World War II.

Major Coastal Defenses Around Narragansett Bay

Fort Wolcott was built on Goat Island in 1795 to protect Newport Harbor. It was quickly supplanted by Fort Adams.

Fort Adams is the most well-known and heavily developed fortification on the Bay. Construction began on Brenton Point just outside Newport Harbor about 1798. Major improvements were made between 1824 and 1858, and during the Civil War, Spanish-American War, and both world wars. By World War II, Fort Adams extended over 150 acres. A portion was acquired and developed as a state park in 1965. The remaining portion was transferred to the state by the Navy in 1978.

Fort Greene, on Easton Point, east of Newport Harbor, was built as a supplement to Fort Adams during an undeclared naval war with France in the late eighteenth century.

Fort Getty, at Beaverhead, was constructed soon after the Spanish-American War on Conanicut Island within sight of Fort Greble and Kearney. It is presently operated by the town of Jamestown as a park for camper-trailers.

Fort Greble began as an earthen battery on Dutch Island and was constructed to protect the West Passage during the Civil War. It was upgraded considerably following the Spanish-American War. The fort had lost its defensive value by World War I, and was used as a hospital and prisoner-of-war camp. It was acquired by the state in 1958.

Fort Kearney was built at the turn of the century at South Ferry, on the West Passage, to the west of Dutch Island. It was obsolete by World War I, and in 1936 it was turned into a marine research laboratory by the University of Rhode Island. It is now the site of the URI Graduate School of Oceanography.

Fort Wetherill, near the Dumplings Rocks on Conanicut Island along the East Passage, began as an unfinished fort in 1798. It was developed as a gun emplacement at the beginning of this century and was acquired by the state in 1972 for use as a park.

**The information describing the military installations on the Bay is taken from Parkman, 1978.*

Fort Church, on Sachuest Point, with Fort Greene, near Point Judith, was an emplacement for long-range, 16-inch guns, which virtually eliminated the need for other Bay fortifications at the beginning of World War II. It is now a federal wildlife refuge.

Navy Bases

Before World War II, the Navy occupied less than 500 acres on Aquidneck Island. By 1973, the Navy controlled 30.7 miles of shoreline and more than 6,000 acres of shorefront property, most of which was obtained during World War II. The Newport Navy Base, which included all operations along the East Passage from Newport Harbor to the Melville Depot, is today an important research, education, and training center, and was the home port of the United States Atlantic Fleet Cruiser-Destoyer Force. The Quonset Point Naval Air Station in the West Passage served as a base for aircraft carriers, and Davisville was a training and staging area for construction battalions. Throughout the 1960s and early 1970s, these bases contributed heavily to growth in the state population and economy. In 1971, about 51,000 persons were employed in Narragansett Bay naval operations, including more than 10,000 civilians, with a total payroll of $318 million.

The Naval Air Station at Quonset Point in 1960. *From the Providence Public Library, Rhode Island Collection.*

Major Navy Installations

Goat Island was acquired soon after the Civil War and was the first permanent Navy installation on the Bay. It was an experimental station for developing torpedoes. The city of Newport purchased the island and undertook a major redevelopment project in the mid-sixties.

Gould Island was obtained in 1919 and was used to expand the operations at Goat Island during World War II. During that war, it became the single largest manufacturing operation in the state, employing 13,000 people to fabricate torpedoes.

Coaster's Harbor Island was the original site of the Naval War College, which opened in 1884. It is presently the location of the Naval Education Training Command, which includes the Officer Candidate School, the Naval War College, and several other operations.

Melville Basin was used in the 1890s as a coaling station for Navy ships. It became an important petroleum depot during World War II.

Coddington Cove, a deep, well-sheltered harbor, was used during World War II as a supply base and as the home port of the Atlantic Cruiser-Destroyer Force until 1973.

South Prudence Island was used during World War II as an ammunition storage depot. The 625-acre site abuts on deep water in the East Passage, and numerous uses have been proposed for the property in recent years, including bulk oil storage and a receiving terminal for liquefied natural gas. It now appears that it will be a focal point for the Bay Islands Park.

Hope Island, east of Quonset Point, was also used for munitions storage. It was acquired by the state in the early 1970s and is now a wildlife management area.

