



An Ecological Profile of the Narragansett Bay National Estuarine Research Reserve

*Edited by Kenneth B. Raposa
and Malia L. Schwartz*





Acknowledgements

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Credits

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Additional copies of this publication are available on CD from the Narragansett Bay National Estuarine Research Reserve, P.O. Box 151, Prudence Island, RI 02872, or may be downloaded at www.nbnerr.org.

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Preface

The National Estuarine Research Reserve (NERR) System is composed of 27 reserves in multiple biogeographic regions along the coastal United States that are dedicated to providing natural sites for conducting research and monitoring to address important coastal management issues. The NERR System incorporates research and monitoring data from these projects into education and coastal training programs to improve coastal management, stewardship, and public awareness. The Narragansett Bay National Estuarine Research Reserve (NBNERR or Reserve) is one of these sites. It is located in the state of Rhode Island and administered by the R.I. Department of Environmental Management in partnership with the Audubon Society of Rhode Island.

As part of the NERR national long-term monitoring program, a comprehensive ecological overview, officially known as the Site Profile, is required for each site. The NBNERR Site Profile, which is presented here, compiles and summarizes relevant literature and data pertaining to the terrestrial, freshwater, and estuarine ecosystems in and around the Reserve in one comprehensive document. It also provides background on the role and history of the NERR System, discusses the chronology, organization, and infrastructure of the NBNERR, and summarizes the human and cultural history of the Reserve. The latter was considered an essential component of this document since it would be difficult to fully understand the ecology of the NBNERR without also knowing the history of human impacts that have previously affected it.

This Site Profile is organized into four sections: an introduction to the NERR and NBNERR, an overview of the ecology of terrestrial and freshwater systems, an overview of the ecology of estuarine systems, and a summary of research and monitoring in the NBNERR. Chapters in the terrestrial section deal with the terrestrial and freshwater habitats found on Prudence, Patience, Hope, and Dyer islands, which are the islands that comprise the Reserve. Even though the Reserve only contains approximately 1,840 acres of Bay waters around these islands, chapters in the estuarine section cover all of Narragansett Bay. This approach was taken to promote a full understanding of the ecology of the estuary, which would not be possible when only

considering the waters that fall within the arbitrary 18-foot depth contour that defines the estuarine extent of the Reserve. A true overview and understanding of the physical, chemical, and biological process at work in the Reserve and Narragansett Bay can only be attained from a Bay-wide perspective.

This document was developed with the goal of providing a valuable resource for anyone interested in working in the NBNERR, including students, researchers, government agencies, coastal managers and decision makers, educators, and the general public. However, it contains information on Narragansett Bay and on estuarine and coastal ecology that may be of interest to a wider audience. The intent of the profile is to provide a general, yet thorough, overview of the ecology of the Reserve and Narragansett Bay, while also providing relevant literature sources for those readers who are interested in pursuing subjects in more detail. Additional information on any topic covered in the Site Profile is also available by contacting the Reserve staff directly (visit www.nbnerr.org for contact information).



visit www.nbnerr.org





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Individual reserves are jointly managed through a federal-state partnership.





CHAPTER 1.

The National Estuarine Research Reserve System

Kenneth B. Raposa



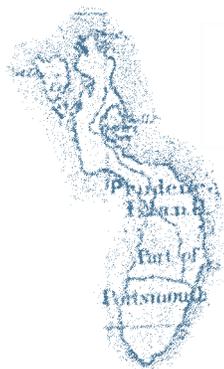


Figure 1.1. The National Estuarine Research Reserve System, including both current and proposed reserves. Shaded states are those that support at least one current or proposed NERR site.

Table 1.1. Selected characteristics of individual NERR sites. The Chesapeake Bay, Md., and North Carolina reserves have multiple units that were designated in different years.

Reserve Name	State	Year Designated	Acres	Biogeographic Region
South Slough	Oregon	1974	4,779	Columbian
Sapelo Island	Georgia	1976	6,110	Carolinian
Rookery Bay	Florida	1978	110,000	West Indian
Apalachicola	Florida	1979	246,000	Louisianian
Elkhorn Slough	California	1979	1,400	Californian
Padilla Bay	Washington	1980	11,000	Columbian
Narragansett Bay	Rhode Island	1980	4,259	Virginian
Old Woman Creek	Ohio	1980	571	Great Lakes
Jobos Bay	Puerto Rico	1981	2,883	West Indian
Tijuana River	California	1982	2,513	Californian
Hudson River	New York	1982	4,838	Virginian
Wells	Maine	1984	1,600	Acadian
Chesapeake Bay	Maryland	1985, 1990	4,820	Virginian
North Carolina	North Carolina	1985, 1991	10,000	Carolinian
Weeks Bay	Alabama	1986	6,016	Louisianian
Waquoit Bay	Massachusetts	1988	2,600	Acadian
Great Bay	New Hampshire	1989	5,280	Acadian
Chesapeake Bay	Virginia	1991	4,435	Virginian
ACE Basin	South Carolina	1992	134,710	Carolinian
North Inlet-Winyah Bay	South Carolina	1992	12,327	Carolinian
Delaware Bay	Delaware	1993	4,930	Virginian
Jacques Cousteau	New Jersey	1998	114,665	Virginian
GTM	Florida	1999	55,000	Carolinian
Kachemak Bay	Alaska	1999	365,000	Fjord
Grand Bay	Mississippi	1999	18,400	Louisianian
San Francisco Bay	California	2003	3,710	Californian
Mission-Aransas	Texas	2006	185,708	Louisianian



The National Estuarine Research Reserve System

In recognition of the importance of the nation's coastal resources, Congress passed into law the Coastal Zone Management Act (CZMA) in 1972. Section 315 of the CZMA authorizes the establishment of the National Estuarine Research Reserve (NERR) System for the purpose of identifying and protecting estuarine habitats in the United States in order to promote estuarine research, monitoring, education, and stewardship. More specifically, the mission of the NERR System as stated in the CZMA is “the establishment and management, through federal-state cooperation, of a national system (National Estuarine Research Reserve System or System) of estuarine research reserves (National Estuarine Research Reserves or Reserves) representative of the various regions and estuarine types in the United States. National Estuarine Research Reserves are established to provide opportunities for long-term research, education, and interpretation.”

As outlined in the CZMA, the specific goals of the NERR System are to:

- Ensure a stable environment for research through long-term protection of NERR resources
- Address coastal management issues identified as significant through coordinated estuarine research within the System
- Enhance public awareness and understanding of estuarine areas and provide suitable opportunities for public education and interpretation
- Promote federal, state, public, and private use of one or more reserves within the System when such entities conduct estuarine research
- Conduct and coordinate estuarine research within the System, gathering and making available information necessary for improved understanding and management of estuarine areas

Current guidance for the NERR System is outlined in the 2003–2008 strategic plan, which also provides a concise version of the mission statement with an accompanying set of strategic goals. According to the strategic plan, the mission of the NERR System is “to promote stewardship of the nation's estuaries through science and education using a system of protected areas.” The current strategic goals are to:

- Improve coastal decision making by generating and transferring knowledge about coastal ecosystems
- Enhance and expand the NERR System
- Increase awareness, use, and support of the reserve system and its estuarine science, education, and stewardship programs

Individual reserves are jointly managed through a federal-state partnership. The federal partner for each reserve is the Estuarine Reserves Division (ERD) of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA). State partners vary by reserve, but include state environmental agencies, universities, and trusts. Funding for each reserve is derived from both federal (70 percent) and state/local (30 percent) sources. This collaboration of state and federal agencies, through the support and management of reserves, ensures that research and monitoring at individual reserves addresses relevant coastal issues at local, regional, and federal levels.

Reserves are designated using a standardized selection process and specific criteria. Priority is given to new reserves that incorporate both a biogeographic subregion and an estuary type not represented by existing reserves. Secondary priority is given to reserves that will fulfill one or more of the above criteria. New reserves are only designated if funds and essential staff and infrastructure are in place to support the operation of the new reserve after designation is complete. Currently, reserves are located in nine of the 11 bioregions in the United States. Additional information on the reserve designation process and on biogeographic subregions can be found at: nerrs.noaa.gov/Background_Bioregions.html.

As of 2008, the system was composed of 27 reserves in 21 states and one territory, including one reserve in Alaska and one in Puerto Rico (Fig. 1.1; Table 1.1). Additional reserves are proposed for designation in Connecticut, Wisconsin, and on the Saint Lawrence River, N.Y. The current system protects approximately 1,323,554 acres of land and water as NERRs to foster estuarine research and monitoring, education, and stewardship.



A significant effort is made to focus individual reserves on regional and national issues that might only be addressed through a coordinated national effort, which is made possible within the NERR framework. Three current programs illustrate this national coordination: the System-Wide Monitoring Program (SWMP), the Graduate Research Fellowship (GRF) Program, and the Coastal Training Program (CTP). In addition, all reserves support an active site-specific research program in order to address topics and issues that are directly relevant to each particular reserve and estuary. Specifics on each of the nationally coordinated programs are provided below, and more detailed information on all NERR programs and on the NERR program in general can be found at www.nerrs.noaa.gov.

The SWMP was established in 1995 as a nationally coordinated effort to monitor water quality conditions at multiple locations in each reserve. More specifically, the goal of the SWMP is to track short-term variability and long-term changes in estuaries and coastal habitats to understand the effects of anthropogenic and natural stressors on ecosystems. SWMP is a combination of three stand-alone but interrelated efforts to conduct: 1) abiotic monitoring of estuarine parameters; 2) biological monitoring; and 3) assessments and mapping of land use and habitat change over time in reserves. Abiotic monitoring includes water quality parameters (e.g., temperature, salinity, and dissolved oxygen), meteorological conditions, and estuarine nutrients and chlorophyll. All data are collected at regular intervals throughout the year, submitted to a designated data management office, and analyzed periodically to identify regional and national trends. Currently, each reserve is required to support at least four water quality monitoring stations, and at least one weather station. In addition, at least one water quality station and one weather station at each site is now equipped to deliver near real-time monitoring data to the Internet.

The GRF program provides funds to qualified master's and doctoral students to conduct research projects in reserves that will help address local, regional, or national management issues. All GRF projects must have study locations within a designated reserve, thus providing the student with an opportunity to work in a living research laboratory. GRF projects are selected to address scientific issues at the local, regional, and national level to ensure that they contribute information to reserve managers and other coastal decision-makers. Up to two students at each reserve are selected for funding through the GRF program each year. Funding is for up to \$20,000 for up to three consecutive years, and can be used for tuition, cost of living, or research supplies.

The CTP provides up-to-date scientific information and skill-building opportunities to coastal decision-makers so that they can make informed decisions on how to best preserve and protect the natural resources of estuaries and their watersheds. The CTP accomplishes this by partnering with various organizations and working closely with the other reserve programs to offer training and products to various audiences. The CTP also works to enhance the collaboration, coordination, and communication between training organizations, as well as facilitates networking and information exchange between coastal decision-makers both within and between communities. While CTP trainings and products offered to decision-makers are not singular or isolated events, ongoing technical assistance and science updates that supplement and support CTP trainings and products are continuously provided.

The National Estuarine Research Reserve System...identifying and protecting estuarine habitats in the United States in order to promote estuarine research, monitoring, education, and stewardship.



CHAPTER 2.

The Narragansett Bay National Estuarine Research Reserve

Kenneth B. Raposa



Figure 2.1. Entrance sign to the NBNERR at the T-wharf in the South Prudence Unit. *Photo from NBNERR photo library.*

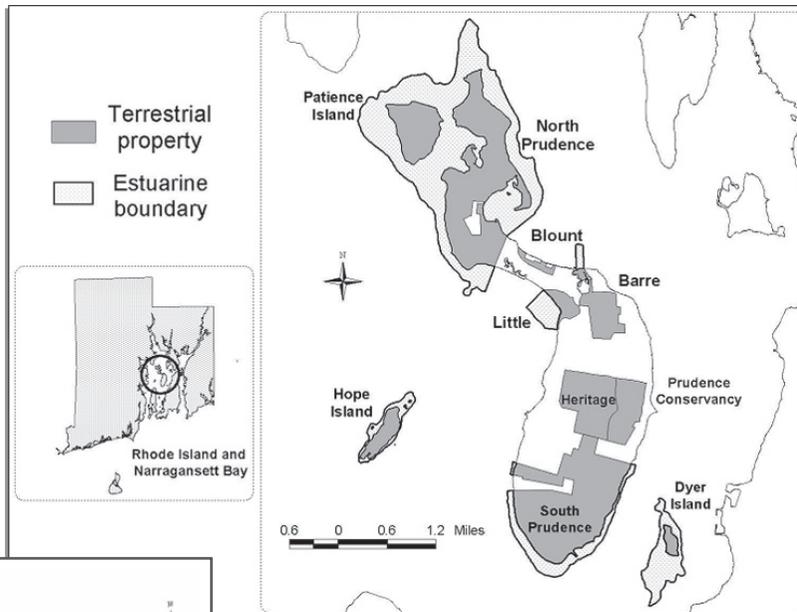


Figure 2.2. Estuarine boundary and terrestrial units of the NBNERR. GIS data sources courtesy of the Rhode Island Geographic Information System (RIGIS; www.edc.uri.edu/rigis/).

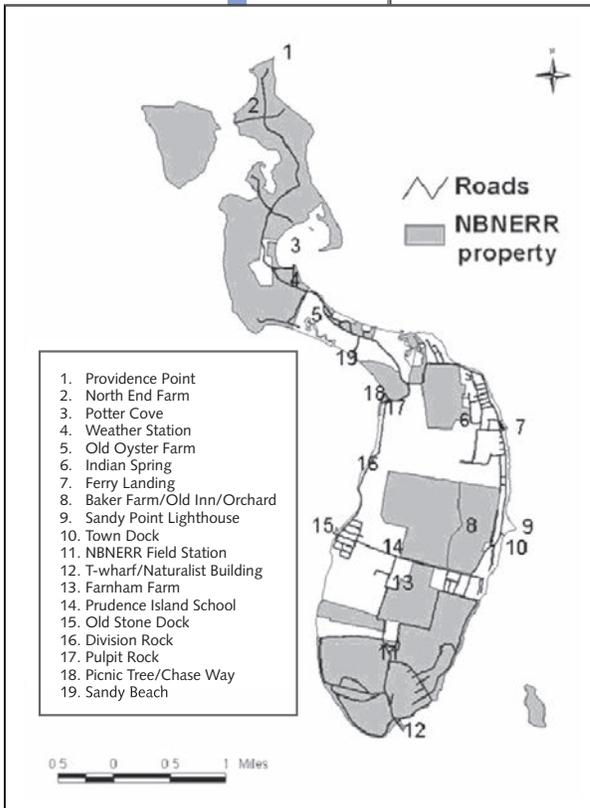


Figure 2.5. NBNERR facilities and other local points of interest on Prudence Island.



Figure 2.3. Aerial view of the T-wharf area on the South Prudence Unit of the NBNERR. Photo from NBNERR photo library.



Figure 2.4. Entrance sign to the Prudence Conservancy Unit of the NBNERR. The Prudence Conservancy owns the land in this unit and functions as one of the Reserve's primary partners. Photo from NBNERR photo library.

Table 2.1. Selected characteristics of units in the NBNERR. Year acquired reflects when the property was obtained, not necessarily the year it was incorporated into the Reserve.¹ Additional, smaller parcels were acquired in later years and merged with the North and South Prudence units.

Unit Name	Year Acquired	Acres (land only)	Owner
Blount	1974	23	State
Hope Island	1975	78	State
North Prudence	1978 ¹	749	State
South Prudence	1980 ¹	820	State
Patience Island	1980	214	State
Barre	1988	153	State
Little	1991	56	State
Heritage	1992	291	State
Prudence Conservancy	1992	167	Prudence Conservancy
Dyer Island	2002	36	State



The Narragansett Bay National Estuarine Research Reserve

The Narragansett Bay National Estuarine Research Reserve (NBNERR or Reserve) is composed of 10 property units on four islands that are located roughly in the center of Narragansett Bay, R.I. (Figs. 2.1, 2.2). Seven units are located on Prudence Island, including the South Prudence (Fig. 2.3) and North Prudence units, which are the two largest units in the Reserve. The full extent of the three other smaller islands, Patience Island, Hope Island, and Dyer Island, comprise the remaining three units (with the exception of one private inholding remaining on Patience Island) (Table 2.1). The NBNERR also bounds all estuarine waters surrounding coastal units out to a depth of 5.4 meters (18 feet), except for waters adjacent to the Blount Unit on central Prudence Island (Fig. 2.2). As of 2008, the NBNERR contained 2,586 acres of land and 1,809 acres of surrounding estuarine water, for a total of 4,395 jurisdictional acres.

The NBNERR was incorporated in 1980, becoming the seventh unit in the NERR System. At the time, the NBNERR was called the Narragansett Bay National Estuarine Sanctuary and was composed of only the North Prudence, Patience Island, and Hope Island units. Other units were incorporated into the Reserve as they were acquired in later years (Table 2.1). The most recent acquisition was Dyer Island, which was purchased in 2002 and will be incorporated into the Reserve after completion of its updated management plan. The R.I. Department of Environmental Management (RIDEM) owns most of the units, except for the Prudence Conservancy Unit, which is owned by the Prudence Conservancy (a local land trust).

All areas in the NBNERR are designated as either 'core' or 'buffer' area, and permitted uses in a given area are dependent on this designation. The NBNERR defines core areas as those "that are essential and representative of natural habitats in the biogeographic region in which the reserve is located. Recreation, habitat manipulation, and other disruptive uses are restricted in core areas"; likewise buffer areas are defined as "those areas that are set aside to further protect core areas. Low-impact recreation, habitat manipulation, and research are permitted in buffer areas" (Beck and Beck, 1998). Current core and buffer designations for Reserve areas can be found on the Reserve's website at: www.nbnerr.org.

The NBNERR operates under a hierarchical framework that includes an overall vision, mission, and a set of goals. The overarching vision of the NBNERR is to be a valued leader, partner, and resource in the long-term collection, synthesis, and dissemination of monitoring and research data for enhanced coastal management within Narragansett Bay and its watershed. Similarly, its mission is to preserve and protect representative estuarine habitats within Narragansett Bay and provide opportunities for long-term research, education, and training for

sound coastal stewardship. Finally, the goals of the Reserve are to:

- Strengthen the protection and management of representative estuarine ecosystems within Narragansett Bay to advance estuarine conservation, research, and education
- Increase the use of Reserve science and sites to address priority coastal management issues within Narragansett Bay and its watershed
- Enhance the ability and willingness for people to make informed decisions and take responsible actions that affect coastal communities and ecosystems

The NBNERR relies heavily on partnerships with other organizations to fulfill its mission and goals. As the Reserve's state partner, RIDEM provides support that is essential to the proper functioning of the NBNERR, including enforcement, administration, and maintenance of grounds, facilities, and vehicles. RIDEM enforcement in the Reserve is limited, as officers are not stationed on Prudence Island. However, when violations are reported, RIDEM Enforcement has the capability of reaching the Reserve via a small fleet of boats. Additional assistance comes from other partners, including the town of Portsmouth, R.I., in which the Reserve lies, the Prudence Conservancy (Fig. 2.4), the Audubon Society of Rhode Island (ASRI), and the University of Rhode Island (URI). Portsmouth employs a police officer on Prudence Island who can assist with law enforcement in the Reserve. URI and ASRI have cooperative agreements with the NBNERR. URI handles and processes all of the NBNERR nutrient and chlorophyll samples collected as part of its SWMP. ASRI assists with staffing, equipment, transportation, and other necessary infrastructure.

As with all NERRs, the NBNERR is staffed by three core positions: a reserve manager, research coordinator, and education coordinator. Additional full-time staff include a coastal training program coordinator, a natural resources/geographic information systems (GIS) specialist, and a marine research specialist. The Reserve is also able to augment its staff with part-time and seasonal summer employees hired through RIDEM or ASRI and with student interns from URI, Roger Williams University (RWU), or other local universities. All staff members are dedicated to carrying out the three main NERR functions of research and monitoring, education, and stewardship.

The NBNERR research and monitoring program emphasizes research conducted both by Reserve staff and by visiting scientists and students, and includes studies conducted in coastal upland and estuarine habitats. Currently, the NBNERR research priorities are:



- Species interactions and relationships to physical, chemical, economic, and social processes
- Changes in species and guild composition, including invasives, and interactions among species and the physical and chemical environment
- Habitat conservation, restoration, and biota use
- Data synthesis, hindcasting, and forecasting
- Monitoring, modeling, and prediction of coastal habitat and ecosystem processes
- Quantitatively examine and model the primary factors that affect fisheries, productivity, and water quality
- Coupling of Reserve ecosystem dynamics to estuarine and regional dynamics including responses to the effects of climate change

In addition, the current objectives of the NBNERR research program are to:

- Conduct and provide opportunities for original basic and applied research regarding coastal and estuarine systems
- Contribute to status and trends assessments and forecasting of environmental quality by tracking short-term variability and long-term changes in biotic and abiotiparameters at the Reserve and within the Narragansett Bay estuary
- Work to protect the ecological integrity of Narragansett Bay by encouraging and assisting in a multiagency approach to research, monitoring, and science-based ecosystem management
- Provide coastal resource managers, the scientific community, and general education practitioners with appropriate scientific and technical information that fosters research, education, stewardship, and informed decision making

The NBNERR research program relies heavily on collaborations with other local research partners to achieve its goals and objectives. For example, the Reserve collaborates with Save The Bay to conduct research on the ecological responses to salt marsh restorations in Narragansett Bay, and with the Atlantic Ecology Division of the U.S. Environmental Protection Agency (EPA) to study aspects of the ecology of wading birds in the Bay, including quantifying the effects of human disturbance on wading-bird foraging. Other research partners include RIDEM, RWU, the Narragansett Bay Estuary Program, and URI, among others. For more information on the NBNERR research program, visit www.nbnerr.org/research.htm.

Additional core programs at the NBNERR include the education, coastal training, and stewardship programs. The Reserve education program currently strives to cultivate an awareness and knowledge of the area's natural resources, on-going research projects, land stewardship practices, and the resources available to the public through recreation, education, and volunteer programs at the Reserve. The education program is also invested in developing and implementing the system-wide K-12 Estuary Education Program, and will

begin Teachers on the Estuary (TOTE) workshops in Rhode Island in 2009. The NBNERR CTP focuses on providing coastal decision-makers with scientific tools that are necessary for making informed management decisions. The primary target audiences of the CTP are municipal staff (including town planners and managers), municipal volunteers, designers and developers, landscape architects, engineers, and attorneys. The focus of the NBNERR Stewardship Program is on effectively managing the Reserve's land and water resources. Specific management issues include the protection of rare species and representative habitats, management of invasive species, and restoration of specific habitats. To carry out each of these functions, the NBNERR emphasizes integration and cooperation among staff members and collaborations with other organizations and partners.

To support its main functions, the NBNERR provides its staff and professional visitors with various facilities that include laboratory space and supplies, a library and conference room, a multi-parameter meteorological station, limited docking facilities, and free overnight housing (Figs. 2.5, 2.6). The Reserve's education center is located within the Reserve's headquarters, as are the staff offices. A small educational kiosk also operates at the T-wharf in the South Prudence Unit during the summer season. Patience, Hope, and Dyer islands are undeveloped and do not have any support facilities.

The Reserve's setting is predominantly natural or rural, in contrast to much of coastal mainland Rhode Island, which is generally heavily developed. Patience, Hope, and Dyer islands are completely uninhabited. Prudence remains mostly undeveloped, but supports small clusters of residential housing and other limited development. The year-round human population on Prudence Island is approximately 150 people, although this peaks to nearly 2,000 people at times during the summer. Prudence Island lacks many amenities, although one small year-round and one summer general store are available, as is an island post office. Transportation to the NBNERR is by private boat or by the Prudence Island auto and passenger ferry (Fig. 2.7), which makes multiple daily round-trips between Bristol, R.I., and Homestead on Prudence Island. All visitors to the Reserve are encouraged to provide their own ground transportation while on Prudence Island. For more information about any aspect of the Reserve, visit the NBNERR website at www.nbnerr.org.

Literature Cited

- Beck, A. and M. Beck. 1998. Narragansett Bay National Estuarine Research Reserve Revised Management Plan 1998. Prepared by RIDEM Narragansett Bay National Estuarine Research Reserve Program and NOAA Sanctuary and Reserves Division. Rhode Island Sea Grant, Narragansett, R.I. 145pp.



Figure 2.6. The overnight cottage can be used by visiting scientists and anyone else who is working for or at the Reserve. *Photo from NBNERR photo library.*



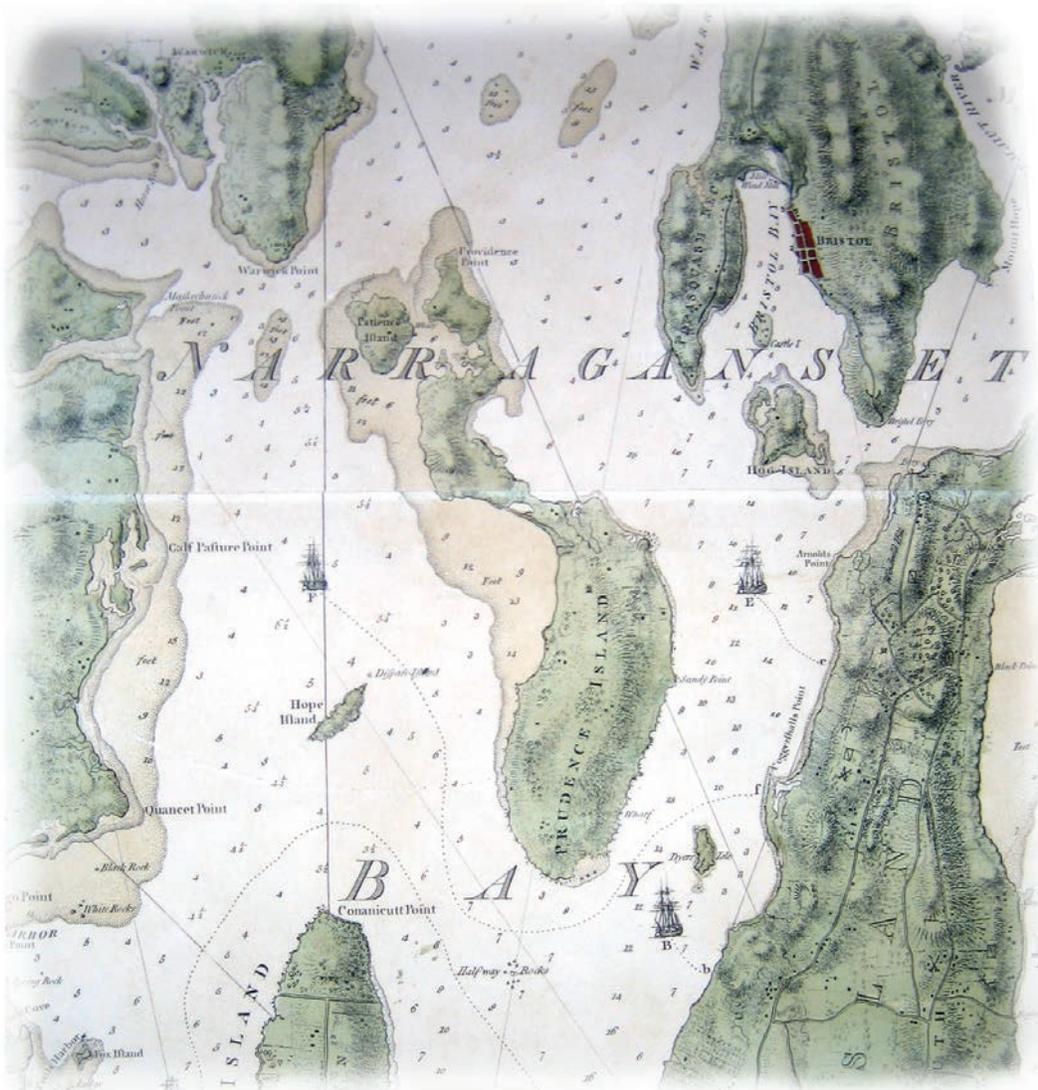
Figure 2.7. The Prudence Island Ferry transports people and vehicles between Prudence Island and Bristol, R.I. *Photo from NBNERR photo library.*



CHAPTER 3.

Human and Land-Use

*Joseph J. Bains and
Robin L.J. Weber*



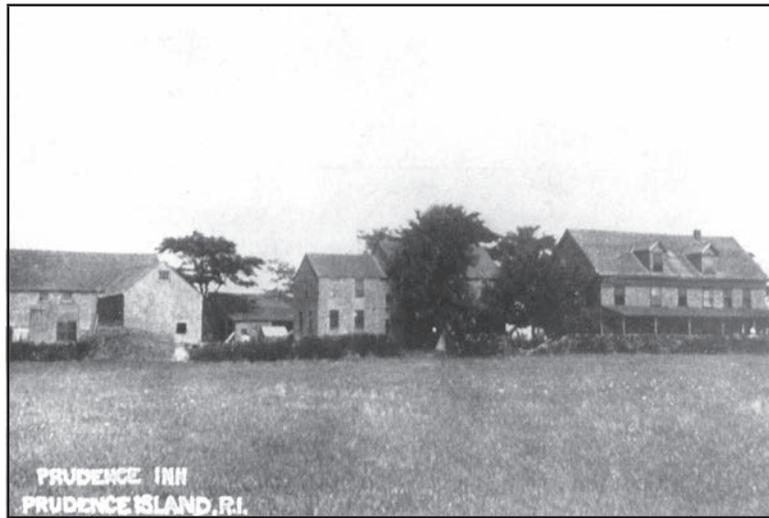


Figure 3.1. The Prudence Inn (built in 1894) contained more than 20 guestrooms. *Postcard reproduction.*





Human and Land-Use History of the NBNERR

Overview

Prudence Island has had a long history of predominantly seasonal use, with a human population that has fluctuated considerably due to changes in the political climate. The location of Prudence Island near the center of Narragansett Bay, although considered isolated and relatively inaccessible by today's standards, made the island a highly desirable central location during periods when water travel was prevalent.

The land-use practices on Prudence Island are generally consistent with land-use practices throughout New England from prehistoric periods through the present. This region was extensively forested prior to European settlement, and the forest was believed to be highly dynamic due to the influence of natural disturbance, changing climate conditions, and the activities of American Indians (Foster and Motzkin, 1998). The use of fire to remove understory vegetation, a common practice of the Indians in this region, resulted in forests that have been described as open and park-like (Morton, 1883[1632]). However, as Indian use of Prudence Island was limited to seasonal activities (Stachiw, 1981), it is possible that the forests on the island would have retained a more natural vegetation composition and structure than forests of nearby coastal areas that were subject to year-round human impacts. Recent investigations of regional land-use history suggest that open-land habitats in pre-European uplands were more uncommon than previously believed; natural and human disturbance was infrequent and generally local to Indian settlements (Foster and Motzkin, 2003).

The colonial influence on the New England landscape is visible today in the form of stone walls, foundations, and forest composition. The impact on the landscape during European settlement in this region was substantial. Much of the forest was cleared for agriculture, pasture, and for timber and cordwood. Initially, areas near the coast and river systems supported the largest population centers. Deforestation began in these areas and spread across the landscape in concert with more widespread settlement throughout the region. The greatest degree of deforestation in New England generally occurred during the postcolonial period (reaching its maximum around the mid-1800s); however, deforestation of Prudence Island is likely to have occurred somewhat earlier, as the most intensive agricultural period occurred prior to the Revolution-

ary War. During the time that forests were being cleared, drainage of coastal and inland wetlands also occurred, which together with the deforestation activities would have altered the hydrology of the region (Niering, 1998). Changes in hydrology would, in turn, influence future vegetation composition. Although reforestation has occurred throughout much of the region, the current forests are dissimilar to the forests that existed prior to European settlement, reflected most notably in the reduction or loss of previously dominant or common species. In addition to forest compositional trends that can be linked to past land use, structurally the forests are most often young and even aged (Foster, 1992).

Agricultural use of the land on Prudence Island began with the establishment of multiple tenant farms on large continuous parcels during the colonial era, then changed to fewer, larger individual farms operated by a small number of tenants throughout the 19th century, and finally progressed to the abandonment of all but a few owner-operated farms by the start of the 20th century. As elsewhere in New England, it wasn't until competition from Midwestern states in the mid- to late 1800s made local farming unprofitable that much of the land on Prudence Island was abandoned as farmland. Generally, the least productive, marginal lands were abandoned first. During the last century, the abandonment of large tracts of land on the island created a patchwork of multi-stage vegetation as each parcel in turn was successionaly reclaimed by grassland and woody species, eventually developing into the forests of today.

Prehistory (prior to 1640)

The islands of Narragansett Bay, with their numerous sheltered coves, likely provided excellent fishing and shellfishing resources that would have been attractive to prehistoric populations. Privately held artifact collections from Prudence Island representing various projectile point styles ranging from Middle Archaic to Late Woodland periods (6,000 B.P. to 4,500 B.P.) serve to support this suggestion. However, these artifact collections are relatively modest and may indicate only limited use of the island throughout its history. A prehistoric survey of Prudence and Patience islands conducted in 1981 identified numerous seasonal campsites where shellfish processing, stone tool manufacturing, and cook-



ing were evident, but also found no strong evidence that permanent, large prehistoric settlements existed on either island (Kerber and Luedtke, 1981).

The absence of permanent settlements and the apparent lack of diversity in activities at identified seasonal campsites on Prudence Island may best be explained by political factors that structured prehistoric communities and their activities. Historically, the jurisdiction of islands has often been ambiguous, leading them to become relatively underutilized neutral territory. It has been suggested that this may account for the limited prehistoric use of both Prudence and Patience islands (Kerber and Luedtke, 1981). Jurisdictional disputes may similarly account for limited use of Prudence Island during the mid-

1600s. Prudence and Patience islands existed on the eastern edge of the Narragansett Indian territory but appeared to be peripheral to their main area of activity (Kerber and Luedtke, 1981). Maytum (1976) suggests that the Wampanoag tribe, with a territory predominantly east

of the Bay, may have inhabited many islands in the Bay prior to the Narragansett tribe expansion into this area. Certainly both tribes claimed ownership of Prudence Island during the early colonial period. The Narragansett tribe attempted to attract European settlement by offering Prudence Island as a gift, first to John Oldham in 1634, then to Roger Williams in 1637. Later, in 1669, King Phillip, sachem of the Wampanoag tribe, gave Prudence Island to John Paine and in 1670, the Wampanoag tribe made the claim that since Prudence Island belonged to them, the transfer of Prudence Island from the Narragansett tribe to Roger Williams was illegal. Although there was a clear dispute as to ownership, the purpose of gifting the island to European settlers was presumably to prevent use of the land by the neighboring tribe and/or to establish a neutral territory.

The Colonial Era (circa 1640 to 1775)

It is probable that, when the first colonists arrived, a mature growth forest of mixed hardwoods and conifers covered Prudence Island. Wild game

and fish were undoubtedly plentiful, potable water sources were abundant, and the soil types would have supported the farming practices of the time. The location of the island in the middle of Narragansett Bay was beneficial in terms of climate and ease of travel.

In 1637, Roger Williams and Gov. John Winthrop of Massachusetts purchased Prudence Island (called Chibachuweisset by the Indians) from the Narragansett sachems, Canonicus and Miantonomi, for 20 fathoms of wampum and two coats. Williams kept the north half of the island for himself, with Gov. Winthrop taking the south half of the island. Although Williams visited the island on a number of occasions, he and Gov. Winthrop were typical

absentee landlords of the time, reflecting property ownership attitudes that were to prevail throughout much of Prudence Island's history.

The settlement of Prudence Island started soon after it was purchased, initially at the north end of the island and slightly later at the extreme south end. Williams established the first small stock farm in the vicinity of Potters and Sheep Pen Cove (at the northern end of Prudence

Island) and his servant Joshua Windsor became the first colonial resident. Although this initial attempt at establishing a stock farm failed, by about 1665, there were a small number of tenants living in the area around Potters Cove and the neck of the island. The main activity associated with these farms appears to have been stock farming, particularly sheep and pigs. These settlers cleared land, pastured their animals, and grew some crops including corn, wheat, and rye. They cut trees for building homes, fences, barns, and used firewood for cooking and heating. Although the activities of these early settlers had some impact, they occupied only a small part of Prudence Island, and their impact was likely to have been minimal. The earliest settlers on the extreme south end of the island probably arrived some time in the 1650s. Within 10 years, there were a number of settlers in this area. The tenants at this end of the island were primarily planters, not stock farmers. Although property ownership would change many times throughout the next century, a small number of individuals continued to own large continuous parcels and these properties were occupied by tenant farmers.

The impact of King Phillip's War (1675–1676) on the inhabitants of Prudence Island was significant, though no battles were fought here.





The war caused many of the residents to confront their isolation and vulnerability and many of them departed the island. Also at this time, lands were becoming available elsewhere, and land ownership would have represented a substantial improvement over continuing as a tenant on Prudence Island (Stachiw, 1981).

As the region became increasingly settled in the years following King Philip's War, tenant farmers eventually returned to Prudence Island. By about 1730, more than 20 small farms had been established across Prudence Island. The island had become somewhat of a market basket, exporting farm produce to other areas of the state, including Newport and Providence. This "golden age of farming" on Prudence Island lasted from about 1735 until 1775.

The first regular ferry service to the island was established in 1742, and the increased accessibility significantly enhanced the desirability of this location. A number of ferries were operated at various times, and these ferries often carried the mail between Providence and Newport, distributing mail to Prudence Island residents and businesses along an overland route between ferry landings located at the north and south ends of the island.

In addition to livestock operations and farming, the island supported at least three grinding mills during the colonial era, two powered by wind, and one by water. It is noteworthy that there was also some type of blacksmith operation, called the "pin factory," that was located near the south end of the island. The island population at this time was sufficient to support not only ferry services, but houses of entertainment or inns, a brick- and pottery-making business, and a shipbuilding operation, as well as institutions dedicated to education and religion. With 20 to 30 farms and various support activities taking place on the island, the impact of human activities had become significant. During the seasonal peaks of activity, the human population on the island reached 2,500 to 3,000.

The Revolutionary War & Its Aftermath (circa 1776 to 1874)

The Revolutionary War had a devastating social and ecological impact on Prudence Island. Due to its relative isolation, Prudence Island and its residents suffered greatly—more so than most other areas of Rhode Island. British soldiers raided the island multiple times and several skirmishes were fought there, starting in January 1776. The island was virtually abandoned from January 1776 until

about 1780. British troops burned nearly all buildings on the island between 1776 and 1778, cut down all the remaining trees on the island for firewood, and confiscated or destroyed everything of value they could find. After the war, many of the prewar residents never returned to the island.

A wealthy Providence merchant purchased large tracts of land on the island following the Revolutionary War and built three new farmhouses in the 1780s—two near the center of the island, and one in the Potters Cove area. The practice of tenant farming resumed at Prudence Island following the construction of these farmhouses.

The farms established after the war were typically larger and fewer in number than their prewar counterparts. By the mid-19th century there were about 12 farms operating on the island, varying in size from 100 to 800 acres. Most of these farms were occupied by tenants. A typical farm on Prudence Island during the mid-19th century would have kept a small number of horses, several oxen, some milk cows, a few pigs, and a larger number of sheep (probably more than 50). This typical farm would also have produced corn, oats, barley, rye, potatoes, and large amounts of hay (Bains, 1997). In addition, butter, milk, wool, and market vegetables would likely have been produced.

In the latter half of the 19th century, two menhaden processing works operated on the island, the Herreshoff works in the Nag Creek area, and the Wilson & Almy works at the extreme south end. During the same time frame, as agriculture grew less and less profitable, some island farmers took to growing Rhode Island bent grass seed and for a period of time grew and sold turf as well. These activities were particularly detrimental to the ecology of certain parts of the island, causing near total loss of topsoil. The turf (and topsoil) removal, coupled with the wind erosion that followed, left large areas in the center and extreme south end of the island nearly devoid of vegetation. The overall decrease in soil productivity as the result of poor farming practices, combined with a reduction in profits due to a supply of cheap agricultural products from the Midwest, contributed to the abandonment of agriculture on Prudence Island (Stachiw, 1981).

From Farming Community to Summer Resort (circa 1875 to 1940)

As farming became less profitable, other opportunities presented themselves toward the end of the 19th century. Since Prudence Island represented an attractive alternative to urban lifestyles, summer visita-



tion to the island by vacationers increased. This new land use resulted in an increase in land values and further subdivision of properties (Stachiw, 1981). Early vacationers were boarded in farmhouses, but demand soon outgrew these few buildings, and several seasonal inns (Fig. 3.1) and boardinghouses were in operation during this era to accommodate the increase in summer visitors.

Prudence Park, the island's first summer resort, was established on the west side of Prudence in 1875. A large wharf was built to accommodate regular steamboat stops on an existing scheduled service that ran between Providence and Newport. The Prudence Park tract was platted into house lots and streets were laid out. Within a short time, a number of houses, as well as a bathing pavilion and bathhouses, were constructed. The regular steamboat service also helped the boarding house industry on the island by providing a convenient mode of transportation.

The development of the eastern shore was facilitated by the establishment of a ferry service between Prudence Island and Bristol in 1904 (Fig. 3.2). The first ferry was a 16-foot-long open boat, and passengers had to be rowed ashore at Prudence. However, this new service offered a much shorter boat ride—when compared to the three-hour steamboat journey from Providence—and multiple trips each day during the summer. An added advantage was that one could board the train in Providence, ride to Bristol, and debark a short distance from the ferry landing. By 1910, a dock had been built at Homestead (the site of the current ferry landing along the eastern shore) and a much larger ferry had been put into service. The result was that by 1920 more than 100 summer cottages had been built along the eastern shore of Prudence Island.

As more vacationers were buying lots and building cottages of their own, fewer visitors were staying at island inns or guesthouses. By 1930, many of the inns had closed. At that time, there were only three working farms on the island and fewer full-time residents than at any time in the previous 150 years. Many island residents made their living on the Bay (e.g., shellfishing, lobstering) and often supplemented their income by provid-

ing support services for the summer residents, such as carpentry or retail merchandising via the grocery/sundry stores that operated seasonally on the island. By 1946, there were 300 cottages and 1,500 seasonal residents on Prudence Island.

The establishment of Prudence Island as a summer resort community and tourist destination can be directly linked to the large-scale abandonment of agriculture across most of the island, freeing large tracts of land for residential development and altering the vegetation composition of the island. In the 1920s, deer returned to Prudence after a long absence. Much of the land on the island was developing into early successional forest, and human activity had become mostly recreational in nature.

Mid-20th Century to the Present (after 1940)

In 1942, a new type of land use was established on Prudence Island when the federal government purchased approximately 625 acres at the south end, which became the site of a U.S. Navy ammunition dump. The alterations done to this property by the Navy were extensive, and nearly every trace of prior uses of this land was removed during the construction of ammunition bunkers and firebreaks. The Navy installation was reduced to caretaker status in 1946, reopened during the Korean War, and remained an active ammunition storage facility until the early 1970s. In 1980, this property was given to the state of Rhode Island as part of the Federal Lands to Parks Program.

Shortly after World War II, in 1950, the federal government announced plans to build an animal research laboratory near the center of Prudence Island at the site of the abandoned Baker Farm. Overwhelming public opposition caused that laboratory to be built elsewhere. This community effort to restrict land use marked the beginning of a conservation and preservation effort that continues today. In 1959, the Baker Farm property was preserved under the ownership of the Rhode Island Heritage Foundation. In the era of conservation that has followed, approximately 70 percent of Prudence Island has been preserved or protected from development.

Although Prudence Island remains primarily a seasonal use destination, the support services that currently exist are fewer in number today than they were at the turn of the previous century. As the tourism industry was developing, Prudence Island had boasted a number of service and entertainment facilities (e.g., stores, farm stands, bakeries, casinos, dance halls, and yacht clubs). Two hurricanes (in

Figure 3.2. Early ferries, shown at the Sandy Point landing, made the development of the eastern shore of the island possible. Postcard reproduction.





1938 and 1954) were responsible for the destruction of many of these facilities, situated as they typically were, near the shoreline. Fire was responsible for destroying others. More recent support services generally emphasize low-impact, outdoor recreational use of the land. A national estuarine sanctuary was established at the north end of the island after that property was purchased from a private owner in 1978, and the state of Rhode Island operated a park on the island on the former Navy property during the 1980s. The greatest manipulations of these properties during that time were the construction and maintenance of hiking trails and campsites. With the establishment of the NBNERR (which manages the former estuarine sanctuary, former Navy lands, and former Rhode Island Heritage Foundation properties, among others) and the Prudence Conservancy, the emphasis on low-impact recreation will likely continue.

At present, the population of full-time residents is growing more rapidly than that of seasonal residents and many of the older cottages are being converted for year-round use. New home construction continues to be slow but constant. Access to Prudence Island is easier today than at any time in the island's history, effectively minimizing the need for additional support services. Although development pressure continues to be a concern, the recent preservation efforts and the continued lack of on-island amenities would suggest that land use on Prudence Island is unlikely to change substantially in the near future.

Land-Use Legacy

From the Colonial era to the current time, the major impacts to land on Prudence Island can be attributed to a few factors. These factors include war (e.g., Revolutionary War, World War II), agricultural and animal husbandry practices (particularly sheep grazing, as well as grass seed and turf production), and natural forces.

Based on the number of natural disturbances that historically have affected the island's ecology, it should be expected that natural disturbance will continue to influence the island's ecosystems. In addition to the hurricanes of 1938 and 1954, which caused substantial property damage and significantly altered shoreline features, other recorded hurricanes (in 1634, 1815, 1869, 1944, 1960, and 1991) presumably impacted both coastal and upland features of Prudence Island as well. At least three droughts have been documented, during the 1830s and 1850s, as well as an unusually severe drought in 1957 that left Indian Spring and Mill Creek (the

primary source of groundwater for island residents at that time) completely dry. As continued natural disturbance is a near certainty, Prudence Island ecosystems are expected to change across various temporal and spatial scales even in the absence of further human interference. These expected natural disturbances will also influence a landscape that is dissimilar to the landscape that was present prior to European settlement, which contained a distinctly different vegetation composition and structure than that which is present today (Foster and Motzkin, 1998). As a result, we cannot know with certainty what the future vegetation assemblages on Prudence Island will resemble.

In addition to the physical remains of past land-use practices on Prudence Island, visible impacts to the vegetation community are also in evidence. Perhaps most notable is the presence of pine barrens, which owe their existence in part to poor agricultural practices, particularly the growth and sale of turf (or sod). This practice resulted in the removal of significant amounts of topsoil in many areas of the island but its impact is most evident in areas overlying sandy subsoils (see Fig. 4.6, page 28). These pine barrens are locally rare and will, over time, be displaced by a mixed hardwood forest in the absence of extensive management. This transition of the pine barrens to a hardwood forest is already well under way. As many of the vegetation complexes that are now present on Prudence Island can be directly linked to intensive human disturbance, it follows that continued human manipulations may be required to maintain these plant assemblages.

Another legacy of past land-use practices is the abundance of invasive plants on Prudence Island. Historical land use has been linked to long-term changes in vegetation and environmental relationships, a shift in dominant species, and reduced community diversity (Foster, 1992). Perhaps more significantly, past land-use practices were determined to be the single strongest predictor of invasive species richness and cover in southern New England (Lundgren et al., 2004). Asiatic bittersweet (*Celastrus orbiculatus*), the most prevalent invasive plant on Prudence Island, has been shown to both suppress native species and to alter vegetation development in early successional forests (Fike and Niering, 1999). The distribution and abundance of this invasive plant is directly responsible for reducing recreational opportunities on Prudence Island by restricting movement through natural areas and by the provision of tick habitat (see Chapter 6). Consequently, as the result of past land-use history, invasive plant removal will likely remain a priority for current and future land managers.



Although it is generally expected that present land-use activities, such as seasonal residential use and low-impact recreation, will continue into the future, particularly in light of the fact that much of the island has been protected from development, an underlying potential for development exists. Recent construction of new residences—generally adjacent to existing residential areas—and renovations of older structures to accommodate greater use throughout the year represent only a slight shift in current land use. This trend has been relatively slow and, at the current rate, the impact on existing island ecosystems is presumably limited. However, a recent buildout analysis of Prudence Island estimated that in excess of 600 additional homes were possible given the current zoning laws and the amount of privately owned vacant land (Portsmouth Planning Department, 2005). Recent land and easement acquisitions by the state and Prudence Conservancy, respectively, have reduced the number of potential new homes to approximately 460. Although much improved, development on this scale, which represents a 100 percent increase over the current number of residences, would almost certainly result in significant impact to island ecosystems, particularly as many of the potential new homesites would be located in areas that are presently undeveloped and represent a range of habitat types. However, the ongoing emphasis on conservation and preservation of land may effectively limit this potential development.

As elsewhere in New England, the greatest human land-use impact on Prudence Island occurred during historic times. Unlike natural disturbances that occur at various temporal and spatial scales, and most often do not impact extensive geographic areas, the impact of European settlement was both widespread and dramatic, occurring within a very limited time frame. Mature growth forests on Prudence Island were completely removed within a scant 150-year period and the land-use practices that followed were intensive, preventing the development of successional communities for an additional 100 years. This extensive manipulation directly impacted animal communities and continues to affect the island's ecology. Although ecosystem change may be considered inevitable, particularly as the impact of changing climate, invasive species, and pollution are realized, it remains a priority for land managers to adopt strategies that protect threatened species and maximize local and regional biodiversity. Human perturbation of Prudence Island ecosystems in recent history makes continued stewardship a necessity.

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CHAPTER 4.

Ecological Geography of the NBNERR

Kenneth B. Raposa





Figure 4.1. Geographic setting of the NBNERR, including the extent of the 4,818 km² (1,853-square-mile) Narragansett Bay watershed. GIS data sources courtesy of *RIGIS* (www.edc.uri.edu/rigis/) and *Massachusetts GIS* (www.mass.gov/mgis/massgis.htm).



Ecological Geography of the NBNERR

Geographic Setting

Prudence Island is located roughly in the center of Narragansett Bay, R.I., bounded by 41°34.71'N and 41°40.02'N, and 71°18.16'W and 71°21.24'W. Metropolitan Providence lies 14.4 kilometers (km) (9 miles) to the north and the city of Newport lies 6.4 km (4 miles) to the south of Prudence (Fig 4.1). Because of its central location, Prudence Island is affected by numerous water masses in Narragansett Bay including nutrient-rich freshwaters flowing downstream from the Providence and Taunton rivers and oceanic tidal water masses moving upstream from Rhode Island Sound. Prudence Island is the third largest island in Narragansett Bay after Aquidneck and Conanicut islands, and is easily the largest island in the Reserve at 1,424 hectares (ha) (3,559 acres).

The other three smaller islands in the Reserve are all located in close proximity to Prudence Island. Patience Island sits 0.16 km (0.1 mile) off the northwest point of Prudence, while Hope Island and Dyer Island lie 2.4 km (1.5 miles) to the west and 1.1 (0.7 mile) km to the southeast of Prudence Island, respectively. In decreasing order, the sizes of these islands are 86 ha (214 acres) (Patience), 31 ha (78 acres) (Hope), and 14 ha (36 acres) (Dyer).

Climate and Weather

The temperate, maritime climate around the Reserve and surrounding mainland is heavily influenced and moderated by Narragansett Bay. Meteorological patterns on mainland Rhode Island are monitored by the NOAA National Weather Service (NWS) at T.F. Greene airport in Warwick, R.I. (on the west side of Narragansett Bay, approximately 16 km (10 miles) south of Providence). A more comprehensive suite of meteorological data is monitored on Prudence Island with a Campbell weather station located near Potter Cove (Figs. 2.5, 4.2). The weather station on Prudence Island was established in 1996 and began continually collecting weather data as part of the NERR System-Wide Monitoring

Program in 2001. Annual weather patterns on Prudence Island are similar to those on the mainland, at least when considering air temperature, wind speed, and barometric pressure (Figure 4.3).

Using recent data collected from the NBNERR weather station, some annual patterns are clear. For example, air temperature, relative humidity, and the amount of photosynthetically active radiation (PAR) all clearly peak during the summer months (Fig. 4.3). The total amount of precipitation is generally highest during spring and fall, but this pattern is not as strong as the former parameters based on these limited data. Wind speed is lowest during the summer and barometric pressure displays no strong annual pattern. Predominant wind directions vary by season (Fig. 4.4). In spring, winds are mostly from the southwest and northeast, but are primarily only from the southwest at lower velocities in the summer. In fall, high velocity northwest winds accompany the southwesterlies, and in winter a mix of northern, northwestern, and southwestern winds is common.

Geology

All of Rhode Island, including Prudence, Patience, Hope, and Dyer islands, has been intermittently buried under glacial ice sheets beginning as far back as the Pleistocene epoch, approximately 2.5 to 3 million years ago. The last of the glaciers retreated from the area during the Wisconsin glaciation, approximately 12,000 years ago. As the glaciers retreated from the area, they deposited vast amounts of till, sand, gravel, and unconsolidated rock over the bedrock (Fig. 4.5). Most of the land on the four islands is composed of thin glacial till over ancient bedrock, with smaller areas of adjacent outwash (Fig. 4.6). Like much of the Narragansett Bay coastline, the bedrock of Prudence, Patience, Hope, and Dyer islands is composed of stratified sedimentary rock from the Pennsylvanian age, while Narragansett Bay itself is an ancient drowned glacial river valley.



Figure 4.2. The NBNERR weather station on Prudence Island. *Photo from NBNERR photo library.*

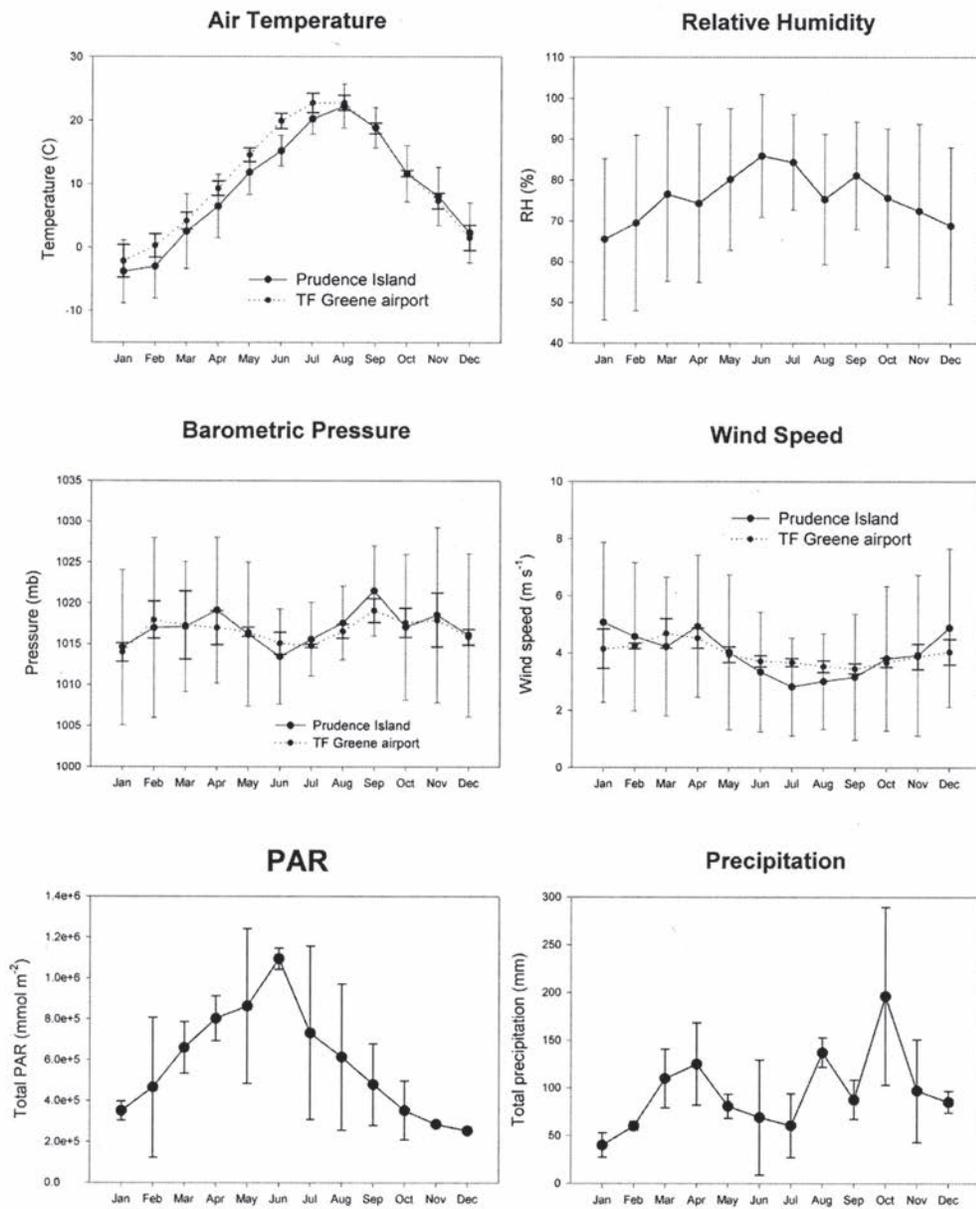


Figure 4.3. Meteorological patterns on Prudence Island and mainland, R.I. Prudence Island data are from 2003–05 from the NBNERR weather station near Potter Cove. Temperature, humidity, pressure, and wind speed plots are monthly averages from 15-minute samples. PAR and precipitation plots are monthly totals from 15-minute samples. Mainland temperature, pressure, and wind speed data were obtained from the NWS at T.F. Greene airport in Warwick, R.I. Temperature and wind speed data are monthly averages from 1999–2004; pressure data are monthly averages from 2001–04. Error bars for all data are standard deviations.

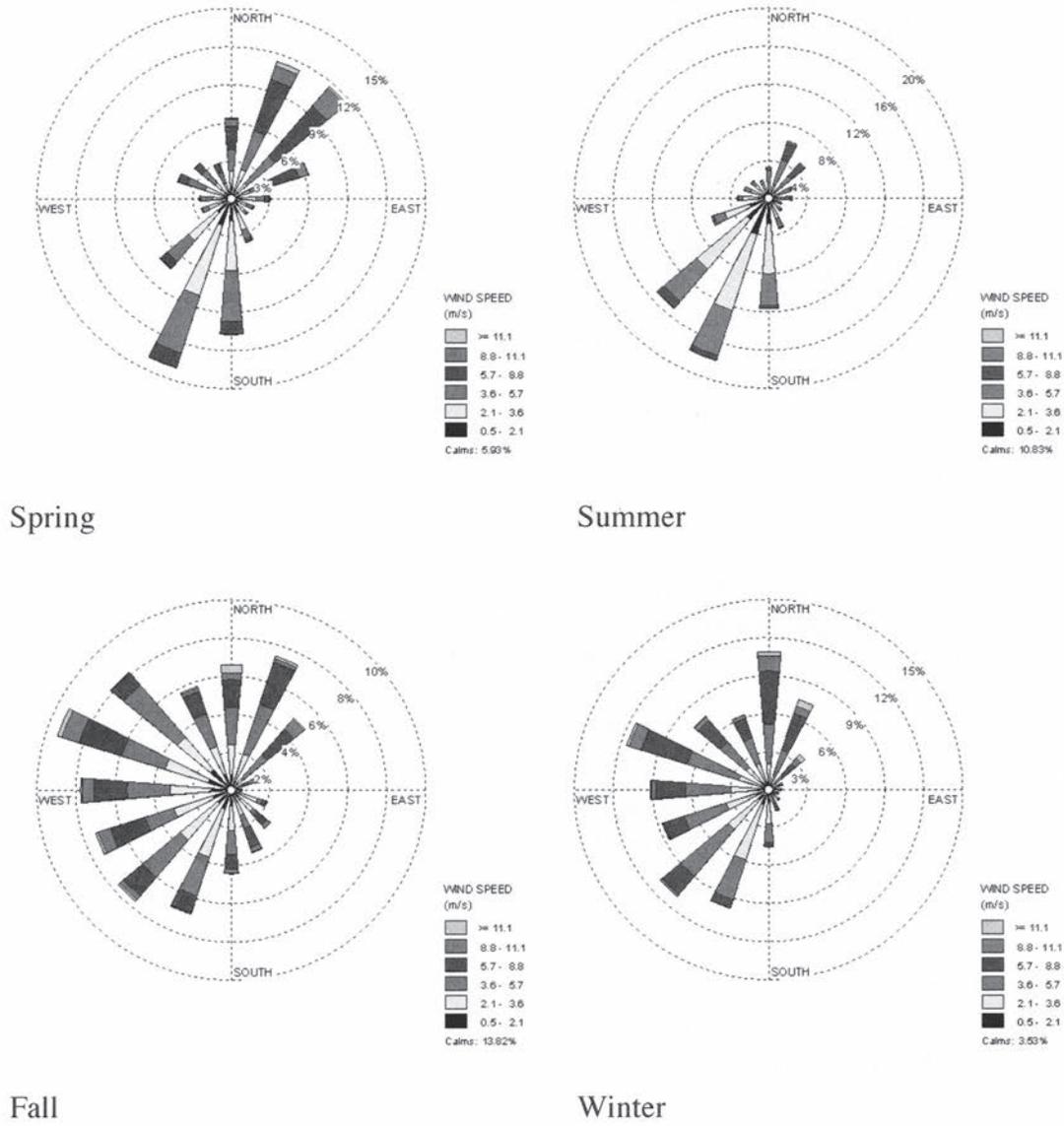


Figure 4.4. Seasonal wind roses from the NBNERR weather station located near Potter Cove on Prudence Island. Data are from 2003–05. All wind rose figures were created using the WRPLOT View software package (©1998–2004 Lakes Environmental Software).



Figure 4.5. Glacial erratics found on a Prudence Island beach. *Photo from NBNERR photo library.*

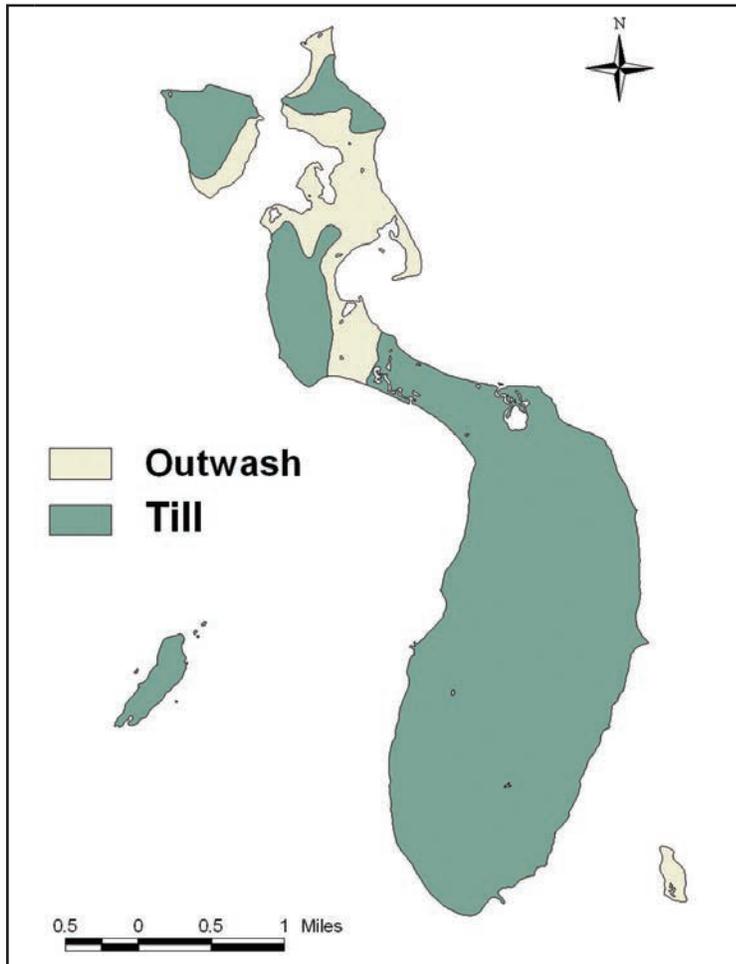


Figure 4.6. Glacial deposits overlying bedrock on Prudence, Patience, Hope, and Dyer islands. *GIS data sources courtesy of RIGIS.*



Figure 4.8. Sandy, well-drained Poquonock soils fronting and supporting pine barrens in the South Prudence Unit of the NBNERR. *Photo from NBNERR photo library.*



Soils

Much of the information on the soils of Prudence, Patience, Hope, and Dyer islands was obtained from the Soil Survey of Rhode Island (Rector, 1981). According to this survey, soils can be classified as soil series, complexes, undifferentiated groups, or miscellaneous areas. A soil series characterizes soils by their profiles. Each series can be further broken into different phases based on characteristics such as slope, wetness, or salinity, among others. For example, the Newport soil series on Prudence Island is present in three phases (A, B, and C phases) based on differences in slope (Table 4.1; Fig. 4.7). A soil complex is an area of at least two soils that are well mixed together or too small to be differentiated on a map. An example of this on Prudence Island is the rock outcrop—Canton complex (Rp). An undifferentiated group is also an area of two or more soils that are not separated simply because there is little value in doing so, and an example from Prudence is the Canton and Charlton fine sandy loams, zero to 3 percent slopes.