Quonset Point was developed as a naval air station in 1939 for pilot training, ship and aircraft maintenance, and coastal defense. About half of the 650-acre airfield was constructed on dredge spoils and fill. Another 200 acres adjacent to the carrier pier were used in the repair and overhauling of aircraft and ships. The aircraft carriers *Wasp* and *Intrepid* used Quonset as their home port until 1972. The Quonset Point Naval Air Station operated at full capacity for nearly 35 years, and was taken over by General Dynamics as a submarine fabrication plant in 1973.

Davisville was developed in 1942, when Quonset Point could no longer handle the staging operations for overseas base construction. As the building of advance bases became more sophisticated, the Navy created the Construction Battalions (Sea Bees), who were trained at nearby Camp Endicott. Davisville was used by the Sea Bees as the principal staging area during the Korean and Vietnam Wars.

Fort Burnside, on Beavertail, at the southern tip of Conanicut Island, served as a marine communications base during and following World War II.

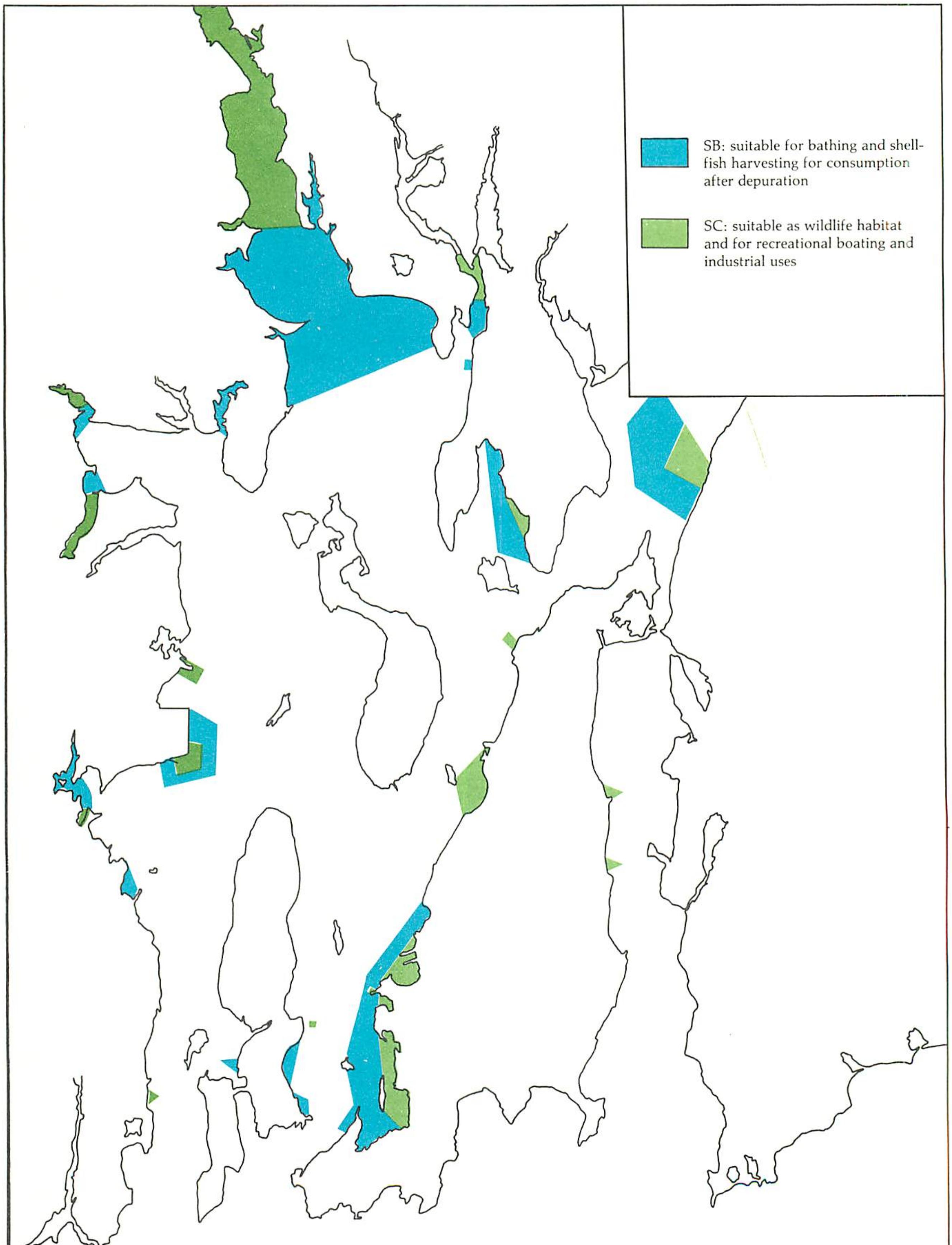
The 1973 Navy Pullout

The Navy announced a sudden and massive reduction of its Narragansett Bay operations in April 1973. Operations at the Quonset Point Naval Air Rework Facility were terminated, and activities at the Newport Naval Base and at Davisville were sharply curtailed. Most of these reductions had been carried out by 1974. Newport remains an important education, training, and research center, but it no longer serves as the home port of the Atlantic Fleet Cruiser-Destroyer Force. Portions of Davisville have been retained as a reserve base, but most of the property, a total of more than 3,000 acres, was declared surplus. This drastic action, combined with the nationwide economic recession of 1975, helped to sharply increase the Rhode Island unemployment rate from 6.3 percent of the work force in 1973 to 7.3 percent in 1974 and 13.9 percent in 1975. The reduction of Navy operations contributed to the net loss in population which the state has recently experienced. The most noticeable population declines are in Middletown and North Kingstown, which were the host communities for the major Navy bases. Rhode Island was faced with a difficult predicament in 1973. The state had lost an important employer and purchaser, and no substitutes were in sight. However, the Navy was leaving behind, at Quonset Point and Davisville, one of the best industrial port facilities on the East Coast. The Navy's occupation of several Bay islands and substantial pieces of shorefront property preserved many miles of Bay coastline from the rampant suburban development which took place after World War II. The pullout therefore presented the state with a unique set of industrial development and recreational opportunities. The process of transferring surplus property to this state and private users was slow and difficult, but it was virtually complete by 1979.

Much of the surplus Navy land has substantiated potential for commercial and industrial use. The Rhode Island Port Authority and Economic Development Corporation was created in 1974 to oversee the redevelopment of ex-Navy holdings. Until transfers of the land were completed, the Port Authority had power to lease buildings and land. The Quonset Point Naval Air Station has become a general aviation airport operated by the state. A large portion of the Naval Air Rework Facility was quickly occupied by the Electric Boat Division of General Dynamics, employing about 5,000 people in the fabrication of submarine components, which are barged to Groton, Connecticut. State plans include upgrading services to support a variety of commercial and industrial firms. Land and piers at Davisville are being used by vessels that service oil-drilling rigs in the mid-Atlantic. Davisville is envisioned by the state as a permanent offshore oil-drilling service base if a significant find of oil or gas is found on Georges Bank off Cape Cod and/or the Baltimore Canyon off the coast of Maryland and New Jersey.

In Newport, the Melville boat basin has been leased and developed as a large and highly successful marina. The Melville fuel pier is being considered as a new fishing port. Portions of the piers at Coddington Cove are being converted to use for shipbuilding and repair, and a portion has been retained for use by the Navy. A mixture of industrial, residential, and recreational uses has been suggested for the various surplus properties, as well as the use of Burma Road along the East Passage as a new highway corridor.

Figure 39. Water quality classifications, 1979. Tidal waters that are not shaded are SA. *From R.I. Dept. of Environmental Management.*



Chapter 14

The Pollution of Bay Waters

The explosive growth in the population of people around Narragansett Bay during the past two centuries has changed the Bay ecosystem. It is not obvious, however, just how significant an impact these changes have had. A great many people are extremely concerned about the pollution of the Bay, but when one digs into the nature and significance of the pollution problem, the firm conclusions that can be drawn become dissatisfyingly few. Perhaps the major reason for this is that pollution is, by definition, a value judgment. Webster's defines "pollute" as "to make unclean, impure or corrupt; defile, dirty." Environmental pollution, therefore, comes down to what is considered "too much" of something that has been added to an environment by man. The various forms of pollution that we perceive in and around the Bay all can be linked to the large number of people that now live around the Bay and use its waters for, among other things, a principal dump for their wastes.