Based on this, 27 different soil types (including multiple phases of the same soil series) are found on Prudence, Patience, Hope, and Dyer islands (Table 4.1; Fig. 4.7). This includes features such as beaches around each of the islands and rocky outcrops along the shore of Hope Island. Based on acreage, the dominant soil types for each island (after summing multiple phases of the same soil series) are the

Newport series (Prudence and Patience islands), the Canton and Charlton complex (Hope), and the Merrimac series (Dyer).

Prudence Island is dominated by non-hydric soils, but approximately 24 percent of the soils on the island are hydric, supporting relatively large areas of wetlands. Although it is composed of a diverse array of soil types, Prudence is ultimately dominated by different phases of both the Newport and Poquonock soil series (856.7 acres and 775.4 acres, respectively). The Poquonock series is notable in that only 2,555 acres of this series are found in Rhode Island as a whole; thus over 30 percent of the statewide total (775 acres) is found on Prudence Island. It is these sandy, well-drained Poquonock soils (Fig. 4.8) that support two areas of globally rare pine barrens found on Prudence—one in the southwest corner of the island and the other directly south of Prudence neck (see Chapter 5).

Soils are even drier on Patience Island, where only 12 percent of the island (26 out of 210 acres) is composed of hydric soils. The hydric soils (Matunuck mucky peat and Stissing silt loam) are associated with a salt and brackish marsh found along the southeast side of the island. Hope Island is listed as being composed entirely of non-hydric soil types, although two small perched wetlands are known to exist. It is unique among the four islands in that it is overwhelmingly dominated by rocky outcrops and the Canton

Table 4.1. Acres of soil types found on Prudence, Patience, Hope, and Dyer Islands. Soil types include soil series (including different phases of the same series), complexes, undifferentiated groups, and miscellaneous areas, but not waterbodies (Rector, 1981). Acreages of Prudence Island soils are presented for different sections of the NBNERR, for the NBNERR as a whole, and for all of Prudence Island.

Soil Type	Prudence					Patience	Hope	Dyer
	North Prudence Unit	Mid Prudence Units	South Prudence Unit	Total NBNERR on Prudence	Total Prudence			
Ba – Beaches	59.37	7.82	11.22	78.41	124.79	12.68	3.27	8.75
Bc – Birchwood sandy loam		5.48	20.30	25.78	122.91			
CeC – Canton and Charlton fine sandy loams		14.02	1.22	15.24	59.00		39.44	
Dc – Deerfield loamy fine sand		1.11		1.11	28.40			
Du – dumps		0.48	3.63	4.11	4.62			
HkD – Hinckley gravelly sandy loam, hilly	15.23			15.23	15.23			
Ma – Mansfield mucky silt loam		36.99		36.99	44.55			
Mk – Matunuck mucky peat	104.33	53.48		157.81	212.14	10.79		5.54
MmA – Merrimac sandy loam	11.72			11.72	11.72			
MmB – Merrimac sandy loam	94.73	4.67		99.40	127.40			11.05
NeA – Newport silt loam		64.26	101.85	166.11	235.89	30.98		
NeB – Newport silt loam	181.52	93.86	66.07	341.45	542.08	47.50		
NeC – Newport silt loam		46.25	8.35	54.6	78.71	7.51		
PmA – Pittstown silt loam	23.96	50.84	24.99	99.79	114.43			
PmB – Pittstown silt loam		6.22	4.13	10.35	34.91			
PsA – Poquonock loamy fine sand, 0–3% slopes		36.51	234.07	270.58	444.96			
PsB – Poquonock loamy fine sand, 3–8% slopes		113.82	26.80	140.62	330.42	30.86		
QoC – Quonset gravelly sandy loam, rolling	132.53	14.21		146.74	208.99	38.07		
Rk – Rock outcrop							17.30	
Rp – Rock outcrop – Canton complex							13.39	
Sb – Scarboro mucky sandy loam	46.32	52.89	63.92	163.13	315.60			
Se – Stissing silt loam		38.98	213.26	252.24	267.43	15.40		
Ss – Sudbury sandy loam	23.59			23.59	23.59			
UAB – Udipsamments, undulating	1.95			1.95	1.95			
UD – Udorthents – Urban land complex			22.48	22.48	22.48			
W – Walpole sandy loam	14.22	2.71	2.87	19.8	35.82	14.55	15.15	15.10
WgA – Windsor sandy loam	7.79	22.84		30.63	112.61			
WgB – Windsor loamy sand	29.29	1.15		30.44	49.84	14.45		

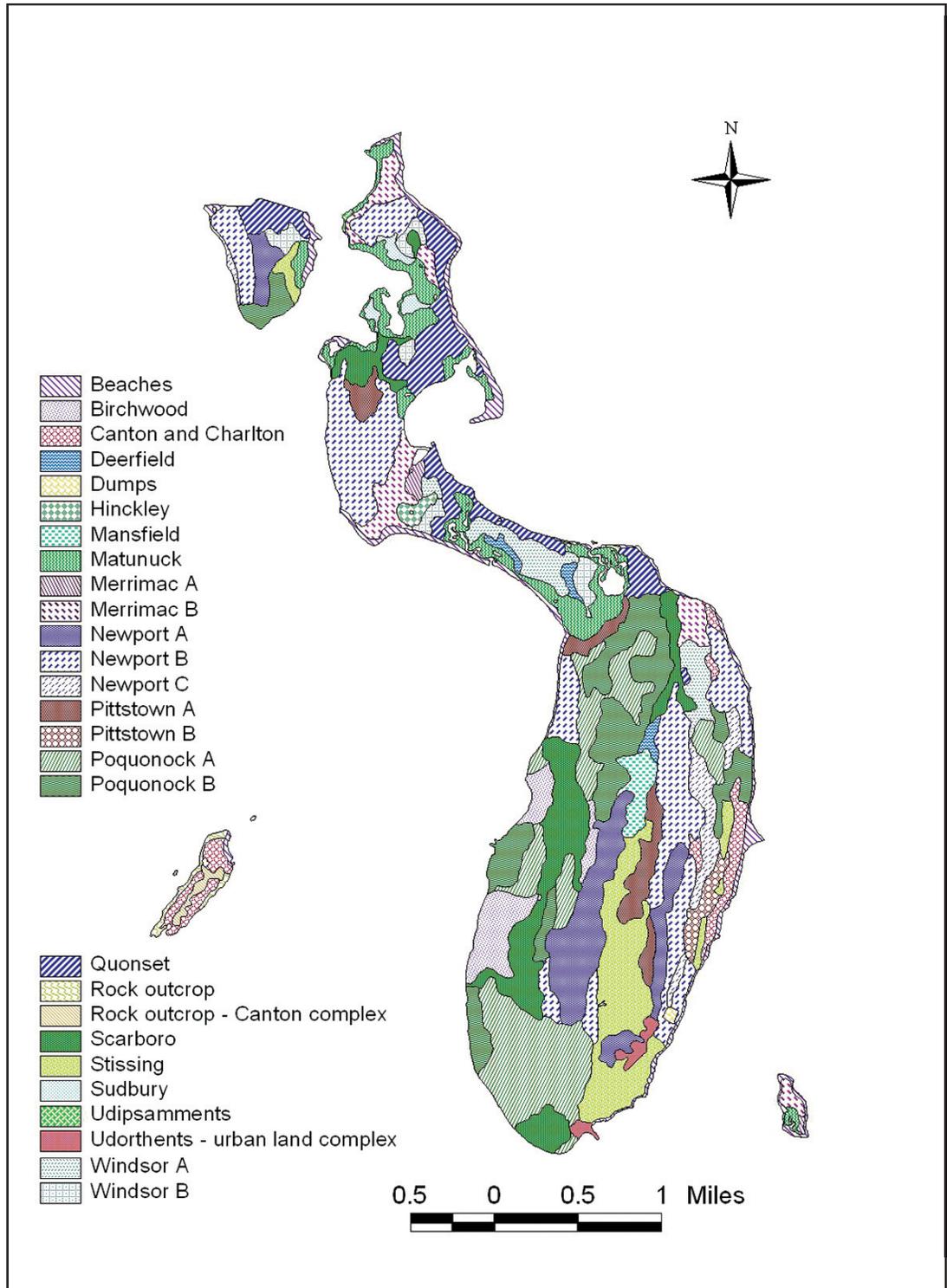


Figure 4.7. Soil types found on Prudence, Patience, Hope, and Dyer islands. GIS data sources courtesy of RIGIS.

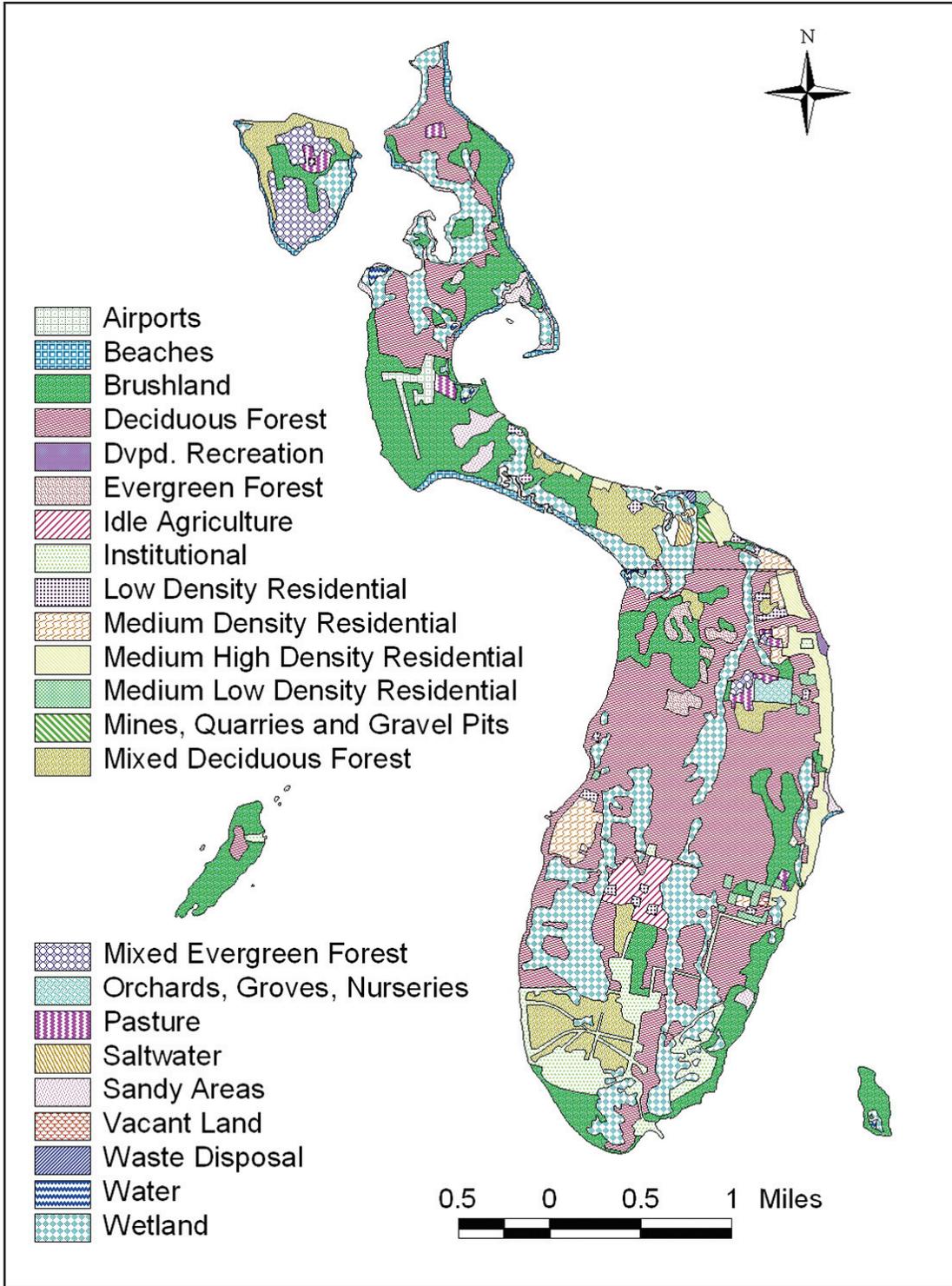


Figure 4.9. Land cover in 1995 on Prudence, Patience, Hope, and Dyer islands. GIS data sources courtesy of RIGIS.



a.



b.



c.

Figure 4.10. Examples of the dominant land cover classes on Prudence Island, including: (a) forest (pine-oak mixed forests are common on Prudence); (b) wetland (in this case, a salt marsh); and (c) brushland (dominated here by briar, *Smilax* spp.). Photos from NBNERR photo library.

Table 4.2. Acres of land cover types on Prudence, Patience, Hope, and Dyer islands based on RIGIS 1995 land-use/land cover coverage. Acreages of Prudence Island land cover classes are presented for different sections of the NBNERR, for the NBNERR as a whole, and for all of Prudence Island.

Land cover type	Prudence				Total Prudence	Patience	Hope	Dyer
	North Prudence Unit	Mid Prudence Units	South Prudence Unit	Total NBNERR on Prudence				
Airports	14.45			14.45	27.33			
Beaches	38.11	4.36		42.47	59.75	16.89		
Brushland	289.4	70.56	122.79	482.75	642.94	30.31	63.88	24.76
Deciduous forest	189.69	413.91	182.81	786.41	1207.65		7.51	
Developed recreation					3.29			
Evergreen forest	1.37	6.44		7.81	40.03			
Idle agriculture		0.1	11.83	11.93	52.14			
Institutional		0.16	163.2	163.36	176.04		2.94	
Low density residential		1.56	1.6	3.16	28.46	0.82		
Medium density residential		0.99		0.99	72.67			
Medium high density residential		2.62	0.03	2.65	120.37			
Medium low density residential		0.23	0.47	0.7	27.81			
Mines, quarries, and gravel pits		0.01		0.01	6.3			
Mixed deciduous forest		15.34	102.91	118.25	209.98	48.27		
Mixed evergreen forest		0.27		0.27	7.72	79.27		
Orchards, groves, nurseries					16.5			
Pasture	8.73	1		9.73	29.31	9.94		
Saltwater		1.52		1.52	10.77			
Sandy areas (not beaches)	49.67		4.71	54.38	60.14			
Vacant land					1.68			
Waste disposal					1.96			
Water	5.2	1.88		7.08	7.08			0.84
Wetland	144.14	142.79	212.34	499.27	743.02	22.91		2.97



and Charlton complex, characterized by a surface where stones and boulders cover between 2 and 10 percent, and where rock outcrops cover up to 10 percent (Rector, 1981). Because of these features, Hope Island resembles the rocky shorelines found in some areas along the southern coast of Rhode Island and along much of the northern New England coast. Dyer Island is also dominated by non-hydric soils (23 acres, compared to six acres of hydric soils). The six-acre hydric soil unit is Matunuck mucky peat that supports a small salt marsh on the southern end of the island.

Land Use and Land Cover

A diverse mosaic of land cover and habitat types exists on Prudence, Patience, Hope, and Dyer islands, in part due to over 300 years of extensive human modifications (see Chapter 3). Detailed land-use and land cover data for the islands (and all of Rhode Island) are available for the years of 1995 and 1998 in the form of GIS coverages that are coded according to the Anderson Level 3 land-use/land cover classification system (RIGIS, 2005). Based on the 1995 coverage, 23 land cover classes are found on the four NBNERR islands (Table 4.2; Fig. 4.9). All of these classes are present on Prudence, but not on Patience (seven land cover classes), Hope (three classes), or Dyer (three classes).

Prudence Island is dominated by secondary growth habitats. Deciduous forest is the largest land cover class (1,208 acres; 34 percent of the island), followed by wetlands (743 acres; 21 percent) and brushland (643 acres; 19 percent) (Fig. 4.10). In contrast, developed land cover classes (e.g., residential areas) comprise only 249 acres, or 7 percent of Prudence Island. Compared to the three other large islands in Rhode Island (Aquidneck, Conanicut, and Block), Prudence Island has by far the least amount of developed and agricultural land and the most forested and brushland, again illustrating the natural setting of Prudence (Rosenzweig et al., 2002).

When considering only the land within the NBNERR on Prudence Island, dominant land cover classes include deciduous forest (32 percent), brushland (23 percent), and wetlands (21 percent) (Table 4.2). However, only 17 land cover classes were identified in the Reserve, due to the absence of orchards and nurseries, mines and quarries, developed recreation areas, waste disposal, and vacant lands. At least 64 percent of the total acreage of each natural land cover class on Prudence Island was located inside Reserve boundaries, with the exception of evergreen forests (only 20 percent of this class

was found in the Reserve). Land cover differed among the units of the NBNERR, but most were again dominated by forest, wetland, and brushland (Table 4.2).

Patience Island is almost completely composed of natural land cover classes, including mixed evergreen forest (79 acres; 38 percent of the island), mixed deciduous forest (48 acres; 23 percent), brushland (30 acres; 14 percent), and wetlands (23 acres; 11 percent). A 0.8-acre of residential development remains on Patience Island due to a lone inholding remaining after the island was purchased by the state.

Hope and Dyer islands differ from both Patience and Prudence in that they are both overwhelmingly dominated by a single land cover class. There are 64 acres of brushland on Hope Island and 25 acres on Dyer, making up 85 percent and 86 percent of the two islands, respectively. The only other land cover classes on these islands are deciduous forest and institutional (remnants from Navy use) on Hope, and water and wetland on Dyer.

Three land cover classes grew by at least 37 acres between 1988 and 1995 on Prudence Island: Ninety-nine acres of mixed deciduous forest, 72 acres of brushland, and 37 acres of deciduous forest grew during this period. Virtually all of these habitat increases occurred on the South Prudence Unit where areas that were abandoned by the Navy began to revert back to a more natural state (Fig. 4.9).

Wetlands

Based on the RIGIS wetlands coverage maps, 10 types of wetlands are found on Prudence, Patience, Hope, and Dyer islands (Fig. 4.11), although most of these are either deciduous forested wetlands and estuarine emergent wetlands (i.e., salt marshes) (Table 4.3). Almost 70 percent of all wetlands occurring on the four islands are protected within the boundaries of the Reserve, including 76 percent of all salt marshes. Compared to Aquidneck, Conanicut, and Block islands, Prudence has by far the greatest proportion of wetlands relative to the total island area (Rosenzweig et al., 2002).

Surficial Hydrology

Surface water bodies that retain water throughout the year are scarce on the four islands in the Reserve. Prudence has a few small year-round ponds, although the exact number is unknown (six were present on the RIGIS ponds coverage, and six

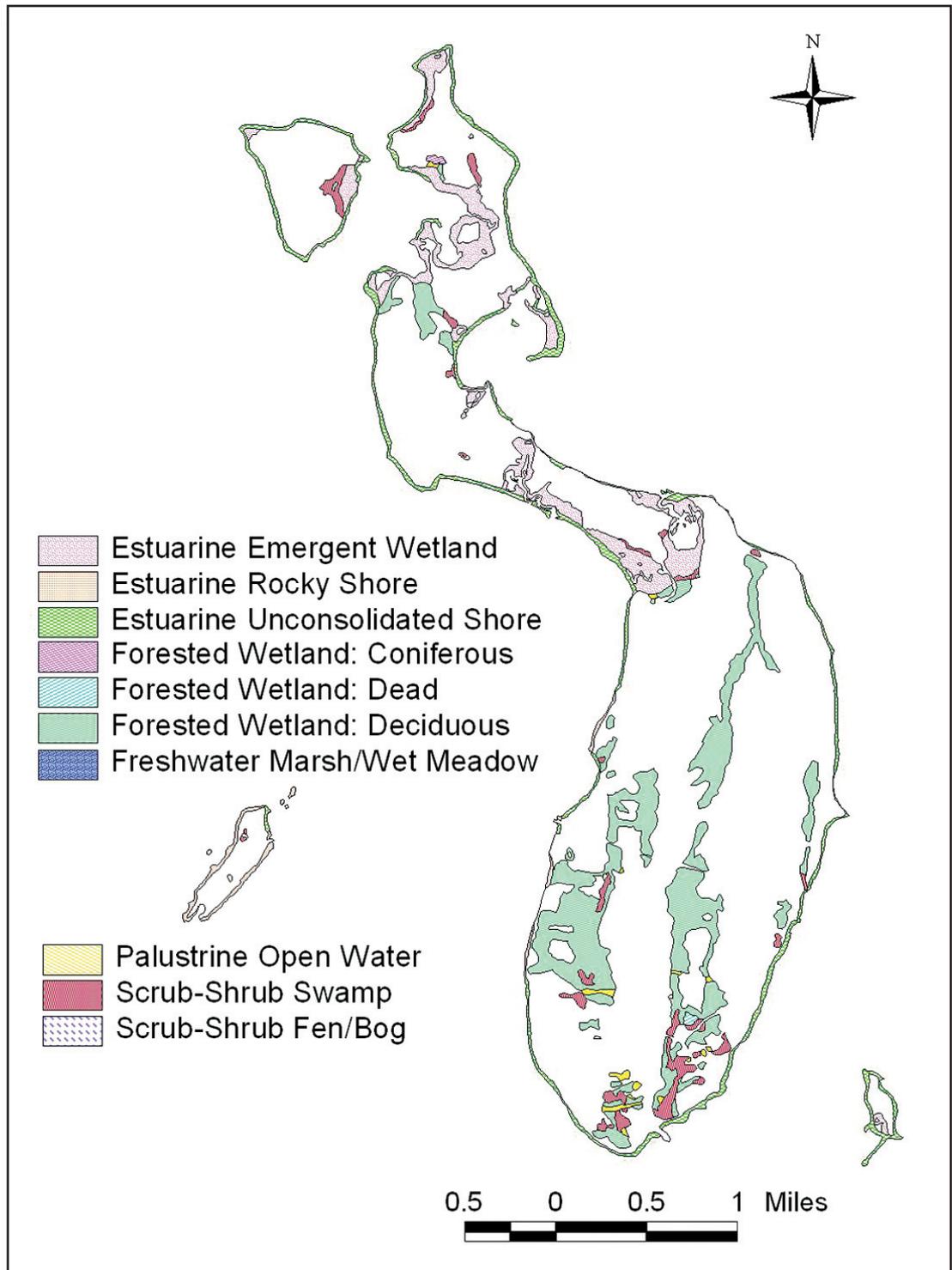


Figure 4.11. Wetlands on Prudence, Patience, Hope, and Dyer islands. GIS data sources courtesy of RIGIS.

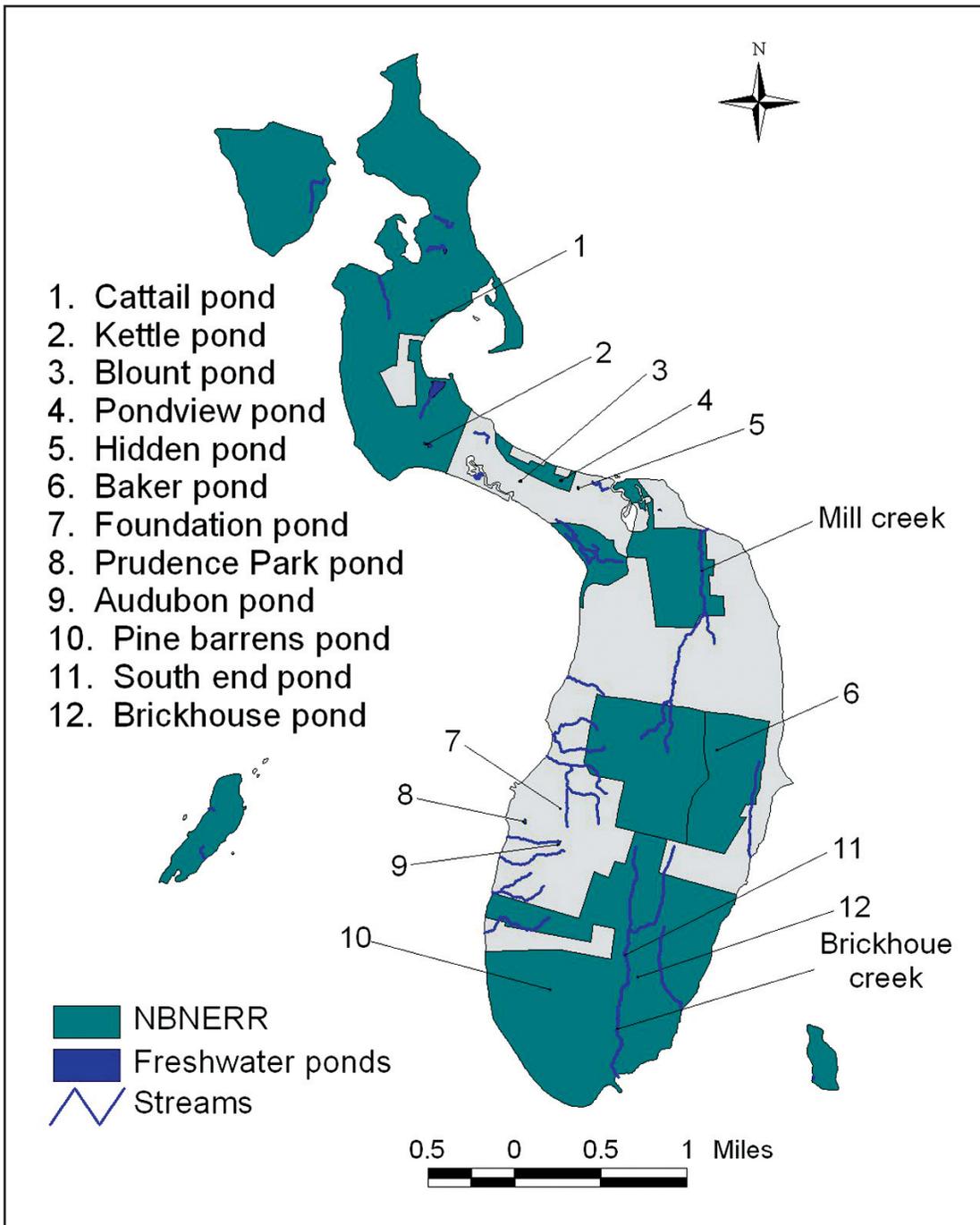


Figure 4.12. Freshwater ponds and streams on Prudence, Patience, Hope and Dyer islands. All pond names are colloquial; ponds were unofficially named by island residents or Reserve staff. GIS data sources courtesy of RIGIS.



Table 4.3. Acres of wetland types on Prudence, Patience, Hope, and Dyer islands based on RIGIS 1995 wetlands coverage. Acreages of Prudence Island wetland classes are presented for different sections of the NBNERR, for the NBNERR as a whole, and for all of Prudence Island.

Wetland class	Prudence					Patience	Hope	Dyer
	North Prudence Unit	Mid Prudence Units	South Prudence Unit	Total NBNERR on Prudence	Total Prudence			
Forested wetland: deciduous	28.55	87.44	156.31	272.30	448.82	0.44		
Estuarine emergent wetland	101.86	47.87		149.73	200.85	12.82		2.97
Estuarine unconsolidated shore	55.18	9.90	21.90	86.98	124.89	19.33	1.07	8.28
Scrub-shrub swamp	9.76	3.21	42.00	54.97	65.62	9.64	0.72	
Estuarine rocky shore			1.12	1.12	7.24		13.13	
Freshwater marsh/wet meadow	0.90	0.64	11.90	13.44	15.09			
Forested wetland: dead				2.57	2.57			
Palustrine open water	0.47		0.51	0.98	1.65		0.78	
Forested wetland: coniferous	2.36			2.36	2.36			
Scrub-shrub fen/bog	0.26			0.26	.26			
All wetlands	202.31	149.48	235.31	587.1	875.58	42.23	15.70	12.32

more were located based on personal observations; Fig. 4.12). Prudence also supports approximately 15.5 km (9.7 miles) of streams (based on the RIGIS streams coverage) and numerous, but unquantified vernal pools. Patience and Dyer islands do not support any standing freshwater ponds or streams (Fig. 4.12; the stream on Patience Island is actually a salt marsh tidal creek). Hope Island has two streams present on it according to the RIGIS coverage in addition to two small freshwater ponds that do not show up on the ponds coverage (personal observation). More detailed maps and information on ponds, vernal pools, and streams on the islands are needed, in part due to mapping inaccuracies on the RIGIS coverages.

Shoreline

Based on the RIGIS Narragansett Bay estuarine habitat coverage, the NBNERR encompasses approximately 29 km (18.2 miles) of estuarine shoreline on Prudence, Patience, Hope, and Dyer islands. The Reserve’s shoreline is composed of five classes, including 15.5 km of beaches (mostly cobble, some sandy), 6.2 km of salt marsh (fringing and meadow marshes), 5.3 km of rocky shore, 1.9 km of upland, and 0.3 km of *Phragmites australis* (Fig. 4.13).

Literature Cited

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Rosenzweig, L., R. Duhaime, A. Mandeville, and P. August. 2002. Ecological geography of Block Island. In: *The Ecology of Block Island*. Pp. 3–12. Edited by Paton, P.W., L.L. Gould, P.V. August, and A.O. Frost. Rhode Island Natural History Survey, Kingston, R.I.



a.

Figure 4.13. Examples of dominant shoreline types in the NBNERR, including: (a) sandy beach; (b) cobble beach; (c) fringing salt marsh; and (d) rock outcrop. Photos from NBNERR photo library.



b.



c.



d.



CHAPTER 5.

NBNERR Flora and Vegetation Communities

Thomas E. Kutcher







NBNERR Flora and Vegetation Communities

This chapter describes terrestrial palustrine and upland plants and plant communities of the NBNERR. Because the properties of the NBNERR occupy only Bay islands, which historically have been largely cleared of native vegetation, theories of island biogeography would predict that plant communities of the Reserve are less diverse than those of mainland coastal Rhode Island. Although no formal studies of island effects have been conducted, the setting of the Reserve certainly offers unique environmental conditions affecting floral ecology. The islands' general lack of top predators and limited emigration opportunities have led to the overpopulation of white-tailed deer (*Odocoileus virginianus*), which may be affecting the entire ecology of the island system due to heavy browsing and grazing pressure (Raposa and Greene, 2003). Also, the narrow shape of the islands offers interior plant species minimal protection from coastal winds and salt spray, which facilitates species adapted to coastal conditions, including aggressively colonizing invasive species such as oriental bittersweet (*Celastrus orbiculatus*) and black swallow-wort (*Vincetoxicum nigrum*).

Anthropogenic factors have strongly influenced the upland flora on Reserve properties and have played a key role in the development of certain upland plant communities. Prudence and Patience islands were almost completely deforested in the 1600s and heavy subsequent farming led to the depletion of much of the fertile topsoil (Chapter 3). Many remnant soils are nutrient poor and excessively drained, which tends to select for species communities adapted to poor soil conditions, such as pitch pine (*Pinus rigida*) dominated mosaics, and relatively stable upland grassland habitats. Human modification of disturbance regimes such as the suppression of fire and localized flooding have limited the occurrence of certain expected early-successional communities and favored progressive change towards more stable forest habitats and associated flora. Former land-use practices have also set the stage for infestation of nuisance and invasive species. For example, historical persistent seasonal clearing in the North Prudence Unit has contributed to a widespread infestation of oriental bittersweet.

Palustrine habitats have also been greatly affected by human impacts, especially since the Navy's occupation of the South Prudence Unit in the mid-1900s. A network of raised Navy roads at least partially impounds every major stream in this Reserve unit. Filling, ditching, and movement of earth, which are evident in aerial photo archives, have also changed natural surficial water regimes. Historic documents indicate that some wetlands were spared from deforestation during the islands' development, but they were not spared from other early ecological impacts such as the likely extirpation of expected ecosystem engineers such as the beaver (*Castor canadensis*) and top predators such as the red wolf (*Canis rufus*), which may partly account for a lack of early successional vegetation and depauperate community composition from overbrowsing, respectively.

Flora

The flora on Prudence Island, and in the NBNERR, has been surveyed periodically for over 20 years. The first known formal plant survey at the Reserve was conducted by Shaughnessy and Golet (1982). A total of 89 species was identified during their inventory of the upland and wetland habitats of the Narragansett Bay Estuarine Sanctuary, which is now the Reserve's North Prudence, Patience Island, and Hope Island units. The Rhode Island Wild Plant Society (1994) later surveyed upland vegetation of the Prudence Conservancy Unit. George and Nichols (1993) identified 160 vascular plant species in Prudence Park on the west side of Prudence Island during a botanical survey conducted for the ASRI. George (1997a, 1997b) again surveyed the properties of the Reserve in 1997, documenting 93 species. Krebs (1997) collected, identified, and pressed botanical samples for display

in the Reserve's education kiosk. Enser et al. (2001) conducted a preliminary inventory of plants in a wet meadow that the Reserve was restoring along the side of the entrance road to the South Prudence Unit. Gould et al. (2002a) followed up the investigation, and also identified species in two NBNERR upland grassland restoration sites, also located in the South Prudence Unit (Gould et al., 2002b, 2002c). Kutcher and Raposa (2005) conducted the first quantitative vegetation survey on Prudence and identified 64 vascular plant species within an Atlantic coastal pine barren mosaic in the South Prudence Unit during the summer of 2004.

Overall, 312 vascular plant species have been identified at the Reserve, including 232 native species and 80 exotics (Appendix 5.1). This compares to 1,980 species (1,307 native and 673 exotics) known to exist in the state according to *The Vascular Flora of Rhode Island: A List of Native and Naturalized Plants* (Gould et al., 1998).

Rare Species

Fourteen state rare native species (according to Gould et al., 1998) have been identified in the Reserve properties on Prudence Island. These include one fern species: leathery grape-fern (*Botrychium oneidense*); three wildflower species: sickle-leaved golden aster (*Chrysopsis falcata*), yellow thistle (*Cirsium horridulum*), and spring ladies' tresses (*Spiranthes vernalis*); one annual herb species: woodland goosefoot (*Chenopodium standleyanum*); three grass species: rigid panic-grass (*Panicum rigidum*), bead-grass (*Paspalum setaceum*), and gama grass (*Tripsacum dactyloides*, Fig. 1); one cactus species: eastern prickly pear (*Opuntia humifusa*); one vine: wild honeysuckle (*Lonicera dioica*); one trailing shrub species: sand dewberry (*Rubus recurvicaulis*); and one tree species: slippery elm (*Ulmus rubra*).



Figure 5.1. The showy inflorescence of the locally rare grass species, gama grass, growing in a salt marsh-upland transition zone in the Reserve's North Prudence Unit. Photo from NBNERR photo library.

Invasive Species

Eighteen exotic species and one naturalized southern U.S. native, the black locust (*Robinia pseudoacacia*), identified at the Reserve are listed as invasive in the *Invasive Species Atlas of New England* (Mehrhoff et al., 2003) (Appendix 5.1). Of these, oriental bittersweet is by far the most problematic species affecting Reserve habitats. Oriental bittersweet is an introduced vine that aggressively out-competes native flora by overtopping the plants and extorting light resources and nutrients. It occurs in virtually all properties of the Reserve, smothering flora and burdening shrubs and trees to the point of structural failure in many cases (Fig. 5.2). At least 31 percent (218 ha) of the Reserve's natural upland is affected by this nuisance species, which is drastically affecting the ecology of many habitats, especially coastal shrublands and forests (Kutcher et al., 2004).

Other invasives are also ubiquitous in the NBNERR habitats. Beach rose (*Rosa rugosa*) dominates at least 14 percent of dune shrublands.



Figure 5.2. A cherry-cedar woodland infested with the invasive vine oriental bittersweet. Low, open-canopy forests and coastal shrublands are most susceptible to this disturbance-loving invasive. Note that the needle-leaved cedars (left and back-center) appear as conical broad-leaved trees due to nearly complete coverage of bittersweet, while cherries in the foreground are now merely acting as frames supporting the aggressive vine. Photo from NBNERR photo library.

Common reed (*Phragmites australis*) dominates at least 43 percent of emergent freshwater habitat and is present in many of the salt marsh systems; multiflora rose (*Rosa multiflora*) is a staple species in coastal shrublands; the aggressive vine black swallow-wort has taken hold of at least two large areas; and autumn olive (*Elaeagnus umbellata*) is common in certain Reserve shrublands. Black locust occurs throughout coastal forest habitats of the North Prudence and Patience Island units, where the exotic maples sycamore maple (*Acer pseudoplatanus*) and Norway maple (*Acer platanoides*) have also escaped cultivation (Kutcher et al., 2004).

Vegetation Communities

The first known inventory of vegetative communities on NBNERR properties was a survey of wetlands conducted by RIDEM for the state in 1988–89. RIDEM inventoried 287 ha of wetlands within the NBNERR by photointerpretation of 1:24,000 aerial photographs (available at www.edc.uri.edu/rigis). Shaughnessy and Golet (1983) conducted a habitat inventory in 1982 for the Narragansett Bay Estuarine Sanctuary and RIDEM. They mapped and inventoried 434 ha of uplands and wetlands in the North Prudence, Patience Island, and Hope Island units via aerial photointerpretation and ground-truthing. An inventory of Reserve plant communities was not conducted again until 2003, when Kutcher et al. (2004) surveyed, mapped, and classified 1,053 ha of upland, wetland, and modified plant communities in GIS format for all lands in

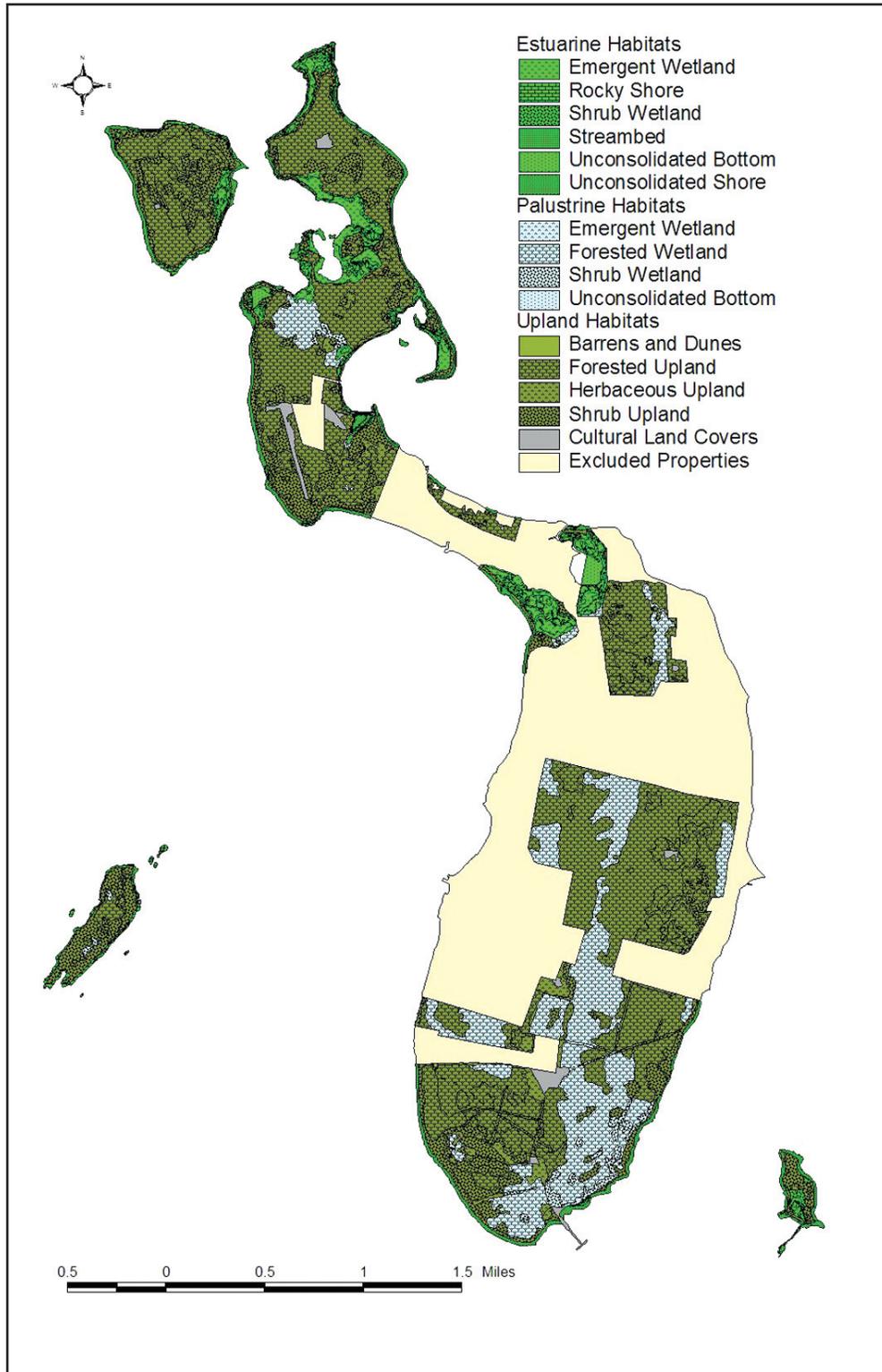


Figure 5.3. Habitats of the NBNERR ordered by system and class. Source: Kutcher et al., 2004.



Figure 5.4. Graphic of Prudence Island from Vigness Raposa (2004) comparing the results of supervised automated classification of 30 m imagery (left) versus the aerial-photointerpreted and field-checked Kutcher et al. (2004) habitat inventory.



Figure 5.5. A roadside incursion of the invasive common reed dominating the brackish zone in a Reserve salt marsh. *Photo from NBNERR photo library.*



the Reserve, also via aerial photointerpretation and ground-truthing (Fig. 5.3). Vigness Raposa (2004) mapped the habitats of Prudence Island via supervised algorithmic classification of remote sensing imagery, using ERDAS software (1999, Landsat-7 Enhanced Thematic Mapper Plus) 30-meter (m) resolution imagery, and the NBNERR classification scheme. An overall accuracy of 78 percent was achieved at the class level of the classification when compared to the ground-truthed Kutcher et al., (2004) inventory (Fig. 5.4).

Habitat and species data referred to in this section are derived from the NBNERR habitat inventory conducted in 2003 (Kutcher et al., 2004) unless otherwise noted. (These data may differ somewhat from those presented in Chapter 4, but this is simply due to the use of different GIS data sources; i.e., RIGIS and Kutcher et al., 2004.)

Palustrine Plant Communities

Terrestrial palustrine plant communities occupy 12 percent (191.4 ha) of all terrestrial habitats of the Reserve. Of these, 92 percent (176.6 ha) is forested, 7.2 percent (13.8 ha) is shrubby, and only 0.5 percent (1.0 ha) is emergent. The freshwater wetlands of the NBNERR occupy hydric Scarborough mucky sand loam and Stissing silt loam soils associated with six minor and two major stream systems of Prudence Island, as well as four small perched depressions on Hope Island and two groundwater seeps abutting the south edge of Nag Marsh (RIGIS, 2003).

Emergent Wetlands

Emergent palustrine wetlands often occur as an early transitional stage in wetland physiognomic development after some type of disturbance (F.C. Golet, personal communication). A lack of emergent wetland habitat in the Reserve may be indicative of a disruption of natural disturbance regimes such as fire and beaver damming. The Reserve contains 0.4 ha of wet meadow habitat, which is maintained by yearly mowing, 0.4 ha of common reed marsh, and 0.1 ha each of cattail (*Typha latifolia*) marsh and fern (*Thelypteris* sp.) wet meadow.

Wet meadows are extremely rich plant communities and, due to the transient nature of their existence and dependence on disturbance, often support uncommon species. Gould et al. (2003a) identified 87 species in a 0.4 ha roadside wet meadow

that the Reserve is restoring in the South Prudence Unit—three of which are Rhode Island State Concern species—while Enser et al. (2001) identified 52 species at this site.

At least 85 percent of NBNERR terrestrial palustrine emergent habitats are affected by colonization of nonnative common reed. Another 2.5 ha of common reed growing in the Reserve's estuarine brackish marshes may act as a seed bank, positioning its colonization in certain disturbance-dependent palustrine emergent wetlands (Fig. 5.5).

Shrub Wetlands

In New England, shrub wetlands generally represent a median stage in progressive wetland change (F.C. Golet, personal communication). NBNERR shrub wetlands exist as three general types: mixed broad-leaved deciduous (BLD) shrub swamps (10.5 ha), thicket swamps (3.0 ha), and sapling swamps (0.4 ha). Due to a lack of natural retrogressive mechanisms, such as flooding or fire, shrub wetlands of the Reserve tend to be edge communities, acting as transition zones between anthropogenically modified and forested wetland habitats, or transitory communities of regrowth in areas that were formerly mechanically cleared.

Mixed BLD shrub swamps of the NBNERR are typically dominated by highbush blueberry (*Vaccinium corymbosum*), arrowwood (*Viburnum dentatum*), tree saplings, and alder (*Alnus* sp.). Thicket swamps are dominated by Bebb's willow (*Salix bebbiana*) and speckled alder (*Alnus rugosa*). They are located along roadside ditches of the Reserve's South Prudence Unit, where old Navy roads impound natural drainage of wetlands above, and in perched depressions on Hope Island. A single BLD sapling swamp occurs as part of a mosaic of fragmented and disturbed habitats within a red maple swamp in the South Prudence Unit. The sapling swamp is dominated by a mix of red maple (*Acer rubrum*) and gray birch (*Betula populifolia*) saplings.

Shrub wetlands of the NBNERR are moderately affected by invasive species. At least 17 percent (2.3 ha) is infested with greater than 25 percent cover of oriental bittersweet. Wetter habitats, such as thicket swamps, generally show less evidence of bittersweet invasion than drier shrub swamps. Autumn olive (*Elaeagnus umbellata*), an aggressive nonnative shrub, also affects a 0.74 ha area of BLD shrub swamp in the South Prudence Unit.



Forested Wetlands

Covering the majority of hydric soils in the Reserve, forested wetlands are generally considered to be the climax and most stable palustrine communities in this region. Virtually all NBNERR forested wetlands are dominated by red maple. Most red maple swamps are associated with the Prudence Island's major stream basins, while a single 1.5 ha red maple swamp occurs south of the Little Unit's Nag Marsh as a groundwater seep.

Red maple swamp overstory species include red maple and tupelo (*Nyssa sylvatica*). Dominant understory species are northern arrowwood, highbush blueberry, and sweet pepperbush (*Clethra alnifolia*), with willow (*Salix* sp.), swamp rose (*Rosa palustris*), bayberry (*Myrica pensylvanica*), poison ivy (*Toxicodendron radicans*), and greenbrier (*Smilax* sp.) also commonly present (Shaughnessy and Golet, 1982).

No formal studies have examined the presence or effects of invasive species in forested wetland habitats of the NBNERR, but impacts to community function from exotic species appear to be minor (personal observation); therefore, it is a low research priority.

Upland Plant Communities

Natural upland plant communities occupy 45 percent (708.1 ha) of all terrestrial properties of the Reserve. Of these, 72 percent (509.2 ha) is forested, 24 percent (166.6 ha) is shrubby, 4.5 percent (31.8 ha) is herbaceous, and less than 0.1 percent (0.4 ha) is barren.

Coastal Dune Plant Communities

Coastal dune habitats within NBNERR boundaries generally occur along sandy shorelines as components of barrier beaches that separate meadow salt marshes from the open waters of Narragansett Bay. The Reserve contains 10.6 ha of coastal dune habitat types, including coastal dune sparse grassland, coastal dune grassland, coastal dune forbs, and coastal dune shrubland.

Coastal dune grasslands are dominated by American beachgrass (*Amophila breviligulata*) or quack grass (*Elytrigia repens*), a nonnative form of wheat primarily used for hay production (Brown, 1979). The only known natural population of eastern prickly pear cactus in the state occurs in the NBNERR coastal dunes (Gould, personal communication), where it grows among sparse dune grasses



Figure 5.6. A locally rare prickly pear cactus blooming in a coastal dune habitat among beach pea (*Lathyrus japonicus*) and quack-grass (*Elytrigia repens*). Photo from NBNERR photo library.

and forb (Fig. 5.6). Coastal dune forb habitats are generally dominated by spearscale (*Atriplex* sp.), beach pea (*Lathyrus japonica*), and water hemp (*Amaranthus cannabinus*), and are usually very dynamic, disturbance-driven communities. Coastal dune shrubland habitats of the Reserve are typically dominated by beach rose, high tide bush (*Iva frutescens*), bayberry, or poison ivy.

Due to their dynamic settings, coastal dune plant communities are susceptible to invasion by aggressive nonnative colonizers. At least 35 percent (3.7 ha) is affected by an invasive plant species. The most common invasive in NBNERR coastal dune habitats is oriental bittersweet. Approximately 1.1 ha of coastal dune habitat is infested by greater than 50 percent cover of bittersweet. Another 0.9 ha is dominated by beach rose, 0.4 ha is severely impacted by the invasion of the nonnative vine black swallow-wort, and 0.7 ha contains the highly toxic, introduced nightshade, jimson weed (*Datura stramonium*). The sea poppy (*Glaucium flavium*) has also been observed recently on the coastal dunes of the Little Unit (personal observation).

Upland Grass and Forb Plant Communities

The NBNERR contains 28.2 ha of herbaceous upland communities. The majority of these (excluding those occurring on coastal dunes) represent a transient stage of successional development. These habitats exhibit various levels of landscape stability, depending mostly on the characteristics of the strata, with grassland communities on the excessively drained, sandy Poquonock soils generally being the most resistant to progressive change. The collective mosaic of these dryer communities with interspersed, small areas of inland sand barren and pitch pine sapling open shrubland habitats



contributes floral and structural diversity to locally rare and valuable pine barren ecosystems both in the South Prudence Unit and in the southern end of the Barre Unit. Herbaceous communities occurring on richer soils are far less stable and must be regularly maintained to prevent the domination of woody vegetation.

Reserve grasslands are primarily dominated by switchgrass (*Panicum virgatum*, 16.4 ha), mixed cool-season grasses (6.1 ha), or little blue-stem (*Schizachyrium scoparium*, 3.1 ha), while forb meadows are dominated by common milkweed (*Asclepias syriaca*, 1.6 ha) or goldenrod (*Solidago* sp., 0.2 ha). According to species surveys conducted by Gould et al. (2002c) and Enser et al. (2001), the NBNERR grasslands are extremely diverse plant communities. Gould's survey revealed 50 species from a small meadow restoration site in the South Prudence Unit, which is dominated by switchgrass and little blue-stem. Among those species reported are the locally rare wildflowers, yellow thistle (*Cirsium horridulum*) and sickle-leaved golden aster (*Chrysopsis falcata*), and a rare bead-grass (*Paspalum setaceum*).

NBNERR herbaceous communities are widely impacted by nonnative species. In grassland communities dominated by native grasses, many of the secondary species, such as fescues (*Festuca* sp.), English plantain (*Plantago lanceolata*), and black knapweed (*Centaurea nigra*) are nonnative. Some mixed grassland habitats are dominated by introduced hay and lawn species. Of the 1.8 ha of forb meadow, 1.4 ha are heavily infested with oriental bittersweet.

Upland Shrubland Plant Communities

The upland shrubland communities of the NBNERR generally exist as one of three general types: (1) relatively structurally stable coastal shrubland communities that are consistently maintained by salt spray and high winds; (2) dense, stable greenbrier (*Smilax rotundifolia*) monocultures; and (3) transient habitats occurring as a successional stage between herbaceous and forested uplands. Coastal shrubland types (129.3 ha) cover most of the undeveloped upland perimeters of Prudence and Patience Island properties, and 84 percent of the total vegetated upland area of the more exposed Hope and Dyer islands, equaling 8.2 percent of the total terrestrial properties of the Reserve and 18 percent of the total uplands. Non-coastal shrublands make up less than 4 percent (26.9 ha) of total Reserve uplands. Large, inland monocultures of greenbrier comprise 62 percent (16.6 ha) of non-coastal shrublands.

Coastal shrubland community types identified in the Reserve are coastal shrubland, coastal greenbrier shrubland, coastal sumac thicket, and coastal dune shrubland. Coastal shrubland habitat types are typically dominated by smooth and shining sumacs (*Rhus glabra* and *R. copallinum*), bayberry, greenbrier, or beach rose. They also commonly include stunted black cherry (*Prunus serotina*), stunted eastern red cedar (*Juniperus virginiana*), fox grape (*Vitis labrusca*), and poison ivy. Non-coastal shrublands are typically dominated by highbush blueberry or bayberry, or are dominated by red maple, pitch pine, or gray birch saplings.

Likely due to the stressful nature of the coastal environment, coastal shrublands of the NBNERR are particularly prone to invasion of the nonnative bittersweet. At least 37 percent (48.0 ha) of all coastal shrublands at the Reserve are affected by its presence and at least 12 percent (15.2 ha) is infested with greater than 50 percent coverage of the vine. Other common invasive species affecting coastal shrublands include multiflora rose, black swallow-wort, and autumn olive. A dense stand of the invasive Japanese knotweed (*Polygonum cuspidatum*) exists among the coastal shrublands on the northeast coast of Patience Island.

Upland Forested Plant Communities

Forested upland plant communities represent the ultimate successional stage in most NBNERR upland settings. The majority (75 percent) of upland habitats on the Prudence and Patience Island units are forested, while the less sheltered uplands of the smaller Dyer and Hope islands are dominated by coastal shrublands. Overall, 72 percent (509.2 ha.) of Reserve upland communities are forested. Of these, 45 percent (227.5 ha) is BLD, 2.0 percent (10.1 ha) is needle-leaved deciduous, 4.1 percent (21.1 ha) is needle-leaved evergreen, and 49 percent (250.6 ha) is mixed.

BLD forested upland habitats of the Reserve generally grow on more protected uplands with fairly rich soils. They are primarily dominated by red maple, white oak (*Quercus alba*), black oak (*Q. veutina*), or black locust. Big-toothed aspen (*Populus grandidentata*), sassafras (*Sassafras albidum*), gray birch (*Betula poulifolia*), tupelo, and naturalized sycamore maple are also common BLD canopy species of the Reserve. Common understory species include greenbrier, blueberry, bayberry, and arrowwood.

A 10.1-ha stand of the nonnative tree, European larch (*Larix decidua*), was planted by the U.S. Navy along the western edge of the South Prudence Unit as a wind break, and has since naturalized and



spread into adjacent grasslands. This is the only needle-leaved deciduous forested habitat type on the Reserve. The understory is dominated by greenbrier (Fig. 5.7).

Needle-leaved evergreen forested uplands of the Reserve are composed of 16.0 ha of coastal eastern red cedar forest, 4.9 ha of pitch pine forests and open woodlands, and 0.2 ha of white pine (*Pinus strobus*). Eastern red cedar forests occur as dense thickets or open woodlands, mostly on the coastal, excessively drained soils of Patience Island. One pure stand of pitch pine covers Pine Knoll in the North Prudence Unit, and open pitch pine woodlands occur at the northern reach of a pine barren ecosystem located in and to the south of the Barre Unit. A single stand of large white pine trees, which was likely cultivated, grows along a trail in the center of the Patience Island Unit.

NBNERR mixed-forest habitats include two general types: oak-pine associations and cherry-cedar associations. Oak-pine associations generally exist along a continuum of seral stages that typically progresses from pitch pine domination to oak (*Quercus* sp.) domination in the absence of a regular, frequent fire regime (Enser and Lundgren, 2003). Typical understory species include high-bush blueberry and greenbrier. A total of 64.5 ha of oak-pine forests dominate the excessively drained Poquonock soils of the Reserve, and are keystone components of locally unique pine barren ecosystems.

A total of 186.0 ha of cherry-cedar forest habitats cover 66 percent of the North Prudence Unit and 46 percent of the Patience Island Unit. They dominate in areas that have relatively rich soils and are somewhat exposed to coastal influence. Cherry-cedar communities are typically open canopy woodlands (30 to 60 percent canopy cover) with dense shrubby understories and are dominated by wild black cherry (*Prunus serotina*) and eastern red cedar (*Juniperus virginiana*), both of which, in stunted form, are major components of coastal

shrubland habitats. Cherry-cedar forests may be co-dominated by red maple or black locust. Shaughnessy and Golet (1983) found the dominant understory species to be arrowwood and bayberry, although recent surveys find the understory largely overgrown with oriental bittersweet (Kutcher et al., 2004).

Oriental bittersweet occurs in at least 33 percent of all upland forests, and infests (with greater than 25 percent total coverage) at least 12 percent. In forests influ-

enced by direct coastal effects, invasion by bitter-sweet is even higher. At least 79 percent of cherry-cedar and eastern red cedar forests are affected by bittersweet and at least 30 percent is infested. The reasons for this extensive invasion are unclear, but Raposa and Greene (2003) suggest that it may be related to selective browsing of over-abundant white-tailed deer on competitive native flora over the unpalatable bittersweet. The invasive common barberry (*Berberis vulgaris*) has also been reported to occur in the understories of Reserve upland forests (George and Nichols, 1993). Another exotic species greatly affecting NBNERR forest ecology is naturalized European larch, which is displacing pitch pine on the Poquonock soils of the South Prudence Unit. Other canopy species, such as naturalized maples and black locust, also displace native forest species in the Reserve's coastal forest habitats.

Pine Barren Mosaics

Pine barrens are regionally and globally rare ecosystems comprising a mosaic of community types, many of which have been previously described in this chapter.

The NBNERR contains 91 ha of Atlantic coastal pine barrens, which are unique to north and mid-Atlantic coastal uplands. NBNERR pine barrens occur primarily on sandy, well-drained Poquonock soils, most of which are nutrient deprived due to historic farming practices. Pine barrens are structurally diverse habitat mosaics that are generally maintained in early to mid-successional stages by regular fire disturbance. The pine barrens of the Reserve are composed of oak and pitch pine dominated forests and adjacent shrublands, grasslands, and sand barrens (Table 5.2, Fig. 5.8). Without regular fire disturbance, Atlantic coastal barrens normally progress into closed-canopy hardwood forests (Howard et al., 2005). Nearly half of the pine barren area within the reserve has progressed to closed canopy oak-pine forest.

Structurally diverse, NBNERR pine barrens offer a unique set of environmental characteristics that support a wide range of specialized, unique, and rare plant and animal species (Kutcher and Raposa,



Figure 5.8. A structurally diverse Atlantic coastal pine barren mosaic located in the NBNERR South Prudence Unit. Photo from NBNERR photo library.

Figure 5.7. A stand of European larch located in the Reserve's South Prudence Unit. This introduced species poses a threat to native habitats due to its ability to colonize xeric soils. Photo from





Habitat Type	Count	Area (ha)
Oak-pine forest	10	44.57
Pitch pine-oak forest	12	19.96
Switchgrass grassland	9	7.30
Pitch pine saplings	6	5.89
Pitch pine woodland	3	4.49
Little bluestem grassland	1	2.65
Pitch pine sapling open shrubland	1	2.53
Mixed BLD saplings	1	1.92
Blueberry shrubland	1	0.63
Bayberry shrubland	1	0.54
Pitch pine forest	1	0.38
Mixed grassland	1	0.29
Inland sand barren	3	0.13
Total		91.28

Table 5.2. Habitats within the pine barren mosaics of the NBNERR derived from Kutcher et al. (2004).

2005). Pine barrens are also a significant contributor to regional and global biodiversity (Howard et al., 2005), but due to fire suppression and development, they are regionally and nationally declining (Grand et al., 2003). The barrens are thus a priority for ecological maintenance and restoration at the NBNERR.

Using quantitative field methods, NBNERR staff assessed the species and structural compositions of vegetation within and across habitats in a 71 ha Atlantic coastal pine barren mosaic located in the South Reserve Unit to serve as an ecological baseline and to identify management priorities (Kutcher and Raposa, 2005). Pine-oak forest habitats managed by prescribed burning until 1998 were found to be dissimilar to unburned areas in crown cover by species and in understory by life form. Pine-oak forest habitat in total was dissimilar to an adjacent

European larch forest habitat in understory by species and life-form. Of four habitat types sampled, pine-oak forest was the richest, while grassland habitat was the most diverse and contributed most to the beta diversity (species diversity across multiple habitats) of the mosaic when added to pine-oak forest. The larch forest was least rich, least diverse, and added the least to beta diversity of the mosaic compared to pine barren communities (Figs. 5.9 and 5.10). Overall, the study suggested that the former burn strategy was effective in stimulating understory function, but ineffective in preventing oak domination; and that refined management strategies should be considered. It also suggested that restoration action may be appropriate in the larch-dominated areas.

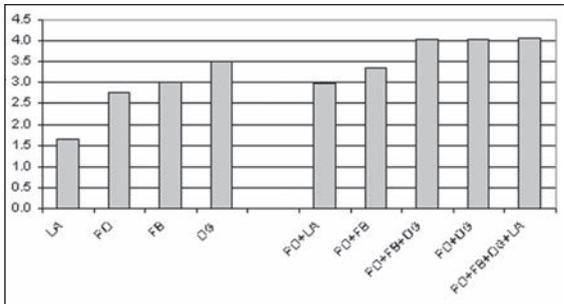


Figure 5.9. Shannon-Wiener indices of species diversity of habitats and habitat combinations of the Atlantic coastal pine barrens of the NBNERR South Prudence Unit. LA = European larch forest, PO = pine-oak forest, FB = linear shrubby firebreak, OG = open grassland. Source: Kutcher and Raposa, 2005.

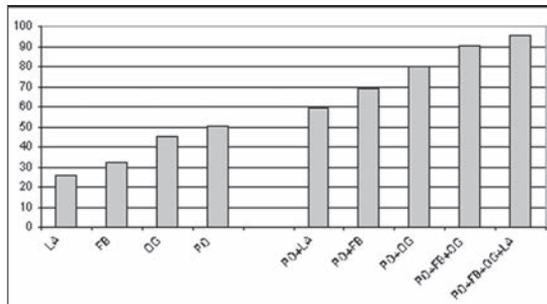


Figure 5.10. Jackknife estimate of richness of habitats and habitat combinations of the Atlantic coastal pine barrens of the NBNERR South Prudence Unit. LA = European larch forest, PO = pine-oak forest, FB = linear shrubby firebreak, OG = open grassland. Source: Kutcher and Raposa, 2005.

Appendix 5.1 Vascular Plants of the Reserve

Compiled from Kutcher and Raposa, 2005; Kutcher et al., 2004; Gould et al., 2002a, b, and c; Enser et al., 2001; George, 1997a and b; Krebs, 1997; Prudence Conservancy, 1994; George, 1993; and Shaughnessy and Golet, 1983.