Pollutants fall into various categories. Nutrients such as nitrogen and phosphorus which are essential for the growth of plants are considered pollutants when they cause "too much" growth. Another important, and closely related, pollutant in aquatic environments is organic matter. Bacteria feed on organic matter and reduce it to its chemical components, and in so doing they consume oxygen. The results of "too much" organic matter and/or "too much" nitrogen and phosphorus are the same — too much demand for oxygen. Thus, the classic characteristic of organically polluted waters (eutrophic waters), either fresh or salt, is the presence of large populations of simple plants that suffocate and die when oxygen levels become too low. An environment containing too little oxygen to support plants is termed "anoxic." The principal organisms that can survive in such environments are bacteria that can feed on organic matter without free oxygen. Their waste product is not the carbon dioxide produced by oxygen-requiring bacteria and plants but hydrogen sulfide, which smells like rotten eggs. Hydrogen sulfide is the classic "stench of polluted waters." This was the smell that made people faint when they crossed the Providence River in the 1850s. The upper river periodically turns anoxic now, usually during prolonged periods of hot weather, and the smell is then all too prevalent.

Another category of pollutants is the bacteria and viruses that may exist in water and, if ingested by man, cause disease. An example is the virus that causes hepatitis. This may be transmitted from infected people through sewage by way of shellfish if they are eaten raw. It is not practically possible to monitor such disease-causing viruses and bacteria directly. Instead, we monitor coliform bacteria, which, although harmless in themselves, can be related to the amount of fecies from warm-blooded animals that are present in the water. When coliform levels in the water exceed levels set by the Food and Drug Administration, the water is classified as polluted, and shellfishing is prohibited.

A third category of pollutants are the nonliving substances that may become poisonous to living things independent of oxygen levels. Here again the crucial question is: When does such a substance attain a sufficient concentration to be labeled as "too high"? Naturally occurring metals such as mercury, cadmium, copper, and lead can all be toxic if present in high concentrations. Some organisms naturally concentrate metals or other substances, and the naturally occurring, or ambient, levels of these substances also vary from one environment to another. These are important considerations when deciding the level of concentration at which a substance becomes a pollutant. Among the most worrying toxins are long-lasting man-made chemical compounds such as DDT and PCBs.

All of this merely illustrates that the term "pollutant" is not easy to define. Matters get more complicated when we attempt to assess the significance of various pollutants we measure in the environment. Once we have found that the organic matter or cadmium in some part of the Bay is higher than it would be if the Bay were in pristine condition, the "So what?" question is frequently difficult to answer. We know the levels at which various substances cause some species of animals to die under controlled laboratory conditions. But we know almost nothing about how various substances cycle through an ecosystem. The ultimate impact of higher-than-ambient but less-than-lethal levels of individual substances in nature is only now beginning to be studied; sublethal effects can take an infinite variety of manifestations. The Environmental Protection Agency and other regulatory agencies have, in the absence of other information, set numerical standards for "acceptable levels" of many substances. However, the criteria by which such standards have been set are in most cases based upon laboratory experiments on single organisms and not on the measured effects of the substance on organisms in their environment.

How Polluted Is the Bay?

According to present pollution standards and available data on various pollutants, most of the Bay is not polluted. The Department of Health, using levels of coliform bacteria as its primary criterion, classifies 80 percent of the Bay as SA and open to shellfishing. An additional 12 percent is SB and suitable for swimming. Polluted waters are concentrated in the upper Bay, and here, by all accepted standards, the pollution problem is indeed severe.

A major reason for the polluted condition of the upper Bay is that the Providence sewage treatment plant at Fields Point is woefully out-of-date and suffering from many years of neglect. In 1979, it broke down completely. Twelve sewage treatment plants discharged 126 million gallons of effluent into Narragansett Bay in 1977, but half of this discharge came out of the Providence plant (1). The problem would be relatively simple to solve if the pollution was due only to a broken-down treatment plant, but this is only one aspect of the problem. The sewers in Providence, East Providence, Pawtucket, and Central Falls are among the oldest in the nation, and they do not separate sewage from rainwater and the many small streams that have been piped into a single wastewater system. The result of such a "combined sewer" system is that the volume of effluent increases dramatically when it rains or thaws. The system is designed so that the runoff water and sewage which is in excess of the volumes that can be handled by the sewage treatment plants will flow directly into the Bay through 95 combined sewer overflows. Many overflows discharge into the Providence River every time there is a rainstorm.

The volumes of effluent that flow every day into the Bay from sewage treatment plants is approximately one-third as great as the daily flow from rivers. The discharge from all the overflows is not routinely monitored, but the amount of pollution delivered to the Bay may be greater than that contained in the treated effluent from the sewage treatment plants.

Another major source of pollution does not flow from rivers, sewer overflows, or treatment plant discharge pipes. This is the "nonpoint" flow, which enters the Bay as runoff from the land. It is extremely difficult to estimate the amount of water that enters the Bay in this manner or its pollution load, but it is believed to be very significant.

Why do we worry about the effluents that flow into the Bay from municipal sewage treatment plants? After all, it is by definition "treated." The problem is that sewage treatment plants are designed primarily to kill off disease-carrying bacteria and viruses and to remove a large proportion of the organic matter from the sewer water. However, municipal treatment plants also receive effluents from factories, and the plants are not designed to remove metals, petroleum, and the various other chemical exotics that end up in sewer water in considerable amounts. The more modern plants are much more efficient at cleaning the sewage they treat, but an old plant like the one at Fields Point, even when it is working, dumps large volumes of many pollutants into the Providence River.

The sewage treatment plant effluents, intermittent sewer overflows, the waters from polluted rivers, and an unknown amount of polluted water from nonpoint sources flowing together into the Providence River make this area the major source of all pollutants to the entire Bay.* Gradients can be measured for all major pollutants, and they begin at their highest levels in the Providence River and are traced down Bay to the Sound, where levels are lowest. These gradients are seen both in the water and in the sediments for nutrients, organics, coliform bacteria, petroleum, and many metals. In most cases, the highest pollution levels are found just below the outfall of the treatment plant.

The Major Pollutants

Organic Matter. In 1977, an estimated 13,000 tons of organic matter were dumped into the Bay by sewage treatment plants. About half came from the Fields Point plant. The addition of organic matter to the upper Bay from nonpoint sources is believed to be im-

**The information on pollutants in the Bay is taken from Olsen and Lee, 1978.*

portant, but there are no reliable estimates for how great this input is. The results of organic loading in the Providence River are all too apparent. Oxygen levels are low and anoxic conditions occasionally exist. The modern Buckland Point municipal plant, however, is probably responsible for a recent decline in the amount of organic matter discharged to the Seekonk River. Evidence for this is a reappearance of mussels where almost no visible marine life had been seen for many years.

Nutrients. The organic matter that flows into the Bay contains large amounts of nitrogen and phosphorus. Nitrogen appears to be the crucial limiting nutrient that

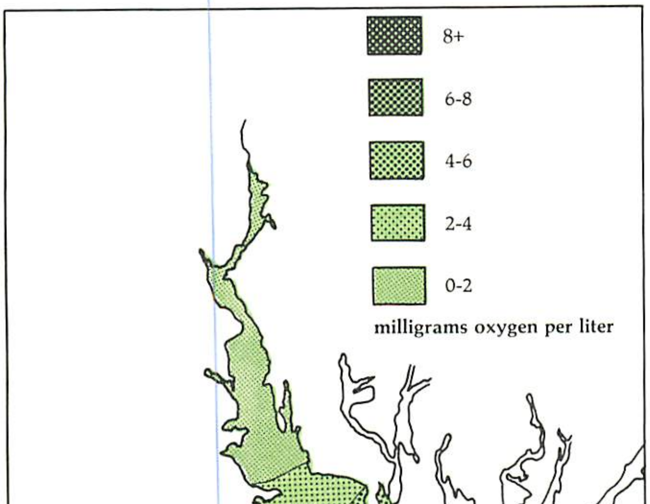


Figure 40. Dissolved oxygen near the bottom. *Drafted from data published in* Bay Watch, *URI, 1972.*

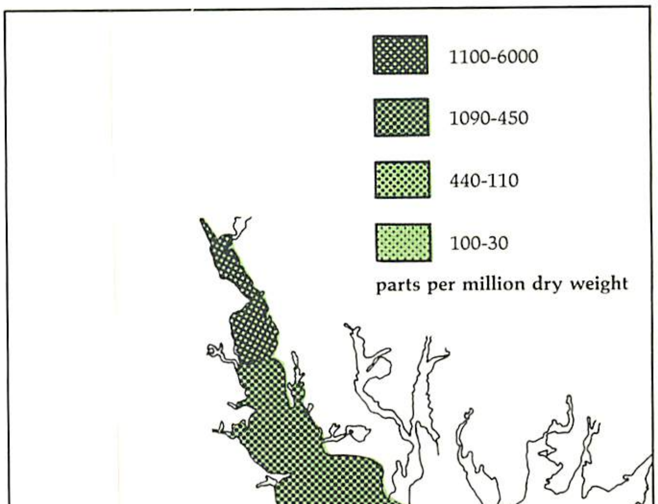


Figure 41. Petroleum hydrocarbons in Bay sediments. *Drafted from data compiled by VanVleet and Quinn, 1978.*