Scientific Name	Common Name	Statewide Abundance
Native Species		
<i>Acer rubrum</i>	red maple	Ubiquitous
<i>Achillea millefolium</i>	common yarrow	Ubiquitous
<i>Agalinis pururea</i>	purple gerardia	Common
<i>Agrostis hyemalis</i>	hairgrass	Ubiquitous
<i>Agrostis perennans</i>	upland bent	Common
<i>Almenchier canadensis</i>	downy shadbush	Common
<i>Alnus rugosa</i>	speckled alder	Common
<i>Amaranthus cannabinus</i>	water hemp	Common
<i>Ambrosia artemisiifolia</i>	common ragweed	Common
<i>Aristida dichotoma</i>	churchmouse three-awn	Common
<i>Aronia arbutifolia</i>	red chokeberry	Common
<i>Aronia melanocarpa</i>	black chokeberry	Common
<i>Asclepias incarnata</i>	swamp milkweed	Common
<i>Asclepias syriaca</i>	common milkweed	Ubiquitous
<i>Aster ericoides</i>	white wreath aster	Common
<i>Aster novi-belgii</i>	New York aster	Ubiquitous
<i>Aster paternus</i>	toothed white-topped aster	Common
<i>Aster racemosus</i>	small white aster	Ubiquitous
<i>Athyrium felix-femina</i>	lady fern	Ubiquitous
<i>Atriplex hastata</i>	orach	Common
<i>Baccharis halimifolia</i>	groundsel-tree	Common
<i>Bartonia virginica</i>	bartonia	Common
<i>Betula alleghaniensis</i>	yellow birch	Common
<i>Betula papyrifera</i>	paper birch	Common
<i>Betula populifolia</i>	gray birch	Ubiquitous
<i>Botrychium oneidense</i>	leathery grape-fern	Rare
<i>Cakile edentula</i>	sea-rocket	Common
<i>Calamagrostis canadensis</i>	blue-joint	Ubiquitous
<i>Calamagrostis cinnoides</i>	reed bentgrass	Common
<i>Carex argyrantha</i>	silvery sedge	Common
<i>Carex bicknellii</i>	Bicknell's sedge	Common
<i>Carex crinita</i>	drooping sedge	Common
<i>Carex debilis</i>	Rudge's sedge	Common
<i>Carex intumescens</i>	bladder sedge	Common
<i>Carex lurida</i>	reddish-yellow sedge	Ubiquitous
<i>Carex scoparia</i>	broom-sedge	Ubiquitous
<i>Carex stipata</i>	awl sedge	Ubiquitous
<i>Carex stricta</i>	tussuck sedge	Common
<i>Carex swanii</i>	Swan's sedge	Common
<i>Carex virescens</i>	ribbed sedge	Common
<i>Carya tomentosa</i>	mockernut hickory	Common
<i>Catalpa speciosa</i>	northern catalpa	Status Undetermined
<i>Celtis occidentalis</i>	northern hackberry	Common
<i>Cephalanthus occidentalis</i>	buttonbush	Common
<i>Chenopodium rubrum</i>	coast blight	Common
<i>Chenopodium standleyanum</i>	woodland goosefoot	Rare
<i>Chimaphila maculata</i>	spotted wintergreen	Common
<i>Chrysopsis falcata</i>	sickle-leaved golden aster	Rare
<i>Cinna arundinacea</i>	wood reedgrass	Common
<i>Cirsium horridulum</i>	yellow thistle	Rare



<i>Clethra alnifolia</i>	sweet pepperbush	Common
<i>Comptonia peregrina</i>	sweet fern	Common
<i>Conyza canadensis</i>	horse-tail	Ubiquitous
<i>Cornus amomum</i>	silky dogwood	Common
<i>Crataegus</i> sp.	hawthorne	Common
<i>Cyperus lupulinus</i>	umbrella-sedge	Common
<i>Cyperus strigosus</i>	false nutsedge	Common
<i>Danthonia spicata</i>	poverty-grass	Ubiquitous
<i>Dennstaedtia punctilobula</i>	hay-scented fern	Common
<i>Distichlis spicata</i>	spike-grass	Common
<i>Drosera rotundifolia</i>	round-leaved sundew	Common
<i>Dryopteris carthusiana</i>	spinulose wood fern	Common
<i>Dulichium arundinaceum</i>	three-way sedge	Common
<i>Echinochloa walteri</i>	water millet	Common
<i>Eleocharis ovata</i>	blunt spike-rush	Common
<i>Eleocharis tenuis</i>	(slender) spike-rush	Common
<i>Elymus virginicus</i>	Virginia wild rye	Common
<i>Eragrostis spectabilis</i>	purple lovegrass	Ubiquitous
<i>Erigeron strigosus</i>	daisy-fleabane	Ubiquitous
<i>Eupatorium fistulosum</i>	purple joe-pye-weed	Common
<i>Euthamia graminifolia</i>	grass-leaved goldenrod	Common
<i>Euthamia tenuifolia</i>	fine grass-leaved goldenrod	Common
<i>Fagus grandifolia</i>	American beech	Common
<i>Fragaria virginica</i>	wild strawberry	Ubiquitous
<i>Fraxinus americana</i>	white ash	Common
<i>Galium palustre</i>	marsh-bedstraw	Common
<i>Gaylussacia baccata</i>	black huckleberry	Common
<i>Glyceria canadensis</i>	Canada manna-grass	Common
<i>Gnaphalium obtusifolium</i>	sweet everlasting	Common
<i>Hamamelis virginiana</i>	witch hazel	Common
<i>Hibiscus moscheutos</i>	rose mallow	Common
<i>Hieracium gronovii</i>	hairy hawkweed	Common
<i>Hudsonia tomentosa</i>	woolly hudsonia	Common
<i>Hypericum canadense</i>	narrow-leaved St. John's-wort	Common
<i>Hypericum gentianoides</i>	pinweed	Common
<i>Hypericum mutilum</i>	dwarf St. John's-wort	Common
<i>Hypericum punctatum</i>	spotted St. John's-wort	Common
<i>Ilex laevigata</i>	smooth winterberry	Common
<i>Ilex opaca</i>	American holly	Common
<i>Ilex verticillata</i>	winterberry	Common
<i>Impatiens capensis</i>	jewel-weed	Ubiquitous
<i>Iris versicolor</i>	northern blue flag	Ubiquitous
<i>Iva frutescens</i>	hightide bush	Common
<i>Juglans nigra</i>	black walnut	Status Undetermined
<i>Juncus brevicaudatus</i>	short-tailed rush	Common
<i>Juncus canadensis</i>	Canada rush	Common
<i>Juncus effusus</i>	soft rush	Common
<i>Juncus gerardii</i>	black grass	Common
<i>Juncus greenei</i>	field rush	Common
<i>Juncus tenuis</i>	path-rush	Ubiquitous
<i>Juniperus virginiana</i>	eastern red cedar	Ubiquitous
<i>Kalmia angustifolia</i>	sheep laurel	Ubiquitous
<i>Kalmia latifolia</i>	mountain laurel	Common
<i>Lathyrus maritimus</i>	beach pea	Common
<i>Lechea maritima</i>	seaside pinweed	Common
<i>Lechea mucrunata</i>	hairy pinweed	Common
<i>Lechea tenuifolia</i>	narrow-leaved pinweed	Common
<i>Leersia oryzoides</i>	rice cutgrass	Common



<i>Lemna minor</i>	small duckweed	Common
<i>Lepidium virginicum</i>	peppergrass	Common
<i>Lespedeza capitata</i>	bush clover	Ubiquitous
<i>Limonium carolinianum</i>	sea lavender	Common
<i>Linaria canadensis</i>	old-field toadflax	Common
<i>Lindera benzoin</i>	spicebush	Common
<i>Lobelia cardinalis</i>	cardinal-flower	Common
<i>Lonicera dioica</i>	wild honeysuckle	Rare
<i>Ludwigia palustris</i>	common water-purslane	Common
<i>Lycopodiella appressa</i>	southern bog-clubmoss	Common
<i>Lycopodium hickeyi</i>	Hickey's tree clubmoss	Common
<i>Lycopodium lucidulum</i>	shining clubmoss	Common
<i>Lycopus americanus</i>	American water horehound	Common
<i>Lycopus virginicus</i>	Virginia water horehound	Common
<i>Lyonia ligustrina</i>	maleberry	Common
<i>Lysimachia quadrifolia</i>	whorled loosestrife	Common
<i>Lysimachia terrestris</i>	yellow loosestrife	Common
<i>Myrica pensylvanica</i>	northern bayberry	Ubiquitous
<i>Nymphaea odorata</i>	fragrant water lily	Common
<i>Nyssa sylvatica</i>	tupelo	Common
<i>Oenothera biennis</i>	evening primrose	Common
<i>Onoclea sensibilis</i>	sensitive fern	Ubiquitous
<i>Opuntia humifusa</i>	eastern prickly-pear cactus	Rare
<i>Osmunda cinnamomea</i>	cinnamon fern	Common
<i>Osmunda regalis</i>	royal fern	Common
<i>Oxalis stricta</i>	wood sorrel	Common
<i>Panicum clandestinum</i>	deer-tongue	Ubiquitous
<i>Panicum dichotomiflorum</i>	fall panic-grass	Ubiquitous
<i>Panicum lanuginosum</i>	woolly panic-grass	Ubiquitous
<i>Panicum rigidulum</i>	rigid panic-grass	Rare
<i>Panicum virgatum</i>	switch-grass	Ubiquitous
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Ubiquitous
<i>Paspalum setaceum</i>	bead-grass	Rare
<i>Picea</i> cv.	spruce cultivar	Status Undetermined
<i>Pinus resinosa</i>	red pine	Common
<i>Pinus rigida</i>	pitch pine	Common
<i>Pinus strobus</i>	white pine	Common
<i>Plantago aristata</i>	bracted plantain	Common
<i>Platanthera clavellata</i>	green woodland-orchid	Common
<i>Platanus occidentalis</i>	sycamore	Common
<i>Pluchea odorata</i>	marsh fleabane	Common
<i>Polygala sanguinea</i>	common milkwort	Common
<i>Polygonella articulata</i>	jointweed	Common
<i>Polygonum sagittatum</i>	arrow-vine	Common
<i>Populus grandidentata</i>	big-toothed aspen	Common
<i>Potamogeton</i> sp.	pondweed	Status Undetermined
<i>Potentilla anserina</i>	silverweed	Common
<i>Potentilla canadensis</i>	dwarf cinquefoil	Ubiquitous
<i>Potentilla simplex</i>	common cinquefoil	Ubiquitous
<i>Prunus maritima</i>	beach plum	Common
<i>Prunus serotina</i>	black cherry	Common
<i>Quercus alba</i>	white oak	Common
<i>Quercus coccinia</i>	scarlet oak	Ubiquitous
<i>Quercus ilicifolia</i>	black scrub-oak	Common
<i>Quercus palustris</i>	pin-oak	Common
<i>Quercus rubra</i>	red oak	Common
<i>Quercus velutina</i>	black oak	Common



<i>Rhexia virginica</i>	meadow-beauty	Common
<i>Rhododendron viscosum</i>	swamp azalea	Common
<i>Rhus copallinum</i>	shining sumac	Common
<i>Rhus glabra</i>	smooth sumac	Common
<i>Rhus typhina</i>	staghorn sumac	Common
<i>Rhynchospora capitellata</i>	(small-headed) beak-rush	Common
<i>Robinia pseudoacacia</i>	black locust	Common
<i>Rosa carolina</i>	pasture-rose	Common
<i>Rosa palustris</i>	swamp rose	Common
<i>Rosa virginiana</i>	wild rose	Common
<i>Rubus alleghaniensis</i>	blackberry	Common
<i>Rubus flagellaris</i>	prickley dewberry	Ubiquitous
<i>Rubus hispidus</i>	swamp-dewberry	Ubiquitous
<i>Rubus recurvicaulis</i>	sand dewberry	Rare
<i>Rudbeckia hirta</i>	black-eyed susan	Ubiquitous
<i>Salicornia bigelovii</i>	dwarf glasswort	Common
<i>Salicornia europea</i>	slender glasswort	Common
<i>Salicornia virginica</i>	woody glasswort	Common
<i>Salix bebbiana</i>	Bebb's willow	Common
<i>Salix discolor</i>	pussy willow	Ubiquitous
<i>Salsola kali</i>	common salt-wort	Ubiquitous
<i>Sambucus canadensis</i>	elderberry	Common
<i>Sassafras albidum</i>	sassafras	Common
<i>Schizachyrium scoparium</i>	little bluestem	Ubiquitous
<i>Scirpus americanus</i>	Olney three-square	Common
<i>Scirpus cyperinus</i>	wool-grass	Common
<i>Scutellaria lateriflora</i>	scullcap	Common
<i>Setaria italica</i>	millet	Common
<i>Sisyrhynchium</i> sp.	blue-eyed grass	Status Undetermined
<i>Smilax glauca</i>	catbrier	Common
<i>Smilax rotundifolia</i>	bullbrier	Ubiquitous
<i>Solidago nemoralis</i>	gray goldenrod	Common
<i>Solidago odora</i>	sweet goldenrod	Common
<i>Solidago puberula</i>	downy goldenrod	Common
<i>Solidago rugosa</i>	rough-stemmed goldenrod	Ubiquitous
<i>Solidago semper-virens</i>	seaside goldenrod	Common
<i>Sparganium androcladium</i>	branching burr-reed	Common
<i>Spartina alterniflora</i>	smooth cordgrass	Common
<i>Spartina patens</i>	salt-hay	Common
<i>Spartina pectinata</i>	prairie cordgrass	Common
<i>Spiraea alba</i>	meadowsweet	Ubiquitous
<i>Spiraea tomentosa</i>	steeple-bush	Ubiquitous
<i>Spiranthes cernua</i>	nodding ladies'-tresses	Common
<i>Spiranthes vernalis</i>	spring ladies'-tresses	Rare
<i>Strophostyles helvula</i>	trailing wild bean	Common
<i>Sueda linearis</i>	southern sea-blite	Common
<i>Symplocarpus foetidus</i>	skunk cabbage	Common
<i>Teucreum canadense</i>	American germander	Common
<i>Thelypteris palustris</i>	marsh fern	Ubiquitous
<i>Thelypteris simulata</i>	Massachusetts fern	Common
<i>Toxicodendron radicans</i>	poison ivy	Ubiquitous
<i>Toxicodendron rydbergii</i>	Rydberg's poison ivy	Common
<i>Triadenum virginicum</i>	marsh St. John's-wort	Common
<i>Trientalis borealis</i>	star-flower	Common
<i>Tripasacum dactyloides</i>	gama grass	Rare
<i>Typha angustifolia</i>	narrow-leaved cattail	Common
<i>Typha latifolia</i>	broad-leaved cattail	Common



<i>Ulmus americana</i>	American elm	Common
<i>Ulmus rubra</i>	slippery elm	Rare
<i>Vaccinium corymbosum</i>	highbush blueberry	Ubiquitous
<i>Viburnum dentatum</i>	northern arrowwood	Ubiquitous
<i>Viola cucculata</i>	marsh blue violet	Common
<i>Viola lanceolata</i>	lance-leaved violet	Common
<i>Viola macloskeyi</i>	northern white violet	Common
<i>Viola sagittata</i>	arrowhead violet	Common
<i>Vitis labrusca</i>	fox grape	Ubiquitous
<i>Xyris torta</i>	twisted yellow-eyed grass	Common
Introduced Species		
<i>Agrostis capillaris</i>	Rhode Island bent grass	Ubiquitous
<i>Agrostis gigantea</i>	redtop	Common
<i>Agrostis stolonifera</i>	creeping bent grass	Ubiquitous
<i>Anthoxanthum odoratum</i>	sweet vernal grass	Common
<i>Asparagus officinalis</i>	asparagus	Common
<i>Centauria dubia</i>	blackish knapweed	Common
<i>Cerastium vulgatum</i>	common mouse-ear chickweed	Ubiquitous
<i>Chenopodium album</i>	lamb's quarters	Common
<i>Chrysanthemum leucanthemum</i>	oxeye daisy	Ubiquitous
<i>Cichorium intybus</i>	chickory	Ubiquitous
<i>Cirsium vulgare</i>	bull thistle	Common
<i>Dactylis glomerata</i>	orchard grass	Ubiquitous
<i>Datura stramonium</i>	jimsonweed	Common
<i>Daucus carota</i>	wild carrot	Ubiquitous
<i>Dianthus armeria</i>	Depford pink	Common
<i>Digitaria sanguinalis</i>	common crabgrass	Ubiquitous
<i>Elytrigia repens</i>	quack grass	Common
<i>Euonymus europaeus</i>	European spindle-tree	Rare
<i>Festuca filiformis</i>	hair fescue	Common
<i>Festuca pratensis</i>	tall fescue	Common
<i>Glaucium flavum</i>	sea poppy	Common
<i>Hieracium caespitosum</i>	yellow hawkweed	Ubiquitous
<i>Hieracium lachenalii</i>	common hawkweed	Status Undetermined
<i>Holcus lanatus</i>	common velvet-grass	Ubiquitous
<i>Hypericum perforatum</i>	common St. John's-wort	Ubiquitous
<i>Hypochoeris radicata</i>	spotted cat's-ear	Common
<i>Larix decidua</i>	European larch	Status Undetermined
<i>Leontodon autumnalis</i>	fall-dandelion	Ubiquitous
<i>Linaria vulgaris</i>	butter-and-eggs	Common
<i>Phleum pratense</i>	timothy	Ubiquitous
<i>Pinus sylvestris</i>	Scotch pine	Common
<i>Plantago lanceolata</i>	English plantain	Ubiquitous
<i>Plantago major</i>	common plantain	Common
<i>Poa compressa</i>	Canada bluegrass	Common
<i>Polygonum aviculare</i>	bird knotweed	Common
<i>Populus alba</i>	white poplar	Common
<i>Prunella vulgaris</i>	heal-all	Ubiquitous
<i>Pyrus communis</i>	common pear	Status Undetermined
<i>Pyrus cv.</i>	crabapple cultivar	Status Undetermined
<i>Pyrus malus</i>	apple	Common
<i>Quercus robur</i>	English oak	Common
<i>Ranunculus repens</i>	creeping buttercup	Status Undetermined
<i>Raphanus raphanistrum</i>	wild radish	Ubiquitous
<i>Rumex acetosella</i>	sheep sorrel	Ubiquitous



<i>Rumex crispus</i>	curly dock	Ubiquitous
<i>Rumex salicifolius</i>	triangular-valved dock	Rare
<i>Setaria glauca</i>	yellow foxtail	Common
<i>Silene latifolia</i>	white campion	Common
<i>Solanum dulcamara</i>	bittersweet nightshade	Ubiquitous
<i>Spergularia marina</i>	seabeach sand-spurry	Common
<i>Stellaria graminia</i>	common stitchwort	Common
<i>Sueda maritima</i>	white sea-blite	Common
<i>Tragopogon dubius</i>	fistulous goats-beard	Status Undetermined
<i>Trichostema dichotomum</i>	bluecurls	Ubiquitous
<i>Trifolium arvense</i>	rabbit-foot clover	Common
<i>Trifolium campestre</i>	low hop-clover	Common
<i>Trifolium pratense</i>	red clover	Ubiquitous
<i>Trifolium repens</i>	white clover	Ubiquitous
<i>Verbascum thapsis</i>	common mullein	Common
<i>Veronica officinalis</i>	common speedwell	Ubiquitous
<i>Vicia cracca</i>	cow vetch	Common
Invasive Exotics		
<i>Acer platanoides</i>	Norway maple	Common
<i>Acer pseudoplatanus</i>	sycamore maple	Common
<i>Ailanthus altissima</i>	tree of heaven	Common
<i>Berberis thunbergii</i>	Japanese barberry	Ubiquitous
<i>Berberis vulgaris</i>	common barberry	Common
<i>Celastrus orbiculatus</i>	Oriental bittersweet	Ubiquitous
<i>Centaurea nigra</i>	black knapweed	Ubiquitous
<i>Elaeagnus umbellata</i>	autumn olive	Ubiquitous
<i>Lonicera japonica</i>	Japanese honeysuckle	Ubiquitous
<i>Lonicera morrowii</i>	Morrow's honeysuckle	Common
<i>Lotus corniculatus</i>	birdsfoot trefoil	Ubiquitous
<i>Phragmites australis</i>	common reed	Ubiquitous
<i>Polygonum cuspidatum</i>	Japanese knotweed	Common
<i>Rhamnus</i> sp.	buckthorn	Common
<i>Rorippa nasturtium-aquaticum</i>	true watercress	Common
<i>Rosa multiflora</i>	multiflora rose	Ubiquitous
<i>Rosa rugosa</i>	beach rose	Common
<i>Vincetoxicum nigrum</i>	black swallow-wort	Common

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CHAPTER 6.

Terrestrial Fauna

Kenneth B. Raposa





Figure 6.1. Researchers from (a) URI and (b) RIDEM conducting research on ticks on Prudence Island using bait stations and flagging techniques. *Photo from NBNERR photo library.*

a.



b.



Figure 6.2. The dung beetle (*Phanaeus vindex*), found for the first time on Prudence Island in September 2005. *Photo by Michael Thomas.*



Terrestrial Fauna of the NBNERR

Invertebrates

Of all the terrestrial faunal groups, invertebrates in general have probably received the least amount of study in the NBNERR. The only data sources that were identified include a recent survey of tiger beetles and moths on Prudence Island, studies on ticks—due to concern surrounding tick-borne diseases—and periodic collections and surveys of various invertebrate groups on Prudence Island.

Mello (2002) conducted a survey of lepidoptera (butterflies and moths) and to a lesser extent tiger beetles in order to determine the species composition, habitat use, and distribution of these invertebrates on Prudence Island. The survey was conducted from May through November 2002 using light traps at 12 stations located in different habitats around the island. Five major habitat types were sampled, including grasslands, grassland/shrub mixes, pine barrens, forest/wetland borders, and dunes. Light trap sampling was augmented by observations and netting of butterflies, tiger beetles, and other insects conducted on 13 dates from May through September. From these efforts, 385 species of macrolepidoptera (large moths), 127 species of microlepidoptera (small moths), 33 butterfly species and five tiger beetle species were collected. Two species of lepidoptera, *Zanclagnatha martha* (pine barrens *Zanclagnatha* moth) and *Poanes viator* (broad-winged skipper) are listed as species of concern in the state. Three species of tiger beetles that were found are also listed in the state, including *Cicindela marginata* and *C. purpurea* (both of concern) and *C. tranquebarica* (threatened). Mello (2002) indicates that all of these species of concern are affiliated with grasslands and/or pine barrens, further indicating the importance of maintaining and restoring these habitats on Prudence Island. Mello also estimated that his study only documented 50 percent of the macrolepidoptera, 15 to 20 percent of microlepidoptera, 67 percent of butterflies, and 60 percent of tiger beetles that might be expected to be found on Prudence Island, illustrating that further surveys are necessary to simply document the species composition of these groups of invertebrates in the NBNERR.

The ticks on Prudence Island have been studied to a greater degree than other invertebrates due to interest in tick-borne diseases (Fig 6.1). These studies have led to an increased understanding of the ecology of these species, especially as it relates to the transmission of tick-borne dis-

eases to humans. Prudence Island is well known as a site where residents and visitors alike exhibit high incidence rates of tick-borne diseases including Lyme disease, babesiosis, and ehrlichiosis. The island supports abundant tick populations due to an overly dense white-tailed deer herd and extensive habitat conditions conducive to tick survival (Raposa and Greene, 2003). Ticks fare well where humidity levels approach 80 percent or higher while they are questing in order to avoid desiccation. These conditions are prevalent on Prudence Island due to the maritime island climate and to the extensive heavy brush and vine cover (e.g., bittersweet) on much of the island.

Prudence Island is home to the deer tick (*Ixodes dammini*), dog tick (*Dermacentor variabilis*), and lone star tick (*Amblyomma americanum*). Hu and Amr (1989) used standard flagging techniques to quantify the relative abundances of the three tick species on the North Prudence Unit of the Reserve in 1988. Of the 120 ticks collected, 49 percent were *I. dammini*; 43 percent were *D. variabilis*, and 8 percent were *A. americanum*. Hyland and Mather (1990) collected ticks from North Prudence a year later, in 1989. In this study, over 1,885 ticks were collected, with 78 percent being *A. americanum*, 18 percent being *I. dammini*, and only 4 percent being *D. variabilis*. Carroll (1990) also used flagging techniques at 10 sites throughout the island to further examine the relative abundance of the three tick species over a larger area. A total of 1,360 ticks were collected, 89 percent of which were *A. americanum*, 6 percent were *D. variabilis*, and 5 percent *I. dammini*. Ticks were collected yet again by Pollack (1996), who stated that of 1,676 ticks, most deer ticks were found at the south end of the island, while most lone star ticks were found at the north end. Dog ticks were fairly evenly distributed throughout the island.

These studies suggest that the dominant species on Prudence Island is probably the lone star tick, *A. americanum*. The differing relative abundances reported by Hu and Amr (1989) are likely due to the fact that they only collected ticks on one date in April when temperatures were 48 F and conditions were damp. Further, larval ticks were not included in this study since they had not yet emerged from eggs. In contrast, Hyland and Mather (1990) collected from May through October and Carroll (1990) collected ticks in July when temperatures were 85 F. Thus, these studies were conducted under conditions more favorable to the collection of all life-history stages of the three tick species.



Carroll et al. (1992) examined the small-scale distribution of the deer tick on residential lawns on Prudence Island. Again using standard flagging techniques, these authors showed that nymphal deer ticks were five times more abundant on lawns adjacent to woods than on lawns adjacent to other lawns. Further, they demonstrated that nymphal deer tick abundance decreased with increasing distance from woods. The prevalence of the Lyme disease-causing spirochete on ticks did not differ between lawn types or among different distances from woods (overall 31 percent of nymphal deer ticks were infected with the spirochete). This indicates that although the risk is decreased, it is still possible to contract Lyme disease on mowed residential lawns.

Work on Prudence Island by Mather and Mather (1990) showed that of the three aforementioned tick species, only *I. dammini* is a competent vector of Lyme disease. They also showed that only *I. dammini* and *D. variabilis* were found using white-footed mice as hosts. However, it was shown earlier that *I. dammini* ticks on Prudence Island carry the causative agents of both Lyme disease (the spirochete *Borrelia burgdorferi*) and human babesiosis (*Babesia microti*) (Anderson et al., 1986). The Anderson et al. (1986) study was designed to test for the presence of both agents on white-footed mice and meadow voles on Prudence and Patience islands. Of the 14 rodents examined, 71 percent were carrying *B. burgdorferi* and 57 percent carried *B. microti*; both agents were found on 36 percent of the rodents. This was the first demonstration that both diseases were present simultaneously in the same small mammal host and the authors suggest that nymphal *I. dammini* may subsequently transmit both diseases to humans.

Aside from these studies on lepidoptera and ticks, the only other sources of information on invertebrates on Prudence Island or in the NBNERR come from periodic invertebrate surveys conducted by visiting researchers. Dragonflies and damselflies were collected from Prudence Island between July 1998 and August 2001 as part of the Rhode Island Odonata Atlas compiled by the Rhode Island Natural History Survey (RINHS). Nine species were collected during this effort, including *Anax junius*, *Enallagma civile*, *Erythrodiplax berenice*, *Ischnura posita*, *Ischnura verticalis*, *Lestes rectangularis*, *Libellula pulchella*, *Pachydiplax longipennis*, and *Sympetrum rubicundulum*. Additional species, including *Pantala flavescens* and *P. hymenaea*, were found on Prudence Island in September 2005 (Brown and Brown, personal communication). Brown and Brown also discovered the presence of the dung beetle (*Phanaeus vindex*) in September

2005 in the South Prudence Unit pine barrens of the Reserve (Fig. 6.2). Prior to this discovery, the only other confirmed sighting of the dung beetle in Rhode Island was on Block Island and, interestingly, the dung beetle on Prudence Island was found using a recent dung pile left by a coyote, which is relatively new to Prudence Island.

It is clear that at present we have only a rudimentary understanding of terrestrial invertebrate species that are present in the Reserve and in other areas of Prudence Island. The studies and surveys conducted to date have resulted in an initial, although far from comprehensive, invertebrate species list. Much more work is needed to simply identify additional species that are present that have not been found in previous efforts. Research and monitoring opportunities focusing on terrestrial invertebrates in the Reserve are plentiful. Beyond species inventories, it is essential to understand how populations of rare and endangered species change over time in response to Reserve land management practices (e.g., the effects of off-road driving, maintenance mowing, and prescribed burning on populations of tiger beetles in the Reserve's pine barrens). It is also important to begin to monitor populations of ticks (and the incidence of contacting tick-borne diseases) to understand how they respond to recent RIDEM efforts to reduce the population of white-tailed deer on Prudence and Patience islands.

Reptiles and Amphibians

Until recently, the only source of information on reptiles and amphibians (collectively referred to as "herpetofauna") in the NBNERR was from inventories conducted by RIDEM periodically between 1985 and 1998. Based on these inventories, herpetofauna were not present on either Patience or Dyer islands (Ferren 1985; Raithel, personal communication). However, three species were documented on Hope Island and a relatively rich herpetological assemblage totaling 15 species was found on Prudence Island (Raithel, personal communication) (Fig. 6.3; Table 6.1).

Additional information is now available from herpetological surveys conducted by the NBNERR beginning in April 2003. Combined with RIDEM inventories, these surveys provide a solid inventory of herpetofauna, as well as relative abundance, distribution, and habitat use patterns for some species. The NBNERR surveys were all conducted on Prudence Island and included spotted salamander egg mass counts, anuran (frogs and toads) calling surveys in permanent and vernal ponds, and salamander counts using artificial cover boards (Raposa and Rehor,



Table 6.1. Reptiles and amphibians observed on Prudence and Hope islands by RIDEM between 1985–1998.

Location	Species	Common name	Total # observations
Prudence Island	<i>Ambystoma maculatum</i>	Spotted salamander	6
	<i>Bufo fowleri</i>	Fowler's toad	6
	<i>Chelydra serpentina</i>	Common snapping turtle	2
	<i>Chrysemys picta picta</i>	Eastern painted turtle	2
	<i>Clemmys guttata</i>	Spotted turtle	2
	<i>Coluber constrictor</i>	Northern black racer	2
	<i>Eurycea bislineata</i>	Northern two-lined salamander	2
	<i>Hemidactylium scutatum</i>	Four-toed salamander	2
	<i>Lampropeltis triangulum</i>	Eastern milk snake	1
	<i>Ophiodrys vernalis</i>	Eastern smooth green snake	4
	<i>Plethodon cinereus</i>	Northern redback salamander	5
	<i>Pseudacris crucifer crucifer</i>	Northern spring peeper	2
	<i>Terrapene carolina</i>	Eastern box turtle	5
	<i>Thamnophis sauritus</i>	Eastern ribbon snake	2
	<i>Thamnophis sirtalis</i>	Eastern garter snake	6
Hope Island	<i>Ophiodrys vernalis</i>	Eastern smooth green snake	1
	<i>Storeria dekayi</i>	Northern brown snake	1
	<i>Thamnophis sirtalis</i>	Eastern garter snake	2

2003). Figure 6.4 shows the locations of each of these NBNERR amphibian surveys.

Spotted salamander egg mass counts were conducted in seven ponds on Prudence Island on April 23, 2003. Three of the seven ponds surveyed contained spotted salamander egg masses and one pond contained 353 egg masses (Raposa and Rehor, 2003), which is one of the highest counts ever recorded in Rhode Island (Timm, personal communication).

Anural call surveys were conducted at seven permanent and vernal ponds on Prudence Island on six dates between April and June 2003. Anuran calling surveys documented the presence of only one species, the Northern spring peeper *Pseudacris crucifer crucifer*. However, this species was found at all but one pond surveyed, and was present on all dates, indicating its ubiquitous nature on Prudence Island. Activity levels of the spring peeper varied temporally during the survey and peaked sharply in late April.

Salamander cover boards were placed along four transects on Prudence Island, with each transect consisting of eight sets of paired boards (16 boards total). Three transects were checked for salamanders on 10 dates in 2003; the fourth transect was established later than the others and was checked only six times. Three species of salamanders were documented during the cover board survey, including the Northern redback (*Plethodon cinereus*), spotted (*Ambystoma maculatum*), and four-toed (*Hemidactylium scutatum*) salamanders. Of these, the Northern redback salamander was by far the most abundant species (87 individuals counted compared to four four-toed and one spotted salamander), and only this species displayed a seasonal pattern, clearly peaking in abundance in early June (Fig. 6.5).

Only one other source was found that provides information on herpetofauna associated with the NBNERR. Satchwill et al. (1981), while reporting results from a fish survey, noted that two Northern diamondback terrapins (*Malaclemys terrapin*) were captured in a fyke net near Jenny Creek marsh on Prudence Island. However, the continued presence of this species cannot be confirmed, as it has not been reported around Prudence Island for over 20 years.

In summary, 17 species of reptiles and amphibians have been documented on Prudence Island, and three have been found on Hope Island. Based on the available information, neither Patience nor Dyer islands support reptiles or amphibians. In contrast, 45 species are reported to occur in the whole of Rhode Island (August et al., 2001). Thus, compared to the mainland, Patience, Hope, and Dyer islands are severely depauperate of herpetological fauna (based on limited information), while Prudence Island, despite its relative small size compared to the mainland, supports just under half of all Rhode Island species. However, aside from species composition lists, and in some cases measures of relative abundance, distribution, and habitat use, very little is known about the ecology of herpetofauna in the NBNERR and it is unknown how these populations are changing over time. As is the case with invertebrates, this situation provides an excellent opportunity for further research into the ecology of herpetofauna in the NBNERR. In particular, more comprehensive surveys should be conducted to confirm or refute the absence of herpetofauna on both Patience and Hope islands. Research also needs to be conducted to explore patterns of distribution and abundance among the islands of the Reserve (in the context of island biogeography) and how herpeto-



Figure 6.3. Several amphibians and reptiles found on Prudence Island include: (a) spotted turtle (*Clemmys guttata*); (b) Northern redback salamander (*Plethodon cinereus*); (c) snapping turtle (*Chelydra serpentina*); and (d) spotted salamander (*Ambystoma maculatum*). Photo from NBNERR photo library.

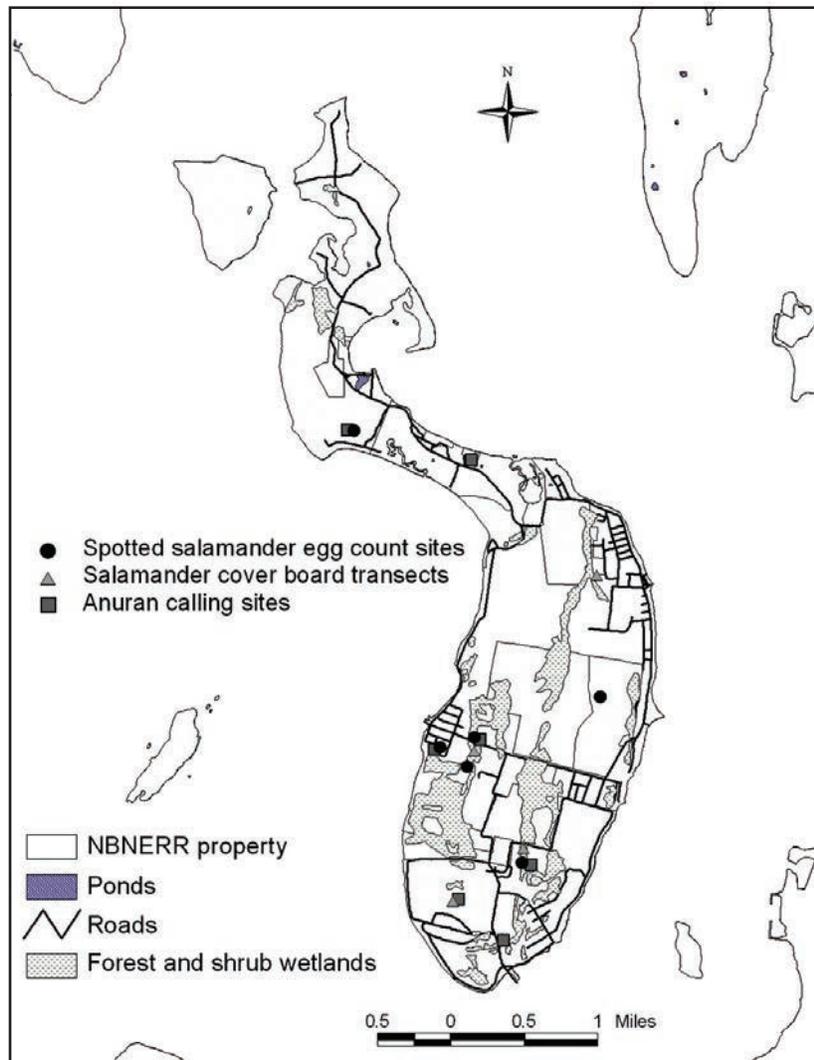


Figure 6.4. Locations of amphibian surveys, including spotted salamander egg mass counts, salamander cover board transects, and anuran calling surveys. Data from Raposa and Rehor, 2003. GIS pond and wetland data courtesy of RIGIS.

fauna respond to upland management and restoration activities.

Birds

Prudence, Patience, Hope, and Dyer islands provide important habitat for an abundant and diverse bird community that attracts birders and researchers alike. The earliest reported bird-related research at the NBNERR began in 1964 when an annual maritime nesting bird monitoring program was initiated around the Rhode Island coastline. This ongoing program includes a number of sites that are now located within the Reserve and is described in detail in Ferren and Myers (1998). Further research on bird communities includes breeding bird surveys that were conducted on Patience Island in 1985 (Ferren, 1985) and on Prudence Island in 1981, 1990, 2003, and 2004 (MacLachlan, 1981; Enser, 1990; Enser et al., unpublished data). A multifaceted study focusing on estuarine waterbirds and migrating songbirds was conducted on Prudence Island in the late 1990s (Osenkowski and Paton, 2000; Paton and Osenkowski, 2000). All of these studies have focused on bird communities or groups of targeted species. In contrast, Diquinzio (2000, 2001) focused her master's thesis on a single species, the salt marsh sharp-tailed sparrow, while she was a graduate research fellow at the Reserve. Ancillary bird data come from wildlife surveys conducted by NBNERR beginning in 2003 (Raposa and Rehor, 2004) and from casual observations and personal communications with local experts.

Maritime Nesting Birds

The longest record of birds in the Reserve comes from a maritime nesting bird monitoring program conducted by RIDEM (Ferren and Myers, 1998; see also Chapter 11, which focuses on estuarine birds throughout Narragansett Bay). This annual survey began in 1964, is ongoing, and covers a period of over 40 years. It involves locating, identifying, and counting all of the nests of a targeted subset of coastal bird species along the coast of Rhode Island, including the shoreline of Narragansett Bay, all of the bay islands, and Block Island. Target species include colonial herons and egrets, glossy ibis (*Plegadis falcinellus*), terns, gulls, and cormorants. Maritime bird nesting sites have been identified throughout coastal Rhode Island and in the Reserve on Hope, Dyer, and Prudence islands (Fig. 6.6). This survey clearly illustrates that the composition and abundance of maritime nesting birds at individual sites can vary considerably over time due to factors that include the

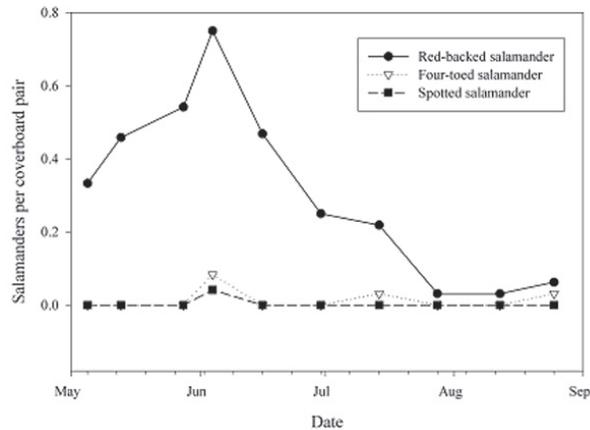
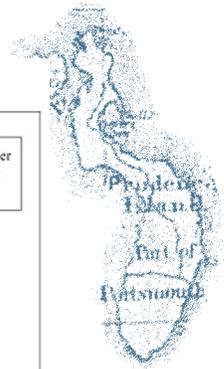


Figure 6.5. Abundance of salamanders found under paired coverboards during 2003 on Prudence Island. Data from Raposa and Rehor, 2003.

return of long-displaced species to Narragansett Bay and significant disturbance-mediated movements of species among island nesting sites (Ferren and Myers, 1998).

Despite its relative large size, Prudence Island has only one location that has been identified as a maritime bird nesting site by Ferren and Myers (1998). Gull Point, a sandy spit with an associated small salt marsh on the northeast side of Potter Cove, has sporadically supported least tern (*Sterna albifrons*) nests beginning in 1984, although none has been recorded there since 1995 (Appendix 6.1). Ferren and Myers (1998) also note, however, that other maritime birds had historically nested on Prudence Island before their study began. They note that common terns were found nesting on Gull Point in 1946 and that a large colony of black-crowned night herons (*Nycticorax nycticorax*) persisted in Crow Swamp near the southwest corner of Prudence in the late 1800s and early 1900s.

In contrast to Prudence and Patience islands (on which maritime birds do not nest), Hope and Dyer islands continually support impressive colonies of nesting maritime birds despite their small size (Fig. 6.7). For example, in 2003 Dyer Island supported over 429 nests of gulls (290 herring gull, *Larus argentatus*, nests; 139 great black-backed gull, *Larus marinus*, nests) and was one of only 10 sites in Rhode Island used by nesting American oystercatchers (*Haematopus palliatus*). Although it no longer does so, Dyer Island also supported a sizable heronry for approximately 13 years between 1980 and 1992. Even more impressive are the nesting colonies found on Hope Island and on some of its surrounding rocky outcrops. Hope Island currently supports one of the most diverse and abundant heronries in Rhode Island and has done so for much of the survey period. Of the three sites in Rhode Island where nesting black-crowned night herons are currently found, Hope Island supports the largest





colony while also supporting large numbers of herring gulls, great black-backed gulls, and double-crested cormorants (*Phalacrocorax auritus*). Hope Island represents such an important nesting area that the state closes the island to human use throughout the nesting period (April 1 through August 15). Surrounding Hope Island are three rocky outcrops, known as Little Gooseberry Island, Despair Island, and Scup Rock, that are also nesting sites for maritime birds including herring gulls, great black-backed gulls (Little Gooseberry Island and Scup Rock), and common terns (*Sterna hirundo*) (Despair Island).

Songbirds

Ferren (1985) conducted the first and only survey of breeding birds (Fig. 6.8) on Patience Island. This was a one-day survey that was conducted by walking in and around the island for four hours (between 1000 and 1400) on 4 June 1985. A total of 324 individual birds representing 35 species was found, although not all of them were confirmed as breeding (Appendix 6.1). The most abundant species were gray catbird (*Dumetella carolinensis*; 56 individuals; 17 percent of the total number of birds), common yellowthroat (*Geothlypis trichas*; 52; 16 percent), rufous-sided towhee (*Pipilo erythrophthalmus*; 31; 10 percent), yellow warbler (*Dendroica petechia*; 17; 5 percent), American redstart (*Setophaga ruticilla*; 17; 5 percent), and white-eyed vireo (*Vireo griseus*; 16; 5 percent). Red-winged blackbird (*Agelaius phoeniceus*), sharp-tailed sparrow (*Ammodramus caudacutus*), and swamp sparrow (*Melospiza georgiana*) were observed in or in close proximity to the small salt marsh along the southeast side of the island, while European starling (*Sturnus vulgaris*), house finch (*Carpodacus mexicanus*), and rock dove (*Columba livia*) were observed in human-modified habitats (open clearings and buildings).

Breeding birds have been surveyed more often on Prudence Island. Andrew MacLachlan, then a RIDEM ranger-naturalist, surveyed breeding and nonbreeding birds during the summer and fall of 1981. Most of the survey was conducted between June and October 1981, although some additional surveys were made in May 1981. Data were collected either by general observations made by the naturalist around the island or during one of four morning walks in the middle and northern sections of Prudence as part of the Breeding Bird

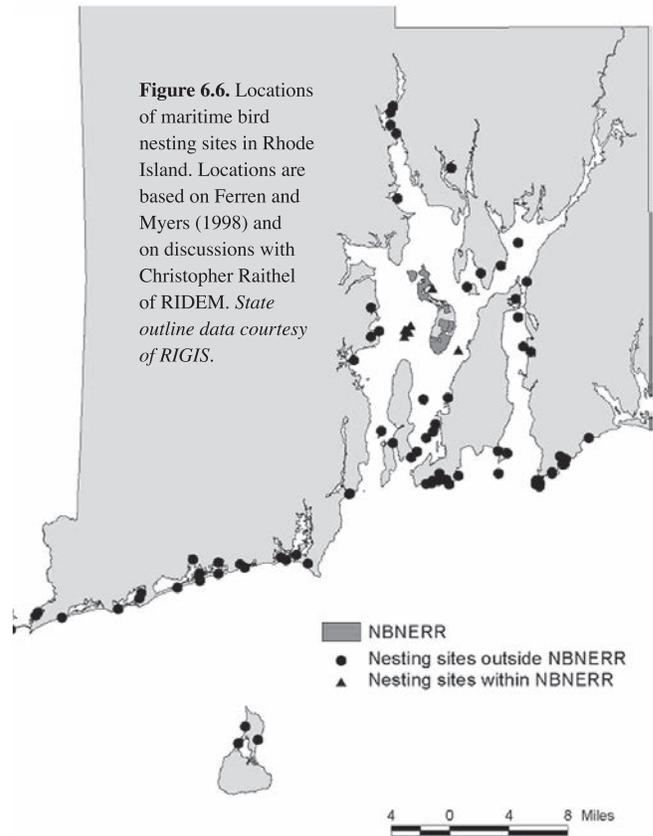


Figure 6.6. Locations of maritime bird nesting sites in Rhode Island. Locations are based on Ferren and Myers (1998) and on discussions with Christopher Raithel of RIDEM. State outline data courtesy of RIGIS.

Atlas project (Enser, 1992). Eighty-one species of birds were observed during this survey, 48 of which may have been breeding (14 species confirmed breeding, 21 probable, 13 possible) (MacLachlan, 1981) (Appendix 6.1). Unfortunately, this study did not include quantitative data on bird abundance, nor did it describe species distributions. Therefore, this study provides only a species list of breeding and nonbreeding birds around Prudence Island at that time.

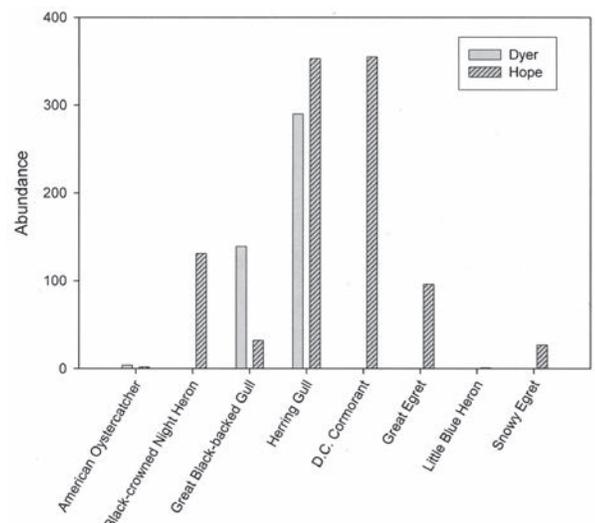


Figure 6.7. Abundance of maritime nesting birds on Dyer and Hope islands in the NBNERR in 2003. Data are from the long-term maritime nesting bird monitoring program, provided by RIDEM.



A more systematic survey of breeding birds was conducted on Prudence Island from 5 June to 8 June 1990 (Enser, 1990). Although the authors of this study used more than one survey method, most of the study was focused on results from point counts. Point counts were made at 59 points along four routes—three walking transects at the north end, southwest corner, and interior of the island, and one driving transect that covered much of Prudence (Fig. 6.9). At each point, recordings were made of all birds seen or heard within 10 minutes. Other techniques (e.g., using prerecorded bird calls and site/species/habitat-specific surveys) were also applied to detect species that might not be found during the early morning point sampling or in habitats where points were located. Eighty-three species of birds were recorded during this survey, 69 of which were considered to be breeding on the island (Appendix 6.1). The other 14 species included wading birds, gulls, and shorebirds, but species names or counts were not provided in the report (Enser, 1990). The most abundant species in this study were gray catbird (119 pairs; 11 percent of the total number of birds), rufous-sided towhee (104; 10 percent), common yellowthroat (93; 9 percent), yellow warbler (66; 6 percent), American robin (*Turdus migratorius*; 57; 5 percent), and house wren (53; 5 percent). These same six species were also observed at the highest number of survey points (i.e., most frequently) indicating their ubiquitous distribution on the island. More recently, Enser's (1990) survey was repeated annually from 2003 through 2006, although results of these surveys have yet to be synthesized.

Mist nets were used to conduct surveys of migrating songbirds on Prudence Island in 1999 (Fig. 6.10) (Osenkowski and Paton, 2000). Mist nets (12 meters (m) long, 30-millimeter (mm) mesh) were used to collect birds at four stations on Prudence. The stations were located on the North Prudence Unit between Narragansett Bay and the north end farm (called the North Reserve Station), in Coggeshall Marsh (Coggeshall Cove Station), adjacent to Nag Marsh near the center of the island (Nag Pond Station), and along a power-line clearing near the NBNERR Learning Center (Power-line Station) (Fig. 6.9). The number of sample dates and number of nets in operation varied among stations, although all sampling occurred between 19 August and 28 October 1999. The total number of net-hours also varied among stations (656 net hours at Power-line, 415 at Nag Pond, 131 at North Reserve, and 249 at Coggeshall Cove). On each sample day, mist-nets were generally operated for five hours, beginning 0.5 hour before sunrise. A total of 2,296 birds representing 63 species were captured during the mist-netting study (Appendix 6.1). The most abundant species

included gray catbird (32 percent of the total by abundance), yellow-rumped warbler (*Dendroica coronata*; 24 percent), ruby-crowned kinglet (*Regulus calendula*; 7 percent), song sparrow (*Melospiza melodia*; 4 percent), and black-capped chickadee (*Parus atricapillus*; 4 percent). Peak captures were made during the second week of October. Species diversity was not considered particularly high when compared to similar monitoring conducted on Block Island, R.I., although the Nag Pond and Coggeshall Cove mist-net stations had capture rates that were high compared to most banding stations in North America (Osenkowski and Paton, 2000).

The salt marshes on Prudence Island support populations of the salt marsh sharp-tailed sparrow. DiQuinzio (2000) and DiQuinzio et al. (2001) examined site fidelity, survival, and nesting ecology of this species in the marshes on Prudence Island and in marshes along mainland Rhode Island from 1994 to 1998. Some notable findings from DiQuinzio et al. (2001) were that adult return rates (after migrating) of adult sharp-tailed sparrows did not differ between marshes on Prudence Island and mainland sites, while return rates of juveniles were significantly higher at Prudence Island marshes (as well as Sachuest Point salt marsh in Middletown, R.I.) than at marshes along the south shore of Rhode Island. It was also found that individual sparrows often moved between nearby marshes on Prudence Island (e.g., between Coggeshall Marsh and Providence Point marsh at the tip of Prudence), but that movements between Prudence and mainland marshes did not occur. The density of adult female sparrows on Prudence Island was 1.1 birds ha⁻¹, which was towards the low end of the range of densities observed at mainland sites (0.7–3.3 birds ha⁻¹) (DiQuinzio, 2000).

Striking differences in nest location and nest success rate were also apparent between Prudence Island and mainland marshes. Most nests (63 percent) on Prudence Island were found in salt meadow habitats, while just over half (51 percent) mainland nest locations were in mixed salt meadow and short *Spartina alterniflora* areas. Nest success on Prudence Island was only 22 percent compared to 74 percent on the mainland. Of the failed nests on Prudence, some (11 percent) were due to predation, but most (78 percent) were due to flooding. DiQuinzio (2000) attributes the high degree of failed nests on Prudence Island to the lack of tidal restrictions and the generally exposed nature of marshes on Prudence Island, which is located in the open center of Narragansett Bay. Thus, despite the relatively pristine nature of the salt marshes on Prudence Island (according to DiQuinzio), the high energy and exposure of these marshes leads to a high



a.



b.

Figure 6.8. Common breeding birds in the NBNERR include: (a) gray catbird (*Dumetella carolinensis*) and (b) yellow warbler (*Dendroica petechia*). Photo from U.S. Fish & Wildlife Service photo library.

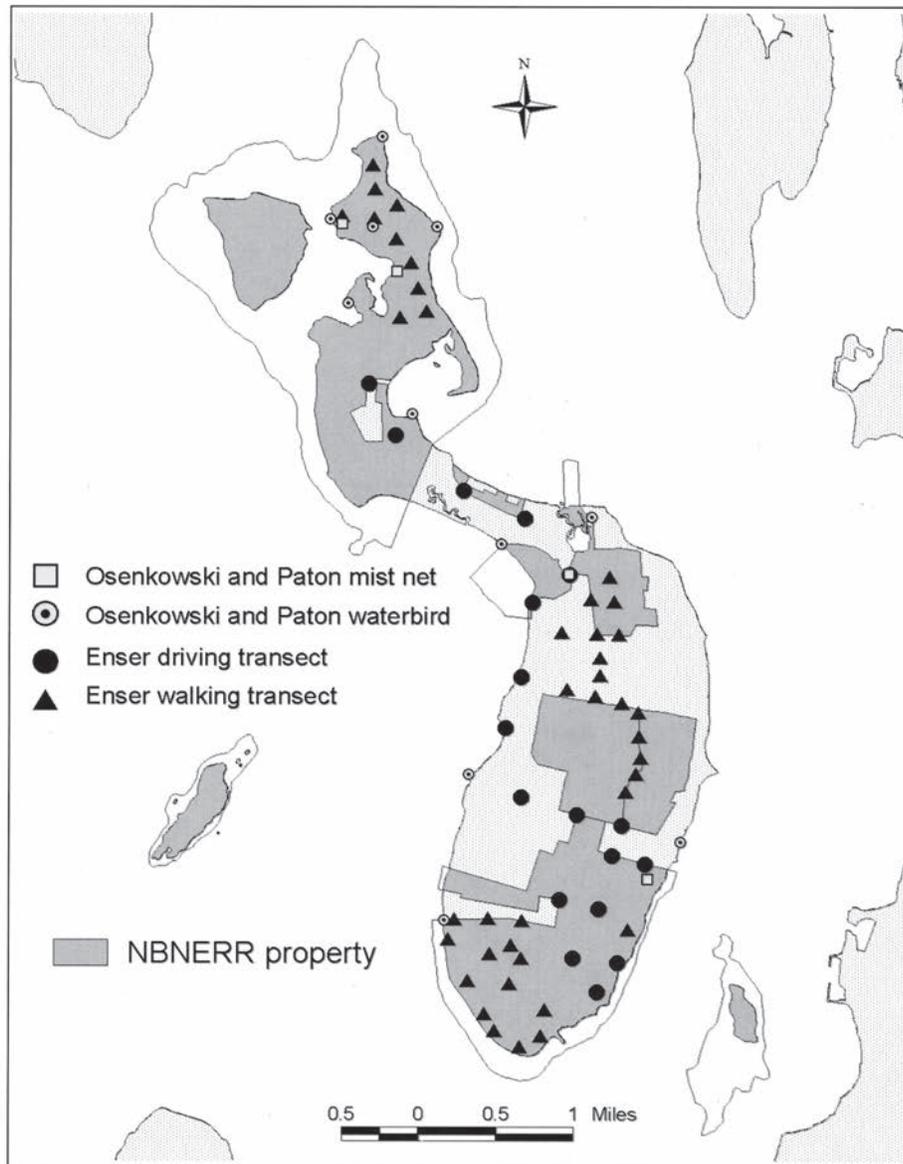


Figure 6.9. Locations of all bird sampling stations on Prudence Island described in Enser (1990) and Osenkowski and Paton (2000). Station locations were approximated based on information and figures provided in the original reports.

degree of failed nests and possibly to the relatively low density of sharp-tailed sparrows as compared to mainland sites. On the other hand, DiQuinzio (2000) also found that the only environmental variable that was positively related to nest success was vegetation cover height (mostly due to high success rates in *Phragmites*). None of the nests on Prudence Island was found in *Phragmites*, which is relatively uncommon on Prudence. This absence also partially explains the low success rate of sharp-tailed sparrow nests on Prudence Island.

Estuarine Waterbirds

A survey of estuarine waterbirds was conducted in 1997 and 1998 to quantify the spatial distribution of birds in the nearshore waters around Prudence Island and to examine seasonal patterns in abundance and distribution (Paton and Osenkowski, 2000). Twelve point-count stations were established around Prudence where nearshore estuarine waters could be observed (Fig. 6.9). Twenty-one surveys were conducted at each station between 20 June 1997 and 10 April 1998. During each survey, counts were made of all birds (including terrestrial birds) that were observed within a 250-m radius during a 5- to 10-minute period. Results were presented for the summer-fall season (all 1997 sampling) and the winter-spring season (1998 sampling). Most of the results from this survey are reported in Paton and Osenkowski (2000), but Osenkowski presents some additional data in an undated supplemental report. According to this study, the most abundant estuarine waterbirds include the herring gull (13.9 percent of all birds, plus an additional 12.9 percent for unidentified gull species), common goldeneye (*Bucephala clangula*; 13.7 percent), American black duck (*Anas rubripes*; 8.7 percent), brant (*Branta bernicla*; 4.4 percent), red-breasted merganser (*Mergus serrator*; 3.8 percent), double-crested cormorant (3.1 percent), horned grebe (*Podiceps auritus*; 2.7 percent), Canada goose (*Branta canadensis*; 2.6 percent), and white-winged scoter (*Melanitta deglandi*; 2.4 percent). Similarly, Raposa and Rehor (2004) found that the most abundant waterbird species were (in decreasing order) the herring gull, Canada goose, American black duck, common goldeneye, brant, bufflehead (*Bucephala albeola*), red-breasted merganser, and great black-backed gull. Although no long-term datasets exist to track trends in waterbird community composition and species abundance, Paton and Osenkowski (2000) suggested that even though waterbirds are currently common around Prudence Island, the numbers do not seem as high

as in the past (e.g., 30 to 40 years ago). As evidence, they note the observation of more than 20,000 scaup off of the north end of Prudence in the 1960s; this is an order of magnitude larger than any waterbird sightings in recent efforts.

Summary

Based on the research described above, 151 species of birds have been observed on and around Prudence, Patience, Hope, and Dyer islands (Appendix 6.1). The Eastern bluebird (*Sialia sialis*), turkey vulture (*Cathartes aura*), snow bunting (*Plectrophenax nivalis*) (Raposa, personal observation), and yellow-breasted chat (*Icteria virens*) (Enser, personal observation) have all been observed on Prudence Island since 2001, bringing the total to 155. This represents just over half (50.3 percent) of the 308 total bird species that are listed as occurring in Rhode Island, not including casual (species that do not normally occur here but have been seen more than five times), accidental (seen less than five times), or hypothetical species (Conway, 1992). This relatively high percentage probably results from multiple interacting factors, including the diversity of terrestrial and estuarine habitats found around the Reserve (Chapter 5), the amount of protected open space on the islands, and the level of effort devoted to surveying birds in the area (i.e., more effort can lead to more species observed).

The diversity of habitats found on the island undoubtedly attracts birds. Vigness Raposa (2004) determined that most of the songbirds examined were distributed around Prudence Island in response to specific habitat types, rather than in response to coarser measures such as vegetation structure. The coastline of Prudence Island is composed of numerous shallow coves that provide protected habitats for rafts of migratory ducks (e.g., bufflehead, merganser, goldeneye) and other species throughout the winter. The dry, sandy areas at the south end and central portions of the island support pine barrens and open grasslands that are utilized heavily by species such as red-tailed hawk (*Buteo jamaicensis*) and American kestrel (*Falco sparverius*) (Figs. 6.11 and 6.12). The numerous meadow and fringe marshes, particularly on the northern half of the island, provide important foraging habitat for wading birds such as great egret (*Casmerodius*



Figure 6.10. URI researchers sampling breeding birds on Prudence Island. Photo from NBNERR photo library.

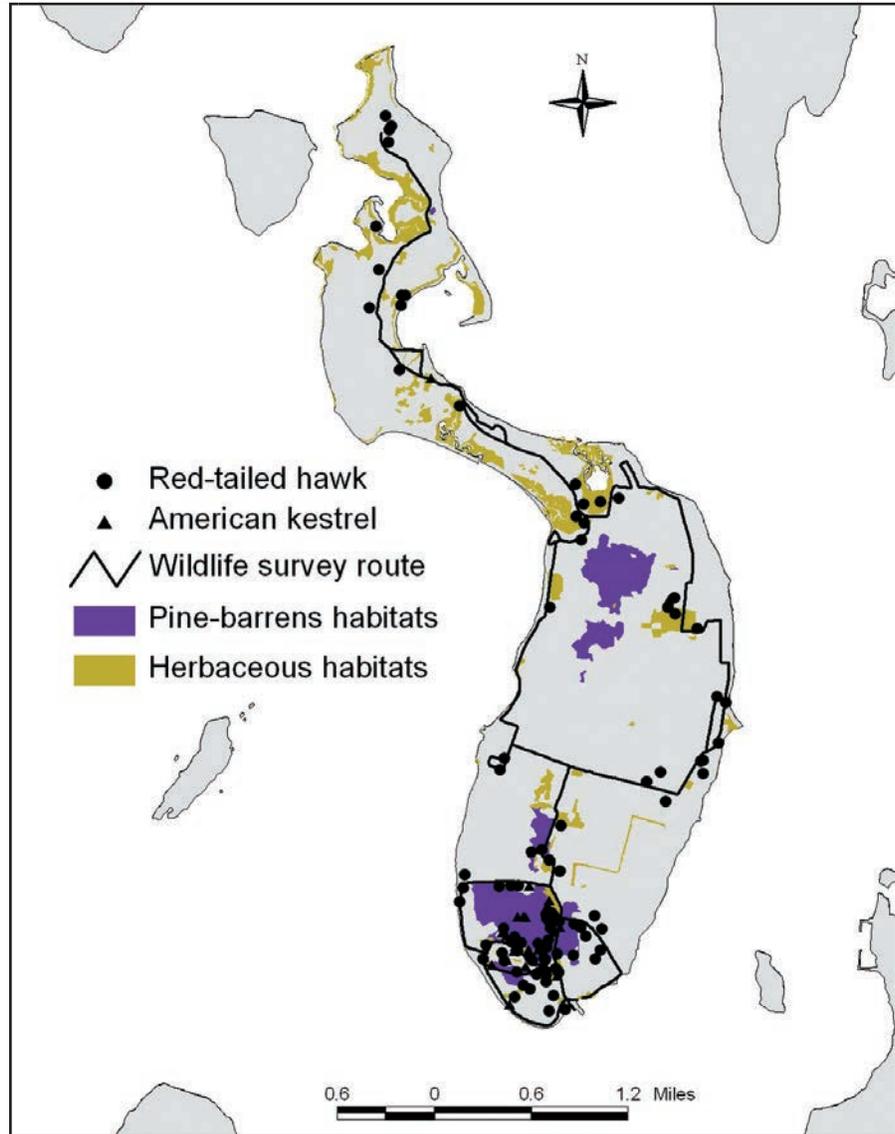


Figure 6.11. Locations of red-tailed hawk and American kestrel observed during the 2003–2004 NBNERR wildlife driving surveys (Raposa and Rehor, 2004) in relationship to pine barrens and herbaceous (including upland grasslands and meadows and estuarine salt marshes) habitats.



a.



b.

Figure 6.12. Common raptors on Prudence Island include: (a) red-tailed hawk (*NBNERR photo library*) and (b) American kestrel (*U.S. Fish & Wildlife Service photo library*).



albus), snowy egret (*Egretta thula*), great blue heron (*Ardea herodias*), and glossy ibis (*Plegadis falcinellus*). The marshes also provide overwintering habitat for ducks, geese, and other species. Numerous small streams that empty into Narragansett Bay from Prudence Island provide freshwater to coastal birds and attract dense concentrations of species such as herring gull, great black-backed gull, brant, Canada goose, mute swan (*Cygnus olor*), ducks, and crows (Raposa, personal observation).

The relatively isolated nature of all four of the islands may also help attract large numbers of maritime wading birds. None of the islands is directly accessible by car (cars on Prudence arrive by ferry), and all but Prudence receive very few visitors. Birds on all of the islands, Prudence included, generally receive very little disturbance from humans. The year-round human population on Prudence is only about 150 people, and even though this swells to over 2,000 at times in the summer, the impenetrable habitats and high tick populations act to keep people out of most of the habitats favored by a number of bird species. Hope Island is the most isolated island in Narragansett Bay; its closest points are the southwest side of Prudence at approximately 1.53 miles and Quonset Point on the mainland at 1.66 miles. The abundant and diverse assemblage of nesting birds on Dyer and Hope islands is undoubtedly due in part to the isolated nature of these islands as well as to the lack of predators such as red fox and raccoon (Raposa and Rehor, 2004).

While it is not possible to quantitatively compare results from the various surveys described above because of differences in sampling techniques, habitats, and sample locations, some patterns are clear. It seems that the most abundant songbird species on Prudence and Patience islands is the gray catbird. It was the most abundant species on Patience (Ferren, 1985) and Prudence (Enser, 1990; Osenkowski and Paton, 2000), and the high abundance of this species is undoubtedly due to the proliferation of the thick undergrowth, brush, and thorn-scrub habitats that this species prefers (Peterson, 1980). Other abundant songbird species such as yellow-rumped warbler, ruby-crowned kinglet, rufous-sided towhee, yellow warbler, and common yellowthroat (Appendix 6.1) also prefer these kinds of habitats along with the marshes and forests that are also common on Prudence. These types of species were relatively less abundant during the Paton and Osenkowski (2000) estuarine waterbird study, although these sampling stations were deliberately selected to observe estuarine waterbirds (e.g., ducks, gulls, geese).

Species that occur in noticeably low numbers in each study represent those that are often

associated with humans, such as the house sparrow (*Passer domesticus*), rock dove, and common grackle (*Quiscalus quiscula*). This is partly due to sample station selection, since sampling stations were not established in the vicinity of Homestead or other residential areas on the island. An exception was the observance of 446 European starlings during the Paton and Osenkowski (2000) estuarine waterbird study. However, large numbers of starlings were observed only at a single station near a residential community along the southeast shore of Prudence Island. More recently, Raposa and Kutcher (unpublished data) sampled breeding birds specifically from residential and forested areas and found striking differences in bird communities among the two treatments, with large numbers of human-associated birds observed in residential areas. Even so, human development is limited on Prudence Island (Chapter 4), and these species are probably not abundant on an island-wide basis.

Some notable species, populations, or communities of birds have been documented on at least one of the islands during the bird surveys described here. For example, Dyer Island is one of only 10 nesting sites in Rhode Island for the locally rare American oystercatcher (Ferren and Myers, 1998), while Hope Island supports the single most species-rich nesting colony of coastal birds in the state. In addition, Prudence Island may support the greatest abundance of breeding screech owls (*Otus asio*) in Rhode Island (Enser, 1990) and has recently been found to support the rare yellow-breasted chat (Enser, personal observation).

In summary, the diversity of natural habitats, both coastal and upland, attracts a rich and diverse avifauna to the islands of the Reserve, providing ample opportunity for bird-watching, monitoring, and research. However, it has been over 18 years since breeding birds were surveyed on Patience Island, and even then the survey was only for four hours on one day. Breeding birds have not been surveyed on Hope or Dyer islands. It is recommended that quantitative surveys be initiated on Patience, Hope, and Dyer islands to provide baseline information on bird use of these islands. It is also recommended that a meta-analysis be performed of breeding bird surveys that have already been conducted (1990, 2003–2006) in order to assess temporal changes in the avifauna of Prudence Island. On a broader scale, it is also essential that the Reserve determine the relative value of each Reserve island for migrating songbirds compared to other locations in Narragansett Bay and on Block Island (renowned as a stopover site for migratory birds) to help guide its habitat stewardship and management programs.



Mammals

Due to limited research, very little is known about the ecology of mammals on Prudence, Patience, Hope, and Dyer islands. The only available sources of information on mammals include a mammal trapping survey conducted in the 1950s (Cronan and Brooks, 1962), recent NBNERR wildlife surveys (Raposa and Rehor, 2004), and annual summaries of deer population dynamics on Prudence Island provided by RIDEM (e.g., Gibson and Suprock, 2000). Ancillary information on small rodent abundance is also available from studies relating to ticks and tick-borne diseases. At best, these data sources allow for the compilation of mammal species lists and a time series record of white-tailed deer population size.

Early Mammal Surveys

The first information on mammals on Prudence Island was collected during a statewide mammal survey conducted by RIDEM, URI, and the U.S. Fish and Wildlife Service between 1955 and 1957 (Cronan and Brooks, 1962). The survey was conducted mainly by trapping, although additional information was obtained through collections of road kill, nuisance animals, and animals that were turned in by the public. This was not a quantitative survey and it was not always clear whether or not certain species were present on Prudence or the other three islands that constitute the NBNERR. Prudence Island was sometimes specifically mentioned, but often all of the islands of Narragansett Bay were collectively mentioned as a group. Based on this survey, gray squirrel (*Sciurus carolinensis*), white-footed mouse (*Peromyscus leucopus*), meadow vole (*Microtus pennsylvanicus*), muskrat (*Ondatra zibethica*), Norway rat (*Rattus norvegicus*), red fox (*Vulpes vulpes*), raccoon (*Procyon lotor*), mink (*Mustela vison*), striped skunk (*Mephitis mephitis*), and white-tailed deer were all present on Prudence Island in the 1950s (Fig. 6.13). The white-footed mouse was also reported on Patience Island. It was also likely that the house mouse (*Mus musculus*), eastern cottontail rabbit (*Sylvilagus floridanus*), and little brown (*Myotis lucifugus*), big brown (*Eptesicus fuscus*), and red (*Lasiurus borealis*) bats were found on Prudence Island during the time of the survey, although this was not explicitly stated.

NBNERR Surveys

More recent mammal data are available from wildlife surveys initiated by the NBNERR in 2003.

The two components of this effort include weekly driving surveys around Prudence Island to document all visible mammals (and other wildlife) and scent stations to determine the presence and general distribution of mammalian scavengers and predators on each of the islands (detailed methods are available in Raposa and Rehor, 2004). The information gained from using scent stations is limited due to a small sample size ($n=12$; nine on Prudence, one each on Patience, Hope, and Dyer) and to a single sampling date (26 March 2003). With this in mind, red fox, raccoon, and feral cat (*Felis domesticus*) were the only species attracted to scent stations on Prudence Island. Red fox and raccoon were frequently observed (six and seven stations visited on Prudence, respectively), suggesting that these two species are ubiquitously distributed around Prudence Island. Red fox was the only species found on Patience Island, and no species were recorded from either Hope or Dyer islands. Although extremely limited, these results from Dyer and Hope islands, when coupled with the presence of established estuarine bird colonies (Ferren and Myers, 1998), support the premise that these islands are not inhabited by predatory mammals.

The most complete dataset regarding mammals on Prudence Island was obtained from a multiyear wildlife driving survey (Raposa and Rehor, 2004). This survey was conducted by driving an approximately 20-mile route around Prudence Island (Fig. 6.14) each week between 6 January 2003 and 18 April 2005. In 2003, four surveys were conducted on each date (at dawn, midday, dusk, and night) to account for diel variability in activity patterns. In 2004 and 2005, this was reduced to only dawn and dusk surveys on each date. Based on 2003 data (compiled by Raposa and Rehor, 2004), eight mammal species were observed on Prudence Island, including white-tailed deer (7,753 total individuals sighted), Eastern cottontail rabbit (252), Eastern gray squirrel (186), red fox (87), raccoon (85), feral cat (65), mink (8), and northern river otter (*Lontra canadensis*) (1). No additional mammal species were observed in either 2004 or 2005. Some species exhibited clear seasonal patterns that may reflect real changes in abundance throughout the year (e.g., more eastern cottontail rabbits are born into the population in spring and summer) (Fig. 6.15). Other changes may simply be due to changes in the detection ability of the observer. For example, the fewer sightings of gray squirrels in summer may simply be due to the difficulty of seeing these smaller animals through thick summer vegetation and leaves in which they are found. This is a problem common to all line-transect surveys (Krebs, 1989), and since detection function was not determined for the NBNERR surveys, care must be taken when interpreting the results. How-



Figure 6.13. Common mammals found on Prudence Island include: (a) red fox and (b) raccoon. *Photo from U.S. Fish & Wildlife Service photo library.*

ever, the NBNERR data are useful for identifying species that are present and where they are typically found on Prudence Island since every sighting location of some target species was located on a map.

The most recent confirmed mammal species present on Prudence Island is the coyote (*Canis latrans*; Fig. 6.16). Anecdotal accounts from Prudence Island residents suggest that one or two animals were present on the island in the past, but these sightings were not officially confirmed. However, in spring 2005 NBNERR staff saw one animal in the pine barrens in the South Prudence Unit, and the presence of at least two coyotes in this area was confirmed in June 2005 by capturing both animals on film using a motion-detection camera. More recently, NBNERR staff members have observed coyote scat on other parts of Prudence Island, including in the North Prudence Unit.

White-Tailed Deer

The white-tailed deer is easily the most abundant and ubiquitous medium-to-large mammal species present on Prudence and Patience islands (Fig. 6.17). Prudence Island is well known as a premier bow-hunting site in New England, and deer are readily visible on much of the island throughout the year. White-tailed deer have been the focus of more monitoring than any other mammal species on Prudence Island, primarily because of their value as a game species, but also due to their effects on island habitats and their role in the life cycle of ticks. Deer were by far the most commonly sighted mammal on Prudence Island during a multiyear driving survey (Raposa and Rehor, 2004), and during this study they were abundant throughout the year (Fig. 6.15) and on all parts of the island.

RIDEM has estimated the size of the deer population, hunting rate, recruitment, mean weight, and other population parameters from 1977 to the

present on Prudence Island (Gibson and Suprock, 2000). Since 1977, the density of white-tailed deer on Prudence Island has exceeded 30 deer km⁻² (79 mile⁻²) according to RIDEM population estimates (Fig. 6.18). Mean density between the years of 1977 and 1999 was 47 deer km⁻² (120 mile⁻²), with a peak of 66 deer km⁻² (169 mile⁻²) in 1993. Between the years of 1991 and 1995, deer density did not drop below 64 deer km⁻² (164 mi⁻²). More recent data indicate that deer numbers remain high on Prudence Island (Gibson, personal communication). When deer herds are overabundant, the results include altered or degraded forest understory (Tilghman, 1989; Healy, 1997), a reduction in food and cover for other species (McShea and Rappole, 1997), and an increase in the abundance of ticks and the incidence of tick-borne diseases among humans (Anderson et al., 1987; Krause et al., 2002). RIDEM recognizes the extreme overabundance of deer on Prudence, and in 2003 and 2004 the agency facilitated the largest hunting quotas yet for deer (over 300 deer were taken each year). It is expected that these quotas and future efforts will lead to the long-term reduction in deer density on the island in order to improve deer health, forest regeneration, and to reduce tick abundance and the incidence of disease (Gibson, personal communication).

Summary

Based on the limited information available, approximately 15 species of mammals are currently present on Prudence Island (assuming that the rodents and bats described in Conan and Brooks (1962) are indeed currently present on the island). Anecdotally, most locals agree that striped skunk was never present on the island, in contradiction with results described by Cronan and Brooks (1962). In contrast, the dearth of information limits the confidence with which the number of mammal species



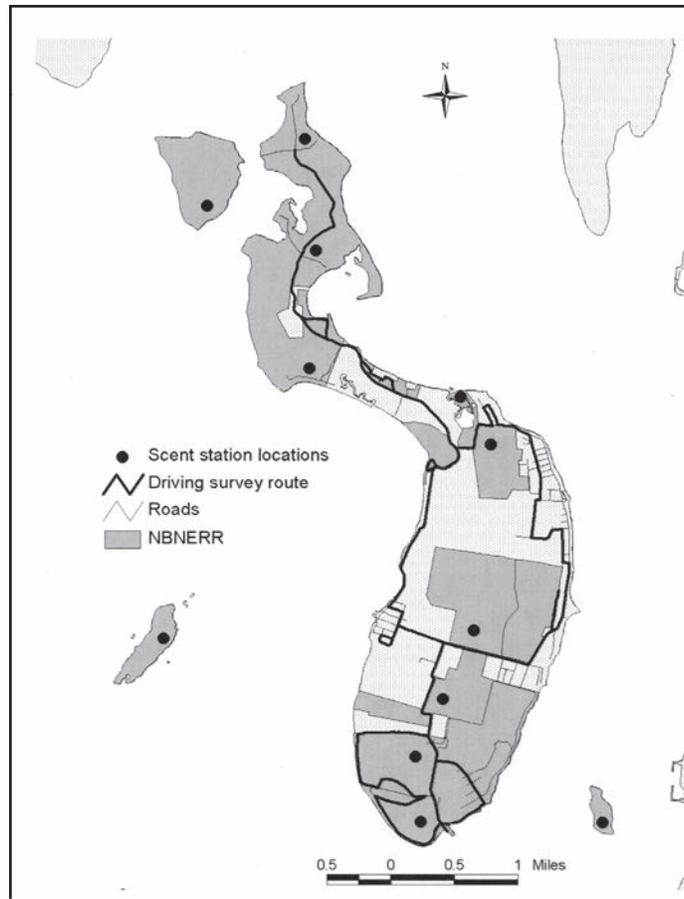


Figure 6.14. Locations of scent stations on each of the NBNERR islands and the driving survey route on Prudence Island.

on Patience, Hope, and Dyer islands can be stated. However, mammalian predators and scavengers are apparently absent from either Hope or Dyer islands, partly explaining the success of the heronries and other colonial wading bird populations on these islands. Also important is the absence of white-tailed deer from Hope and Dyer islands. This absence helps to limit the abundance of ticks and probably helps limit the distribution of invasive species, such as Asiatic bittersweet, that are resistant to deer browsing (Ward, 2000). Thus, the absence of deer from these islands may help result in substantially different floral and faunal communities compared to Prudence and Patience islands, suggesting that these higher trophic-level species are exhibiting some degree of top-down control on island ecosystem function.

Due to the limited body of work on mammals it is essential that more research be conducted to better understand the functional roles of mammals on the NBNERR island ecosystems. It would also be useful to understand how these species are responding to human activities and manipulations (e.g., prescribed burns and the creation of wildlife

openings) on these island settings. Additional quantitative surveys of white-tailed deer populations on Prudence Island are needed in recognition of the limits of semiannual spotlight surveys (the RIDEM Division of Fish and Wildlife conducts one evening spotlight survey in spring and again in fall, and the NBNERR driving surveys clearly demonstrate that there is high variability in deer sightings on a weekly basis (Fig. 6.15)). It is also essential to determine which habitats and areas of the island deer are using during different times of the year and the ecological effects of the deer herd reductions that are currently under way (Gibson, personal communication). In addition, a prime opportunity now exists to study the effects of the introduction of a top predator (the coyote) to Prudence Island, which has been lacking such a predator (aside from humans) for at least hundreds of years. Coyotes that are new to the island will surely find ample food supplies in the form of deer, and other small mammals and animals. Their effects on the deer herd and in turn other ecosystem components on Prudence should be monitored and studied to document the effects of predator reintroduction and to determine the extent to which top-down control affects coastal New England island ecosystems.

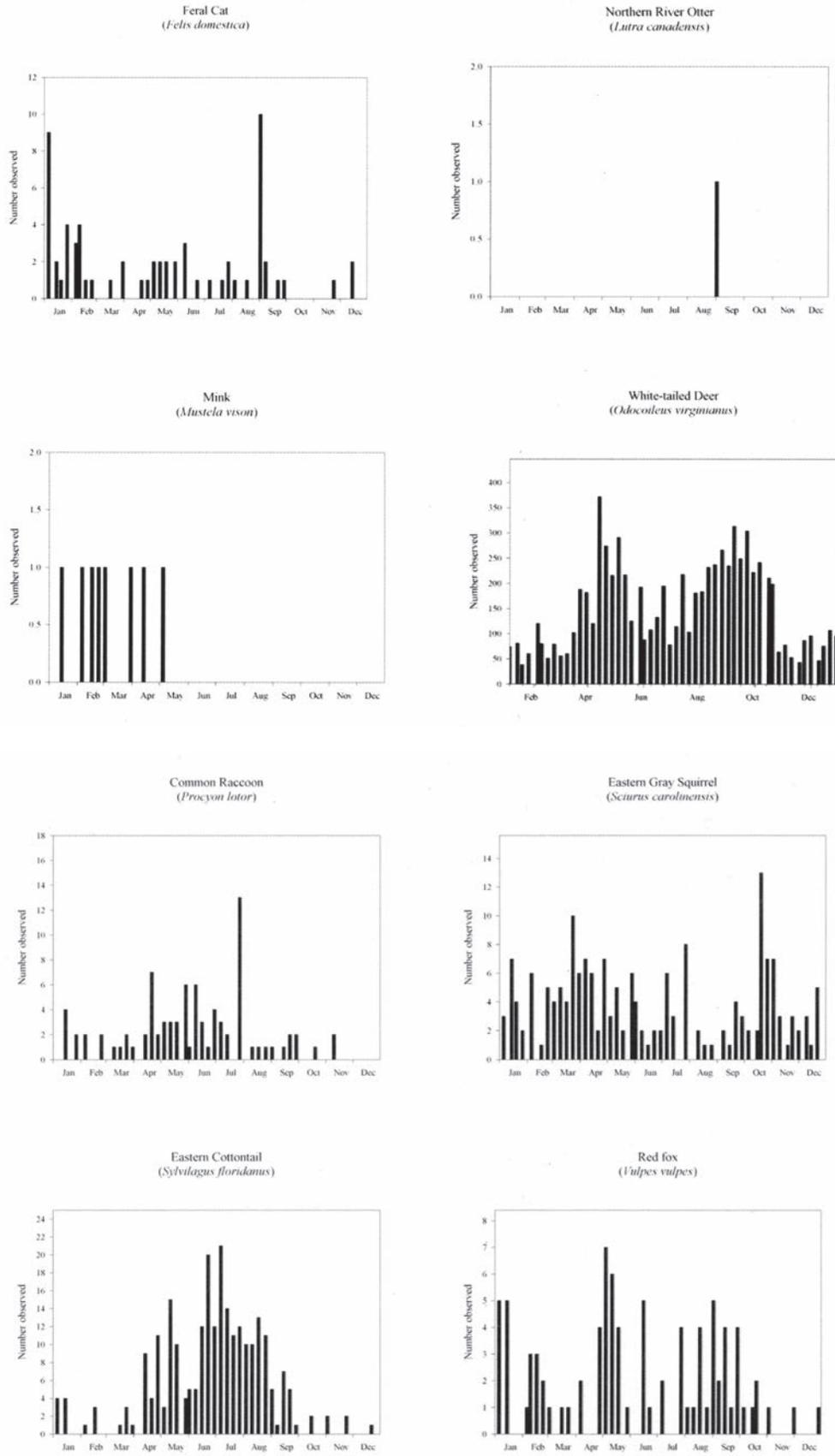


Figure 6.15. The number of sightings of mammal species over time on Prudence Island in 2003. All sighting data are from wildlife driving surveys conducted by the NBNERR (Raposa and Rehor, 2004).



Figure 6.16. The coyote has recently been discovered on Prudence Island. *Photo by Numi Mitchell, The Conservation Agency.*



Figure 6.17. The white-tailed deer is the most conspicuous mammal on Prudence Island. It is often overabundant on the island, exacerbating problems with invasive plant species and ticks and tick-borne diseases. *Photo from NBNERR photo library.*

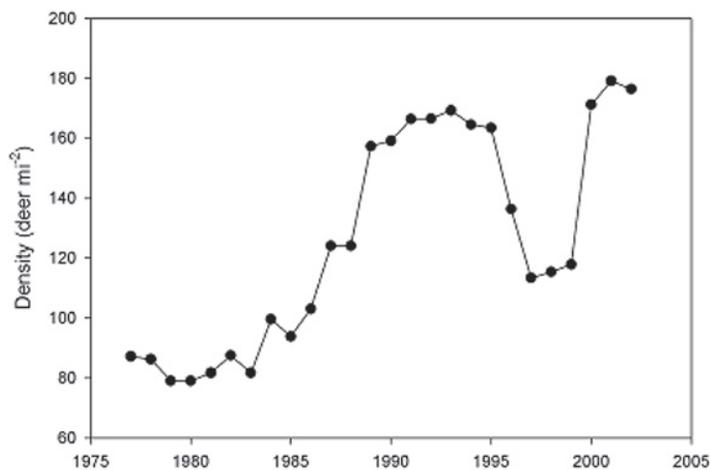


Figure 6.18. Density of white-tailed deer on Prudence Island from 1979–2002. Density values were calculated by dividing the size of the total population by the area of Prudence Island (14.4 km²). *Deer population data through 1999 are from Gibson and Suprock (2000); data from 2000 through 2002 are from Gibson (personal communication).*



Appendix 6.1 Birds of the Reserve

Abundance of bird species observed or captured on Prudence, Patience, Hope, or Dyer islands from studies summarized in this chapter. For each species, the island(s) where it was observed is noted, along with the data source and season. * = species was present; B = species was present and considered breeding; x = nesting birds were present; w/s = winter/spring; s/f = summer/fall. For the Enser (1990) study, all species indicated in this table were considered breeding by Enser. Those indicated with numbers are the species that were enumerated by Enser; those indicated with a "B" were simply noted in the original text as breeding. Species names and associations are in accordance with the American Ornithologists' Union checklist.

Family	Species	Common Name	Ferren	Maclachlan	Enser 1990	Paton and	Paton and	Paton et al.	Ferren and
			1985	1981		Osenkowski	Osenkowski	2000	Myers
			Patience	Prudence	Prudence	Prudence w/s	Prudence s/f	Prudence	PPHD
								(banding)	
Anatinae	<i>Aix sponsa</i>	wood duck			B				
	<i>Anas acuta</i>	Northern pintail				3			
	<i>Anas americana</i>	American wigeon				11			
	<i>Anas platyrhynchos</i>	mallard				8	2		
	<i>Anas rubripes</i>	American black duck		B	B	1392	159		
	<i>Anas strepera</i>	gadwall					26		
	<i>Aythya marila</i>	greater scaup				3			
	<i>Aythya sp.</i>	scaup sp.				2			
	<i>Branta bernicla</i>	brant				775	1		
	<i>Branta canadensis</i>	Canada goose		*	B	369	96		
	<i>Bucephala albeola</i>	bufflehead				204	55		
	<i>Bucephala clangula</i>	common goldeneye				1932	505		
	<i>Bucephala islandica</i>	Barrow's goldeneye				3	2		
	<i>Clangula hyemalis</i>	long-tailed duck				3			
	<i>Cygnus olor</i>	mute swan			B	2			
	<i>Lophodytes cucullatus</i>	hooded merganser				5	10		
	<i>Melanitta fusca</i>	white-winged scoter		*		46	387		
	<i>Melanitta nigra</i>	black scoter				1			
	<i>Melanitta perspicillata</i>	surf scoter				2			
	Phasianidae	<i>Mergus serrator</i>	red-breasted merganser				592	92	
<i>Phasianus colchicus</i>		ring-necked pheasant		B	9				
Odontophoridae	<i>Colinus virginianus</i>	common bobwhite			2				
Gaviidae	<i>Gavia immer</i>	common loon		*		19	1		
Podicipedidae	<i>Podiceps auritus</i>	horned grebe				369	105		
	<i>Podiceps grisegena</i>	red-necked grebe				3			
Phalacrocoracidae	<i>Phalacrocorax auritus</i>	double-crested cormorant		*		7	552		x
	<i>Phalacrocorax carbo</i>	great cormorant				113	2		
	<i>Phalacrocorax sp.</i>	cormorant sp.				14	1		
Ardeidae	<i>Ardea alba</i>	great egret		*		4	89		x
	<i>Ardea herodias</i>	great blue heron		*		4	4		
	<i>Bubulcus ibis</i>	cattle egret							x
	<i>Butorides striatus</i>	green heron		*	B				
	<i>Egretta caerulea</i>	little blue heron		*			4		x
	<i>Egretta thula</i>	snowy egret		*			127		x
	<i>Egretta tricolor</i>	tricolored heron					2		
	<i>Nycticorax nycticorax</i>	black-crowned night heron		*			1		x
	<i>egret sp.</i>	egret sp.					1		
Threskiornithidae	<i>Plegadis falcinellus</i>	glossy ibis		*			17		x
Accipitridae	<i>Accipiter cooperii</i>	cooper's hawk		*		1			
	<i>Accipiter striatus</i>	sharp-shinned hawk		*		4		1	
	<i>Buteo jamaicensis</i>	red-tailed hawk		B		8			
	<i>Buteo platypterus</i>	broad-winged hawk		*					
	<i>Circus cyaneus</i>	northern harrier		*		2			
	<i>Pandion haliaetus</i>	osprey		*			4		
Falconidae	<i>Falco sparverius</i>	American kestrel		B	B	2			
Haematopodidae	<i>Haematopus palliatus</i>	American oystercatcher					8		x
	<i>Charadrius semipalmatus</i>	semipalmated plover		*			12		
Charadriidae	<i>Charadrius vociferus</i>	killdeer			B				
	<i>Pluvialis squatarola</i>	black-bellied plover		*			1		
	<i>plover sp.</i>	plover sp.					1		
	<i>Actitis macularia</i>	spotted sandpiper		*			4		
Scolopacidae	<i>Arenaria interpres</i>	rusty turnstone		*			27		
	<i>Calidris alba</i>	sanderling		*		26			
	<i>Calidris minutilla</i>	least sandpiper					13		
	<i>Catoptrophorus semipalmatus</i>	willet					2		
	<i>Scolopax minor</i>	American woodcock			B				
	<i>Tringa melanoleuca</i>	greater yellowlegs		*			1		
	<i>Larus argentatus</i>	herring gull		*		1182	1300		x
	<i>Larus atricilla</i>	laughing gull		*			95		
Laridae	<i>Larus delawarensis</i>	ring-billed gull					22		
	<i>Larus marinus</i>	great black-backed gull		*		375	330		x
	<i>Larus philadelphia</i>	Bonaparte's gull		*		24	9		
	<i>Larus sp.</i>	gull sp.					2295		
	<i>Sterna albifrons</i>	least tern		*			16		x
	<i>Sterna dougallii</i>	roseate tern					2		



	<i>Sterna hirundo</i>	common tern		*			54		x	
	<i>Sterna sp.</i>	tern sp.					3			
Columbidae	<i>Columba livia</i>	rock pigeon	9	B	B	28	10			
	<i>Zenaidura macroura</i>	mourning dove			B	39	36	55		
Cuculidae	<i>Coccyzus americanus</i>	yellow-billed cuckoo		B						
Strigidae	<i>Bubo virginianus</i>	great horned owl			B					
	<i>Otus asio</i>	screech owl		*	B					
Caprimulgidae	<i>Caprimulgus vociferus</i>	whip-poor-will		B	B					
Apodidae	<i>Chaetura pelagica</i>	chimney swift			B					
Trochilidae	<i>Archilochus colubris</i>	ruby-throated hummingbird	1	B	B					
Alcedinidae	<i>Megasceryle alcyon</i>	belted kingfisher		*			4			
Picidae	<i>Colaptes auratus</i>	common flicker	1	B	13	23	6	4		
	<i>Melanerpes erythrocephalus</i>	red-headed woodpecker		*						
	<i>Picoides pubescens</i>	downy woodpecker		B	2			8		
	<i>Picoides villosus</i>	hairy woodpecker			B			1		
		woodpecker sp.						3		
Tyrannidae	<i>Contopus virens</i>	Eastern wood pewee		B	10			2		
	<i>Empidonax traillii</i>	willow flycatcher			3			1		
	<i>Empidonax vireescens</i>	acadian flycatcher						1		
	<i>Myiarchus crinitus</i>	great crested flycatcher	1		7			2		
	<i>Sayornis phoebe</i>	Eastern phoebe			B	1	2	7		
Vireonidae	<i>Tyrannus tyrannus</i>	Eastern kingbird	2	B	5		17			
	<i>Vireo griseus</i>	white-eyed vireo	16	B	34			20		
	<i>Vireo olivaceus</i>	red-eyed vireo		*	27			4	8	
Corvidae	<i>Vireo philadelphicus</i>	Philadelphia vireo						1		
	<i>Corvus brachyrhynchos</i>	American crow	10	B	B	80	1089			
	<i>Corvus ossifragus</i>	fish crow					3			
	<i>Corvus sp.</i>	crow sp.					105	142		
	<i>Cyanocitta cristata</i>	blue jay		B	16		9		3	
Hirundinidae	<i>Hirundo rustica</i>	barn swallow	1	B	2			35		
	<i>Stelgidopteryx serripennis</i>	Northern rough-winged swallow	1							
	<i>Tachycineta bicolor</i>	tree swallow	1	B	1			125		
Paridae		swallow sp.						401		
	<i>Baeolophus bicolor</i>	tufted titmouse	1	B	20				9	
Sittidae	<i>Parus atricapillus</i>	black-capped chickadee	2	B	25	40	9	82		
	<i>Sitta carolinensis</i>	white-breasted nuthatch		B	1					
Certhiidae	<i>Certhia americana</i>	brown creeper							1	
Troglodytidae	<i>Thryothorus ludovicianus</i>	Carolina wren	2	B	24	3			18	
	<i>Troglodytes aedon</i>	house wren	10	B	53			2	7	
Regulidae	<i>Regulus calendula</i>	ruby-crowned kinglet							164	
	<i>Regulus satrapa</i>	golden-crowned kinglet					6		34	
Turdidae	<i>Catharus fuscescens</i>	veery	9	B	38			6	8	
	<i>Catharus guttatus</i>	hermit thrush							8	
	<i>Catharus minimus</i>	gray-cheeked thrush							1	
	<i>Hyalocichla mustelina</i>	wood thrush	2	B	26				3	
	<i>Turdus migratorius</i>	American robin	6	B	57	43	79	21		
Mimidae	<i>Dumetella carolinensis</i>	gray catbird	56	B	119			88	727	
	<i>Mimus polyglottos</i>	Northern mockingbird		B	10	24	47	3		
Sturnidae	<i>Toxostoma rufum</i>	brown thrasher		B	13			7	7	
	<i>Sturnus vulgaris</i>	European starling	14	B	8	446	143			
Bombycillidae	<i>Bombycilla cedrorum</i>	cedar waxwing	1	B	5		27		1	
Parulidae	<i>Dendroica caerulescens</i>	black-throated blue warbler							9	
	<i>Dendroica coronata</i>	yellow-rumped warbler		*					543	
	<i>Dendroica discolor</i>	prairie warbler	3	B	15			8	4	
	<i>Dendroica palmarum</i>	palm warbler							13	
	<i>Dendroica pensylvanica</i>	chestnut-sided warbler		B	11			2		
	<i>Dendroica petechia</i>	yellow warbler	17	B	66			20		
	<i>Dendroica pinus</i>	pine warbler			3					
	<i>Dendroica striata</i>	blackpoll warbler							40	
	<i>Dendroica virens</i>	black-throated green warbler							2	
	<i>Geothlypis trichas</i>	common yellowthroat	52	B	93			25	38	
	<i>Icteria virens</i>	yellow-breasted chat								2
	<i>Mniotilta varia</i>	black-and-white warbler				10				5
	<i>Oporornis agilis</i>	Connecticut warbler								1
	<i>Seiurus aurocapilla</i>	ovenbird				5		1		7



	<i>Seiurus noveboracensis</i>	Northern waterthrush						1
	<i>Setophaga ruticilla</i>	American redstart	17	B	36		3	11
	<i>Vermivora pinus</i>	blue-winged warbler			12			3
	<i>Vermivora ruficapilla</i>	Nashville warbler						7
	<i>Wilsonia pusilla</i>	Wilson's warbler						1
Thraupidae	<i>Piranga olivacea</i>	scarlet tanager			3			3
Emberizidae	<i>Ammodramus caudacutus</i>	saltmarsh sharp-tailed sparrow	3	B	B		2	1
	<i>Ammodramus maritimus</i>	seaside sparrow		B				
	<i>Junco hyemalis</i>	dark-eyed junco				29		75
	<i>Melospiza georgiana</i>	swamp sparrow	1					49
	<i>Melospiza melodia</i>	song sparrow	13	B	42	91	93	94
	<i>Passerculus sandwichensis</i>	savannah sparrow						5
	<i>Pipilo erythrophthalmus</i>	Eastern towhee	31	B	104	3	51	43
	<i>Spizella arborea</i>	American tree sparrow				37	1	1
	<i>Spizella pusilla</i>	field sparrow			14		1	6
	<i>Zonotrichia albicollis</i>	white-throated sparrow				39		77
	<i>Zonotrichia leucophrys</i>	white-crowned sparrow		*				3
		sparrow sp.						85
Cardinalidae	<i>Cardinalis cardinalis</i>	Northern cardinal	10	B	20	6	5	33
	<i>Passerina cyanea</i>	indigo bunting						1
	<i>Pheucticus ludovicianus</i>	rose-breasted grosbeak			2			1
Icteridae	<i>Agelaius phoeniceus</i>	red-winged blackbird	5	B	5	64	30	
	<i>Icterus galbula</i>	Baltimore oriole		B	2			1
	<i>Molothrus ater</i>	brown-headed cowbird	1	B	21	4	10	
	<i>Quiscalus quiscula</i>	common grackle	5	B	11			12
Fringillidae	<i>Carduelis tristis</i>	American goldfinch	5	B	18	3	74	48
	<i>Carpodacus mexicanus</i>	house finch	11	B	14	7	1	11
	<i>Carpodacus purpureus</i>	purple finch	4		1		6	5
Passeridae	<i>Passer domesticus</i>	house sparrow			B	5	4	

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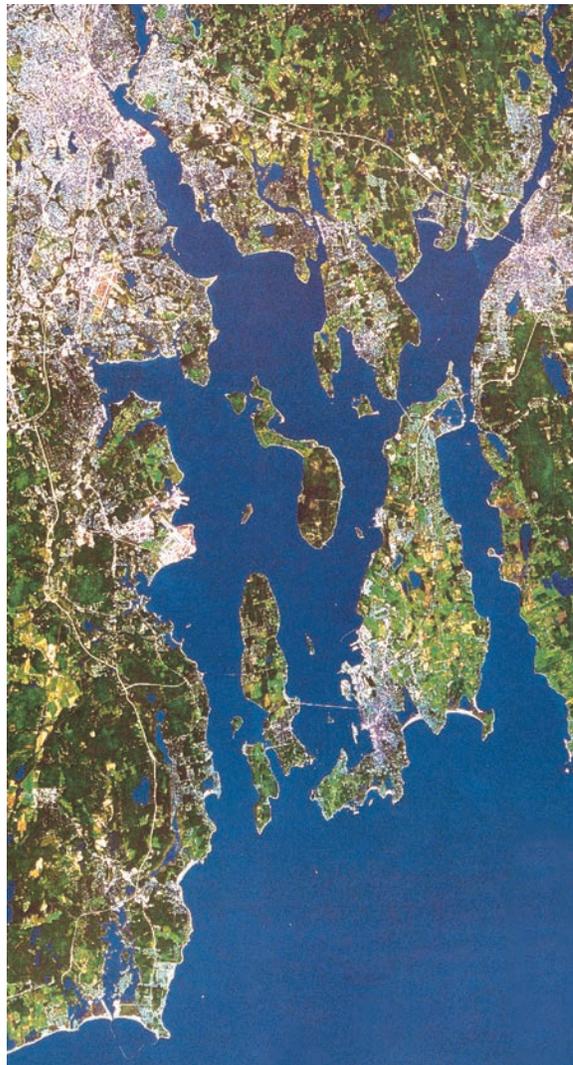
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CHAPTER 7.

Ecological Geography of Narragansett Bay

Kenneth B. Raposa



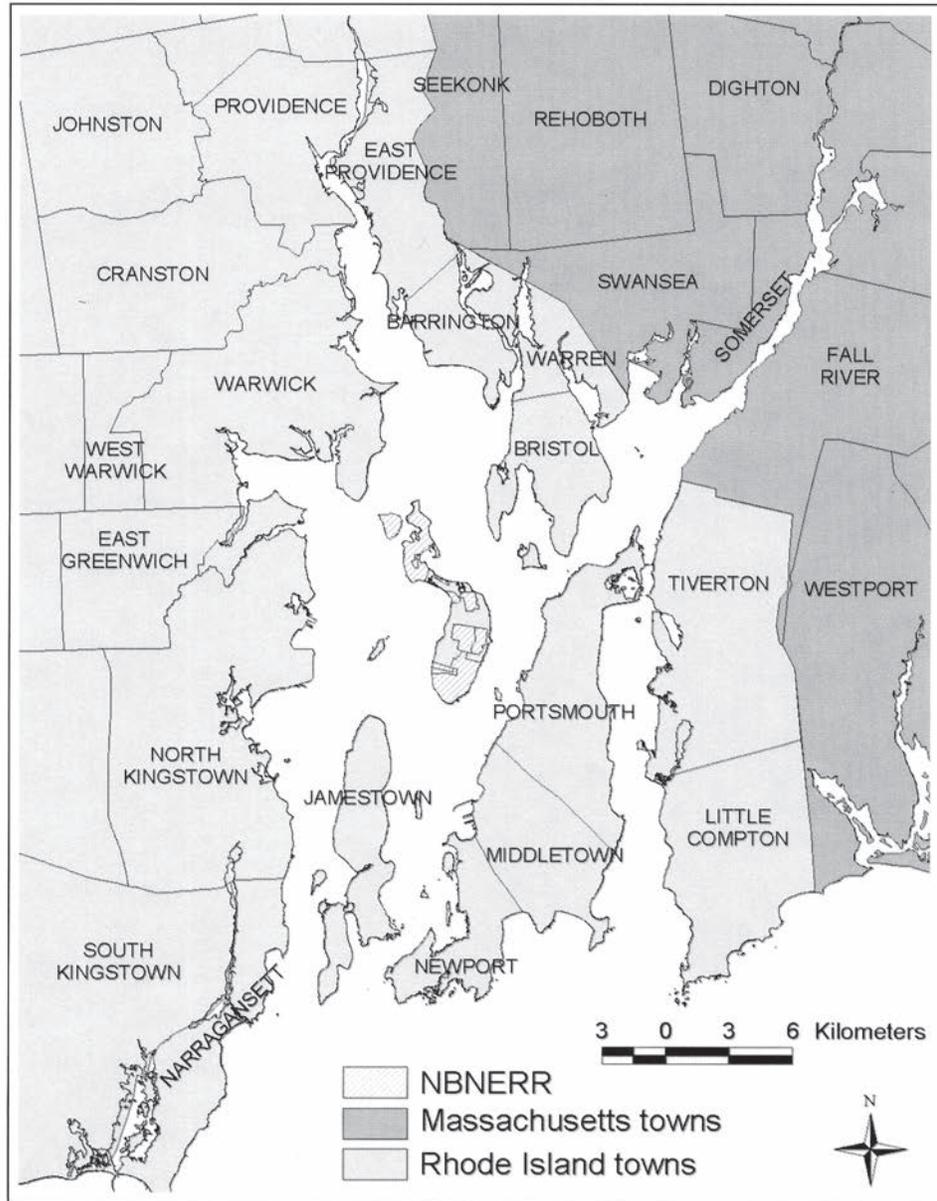


Figure 7.1. Map of Narragansett Bay illustrating the surrounding towns of Rhode Island and southeastern Massachusetts. *Data source: RIGIS.*

Ecological Geography of Narragansett Bay

Introduction

Narragansett Bay is a temperate, well-mixed estuary located mostly within the state of Rhode Island. The Bay essentially bisects Rhode Island in a north-south direction with metropolitan Providence lying at its head and Newport, a major tourist destination, lying on Aquidneck Island lower in the Bay (Fig. 7.1). Narragansett Bay is enclosed by land to the east, north, and west, and is connected to Rhode Island and Block Island sounds to the south. Sitting between Long Island, N.Y., and Cape Cod, Mass., the Bay is in relative close proximity to other prominent Northeast estuaries including Long Island Sound (N.Y.), Buzzard's Bay (Mass.), Waquoit Bay (Mass.), Cape Cod Bay, Massachusetts Bay, and Great Bay (N.H.).

Narragansett Bay is often colloquially divided into 10 sub-bay regions generally defined by their relative location in the Bay. The largest of these regions includes the upper Bay, upper and lower West passages, upper and lower East passages, Mount Hope Bay, and the Sakonnet River (Fig. 7.2). The dominant rivers entering into Narragansett Bay include the Providence and Seekonk rivers, the Palmer and Barrington rivers, and the Taunton River. Narragansett Bay's shoreline includes numerous coves and embayments, the largest being Mount Hope Bay and Greenwich Bay, and its waters are dotted with 39 islands, the largest being Aquidneck, Conanicut, and Prudence islands (Figs. 7.2, 7.3).

The size of Narragansett Bay varies depending on which features are included. If Mount Hope Bay and the Sakonnet River are included, the Bay extends approximately 45 km from north to south, and 18 km at its widest point from west to east (Chinman and Nixon, 1985), covering an area of approximately 342 km² (147 miles²). Although Narragansett Bay is often referred to as a shallow estuary, its water depth actually varies considerably. Depth averages approximately 9.0 m throughout the Bay, but is shallower in the West Passage (7.5 m average) and considerably deeper in the East Passage (15.2 m) (Fig. 7.4).

The Narragansett Bay watershed is composed of nine subwatersheds draining an area of approximately 4,836 km² (Pilson, 1985), 39 percent of which is in Rhode Island and 61 percent in neighboring Massachusetts (Fig. 7.5). The watershed contains

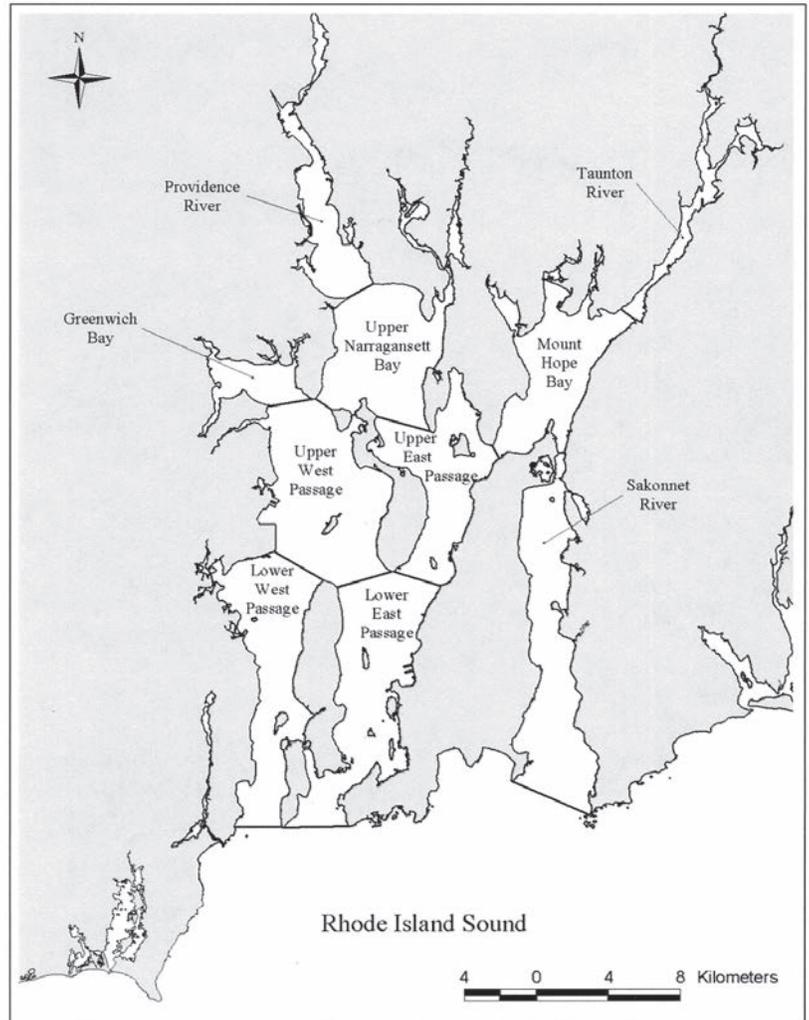


Figure 7.2. Commonly recognized subdivisions within Narragansett Bay. *Data sources: RIGIS and Lee et al. (2000).*

a diverse group of land cover classes including industrial, residential, agricultural, and forested and natural lands. Narragansett Bay has a low ratio of watershed drainage area to estuarine water surface area, similar to other estuaries in New England and along the Mid-Atlantic, and generally much smaller than those estuaries found along the southeast Atlantic and the Gulf of Mexico (Roman et al., 2000).

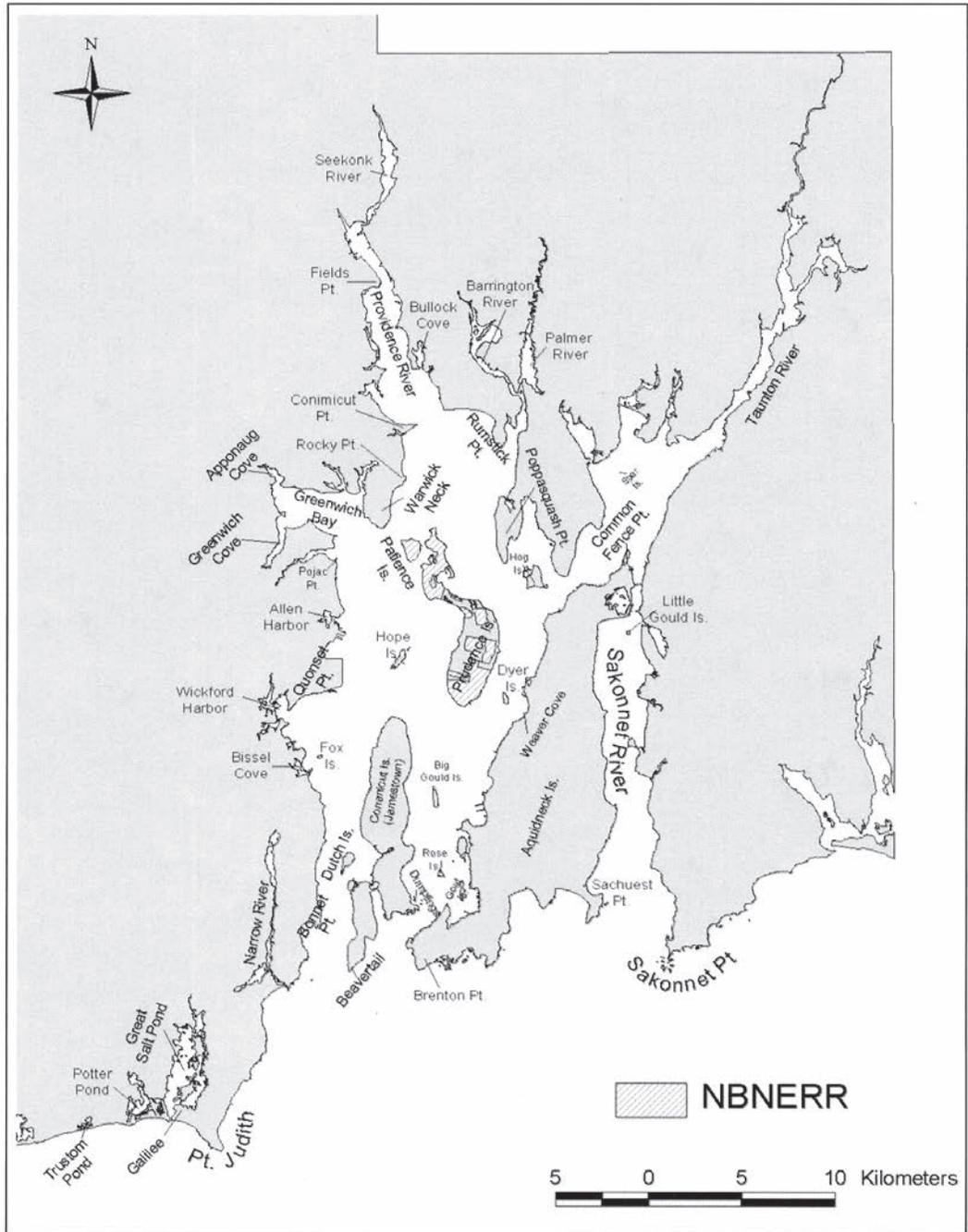


Figure 7.3. Common landmark features in Narragansett Bay, including islands, points, rivers, coves, and embayments.
 Data source: *RIGIS*.

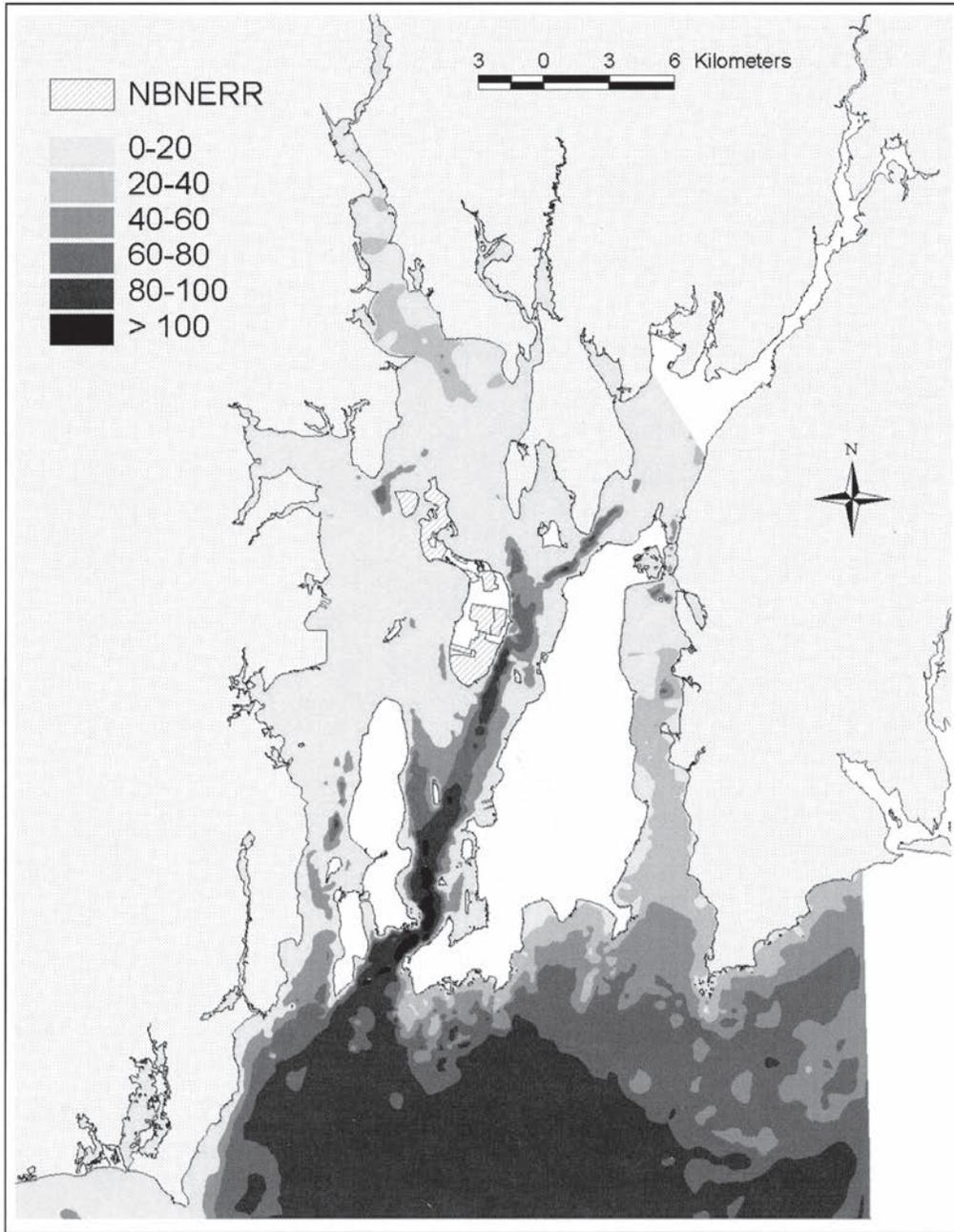


Figure 7.4. Narragansett Bay bathymetric map, with depth intervals illustrated in feet. The deeper East Passage is clearly visible along the eastern side of Prudence Island and the NBNERR. *Data source: RIGIS.*

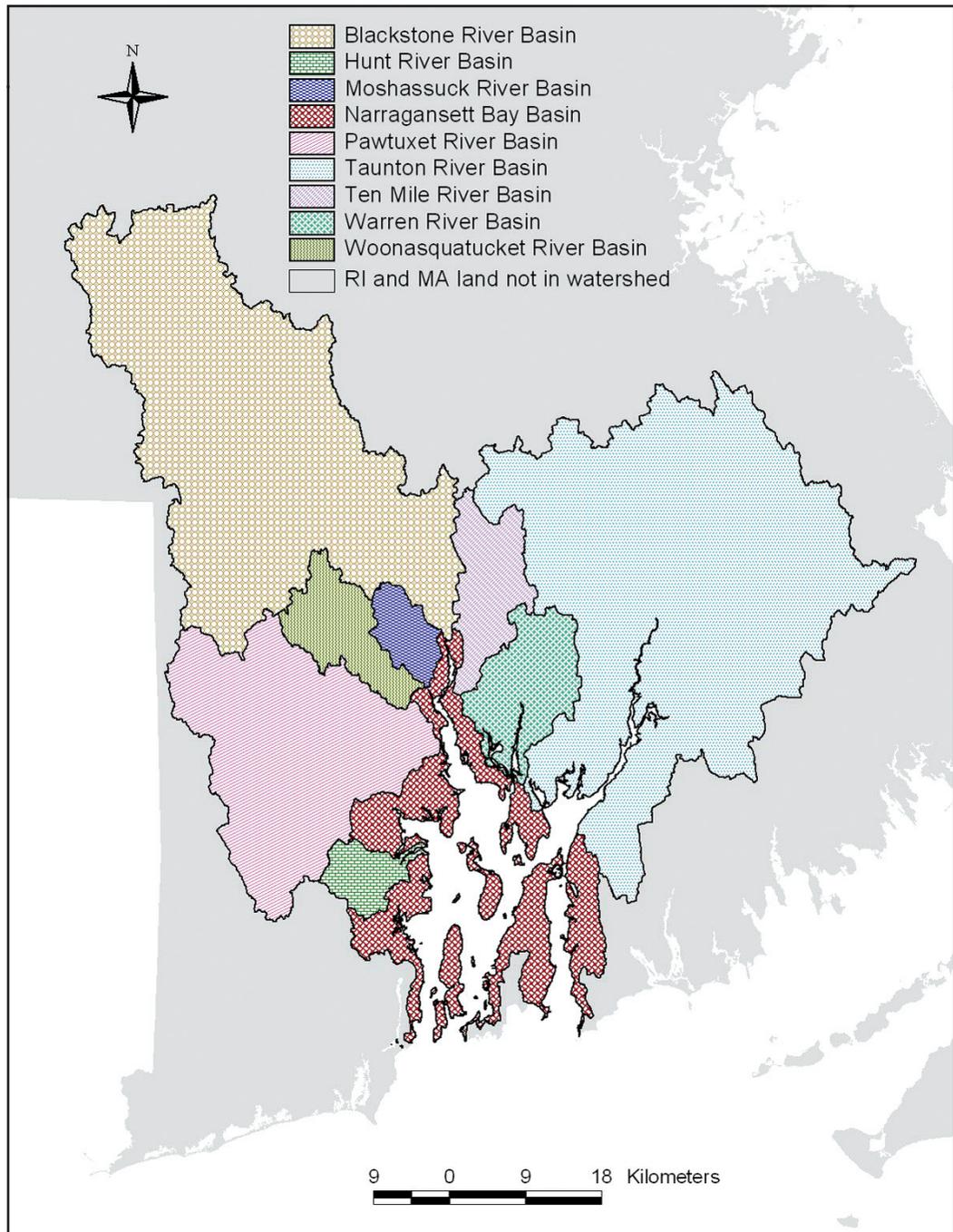


Figure 7.5. The watershed and subwatershed basins of Narragansett Bay. Data sources: RIGIS and Massachusetts GIS (www.mass.gov/mgis/massgis.htm).



Geography and Sediments

Narragansett Bay is a drowned river valley estuary made up of three ancient drowned river valleys commonly known as the East Passage, West Passage, and Sakonnet River. The Bay and its watershed as they exist today were largely shaped by the repeated advance and retreat of glaciers (or ice sheets several thousand feet thick) since the Pleistocene epoch between 2.5 and 3 million years ago. The last of these glaciers, the late Wisconsin ice sheet, covered the region 18,000 years ago and finally retreated 10,000 to 12,000 years ago. The terminal moraine of this last glacial event reached just south of the mouth of the Bay, to Long Island, Block Island, Martha's Vineyard, and Nantucket.

Narragansett Bay lies within the ancient Narragansett Basin. It is lined with bedrock composed of Pennsylvanian age rocks, including sedimentary conglomerates, sandstones, and shales (McMaster, 1960). As the glaciers retreated, they covered this bedrock with drift deposits that are composed of unconsolidated layers of boulder, cobble, gravel, sand, silt, and clay (McMaster, 1960). More recently, materials that have eroded and washed into the Bay, primarily from riverine sources, have overlain the older glacial deposits. It has been estimated that these recent sediment deposits may reach up to 5 m in depth. Total sediment depth in Narragansett Bay, including the older glacial and more recent riverine deposits, varies greatly but generally ranges between 15 to over 100 m thick (McMaster, 1960).

Eleven sediment types have been identified in Narragansett Bay, ranging from clayey silt to coarse gravel (McMaster, 1960). The distribution of these sediment types largely depends on currents and circulation patterns, which generally result in finer grained materials, such as sand-silt-clay and clayey silt, being located in the middle and upper portions of the Bay and in protected coves and harbors (Fig. 7.6). Coarser sediments, mostly sandy, are found in the lower reaches of the Bay and in constricted areas where current velocities are greater. Overall, most of the bottom of Narragansett Bay is covered with finer grained detritus, clay-silt and sand-silt-clay sediments.

The effects of the glaciers are also clearly seen along the shoreline of Narragansett Bay, which is dominated by narrow cobble beaches (see Fig. 4.13, page 36). Sandy beaches are found along much of the south shore of Rhode Island, but are limited to a relatively few small areas in Narragansett Bay proper. The famous rocky New England shore is also found in Narragansett Bay, most notably at Beavertail (the southern extent of Conanicut Island),

Brenton Point on Aquidneck Island, and along Hope Island (Fig. 7.3). Other shoreline types common in Narragansett Bay include fringing and meadow salt marshes in low-energy, depositional areas, and human-modified and bulkheaded shorelines. It has been estimated that these human-modified shorelines compose 25 percent of Narragansett Bay's perimeter (Keller et al., 1996).

Physical and Chemical Characteristics

Tides are semidiurnal (two tides per day) in Narragansett Bay, with an average range of 1.1 m at the mouth of the Bay and 1.4 m at the head. Tides are a dominant forcing function in the Bay as the mean tidal prism is about 13 percent of the mean volume of the Bay and over 250 times the mean river flow entering the Bay during a tidal cycle (Kremer and Nixon, 1978). Tidal mixing is also the dominant factor affecting circulation patterns in Narragansett Bay, although nontidal currents produced by salinity and temperature gradients within the Bay and wind-driven currents are also important. Currents associated with tidal mixing can reach up to 77 centimeters per second (cm s^{-1}) with higher velocities associated with constricted areas and away from the shoreline or sediment where friction acts to reduce current velocities. Nontidal currents include the southerly flow of less-saline surface water out of the Bay and the concurrent northerly flow of more saline, deeper water into the Bay. These currents are generally lower than those generated by tidal forcing and are approximately 10 cm s^{-1} . Although relatively slow, these nontidal currents act to slowly flush water out of Narragansett Bay and into Rhode Island Sound. Pilson (1985) has estimated that it takes anywhere between 10 and 40 days for a particle of water to move from the Port of Providence to the mouth of the Bay and that the average residence time for such a particle in the Bay is 26 days.

Winds also affect the currents, circulation, and mixing in Narragansett Bay. Although highly variable, winds are generally out of the southwest in summer and from the northwest in winter (see Fig. 4.4, page 27). Summer southwesterly winds can act to move and pile up water towards the head of the Bay, while the opposite is true of winter northwesterly winds. In addition, surface waves generated by wind can exceed 1.3 m in the Bay.

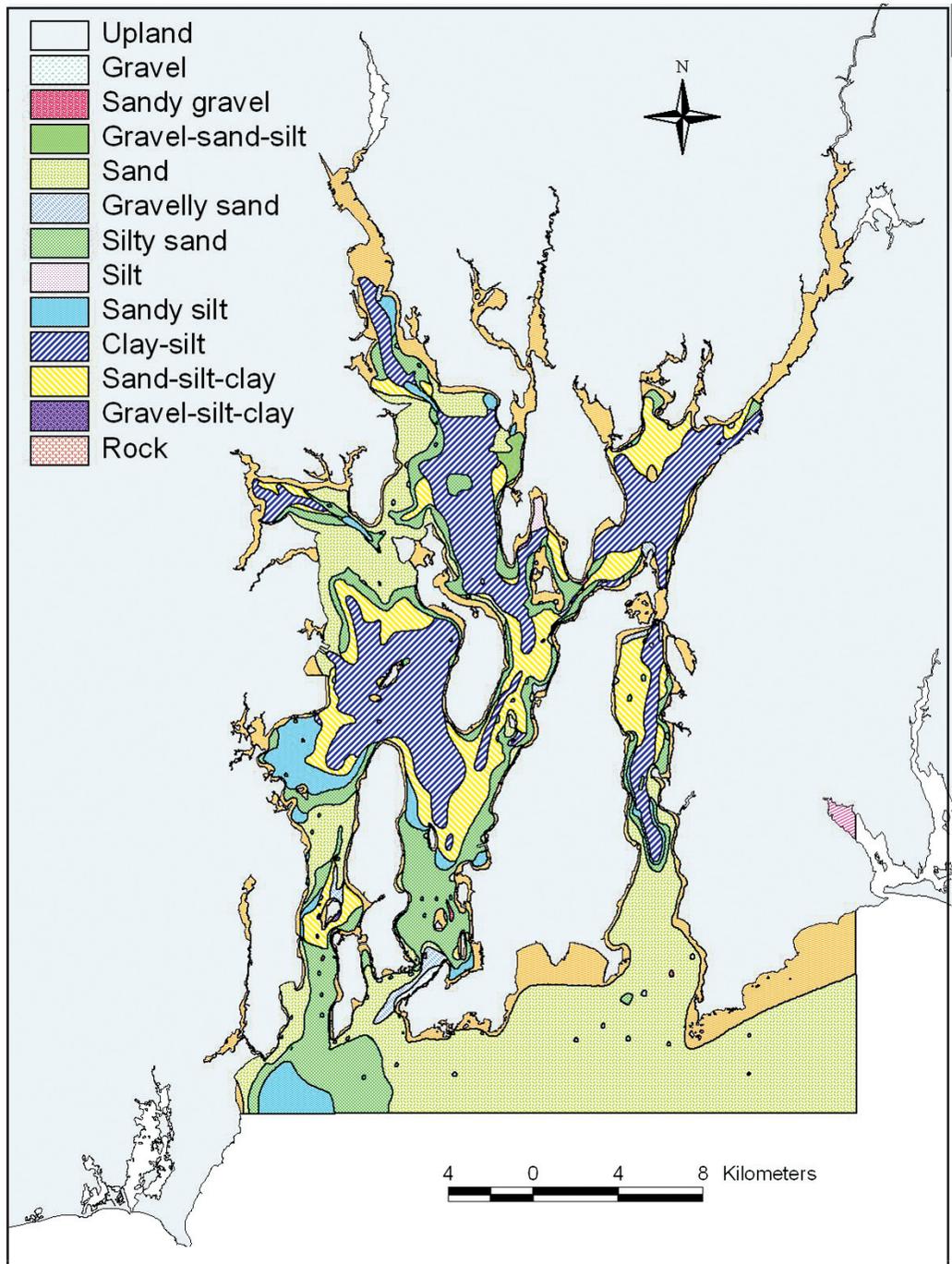


Figure 7.6. Sediments of Narragansett Bay. All sediment data are from McMaster (1960). Unclassified areas were either not sampled or not coded during the study. Note the dominance of clay-silt sediments in the mid- and upper Bay regions, and the coarser sediments lower in the Bay. Data sources: RIGIS and Lee et al. (2000).



Narragansett Bay receives freshwater inputs from a variety of sources including rivers, groundwater, direct precipitation, wastewater treatment facilities, and combined sewer overflows (CSOs). Riverine inputs make up approximately 80 percent of the freshwater inputs to the Bay with an average of 2,400 million gallons per day (MGD) of freshwater entering Narragansett Bay through rivers, mostly from the Blackstone (upstream reach of Seekonk River), Taunton, and Pawtuxet Rivers (entering Narragansett Bay between Fields Point and Conimicut Point) (Ries, 1990). The remaining dominant freshwater inputs into Narragansett Bay include direct precipitation (13 percent; 310 MGD) and wastewater treatment facilities (9 percent; 248 MGD) (Ries, 1990). Lesser or unknown inputs of freshwater are from CSOs and from groundwater, respectively. There can be substantial variability in freshwater inputs to the Bay on multiple temporal scales. Riverine inputs vary seasonally, being highest in winter and lowest in summer, while inputs from CSOs increase dramatically after heavy rain events.

The mixing of freshwater inputs with seawater results in salinities in Narragansett Bay that range between 24 ppt in the Providence River and 32 ppt at the mouth of the Bay (Kremer and Nixon, 1978). Salinities can be substantially lower in the surface waters at the head of the Bay and in landward areas of small coves, embayments, and salt marshes, especially after rain events when runoff is high. As opposed to the more pronounced horizontal salinity gradient, the vertical gradient is generally less than 2 ppt throughout the Bay (Pilson, 1985). Figure 7.7 B shows seasonal patterns of salinity at two of the NBNERR water-quality monitoring stations located around Prudence Island.