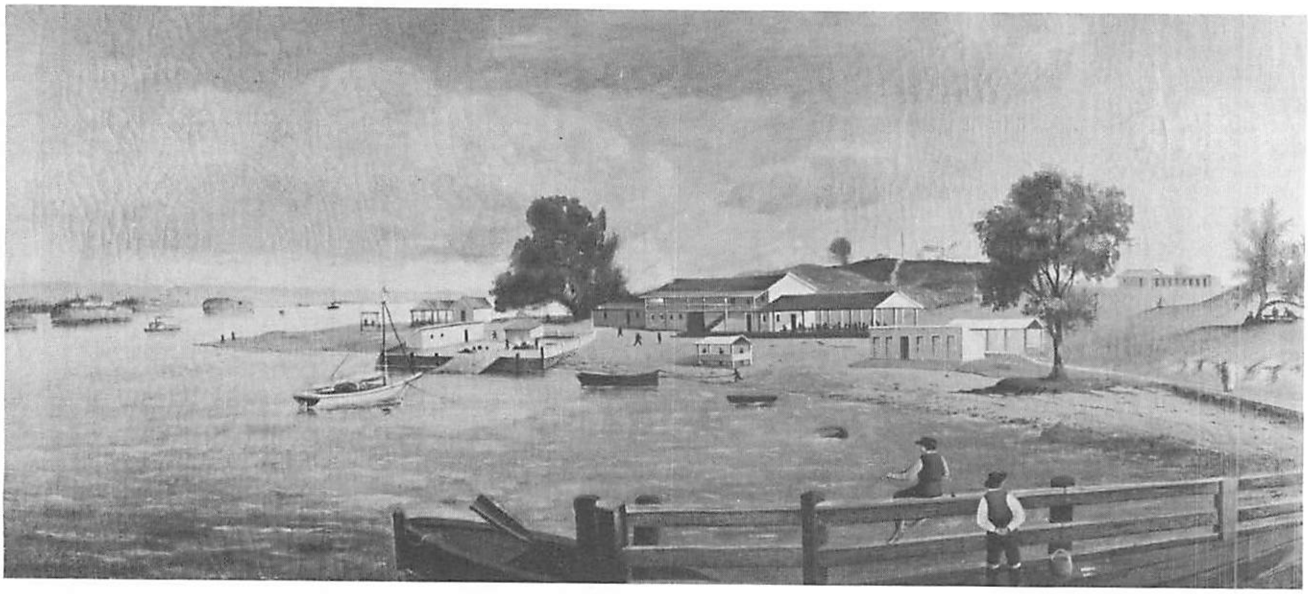
regulates phytoplankton abundance in the Bay during the summer. Similar amounts of both nitrogen and phosphorus are contained in sewage treatment plant effluents, as in the waters that flow from rivers into the Bay. The addition of these volumes of the two major nutrients are clearly important, and doubtless have an important impact on the phytoplankton of the upper Bay, if not the entire Bay ecosystem.

Coliform Bacteria. Because of levels of coliforms in surface waters above Conimicut and Nayatt Points, the Department of Health permanently closed the Providence River to shellfishing. An additional, conditional area that extends down to the north end of Prudence Island is closed to shellfishing after half an inch of rain or more in Providence. Areas adjacent to any treatment plant outfall or marina are also declared off-limits to shellfishing, whether or not coliform levels exceed the prescribed limits for SA waters.

Petroleum Hydrocarbons. The effluents from the Fields Point treatment plant have been found to contain high levels of petroleum. The few data on petroleum in the effluents from other plants suggest that it is reasonable to estimate that they contain half as much petroleum as Fields Point effluents. If this estimate is correct, then some 200 tons of petroleum are discharged into the Bay each year by sewage treatment plants. This is more than twice the oil that is spilled in the Bay during an average year. Very high concentrations of petroleum are found in bottom sediments near the Fields Point outfall (5,400 to 5,700 parts per million), and the gradient declines to 500 ppm in other parts of the Providence River, to 50 ppm at the mouth of the Bay. Petroleum has also been found in Bay quahogs. Petroleum is known to be toxic to some organisms at very low concentrations, but it is very difficult to assess the impact of these inputs on the Bay ecosystem.

Metals. The following table provides estimates of the annual input of various metals to the Bay from routinely monitored municipal and industrial treatment plants:

Metal	*Kg per year*	*Pounds per year*
Cadmium	1,430	3,146
Lead	1,470	3,234
Mercury	120	264
Copper	10,800	23,760
Chromium	18,600	40,920
Zinc	162,400	357,280
Nickel	98,900	217,580



Fields Point, site of the present Providence municipal sewage treatment plant, around 1880. *From the Rhode Island Historical Society.*

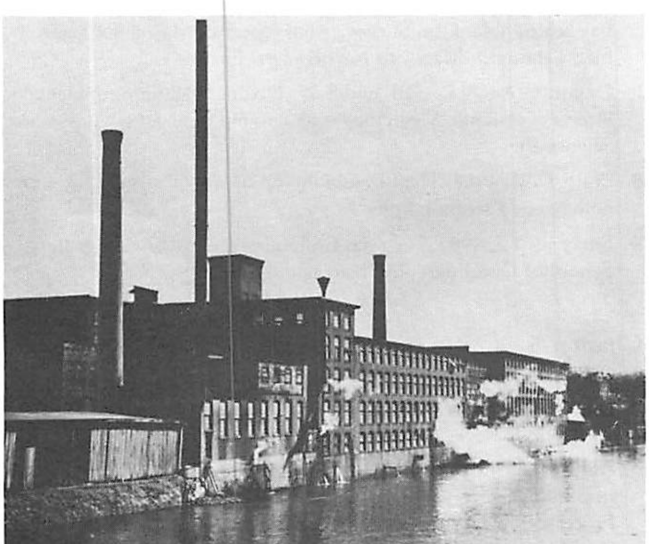
Industrial treatment plant effluents contribute only one percent or less of the flow of any one of these metals into the Bay. The input from municipal treatment plants is probably so high because much of the Providence jewelry industry operates in small shops that dump their wastes into the sewers without pretreatment. The concentration of metals in Bay sediments, with minor exceptions in some locations for copper and chromium, fall well below the "alert levels" set by the federal Food and Drug Administration. Concentrations at "alert levels" are not presumed to be dangerous but are designed to warn of potential problems if the trend continues.

Pesticides and Other Man-made Compounds. There are very few data on the levels of pesticides and other toxic chemical compounds in the Bay environment. PCBs (polychlorinated biphenyls), which are used in manufacturing storage batteries and are highly toxic and long-lasting, are present, but apparently in small amounts. Pesticides also do not appear to be present in significant amounts.

It is obvious that the burgeoning population of people in the Bay's watershed is causing pollutants to mix with the Bay's waters and build up in the sediments. In some places, most obviously in the upper Providence River, the Bay is clearly polluted and the ecosystem is badly degraded. The fact that all forms of pollution can be traced as gradients from the Providence River to the Sound is worrying, particularly since the pollutants that accumulate in the sediments degrade slowly, if at all. Water pollution in the upper Bay, besides causing a severe aesthetic problem, has caused the Bay's most productive shellfish beds to be placed off-limits to fishermen. The gross pollution of sediments in the Port of Providence, Pawtucket Cove, and elsewhere have made finding a site for the disposal of spoils from desperately needed dredging projects a seemingly impossible task. The price for this pollution, in terms of fisheries and port activity alone, has therefore already been high.

We must hope that in the future money will be found to rebuild the Fields Point treatment plant and solve the problem of the sewer overflows. We can certainly reduce the amount of organic matter and nutrients that presently flow into the Providence River, and this would probably have a major effect on the plant and animal life. Better pretreatment of industrial wastes may cut back on the inflow of metals and chemicals. A crankcase oil recycling program could make a big difference in the amount of petroleum that is presently finding its way into sewers. Major improvements can therefore be made, but the defiling of our environment will never cease completely because the great number of people living around the Bay must dispose of large volumes of waste. Unfortunately, disposal of wastes on the land, in the ocean, or in the air present as many and, in some cases, more problems than disposal in the Bay.