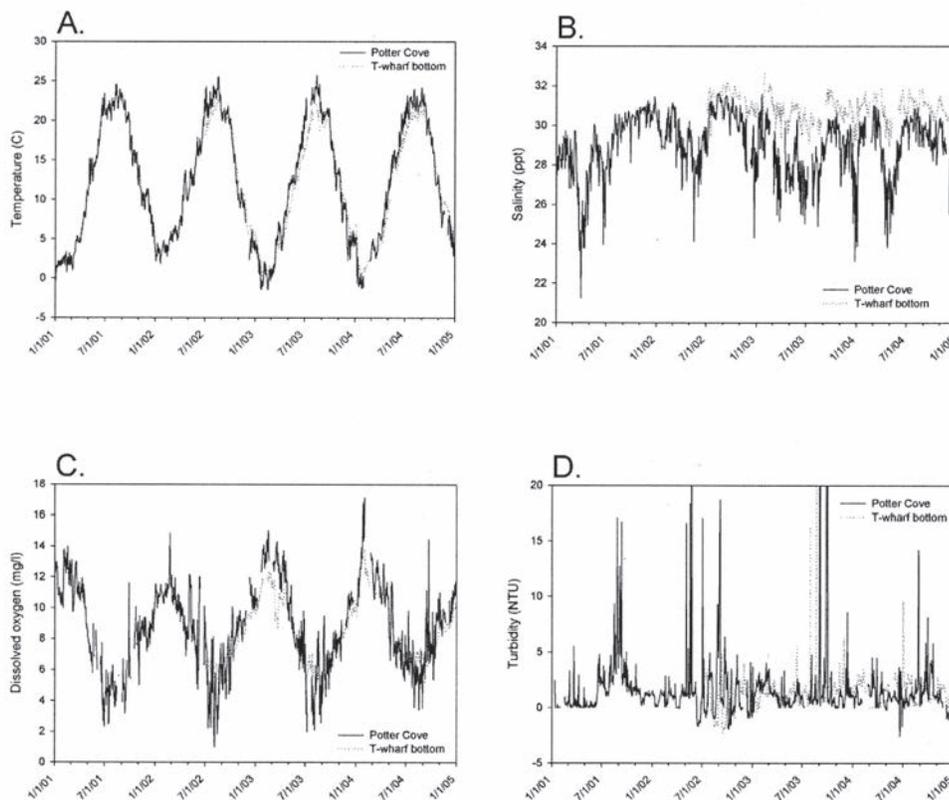


Figure 7.7. Time series of water-quality parameters in Narragansett Bay. All data were taken from the NBNERR SWMP stations at T-wharf and Potter Cove between January 2001 and December 2004. At both stations, readings were taken from approximately 1 m from the bottom. A. temperature; B. salinity; C. dissolved oxygen; D. turbidity.



Temperature

Water temperatures in Narragansett Bay range between minus 0.5°C and 24°C over an annual cycle (Kremer and Nixon, 1978). The seasonal cycle is predictable, with highest temperatures occurring in the summer and the coldest in winter (Figs. 7.7A, 7.8). This cycle lags the similar solar radiation cycle by about 40 days (Kremer and Nixon, 1978). Thermal stratification of the water column generally only occurs in the upper reaches of the Bay and its associated rivers; thus Narragansett Bay is generally referred to as a well-mixed estuary. Recently, Nixon et al. (2003) showed that water temperatures in Narragansett Bay are increasing. Between the 1890s and 1990s, mean temperatures in the lower Bay increased from about 3.1°C to 4.6°C in winter and from 18.7°C to 19.5°C in summer, with most of the increase occurring in the last 30 years. Nixon et al. (2003) concluded that these temperature increases resulted in Narragansett Bay being, on average, over 10°C for 13 days longer in the 1990s than in the 1890s, and above 20°C for 17 days longer. These increases and subsequent changes in the temperatures of Narragansett Bay water appear to be affecting the biology and functioning of the Bay (Keller and Klein-MacPhee, 2000; DeLong et al., 2001; Sullivan et al., 2001; Oviatt et al., 2002).



Figure 7.8. Ice is common in coves, marshes, and in the upper reaches of Narragansett Bay in winter. In some years, temperatures are cold enough for ice to form around the shores of Prudence Island, shown here. *Photo from NBNERR photo library.*

Dissolved Oxygen

Dissolved oxygen levels in Narragansett Bay follow a typical seasonal pattern with lower levels observed in the summer months and higher levels observed in the winter and early spring (i.e., the inverse of temperature) (Fig. 7.7C). This pattern reflects the warmer temperatures and higher biological demand for oxygen in the summer, both of which

act to lower the concentration of dissolved oxygen during this time; the opposite is true during winter. Superimposed on this seasonal cycle are strong diel changes in dissolved oxygen. On a given day, oxygen concentrations are lowest during the early morning hours, after respiration throughout the night, and then increase throughout the day as photosynthesis replenishes dissolved oxygen to the water.

Recent surveys (Fig. 7.9) have demonstrated that substantial areas in the upper Bay, and in Greenwich Bay and the Providence River in particular, are subjected to relatively extended periods of hypoxia (when dissolved oxygen levels fall below 3.0 milligrams per liter (mg l^{-1}) or 40 percent saturation) (Saarman, 2001). While hypoxia is a natural occurrence in highly productive estuarine waters, including in Narragansett Bay, this work illustrated that the issue of hypoxia is more extensive than previously thought. Moreover, while the surveys that formed the basis of this study were one-day snapshots in each of July, August, and September 2001, additional time series data confirmed that periods of hypoxia are not uncommon events during these months; hypoxic events lasting between one and 16 days in length occurred in all three months. Saarman (2001) concluded that hypoxic waters were originating within Narragansett Bay itself, that stratification of the water column and development of a strong pycnocline were significant precursors to the development of hypoxic conditions, and that shallow regions of the Bay that receive elevated inputs of nutrients (Greenwich Bay and the Providence River, in particular) may be important areas where hypoxic conditions form and then advect into other areas in Narragansett Bay. It is thought that hypoxic conditions, and more extreme anoxic conditions, are resulting in large-scale die-offs of blue mussel (*Mytilus edulis*) in the Bay and fish kills in Greenwich Bay (in 2003, Fig. 7.10), respectively (RIDEM, 2003; Altieri and Witman, 2006).

Current or planned efforts to reduce nutrient inputs to Narragansett Bay include increased sewerage of residential areas surrounding Greenwich Bay, retention and treatment of nutrient-laden storm water after significant rain events, and implementation of tertiary treatment in major wastewater treatment facilities (RIDEM, 2000). However, the effects of such nutrient reductions on hypoxia in Narragansett Bay remain unclear. A recent synthesis has shown that the large 2003 hypoxic event and fish kill was only the second one of this magnitude and severity in over a century (Nixon et al., 2007). In addition, long-term data are not available to determine if hypoxic events are actually increasing in frequency and intensity in Narragansett Bay over time. Another recent study in Greenwich Bay found that over 45



Figure 7.9. Researchers and students from multiple agencies and institutions collaborate to conduct dissolved oxygen surveys in Narragansett Bay. Here the team is calibrating the water quality sondes at T-wharf on Prudence Island. *Photo from NBNERR photo library.*

percent of the nitrogen entering Greenwich Bay comes from Narragansett Bay proper (Dimilla, 2006). Thus, localized efforts to reduce nutrient levels and hypoxia in Greenwich Bay (i.e., through residential sewerage) may not be enough to fully address these issues in this area.

Water Clarity

The waters of Narragansett Bay are relatively clear, with extinction coefficients having been measured between 0.58–0.76 m^{-1} (Schenck and Davis, 1973). These values are lower than most estuaries located farther south such as in the Mid-Atlantic, Southeast, and along the Gulf of Mexico (Roman et al., 2000). The relatively high water clarity in Narragansett Bay and in other Northeast estuaries can be attributed to factors such as small watershed drainage basins, low freshwater flow rates, and relatively high forest cover in the Northeast as compared to more southern areas (Roman et al., 2000). Water clarity exhibits a strong seasonal cycle in Narragansett Bay. Clarity, as measured by secchi depth, is highest during the first four months of the year, rapidly decreases until early summer, and then gradually increases again into autumn (Borkman and Smayda, 1998). Data from the Reserve's SWMP show a similar pattern (Fig. 7.7D). Borkman and Smayda (1998) also detected a significant increase in secchi depth (i.e., better water clarity) from 1972 through 1996 in lower Narragansett Bay. During this time, secchi depth increased by a linearized rate of 0.05 $m yr^{-1}$. The increase in water clarity was directly attributed to an approximately 75 percent reduction in total suspended solid loads to the Bay from wastewater treatment plants.

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Figure 7.10. The results of the 2003 fish kill in Greenwich Bay that was caused by hypoxia and anoxia. *Photo from NBNERR photo library.*



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CHAPTER 8.

Estuarine Habitats of Narragansett Bay

Malia L. Schwartz



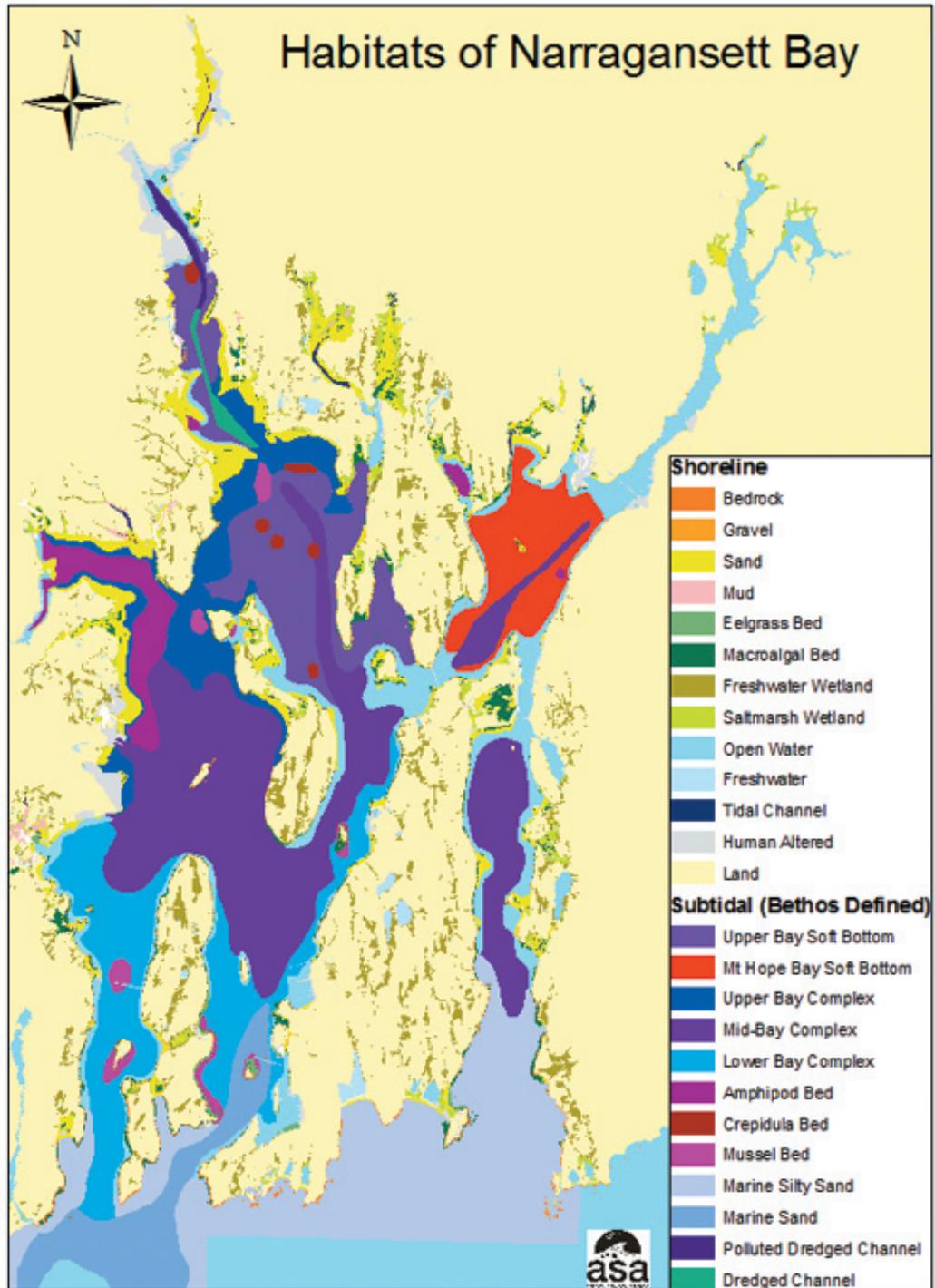


Figure 8.1. Estuarine habitats of Narragansett Bay. Source: French et al., 1992. Image courtesy Applied Science Associates.



Estuarine Habitats of Narragansett Bay

Introduction

Estuarine habitats support some of the most productive floral and faunal communities on Earth, and the habitats of Narragansett Bay are no exception. Many different habitat types are found in and around the Bay, including open water, salt marshes, subtidal bottom habitat, brackish waters, a complex intertidal zone of sandy beaches, mud and sand flats, and rocky intertidal areas, submerged aquatic vegetation with macroalgal and eelgrass beds, and human-modified shorelines (Fig. 8.1).

The productivity and variety of estuarine habitats foster an abundance and diversity of wildlife. Shorebirds, fish, crabs and lobsters, marine mammals, clams and other shellfish, marine worms, sea birds, and reptiles are just some of the animals that make their homes in and around estuaries. These animals are linked to one another, and to an assortment of specialized plants and microscopic organisms, through complex food webs and other interactions (EPA, 1998).

In addition to serving as important habitat for wildlife, fringing estuarine wetlands also perform other valuable services. Water draining from the uplands carries sediments, nutrients, and other pollutants. As the water flows through wetlands such as swamps and salt marshes, much of the sediments and pollutants are filtered out. This filtration process creates cleaner and clearer water, which benefits both people and marine life. Wetland plants and soils also act as a natural buffer between the land and ocean, absorbing floodwaters and dissipating storm surges. This protects upland habitats as well as economically valuable real estate from storm and flood damage. Salt marsh grasses and other estuarine plants also help prevent erosion and stabilize the shoreline (EPA, 1998).

Narragansett Bay is one of the best-studied estuaries in the world (Ely and Crist, 2001), and its habitats have been the subject of in-depth research for over 30 years.

Figure 8.2. Salt marshes, such as Round Marsh in Jamestown, R.I., are some of the most ecologically valuable habitats in Narragansett Bay. *Photo by Malia Schwartz.*



This chapter provides an overview of the major habitat types of Narragansett Bay and, where appropriate, makes specific reference to those habitats found on and around the islands of the NBNERR. It also delves into the basic life histories and ecology of the organisms found in these habitats that are then expanded on in subsequent chapters. And finally, it gives examples of habitat restoration efforts ongoing in several Bay habitats.

Open Water

The open water, or pelagic, habitat is the dominant habitat in Narragansett Bay, based on area. The Bay itself is a phytoplankton-based ecosystem with relatively little salt marsh or macroalgae. The pelagic habitat is a dynamic environment with tidally and wind-driven circulation and freshwater inputs (French et al., 1992). A wide variety of plankton, benthic communities (Chapter 9), and nekton (Chapter 10) are found in and under the open water habitat of Narragansett Bay. In turn, this habitat provides food for a diverse assemblage of birds, as well as for marine mammals and occasional sea turtles (Chapter 11). The pelagic habitat also supports a number of commercial and recreational fisheries and shellfisheries.

Salt Marshes

While only covering a small surface area in Narragansett Bay, estuarine emergent wetlands, or salt marshes, are some of the most ecologically valuable habitats in the Bay (Fig. 8.2). Salt marshes protect coastal areas from erosion, remove nutrients from overenriched waters, provide sheltered habitat for key resource species, serve as nursery grounds for fish and shellfish, and are a major food source for the organisms that live there (Tiner, 1984).

A primary source of food in salt marshes is in the form of decomposing



plant material, or detritus. Detritus is the base of an aquatic food web supporting higher consumers and commercial species. Animals such as shrimp, snails, clams, worms, and killifish consume plant breakdown products, graze on microscopic organisms growing on the surface of the detritus (Beck and Beck, 1998), or scour epibenthic algae off the sediments. To illustrate the interwoven nature of this food web, research by Nixon and Oviatt (1973a) in Bisset Cove reported that excretion and fecal pellets produced by foraging grass shrimp provided nutrients for enhanced development of bacteria and algae on the detritus. In turn, forage fish (e.g., anchovies, silversides, sticklebacks, mummichogs) and small invertebrates (e.g., grass shrimp and worms) are then consumed by commercial and recreational fish species, including winter flounder (*Pseudopleuronectes americanus*), striped bass (*Morone saxatilis*), and bluefish (*Pomatomus saltatrix*) (Beck and Beck, 1998).

Salt marshes are characterized by two general vegetative zones based on differences in tidal flooding—regularly flooded low marsh and irregularly flooded high marsh. In the low marsh—the area covered by each day’s high tides—vegetation is dominated by a single plant, the tall form of smooth cordgrass, *Spartina alterniflora*, which typically grows 90–180 cm (3–6 feet) high (Beck and Beck, 1998). In addition, filamentous algae and diatoms are found at the base of the grasses growing in the flooded part of the marsh (Donaldson, 1995). Where the tall cordgrass meets the water’s edge, the mud is home to densely packed beds of ribbed mussels, and around the plants’ roots, one can find small holes that form the openings to fiddler crab burrows. Moving away from the water, at the edge of the border marked by the high-tide line, the cordgrass is short, less than 30 cm tall (Bertness, 1992).

In addition to providing food and shelter to

the organisms that inhabit the low marsh, *S. alterniflora* has also been shown to be an effective nutrient sink, able to capture and hold available inorganic nutrients, such as nitrogen and phosphorus and trace elements, then slowly release them as the plants die, decay, and are carried into the estuary to serve as a rich source of detrital food (Nixon and Oviatt, 1973b).

In contrast to the low marsh, the high marsh is a mosaic of species, the occurrence of each being precisely determined by the elevation and resultant amount of tidal flooding. The high marsh is characterized by salt-marsh hay (*S. patens*), spike grass (*Distichlis spicata*), glassworts (*Salicornia spp.*), sea lavender (*Limonium nashii*), salt marsh aster (*Aster tenuifolius*), black grass (*Juncus gerardii*), and hightide bush (*Iva frutescens*). Salt marsh pools and tidal creeks can also be vegetated with widgeon grass (*Ruppia maritima*), sea lettuce (*Ulva lactuca*), and other macroalgae (Beck and Beck, 1998).

In Narragansett Bay, salt marshes cover about 1,120 ha (2,800 acres). There are also roughly 80 km of narrow, fringing marshes—marshes that line the edge of rocky shores or developed areas. French et al. (1992) reported on the species composition and relative abundance of salt marsh plants in eight salt marshes around Narragansett Bay. The surveyed marshes included: 1) Watchemoket Cove, East Providence; 2) Hundred Acre Cove, Barrington; 3) Chase Cove, Warren; 4) Common Fence Point, Portsmouth; 5) Bisset Cove, North Kingstown; 6) Round Swamp, Jamestown; 7) Weaver Cove (Melville), Portsmouth; and 8) Emily Ruecker Wildlife Marsh, Tiverton. At the seven sites that could be sampled (Weaver Cove was too degraded), *S. alterniflora* dominated the low marsh and *S. patens*, the high marsh. Both species are perennial grasses, annually producing large amounts of organic matter that are exported from the marshes into the detrital

Table 8.1. Relative coverage (%) of dominant high and low marsh species for seven salt marshes within Narragansett Bay. Sp = *Spartina patens*, Ds = *Distichlis spicata*, Ap = *Atriplex patula*, Sa (t) = *Spartina alterniflora* (tall), Sa (s) = *Spartina alterniflora* (short), Jg = *Juncus gerardii*, If = *Iva frutescens*, Se = *Salicornia europea*, Ss = *Solidago sempervirens*, Lc = *Limonium carolinianum*, At = *Aster tenuifolius*, Pm = *Plantago maritima*. Data from French et al., 1992.

High marsh	Sp	Ds	Ap	Sa (t)	Sa (s)	Jg	If	Se	Ss	Lc	At	Pm
Bisset Cove	53.6	14.2	0.6	0	0	17.2	0.6	0	11.2	0	0.6	1
Ruecker Wildlife Marsh	47.8	34.8	0	2.7	6.7	0.4	0.4	7.2	0	0	0	0
Round Swamp	82.7	12.5	0	2.0	0	0	0	0	0	2.0	0	0.8
Watchemoket Cove	94.1	4.7	0.6	0	0	0	0	0	0.6	0	0	0
Hundred Acre Cove	57.1	40.8	0	0	0	2.1	0	0	0	0	0	0
Common Fence Point	81.3	18.1	0.6	0	0	0	0	0	0	0	0	0
Chase Cove	72.2	27.8	0	0	0	0	0	0	0	0	0	0
Low marsh	Sa (t)	Ds	Sp	Se	Sa (s)	Ap						
Bisset Cove	7.9	4.2	18.5	0	68.8	0.6						
Ruecker Wildlife Marsh	100	0	0	0	0	0						
Round Swamp	76.2	0	21.9	1.9	0	0						
Watchemoket Cove	97.3	0.9	0	0	0	1.8						
Hundred Acre Cove	80.1	8.3	9.3	2.3	0	0						
Common Fence Point	98.4	0.8	0	0.8	0	0						
Chase Cove	89.6	7.8	1.9	0.7	0	0						



food web or deposited within the marshes, contributing to the underlying peat (Nixon, 1982; Teal and Teal, 1962). Table 8.1 shows the relative coverage of species found in the seven study sites that were examined.

Within the boundaries of the NBNERR, salt marshes are found in the North Prudence Unit (102 acres) and Barre and Little units (48 acres), on the east shore of Patience Island (13 acres), and in a small area on Dyer Island (3 acres) (see Table 4.3, page 36; Fig. 4.11, page 34). As with the previous examples, the salt marshes of the Reserve are dominated by *S. alterniflora* and *S. patens*, and are influenced by the adjoining Bay rather than landward processes. They are laced with irregular creeks, ponds, potholes, and man-made drainage ditches (Beck and Beck, 1998). Seventy-six percent of the salt marshes occurring on the islands of the Reserve are protected within NBNERR boundaries (Rosenzweig et al., 2002).

Salt Marsh Restoration

Despite their documented ecological and societal importance, over half the estuarine wetlands originally occurring in the continental United States have been destroyed, largely as a result of urbanization (Tiner, 1984; Tiner et al., 2004). But public concern, coupled with increased public awareness of the functions and values of estuarine wetlands, has provided the impetus for salt marsh restoration (Shisler, 1990). In Rhode Island, recent attempts have been made to restore once-productive salt marsh habitats.

Within Narragansett Bay, a salt marsh restoration effort was undertaken at Sachuest Point salt marsh on Aquidneck Island. In March 1998, tidal flow to the formally restricted portion of the marsh was reestablished with the construction of additional culverts, marsh pools, creeks, and ditches (Roman et al., 2002) (Fig. 8.4). One year after tidal restoration, the tidal range was equivalent to that of the unrestricted portion of the marsh, and vegetation composition had begun to return to normal unrestricted salt marsh conditions, most notably an increase in the abundance of *S. alterniflora* and *S. patens*, and decrease in the height of *Phragmites australis*. An increase in the nekton density and species richness of the restoring marsh also occurred (Roman et al., 2002). Sachuest Point is a prominent example of salt marsh restoration in Narragansett Bay; however, many other similar examples exist, including Potter Pond (Prudence Island) in the NBNERR, Gooseneck

Marsh (Newport), Walker Farm (Barrington), and Silver Creek (Bristol).

Benthic Habitat

Occurring below the low-tide line, the subtidal, benthic (bottom) habitat of Narragansett Bay is composed of soft, unvegetated sediments, predominantly clayey silt and sand-silt-clay. This habitat is found throughout the mid- and upper Bay and in protected coves and embayments. Coarser, sandy sediments are found in the lower Bay (see Fig. 7.6, page 84). Sub-tidal waters support a diverse benthic community of molluscs, crabs, and worms that live in and on the sediments (Fig. 8.5). The northern quahog (*Mercenaria mercenaria*) is the most commercially important species with a smaller fishery in the Bay for the American lobster (*Homarus americanus*). Blue mussels (*Mytilus edulis*) are abundant intertidally, in shallows with hard substrates (French et al., 1992), and in two big commercial beds in the lower West Passage at depths of 12–18 m (40–60 feet) (S. Nixon, personal communication).

There are 13 benthic habitat types found in the waters of Narragansett Bay (Table 8.2, Fig. 8.1). Organisms found in the lower Bay and at depths greater than 12 m (40 feet) in the mid-Bay are adapted to true marine conditions. Evidence of this historically could be seen in sea scallop beds off Gould Island, ocean quahogs in the East Passage, and populations of surf clams 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 blue mussels and slipper shells (*Crepidula fornicata*) found in densities high enough to affect the distribution of other species and sediment characteristics. (Olsen et al., 1984; French et al., 1992).

In areas of deep water in the mid-Bay, where sediments are soft and salinities high, a deposit-feeding community flourishes that is dominated by two species of small clams, *Yoldia limatula* and *Nucula annulata*, and the catworm, *Nephtys incisa*, as well as the coot clam, *Mulinia lateralis*, and a polychete worm, *Mediomastus ambiseta*. This community is widespread on soft bottom and is also found at the bottom of dredged channels. These 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 mechanism of filter feeders, they are largely excluded from such areas. Currents occasionally sweep these nutrient-rich pellets into suspension, thus enriching the water. (Olsen et al., 1984; French et al., 1992).

Historically, the upper Bay was rich in oysters (*Crossostrea virginica*), quahogs, and soft-shelled clams (*Mya arenaria*) (Olsen et al., 1984). While quahogs are still abundant, some of the most productive shellfishing grounds, including the Providence River and Greenwich Bay (see Fig. 7.2, page 79), are often conditionally or permanently closed to harvesting due to bacterial pollution.

Parts of the “upper Bay complex” (Table 8.2, BUB), such as the habitat surrounding North Prudence and Patience Island, are characterized by various sandy sediment types. The tube-dwelling amphipod crustacean, *Ampelisca abdita*, can be found in dense mats in this habitat, as are quahog beds, which sustain lucrative commercial and recreational shellfish harvests (Fig. 8.6). In addition, the *Ampelisca* themselves are an important food source for fish, notably winter flounder (French et al., 1992; Olsen et al., 1984).

Rocky Reefs

Narragansett Bay has few natural rocky reefs (e.g., off Hope Island), but the West Passage of Narragansett Bay near Dutch Island is home to six small artificial rocky reefs. Constructed by NOAA Fisheries with settlement money from the 1989 *World Prodigy* oil spill, the reefs—made of two different sizes of quarried cobble—were built to enhance lobster stocks in the Bay by providing new shelters created by the artificial reefs (Schwartz, 1996).

Castro (2003) examined the effects of habitat enhancement and stock enhancement on the abundance of American lobster inhabiting the artificial reefs. Reefs were monitored for six months pre-construction and five years post-construction using a combination of visual surveys by scuba divers, trap sampling, a tag-recapture program, and airlift sampling for young-of-the-year. Castro (2003) found an approximate population size of 1,250 lobsters at the reef sites, calculated from tag-recapture and visual survey information. In addition, a significant increase in the number of naturally settling young-of-the-year was noted at the reef sites compared to pre-reef conditions. While the addition of hatchery-reared lobsters (stock enhancement) did not contribute to enhancement at the reef sites, the addition of the reefs (habitat enhancement) did significantly increase the numbers of lobsters in Dutch Harbor

through increased settlement and migration (Castro, 2003).

In addition to the Dutch Harbor reefs, an artificial reef-site was constructed in Mount Hope Bay as part of a Rhode Island Experimental Program to Stimulate Competitive Research (EPSCoR) project to study the role of artificial reefs in oyster enhancement and finfish habitat restoration in Narragansett Bay (EPSCoR, 2007; www.riepscor.org/summer2007/project34.html). And when the R.I. Department of Transportation and Federal Highway Administration approved the demolition of the old Jamestown Bridge, artificial reefs were created with the concrete rubble from the bridge at several deep-water sites at the bottom of Rhode Island Sound (Berman, 2006).

Brackish Habitat

Portions of Narragansett Bay where salinity levels are reduced by freshwater dilution are important for supporting important resource species such as oyster, soft-shell clam, and blue crab (*Callinectes sapidus*) (Fig. 8.7). However, the value of these brackish habitats can be compromised by their location at river mouths and within coves that are often subjected to intense physical disturbance from dredging and filling, and which serve as sinks for local and watershed contaminants. Brackish areas in Narragansett Bay tend to be small since many streams enter the water from steeply sloping shores or over dams; the Tauton River is an exception, having a long tidal reach (French et al., 1992).

All brackish areas studied in Narragansett Bay supported species adapted to shallow water with low and variable salinity, extremes in temperature, and high concentrations of organic detritus. These include molluscs (*Hydrobia totteni*, *Illyanassa obsoleta*, *Macoma balthica*, and *Mya arenaria*) and polychaetes (*Neanthes succinea*, *Polydora ligni*, *Scolecopides viridis*, and *Streblospio benedicti*). The brackish fauna of the Kickemuit River, which empties into Mount Hope Bay, R.I., included a number of species not found, or rare, in other brackish areas, such as the gastropods *Sayella fusca* and *Odostomia trifida* and the amphipod *Paraphoxus spinosus*. These may be sensitive species that have been eliminated from polluted areas (French et al., 1992).



Figure 8.4. Tidal flow was restored to a previously restricted portion of Sachuest Marsh by constructing a new culvert (top) as well as marsh pools, creeks, and ditches (bottom). Photos by John Catena, NOAA Restoration Center.



Figure 8.5. A benthic community. Illustration by S.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 trivittatus*. (J) Worm casting. (K) Macoma clam, *Macoma balthica*. (L) Nematodes. (M) Nut clams, *Nucula proxima*. Source: Olsen et al., 1984.

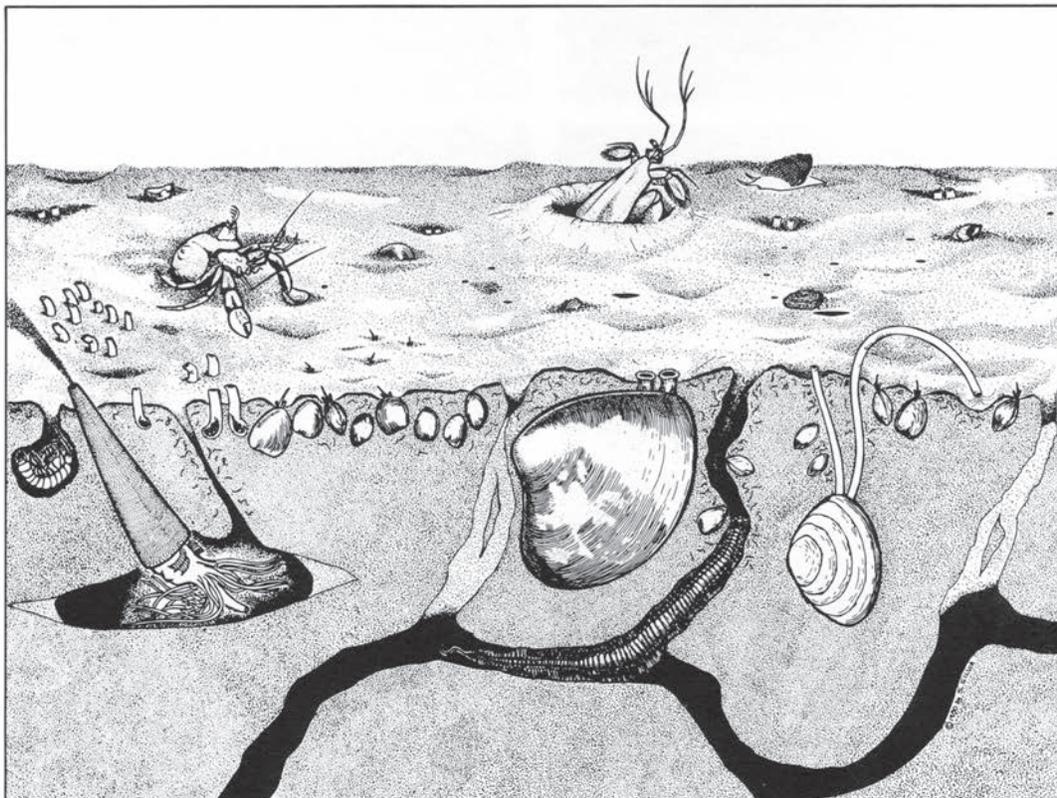
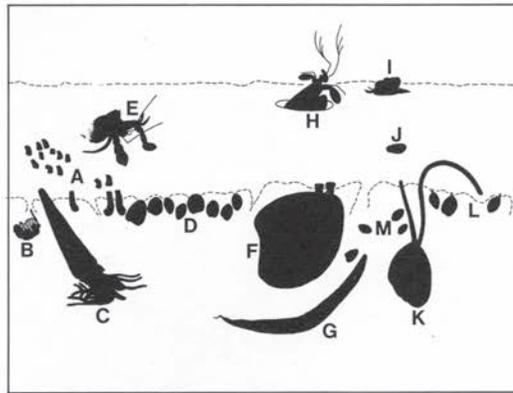


Table 8.2. Thirteen benthic habitat types indicated on the Narragansett Bay map of habitats (Fig. 8.1). Data from French et al., 1992.

Name	Abbrev.	Description
Marine sand	BSA	Silty sand typical of Rhode Island Sound and extending up into the East Passage. Fauna characterized by marine spp. such as <i>Astarte</i> , <i>Cyclocardium</i> , <i>Byblis serrata</i> , and <i>Arctica islandica</i>
Marine silty sand	BSS	Habitat found at the mouth of the Bay and in Rhode Island Sound. Characterized by fine sands with marine spp. such as <i>Spisula</i> , <i>Echinarachnius</i> , and <i>Spiophanes bambyx</i>
Lower Bay complex	BLB	Composed of a variety of mixed sediments containing sand. <i>Mytilus</i> and <i>Crepidula</i> shells may be locally abundant. Mid-estuarine and estuarine-offshore spp. found here include <i>Pherusa affinis</i> , <i>Aricidea</i> and <i>Ampelisca vadorum</i>
Mid-Bay complex	BMB	Habitat found in the deeper water of the mid-Bay, channels of Mt. Hope Bay, and the upper Bay on clayey silt and sand-silt-clay. The fauna are mid-estuarine and estuarine-offshore and include <i>Mulina</i> , <i>Mediomastus</i> , <i>Nucula annulata</i> , <i>Nephtys</i> , and <i>Yoldia</i>
Upper-Bay complex	BUB	Composed of various sediment types containing sand, with tidal current features and <i>Mytilus</i> and <i>Crepidula</i> beds
Mussel (<i>Mytilus edulis</i>) beds	BME	
<i>Crepidula</i> beds	BCF	
Amphipod beds	BAA	
Mt. Hope Bay soft bottom	BMH	Clayey-silt and sand-silt-clay habitat found in the non-channel areas of Mt. Hope Bay. Mid-estuarine spp. include <i>Spiochaetopterus</i> , while <i>Nucula</i> , <i>Nephtys</i> , <i>Yoldia</i> , and <i>Ampelisca abdita</i> are of lesser importance
Upper Bay soft bottom	BUS	Softer sediments of the upper Bay and lower Providence River. Its low diversity fauna includes mid-estuarine spp. and high levels of eutrophication indicators such as <i>Streblospio</i> and <i>Mediomastus</i>
Estuarine dredged channel	BLP	Habitat on the soft sediments of the lower Providence River channel includes a low density of mid-estuarine species, much like BMB, but fewer in number
Polluted dredged channel	BUP	Upper channel of the Providence River and Seekonk River have a fluid, non-cohesive bottom low in oxygen. Fauna consists of greatly reduced diversity and density of pollution-resistant spp.
Shallow undredged brackish	BSU	Undredged areas of the Seekonk River and other shallow brackish areas with fine sand and silt bottoms with brackish water spp. such as <i>Macoma balthica</i> , <i>Scolecoplepides</i> , <i>Cyathura</i> , and <i>Mya</i>



Intertidal Zone

The intertidal, or littoral, zone—the area above the low-water mark and below the high-tide line—of Narragansett Bay is composed largely of narrow cobble beaches. Within the NBNERR, beaches (some sand, mostly cobble) are found on Prudence, Patience, Hope, and Dyer islands; mud or sand flats can be seen in the North Prudence Unit; and rocky intertidal areas are found on Hope Island and at the southern end of Prudence Island (Beck and Beck, 1998).

Organisms that live in the intertidal zone are adapted to an environment of harsh extremes. Temperature, desiccation, salinity, and wave action can vary widely depending on the area inhabited. One easily visible feature of intertidal communities is “vertical zonation,” where the community is divided into distinct vertical bands of specific species going up the shore. Typically, species’ ability to cope with desiccation determines their upper limits, while competition with other species sets their lower limits.

In the “upper littoral” subzone, which is flooded only during the day’s high tides, the environmental fluctuations are most dramatic. The duration of submersion is not long enough to sustain large amounts of vegetation, but some do survive. In Narragansett Bay, the predominant organisms in this subzone are barnacles, small gastropods, isopods, mussels, sea stars, and whelks. The upper littoral can also contain rock pools inhabited by small fish (Fig. 8.8).

In contrast, the “lower littoral” subzone is mostly submerged—it is only exposed during low tides. This area is teeming with life—the most notable difference in this subzone is that there is much more marine vegetation, especially seaweeds, or macroalgae. Organisms in this subzone generally are not well adapted to periods of dryness and temperature extremes. Some of the organisms in this area include anemones, crabs, green algae, hydroids, isopods, mussels, nudibranchs, sculpins, sea cucumber, sea lettuce, sea stars, sea urchins, shrimp, snails, sponges, tube worms, and whelks. Creatures living in this subzone can grow to larger sizes because there is more productivity in the lower littoral and because marine vegetation can grow to much greater sizes due to the better water coverage—the water is shallow enough to allow light to reach the vegetation, nutrients are supplied on a regular basis, and the salinity is close to that of full seawater. This area is also protected from large predators such as large fish because of the wave action and the water still being relatively shallow (Bertness et al., 2001).

Submerged Aquatic Vegetation

Eelgrass

Eelgrass, *Zostera marina*, is a rooted, submerged flowering plant typically found in coastal and marine habitats (Fig. 8.9). Eelgrass contributes significantly to the health and productivity of these habitats (Keller et al., 1996). It plays an important role in the life cycles of scallops, crabs, finfish, geese, and ducks. The dense meadows of eelgrass provide breeding and nursery areas for young finfish and shellfish as well as a substratum for attachment in the water column and protection from predators (Thayer et al., 1984). In fact, recent studies in Rhode Island (Harris et al., 2004) have documented that eelgrass beds—even those of modest density—increase survivorship of tautog (*Tautoga onitis*), cunner (*Tautoglabrus adspersus*), and silversides (*Menidia menidia*), but do not affect predation by bluefish (*Pomatomus saltatrix*) on Atlantic menhaden (*Brevoortia tyrannus*). These findings suggest that eelgrass habitats indeed serve a functional role as refuges from predation for some prey fish.

During its life cycle, eelgrass typically breaks away from the base shoots and becomes an important component of the detrital pathway. Detritivores begin to break down the leaves into smaller particles which are then consumed by bacteria and fungi. Many invertebrates also consume the decaying eelgrass and then become food for larger life forms, such as fish and crabs (Keller et al., 1996).

Eelgrass communities are also valuable sediment traps and help stabilize bottom sediments



Figure 8.7. Brackish water habitats, such as at the mouth of the Narrow River in Narragansett, support important resource species, but are also often compromised because they serve as sinks for local and watershed contaminants. *Photo by Malia Schwartz.*

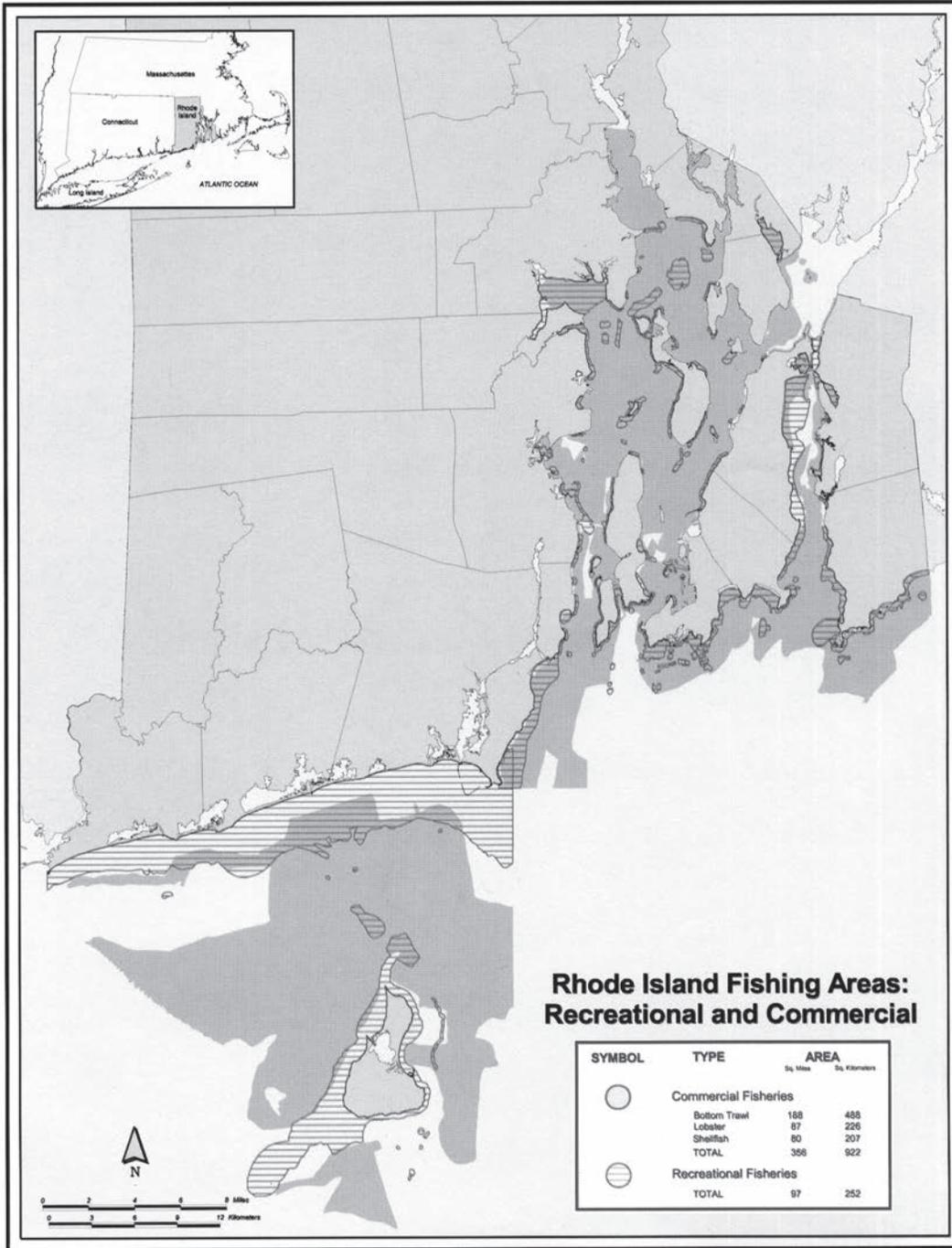


Figure 8.6. Narragansett Bay provides ideal habitat for commercial and recreational fisheries. *Source: Rhode Island Marine Resource Uses Project.*



(Thayer et al., 1975). Their leaves act as dampers in the water and reduce wave motion. Eelgrass meadows remove both suspended sediments and nutrients from the water column. High levels of nutrients entering a system from developed areas are taken up by eelgrass rather than being passed downstream where they might add to the level of pollution in a system (Keller et al., 1996). Historically, eelgrass beds could be found throughout the Bay and thrived even in the more polluted areas of the upper Bay and Providence River (Nixon et al., 2007).

The current distribution of eelgrass in Narragansett Bay is patchy (Fig. 8.10). It is limited to shallow embayments with mud-sand substrata since the rhizome is buried in the sediment and leafy shoots arise annually. Eelgrass beds have been reported in the southern East Passage around Newport (Brenton Cove and Coasters Harbor Island), on the east side of Conanicut Island (east of Beavertail State Park, Mackerel Cove, and Fort Wetherill State Park), and around Rose Island. Small patches have been reported in the West Passage north of Bonnet Point, on the east side of Dutch Island in Wickford, and in East Greenwich Cove (Keller et al., 1996). A 1989–1990 macroalgal survey (French et al., 1992) extended what was earlier limited to locations along the eastern shore of Conanicut Island to the eastern and western shores of the Sakonnet River. Within the NBNERR, lush eelgrass meadows could be found in the shallow waters of the Reserve until the 1930s. Today, only two healthy beds exist within the boundary of the NBNERR. The largest bed extends from the south end/ T-wharf area on Prudence for over 364 m (400 yards) north along the east shore. A much smaller bed exists south of Sheep Pen Cove (Beck and Beck, 1998).



Figure 8.8. Beavertail's rocky shores contain small tide pools that are home to creatures that can tolerate the extreme environmental fluctuations characteristic of the upper intertidal zone. Photo by Malia Schwartz.

Eelgrass Restoration

In the 1930s, a virulent fungal disease swept through eelgrass beds in North America and Europe and almost completely eliminated the plants from many areas (den Hartog, 1987). A slow recovery over the next 30 years renewed scientific interest in the ecology and reproduction of *Zostera*, and numerous studies began to reveal the importance of eelgrass habitats. Ironically, the recovery of eelgrass, at least along the U.S. East Coast, coincided with the migration of the human population to the coast, the increasing use of nitrogen fertilizer following World War II, and increasing atmospheric emissions of nitrogen from electric power generation and trans-



Figure 8.9. A plug of eelgrass, shown after transplant into one of 10 locations in Narragansett Bay as part of an eelgrass restoration effort. Photo by Jerry Prezioso, NOAA.

portation. The increasing inputs of sediment and nutrients combined to reduce coastal water clarity. As a result, the natural recovery of eelgrass largely stopped, and the plants were lost once again from many bays and estuaries. It is estimated that from one- to two-thirds or more of the once-recovered eelgrass has been lost (Fonseca et al., 1998; Hurley, 1992; Orth and Moore, 1983; Short et al., 1996).

However, this loss of eelgrass has stimulated growth in the area of eelgrass research, restoration, and recovery. Rhode Island Sea Grant researchers used mesocosm tanks, which replicated the coastal lagoons where eelgrass grows, to examine the effects of nutrients, temperature, shoot density, and ecosystem value of eelgrass (Bintz and Nixon, 2001; Harris et al., 2004). This led not only to new understanding of eelgrass ecology, but also to new approaches to restoring eelgrass beds through the use of seeds (Granger et al., 2002).



Figure 8.10. Eelgrass distribution (green/yellow) in Narragansett Bay. Map courtesy Michael Bradley, URI Environmental Data Center.



With funding from the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) and Rhode Island Sea Grant, Granger and colleagues developed techniques for harvesting, preparing, and storing eelgrass seed for later planting (Granger et al., 2002). The investigators went on to develop a “seeding sled”—a device towed under water that creates furrows, injects a seed-gelatin matrix into the sediments, and covers the seeds (Fig. 8.11). The researchers’ mesocosm studies demonstrated 50 percent seed survival using these methods—unheard of success compared with past seed-based restoration efforts (Granger et al., 2002). This work was field-tested in Narragansett Bay in Reserve waters (see Chapter 13) and provided a link to the goals of the NBNERR to reestablish eelgrass in selected areas with a high potential for successful restoration (Beck and Beck, 1998).

Macroalgal Beds

In shallow areas, macroalgae may contribute significantly to primary production particularly via contributions to detrital food chains (Mann, 1972; 1973) (Fig. 8.12). They provide habitat for a variety of organisms, such as bay scallop (*Argopecten irradians*) (Hicks, 1986), and when sessile, may integrate the history of a water mass. Consequently, rugged species such as *Ulva latuca*, *Fucus vesiculosus*, and *Chondrus crispus* serve as useful bioaccumulators of pollutants (Levine

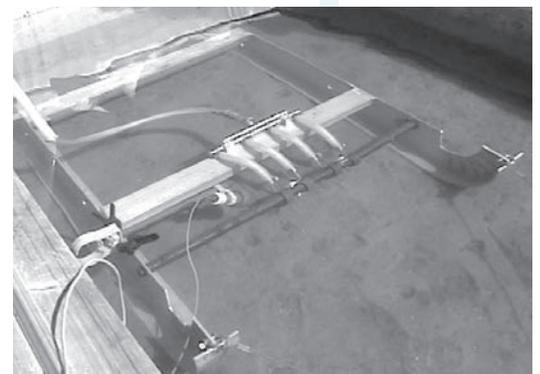


Figure 8.11. The eelgrass seeding sled, developed by URI researchers, was field-tested in NBNERR waters. Photo by Stephen Granger, URI Graduate School of Oceanography (GSO).



and Wilce, 1980; Sears and Battaglia, 1990), and therefore, changes in their abundance and distribution can be an indicator of degradation or recovery of an area.

But macroalgal proliferation can also cause degradation in an ecosystem. Increased nutrients, especially nitrogen and phosphorus, coming into an embayment from human sources can overstimulate plant growth—a process called eutrophication. If large amounts of seaweed accumulate, they may clog beaches and boating areas and cause odor problems when they decompose (Granger et al., 2000). More importantly, when the plants die and are decomposed by bacteria, oxygen in the water is depleted. Granger et al. (2000) conducted an assessment of eutrophication in Greenwich Bay in which they quantified the biomass of macroalgae at different times during the summer to predict the amount of oxygen consumption that might occur when the seaweeds died and decomposed in the bottom water. The major species they found were *U. lactuca* and *Gracilaria tikvahiae*, with lesser amounts of *U. linza* (Fig. 8.13). They determined that, while the macroalgae in the coves may have some impact on bottom-water dissolved oxygen if the coves became stratified, this impact was unlikely to be significant (Granger et al., 2000).

Seaweeds have been studied in Narragansett Bay since the mid-1800s (Fig. 8.14). Much of the published information as well as unpublished material was synthesized by French et al. (1992) and combined with a broad scale and semiquantitative sampling program to compile maps of macrophyte distributions within the Bay. Table 8.3 lists the macrophyte species collected during a 1989–1990 survey. Species diversity was highest where water from Rhode Island Sound entered the Bay through the East Passage and Sakonnet River. The number of macroalgal species found in the low intertidal was consistently higher than the upper subtidal. Red algae predominated in the subtidal zone (French et al., 1992).

According to the survey, the dominant species in the Bay were *Chondrus*, *Codium*, *Fucus*, *Ulva*, *Ascophyllum*, and *Laminaria*. *Chondrus*, *Codium*, *Fucus*, and *Ascophyllum* appeared throughout the Bay, while *Ulva* also extended into the tributaries. For the most part, *Fucus* and *Ascophyllum* were restricted to intertidal zones, while *Codium* and *Ulva* were a major component of both intertidal and subtidal zones. Compared with estuaries north of Cape Cod, Narragansett Bay

has fewer species but a larger proportion that extend to the tropics (French et al., 1992).

Human-Modified Shorelines

Within Narragansett Bay, over half the shoreline has been “hardened” by human-made structures (RIGIS, 2006) (Fig. 8.15). These structures include bulkheads or seawalls that were designed to prevent erosion (Fig. 8.16). However, most coastal erosion in the Bay results from major storms, such as hurricanes and nor’easters. Sometimes these structures actually hasten erosion by concentrating the wave energy in the area of the barrier (Keller, et al., 1996). Under changing climate conditions and rising sea level, this effect will be intensified. The R.I. Coastal Resources Management Council’s (CRMC) webpage on “Climate Change & Sea Level Rise” offers resources for information and related links on the topic. Visit www.crmc.ri.gov/climatechange.html. In addition, the CRMC had adopted new shoreline maps for Rhode Island’s coast, detailing erosion rates for the shoreline. The maps are available at www.crmc.ri.gov/maps/shoreline.html.

Marinas as Habitat

Besides those structures built along the shore to prevent erosion, another type of human-modified structure along the shoreline is marinas (Fig. 8.17). A study by Nixon et al. (1973) provided one of the first attempts to look at marinas as habitat. They made basic ecological measurements of marina system production, respiration, species diversity, and major populations for comparison with those of estuarine salt marshes and other natural communities.

In their study, Nixon et al. (1973) compared two coves that both open into Wickford Harbor—Wickford Cove, which has three marinas and



Figure 8.12. Seaweeds, or macroalgae, contribute significantly to primary production in estuarine habitats. Photo by Malia Schwartz.



Figure 8.14. Seaweeds provide habitat for a variety of organisms. Their ecology has been studied extensively in Narragansett Bay. Photo by Malia Schwartz.



numerous moorings, and Mill Creek, which is bordered by fringing *S. alterniflora* marsh with no boats, docks, or moorings. They found that the two ecosystems were strikingly similar in many respects. Fish species were similarly diverse in the marina and the marsh habitats, but abundance was greater in the marsh cove due to the presence of dense juvenile menhaden schools. Additionally, the fouling communities that grow on the undersurface of floats and wooden dock pilings of marinas appeared to be a food source for juvenile mummichogs (*Fundulus heteroclitus*) and likely serve as additional food sources to complement the detritus input from the salt marsh. Based on their findings, Nixon et al. (1973) concluded that in most respects, the marina cove and the marsh cove appeared not only to be similar, but also compatible ecological systems.

More recently, the concept of marinas as habitat has taken hold in the aquaculture industry. Innovative aquaculture techniques are using floating docks in marinas as platforms for the nursery culture of shellfish seed as a means to efficiently utilize valuable shoreline space (Scott et al., 2000). Shellfish seed, such as oyster, quahog, or scallop, are hung in bags on the underside of docks. There, they filter-feed on a variety of organisms in the water column, which, in addition to enhancing shellfisheries, also have the added benefit of removing excess nutrients from the Bay and improving water quality (Scott et al., 2000).

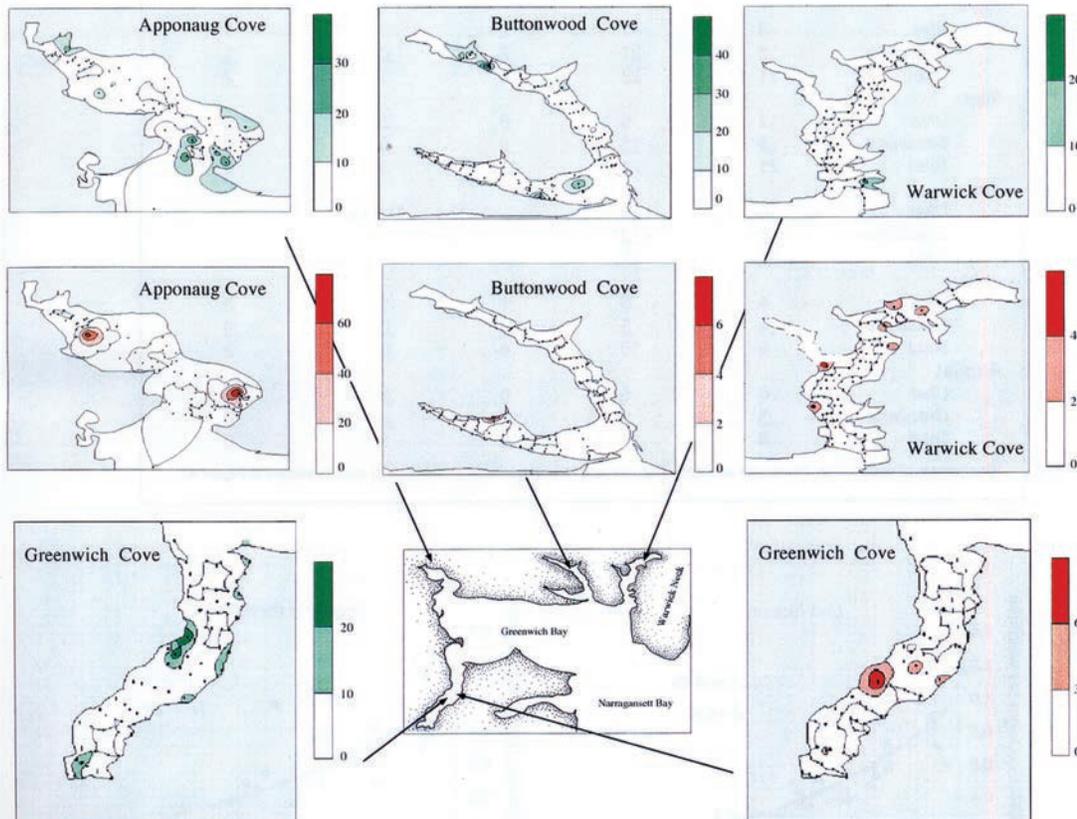


Figure 8.13. Biomass of *Ulva* (a green algae) and *Gracilaria* (a red algae) in the major coves of Greenwich Bay in July 1997. Units are in grams dry weight/m². Dots show sampling locations. Source: Granger et al., 2000.

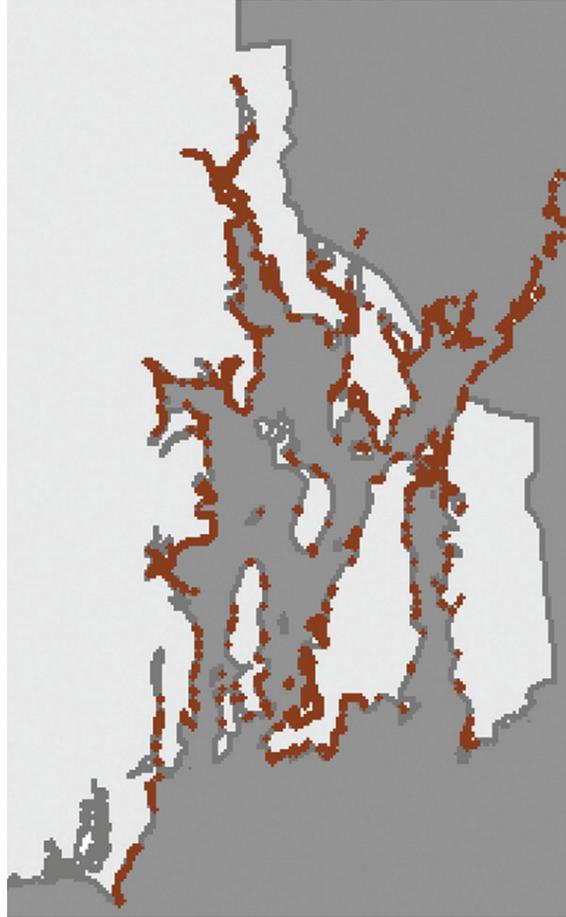


Figure 8.15. Within Narragansett Bay, over half of the shoreline is “hardened” with human-made structures (red areas). *Data source: RIGIS.*



Figure 8.16. This bulkhead at State Pier #5 in Narragansett provides a sheltered cove to tie up, launch a boat, fish, or scuba dive. Human-made structures are designed to prevent erosion and provide sheltered areas for human use. *Photo by Malia Schwartz.*



Figure 8.17. This marina in Wickford Cove provided an ideal study site to explore the role of marinas as habitat. *Photo by Malia Schwartz.*



Table 8.3. Macrophyte species collected during a 1989–1990 survey in Narragansett Bay. Species names read across, then down. Data from French et al., 1992. Note: The genus *Enteromorpha* was recently reclassified as *Ulva*.

Chlorophyta	
<i>Blidingia minima</i>	<i>Bryopsis plumose</i>
<i>Chaetomorpha aerea</i>	<i>C. linum</i>
<i>Cladophora albida</i>	<i>C. sericea</i>
<i>Codium fragile</i>	<i>Enteromorpha compressa</i>
<i>E. flexuosa</i>	<i>E. intestinalis</i>
<i>E. linza</i>	<i>E. prolifera</i>
<i>Kommannia leptoderma</i>	<i>Monostroma grevillei</i>
<i>M. oxyspermum</i>	<i>Protomonostroma undulatum</i>
<i>Rhizoclonium reparium</i>	<i>Spongomorpha arcta</i>
<i>S. lanosa</i>	<i>Ulothrix flacca</i>
<i>Ulva latuca</i>	<i>Urospora penicilliformis</i>
Phaeophyta	
<i>Ascophyllum nodosum</i>	<i>Chorda filum</i>
<i>Cladostephon zosteriae</i>	<i>Cladostephus spongiosus</i>
<i>Desmarestia viridis</i>	<i>Desmotrichum undulatum</i>
<i>Dictyosiphon foeniculaceus</i>	<i>Ectocarpus siliculosus</i>
<i>Elaschista fucicola</i>	<i>Fucus evanescens</i>
<i>F. spiralis</i>	<i>F. vesiculosus</i>
<i>Giffordia granulosa</i>	<i>Laminaria digitata</i>
<i>L. saccharina</i>	<i>Leathesia difformis</i>
<i>Petalonia fascia</i>	<i>Pilayella littoralis</i>
<i>Punctaria latifolia</i>	<i>Ralfsia verrucosa</i>
<i>Scytosiphon lomentaria</i>	
Rhodophyta	
<i>Agardhiella subulata</i>	<i>Ahnfeltia plicata</i>
<i>Antithamnion cruciatum</i>	<i>Audouinella</i> sp.
<i>Bangia atropurpurea</i>	<i>Bonnemaisonia hamifera</i>
<i>Callithamnion baileyi</i>	<i>C. byssoides</i>
<i>C. tetragonum</i>	<i>Ceramium elegans</i>
<i>C. rubrum</i>	<i>Champia parvula</i>
<i>Chondrus crispus</i>	<i>Corallina officinalis</i>
<i>Cystoclonium purpureum</i>	<i>Dasya baillouviana</i>
<i>Dumontia contorta</i>	<i>Encrusting corallines</i>
<i>Gelidium pusillum</i>	<i>Gloiosiphonia capillaries</i>
<i>Gracilaria tikvahiae</i>	<i>Griffithsia globulifera</i>
<i>Ginnellia Americana</i>	<i>Hildenbrandia rubra</i>
<i>Lomentaria baileyana</i>	<i>Mastocarpus stellatus</i>
<i>Palmaria palmata</i>	<i>Phycodrys rubens</i>
<i>Phyllophora pseudoceranooides</i>	<i>P. truncata</i>
<i>Plumaria elegans</i>	<i>Pneophyllum lejolisii</i>
<i>Polyides rotundus</i>	<i>Polysiphonia denudata</i>
<i>P. fibrillose</i>	<i>P. harveyi</i>
<i>P. lanosa</i>	<i>P. nigra</i>
<i>P. nigrescens</i>	<i>P. novae-angliae</i>
<i>P. urceolata</i>	<i>P. umbrilicalis</i>
<i>Porphyra umbilicalis</i>	<i>Pterothamnion plumula</i>
<i>Rhodomeia confervoides</i>	<i>Scagelia pylaisaei</i>
<i>Titanoderma pustulatum</i>	
Cyanophyta	
<i>Callithrix</i> sp.	<i>Microcoleus lyngbyaceus</i>
Chrysophyta	
<i>Berkeleya rutilens</i>	<i>Grammatophora angula</i>
<i>Licomorpha</i> sp.	<i>Melosira</i> sp.
<i>Vaucheria</i> sp.	

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CHAPTER 9.

Plankton and Benthos

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Plankton and Benthos

Introduction

Narragansett Bay has historically been considered a phytoplankton-based estuary. In part, this is due to the geomorphology of the Bay itself; since much of the Bay is relatively deep (see Fig. 7.4, page 81), submerged aquatic vegetation (SAV; macroalgae and eelgrass, *Zostera marina*) is limited in distribution and cover. Coves, embayments, marshes, and other shallow areas typically support dense and productive SAV (primarily macroalgae), but on a Bay-wide scale, phytoplankton is the dominant primary producer (Kremer and Nixon, 1978; Kremer, 1990). Phytoplankton composition and production is variable among regions of the Bay and over different temporal cycles. It is directly grazed by zooplankton in the water column and provides a critical food source for benthic organisms. The purpose of this chapter is to provide an overview of plankton (both phyto- and zoo-) and benthic communities in Narragansett Bay by discussing spatial and temporal patterns in composition, abundance, biomass and production, plankton-benthos interactions, and long-term trends and changes.