One of the great values of the Bay to our society has been, and continues to be, its wonderful ability to dilute and assimilate wastes. How much waste is too much and what are the alternatives? These questions will always be open to debate.



The Paramount Printing and Finishing Company in Pawtucket.
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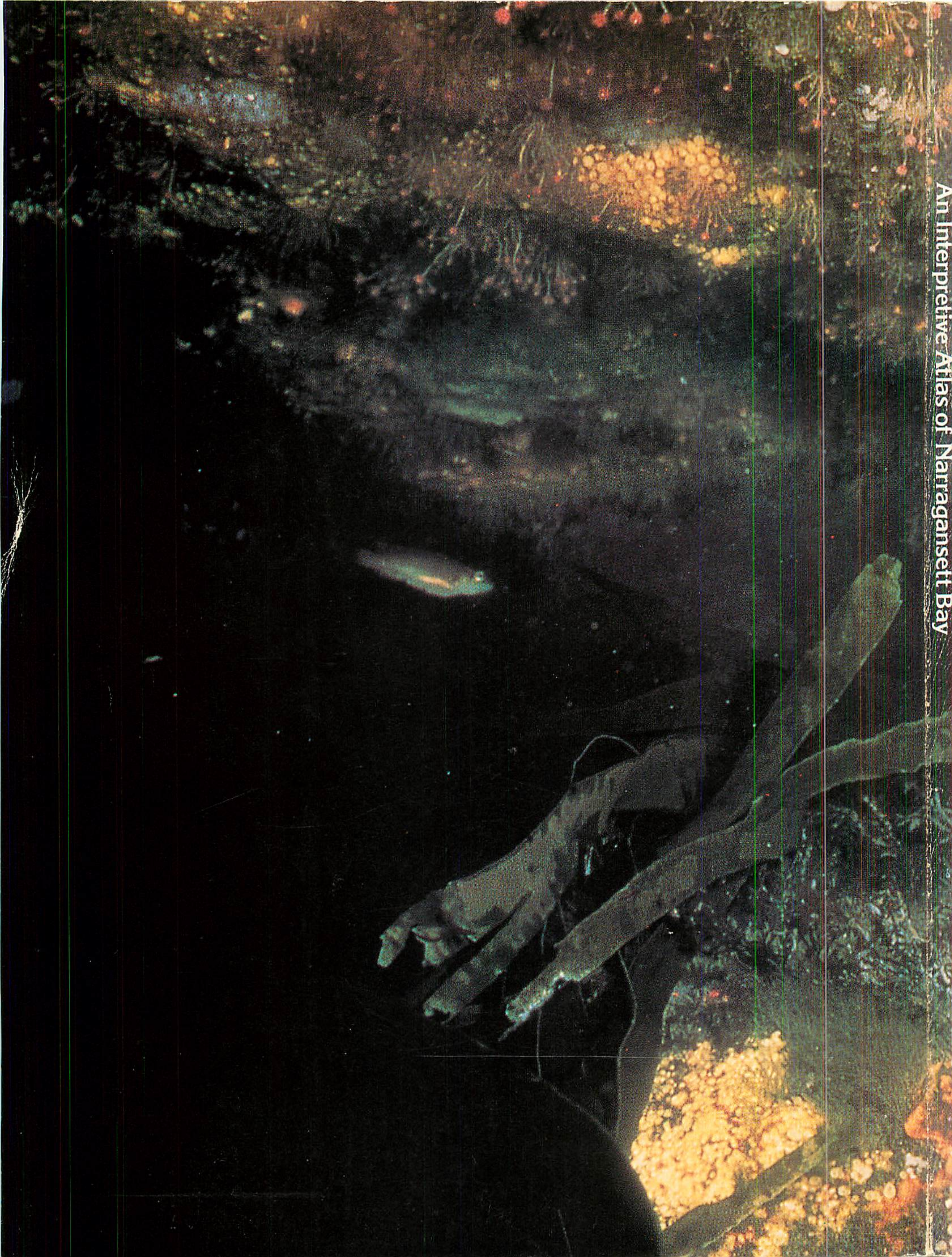
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