Phytoplankton

Community Composition

Narragansett Bay supports a rich phytoplankton assemblage (Appendix 9.1) that researchers have been studying for over five decades (although some basic species composition lists date back to the early 1900s). The number of phytoplankton species present in Narragansett Bay is predictably variable among different studies. For example, an early 10-month study documented approximately 75 species of phytoplankton (Smayda, 1957), while a longer-term study from 1959–1980 identified 138 phytoplankton taxa (Karentz and Smayda, 1984). The variability in the number of phytoplankton species among different studies is due in part to differences in the timing and location of sampling and to different sampling techniques. However, one consistent result among all studies is that diatoms and, to a lesser extent, dinoflagellates overwhelmingly dominate the phytoplankton community in Narragansett Bay. Of the 138 taxa identified by Karentz and Smayda (1984), 84 were diatoms and 30 were dinoflagellates. Similarly, Smayda (1957) found that

nine diatom and four dinoflagellate species comprised 94 percent of the phytoplankton community.

Diatoms and flagellates exhibit a conspicuous alternating cycle of abundance in Narragansett Bay over the course of a year (Pratt, 1959; Durbin and Durbin, 1981). Diatoms tend to dominate during late winter through spring (January through May), when flagellate abundance is lowest. Diatoms begin to decline in the spring when flagellate numbers begin to rise, and by early summer flagellates reach their annual maximum. Diatoms again dominate at the end of the summer, but fall off again in late autumn (Pratt, 1959).

Microplankton (20–200 micrometers (μm)), primarily diatoms, are generally reported as the dominant size fraction in Narragansett Bay. However, nanoplankton in the 2–20 μm size range are typically an order of magnitude more abundant than microplankton but are not often identified to species (Oviatt, personal communication). Microplankton include the most abundant diatom in the Bay, *Skeletonema grethae* (formerly misidentified as *S. costatum* (Sarno et al., 2005)), which Smayda (1957) found during all four seasons, comprising over 81 percent of the total phytoplankton population. Similarly, over a 22-year period, Karentz and Smayda (1984) found that *S. grethae* occurred in 88 percent of all samples collected and displayed a bimodal annual abundance with the highest cell counts in late winter-early spring and mid-summer, and lower counts in June and July.

In addition to *S. grethae*, Karentz and Smayda (1984) found that several other phytoplankton species are also numerically abundant in Narragansett Bay, including *Detonula confervacea*, *Asterionella glacialis*, *Olisthodiscus lutes*, and *Thalassiosira nordenskiöldii*. From 1959–1980, *D. confervacea* ranked second most abundant behind *S. grethae* and was a characteristic member of the winter phytoplankton assemblage in Narragansett Bay, occurring between January and March (although this species is now much less abundant and even absent in some years due to warming water temperature (Paul Hargraves, personal communication)). *A. glacialis* was found to be the third most numerically dominant species in Narragansett Bay, was present throughout the year, and was most abundant in late summer and winter. The fourth most abundant species was *O. lutes*, which occurred from May through December and was most abundant when *S. grethae* abundance was low. *Thalassiosira* sp. first appeared in Narragansett Bay in 1967 and has



continually increased since then to the point where it ranked sixth in total cell abundance and fifth in frequency over the 22-year study period (Karentz and Smayda, 1984).

Biomass and Production

Phytoplankton biomass (expressed as chlorophyll *a*) generally exhibits variable seasonal patterns in Narragansett Bay. Often, the typical signature seasonal event in Narragansett Bay is the winter-spring phytoplankton bloom (Fig. 9.1) (Pilson, 1985; Li and Smayda, 1998; Oviatt et al., 2002). Winter-spring bloom inception is variable among years, but typically occurs between November and March. The time and magnitude of the bloom maximum is also highly variable; the peak can occur as early as January, when it is most frequently observed, or as late as April (Smayda, 1998). However, major blooms are not restricted to the annual winter-spring bloom and instead have been observed during most times of the year. In fact, from 1973–1990 major phytoplankton blooms occurred in January, February, March, April, June, August, September, November, and December (Li and Smayda, 1998). Li and Smayda (1998) further documented that the frequency and magnitude of blooms were higher from late autumn through spring (e.g., October to April) than during the summer, with chlorophyll levels exceeding 150 mg m⁻² in January and reaching only 80 mg m⁻² in July.

Phytoplankton dynamics in Narragansett Bay, including the winter-spring bloom, are affected by numerous, often interacting factors including light, temperature, nutrient concentrations, grazing, and competition among other phytoplankton species (Hargraves, 1988). The classic view of the winter-spring bloom holds that phytoplankton is light limited during winter and is therefore unable to bloom until water column stratification occurs. However, although temperature and irradiance, either acting independently or synergistically, have been identified as bloom triggers, so has the removal of nutrient limitation and the release of grazing pressure (Smayda, 1998). Indeed, Keller et al. (1999) has suggested that the annual winter-spring bloom in temperate areas is controlled by low temperatures that lead to a relaxation in grazing pressure. Li and Smayda (1998) further suggest that temperature may have less of a direct effect and more of an indirect effect in that it can increase zooplankton grazing. In addition, summer phytoplankton blooms may be indirectly regulated by ctenophores (*Mnemiopsis lledyii*), which directly graze upon herbivorous zooplankton (Deason and Smayda, 1982). It seems clear

that since the timing of the bloom can be highly variable in the Bay in different years, the bloom—or any bloom throughout the year—is ultimately controlled by multiple interacting factors that vary year to year (Smayda, 1998).

Although it varies by location, phytoplankton primary production generally averages approximately 300 grams of carbon per square meter per year (g C m⁻² yr⁻¹) on a Bay-wide scale (Hargraves, 1988; Oviatt et al., 2002). However, phytoplankton primary production is also highly variable both within and among years, and different results are reported from different studies—in part a reflection of different methods of measuring production. For example, Durbin et al. (1975) reported that primary production was highest during the winter-spring bloom as well as during the summer nanoplankton (tiniest plankton) blooms. Later, Durbin and Durbin (1981) found that compared to summertime values, production was relatively low even during the winter-spring bloom due to the effects of low temperatures (Durbin and Durbin, 1981). More recently, Oviatt et al. (2002) found that production was generally highest during the summer but differences in timing were apparent depending on location within the Bay. A review of all available data at the time, however, concluded that production is generally highest during mid- to late summer, while lowest production values occur from November through January and are approximately an order of magnitude lower than summer values (Hinga et al., 1989).

Spatial Patterns

Phytoplankton abundance and biomass predictably vary among different areas of Narragansett Bay. A conspicuous pattern is that phytoplankton abundance and biomass is higher in the upper regions of the Bay, including the Providence River and Mount Hope Bay, than in the remainder of the Bay. In other words, phytoplankton exhibits changes along a north-south gradient in Narragansett Bay, and this pattern may be a result of increased nutrient input into the upper Bay from sewage plants and other inputs, and to greater mixing with nutrient-poor shelf water lower in the Bay (Durbin and Durbin, 1981). For example, Oviatt et al. (2002) found that mean nutrient concentrations decreased by 75 percent from the Providence River to Rhode Island Sound and mean chlorophyll values dropped from 13 micrograms per liter (µg L⁻¹) in the Providence River to 3 µg L⁻¹ in Rhode Island Sound. Seasonal patterns in phytoplankton also differ around the Bay; a large, distinct chlorophyll maximum is



a.
b.

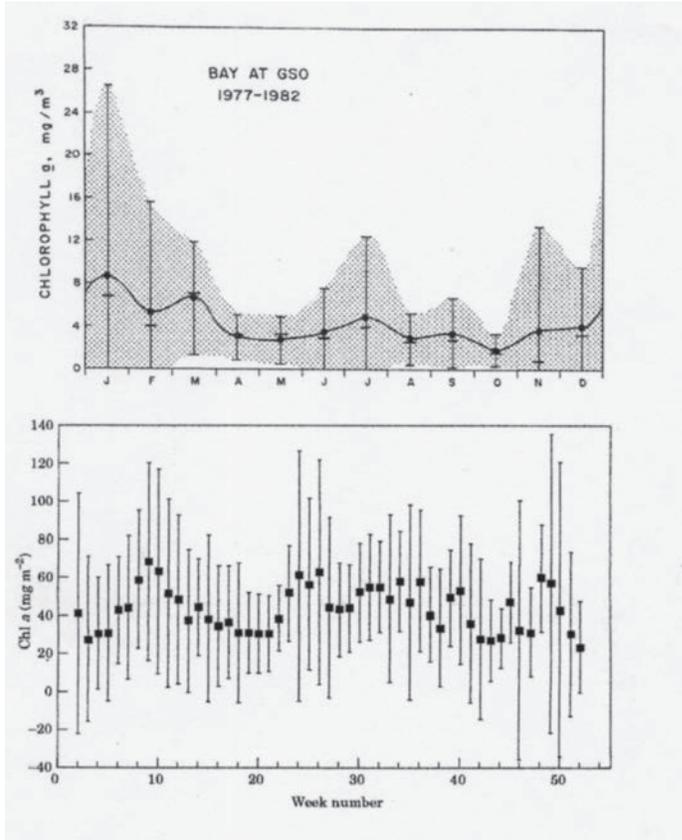


Figure 9.1. Seasonal changes in chlorophyll *a* in Narragansett Bay, Rhode Island. (a) Reproduction of Figure 7 from Pilson (1985) illustrating chlorophyll concentrations from the dock at the GSO from 1977–1982. Error bars are two standard deviations and the shaded areas represent the field where 95 percent of the observations are likely to be found. (b) Reproduction of Figure 3 from Li and Smayda (1998) showing weekly mean chlorophyll in Narragansett Bay from 1973–1990. It is clear from both figures that high chlorophyll levels occur during the winter-spring bloom and that concentrations vary throughout the year due to periodic blooms of varying intensity.

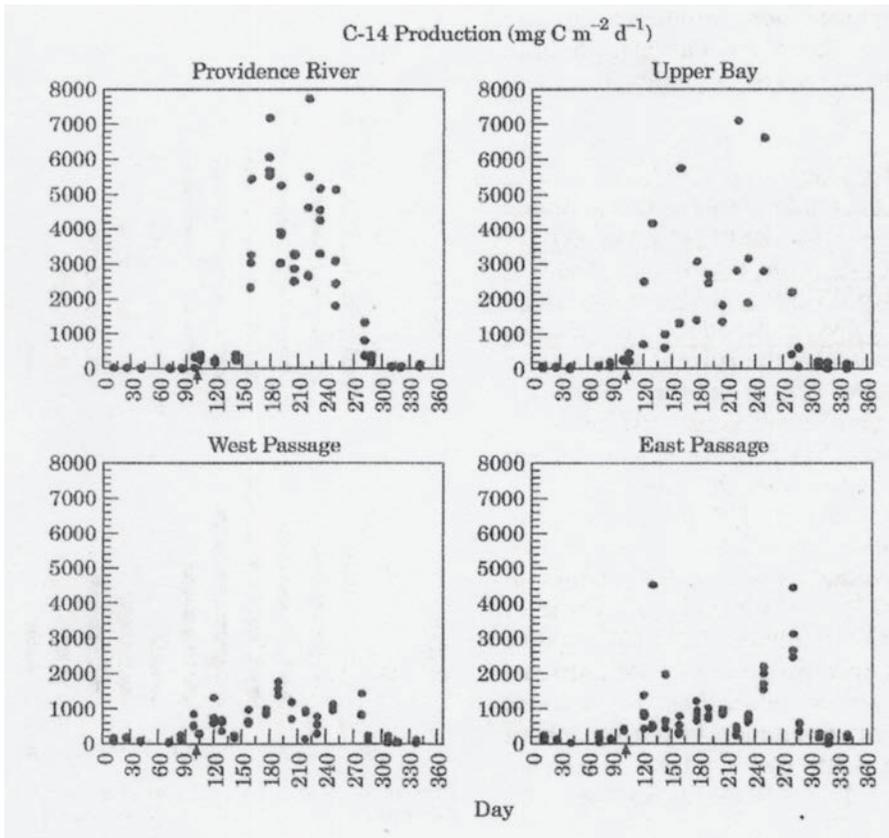


Figure 9.2. Reproduction of Figure 4 from Oviatt et al. (2002) showing phytoplankton primary production in different regions of Narragansett Bay using the C^{14} method. Data were collected every two weeks from April 1997 through April 1998. Note the very high production levels in the Providence River and upper Bay during summer and, in contrast, the two smaller production spikes in spring and early fall in the East Passage.



found during the summer in the Providence River and upper Bay, but smaller chlorophyll maximums can also occur in spring and fall in both the East and West passages (Fig. 9.2) (Oviatt et al., 2002).

Primary production levels mirror the gradients in chlorophyll and nutrient concentrations. Production values are highest in the Providence River and upper Bay and decrease while moving south throughout the Bay towards its mouth. For example, Oviatt, et al. (2002) recorded a high production of $492 \text{ g C m}^{-2} \text{ yr}^{-1}$ in the Providence River and a low of $152 \text{ g C m}^{-2} \text{ yr}^{-1}$ at the seaward extent of sampling (the dock at GSO in the lower West Passage). This trend is consistent even among studies using different techniques for measuring productivity (see discussions in Keller et al. (1996) and Hargraves (1988)).

Zooplankton

Community Composition

The zooplankton community in Narragansett Bay (Appendix 9.2) can be grouped according to size and type. The three general size groups of zooplankton include microzooplankton (typically less than 60–80 μm in length; e.g., tintinnids), mesozooplankton (typically between 80 μm and approximately 3 mm in length; e.g., copepods, cladocerans, and rotifers), and macrozooplankton (greater than 3 mm; e.g., gelatinous zooplankton such as the ctenophore, *M. lledyii*). In addition, the two types of zooplankton include the holoplankton, which spend their entire lives as plankton, such as copepods, and meroplankton, which include planktonic larval stages of animals such as bivalves and worms. Discerning trends and spatial and temporal patterns in zooplankton is difficult in Narragansett Bay because most studies used different sampling methods and mesh sizes, and many only sampled a small number of stations or for a short period of time, depending on the question under investigation. However, some general patterns have emerged in terms of the composition of the zooplankton community and overall, large-scale spatial and temporal patterns.

By far, the most conspicuous group of zooplankton in Narragansett Bay is copepods. The Bay's zooplankton community is consistently dominated by the two species of copepods, *Acartia tonsa* and *Acartia hudsonica* (Durbin and Durbin, 1988). Their overall dominance of the zooplankton community was demonstrated by Durbin and Durbin (1981), who found that these two species

(combining the nauplii, copepedite, and adult stages) composed 74 percent and 54 percent of total zooplankton abundance in the lower and upper Bay, respectively. Other species, though less abundant, are important components of the Narragansett Bay zooplankton community, including certain meroplankton (e.g., bivalve larvae, polychaete larvae), rotifers, the cladoceran, *Podon polyphemoides*, and in the summer, *M. lledyii* (Durbin and Durbin, 1981).

Temporal and Spatial Patterns

Zooplankton in Narragansett Bay varies seasonally in terms of species composition, total abundance, and total biomass, and these changes are generally in response to temperature. The two dominant copepod species demonstrate an oscillating pattern of abundance with *A. hudsonica* being most abundant in winter and spring, and *A. tonsa* dominating in summer and fall (Durbin and Durbin, 1981). However, more recent work has demonstrated a change in *M. lledyii* abundance in response to warming temperatures, resulting in a concurrent near extirpation of *A. tonsa* in Narragansett Bay (Costello et al., 2006). Overall peaks in zooplankton biomass can occur in spring (March through May), summer (primarily July), and, to a lesser extent, in early fall (September–October) (Fig. 9.3) (Durbin and Durbin, 1981).

Unlike phytoplankton, zooplankton biomass does not appear to differ substantially between upper and lower Bay areas, except near the Bay mouth where biomass drops quickly as coastal species replace estuarine species (Durbin and Durbin, 1988). Abundance of individual species and of all zooplankton combined also does not differ significantly between upper and lower Bay stations (Durbin and Durbin, 1981). However, the abundance of some of the more abundant zooplankters is reduced while moving from the Bay into the adjacent Block Island Sound, although these patterns are generally based on samples taken from a small number of stations. For example, species such as *A. hudsonica*, *A. tonsa*, *Podon* sp., and bivalve and polychaete larvae are much more abundant in upper Bay areas as compared to Block Island Sound where coastal species are more prevalent (Frolander, 1955; Durbin and Durbin, 1988).

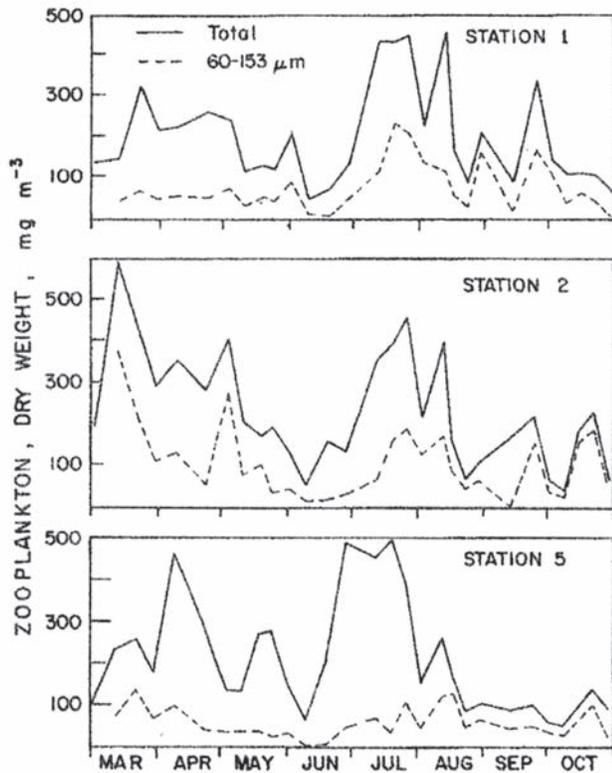


Figure 9.3. Reproduction of Figure 6 from Durbin and Durbin (1981) showing seasonal patterns of zooplankton biomass for all zooplankton combined and for the 60–153 μm size fraction. Data were collected at approximately weekly intervals from March to October 1976. Note the consistently high zooplankton biomass at all stations during summer.

Benthic Communities

Used here, benthic organisms are considered to be those living within or directly on the surface of the sediments or hard-bottom substrates within Narragansett Bay (Fig. 9.4). This includes infauna and epibenthic organisms such as polychaete worms, nematodes, bivalves, and amphipods and other small crustaceans (Appendix 9.3). It does not necessarily include other epibenthic and burrowing species such as crabs and bottom fish, which are considered in more detail the nekton chapter (even though these species are intimately associated with the benthos of Narragansett Bay).

Although Narragansett Bay is a phytoplankton-based estuary, it has long been recognized that the benthos and its associated communities play an integral role in Bay-wide processes and are intimately coupled with the water column (e.g., benthic-pelagic coupling is strong in Narragansett Bay). As such, benthic communities have been intensely studied in the Bay for at least 50 years (see review in Frithsen, 1989). Unfortunately, differences among studies in terms of sampling gear, sieve size, study year, and sample location make it difficult to synthesize all available benthic data. Frithsen (1989) assessed the effects of these differences among studies and produced an excellent review of the knowledge

of the benthic communities in Narragansett Bay through the late 1980s.

The species composition of benthic communities in the Bay is difficult to generalize because of the issues mentioned above and because the different faunal groups that are considered part of the benthos (e.g., meiofauna vs. macrofauna). However, some conspicuous benthic species that are often frequent and abundant include *Nephtys incisa*, *Nucula annulata*, *Mediomastus ambiseta*, the polychaete *Streblospio benedicti*, and the tube-dwelling amphipod *Ampelisca spinipes*. Other larger species include the commercially important quahog clam, the mat-forming slipper-shell clam, and the bed-forming blue mussel. All told, Frithsen (1989) lists 546 species or groups of species as identified from the benthos of Narragansett Bay.

Spatial Patterns

Benthic communities in Narragansett Bay vary over multiple scales ranging from sub-meter to multi-kilometer as a result of the influence of a variety of independent and interacting factors, including sediment type and grain size, sediment organic content, anthropogenic inputs, salinity, and oxygen concentration. The benthos is also largely affected



Figure 9.4. *Left:* Students from the Marine Ecosystems Research Laboratory at GSO collect benthic samples in Narragansett Bay. *Below:* Tube-dwelling bamboo worm *Clymenella* sp. Photo courtesy Chris Calabretta, GSO.



by the amount of organic matter that is produced by phytoplankton in the overlying water column. For example, Rudnick and Oviatt (1986) reported that approximately 40 percent of the phytoplankton biomass that is produced during winter-spring blooms drops to the Bay bottom where it is utilized by benthic communities.

A number of studies have found that, as is the case with zooplankton, Narragansett Bay benthic communities do not generally exhibit a strong north-south gradient throughout the length of the Bay. Instead it is thought that observed spatial patterns were likely due to location-specific differences in sediment characteristics (see Fig 7.6, page 84) (Phelps, 1958; Chowder and Marching, 1967; Myers and Phelps, 1978). At a smaller scale, however, some patterns and gradients emerge. For example, multiple studies have documented an increase in benthic species richness and macrofaunal abundance while moving south within the Providence River and upper Bay away from metropolitan Providence (Pratt, 1972; Pratt and Bisagni, 1976), and have linked this trend to differences in organic loadings, oxygen levels, and phytoplankton (Frithsen, 1989).

Benthic communities have been investigated in other smaller regions of Narragansett Bay, and some of the most intense sampling (although it is largely old data) comes from Greenwich Bay (see Fig 7.2, page 79). For example, Stickney and Stringer (1957) sampled over 200 stations from within Greenwich Bay in 1951 and 1952 in an attempt to correlate benthic communities with the quahog. Although this study could not ultimately relate the quahog to benthic communities, some patterns were found. For example, the most extensive benthic community in Greenwich Bay was the one dominated by the amphipod *A. spinipes*, and this community was generally found associated with mud sediments. In contrast, sandy sediments were dominated by the slipper-shell clam and other associated species such as the jingle shell, *Anomia simplex*, and the clam worm, *Nereis succinea*.

Temporal Patterns

Benthic meiofauna and macrofauna exhibit similar patterns across the seasons and these patterns



are in part related to plankton dynamics in the overlying water column. The signature seasonal pattern is one of increased abundance and biomass in spring (i.e., May and June), followed by a decrease in both summer and fall (Fig. 9.5) (Grassle et al., 1985; Rudnick et al., 1985). It is likely that the increase in biomass and abundance in spring is primarily a response to the deposition and accumulation of organic matter from the winter-spring phytoplankton bloom (zooplankton predation during this time is largely minimal due to cold water temperatures). However, Rudnick et al. (1985) suggest that rapidly increasing sediment temperatures during this time (from 2°C to approximately 13°C by May) may also strongly affect benthic communities. It is also possible that the seasonal dynamics of Narragansett Bay benthic communities are affected by other factors (e.g., predation) (Frithsen, 1989), and ultimately these temporal patterns are probably affected by multiple factors working in concert.

Long-term Trends in Plankton and Benthos

Plankton, but not necessarily benthic, communities in Narragansett Bay are clearly changing over time. Notable patterns include changes in the timing and magnitude of the winter-spring phytoplankton bloom and an interrelated decrease in phytoplankton biomass. These changes are complex and are being driven by numerous interacting factors, including warming water temperature and increasing anthropogenic nutrient inputs over time.

Phytoplankton community structure has remained relatively similar in the mid- and lower Bay since at least the late 1950s (Hinga et al., 1989), although some recent changes have been observed due to warming water temperatures. However, phytoplankton biomass has been decreasing over time in Narragansett Bay. From 1973 to 1990, chlorophyll *a* levels have decreased by approximately half, from 60 mg m⁻² in 1973 to 30 mg m⁻² in 1990, possibly due to factors that include zooplankton grazing, warmer water temperatures, and higher wind speeds (Li and Smayda, 1998; Smayda, 1998). Further, the duration and intensity of the winter-spring bloom has been decreasing since the 1970s, and in some years the bloom has failed to occur entirely (Oviatt, 1994; Oviatt et al., 2002). This trend is probably related to warming water temperatures, since chlorophyll records show that intense winter-spring blooms occur primarily when temperatures remain less than 3.5°C (Oviatt et al., 2002), and winter water temperatures have risen about 1.5°C in Narragansett Bay since the 1890s (Nixon et al., 2003). Although water temperature may ultimately affect and control winter-spring blooms and phytoplankton dynamics, it does so indirectly through the mechanism of zooplankton grazing (Li and Smayda, 1998). Experimental studies in mesocosms with elevated winter temperatures have shown that zooplankton or benthic grazing or both may control the winter-spring diatom bloom (Oviatt et al., 2002), and during exceptionally warm winters, zooplankton may even prevent the initiation of the winter-spring bloom (Keller et al., 1999).

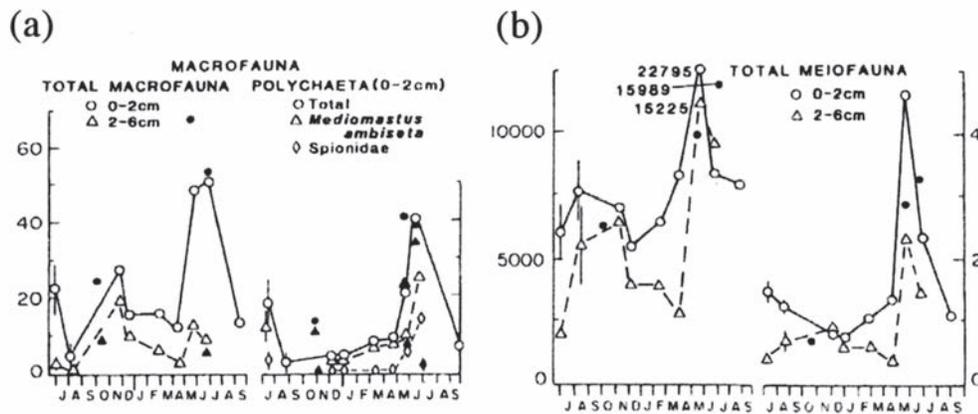


Figure 9.5. Partial reproduction of Figure 2 from Rudnick et al. (1985). (a) Abundance of total macrofauna (left panel) and polychaetes (right panel) over time. (b) Abundance (left panel) and biomass (right panel) of total meiofauna over time. Abundance is presented as number of individuals m⁻² and biomass is presented as grams of ash-free dry weight m⁻². All data were collected between 1977 and 1980 from the top 2 cm of sediment from a station located to the north of Jamestown, R.I. Note the rapid summertime increase in benthic fauna in all cases followed by an equally rapid decrease later in the same season.



It appears that phytoplankton bloom dynamics underwent a dramatic change between the 1960s and 1970s. Specifically, the warm spring temperatures of 1969 may have initiated profound changes in the biology of Narragansett Bay by stimulating a shift in the timing of the annual phytoplankton maximum (Karentz and Smayda, 1998). From 1959 to 1969, the annual phytoplankton maximum generally occurred in winter (January through March); in the following decade, the maximum switched and occurred primarily during the summer (June–September). Severe differences in sampling methodologies make discerning long-term trends in benthic assemblages difficult. Based on earlier research, it seemed clear that benthic community composition and the abundance of dominant benthic species underwent dramatic changes over the last 50 years. Conspicuous among the supposed changes was the dramatic shift around the 1970s from a *Nephtyes-Nucula* dominated community to one that was dominated by *Mediomastus* and *Nucula* (Frithsen, 1989). This switch would appear to have resulted in a dramatic increase in the overall benthic faunal abundance, due mostly to exceptionally high densities of *Mediomastus*. If true, the timing and ecological response of this switch would suggest a benthic response to higher inputs of anthropogenic organic matter, since *Mediomastus* has been shown experimentally to rapidly increase in abundance and biomass in response to increased nutrient enrichment (Frithsen, 1989). However, recent work indicates that earlier workers likely failed to discern the thread-like *Mediomastus* from detritus, suggesting that there probably has not been a change in dominant benthic species assemblages over time (Ellis, 2002; Oviatt, personal communication).

It is apparent that many of the changes in plankton and benthic communities in Narragansett Bay are directly linked to changes in the Bay that are, in part, a result of human activities, including increases in water temperatures and nutrient concentrations. As a plankton-based estuary, any changes to the plankton-benthic food web can have subsequent changes to Narragansett Bay as a whole. For

example, concurrent with the long-term decrease in chlorophyll has been an increase in water clarity as measured by secchi depths (Borkman and Smayda, 1998), which should ultimately affect the production and distribution of light-limited SAV species, such as eelgrass.

These resources must continue to be studied and monitored, especially over the long term as further human-induced changes are inevitable. For example, the planned decrease in nutrient inputs to the Bay from some of the major sewage treatment plants in the watershed will potentially have a dramatic effect on phytoplankton dynamics, and thus, whole Bay processes. There is a need for comprehensive monitoring programs that focus on high spatial coverage throughout Narragansett Bay and frequent sampling intervals. Long-term chlorophyll monitoring at multiple stations by the NBNERR, RIDEM, GSO, and others should ultimately provide an excellent record of phytoplankton biomass in Narragansett Bay over time, including any responses to further human-induced changes to the estuary.



Appendix 9.1 Phytoplankton of Narragansett Bay

List of phytoplankton species known to occur in Narragansett Bay. Species names read across, then down.
Compiled in Keller et al. (1996) using data from Hargraves (1988) and Hinga (1989).

Class Bacillariophyceae

Order Centrales

<i>Actinoptychus senarius</i>	<i>Attheya decora</i>
<i>Bacteriastrum delicatulum</i>	<i>B. hyalinum</i>
<i>Biddulphia alternans</i>	<i>Cerataulina pelagica</i>
<i>Chaetoceros affinis</i>	<i>C. amanita</i>
<i>C. atlanticus</i>	<i>C. borealis</i>
<i>C. brevis</i>	<i>C. ceratosporus</i>
<i>C. compressus</i>	<i>C. constrictus</i>
<i>C. convolutus</i>	<i>C. coronatus</i>
<i>C. costatus</i>	<i>C. crinitus</i>
<i>C. curvisetus</i>	<i>C. danicus</i>
<i>C. debilis</i>	<i>C. decipiens</i>
<i>C. densus</i>	<i>C. diadema</i>
<i>C. didymus</i>	<i>C. eibenii</i>
<i>C. fallax</i>	<i>C. gracillis</i>
<i>C. holsaticus</i>	<i>C. ingolfianus</i>
<i>C. laciniatus</i>	<i>C. lauderi</i>
<i>C. lorenzianus</i>	<i>C. pelagicus</i>
<i>C. perpusillus</i>	<i>C. pseudocurvisetus</i>
<i>C. radicans</i>	<i>C. rostratus</i>
<i>C. seiracanthus</i>	<i>C. septentrionalis</i>
<i>C. similis</i>	<i>C. simplex</i>
<i>C. socialis</i>	<i>C. subtilis</i>
<i>C. tenuissimus</i>	<i>C. teres</i>
<i>C. tortissimus</i>	<i>Chaetoceros</i> spp.
<i>Corethron criophilum</i>	<i>Coscinodiscus asteromphalus</i>
<i>C. centralis</i>	<i>C. concinnus</i>
<i>C. granii</i>	<i>C. oculus-iridis</i>
<i>C. wailesii</i>	<i>Cyclotella caspia</i>
<i>C. meneghiniana</i>	<i>C. striata</i>
<i>Detonula confervacea</i>	<i>D. delicatula</i>
<i>D. pumila</i>	<i>Ditylum brightwelli</i>
<i>Eucampia zoodiacus</i>	<i>Guinardia flaccida</i>
<i>Hemiaulus sinensis</i>	<i>Lauderia annulata</i>
<i>Leptocylindrus danicus</i>	<i>L. mediterraneus</i>
<i>L. minimus</i>	<i>Lithodesmium undulatum</i>
<i>Minidiscus trioculatus</i>	<i>Minutocellus polymorphus</i>
<i>Odontella sinensis</i>	<i>Paralia sulcata</i>
<i>Porosira glacialis</i>	<i>Rhizosolenia alata</i>
<i>R. calcar-avis</i>	<i>R. delicatula</i>
<i>R. fragilissima</i>	<i>R. imbricata</i>
<i>R. pungens</i>	<i>R. setigera</i>
<i>R. stollerfothii</i>	<i>R. styliformis</i>
<i>Roperia tessellata</i>	<i>Skelotenema costatum</i>
<i>Stephanopyxis palmeriana</i>	<i>S. turris</i>
<i>Thalassiosira anguste-lineata</i>	<i>T. binata</i>
<i>T. bioculata</i>	<i>T. constricta</i>
<i>T. decipiens</i>	<i>T. delicatula</i>
<i>T. eccentrica</i>	<i>T. gravida</i>
<i>T. mala</i>	<i>T. nordenskioldii</i>
<i>T. oestrupii</i>	<i>T. profunda</i>
<i>T. pseudonana</i>	<i>T. rotula</i>
<i>T. solitaria</i>	<i>T. weissflogii</i>
<i>Thalassiosira</i> spp.	

Order Pennales

<i>Asterionella bleakleyi</i>	<i>A. glacialis</i>
<i>A. notata</i>	<i>Cylindrotheca closterium</i>
<i>Nitzschia pseudodelicatissima</i>	<i>N. pungens</i>
<i>N. seriata</i>	<i>Thalassionema nitzschiodes</i>
<i>Thalassiothrix frauenfeldii</i>	

Class Dinophyceae

<i>Amphidinium carteri</i>	<i>A. sphenoides</i>
<i>Amphidinium</i> sp.	<i>Ceratium furca</i>
<i>C. fuscus</i>	<i>C. ineatum</i>
<i>C. longipes</i>	<i>C. minutum</i>
<i>C. tripos</i>	<i>Cochlodinium</i> spp.
<i>Dinophysis acuminata</i>	<i>D. caudata</i>
<i>D. norvegica</i>	<i>D. rotundata</i>
<i>Dissodinium pseudolunula</i>	<i>Gonyaulax digitale</i>
<i>G. polyedra</i>	<i>Gonyaulax</i> sp.
<i>Gymnodinium abbreviatum</i>	<i>G. splendens</i>
<i>Gymnodinium</i> spp.	<i>Gyrodinium aureolum</i>
<i>G. spirale</i>	<i>G. uncatenum</i>
<i>Gyrodinium</i> spp.	<i>Helogolandinium subglobosum</i>
<i>Heterocapsa triquetra</i>	<i>Katodinium rotundatum</i>



Appendix 9.1. Continued

<i>Oxyrrhus marina</i>	<i>Paulsenella chaetoceratis</i>
<i>Polykrikos schwarzii</i>	<i>Prorocentrum balticum</i>
<i>P. gracile</i>	<i>P. micans</i>
<i>P. minimum</i>	<i>P. scutellum</i>
<i>P. triestinum</i>	<i>Protogonyaulax tamarensis</i>
<i>Protoperdinium bipes</i>	<i>P. conicum</i>
<i>P. depressum</i>	<i>P. excentricum</i>
<i>P. granii</i>	<i>P. leonis</i>
<i>P. minutum</i>	<i>P. steinii</i>
<i>Protoperdinium</i> spp.	<i>Scrippsiella trochoidea</i>

Additional phytoplankton species

<i>Apedinella spinifera</i>	<i>Aureococcus anophagefferis</i>
<i>Carteria</i> sp.	<i>Chlamydomonas</i> sp.
<i>Chlorella</i> sp.	<i>C. salina</i>
<i>Chroomonas</i> spp.	<i>Chrysochromulina ericina</i>
<i>C. parkae</i>	<i>Chrysochromulina</i> spp.
<i>Coccolithus pelagicus</i>	<i>Cricosphaera roscoffensis</i>
<i>Cryptomonas</i> spp.	<i>Dichtyocha fibula</i>
<i>Dinobryon balticum</i>	<i>Distephanus speculum</i>
<i>Dunaliella</i> sp.	<i>Ebria tripartita</i>
<i>Euglena proxima</i>	<i>Euglena</i> spp.
<i>Eutreptia scotica</i>	<i>Eutreptiella hirudoidea</i>
<i>Eutreptiella</i> sp.	<i>Fibrocapsa japonica</i>
<i>Hemiselmis</i> sp.	<i>Hermesinum adriaticum</i>
<i>Heteronema acus</i>	<i>Isochrysis</i> sp.
<i>Mesocena polymorpha</i>	<i>Micromonas pusilla</i>
<i>Nannochloris</i> sp.	<i>Nephroselmis rotunda</i>
<i>Nephroselmis</i> sp.	<i>Ochromonas</i> sp.
<i>Olisthodiscus luteus</i>	<i>Oltmannsielloopsis virida</i>
<i>Paraphysomonas</i> sp.	<i>Pavlova gyrams</i>
<i>Pavlova</i> sp.	<i>Pedinomonas minor</i>
<i>Phaeocystis pouchetii</i>	<i>Pseudopedinella pyriformis</i>
<i>Pterosperma</i> sp.	<i>Pyramimonas amyliifera</i>
<i>P. torta</i>	<i>Pyramimonas</i> sp.
<i>Spirulina subsalsa</i>	<i>Synechococcus</i> sp.
<i>Tetraselmis</i> spp.	<i>Urceolus</i> sp.

Appendix 9.2. Zooplankton of Narragansett Bay

List of dominant zooplankton known to occur in Narragansett Bay. Names of zooplankton read across, then down. Data from Keller et al. (1996).

Copepods

<i>Acartia hudsonica</i>	<i>A. tonsa</i>
<i>A. longiremis</i>	<i>Calanus finmarchicus</i>
<i>Centropages hamatus</i>	<i>C. typicus</i>
<i>Corycaeus</i> sp.	<i>Cyclops</i> sp.
<i>Eurytemora</i> sp.	<i>Harpacticoid</i> sp.
<i>Hemicyclops</i> sp.	<i>Labidocera aestiva</i>
<i>Metridia lucens</i>	<i>Microsetella norvegica</i>
<i>Oithona colcarva</i>	<i>O. similis</i>
<i>Oncea</i> sp.	<i>Paracalanus parvus</i>
<i>Parvocalanus crassirostris</i>	<i>Pseudocalanus minutus</i>
<i>Pseudodiaptomus coronatus</i>	<i>Rhincalanus nasutus</i>
<i>Temora longicornis</i>	<i>Tortanus discaudatus</i>

Cladocera

<i>Evadne nordmanni</i>	<i>E. spinifera</i>
<i>Penilla avirostris</i>	<i>Podon</i> sp.

Meroplankton

Balanus larvae	Bivalve larvae
Bryozoan larvae	Decapod larvae
Gastropod larvae	Polychaete larvae

Other Holoplankton

Chaetognaths	Ctenophores
Medusae	Oikopleura
Rotifers	



Appendix 9.3. Benthic Species of Narragansett Bay

Benthic species known to occur in Narragansett Bay listed by group and family. Species names read across, then down. List compiled in Keller et al. (1996) using data from Frithsen (1990).

Polychaeta		
Flabelleridae	<i>Pherusa affinis</i>	<i>G. capitana</i>
Glyceridae	<i>Glycera americana</i> <i>G. dibranchiata</i>	<i>Glycera</i> spp. <i>Goniada maculata</i>
Goniadidae	<i>Glycinde solitaria</i> <i>Goniadella gracilis</i>	<i>Ophioglycera gigantea</i> <i>Microphthalmus aberrans</i> <i>Microphthalmus</i> spp.
Hesionidae	<i>Gyptis vittata</i> <i>M. szcelkowi</i> <i>Podarke obscura</i>	<i>L. tenius</i> <i>Ninoe nigripes</i>
Lumbrineridae	<i>Lumbrineris fragilis</i> <i>Lumbrineris</i> spp. <i>Magelona</i> spp.	
Magelonidae	<i>Asychis carolinae</i> <i>Asychis</i> spp. <i>C. torquata</i> <i>Clymenella</i> spp. <i>Euclymene</i> spp. <i>Macroclyme zonalis</i> <i>Microclymene zonalis</i>	<i>A. elongata</i> <i>Clymenella mucosa</i> <i>C. zonalis</i> <i>Euclymene reticulata</i> <i>Gravierella</i> spp. <i>Maldane sarsi</i> <i>Rhodine attenuata</i>
Maldanidae	<i>Aglaophamus</i> sp. <i>Nephtys caeca</i> <i>N. incisa</i> <i>N. picta</i>	<i>A. verrilli</i> <i>N. ciliata</i> <i>N. ingens</i> <i>Nephtys</i> spp. <i>Nereis acuminata</i> <i>Paranaitis speciosa</i> <i>P. groenlandica</i> <i>P. mucosa</i>
Nephtyidae	<i>Nephtys caeca</i> <i>N. incisa</i> <i>N. picta</i>	
Nereidae	<i>Neanthes virens</i>	
Phyllococeidae	<i>Eumida sanguinea</i> <i>Phyllococe arenae</i> <i>P. maculata</i> <i>Phyllococe</i> spp. Unknown	
Poecilochaetidae	Unknown	
Polygordiidae	<i>Polygordius</i> spp. <i>Gattyana cirrhosa</i> <i>H. imbricata</i> <i>Lepidametria</i> spp. <i>L. sublevis</i> <i>Sabellaria vulgaris</i>	<i>Harmothoe extenuata</i> <i>Harmothoe</i> spp. <i>Lepidonotus squamatus</i>
Polynoidea	<i>Chone americana</i> <i>Euchone</i> spp. <i>Lanonome kroyen</i> <i>Potamilla myriops</i> <i>Pseudopotamilla reniformis</i> <i>Sabella</i> spp. <i>Scalibregma inflatum</i> <i>Hydroides dianthus</i> <i>Spirorbis</i> spp.	<i>Euchone incolor</i> <i>Jasmineira</i> spp. <i>Manayunkia</i> spp. <i>P. neglecta</i> <i>Sabella microphthalmia</i>
Sabellariidae	<i>Chone americana</i> <i>Euchone</i> spp. <i>Lanonome kroyen</i> <i>Potamilla myriops</i> <i>Pseudopotamilla reniformis</i> <i>Sabella</i> spp.	
Sabellidae	<i>Chone americana</i> <i>Euchone</i> spp. <i>Lanonome kroyen</i> <i>Potamilla myriops</i> <i>Pseudopotamilla reniformis</i> <i>Sabella</i> spp.	
Scalibregmidae	<i>Scalibregma inflatum</i>	
Serpulidae	<i>Hydroides dianthus</i> <i>Spirorbis</i> spp.	<i>H. uncinata</i>
Sigalionidae	<i>Pholoe minuata</i> <i>S. limicola</i>	<i>Sthenelais boa</i> <i>Sthenelais</i> spp. <i>Sphaerodorum gracilis</i> <i>Boccardia hamata</i> <i>Minuspio</i> spp. <i>P. ciliata</i>
Sphaerodoridae	<i>Ephesiella minuata</i>	
Spionidae	<i>Anaspio</i> spp. <i>Dispio uncinata</i> <i>Polydora caulleri</i>	
Archiannelida		
Nerillidae	Unknown	
Oligochaeta		
Tubificidae	<i>Limnodriloides medioporus</i> <i>Tubificoides</i> spp.	<i>Peloscolex gabriellae</i>
Bivalvia		
Arcidae	<i>Anadara transversa</i>	
Astartidae	<i>Astarte undata</i>	<i>Astarte</i> spp.
Cardiidae	<i>Cardium pinnulatum</i> <i>Laevicardium mortoni</i>	<i>Cerastoderma pinnulatum</i>
Carditidae	<i>Cardita borealis</i>	
Corbulidae	<i>Corbula contracta</i>	
Hiatellidae	<i>Hiatella arctica</i>	
Leptonidae	<i>Rochefortia cunata</i>	
Lyonsiidae	<i>Lyonsia arenosa</i>	<i>Lyonsia hyalina</i>
Mactridae	<i>Mulinia lateralis</i>	<i>Mercenaria mercenaria</i>
Montacutidae	<i>Mysella</i> spp.	
Myidae	<i>Mya arenaria</i>	
Mytilidae	<i>Crenella decussata</i> <i>Crenella</i> spp. <i>Modiolus demissus</i> <i>Mytilus edulis</i> <i>Yoldia limatula</i>	<i>C. glandula</i> <i>Modiolaria lateralis</i> <i>Modiolus</i> spp. <i>Mytilus</i> spp. <i>Y. sapotilla</i> <i>N. delphinodonta</i>
Nuculanidae	<i>Nucula annulata</i> <i>N. proxima</i>	
Nuculidae	<i>Nucula annulata</i> <i>N. proxima</i>	
Ostreidae	<i>Crassostrea virginica</i>	
Pandoridae	<i>Pandora gouldiana</i>	
Pectinidae	<i>Aequipecten irradians</i>	
Periplomatidae	<i>Periploma fragilis</i>	<i>P. papyratium</i>

Appendix 9.3. Continued

	Petricolidae	<i>Petricola pholadiformis</i>	
	Pinnidae	Unknown	
	Solecurtidae	<i>Tagelus</i> spp.	
	Solemyacidae	<i>Solemya velum</i>	
	Solenidae	<i>Ensis directus</i>	<i>Solen viridis</i>
Gastropoda			
	Pyramidillidae	<i>Odostomia trifida</i>	<i>Sayella fusca</i>
		<i>Turboinna elegantula</i>	<i>T. interrupta</i>
		<i>Turbonilla</i> spp.	
	Retusidae	<i>Retusa canaliculata</i>	<i>R. obtusa</i>
	Rissoidae	<i>Alvania excrata</i>	
	Scaphandridae	<i>Acteocina canaliculata</i>	<i>Cylichna oryza</i>
		<i>Cylichna</i> spp.	<i>Tomatina canaliculata</i>
		<i>Tagelus divisus</i>	
	Solecurtidae	<i>Trichotropis conica</i>	
	Trichotropidae	<i>Turritella</i> spp.	
	Turritellidae		
Arachnida			
	Pellenidae	<i>Callipallene brevirostris</i>	
	Tanystylidae	<i>Tanystylum orbiculare</i>	
Pycnogonida			
	Unknown	Unknown	
Merostomata			
	Limulidae	<i>Limulus polyphemus</i>	
Insecta			
	Unknown	Unknown	
Crustacea			
	Unknown	Unknown	
Amphipoda			
	Ampeliscidae	<i>Ampelisca abdita</i>	<i>A. agassizi</i>
		<i>A. macrocephala</i>	<i>A. spinipes</i>
		<i>A. vadorum</i>	<i>A. verrilli</i>
		<i>Ampelisca</i> spp.	<i>Byblis serrata</i>
	Ampithoidae	<i>Ampithoe valida</i>	<i>Ampithoe</i> spp.
	Acridae	<i>Lembos websteri</i>	<i>Leptocheirus pinguis</i>
		<i>L. plumulosus</i>	<i>Microdeutopus anomalus</i>
		<i>M. gryllotalpa</i>	<i>Uniciola irrorata</i>
	Argissidae	<i>Argissa hamatipes</i>	
	Bateidae	<i>Batea catharinensis</i>	
	Caprellidae	<i>Aiginina longicomis</i>	<i>Caprella penantis</i>
		<i>C. septentrionalis</i>	<i>C. unica</i>
		<i>Luconacia incerta</i>	<i>Paracaprella tenuis</i>
	Corophiidae	<i>Corophium acherusicum</i>	
Cumacea			
	Unknown	Unknown	
Mysidacea			
	Mysidae	<i>Heteromysis formosa</i>	<i>H. odontops</i>
		<i>Mysis stenolepsis</i>	<i>Neomysis americana</i>
		<i>Neomysis</i> spp.	
Decapoda			
	Axiidae	<i>Axius serratus</i>	
	Callinassidae	<i>Callinassa atlantica</i>	
	Cancridae	<i>Cancer irroratus</i>	<i>Cancer</i> spp.
	Crangonidae	<i>Crangon septemspinosa</i>	
	Hippolytidae	<i>Eualus pusiulus</i>	
	Majidae	<i>Libinia dubia</i>	<i>L. emarginata</i>
		<i>Libinia</i> spp.	
	Paguridae	<i>Pagurus longicarpus</i>	<i>Pagurus</i> spp.
	Palaemonidae	<i>Palaemonetes pugio</i>	<i>P. vulgaris</i>
	Pinnotheridae	<i>Pinnixa chaetoptera</i>	<i>P. sayana</i>
		<i>Pinnotheres maculatus</i>	<i>P. ostreum</i>
	Portunidae	<i>Carcinus maenas</i>	<i>Ovalipes ocellatus</i>
	Opogebiidae	<i>Upogebia affinis</i>	
	Xanthidae	<i>Neopanope texanasi</i>	
Cirripedia			
	Balanidae	<i>Balanus balanoides</i>	<i>B. crenatus</i>
Ostracoda			
	Unknown	<i>Cylindroleberis mariae</i>	
Stomatopoda			
	Leuconidae	<i>Eudorella pusilla</i>	
	Squillidae	<i>Squilla empusa</i>	
Turbellaria			
	Leptoplanidae	<i>Leptoplana</i> spp.	
	Sylochidae	<i>Stylochus ellipticus</i>	
Hydrozoa			
	Campanulariidae	<i>Obelia</i> spp.	
	Hydractiniidae	<i>Hydractinia</i> spp.	
	Tubulariidae	<i>Tubularia</i> spp.	
Anthozoa			
	Astrangiidae	<i>Astrangia danae</i>	
	Cereianthidae	<i>Cerianthopsis americanus</i>	
	Edwardsiidae	<i>Edwardsia sipunculoides</i>	



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CHAPTER 10.

Nekton

Kenneth B. Raposa







Nekton

Introduction

Nekton generally refers to free-swimming organisms including invertebrates, fish, and marine turtles and mammals. In estuaries, however, this term typically refers to fishes and decapod crustaceans. Nekton is a critical functional component of estuarine ecosystems. Some estuarine nekton species are commercially and recreationally important, while others provide food for birds, mammals, and larger fish (Friedland et al., 1988; Sekiguchi, 1995; Smith, 1997). Some species of nekton can physically transfer organic materials between intertidal and subtidal estuarine habitats (Cicchetti, 1998), and as a guild, nekton can be used as an indicator of estuarine condition (Deegan et al., 1997). In some situations, nekton can exert substantial top-down control over estuarine system processes (Silliman and Bertness, 2002). Nekton is also a charismatic group of species that the public can easily relate to; it therefore can provide an important link between estuarine science and education or policy.

Narragansett Bay provides refuge, spawning, and foraging habitats for a diverse assemblage of nekton. Due to its location in southern New England, Narragansett Bay supports species from northern, boreal areas as well as species from subtropical and tropical climates over an annual cycle. These species include permanent and seasonal residents, seasonal and occasional visitors, anadromous and catadromous species, and accidentals and strays. Narragansett Bay provides support functions for all life history stages of nekton, including planktonic, larval, juvenile, and adult stages. When present in Narragansett Bay, these nekton have available to them a wide variety of habitats that include open water, unvegetated bottoms, intertidal beaches, salt and brackish marshes, SAVs, tidal freshwater creeks, rocky reefs, and human-modified shorelines.

Many species of nekton in Narragansett Bay support commercial or recreational fisheries (DeAlteris et al., 2000) and thus have been the focus of numerous research and monitoring programs. Based on data from several ongoing nekton monitoring programs, a great deal is known about the long-term trends in species abundance and biomass as well as distribution patterns over time. Aside from this, surprisingly little research has actually been done that specifically examines the ecology and functional role of most fish species in Narragansett Bay. For example, Keller et al. (1996) indicates that we still do not fully understand why the abundance of some

species varies considerably over time independent of fishing pressure.

The goal of this chapter is to provide an ecological overview of nekton from two major zones of the Bay (open water and shore) and another overview focusing on ichthyoplankton. Open water nekton include those species that typically are found in the deepwater areas of the Bay, either in pelagic or demersal habitats, and those that are typically captured with a trawl. Shore-zone or intertidal nekton include those species that are found in shallow water habitats of the Bay that include salt marshes, eelgrass beds, coves, embayments and unvegetated shallows.

Open-water Nekton

One of the first studies that focused on fishes in the open waters of Narragansett Bay was conducted over 30 years ago by Oviatt and Nixon (1973). These authors used a trawl to sample from nine regular and 13 occasional stations in Narragansett Bay for one year. Forty-four species were documented in Narragansett Bay. Although typical of temperate estuaries, a small number of species dominated the catch (in this study, the 10 most abundant species made up 91 percent of the catch). This study also demonstrated that:

- The composition of the fish community in Narragansett Bay is comparable to those in Block Island and Long Island sounds.
- Fish abundance and biomass per unit area are comparable to other New England coastal and offshore areas, although standing crop was much less than in kelp forests, coral reefs, and salt marshes.
- Winter flounder (*Pseudopleuronectes americanus*) was easily the most abundant species, making up 36 percent of the catch.
- Spatial patterns in fish distribution were not apparent except that diversity was highest near the mouth of the Bay.
- The demersal fish in Narragansett Bay may be important in regulating the diversity and abundance of the benthos.

Oviatt and Nixon's work was limited in that it only documented the fish of Narragansett Bay at one point in time. For example, although winter flounder dominated in 1971–72, this and other

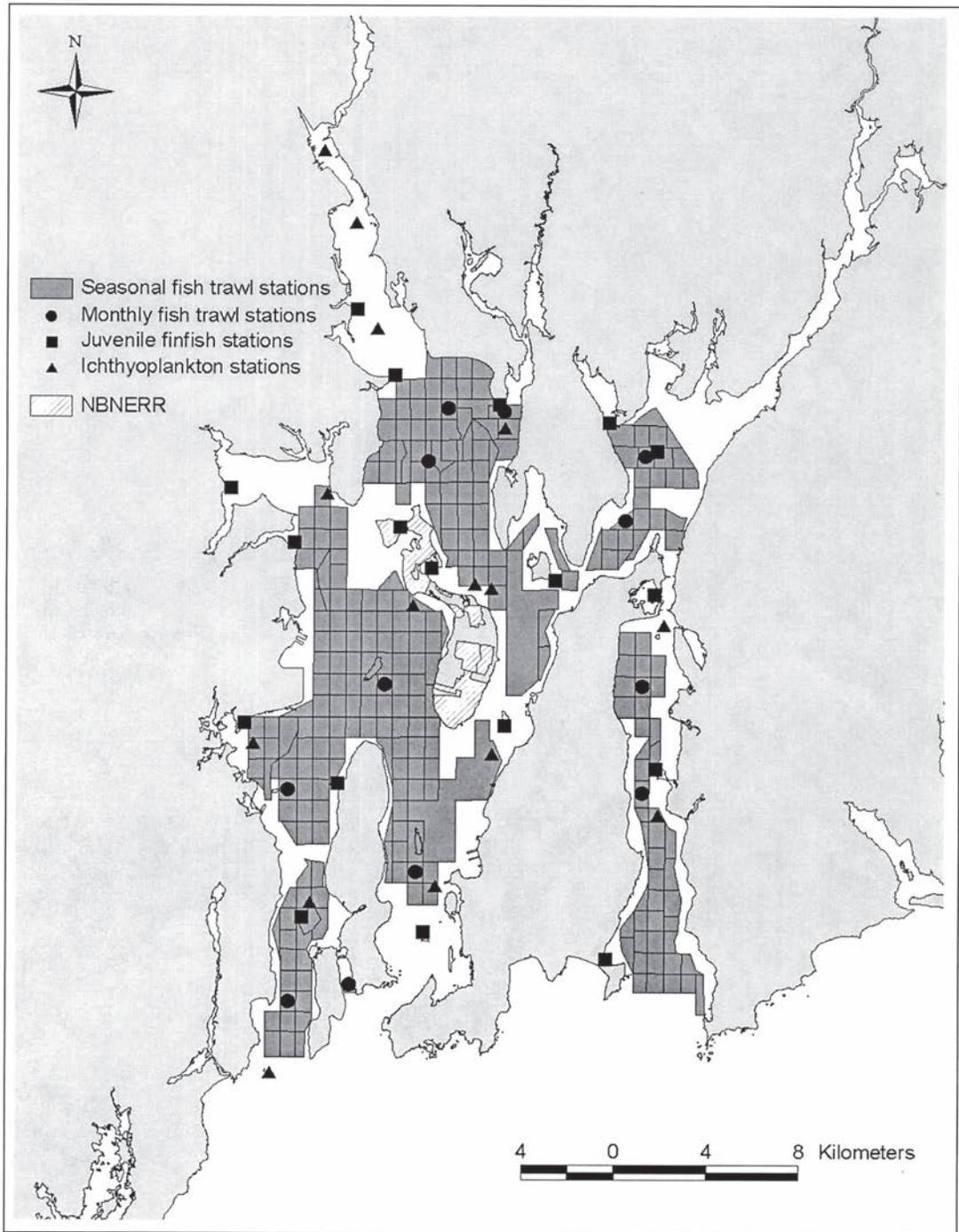


Figure 10.1. Locations of sampling stations that are part of the seasonal and monthly fish trawl survey, the juvenile finfish survey, and the Keller et al. ichthyoplankton survey that are discussed in this chapter.



demersal species have declined dramatically in subsequent decades (Oviatt et al., 2003). In recognition of the need for detailed fisheries data over time, two long-term monitoring programs were initiated in the open waters of Narragansett Bay. These programs are the RIDEM sportfish trawl survey throughout Narragansett Bay and in Rhode Island and Block Island sounds (e.g., Lynch, 2000), and the GSO fish trawl survey (Jeffries and Johnson, 1974; Jeffries and Terceiro, 1985; Jeffries et al., 1989). The GSO trawl survey is the longer running of the two, dating back to 1959; however, this survey is spatially limited since samples are only collected from two stations in the West Passage of Narragansett Bay. In contrast, the RIDEM trawl survey began 20 years later in 1979, but it samples throughout the entire Bay (Fig. 10.1) and thus provides a more comprehensive dataset in terms of combining temporal and spatial coverage. The RIDEM program has two components: a monthly survey at 12 fixed stations in the Bay that began in 1990, and a seasonal survey in spring and fall at approximately 50 stations (selected randomly from approximately 265 stations located throughout the Bay) that began in 1979.



From 1979 through 2003, 107 species (mostly fish, a few crustaceans, and one bivalve species) have been collected from the combined efforts of the RIDEM monthly and seasonal fish trawls. However, the mean number of species in any given year is much less, averaging 57 species per year from the monthly program and 45 species per year from the seasonal program (Fig 10.2). This illustrates the value of the two programs—more species are observed annually with the monthly effort, which provides a more comprehensive overall view of fish community composition and structure, while the seasonal program provides more information on the Bay-wide distribution of common species because more stations are sampled. Based on abundance from the seasonal data, five species make up greater than 90 percent of the community found in Narragansett Bay since 1979. In decreasing abundance, these species include bay anchovy (*Anchoa mitchilli*, 51 percent of total abundance), scup (*Stenotomus chrysops*, 19 percent), longfin squid (*Loligo pealei*, 8 percent), menhaden (*Brevoortia tyrannus*, 6 percent), and butterfish (*Peprilus triacanthus*, 5 percent) (Appendix 10.1). Using the same data, but considering biomass, 13 species make up over 90 percent of the total nekton biomass. In decreasing order, these species are scup (19 percent),

winter flounder (18 percent), American lobster (9 percent), skates (Rajidae, 9 percent), windowpane flounder (*Scophthalmus aquosus*, 6 percent), longfin squid (6 percent), tautog (*Tautoga onitis*, 6 percent), butterfish (5 percent), summer flounder (*Paralichthys dentatus*, 4 percent), bay anchovy (3 percent), weakfish (*Cynoscion regalis*, 2 percent), Atlantic herring (*Clupea harengus*, 2 percent), and bluefish (*Pomatomus saltatrix*, 2 percent). Based on biomass, the nekton species that dominate Narragansett Bay are primarily demersal species such as flounders, lobster, and skates. However, based on abundance, the opposite is true where the dominant species are mostly small, schooling, pelagic species.

The data from the RIDEM trawl programs are particularly useful for observing trends in fish over time and at a Bay-wide scale.

There is no clear trend in the annual number of species in Narragansett Bay (Fig. 10.2), nor is there a trend in total fish biomass over time (Fig. 10.3). In contrast, total abundance is tending to increase over time, mostly due to increases in small pelagic schooling fish such as Atlantic menhaden and bay anchovy. In fact, these data have documented a shift in species abundance patterns in Narragansett Bay. The Bay is undergoing a shift from a community

dominated by demersal species to a system dominated by pelagic species that may be due to climate and bottom-trawl fishing (Oviatt et al., 2003). Further, data from the seasonal trawl survey illustrate that this trend is occurring on a Bay-wide scale. For example, using GIS, it is clear that the abundance of the commercially important winter flounder has been in steady decline since at least the beginning of the survey, and this decline is evident throughout Narragansett Bay (Fig. 10.4). Similar patterns have been observed for other demersal species, including those that are not exposed to fishing pressure (e.g., hogchoker, *Trinectes maculatus*) (Lynch, personal communication).

In contrast to the abundance of long-term monitoring data, surprisingly little research on open-water nekton in Narragansett Bay has been conducted, especially recently. However, there are some notable recent examples. Durbin and Durbin (1998) used a bioenergetic model to examine the effects of menhaden predation on phytoplankton in Narragansett Bay. DeAlteris et al. (2000) used monitoring and landing data to summarize the status and trends of many of Narragansett Bay's commercial fisheries. Lapolla (2001a, 2001b) examined a number of population characteristics of the bay anchovy in

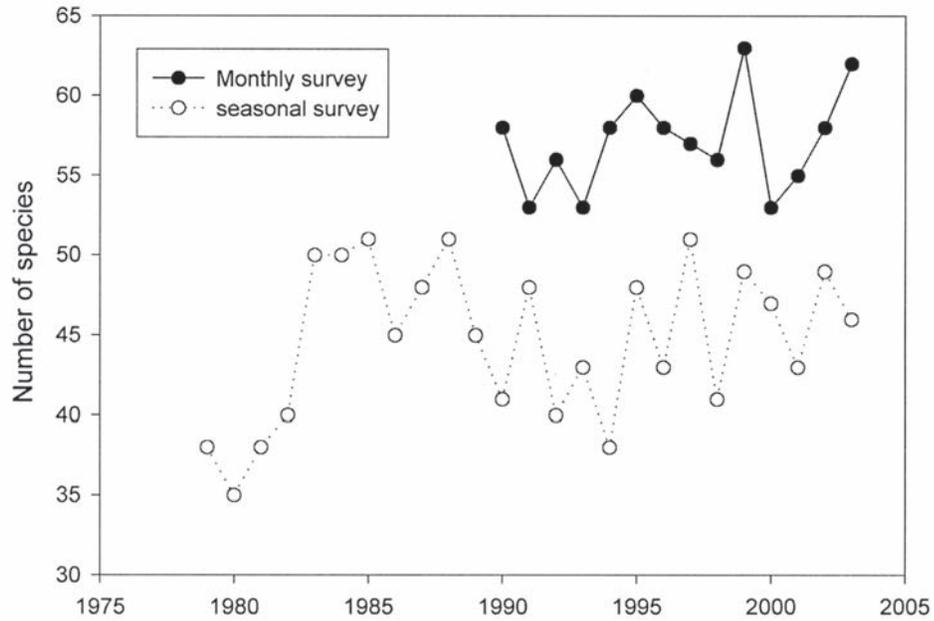


Figure 10.2. The average annual number of species of nekton in Narragansett Bay as determined from the RIDEM seasonal and monthly fish trawl program. Nearly all the species are fishes; relatively few are invertebrates.

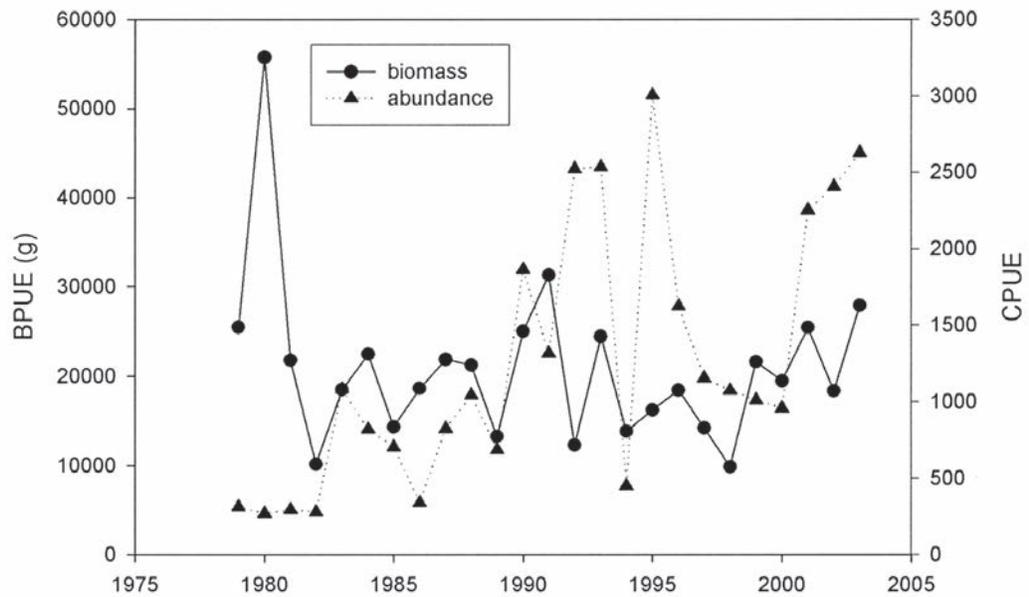


Figure 10.3. Mean catch (abundance) (number of individuals captured per trawl; CPUE) and mean biomass (biomass in grams per trawl; BPUE) between 1979 and 2003 from the RIDEM seasonal fish trawl.

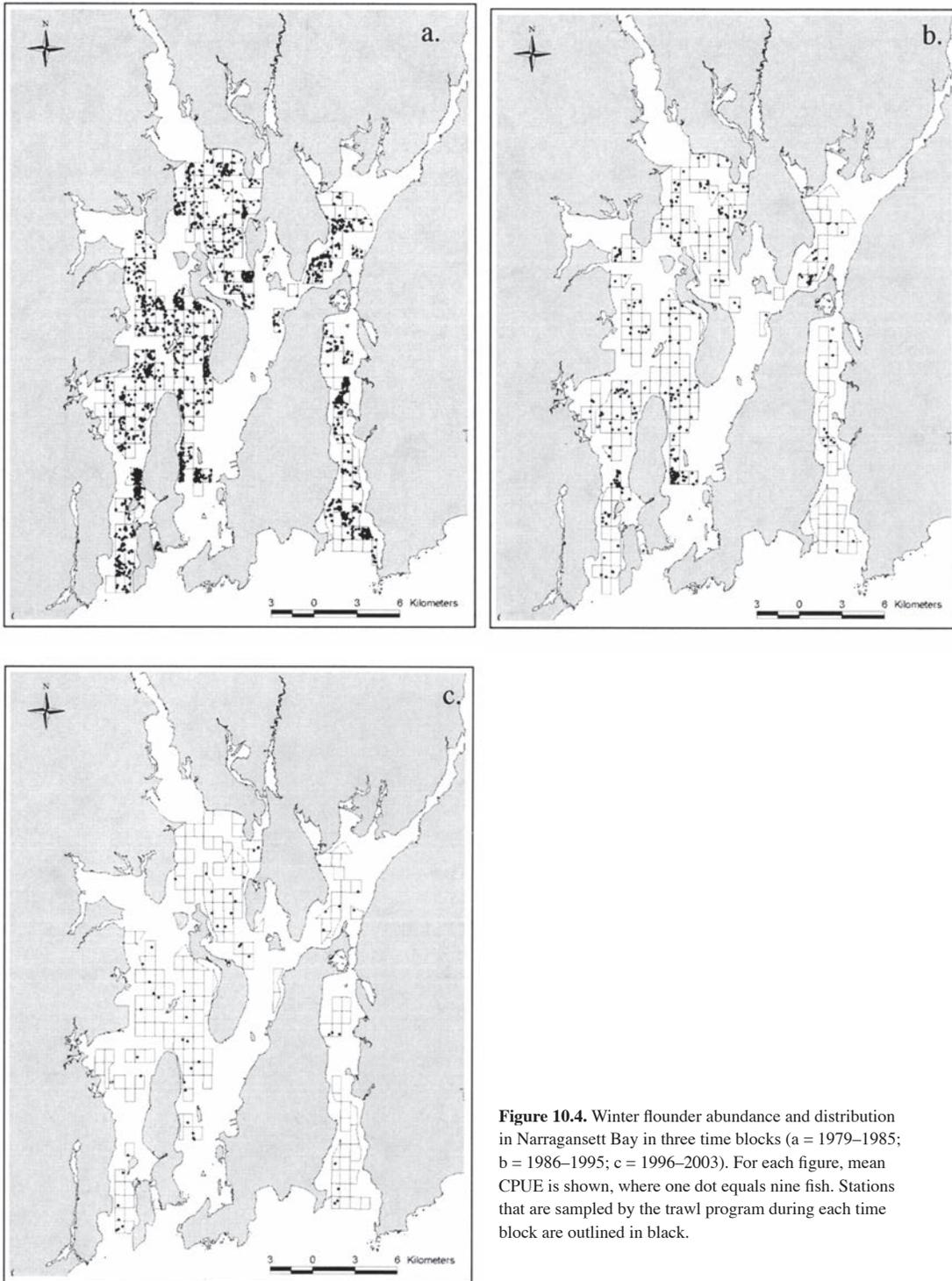


Figure 10.4. Winter flounder abundance and distribution in Narragansett Bay in three time blocks (a = 1979–1985; b = 1986–1995; c = 1996–2003). For each figure, mean CPUE is shown, where one dot equals nine fish. Stations that are sampled by the trawl program during each time block are outlined in black.



Figure 10.5. Researchers conducting the RIDEM juvenile finfish seine survey. Photo by J. Christopher Powell, RIDEM.

Narragansett Bay, including population structure, growth, mortality, and spawning season. Meng et al. (2001) found that winter flounder growth rates in Narragansett Bay were lower in the upper Bay, suggesting that anthropogenically lowered dissolved oxygen levels had a negative impact on this species. More recently, Oviatt et al. (2003) used historic and current data to demonstrate the dramatic effects humans have had on the fishes of Narragansett Bay through fishing pressures, and Castro and Angell (2000), Castro et al. (2005), and Cobb and Castro (2006) have examined aspects of the emergence, spread, and severity of lobster shell disease in the Bay.

Shore-zone and Intertidal Nekton

Shallow estuarine waters provide critical nursery habitats for juvenile estuarine fish and permanent habitats for some abundant forage species. These types of habitats are often at risk, however, due to their proximity to the land and thus the activities of humans. Nekton in shallow, shore-zone habitats are monitored monthly from June through October by RIDEM with a juvenile finfish seining survey at 20 nearshore stations in Narragansett Bay (Fig. 10.5). Since the inception of this program in 1990, 78 species (or undifferentiated species within the same family, e.g., gobidae, bothidae) have been collected from nearshore and shore-zone habitats as part of this monitoring program. Based on abundance, the most common species include Atlantic menhaden (62 percent of total abundance), silversides (*Menidia* spp., 8 percent), river herring species (6 percent), bluefish (*Pomotomus saltatrix*, 4 percent), winter flounder (3 percent), striped killifish (*Fundulus majalis*, 3 percent), sea herring species (3 percent), and bay anchovy (2 percent) (Appendix

10.2). Meng and Powell (1999) used these data to explore relationships between fish communities and habitats. This study found that separate analyses of fish communities and their habitats correlated well. In addition, it was found that total abundance, species richness, and the number of winter flounder were highest at an upper Bay station. This is contrary to the findings of Oviatt and Nixon (1973); however, the two studies used different gears to sample different age classes of fish, and the two studies were conducted over 25 years apart. Dorf and Powell (1997) used these same seining data to document the distribution and habitat preferences of juvenile tautog, a recreationally important species, in Narragansett Bay. More recently, DeLong et al. (2001) used data from this survey in a model to examine the effects of density and environmental conditions on the growth of juvenile winter flounder.

Nekton has also been sampled extensively from salt marsh habitats around Narragansett Bay and the south shore of Rhode Island (Fig. 10.6). As with salt marshes elsewhere, marshes in Rhode Island clearly support highly abundant and produc-





tive nekton communities (Raposa, 2002; Meng et al., 2004). Quantitative data collected from three salt marshes around Rhode Island show that these marshes are consistently dominated by very few species (i.e., species diversity is low). These species include the common mummichog (*Fundulus heteroclitus*), striped killifish, sheephead minnow (*Cyprinodon variegatus*), Atlantic and inland silversides (*Menidia menidia* and *Menidia beryllina*, respectively), and grass shrimp (*Palaemonetes* spp.) (Appendix 10.3). Less abundant, though ecologically important, species that also use Narragansett Bay salt marshes include juvenile winter flounder, sticklebacks (e.g., three-spined *Gasterosteus aculeatus*, fourspine *Apeltes quadracus*, and nine-spined *Pungitius pungitius*), American eel (*Anguilla rostrata*), and blue crab (*Callinectes sapidus*). The data in Appendix 10.3 further indicate that while general patterns of species composition are similar among marshes, large differences in density exist (e.g., *Palaemonetes pugio*). Halpin (1997) also noted substantial differences in mummichog use among different Narragansett Bay salt marshes. The factors that contribute to differences in nekton composition and abundance among salt marshes in Narragansett Bay are largely unknown and need to be identified and examined, especially in light of ongoing and future marsh restoration efforts.

Marsh nekton species can move among and utilize multiple marsh habitats (e.g., creeks, pools, vegetated marsh surface) depending on life history stage and tide stage. Roman et al. (2003) showed that more species were found in subtidal creeks and pools when compared to intertidal marsh habitats in the Sachuest Point salt marsh in Middletown, R.I. Data from Raposa (2002) in the Galilee, R.I., salt marsh indicate that nekton tend to be more abundant in subtidal, rather than intertidal, marsh creeks. In nearby Cape Cod, Mass., Raposa (2003) showed that mummichogs moved into soft-substrate pools in fall where they burrowed into the sediments to overwinter. A given marsh is a dynamic place with multiple habitats interacting to support nekton. Threats to some of these habitats in Rhode Island marshes include the invasion of high marsh by the common reed, *Phragmites australis*, the loss of marsh pools due to historic ditching, and tidal restrictions that limit nekton access to marsh surface habitats, which are used for foraging, nursery, and refuge.

The restoration of tide-restricted salt marshes around Narragansett Bay is clearly returning natural and abundant nekton communities to marshes that supported a dysfunctional and depleted community. Studies indicate that removing tide-restricting structures results in improved nekton function, and that the more severe the restriction, the more negatively

affected the nekton community is, and the more positive the response is after restoration (Raposa, 2002; Raposa, unpublished data; Raposa and Roman, 2003; Roman et al., 2003). A consortium of agencies, including the R.I. Coastal Resources Management Council, the Narragansett Bay Estuary Program, and Save The Bay, among others, has identified salt marshes around Narragansett Bay that are in need of restoration, and some of these efforts are under way. If previous results hold true, these restoration efforts should continue to return nekton communities to more natural conditions representative of unrestricted salt marshes. In addition to removing tidal restrictions, efforts should seek to restore pool habitats that were lost from ditching. Salt marsh pools can support dense nekton assemblages (Raposa and Roman, 2001), and if the pools are shallow enough, this nekton provides attractive forage for wading birds.

Ichthyoplankton

Ichthyoplankton (eggs and larvae) are early life-history stages of nekton that are useful for understanding adult spawning patterns and temporal fluctuations in the abundance of juvenile and adult nekton. Ichthyoplankton are particularly abundant in estuaries in part due to the use of these areas as spawning and nursery grounds by nekton species. In recognition of this, and to help fill a critical data gap, multiple surveys and ichthyoplankton monitoring programs were initiated in Narragansett Bay. The first survey occurred in 1957–1958 and included sampling in the lower East Passage of Narragansett Bay and in Mount Hope Bay (Herman, 1963). Another survey occurred in 1972–1973 and included 160 total stations divided among 10 sectors in Narragansett Bay (Bourne and Govoni, 1988; hereafter referred to as the MRI (Marine Research Inc.) survey). Almost 20 years later, similar methods were used by Keller et al. (1999; hereafter referred to as the Keller survey) to collect newer data from 1989–1990 and to explore changes in ichthyoplankton composition and abundance over time. The most recent effort is a partnership between URI and RIDEM to collect annual data beginning in 2002 to observe ichthyoplankton trends over an even longer time period (Klein-MacPhee et al., 2002). The combined data from these programs provide a baseline for examining trends in composition, relative abundance, distribution, and seasonal abundance of ichthyoplankton in Narragansett Bay.



Ichthyoplankton on the whole display a clear seasonal pattern in abundance, with a distinct peak in eggs in June and in larvae slightly later in July. This pattern was observed in both the MRI and Keller surveys. The total number of ichthyoplankton species was also similar between the two surveys (43 in the MRI survey; 41 in the Keller survey), but differences in the abundance of dominant species were apparent. In 1972–73 the most abundant species included cunner (*Tautoglabrus adspersus*), tautog, bay anchovy, Atlantic menhaden, scup, and weakfish; in 1989–90 the dominant species included bay anchovy, tautog, and cunner, but menhaden, scup, and weakfish were not abundant. Egg and larval (all species combined) densities were considerably lower in 1989–90 compared to the MRI survey. Abundance of some species declined substantially in the highly impacted upper Bay, Providence River, and Greenwich Bay areas. In fact, Keller et al. (1999) indicate that there was a general shift in ichthyoplankton distribution down-Bay away from these impacted areas. It was not clear whether this was due to reduced adult spawning in the upper Bay regions, or to higher mortality of ichthyoplankton while in these areas. In either case, upper Bay regions that were known as important historic spawning and nursery areas for some important nekton species now seem to have lost some of that value, perhaps due to impacts from human activities.

Summary

In addition to the impacts to ichthyoplankton outlined above, the abundance, distribution, growth, and survival of juvenile and adult nekton in Narragansett Bay are also affected by human activities. Commercial fishing has depleted many fish populations over at least a century (Oviatt et al., 2003), and fishing pressures continue to exert considerable influence. Substantial areas of important nursery habitats such as eelgrass and salt marshes have been extensively degraded or lost. Eutrophication and the resultant increase in the frequency and duration of hypoxia forces fish to either move out of the affected areas or suffer negative impacts. Meng et al. (2001) demonstrated that winter flounder growth and survival decreased in upper Bay areas where water quality and dissolved oxygen conditions are poor. In the summer of 2003, a large fish kill (over 1 million Atlantic menhaden) occurred in Greenwich Bay when excessive nutrients and physical processes combined to create an extensive anoxic event (RIDEM, 2003). However, despite all of these pressures, Narragansett Bay and its habitats continue to support an abundant and diverse nekton assemblage, albeit one whose composition appears to be shifting over time.



Figure 10.6. Using a throw trap to quantitatively sample nekton from salt marsh habitats. Photo from NBNERR photo library.





Appendix 10.1. Abundance and Biomass of Nekton Species

Abundance and biomass of nekton species collected during the RIDEM seasonal trawl survey. For each species, mean abundance (catch per unit effort, CPUE) and mean biomass (biomass per unit effort, BPUE) are provided as averages between 1979 and 2003. Averages for spring, fall, and all data combined are provided.

Species	Common name	CPUE			Species	Common name	BPUE		
		Spring	Fall	Total			Spring	Fall	Total
<i>Anchoa mitchilli</i>	Bay anchovy	11.65	1213.08	600.42	<i>Stenotomus chrysops</i>	Scup	920.29	7024.48	3911.69
<i>Stenotomus chrysops</i>	Scup	7.41	439.56	219.19	<i>Pseudopleuronectes americanus</i>	Winter flounder	5609.57	1812.89	3748.98
<i>Loligo pealei</i>	Longfin squid	4.17	178.85	89.77	<i>Homarus americanus</i>	American lobster	1641.79	2041.53	1837.69
<i>Brevoortia tyrannus</i>	Atlantic menhaden	0.05	144.19	70.68	Rajidae	Skates	2613.60	1006.83	1826.19
<i>Pepilus triacanthus</i>	Butterfish	2.56	129.18	64.62	<i>Scophthalmus aquosus</i>	Windowpane	1526.77	1047.50	1291.90
<i>Pseudopleuronectes americanus</i>	Winter flounder	40.21	20.97	30.79	<i>Loligo pealei</i>	Longfin squid	324.67	2172.53	1230.23
<i>Clupea harengus</i>	Atlantic herring	44.38	5.19	25.18	<i>Tautoga onitis</i>	Tautog	1465.55	965.02	1220.26
<i>Cynoscion regalis</i>	Weakfish	0.00	39.53	19.38	<i>Pepilus triacanthus</i>	Butterfish	148.57	1788.75	952.35
<i>Pomatomus saltatrix</i>	Bluefish	0.00	17.63	8.64	<i>Paralichthys dentatus</i>	Summer flounder	84.12	1634.31	843.80
<i>Menidia menidia</i>	Atlantic silverside	3.40	13.19	8.20	<i>Anchoa mitchilli</i>	Bay anchovy	16.13	1195.97	594.32
<i>Scophthalmus aquosus</i>	Windowpane	8.09	8.08	8.08	<i>Cynoscion regalis</i>	Weakfish	8.36	880.81	435.91
<i>Homarus americanus</i>	American lobster	5.89	8.72	7.28	<i>Clupea harengus</i>	Atlantic herring	673.32	40.93	363.41
<i>Alosa pseudoharengus</i>	Alewife	3.11	8.65	5.83	<i>Pomatomus saltatrix</i>	Bluefish	5.57	707.27	349.45
<i>Selene setapinnis</i>	Atlantic moonfish	0.00	9.13	4.47	<i>Mustelus canis</i>	Smooth dogfish	21.10	628.16	318.60
Rajidae	Skates	5.19	1.86	3.56	<i>Prionotus evolans</i>	Striped searobin	41.13	510.10	270.95
<i>Alosa aestivalis</i>	Blueback herring	4.37	0.88	2.66	<i>Brevoortia tyrannus</i>	Atlantic menhaden	1.80	360.91	177.79
<i>Urophycis chuss</i>	Red Hake	2.69	1.45	2.08	<i>Limulus polyphemus</i>	Horseshoe crab	44.60	282.14	161.01
<i>Trinectes maculatus</i>	Hogchoker	0.21	2.87	1.51	<i>Urophycis chuss</i>	Red Hake	165.80	123.26	144.95
<i>Tautoga onitis</i>	Tautog	0.91	1.26	1.08	<i>Trinectes maculatus</i>	Hogchoker	17.27	255.90	134.21
<i>Paralichthys dentatus</i>	Summer flounder	0.08	2.05	1.05	<i>Macrozoarces americanus</i>	Ocean pout	221.01	0.00	112.71
<i>Paralichthys oblongus</i>	Fourspot flounder	0.40	1.59	0.99	<i>Prionotus carolinus</i>	Northern searobin	146.76	74.03	111.12
<i>Urophycis regia</i>	Spotted Hake	1.05	0.64	0.85	<i>Alosa pseudoharengus</i>	Alewife	110.58	110.91	110.74
<i>Merluccius bilinearis</i>	Silver hake	0.74	0.66	0.70	<i>Alosa aestivalis</i>	Blueback herring	106.59	17.87	63.11
<i>Centropristis striata</i>	Black sea bass	0.04	1.33	0.67	<i>Hemirhamphus americanus</i>	Sea raven	119.18	1.31	61.42
<i>Prionotus carolinus</i>	Northern searobin	0.41	0.66	0.53	<i>Paralichthys oblongus</i>	Fourspot flounder	80.74	32.43	57.07
<i>Prionotus evolans</i>	Striped searobin	0.12	0.94	0.52	<i>Opsanus tau</i>	Oyster toadfish	6.85	104.49	54.70
<i>Tautoglabrus adspersus</i>	Cunner	0.51	0.45	0.48	<i>Urophycis regia</i>	Spotted Hake	17.30	78.69	47.38
<i>Syngnathus fuscus</i>	Northern pipefish	0.12	0.67	0.39	<i>Morone saxatilis</i>	Striped bass	13.95	62.97	37.97
<i>Mustelus canis</i>	Smooth dogfish	0.01	0.58	0.29	<i>Centropristis striata</i>	Black sea bass	13.87	56.15	34.59
<i>Macrozoarces americanus</i>	Ocean pout	0.42	0.00	0.22	<i>Merluccius bilinearis</i>	Silver hake	29.11	22.66	25.95
<i>Opsanus tau</i>	Oyster toadfish	0.03	0.39	0.20	<i>Tautoglabrus adspersus</i>	Cunner	32.97	15.88	24.60
<i>Menticirrhus saxatilis</i>	Northern kingfish	0.00	0.38	0.19	<i>Selene setapinnis</i>	Atlantic moonfish	0.00	49.00	24.01
<i>Alosa sapidissima</i>	American shad	0.25	0.04	0.15	<i>Menidia menidia</i>	Atlantic silverside	18.86	22.12	20.46
<i>Ammodytes americanus</i>	American sand lance	0.27	0.00	0.14	<i>Menticirrhus saxatilis</i>	Northern kingfish	0.00	36.77	18.02
<i>Trachurus lathami</i>	Rough scad	0.00	0.20	0.10	<i>Squalus acanthias</i>	Spiny dogfish shark	13.93	2.83	8.49
<i>Gadus morhua</i>	Atlantic Cod	0.19	0.00	0.10	<i>Alosa sapidissima</i>	American shad	9.06	5.90	7.51
<i>Osmerus mordax</i>	Rainbow smelt	0.14	0.06	0.10	<i>Myoxocephalus octodecemspinos</i>	Longhorn sculpin	13.34	0.45	7.02
<i>Hemirhamphus americanus</i>	Sea raven	0.18	0.00	0.09	<i>Aequipecten irradians</i>	Sea scallop	1.04	10.26	5.56

Appendix 10.1 Continued



<i>Citharichthys arctifrons</i>	Gulfstream flounder	0.07	0.10	0.08	<i>Leiostomus xanthurus</i>	Spot	1.64	6.15	3.85
<i>Limulus polyphemus</i>	Horseshoe crab	0.03	0.14	0.08	<i>Trachurus lathami</i>	Rough scad	0.04	7.61	3.75
<i>Myoxocephalus aeneus</i>	Grubby	0.14	0.01	0.08	<i>Microgadus tomcod</i>	Atlantic tomcod	5.90	1.36	3.67
<i>Selene vomer</i>	Lookdown	0.09	0.06	0.07	<i>Urophycis tenuis</i>	White hake	6.21	0.23	3.28
<i>Sphyræna borealis</i>	Northern sennet	0.00	0.14	0.07	<i>Pollachius virens</i>	Pollock	6.11	0.00	3.12
Gobiidae	Gobies	0.01	0.13	0.07	<i>Anguilla rostrata</i>	American eel	4.85	0.58	2.75
<i>Pholis gunnellus</i>	Rock gunnel	0.04	0.09	0.07	<i>Myoxocephalus aeneus</i>	Grubby	4.53	0.29	2.45
<i>Microgadus tomcod</i>	Atlantic tomcod	0.09	0.04	0.06	<i>Priacanthus arenatus</i>	Bigeye	0.00	4.55	2.23
<i>Myoxocephalus octodecemspinos</i>	Longhorn sculpin	0.09	0.01	0.05	<i>Enchelyopus cimbrius</i>	Fourbeard rockling	1.40	2.95	2.16
<i>Aequipecten irradians</i>	Sea scallop	0.00	0.10	0.05	<i>Scomber scombrus</i>	Atlantic mackeral	0.44	3.54	1.96
<i>Priacanthus arenatus</i>	Bigeye	0.00	0.09	0.04	<i>Osmerus mordax</i>	Rainbow smelt	3.43	0.30	1.89
<i>Urophycis tenuis</i>	White Hake	0.07	0.02	0.04	<i>Syngnathus fuscus</i>	Northern pipefish	0.67	2.50	1.57
<i>Enchelyopus cimbrius</i>	Fourbeard rockling	0.02	0.06	0.04	<i>Lophius americanus</i>	Goosefish	2.68	0.40	1.56
<i>Anchoa hepsetus</i>	Striped anchovy	0.00	0.07	0.03	Gobiidae	Gobies	0.07	2.78	1.40
<i>Brosme brosme</i>	Cusk	0.06	0.00	0.03	<i>Synodus foetens</i>	Inshore lizardfish	0.00	2.76	1.35
<i>Morone saxatilis</i>	Striped bass	0.03	0.03	0.03	<i>Sphoeroides maculatus</i>	Northern puffer	0.00	2.48	1.22
<i>Scomber scombrus</i>	Atlantic mackeral	0.00	0.06	0.03	<i>Citharichthys arctifrons</i>	Gulfstream flounder	0.68	1.33	1.00
<i>Orthopristis chrysoptera</i>	Pigfish	0.00	0.04	0.02	<i>Ammodytes americanus</i>	American sand lance	1.62	0.00	0.83
<i>Sphoeroides maculatus</i>	Northern puffer	0.00	0.04	0.02	<i>Sphyræna borealis</i>	Northern sennet	0.00	1.57	0.77
<i>Mullus auratus</i>	Red goatfish	0.00	0.04	0.02	<i>Caranx hippos</i>	Crevalle jack	0.00	1.48	0.72
<i>Synodus foetens</i>	Inshore lizardfish	0.03	0.04	0.02	<i>Caranx crysos</i>	Blue runner	0.00	1.45	0.71
<i>Leiostomus xanthurus</i>	Spot	0.01	0.03	0.02	<i>Brosme brosme</i>	Cusk	1.25	0.00	0.64
<i>Gaidropsarus ensis</i>	Threebeard rockling	0.01	0.03	0.02	<i>Gaidropsarus ensis</i>	Threebeard rockling	0.29	0.97	0.62
<i>Caranx crysos</i>	Blue runner	0.00	0.02	0.01	<i>Gadus morhua</i>	Atlantic Cod	0.95	0.05	0.51
<i>Anguilla rostrata</i>	American eel	0.01	0.01	0.01	<i>Etrumeus teres</i>	Roung herring	0.00	1.01	0.50
<i>Caranx hippos</i>	Crevalle jack	0.00	0.02	0.01	<i>Cryptacanthodes maculatus</i>	Wrymouth	0.87	0.00	0.44
<i>Conger oceanicus</i>	Conger eel	0.00	0.01	0.01	<i>Mullus auratus</i>	Red goatfish	0.00	0.76	0.37
<i>Selar crumenophthalmus</i>	Bigeye scad	0.00	0.01	0.01	<i>Conger oceanicus</i>	Conger eel	0.00	0.75	0.37
<i>Synodus synodus</i>	Red lizardfish	0.00	0.01	0.01	<i>Pholis gunnellus</i>	Rock gunnel	0.41	0.16	0.29
<i>Lophius americanus</i>	Goosefish	0.01	0.00	0.01	<i>Selar crumenophthalmus</i>	Bigeye scad	0.00	0.56	0.27
<i>Pollachius virens</i>	Pollock	0.01	0.00	0.01	<i>Synodus synodus</i>	Red lizardfish	0.00	0.53	0.26
<i>Pristigenys alta</i>	Short bigeye	0.00	0.01	0.01	<i>Scomberomorus maculatus</i>	Spanish mackeral	0.00	0.51	0.25
<i>Melanogrammus aeglefinus</i>	Haddock	0.01	0.00	0.00	<i>Selene vomer</i>	Lookdown	0.21	0.27	0.24
<i>Monacanthus hispidus</i>	Planehead filefish	0.00	0.01	0.00	<i>Cyclopterus lumpus</i>	Lumpfish	0.45	0.00	0.23
<i>Fistularia tabacaria</i>	Bluespotted cornetfish	0.00	0.01	0.00	<i>Peristedion miniatum</i>	Armored searobin	0.37	0.00	0.19
<i>Upeneus parvus</i>	Dwarf goatfish	0.00	0.01	0.00	<i>Anchoa hepsetus</i>	Striped anchovy	0.00	0.30	0.15
<i>Cyclopterus lumpus</i>	Lumpfish	0.01	0.00	0.00	<i>Myoxocephalus scorpius</i>	Shorthorn sculpin	0.28	0.00	0.14
<i>Myoxocephalus scorpius</i>	Shorthorn sculpin	0.01	0.00	0.00	<i>Monacanthus hispidus</i>	Planehead filefish	0.00	0.28	0.14
<i>Lepophidium profundorum</i>	Fawn eelpout	0.01	0.00	0.00	<i>Pristigenys alta</i>	Short bigeye	0.00	0.28	0.13
<i>Squalus acanthias</i>	Spiny dogfish shark	0.00	0.00	0.00	<i>Morone americana</i>	White perch	0.24	0.00	0.12
<i>Cryptacanthodes maculatus</i>	Wrymouth	0.01	0.00	0.00	<i>Orthopristis chrysoptera</i>	Pigfish	0.00	0.24	0.12
<i>Lutjanus campechanus</i>	Red snapper	0.00	0.00	0.00	<i>Aluterus schoepfi</i>	Orange filefish	0.00	0.17	0.09
<i>Petromyzon marinus</i>	Sea lamprey	0.00	0.00	0.00	<i>Fistularia tabacaria</i>	Bluespotted cornetfish	0.00	0.17	0.08
<i>Scomberomorus</i>	Spanish	0.00	0.00	0.00	<i>Petromyzon marinus</i>	Sea lamprey	0.11	0.00	0.06



Appendix 10.1. Continued

<i>maculatus</i>	mackerel								
<i>Peristedion miniatum</i>	Armored searobin	0.00	0.00	0.00	<i>Pleuronectes ferrugineus</i>	Yellowtail flounder	0.10	0.00	0.05
<i>Decapterus macarellus</i>	Mackerel scad	0.00	0.00	0.00	<i>Lepophidium profundorum</i>	Fawn eelpout	0.08	0.00	0.04
<i>Aluterus schoepfi</i>	Orange filefish	0.00	0.00	0.00	<i>Upeneus parvus</i>	Dwarf goatfish	0.00	0.09	0.04
<i>Ulvaria subbifurcata</i>	Radiated shanny	0.00	0.00	0.00	<i>Decapterus macarellus</i>	Mackerel scad	0.00	0.08	0.04
<i>Etropus microstomus</i>	Smallmouth flounder	0.00	0.00	0.00	<i>Lutjanus campechanus</i>	Red snapper	0.00	0.07	0.04
<i>Gasterosteus aculeatus</i>	Stickleback threespine	0.00	0.00	0.00	<i>Decapterus punctatus</i>	Round scad	0.00	0.02	0.01
<i>Apeltes quadracus</i>	Fourspine stickleback	0.00	0.00	0.00	<i>Apeltes quadracus</i>	Fourspine stickleback	0.02	0.00	0.01
<i>Decapterus punctatus</i>	Round scad	0.00	0.00	0.00	<i>Epinephelus niveatus</i>	Snowy grouper	0.00	0.02	0.01
<i>Etrumeus teres</i>	Roung herring	0.00	0.00	0.00	<i>Melanogrammus aeglefinus</i>	Haddock	0.02	0.00	0.01
<i>Cyprinodon variegatus</i>	Sheepshead minnow	0.00	0.00	0.00	<i>Cyprinodon variegatus</i>	Sheepshead minnow	0.01	0.00	0.00
<i>Epinephelus niveatus</i>	Snowy grouper	0.00	0.00	0.00	<i>Gasterosteus aculeatus</i>	Stickleback threespine	0.01	0.00	0.00
<i>Morone Americana</i>	White perch	0.00	0.00	0.00	<i>Etropus microstomus</i>	Smallmouth flounder	0.00	0.00	0.00
<i>Pleuronectes ferrugineus</i>	Yellowtail flounder	0.00	0.00	0.00	<i>Ulvaria subbifurcata</i>	Radiated shanny	0.00	0.00	0.00
Total		150.17	2256.47	1182.36	Total		16331.13	25235.62	20694.83

Appendix 10.2. Species Composition and Abundance of Fishes

Species composition and abundance of fishes collected between 1990 and 2003 during the RIDEM juvenile finfish seining survey. For each species, the average number per seine (across all 20 stations and all years) is shown for each month of the survey and for the entire survey (across all months).

Species	Common Name	Jun	Jul	Aug	Sep	Oct	Average
<i>Brevoortia tyrannus</i>	Atlantic menhaden	1.69	4.35	1060.21	74.32	310.31	293.31
<i>Menidia</i> spp.	Silverside	18.12	44.17	49.85	47.77	31.05	38.44
River herring spp.	River herring	27.29	81.24	9.94	17.75	1.11	27.48
<i>Pomotomus saltatrix</i>	Bluefish	0.68	16.39	40.17	25.81	0.32	16.85
<i>Pseudopleuronectes americanus</i>	Winter flounder	25.81	29.01	14.92	5.39	4.68	15.67
<i>Fundulus majalis</i>	Striped killifish	6.71	12.67	23.60	19.91	14.55	15.59
Sea herring spp.	Sea herring	62.90	1.05	0.27	4.91	0.04	13.25
<i>Anchoa mitchilli</i>	Bay anchovy	34.51	7.94	0.16	4.01	14.84	11.84
<i>Fundulus heteroclitus</i>	Mummichog	7.38	12.02	13.47	9.53	7.85	10.09
<i>Tautoga onitis</i>	Blackfish	1.65	8.13	14.97	8.04	2.24	7.10
<i>Menticirrhus saxatilis</i>	Northern kingfish	0.03	3.30	11.33	3.18	0.09	3.61
<i>Tautoglabrus adspersus</i>	Cunner	0.47	3.18	5.71	4.69	1.33	3.13
<i>Stenotomus chrysops</i>	Scup	0.01	1.43	10.25	0.80	< 0.01	2.54
<i>Ammodytes</i> spp.	Sandlance	7.26	0.27	0.36	0.06	0.70	1.67
<i>Cynoscion regalis</i>	Weakfish	< 0.01	3.18	3.69	0.02	< 0.01	1.40
<i>Microgadus tomcod</i>	Tomcod	3.87	1.28	0.35	0.37	0.13	1.16
Gasterosteidae	Stickleback	1.38	1.59	0.86	0.39	1.43	1.13
<i>Syngnathus fuscus</i>	Northern pipefish	1.78	1.35	1.27	0.58	0.56	1.10
<i>Myoxocephalus aeneus</i>	Grubby sculpin	0.78	0.77	0.97	1.92	0.65	1.02
<i>Cyprinodon variegatus</i>	Sheepshead minnow	0.03	0.43	0.31	1.79	1.29	0.78
<i>Prionotus</i> spp.	Searobin	0.08	1.91	1.46	0.06	< 0.01	0.71
Mugilidae	Mullet	0.03	0.47	0.83	0.49	0.07	0.38
<i>Morone saxatilis</i>	Striped bass	0.32	0.24	0.35	0.24	0.15	0.26
<i>Caranx hippos</i>	Crevalle jack	< 0.01	0.03	0.94	0.21	< 0.01	0.24
Cyprinodontidae	Killifish spp.	0.28	0.58	0.18	0.08	0.08	0.24
<i>Trachinotus falcatus</i>	Permit	< 0.01	0.02	0.57	0.35	0.12	0.22

Appendix 10.2. Continued



<i>Sphoeroides maculatus</i>	Northern puffer	< 0.01	0.44	0.50	0.08	< 0.01	0.21
<i>Anguilla rostrata</i>	American eel	0.24	0.23	0.43	0.08	0.01	0.20
<i>Pollachius virens</i>	Pollock	1.01	< 0.01	< 0.01	< 0.01	< 0.01	0.19
<i>Scomber scombrus</i>	Atlantic mackerel	0.04	0.75	< 0.01	< 0.01	0.02	0.16
<i>Scophthalmus aquosus</i>	Windowpane flounder	0.20	0.28	0.10	0.11	0.08	0.15
<i>Merluccius bilinearis</i>	Silver hake	< 0.78	0.01	< 0.01	< 0.01	< 0.01	0.15
Gobiidae	Goby	0.25	0.25	0.12	0.04	0.07	0.14
<i>Centropristis striata</i>	Black sea bass	< 0.01	< 0.01	0.46	0.20	< 0.01	0.13
<i>Caranx bartholomaei</i>	Yellow jack	< 0.01	< 0.01	0.02	0.56	< 0.01	0.11
<i>Osmerus mordax</i>	Smelt	0.31	0.06	0.01	0.01	< 0.01	0.08
<i>Opsanus tau</i>	Toadfish	0.04	0.09	0.14	0.03	0.02	0.06
<i>Peprilus triacanthus</i>	Butterfish	< 0.01	0.22	0.06	0.01	< 0.01	0.06
<i>Caranx</i> spp.	Jack spp.	< 0.01	0.02	0.07	0.20	< 0.01	0.06
Synodontidae	Lizardfish	< 0.01	0.02	0.07	0.16	0.01	0.05
<i>Lucania parva</i>	Rainwater killifish	0.02	0.06	0.06	< 0.01	0.07	0.04
<i>Urophycis regia</i>	Spotted hake	0.16	0.01	< 0.01	< 0.01	0.02	0.04
<i>Etropus microsomus</i>	Smallmouth flounder	0.02	< 0.01	< 0.01	0.05	0.05	0.02
Bothidae	Lefteye flounder	0.01	< 0.01	0.01	0.03	0.06	0.02
<i>Alosa sapidissima</i>	American shad	< 0.01	0.09	< 0.01	< 0.01	0.01	0.02
<i>Leiostomus xanthurus</i>	Spot	0.02	0.02	0.03	< 0.01	0.03	0.02
<i>Paralichthys dentatus</i>	Fluke	0.02	0.04	0.01	0.01	0.01	0.02
<i>Urophycis chuss</i>	Red hake	0.08	0.02	< 0.01	< 0.01	< 0.01	0.02
<i>Fundulus diaphanus</i>	Banded killifish	0.09	< 0.01	< 0.01	< 0.01	< 0.01	0.02
<i>Caranx crysos</i>	Blue runner	< 0.01	0.01	0.07	< 0.01	< 0.01	0.02
<i>Strongylura marina</i>	Needlefish	< 0.01	< 0.01	< 0.01	0.07	< 0.01	0.02
<i>Pholis gunnellus</i>	Rock gunnel	< 0.01	0.01	0.01	0.01	0.01	0.01
<i>Fistularia tabacaria</i>	Bluespotted coronetfish	< 0.01	< 0.01	0.02	0.01	0.01	0.01
<i>Lutjanus griseus</i>	Gray snapper	< 0.01	0.01	0.02	0.01	< 0.01	0.01
<i>Hippocampus erectus</i>	Seahorse	< 0.01	0.01	0.01	0.02	0.01	0.01
Clupeidae	Herring	0.02	0.02	< 0.01	< 0.01	< 0.01	0.01
<i>Sphyaena borealis</i>	Northern sennet	< 0.01	< 0.01	0.03	< 0.01	< 0.01	0.01
<i>Enchelyopus cimbrius</i>	Fourbeard rockling	0.03	< 0.01	< 0.01	< 0.01	< 0.01	0.01
<i>Gadus morhua</i>	Cod, Atlantic	0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Citharichthys arctifrons</i>	Gulfstseam flounder	0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01
<i>Raja erinacea</i>	Little shad	< 0.01	< 0.01	< 0.01	0.01	0.01	< 0.01
<i>Decapterus macarellus</i>	Scad	0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01
Mullidae	Goatfish	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Selene vomer</i>	Lookdown	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01
Balistidae	Filefish	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Eucinostomus argenteus</i>	Spotfin mojarra	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01
Ostraciidae	Boxfish	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Paralichthys oblongus</i>	Fourspotted flounder	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01
<i>Dactylopterus volitans</i>	Gumard	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Engraulis eurystole</i>	Silver anchovy	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Chaetodon</i> spp.	Butterflyfish	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Trinectes maculatus</i>	Hogchoker	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Chilomycterus</i> spp.	Burrfish	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Dorosoma cepedianum</i>	Gizzard shad	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Lophius americanus</i>	Monkfish	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Morone Americana</i>	White perch	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Naucrates doctor</i>	Pilotfish	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
<i>Scomber japonicus</i>	Chub mackerel	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01



Appendix 10.3. Nekton Density in Salt Marshes

Nekton density in the Sachuest Point, Coggeshall, and Galilee salt marshes in Rhode Island. All data were collected with the same methods (with a 1 m² throw trap when the marsh surface was drained), in similar habitats (e.g., creeks and pools), and are thus comparable. Galilee data are from restricted, restoring, and unrestricted marsh areas from June through September 1997–1999. Sachuest Point data are from restricted, restoring, and unrestricted marsh areas from June through October 1997–1999. Coggeshall is an unrestricted marsh and these data are from July and September 2000, 2003, and 2004.

Species	Common name	Galilee	Sachuest Point	Coggeshall	Average
<i>Palaemonetes pugio</i>	Daggerblade grass shrimp	15.30	4.29	136.60	52.06
<i>Fundulus heteroclitus</i>	Mummichog	12.70	12.46	18.05	14.40
<i>Pagurus</i> spp.	Hermit crab	0.01	0.00	8.36	2.79
<i>Cyprinodon variegatus</i>	Sheepshead minnow	4.30	1.52	0.89	2.24
<i>Fundulus majalis</i>	Striped killifish	3.14	0.23	1.29	1.55
<i>Menidia menidia</i>	Atlantic silverside	3.54	0.18	0.22	1.31
<i>Crangon septemspinosa</i>	Sand shrimp	0.15	0.01	2.18	0.78
<i>Menidia beryllina</i>	Inland silverside	0.31	0.34	0.45	0.37
<i>Carcinus maenas</i>	Green crab	0.27	0.07	0.42	0.25
<i>Lucania parva</i>	Rainwater killifish	0.12	0.01	0.23	0.12
<i>Anguilla rostrata</i>	American eel	0.02	0.12	0.19	0.11
<i>Callinectes sapidus</i>	Blue crab	0.22	0.06	0.01	0.10
<i>Mugil curema</i>	White mullet	0.05	0.20	0.01	0.08
<i>Panopeus herbstii</i>	Black-fingered mud crab	0.00	0.00	0.19	0.06
<i>Brevoortia tyrannus</i>	Atlantic menhaden	0.08	0.02	0.03	0.04
<i>Apeltes quadracus</i>	Fourspine stickleback	0.01	0.00	0.10	0.04
<i>Centropristis striata</i>	Black sea bass	0.00	0.08	0.00	0.03
<i>Gobiosoma ginsburgi</i>	Seaboard goby	0.00	0.07	0.00	0.02
<i>Pseudopleuronectes americanus</i>	Winter flounder	0.01	0.00	0.07	0.02
<i>Ovalipes ocellatus</i>	Lady crab	0.00	0.00	0.05	0.02
<i>Pungitius pungitius</i>	Ninespine stickleback	0.02	0.01	0.01	0.01
<i>Syngnathus fuscus</i>	Northern pipefish	0.00	0.00	0.02	0.01
<i>Notropis</i> sp.	Shiner	0.00	0.01	0.00	< 0.01
<i>Tautoga onitis</i>	Tautog	0.00	0.00	0.01	< 0.01
<i>Limulus polyphemus</i>	Atlantic horseshoe crab	0.01	0.00	0.00	< 0.01
<i>Alosa aestivalis</i>	Blueback herring	0.00	< 0.01	0.00	< 0.01

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CHAPTER 11.

Aquatic Birds, Marine Mammals, and Sea Turtles

Kenneth B. Raposa



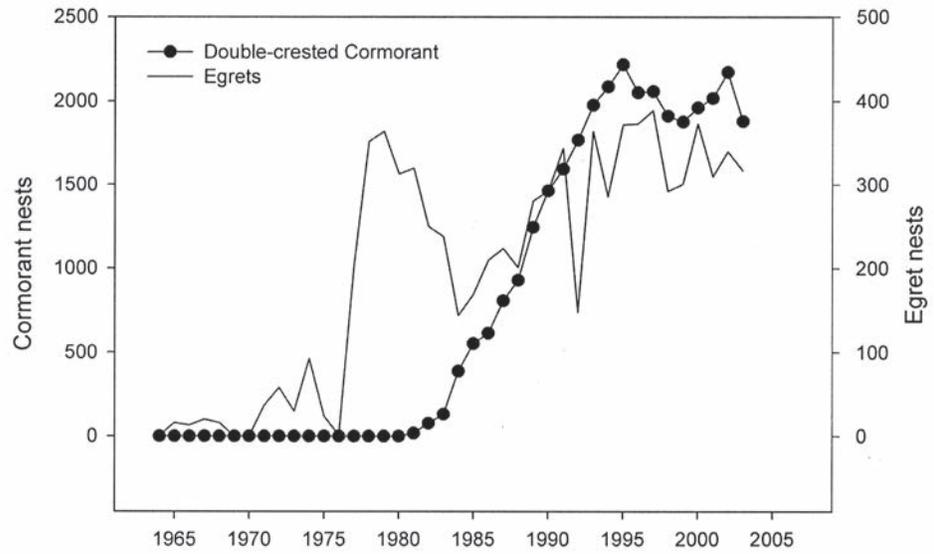


Figure 11.1. Long-term increase in the number of double-crested cormorant and egret (great and snowy egrets combined) nests in Narragansett Bay and Rhode Island. Totals for each year are sums of all the nests at all sites counted by RIDEM.



Figure 11.2. Double-crested cormorants in the waters around Prudence Island, R.I. *Photo from NBNERR photo library.*



Aquatic Birds, Marine Mammals, and Sea Turtles

Aquatic Birds

Narragansett Bay and its associated habitats provide foraging, nesting, and resting habitat for a variety of bird species. According to French et al. (1992), approximately 40 percent of all breeding bird species in Rhode Island, and 57 percent of wintering birds, use coastal habitats along Narragansett Bay for nesting. In all, 187 species of birds are considered to be associated with Narragansett Bay and its coastal habitats (French et al., 1992). Among the more frequent and abundant guilds are waterfowl (geese and ducks); shorebirds (e.g., plovers and sandpipers); wading birds (e.g., herons and egrets); raptors, gulls and terns; and songbirds. Research focusing on the ecology of most of these groups in Narragansett Bay is largely lacking, although Ferren and Myers (1998) and Trocki (2003) provide excellent data for understanding population trends and habitat use of colonial wading and nesting birds, and McKinney (2005) provides some excellent initial data on waterfowl community composition, distribution, and habitat use in Narragansett Bay.

Colonial Nesting Birds

In 1964, Ferren and Myers (1998) began monitoring the number of nests of selected coastal bird species along the entire Rhode Island coast, including Narragansett Bay (see Chapter 6 for NBNERR-specific results from this survey). These species include gulls (primarily herring gull (*Larus argentatus*) and great black-backed gull (*Larus marinus*)), terns (common tern (*Sterna hirundo*) and least tern (*Sterna albifrons*)), waders (great egret (*Casmerodius albus*), snowy egret (*Egretta thula*), cattle egret (*Bubulcus ibis*), little blue heron (*Florida caerulea*), and glossy ibis (*Plegadis falcinellus*)), piping plover (*Charadrius melodus*), double-crested cormorant (*Phalacrocorax auritus*), and American oystercatcher (*Haematopus palliatus*). To date, approximately 90 nesting locations have been identified along the Rhode Island coast (see Fig. 6.6, page 62). All of these sites are not necessarily used simultaneously in a given year, however, since the nesting patterns of most species change over time (Ferren and Myers, 1998). Many of the undeveloped Narragansett Bay islands support abundant and sometimes diverse nesting bird communities. In

particular, Hope, Rose, and Little Gould islands support rich heronries (mixed-species aggregations of nesting herons and egrets), while gulls/cormorants are abundant on Hope, Dyer, Little Gould, and West islands, among others. The monitoring program initiated by Ferren and Myers (1998) has been critical for documenting the dramatic return and subsequent increase in abundance of formerly displaced species, including cormorants and long-legged waders that responded, in part, to measures taken to directly protect these species and their nesting habitats (Fig 11.1).

The double-crested cormorant (Fig. 11.2; hereafter cormorant since the great cormorant (*Phalacrocorax carbo*) is generally much less abundant in Narragansett Bay) is now a conspicuous and abundant seasonal component of the estuarine bird fauna in Narragansett Bay. Cormorants are present throughout the year in Narragansett Bay, but are much more common in summer and are especially abundant during the spring and fall migrations (Conway, 1992). Cormorants can be seen foraging and resting throughout most areas of the Bay, including open water, coves, embayments, and marinas. Based on RIDEM surveys, the number of cormorant nests in Narragansett Bay has risen from zero as late as 1980 to 1,880 in 2003, with a peak of 2,217 nests in 1995 (Fig. 11.1) (Ferren and Myers, 1998; Raithel, unpublished data). Abundant nesting colonies are generally found on only a handful of islands, including Little Gould, West, and East islands (all of which are found in the Sakonnet River) and Hope Island in the West Passage. The abundance of cormorants has risen to such a degree that there is now concern about their potential impacts to commercial fishery stocks (e.g., winter flounder, *Pseudopleuronectes americanus*) in Narragansett Bay. To examine this objectively, French McCay and Rowe (2004) conducted a bioenergetic analysis of cormorant feeding in Narragansett Bay, based on cormorant abundance, foraging area, and feeding requirements. They determined that cormorants probably consume less than 10 percent of the winter flounder young-of-the-year annually in Narragansett Bay and suggest—in agreement with similar studies conducted in other locations—that cormorant predation generally has a much lower impact on fishery species than does human fishing.

Wading bird colonies, composed of species such as great egret, snowy egret, cattle egret, little



blue heron, and glossy ibis, are found on a few of Narragansett Bay's islands including Hope, Little Gould, and Rose islands. Hope Island is considered to be one of the most important heronries in the Bay, to the point where the state now restricts human activities on the island throughout the nesting season. The species composition of the Hope Island heronry is variable among years, but can include great egret, snowy egret, black-crowned night heron (*Nycticorax nycticorax*), glossy ibis, cattle egret, and little blue heron—all of which nest among abundant gull and cormorant populations. However, even though Hope and other Bay islands currently support substantial heronries, events recorded by Ferren and Myers (1998) illustrate that this was not always the case, and that other islands that do not currently support heronries may do so in the future. For example, in 1983–84 the heronry on Hope Island was almost completely abandoned. The emigrating birds moved to nest on Big Gould, Dyer, and Rose islands, with Hope remaining mostly unutilized throughout the mid-1980s (Ferren and Myers, 1988). After 1989, the heronry, along with newly returning cormorants, began to reestablish itself on Hope Island. The exact cause of the Hope Island abandonment is unclear, and may be due to bird-inflicted damage to nesting vegetation from guano, as suggested by Ferren and Myers (1988), or possibly to the presence of red fox on the island (Raithel, personal communication). A similar abandonment of the heronry from Little Gould Island in the 1970s illustrates that this was not an isolated incident. These events clearly indicate that the spatially and temporally dynamic nesting patterns of herons, egrets, and associated nesting birds necessitates the protection and preservation of natural habitats on other Narragansett Bay islands. This is true even if a particular island does not currently support a heronry or other nesting birds; if another heronry abandonment occurs in the future, displaced birds will need other islands to colonize and nest.

Although wading bird nesting areas on Bay islands are well known and many are protected, the factors that affect selection and use of foraging habitats in Narragansett Bay are less clear. Herons and egrets are commonly observed foraging in fringing and meadow salt marshes around Narragansett Bay, and it is generally accepted that marshes provide important foraging habitat for these birds. A recent study (Trocki, 2003) provides some of the first information about how and why wading birds use salt marshes in Narragansett Bay as foraging habitat. Trocki (2003) found that the number of birds foraging in a marsh correlates well with marsh area, but bird density does not (i.e., as marsh area increases, so does the number of foraging birds but not bird

density). Trocki (2003) also found that wading birds strongly preferred isolated salt marsh pools as foraging microhabitat within a marsh, and concluded that the lack of marsh pools (often resulting from ditching) is the primary factor limiting the abundance of these birds on a Bay-wide scale (e.g., the number of wading birds nesting in Rhode Island has remained stable in recent years even though not all potential nesting areas are used in any given year (Ferren and Myers, 1998)). Thus, Trocki's study suggests that future marsh restoration should also consider marsh pool creation if increasing wading bird numbers is a primary goal of restoration.

Waterfowl

Narragansett Bay is used extensively by a variety of waterfowl that includes diving and dabbling ducks and swans and geese (Fig. 11.3). While some of these species (e.g., Canada goose (*Branta canadensis*), American black duck (*Anas rubripes*), and mallard (*Anas platyrhynchos*)) utilize Bay waters throughout the year, many others use the Bay primarily for overwintering (Conway, 1992). Based on annual winter surveys conducted from 2002 to 2004, 23 of the 55 native species of North American waterfowl (42 percent) use Narragansett Bay in winter (McKinney, 2005). The most abundant species according to these surveys are scaup (*Aythya* spp.), Canada goose, common goldeneye (*Bucephala clangula*), common eider (*Somateria mollissima*), and brant (*Branta bernicla*) (Table 11.1). Twelve additional waterfowl species were considered to be regular winter inhabitants. Densities of winter waterfowl in Narragansett Bay average 39 birds km^{-1} , which is comparable to nearby Boston Harbor but less than in Chesapeake Bay (36 and 55 birds km^{-1} , respectively) (McKinney, 2005).

Waterfowl species do not appear to be randomly located around Narragansett Bay; instead, these birds may select for specific habitats that have certain landscape characteristics. For example, specific groups of waterfowl in Narragansett Bay were found to be associated with salt marsh-dominated coves or rocky headland habitats near the mouth of the Bay (McKinney, 2005). Waterfowl using salt marsh and shallow cove habitats favored sites that were abutted by forest and residential land-use types. McKinney (2005) suggests that species select these areas within Narragansett Bay because trees and/or houses reduce wind velocity and because hunting is not permitted near residential areas (McKinney also found that waterfowl species richness decreased with increasing hunting activity). By design, McKinney's work was exploratory in nature



Table 11.1. Relative abundance of waterfowl and associated species in winter in Narragansett Bay and around Prudence Island. Data were collected in 2004 and 2005 by volunteers coordinated by the EPA in Narragansett, R.I. All data were provided by Richard McKinney (unpublished).

Species	Common name	Prudence Island		Narragansett Bay	
		2004	2005	2004	2005
<i>Anas americana</i>	American wigeon	0	2	1060	123
<i>Anas platyrhynchos</i>	Mallard	5	4	1320	1478
<i>Anas rubripes</i>	American black duck	139	276	983	1474
<i>Anas strepera</i>	Gadwall	0	3	395	61
<i>Aythya affinis</i>	Lesser scaup	0	0	0	368
<i>Aythya marila</i>	Greater scaup	4	0	3576	7889
<i>Branta bernicla</i>	Brant	60	468	1911	1434
<i>Branta canadensis</i>	Canada goose	53	390	2037	4008
<i>Bucephala albeola</i>	Bufflehead	74	11	718	470
<i>Bucephala clangula</i>	Common goldeneye	695	70	2323	849
<i>Clangula hyemalis</i>	Old-squaw	0	0	0	1
<i>Cygnus olor</i>	Mute swan	7	0	523	677
<i>Gavia immer</i>	Common loon	1	0	47	25
<i>Histrionicus histrionicus</i>	Harlequin duck	0	0	105	66
<i>Larus spp.</i>	Gulls	570	518	4015	3789
<i>Lophodytes cucullatus</i>	Hooded merganser	0	0	33	70
<i>Melanitta deglandi</i>	White-winged scoter	0	3	411	3
<i>Melanitta nigra</i>	Black scoter	0	0	198	99
<i>Melanitta perspicillata</i>	Surf scoter	0	2	3	33
<i>Mergus merganser</i>	Common merganser	0	5	0	23
<i>Mergus serrator</i>	Red-breasted merganser	21	11	824	404
<i>Phalacrocorax spp.</i>	Cormorants	0	1	1	5
<i>Podiceps auritus</i>	Horned grebe	6	0	127	19
<i>Somateria mollissima</i>	Common eider	0	0	941	2465

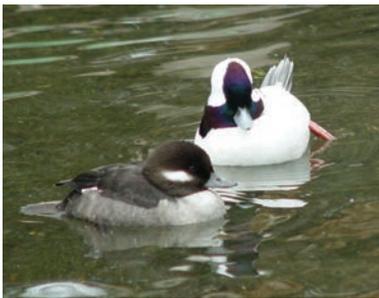


Figure 11.3. Examples of common waterfowl in Narragansett Bay, including bufflehead (far left), harlequin duck (left), and hooded merganser. Photos by R. McKinney, EPA.

and has raised some important questions about winter waterfowl use of microhabitats in Narragansett Bay that should be investigated. In particular, the effects of human disturbance, including coastal development and shoreline modification, hunting, and eutrophication and its resultant biotic changes, need scientific attention.

Marine Mammals

The mammals that use Narragansett Bay and its associated coastal habitats include those that are facultative terrestrial species as well as true marine

mammals such as cetaceans and pinnipeds. According to French et al. (1992), at least 33 land-based mammals use Narragansett Bay coastal habitats (including coastal shrublands and forests); approximately half directly use shore-zone areas of the Bay. The Bay's beaches, salt marshes, and other shoreline types provide ample foraging opportunities for species such as white-tailed deer (*Odocoileus virginianus*), coyote (*Canis latrans*), red fox (*Vulpes vulpes*), raccoon (*Procyon lotor*), American mink (*Mustela vison*), striped skunk (*Mephitis mephitis*), northern river otter (*Lontra canadensis*), Norway rat (*Rattus norvegicus*), muskrat (*Ondatra zibethica*), and multiple species of bats. Mice (white-footed *Peromyscus leucopus*, meadow jumping *Zapus*



hudsonius and house *Mus musculus*), meadow voles (*Microtus pennsylvanicus*), and masked shrews (*Sorex cinereus*) may also nest in the upper portions of salt marshes around the Bay (Nixon, 1982).

Among the marine mammals that are found in Narragansett Bay, the harbor seal (*Phoca vitulina*) is the only regular, abundant species (Fig. 11.4). The most comprehensive research focusing on harbor seals in Narragansett Bay was a study conducted by Schroeder (2000) who examined trends in population size and haul-out use. According to Schroeder (2000), harbor seals typically arrive in Narragansett Bay in late September or early October, increase in numbers through March, and leave the Bay by early May (Fig. 11.5). While they are in Narragansett Bay, harbor seals forage in subtidal areas and use rocky outcrops as haul-out sites for resting. Schroeder (2000) identified 27 sites that are used as haul-outs by harbor seals in Narragansett Bay and on Block Island. Twelve of these were considered primary sites (based on the number of seals and also monitoring effort), and among these, Rome Point in North Kingstown consistently supported some of the highest numbers of seals. Other primary haul-out sites include Brenton Point (off Newport), Citing Rock (off Rose Island), and Cold Spring Rock (north of Rome Point, near Wickford Harbor) (Fig. 11.6). Other sites, including Seal Rock (off Hope Island) and Cormorant Cove (on Block Island) also support large numbers of hauled out seals, but these sites are monitored too infrequently to assess true haul-out patterns, and are thus not considered primary. Over the last 13 years, the number of harbor seal haul-out sites in Narragansett Bay has more than tripled (Schroeder, 2000). This is a direct result of an expanding harbor seal population in Narragansett Bay that has increased by a factor of 10 in the last 40 years, and has quadrupled since 1987 (Schroeder, 2000).

A smaller, unpublished study that examined nocturnal behaviors of harbor seals in the NBNERR was conducted by Norris (2005), then an under-

graduate at Roger Williams University in Bristol, R.I. Norris (2005) observed seals in the winter of 2004 at the T-wharf haul-out site on the south end of Prudence Island and found that seals hauled out in similar numbers at this site during the day and at night (average of 22 during the day; 16 at night). She also found that temperature and wind speed had no effect on the numbers of seals that were hauled out and that the number of seals exhibiting scanning behavior depended on the size of the group that was hauled out. Two to four scanners were used when the number of hauled out seals ranged from 10 to 40; however, only one seal scanned if the number hauled out was less than seven. This pattern was the same during the day and at night.

Harbor seal populations have been increasing throughout much of the northwest Atlantic (Waring et al., 2004), including in Narragansett Bay, where a steadily increasing population uses an increasing number of haul-out sites. Higher numbers of seals have prompted concern over the resultant effects on commercially important fish stocks in the region (Baraff and Loughlin, 2000). However, recent research shows that these concerns may be largely unwarranted in Narragansett Bay. Nicotri and Webb (unpublished data) have used bioenergetic models to estimate that the winter seal population in the Bay consumes only 0.15 to 0.40 percent of the total commercial landing for all species, which suggests that the effects of seal foraging on fish stocks is minimal, at least in Narragansett Bay.

Other than harbor seals, Narragansett Bay is not commonly frequented by marine mammals. As such, published scientific accounts or marine mammal sighting lists specific to Narragansett Bay are rare. The best available information is a list of strandings and live sightings of marine mammals in Narragansett Bay and along coastal Rhode Island (Robert Kenney, personal communication). This list includes 15 additional species of marine mammals sighted (dead or alive) at some point in Narragansett Bay or along the south shore of Rhode Island. These species include the gray seal (*Halichoerus grypus*), harp seal (*Pagophilus groenlandicus*), hooded seal (*Cystophora cristata*), North Atlantic right whale (*Eubalaena glacialis*), humpback whale (*Megaptera novaeangliae*), fin whale (*Balaenoptera physalus*), northern minke whale (*Balaenoptera acutorostrata*), dwarf sperm whale (*Kogia sima*), long-finned pilot whale (*Globicephala melas*), Risso's dolphin (*Grampus griseus*), Atlantic white-sided dolphin (*Lagenorhynchus acutus*), bottlenose dolphin (*Tursiops truncatus*), striped dolphin (*Stenella coeruleoalba*), harbor porpoise (*Phocoena phocoena*), and West Indian manatee (*Trichechus manatus*).



Figure 11.4. A harbor seal in Narragansett Bay. Photo from NOAA's Estuarine Research Reserve Collection.

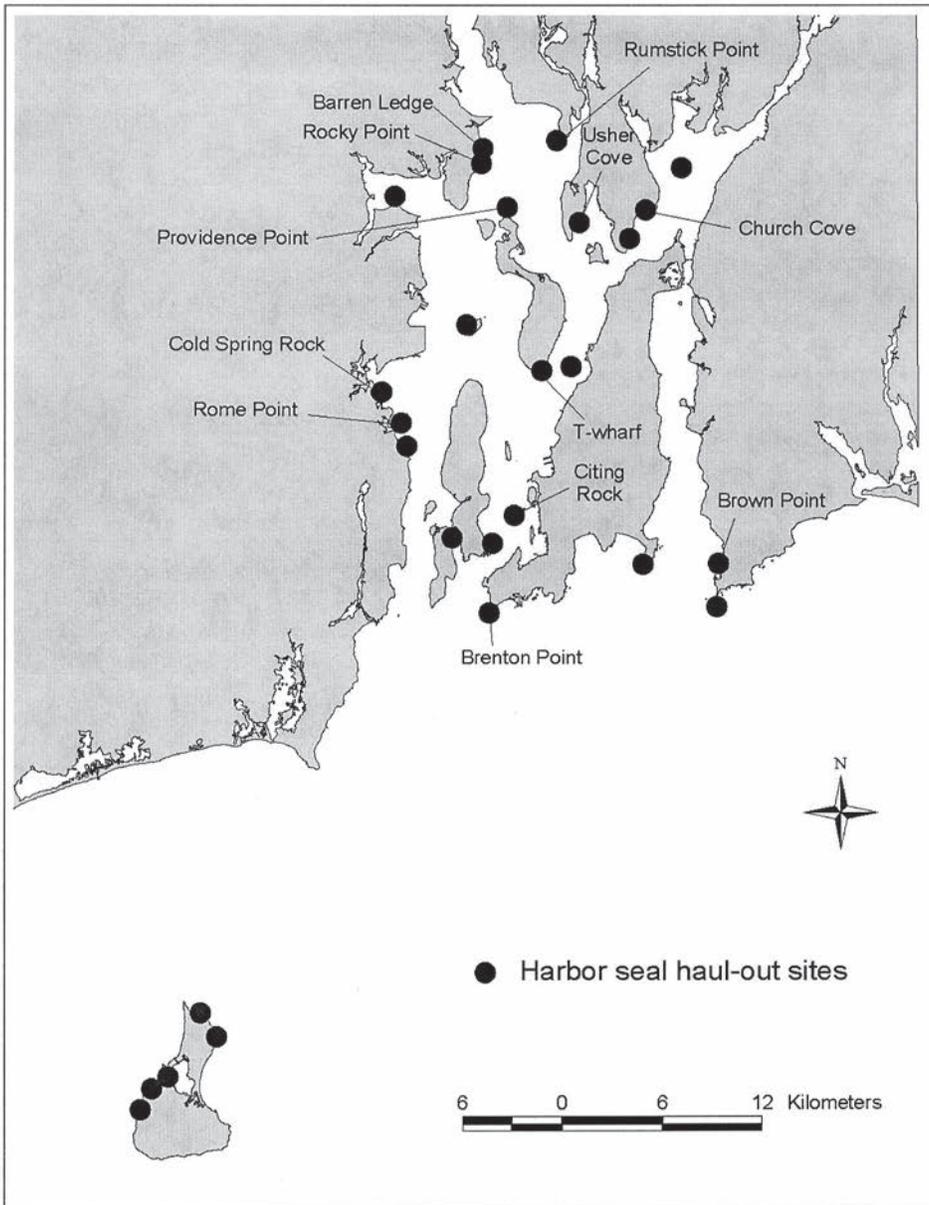


Figure 11.6. Locations of seal haul-out sites in Narragansett Bay and on Block Island, according to Schroeder (2000). Locations that are considered as primary haul-out sites by Schroeder are labeled.

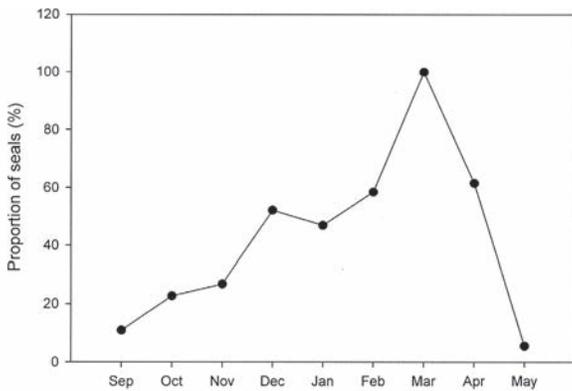


Figure 11.5. The relative abundance of harbor seals observed from September through May, expressed as a percentage of maximum abundance in March. Data are from 1993 to 2002, and were derived from monitoring efforts coordinated by Save The Bay and Schroeder (2000).

Sea Turtles

While not often thought of as local residents, sea turtles are regular summer visitors to Rhode Island waters—some making their way into Narragansett Bay. They are sighted in state waters from late June through October, when they migrate south to their wintering grounds. Data from NOAA’s Sea Turtle Stranding and Salvage Network (STSSN) and from the newly created R.I. Sea Turtle Disentanglement Network (RISTDN) document the occurrence of leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), and Kemp’s ridley (*Lepidochelys kempfi*) sea turtles in the Bay (Schwartz and Beutel, 2006; Wynne and Schwartz,



1999; H. Medic, personal communication). The leatherback is highly pelagic, traversing Rhode Island Sound but not usually venturing into the Bay farther north than its mouth. Nevertheless, in 2007, a leatherback was successfully disentangled from a buoy line off Hope Island, part of the NBNERR (M. Schwartz, personal communication) (Fig. 11.7). The loggerhead and Kemp's ridley sea turtles have been sighted (dead and alive) in the Bay around Conanicut and Aquidneck islands and likely make their way to the NBNERR as well (Schwartz and Beutel, 2006; Schwartz, personal communication; Medic, personal communication).



Figure 11.7. A leatherback sea turtle was successfully disentangled from a buoy line near Hope Island, part of the NBNERR. Photo courtesy RISTDN.

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CHAPTER 12.

Human Impacts on Narragansett Bay

Thomas E. Kutcher





Figure 12.1. Circa 1920 penny postcard depicting Slater Mill and subsequent industrialization on the Blackstone River. Photo from USGenWeb Archives.





Human Impacts on Narragansett Bay

Once considered the most industrialized estuary in the world, Narragansett Bay has endured a long history of human impacts—some transient, some dynamic, some chronic, and some historic yet persistent. Human impacts are numerous and vary widely temporally, spatially, and functionally. It may be safe to say that every ecological function of Narragansett Bay has been directly or indirectly impacted by human activity. To list and provide detailed information on every historic impact to the Bay is well beyond the scope of this chapter, and would certainly fill an entire book. What follows, therefore, is a brief history of consequential human activities on Narragansett Bay and a discussion of the major anthropogenic impacts that affect the present ecology, value, and aesthetics of the Bay.

Prehistoric Human Use

The first evidence of post-glacial human occupation in the Narragansett Bay watershed is located on Conanicut Island and dates back roughly 5,000 years. Two Algonquin tribes, the Narragansetts of the West Bay and the Wampanoags of the East Bay, subsisted off of the resources within and surrounding the Bay. Natives numbered approximately 8,000 in total. The Algonquins may have had a minor ecological impact on Narragansett Bay and the surrounding upland habitats, harvesting fish and shellfish, hunting keystone species, and clearing land for subsistence farming by burning. However, from an ecological perspective, influences of native peoples were relatively minor and the precolonial environment is thus generally considered to be the natural background condition (e.g., King et al., 1995; Nixon, 1995).

Preindustrial Use

European colonists first settled the Narragansett Bay watershed in 1636 along the shores of the Providence River (Keller, 1996). Colonization spread quickly south along the East Bay to Aquidneck Island, and down the West Bay to Wickford. The temperate climate, long growing season, and loamy soils along the immediate coast of Rhode Island and southern Massachusetts were ideal for

farming, and coastal land along the upper Bay was extensively cleared for agriculture and lumber production during the 17th and 18th centuries. Agriculture was the dominant coastal land use in the Narragansett Bay watershed until population growth and demand for labor housing associated with industrialization and urbanization became prevalent in the early 1900s. Land clearing and agriculture have historically and presently affected the water column and benthic quality of the Narragansett Bay and its tributaries by contributing to nutrient loading and siltation.

Finfish and shellfish fisheries have historically been major sources of sustenance and income for inhabitants of the Narragansett Bay watershed from early colonial times until present. Narragansett Bay was a rich fishing ground until the mid-1800s, when pelagic and anadromous fish stocks succumbed to the pressures of trap fishing and industrialization, respectively (Oviatt et al., 2003). Heavy, persistent fishing pressure and practices have, in part, caused many Bay stocks to dwindle, and the finfishery has shifted primarily to coastal waters outside of the estuary. Today, the shellfishery is the most important commercial fishery in the Bay (DeAlteris et al., 2000).

The natural deep channels and protected harbors of Narragansett Bay were ideally suited to support the shipping trades. As early as the 1700s, Rhode Island ports were involved in a lucrative shipping trade of crops, slaves, and rum with Europe, South America, Africa, and the West Indies (Childress et al., 1996). In 1853, the Army Corps of Engineers dredged a 3 m (10-foot) deep, 30 m (100-foot) wide channel into the Port of Providence to allow for the entry of large freight vessels. By 1965, Providence was the fourth largest port in New England. Regular marine shipping continues with the present importation of fossil fuels and automobiles (Harrington, 2000). Presently, approximately 13 million tons of cargo are imported into Narragansett Bay each year (U.S. Army Corps of Engineers, 2005). Shipping has led to modifications of the shoreline, driven the dredging of deepwater channels, and introduced invasive marine species from foreign bilge water and bottom fouling.



Industrialization

Historians often credit Slater Mill as being the birthplace of the Industrial Revolution in America. This textile mill was constructed by Samuel Slater in 1793 on the Blackstone River—one of the two main tributaries to Narragansett Bay—and was powered by damming the river to create a millpond that reserved the potential energy of the descending water for controlled and constant availability (Fig. 12.1). The success of the mill spawned 19th century entrepreneurs to build small and large mills on nearly every tributary to the Bay. Metal milling operations arose to supply the demand for textile machinery, followed by the manufacture of items of precious metals. As mill dams were constructed, they constricted water flow and fish passage on

virtually all tributaries to the Bay, which has had numerous ecological effects, including the decimation of anadromous fish populations.

By 1900, hundreds of Narragansett Bay watershed textile and metal mills were using Bay tributary waters for power, processing, and washing of materials, and for direct waste discharge. And, with the invention of the steam turbine, many industries replaced hydropower with more flexible fossil fuel power, which introduced various hydrocarbon-derived pollutants into the Bay system. Overall, the numerous consequences of industrialization to Narragansett Bay included severely polluted waters and sediments and greatly debilitated hydrologic and biological processes.

Population Growth and Sprawl

During the 1800s, the population of Rhode Island was growing faster than any other New England state. The livelihood of residents that once depended largely on the exploitation of local

resources was shifting to manufacturing and export. Between 1860 and 1920, the population of Rhode Island tripled, and industrial employment doubled (Harrington, 2000). During that period, immigrants came to America to labor on public works projects or in the textile mills and metals factories. Meanwhile, agriculture declined as the work force shifted from fields to factories and urbanization began.

As commerce and population grew with the industrialization and urbanization of the watershed so did the need for infrastructure, in the form of streets, dredged waterways, railroads, and urban sewage systems. In 1870 the city of Providence constructed a sewer system that conveyed the city's sewage through a series of 65 sewer outfalls directly into Providence's rivers and harbor. Processing of Providence sewage by chemical precipitation began

in 1901 at Field's

Point, but the plant was already inadequate to keep up with the growing popula-



Figure 12.2. Military installation on Gould Island in the lower East Passage. This site housed a torpedo testing facility during the mid-20th century and is now largely reclaimed by vegetation. *Photo from the National Archives.*

tion by 1910 (Nixon, 1995). The city then began dumping large quantities of precipitated sludge into Narragansett Bay, just east of Prudence Island, which continued until 1950 (Nixon, 1995).

Military Occupation

Since the establishment of the Continental Navy in 1775, the U.S. military has occupied various key strategic areas within Narragansett Bay—mostly prominent coastal points and nearly every Bay island—to protect the security of the Bay's civilians as well as valuable resources. Many of these outposts began as forts to house cannons and guns to stop penetration of Bay waters by enemy ships. Over time, the Navy developed numerous in-Bay sites as huge military ports, torpedo development facilities, shipbuilding operations, and naval air stations



(U.S. Navy, 2005, Fig. 12.2). Military operations modified coastal lands and shorelines as necessary to meet their changing needs. During the early and mid-1900s, the Navy developed at least 6,000 acres of coastal lands along 31 miles of the Narragansett Bay shoreline, which included the filling of at least 400 acres of the Bay to expand Quonset Point Air Station (U.S. Navy, 2005). Military waste, including hazardous pollutants, was routinely disposed of in coastal landfills and salt marshes, which at that time were generally considered valueless. Navy dumpsites are responsible for at least seven identified superfund sites in Rhode Island (EPA, 2005). The Navy also used the Bay waters extensively as a training ground and as a testing site for maritime weaponry, including torpedoes and mines, some of which remain on the seafloor.

Anthropogenic Impacts to Narragansett Bay

Physical and Hydrologic Modifications

The physical structure, hydrology, temperature, and chemistry of Narragansett Bay have been greatly affected since colonization of the watershed in the 1700s. Development of the watershed and industrialization of the tributaries were and are the basic anthropogenic forces altering the natural physical processes that drive the Bay's estuarine functions. Modifications to the watershed for transportation, industry, residence, and infrastructure, in the forms of damming of tributaries, impoundment of salt marshes, construction of hard shoreline and roadways, dredging, canalization and diversion of waterways, filling of wetlands and shorelines, withdrawal of fresh water, massive inputs of effluent, and removal of vegetative coastal and riparian buffers all contribute to changes in Bay flow patterns, salinity, temperature, and tidal influence.

Physical modifications have been directly imposed on virtually all systems of Narragansett Bay, including the tributaries, coastal wetlands, and the seafloor. Over 1,100 dams have been constructed on virtually every tributary to the Bay, mostly to support numerous small and large mills within the watershed (Hale, 1988). Most of these delinquent dams remain as relics. Over 680 ha (1,700 acres) (48 percent) of estuarine marshes have been ditched and/or impounded, and over one-third of all coastal wetland buffer area (150 m buffer zone) has been developed (Tiner et al., 2004). In total, 52 percent

(214.5 km) of Narragansett Bay's shoreline has been developed into hardened shoreline (derived from RIGIS, 2006). From 1950 to 1990, 15 percent of estuarine wetlands were lost (mostly due to filling), including 124 ha of coastal marshes (Tiner et al., 2004). In deepwater habitats, three major dredged channels are maintained to connect the deep river valleys of the Bay with major ports on the Providence and Taunton rivers and in Quonset Point. The Providence River channel, the largest of the three, is 27 km long and at the time of construction it was 183 m (600 feet) wide and 12 m (40 feet) deep, running through surrounding waters ranging from zero to 12 m (1 to 40 feet) deep.

Water withdrawals from the Bay and its tributaries for residential, industrial, and power production uses have affected temperatures, salinities, and flow patterns in the Bay. Most notably, the Brayton Point Station, the largest coal-fired power plant in the Northeast, has been extracting, warming, and reintroducing seawater to the Mount Hope Bay (the northeast sub-embayment of Narragansett Bay) since 1986. The plant has been permitted to cycle up to 1.45 billion gallons per day (BGD) through a once-through cooling system with a maximum output temperature of 95 F and a maximum change in temperature of +22 F (Massachusetts Department of Environmental Protection (MADEP), 2002). The current average discharge plume of the plant (0.98 BGD) causes a rise of over 1.5 F (MADEP maximum standard) over background temperature to 2,350 ha (60 percent) of Mount Hope Bay (MADEP, 2002). In total, Brayton Point Station cycles the equivalent of the entire contents of Mount Hope Bay approximately every 21 days (J. Quinn, personal communication).

Physical anthropogenic changes in the surrounding watershed further impact Narragansett Bay by affecting the natural hydrography. By 1995 over 30 percent of the watershed was developed including nearly 6,000 miles of public roads. Several of the urbanized subwatersheds within Narragansett Bay contain more than 15 percent impervious surface, which is an EPA benchmark for ecologically impaired watersheds (Crawley, 2000). Due to the relatively small natural input of fresh water to Narragansett Bay (2.4 billion gallons, less than 1 percent of total Bay volume, entering daily), wastewater inputs comprise a relatively large percentage (more than 4 percent) of the total freshwater inputs.

In effect, physical development of the surrounding watershed contributes to the pollution of the Narragansett Bay in nearly every aspect, but most directly it creates urban runoff. Urban runoff is the flash runoff of surface water from a watershed



due to highly impervious surfaces quickly channeling water off of the watershed and into the receiving water body. With the high velocity and lack of impounding structure in urban areas, any pollutants entrained in the runoff are carried, usually through specifically designed conduits, directly into the receiving water bodies without natural filtration processes offered by vegetated riparian areas (Fig. 12.3). Urban runoff contributes to pathogen, toxic metal, and hydrocarbon pollution in the Bay.

In addition to contributing indirectly to pollution impacts, physical changes to the hydrology and structure of the Bay's tributaries, coastlines, and bottom have had several direct impacts on Narragansett Bay's ecology. Loss of estuarine wetlands directly reduces critical habitat for a variety of nekton and avian species and reduces the filtering effect on watershed runoff. Impoundment of Narragansett Bay wetlands has been found to lead to the widespread establishment of invasive vegetation due to lowering marsh salinities (Bertness, 1999). From 1950 to 1990, 97 ha of marsh were overtaken by the invasive reed *Phragmites australis* (Tiner et al., 2004). Impoundment also often results in degraded nekton assemblages within marshes (Raposa and Roman, 2003). The damming of tributaries has led to the downfall of anadromous fish stocks, beginning with the extirpation of Atlantic salmon (*Salmo salar*) by 1830, and continuing with a chronic demise in once robust river herring (*Alosa* spp.) runs (NBEP, 2006). Currently, only 18 of the historic 45 runs still support anadromous fish. Damming also raises the temperature of waters entering the Bay, traps and concentrates polluted sediments, buffers natural flow variations, and alters the compositions of riverine flora and fauna (Erkan, 2002). The ongoing maintenance of miles of dredged deepwater channels also affects the Bay's ecosystem health. Dredging causes a direct loss of benthos and also reintroduces buried toxins, such as heavy metals and synthetic organic compounds, to the living water column and aerobic benthic zones.

Nutrient Loading

For over a century, Narragansett Bay has been receiving a substantial loading of anthropogenic nutrients, most notably in various forms of nitrogen and phosphorus. Nutrient inputs are specifically correlated with the widespread use of running water, which began in the late 1800s (Nixon et al., 2005). The two major sources of nutrient inputs to Narragansett Bay are the major public wastewater treatment facilities (WWTFs) that discharge directly into the Bay and the major tributaries (riverine in-



Figure 12.3. A highly modified and industrialized upper reach of the Providence River in Narragansett Bay. Note highway storm drain pipes discharging directly into the river. Photo from NBNERR photo library.

put), which act to combine nutrients from upstream WWTFs, individual sewage disposal systems (ISDSs), and runoff from their respective contributing sub-watersheds. Total riverine input is the major source of nitrogen entering the Bay (Nixon et al., 2005). However, if all WWTFs are taken into account, including those discharging into rivers, WWTFs currently contribute approximately 70 percent of the total nitrogen load entering the Bay, while runoff carrying nutrients from atmospheric deposition and agriculture contributes most of the balance (22 percent and 6 percent, respectively; Nixon et al., 2005). Direct atmospheric and ground-water sources are thought to be minor (Carey et al., 2005).

Currently, total inputs from Narragansett Bay's five major tributaries contribute 1.5 times the nitrogen and 2.7 times the phosphorus to the Bay as the three combined largest WWTFs (Field's Point, Bucklin Point, and East Providence), dispensing an estimated 2,590 metric tons (MT) of total nitrogen and 271 metric tons of total phosphorus per year into the Bay (Nixon et al., 2005). Nitrogen enters the Bay from rivers mainly in the form of dissolved inorganic nitrogen, mostly derived from WWTF discharges during high river flow periods in spring and in fall storms (Carey et al., 2005). Phosphorus enters from rivers mostly in the forms of inorganic phosphate and particulate phosphorus (Nixon et al., 2005).

Over 290,000 cubic meters per day of effluent enter Narragansett Bay directly from the three large sewage treatment facilities. Nixon et al. (2005) estimated that, combined, the three big WWTFs contribute 1,650 MT and 120 MT per year of total nitrogen and phosphorus, respectively. Nitrogen inputs from major WWTFs have changed little since

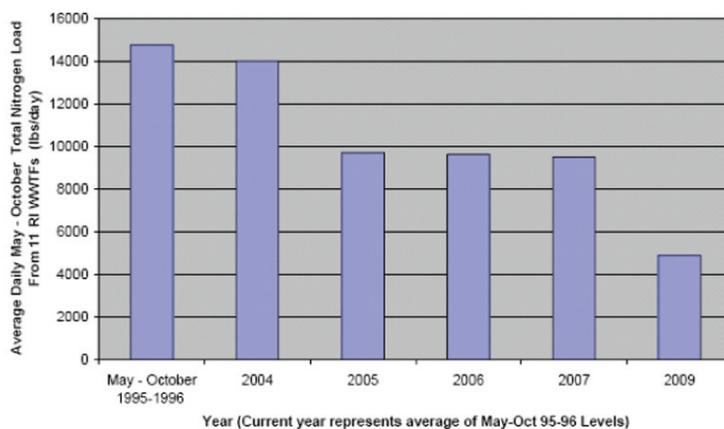


Figure 12.4. Projected yearly reductions in nitrogen loads from major Rhode Island WWTFs on Narragansett Bay. *Reproduced from RIDEM, 2005.*

to depauperate assemblages of small, short-lived worms and clams (Deacutis, 1998; Carey et al., 2005). Hypoxic and anoxic events have also been responsible for recent fish kills in the Bay (e.g., RIDEM, 2003; RIDEM, 2004).

The Rhode Island Governor's Commission enacted a "Plan for Managing Nutrient Loadings to Rhode Island Waters" (RI General Law 46-1-3(25)) in 2004 to reduce, by 50 percent, dissolved nutrients entering the Bay from 11 major WWTFs by 2009 (RIDEM, 2005; Fig. 12.4). This is expected to result in a 48 percent reduction in total summertime nitrogen loads to the Bay (Carey et al., 2005). Reduction of nutrients has been shown to restore expected ecological functions to estuarine systems (Mallin et al., 2005). Scientists expect a recovery of diversity and productivity in the degraded benthos of the upper Bay in response to lower nutrient loads, but are uncertain whether it will lead to a rebound in eelgrass abundance (Carey et al., 2005).

the mid-1970s, with reduced inputs from the Field's Point facility being offset by increased inputs from the Bucklin Point facility, while phosphorus inputs have decreased significantly during that time. Nitrogen enters mainly in the form of ammonia (approximately 60 percent) followed by organic nitrogen and nitrites/nitrates, while the state of phosphorus entering has not been determined for sewage effluent (Nixon et al., 2005).

Nutrient loading is considered by some ecologists to be the most serious and widespread pollution impact currently occurring in Narragansett Bay, decreasing benthic biodiversity and altering valuable ecosystem functions (e.g., Deacutis, 1998; Carey et al., 2005). Nitrogen is considered the limiting nutrient to primary production in the Bay, while phosphorus and other nutrients may have lesser effects on certain ecosystem processes (Carey et al., 2005). Overloading the Bay with these nutrients has led to widespread eutrophication (over-production in primary producers such as phytoplankton and macroalgae, especially *Ulva* sp.), primarily in the upper reaches. This has ultimately impacted the ecology of much of the Bay ecosystem. One impact is high turbidity, which remains a primary cause in the stress or complete elimination of eelgrass (*Zostera marina*) from historic areas (visit www.edc.uri.edu/restoration/html/intro/sea.htm). Eelgrass forms an important Bay habitat type that provides cover for many juvenile and adult marine species and thus its decline has had ascending trophic effects on the ecosystem.

Another effect of eutrophication on Narragansett Bay is the regular seasonal occurrence of hypoxic and anoxic events, especially in areas of the upper Bay near the sources of nutrients. Middle and lower Bay segments are subject to periodic and infrequent hypoxic events, respectively (Carey et al., 2005). Habitats subjected to regular oxygen depletion have been degraded, with shifts in benthos from expected diverse faunal assemblages of large species such as American lobster (*Homarus americanus*), crabs, and mantis shrimp (*Squilla empusa*)

Toxic Metals

The sediments and waters of Narragansett Bay have been contaminated with a variety of anthropogenic metals contributed by numerous sources over the course of developed history. Significant inputs of metals to Narragansett Bay began as industrialization led to prevalent machinery and jewelry base-metal industries on Narragansett Bay tributaries during the mid-1800s. Metal-rich manufacturing wastes from these and other industries were dumped directly into the Bay and its tributaries until about 1910, when the Field's Point treatment facility began treating combined household, street runoff, and industrial effluent (Nixon, 1995). From 1909 to 1950, metal-laden solids were precipitated from the Field's Point effluent and dumped directly into the mid-Bay, just south of Prudence Island (Nixon, 1995). As a result, various anthropogenic metals are known to exist throughout the Bay in various levels of concern. These include arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, and zinc. All facets of industrialization and subsequent urbanization of the



	Year					
	1900 ^a	1925 ^a	1950 ^a	1986 ^b	1988 ^b	1993 ^c
Cd	<1.3	<1.4	1.9	0.6 (0.14)	0.6	<0.1
Cr	13	17	22	2.3	1.2	1.4
Cu	54	76	104	35 (18-23)	6.8	6.4
Pb	15	16	22	5.9 (1.8)	3.3	0.9
Ni	<31	<51	71	40 (20)	23	15
Zn	90	125	171	54	25	6.6
Ag				1.8		0.4

Table 12.1. Partial reproduction from Nixon (2005) presenting a comparison of estimated inputs of various metals to Narragansett Bay from the Fields Point WWTF in metric tons per year.

watershed, including fossil fuel use, the widespread use of automobiles, construction, street paving, and indoor plumbing, contributed to a snowballing of metal inputs, peaking around the 1950s when environmental regulations began to be implemented (Table 12.1).

Metals have entered Narragansett Bay through several interconnected modes: riverine inputs, WWTF discharges, direct point and nonpoint discharges, and direct atmospheric deposition. Rivers and WWTFs have historically been, and remain, the main sources of metal inputs into Narragansett Bay, while direct atmospheric deposition has been a significant source of only lead, mostly during the leaded gas era (Nixon, 1995). River and upstream inputs increased with urbanization of the watershed, as metals from atmospheric deposition and automobile byproducts were efficiently and quickly transported from the roofs, streets, and sidewalks of urban areas into the tributaries in the form of urban runoff. Narragansett Bay tributaries also carry the discharges of some 22 WWTFs and numerous industries (RIDEM, 2003). Rivers currently contribute the most cadmium, lead, zinc, copper, nickel, and chromium, while WWTFs contribute the highest amount of silver (Nixon, 1995).

Due to environmental regulations imposed in recent decades, metal inputs to Narragansett Bay have diminished, but high concentrations of these contaminants remain buried in Bay sediments. Decreases in inputs have resulted from air and water pollution legislation, the shift from wood and coal to oil and natural gas, application of stack emission reduction devices, removal of lead from gasoline, termination of sludge-dumping in the Bay, upgrading of WWTFs, and the loss of primary metal industries in the watershed (King et al., 1998; Greene and Deacutis, 2000; Nixon, 1995). In fact, Nixon (1995) estimated that fewer metals were entering the Bay from watershed discharges than from the open ocean. However, high concentrations of persistent metals remain within bottom sediments in many areas of the Bay and its tributaries. King et al. (1995) found the dam-impounded sediments of the Bay's major tributaries often exceeded the "effects range-median" (ERM) sediment quality guidelines (EPA Sediment Effect Concentrations: "a level above

which indicates frequent adverse biological effects") for cadmium, chromium, copper, lead, nickel, silver, and zinc. Some of these concentrations were among the highest ever observed in the United States. They also noted that large areas of the upper Bay also exceeded sediment quality guidelines. Overall, the National Status and Trends Program, conducted by NOAA in 1989, found Narragansett Bay to rank among the top 20 most contaminated embayments in the country for mercury, selenium, and silver, as well as ranking sixth of 72 for copper, eighth of 45 for lead, and 21st of 145 for nickel contamination in *M. edulis* flesh concentrations (Keller et al., 1996). In more recent studies, King et al. (2003) found concentrations of several metals to be above "effects range-low" (ERL) values in the sediments around a remediated military superfund site near Quonset Point, while Hanson et al. (2002) found similar results in the sediments at Potter Cove in the NBNERR North Prudence Unit.

In general, the highest concentrations of metals in the sediments of Narragansett Bay are located near historic sources in the upper Bay and decrease exponentially with distance down-Bay (King et al., 1995). Core samples collected by King et al. (1995) suggest that as sediments are disturbed by such processes as bioturbation or dredging, metals are resuspended and transported down the Bay with the net flow of the estuary; thus, areas away from the source are becoming more contaminated, while upstream areas are becoming less contaminated (Ely and Trew Crist, 2001).

Sediments contaminated with metals can have harmful effects on marine and human life, but knowledge of the extent of direct effects on Bay life is limited, due to confounding factors such as nutrient loading, Bay warming, and the complex nature of effective bioavailability. Metals vary widely in toxicity, bioavailability, and the degree in which they are bioaccumulated, depending on various physical factors such as temperature, salinity, and sediment composition. Because metal inputs have dramatically declined, most Bay metals are remnants of historic sources, buried in the sediments in reduced states and are not readily bioavailable. In general, metals in the sediments most directly affect



shellfish and other burrowing fauna. King et al. (1995) found a weak relationship between sediment concentrations and flesh concentrations in *M. mercenaria* for copper and cadmium, and no relationship for nickel, chromium, or lead, but they observed a stronger correlation between *M. mercenaria* tissues and effective water-column metal concentrations (likely due to increased bioavailability of oxidized metals), which has implications for dredging and dam remediation projects. RIDEM (2004) does not consider current levels of toxic metals buried in Bay sediments to pose an immediate public human health threat, primarily because contaminated areas exist mostly in the upper reaches of the Bay where shellfishing is already banned due to sewage contamination.

Petroleum Hydrocarbons and Polycyclic Aromatic Hydrocarbons

Petroleum hydrocarbons (PHCs) encompass the total suite of hydrocarbon compounds derived from petroleum oil, while polycyclic aromatic hydrocarbons (PAHs) are toxic constituents of PHCs, created during PHC combustion. PHCs and PAHs enter Narragansett Bay primarily through chronic urban runoff that is introduced to Bay waters via combined WWTFs and rivers, although direct atmospheric deposition and direct industrial discharge may also be significant contributors (Latimer and Quinn, 1998; Hartmann et al., 2004). Large accidental spills only constitute about 2 percent of all oil entering the Bay (Keller et al., 1996). Major chronic sources of PHCs are thought to originate primarily from used crankcase oil, either being illegally discharged directly into the environment or from runoff carrying roadway oil into storm drains (Latimer and Quinn, 1998). In addition to pervasive crankcase oil, Latimer and Quinn (1998) also found a high incidence of No. 2 and No. 6 fuel oil constituents in riverine samples, as well as gasoline or kerosene-like components in the Moshassuck River, which likely result from leaking tanks or spillage. Significant PAH inputs currently originate in the Bay's watershed as both petrogenic (from petroleum) and pyrogenic (from combustion) hydrocarbons. Creosote (from treated piles and bulkheads), coal combustion (possibly from two power plants on the Taunton River in Massachusetts), and diesel exhaust are thought to be the major contributors (Hartmann et al., 2003). Higher molecular weight species are most likely to settle in Bay sediments.

Annual loads of total PHCs to Narragansett Bay are estimated to be 420 MT, including approxi-

mately 240 MT dry-season chronic inputs (150 MT from WWTF, 64 MT from rivers, and 27 MT from other surface water sources) and approximately 180 MT of wet-weather and other event-driven inputs (Latimer and Quinn, 1993). Total input is roughly the equivalent 128,000 gallons of oil per year, but, due to considerable pyrogenic sources, contains a much higher aromatic (PAH) fraction (Latimer and Quinn, 1993). Hartmann et al. (2006) ran sediment grab-sample transects (41 samples total) down both the East and West passages and found that PAH concentrations were highest at the industrialized head of the Bay and lowest toward the mouth, suggesting urban runoff and WWTF sources, with the Barrington, Taunton, and Seekonk/Providence rivers having the highest values.

In 1993, annual loads of total PHCs in Narragansett Bay were estimated to be 37 ± 17 micrograms per liter ($\mu\text{g l}^{-1}$) in the Bay's main-stem rivers—substantially higher than the reference level of $10 \mu\text{g l}^{-1}$ reported in prior studies to be harmful to certain biota, including the American lobster—a locally valuable commercial species. Eighty-six percent of samples were above that value. Hartmann et al. (2006) found a mean concentration of PAHs in the sediments of the Narragansett Bay of 21 micrograms per gram ($\mu\text{g g}^{-1}$), which was well above ERL ($4.02 \mu\text{g g}^{-1}$) sediment quality guidelines. Overall, 73 percent (30) of their stations exceeded ERL values, while 12 percent (5) were above the ERM guideline of $44.8 \mu\text{g g}^{-1}$. Toxicity of each hydrocarbon component varies, but chronic exposures to total hydrocarbons have shown effects in winter flounder physiology at concentrations of $1 \mu\text{g g}^{-1}$ and on benthic macrofauna communities at $0.09\text{--}0.18 \mu\text{g g}^{-1}$ (Keller et al., 1996).

The various components of PHCs contain a wide range of compounds that are highly toxic to marine and human life, with aromatic and mid-weight components (such as diesel due to its high aromatic fraction and persistent physical properties) being the most toxic (Clark, 2001). Pruell et al. (1984) found that *M. mercenaria* samples purchased at Rhode Island commercial seafood stores—which the authors presumed were locally caught—were contaminated with levels of biogenic hydrocarbons that exceeded levels found in samples from a control site in the lower Bay. King et al. (1993) found a strong correlation between sediment concentrations and tissue concentrations of PAHs among Narragansett Bay *M. mercenaria*. Although PAHs are considered to be carcinogenic, no state—Massachusetts or Rhode Island—or federal standards are set for concentrations of any PHCs in seafood (Pruell et al., 1984; J. Migliore, personal communication).



Synthetic Organic Compounds

Synthetic organic compounds are anthropogenic, potent, and generally highly conservative pollutants that are composed of a wide range of organochlorines and other halogenated hydrocarbons. They include industrial solvents, chlorofluorocarbons (CFCs), flame-retardants, polychlorinated biphenyls (PCBs), and pesticides such as DDT, ‘-drins’, lindane, hexachlorobenzene (HCB), toxophene, and dioxins (Clark, 2001). Synthetic organic contaminants enter Narragansett Bay from a wide range of sources, including rivers, point sources, atmospheric deposition and spills, and adsorb to particulate matter that settles to the seafloor, where it can remain in the sediments almost indefinitely (Quinn and King, personal communication). Many of these compounds were extensively produced and utilized in and around the Narragansett Bay watershed in support of modern agriculture and infrastructure systems during the mid-1900s. In response to worldwide environmental and human health impacts brought to light mostly during the 1960s, production and use of most of these compounds has been highly regulated or halted since the 1970s and 1980s (Clark, 2001). Although PCBs and DDT have been banned from sale in the United States, they both remain measurable in Narragansett Bay waters (Keller et al., 1996).

The most notable suite of synthetic organic compounds currently affecting Narragansett Bay is PCBs, which were produced mainly for use in electrical capacitors and transformers. The Blackstone River is by far the greatest contributor of PCBs, carrying 93 percent of total PCBs entering the Bay from rivers (Latimer et al., 1990; J.G. Quinn, personal communication). Latimer et al. (1991) and Quinn and King (personal communication) found that PCB levels in sediments were highest in the industrialized source areas in the extreme upper Bay and decreased in a linear fashion down-Bay due to sediment transport, with 90 percent of contaminants accumulated in the Providence River (Latimer and Quinn, 1996, Fig. 12.5). King et al. (1995) found that sediments in the Seekonk River and northern and middle sections of the Providence River contain concentrations exceeding ERM quality guidelines. Mid-bay areas situated near point sources such as in Newport and Quonset Point also contain elevated levels of PCBs. Latimer et al. (1996) found mean PCB concentrations in Narragansett Bay sediments of 390 ppm, ranging from about 1,000 ppm in the Providence River to less than 10 ppm near the mouth of the Bay. Total annual flux to the sediments of the Bay is approximately 0.1 MT (J.G. Quinn, personal communication). Quinn and King (personal

communication) also found high concentrations of the flame suppressant polybrominated diphenyl ether (PBDE) in the sediments in Pawtuxet Cove and at Bucklin Point in the Upper Bay. PBDE is structurally similar to PCBs and is believed to have similar function and toxicity.

Synthetic organic compounds are considered the most highly toxic and mutagenic of all marine pollutants. They are a particular threat to species in higher trophic levels, as they tend to bioaccumulate and biomagnify in fatty tissues (Clark, 2001). However, because their effects are not typically acute, little is known about their direct impacts on Bay or human life. King et al. (2005) found a strong correlation between surface sediment concentrations and tissue concentrations in *M. mercenaria* for five organic compounds including benzotriazoles and PCBs. Jeon and Oviatt (1991; in Keller et al., 1996) assessed concentrations of toxic contaminants in Narragansett Bay blue mussel, quahog, and winter flounder and found that PCB concentrations were generally higher in tissues of animals in the upper Bay. Of 42 coastal sites ranked for contamination by NOAA in 1989, Narragansett Bay ranked 14th for PCB concentrations in flounder. Strong correlations between PCB burdens and liver disease in winter flounder have since been revealed (Keller et al., 1996).

Another notable environmental consequence of synthetic organic pollution is that it limits riverine restorations, specifically the removal of relic dams, due to high concentrations in impounded sediments. High costs of removing and disposing of contaminated sediments are often prohibitive to riparian restoration efforts in the Narragansett Bay watershed (T. Ardito, personal communication).

Aquatic Nuisance Species

Historically, nonindigenous marine species (or aquatic nuisance species) have entered Narragansett Bay mainly through passive introduction via the shipping trades. The primary vector has been bilge water effluence, although ship fouling, aquaculture importation, and ornamental escape may have been instrumental for certain species (Narragansett Bay Estuary Program (NBEP), 2005; Cute and Hobbs, 2000; Massachusetts Invasive Species Working Group (MAISWG), 2002). Estuaries are generally considered the most vulnerable waters to invasion of aquatic nuisance species due to the extended time international ships spend in estuarine ports. Narragansett Bay, as a net importer of goods, supports less ballasted incoming international shipping traffic than many major ports, and is thus considered by some to have a relatively low risk of invasion

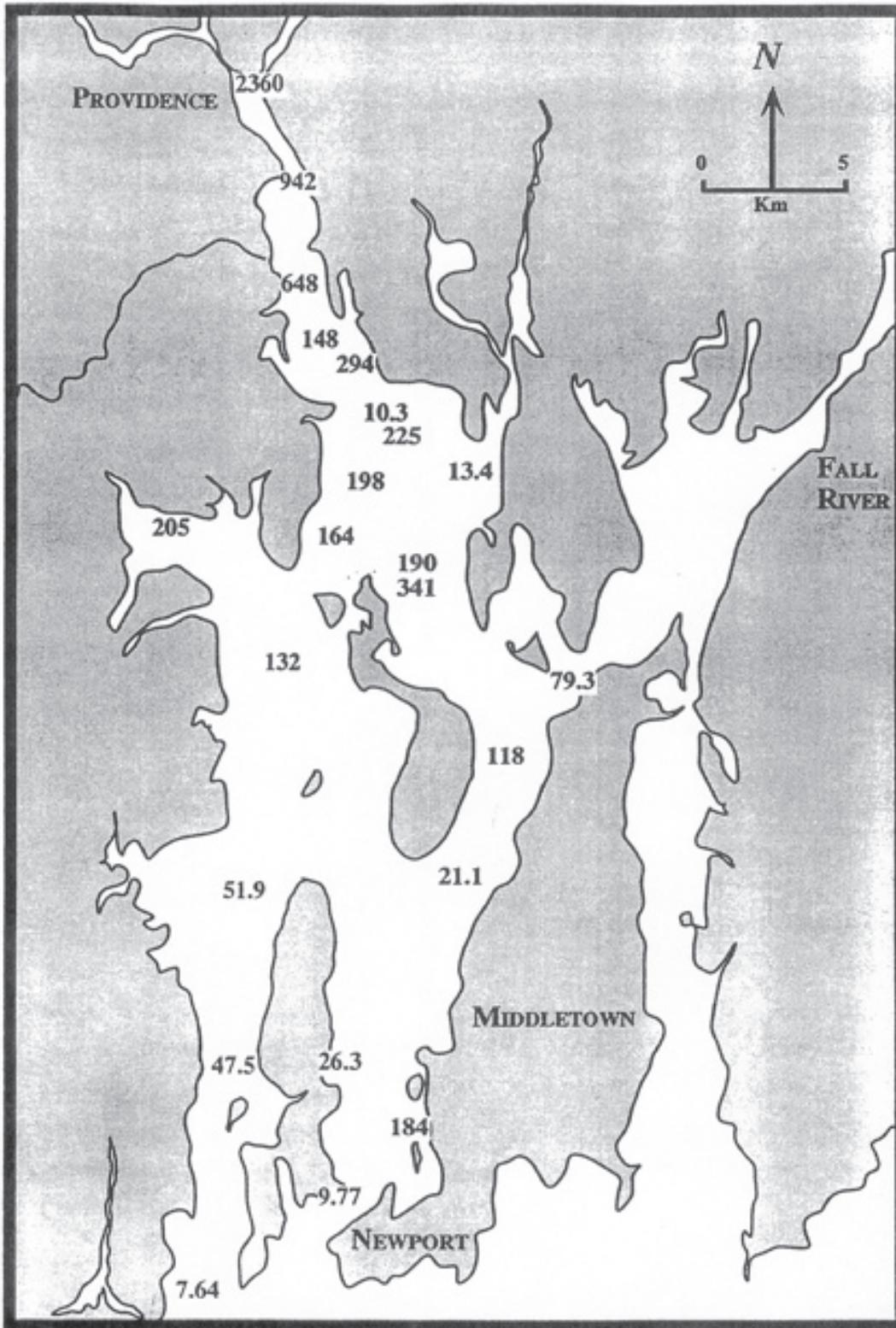


Figure 12.5. A reproduction from King et al. (1995) depicting concentrations of total PCBs (ng/g) in the surface sediments of Narragansett Bay. Note that the concentrations are highest in the industrialized upper Bay and diminish while moving down the Bay (a trend that holds for most contaminants in the Bay).

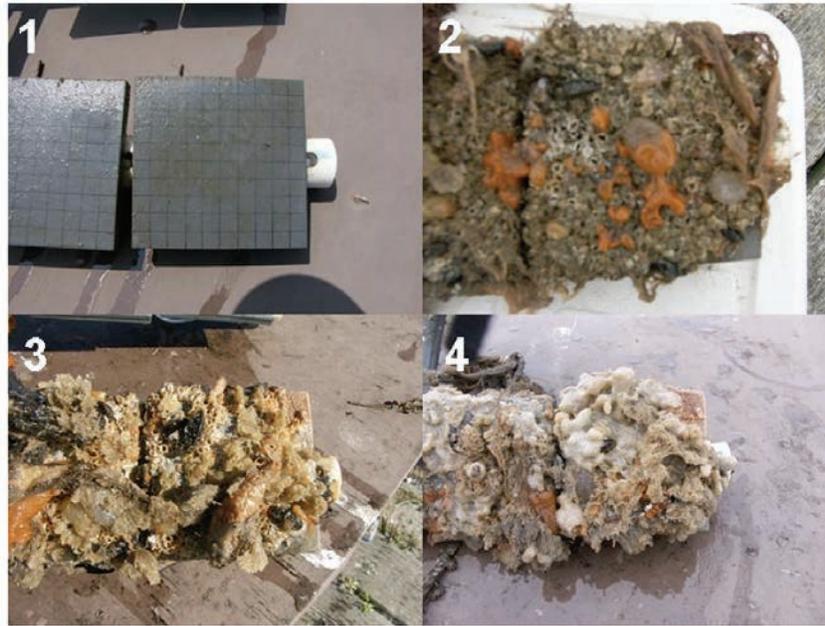


Figure 12.6. A time-series account of species recruitment on a Whitlatch settling plate set off the T-wharf in the NBNERR in 2005 by URI graduate student Linda Auker. Note how expected species such as barnacles (*Semibalanus balanoides*) and blue mussels (*Mytilus edulis*) are almost entirely overtaken by invasive tunicates. Photo from NBNERR photo library.

(NBEP, 2005). Others consider the Bay ecosystem to be at a high risk of invasion due to recent glacial history resulting in an under-saturated ecosystem (e.g., Bertness, 1999). Cute and Hobbs (2000) found that rates of invasion within Narragansett Bay have generally been increasing since 1900, which follows regional and global trends (NBEP, 2005).

Several aquatic nuisance species are widespread and abundant in Narragansett Bay. These include long-time invasives such as the common periwinkle (*Littorina littorea*), which was introduced from Europe circa 1840, and the green crab (*Carcinus maenas*), which was introduced from Europe circa 1841; and recent introductions such as the red seaweed *Grateloupia turuturu*, which was introduced from the West Pacific circa 1996, and the Asian shore crab (*Hemigrapsus sanguineus*), which was introduced from the West Pacific circa 1988 (Cute and Hobbs, 2000) and currently is showing rapid growth around Prudence Island (NBEP, 2005).

The only known formal inventory of aquatic nuisance species in Narragansett Bay is a rapid assessment of floating dock fouling communities that was conducted over a four-day period in 2000 (Cute and Hobbs, 2000). Of 149 species catalogued during that assessment, 22 species in 11 phyla were determined to be nonindigenous, while 17 species in four phyla were determined to be cryptogenic (of undetermined origin). Due to the nature of the assessment, all nonindigenous species found were either seaweeds or sessile invertebrates, with the exceptions of the green crab and the Asian shore crab.

The MAISWG (2002) compiled a list of problematic marine invaders and marine species of concern for the Massachusetts Aquatic Invasive Species Management Plan. Problematic invaders occurring in Narragansett Bay include green crab; Asian shore crab; lace bryozoan (*Membranipora membranacea*); the green alga dead-man's fingers (*Codium fragile* var. *tomentosoides*); six tunicates including *Styela clava*, *S. canopus*, *Diplosoma listerianum*, *Asciliella aspersa*, *Botryllus schlosseri*, and *Botrylloides violaceus*; and numerous shellfish pathogens including MSX (*Haplosporidian nelsoni*), SSO (*H. costalis*), Dermocystidium (*Perkinsus marinus*), and QPX, an unidentified quahog parasite. Threatening species, those that are not yet present but pose considerable threats to native ecosystems, include the veined rapa whelk (*Rapana vanosa*) from Japan; Nori (*Porphyra yezoensis*), an edible Asian red alga commercially cultivated in the Gulf of Maine; the Chinese mitten crab (*Eriocheir sinensis*); the intentionally cultivated Pacific oyster (*Crassostrea gigas*); and the "killer algae" *Caulerpa taxifolia*, which is an escaped ornamental alga associated with marine aquaria (MAISWG, 2002).

Aquatic invasive species have had long-term, wide-ranging effects on Narragansett Bay ecosystems and on fisheries. Significant impacts are community changes due to competitive dominance and predation and transmission of disease. For example, the ubiquitous green crab is known to compete with native crabs for food resources, and prey upon the commercially important clam species *Mya arenaria* and *Mytilus edulis* (Flimlin and Beal, 1993). Since

its introduction, the green crab has become one of the most dominant omnivorous shoreline consumers in the Northeast. The common periwinkle is the most abundant grazer in the Bay's intertidal habitats and has effectively driven the ecology of all Bay cobble and rock beach ecosystems via top-down control of algae and seaweeds and displacement of expected species (Bertness, 1999; Fig. 12.6). The alga dead man's fingers has also been found to affect cobble beach communities by contributing to the dislodgement of cobbles due to increased drag, and introduced tunicates are responsible for the displacement of native fouling organisms (Bertness, 1999). The invasive shellfish parasites MSX and *Dermocystidium* have been implicated in the continued scarcity of the once abundant and economically important native, the American oyster (*Crassostrea virginica*), in Narragansett Bay (RIDEM, 2004b).

Extraction of Biotic Resources

Since the 1800s finfish and shellfish in Narragansett Bay have been greatly affected, both in community composition and abundance, by fishing. Commercial fishing practices have evolved from early gears, such as the small trap, hand-line, hand dredge and tong, and small surface net, to massive, modern, efficient, and potentially destructive gears, such as the otter trawl, hydraulic dredge, long-line, and gillnet. Recreational fishing has also persisted throughout the period. A drop in finfish stock has driven most commercial finfishing out of the Bay and into coastal waters, while Bay shellfishing and recreational fishing remain important. Commercial fisheries data have been used to indicate fish abundance and community composition, and, coupled with trawl data captured by the RIDEM from 1960 to 2000, have shed light on fish populations and the effects of fisheries on the Bay.

Oviatt et al. (2003) analyzed historic and current fisheries and trawl data to explore trends and formulate hypotheses in finfish abundance and community structure in Narragansett Bay over time. Rhode Island fishery survey data compiled from the 1860s and the mid-1900s revealed a shift in target species from primarily in-Bay species to a mix of in-Bay and offshore species. More recently, RIDEM trawl surveys conducted within Narragansett Bay revealed that overall biomass of demersal species has decreased by a

factor of four in recent times. Biomass of pelagic species changed little, but species composition has shifted, with a decrease in scup biomass and an increase in bluefish, butterfish, and bay anchovy biomass. Historically important codfish, tautog, and alewife populations no longer support distinct commercial fisheries due to drastically reduced numbers (Oviatt et al., 2003).

The Narragansett Bay shellfish fishery has persisted since early times, but also with shifts in targeted species from the American oyster, the soft-shelled clam (*Mya arenaria*), and the bay scallop (*Argopecten irradians*) to the American lobster and the quahog more recently (Fig. 12.7). Oviatt et al. (2003) theorize that this shift may be associated with competitive release resulting from changes in demersal finfish assemblages, with the shift in harvest being a direct reaction to population shifts in respective species. Currently, approximately 8 million pounds of quahogs are extracted from Bay waters annually (see *NBEP.org*). Overall, it is estimated that shellfish biomass has dropped 17 percent since 1960 and 88 percent since 1898 (Oviatt et al., 2003).

Both direct and indirect harvesting pressures have been implicated as instrumental factors driving finfish and shellfish population shifts in Narragansett Bay. Oviatt et al. (2003) estimated that between the mid-1800s and mid-1900s, finfish catches within Narragansett Bay actually exceeded the Bay's capacity for production, and fish populations were apparently repopulating the Bay from nearby offshore waters. Currently, due to recent heavy fishing pressure in these nearby offshore waters, those populations no longer exist. Fish trapping, which was the most highly utilized and effective harvesting method employed in early times, is thought to have affected target populations while otherwise minimally impacting the environ-



Figure 12.7. A quahog fisherman digging from a small, modern, commercial skiff in upper Narragansett Bay. Inconsistent with trends in sophisticated modern gear, quahogs are harvested manually with a long hand rake known as a bullrake or by diving. Photo from NBNERR photo library.



ment (Oviatt et al., 2003). However, efficient but destructive commercial fishing practices of the last century, especially scallop dredging and trawling, have greatly impacted benthic habitat, which in turn may have effected the recruitment of various commercial species, including the once commercially important bay scallop. Relative abundance of total fish yield has declined an estimated 81 percent since 1891, attributed mostly to impacts of trawl fishing in the past 40 years (Oviatt et al. 2003). The dynamics between fishing pressure and populations of target species are tightly intertwined in such a small ecosystem as Narragansett Bay, yet direct relationships are often confounded by many other natural and anthropogenic factors, such as extreme weather events, siltation, warming, impasse, toxins, hypoxia, and disease, many of which may act synergistically (DeAlteris et al., 2000). Thus, harvest restrictions imposed within the last century have had limited success in restoring target populations.

Summary

A long history of human exploitation has affected virtually every ecological function in Narragansett Bay and its watershed. Sources of degradation and pollution are centered in and around industrial and residential growth centers, mostly in the upper Bay near the Providence and Fall River metropolitan areas, although effects are often widespread. There is a distinct gradient in nearly all contaminants, ranging from high levels of contamination in the upper Bay to relatively low levels in the lower Bay. For persistent contaminants buried within Bay sediments, this gradient is slowly moving down-Bay as sediments are resuspended by activities such as dredging, trawling, and bioturbation, and resettle in lower reaches. Modifications to natural hydrologic systems have directly affected or facilitated environmental degradation throughout the Narragansett Bay watershed. Widespread damming, watershed urbanization, and diversion, canalization, and dredging of waterways have directly contributed to fish impasse, urban runoff, and habitat loss, while indirectly contributing to water and sediment pollution.

Nutrient loading perhaps has the greatest immediate impact on Narragansett Bay ecology, having ascending trophic effects on all biota and direct effects on certain benthic species through oxygen depletion associated with eutrophication. Nutrients enter the Bay primarily through WWTF effluent, both directly and via riverine transport. Steps are currently being taken to reduce nutri-

ent loading to the Bay by 50 percent by 2009, but under changing climate conditions, these reductions could have as-yet-unknown consequences on Bay productivity. Persistent pollutants, such as metals, synthetic organic compounds, and PHCs also enter the Bay through direct WWTF discharge and riverine sources, but are also attributed to urban runoff. Sediments in the upper reaches of Narragansett Bay and its main-stem rivers contain some of the highest concentrations of persistent contaminants on record, yet due to current limited bioavailability, have limited immediate impacts on Bay life. They do, however, limit hydrologic restoration efforts, especially riparian restoration, due to the probability of resuspension.

The Narragansett Bay ecosystem has also responded to direct anthropogenic inputs and withdrawals of biota. Aquatic nuisance species, introduced primarily through fouling and bilge exhaust associated with the shipping trades, have been affecting trophic dynamics since the 1800s. Currently, exotic shellfish diseases are impacting economically important species, such as the American oyster. A long history of persistent fishing has also affected Bay ecology through direct extraction and ascending and cascading trophic consequences. Efficient, but sometimes destructive, modern fishing practices are thought to also directly degrade benthic systems.

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CHAPTER 13.

Research and Monitoring at the NBNERR

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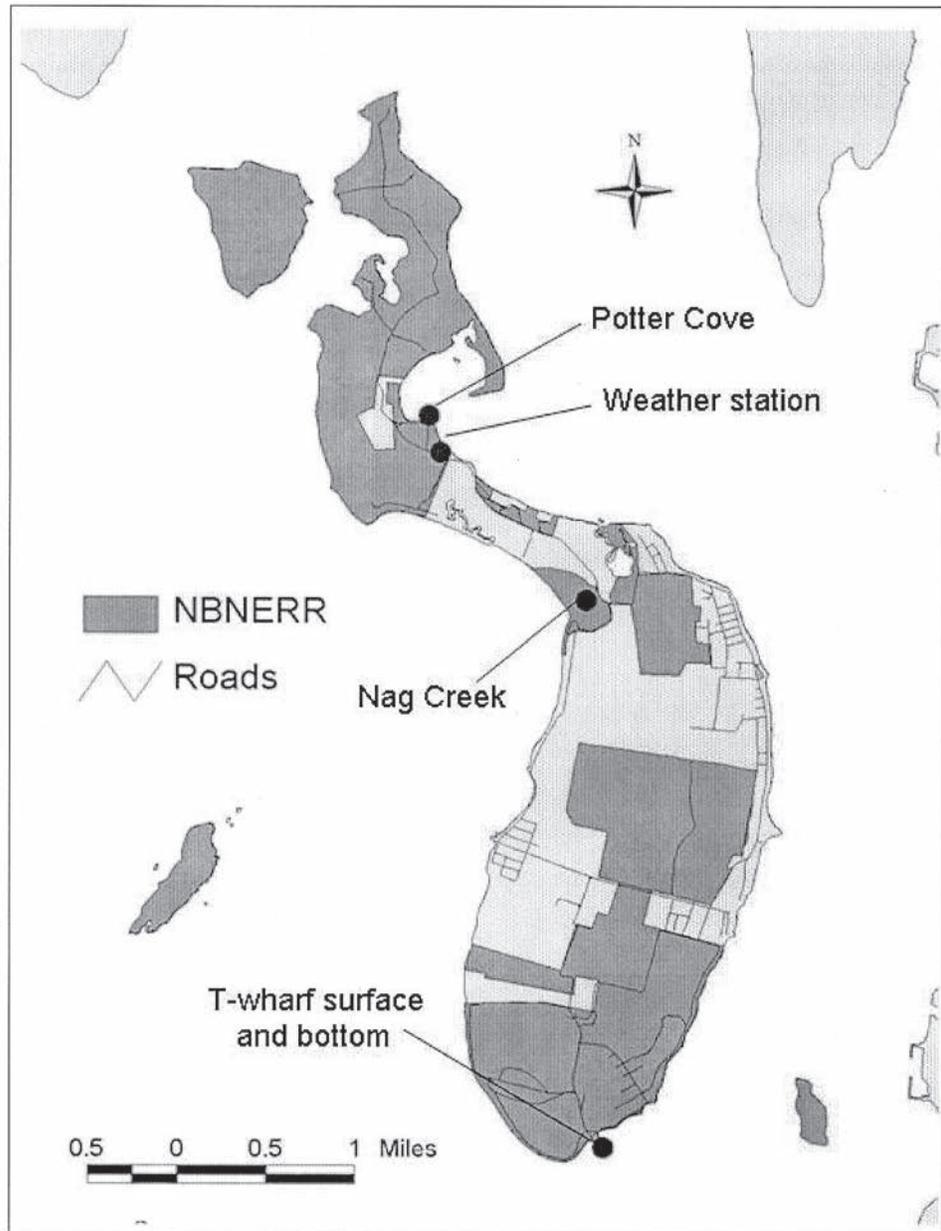


Figure 13.1. Locations of the NBNERR SWMP water quality and meteorological monitoring stations.

Figure 13.2. The System-Wide Monitoring Program at T-wharf on Prudence Island. Two water quality sondes are continuously deployed in PVC tubes extending into the Bay and data are transmitted near real time via telemetry. Nutrient and chlorophyll samples are also collected using the ISCO sampler shown here on the pier. Photo from NBNERR photo library.





Research and Monitoring at the NBNERR

One of the primary goals of the NERR System is to protect natural habitats that are representative of the biogeographic regions in which they are located in order to provide platforms for conducting estuarine research and monitoring. This vision is realized at the NBNERR, where research and monitoring is conducted by scientists from a variety of academic, government, nonprofit, and private institutions and by an active internal NBNERR research program. The Reserve provides financial support to two graduate students per year through the NERR Graduate Research Fellowship (GRF) program to conduct high-quality research in the Narragansett Bay watershed. Aside from this, the NBNERR does not provide financial assistance or funding to outside researchers to conduct research and monitoring. Instead, it provides information, collaboration, and logistical help to researchers working in the NBNERR and throughout Narragansett Bay (the NBNERR has a jurisdictional boundary out to the 5.4 m (18-foot) depth contour around its properties, but focuses its research and monitoring program throughout all of Narragansett Bay to address questions relevant to the current needs and issues facing the Bay and watershed). The work of visiting students and scientists is augmented by research and monitoring conducted by Reserve staff. Research at the NBNERR is directed by the Reserve's research coordinator, but is also conducted by other staff members that include water quality, natural resources, and GIS specialists, volunteers, and student interns.

The goal of this section is to provide an overview of all the research and monitoring activities that have taken place in, or have been associated with, the NBNERR since its inception. This includes national NERR programs (e.g., the SWMP), research and monitoring that is conducted by NBNERR staff scientists, and work done by visiting researchers who either conduct research directly in the NBNERR or are assisted in some way by the Reserve in their efforts elsewhere in Narragansett Bay and its watershed.

NERR Programs

System-Wide Monitoring Program

The primary long-term monitoring program at the Reserve is the SWMP. Nationally, the goal of SWMP is to track short-term variability and long-term change in estuarine water quality parameters. The first phase of this program is accomplished by

continuously deploying automated dataloggers at stations located strategically around each Reserve in the NERR System. As the NERR program has grown so has the SWMP, which has undergone systematic expansion and enhancement since 1992 (Ross, 2003). At the NBNERR, the SWMP began in 1995 with the deployment of Yellow Springs Instruments' (YSI) water quality sondes at Potter Cove and T-wharf, both located on Prudence Island (Fig. 13.1). These two sites were selected in accordance with NERR guidance that recommended the selection of one site in an impacted area (i.e., Potter Cove) and one in a relatively pristine area (i.e., T-wharf). In 2001, the SWMP was expanded by adding two more water quality monitoring sites to each Reserve. At the NBNERR, one additional site was added in a salt marsh creek in Nag West Marsh, and the fourth site was established at T-wharf (Fig. 13.1). It was determined that the original T-wharf station was situated in the immediate region of the pycnocline that seasonally occurred at this site. This led to a confounding situation where data were sometimes collected from distinct layers either above or below the pycnocline depending on season and tide stage. In order to collect discrete datasets from both the surface and bottom water layers at T-wharf to examine stratification patterns, the original site was abandoned and moved further out on T-wharf where the water is deeper. At this new site, two sondes are maintained, one each in the surface and bottom layers (Fig. 13.2). The original T-wharf station was maintained for approximately two weeks after establishing the new surface and bottom stations in order to collect overlapping data for comparing new and old stations.

The rationale for the current distribution of SWMP stations at NBNERR is to collect data along a gradient in habitat types, from salt marsh (Nag Creek) to shallow cove (Potter Cove) to open Bay water (T-wharf surface and bottom). Each sonde collects data every 15 minutes on water temperature, salinity, depth, dissolved oxygen, turbidity, and pH. In addition, a chlorophyll sensor (which is not required for the national SWMP program) was added to the T-wharf surface sonde in January 2003 and to the remaining three stations in June 2003.

In 2002, the national SWMP program was expanded again when dissolved nutrient and chlorophyll monitoring was initiated at each NERR site (Ross, 2003). Each site began collecting nutrient and chlorophyll data using replicated water grabs once per month from each of the four water quality monitoring stations. In addition, one site was selected



where the same data would be collected approximately every two hours over a 24-hour period using an automated ISCO (Teledyne ISCO, Inc.) sampler. Thus, this program was designed to capture data that reflect spatial, seasonal (using the monthly grabs at four stations), and diel (using the ISCO sampler) patterns. The NBNERR began collecting monthly nutrient and chlorophyll samples in March 2003 from each of the four water quality stations, and ISCO samples from T-wharf bottom in August 2003.

A complement to the SWMP water quality monitoring effort is the concurrent collection of meteorological data from at least one weather station at each NERR site. The rationale for this is that some patterns and trends observed in water quality parameters could potentially be explained or related to meteorological patterns. At the NBNERR, equipment was purchased to establish a Campbell weather station near Potter Cove in 1996 (Fig. 13.1). However, the regular collection of all meteorological data did not occur until February 2002. Since then, air temperature, relative humidity, barometric pressure, wind speed and direction, ambient solar radiation (PAR), and precipitation have been collected nearly continuously.

All water quality and meteorological data are passed through rigorous standardized quality control measures, first at the NBNERR and later through the Centralized Data Management Office (CDMO), a group located at the North Inlet-Winyah Bay NERR in South Carolina that oversees and manages all SWMP data collected by NERR sites. Once data have passed quality control, they are posted on the Internet at www.nerrs.noaa.gov/Monitoring/Water.html and are available for user download. More recent data that have not been posted on the web can be requested directly from the NBNERR research coordinator. In addition, data from the T-wharf bottom water quality station and the weather station are now equipped with near real-time telemetry capabilities, and these data can be viewed on the Internet at www.weather.gov/oh/hads.

NBNERR SWMP data are actively downloaded from the Internet and requested from the Reserve for a variety of purposes. For example, a graduate student from Brown University has used NBNERR SWMP data in his efforts to examine the relationship between dissolved oxygen levels in Narragansett Bay and blue mussel mortality, a relationship that ultimately affects multiple estuarine trophic linkages. A professor from Roger Williams University in Bristol, R.I., has requested salt marsh SWMP data for use in a marine ecology undergraduate course. In addition, the RIDEM recently used SWMP data from both Potter Cove and T-wharf to help determine the extent of a recent anoxic event in

nearby Greenwich Bay that killed over one million estuarine fish, mostly Atlantic menhaden.

Graduate Research Fellowship Program

As of 2008, the NBNERR has supported the research of seven graduate students with funding through the GRF Program. Four of these fellows have come from Brown University and the other three from the University of Rhode Island (Fig. 13.3). These students have conducted research on a wide range of topics, including the ecology of cobble beach plant communities, the ecology of migratory sharp-tailed sparrows, salt marsh trophic dynamics, and the effects of winter water temperatures on the ecology of ctenophores in Narragansett Bay.

The first NBNERR GRF fellows were John Bruno from Brown University and Deborah DiQuinzio from the University of Rhode Island, both of whom received their initial funding in 1997. Bruno's research investigated various aspects of the ecology of cobble beach plant communities in Narragansett Bay. The first part of his research found that fringing *Spartina alterniflora* beds along cobble beach shorelines facilitate the formation of diverse plant assemblages behind them (Bruno, 2000). These communities formed because the *S. alterniflora* beds reduced water flow velocity and stabilized the substrate, enabling other plant seedlings to survive. Further research showed that the relationship between the foundation *S. alterniflora* beds and the cobble beach plant communities behind them depended on the size of the *S. alterniflora* bed. Most beds were less than 30 m in length and did not support any cobble beach plant species (Bruno and Kennedy, 2000). There was a strong, positive correlation between *S. alterniflora* bed size and cobble beach plant species richness, due to the fact that longer beds reduced wave-related disturbance more than shorter beds.

DiQuinzio's research as an NBNERR GRF focused on the ecology of the salt marsh sharp-tailed sparrow in Rhode Island salt marshes. More specifically, her research examined sharp-tailed sparrow site fidelity patterns, return rates, survival rates, and movement patterns among salt marshes in Rhode Island. This work showed that sharp-tailed sparrows exhibited moderate breeding site fidelity and strong natal philopatry in Rhode Island (i.e., these birds showed a strong tendency to return to breed within their natal home range) (DiQuinzio et al., 2001). Further research examined the nesting ecology of sharp-tailed sparrows in a tide-restricted salt marsh in southern Rhode Island compared to



unrestricted marshes elsewhere, including in the NBNERR. From this work it was shown that salt marsh sharp-tailed sparrows tended to nest in short grasses, including salt marsh hay (*Spartina patens*), short cordgrass (*S. alterniflora*), and short common reed (*Phragmites australis*). After restoration of the tide-restricted site, 91 percent of nests failed due to increased tidal flooding, indicating that restoration efforts may have short-term negative impacts on sharp-tailed sparrow populations (DiQuinzio et al., 2002).

The next two fellows, Brian Silliman and Andrew Altieri, were both from Brown University. Silliman was funded from 2000 to 2002 and Altieri from 2001 to 2003. Silliman's research focused on investigating the degree to which top-down and bottom-up forces control the structure of salt marsh plant communities at different latitudes. This included conducting similar studies in both the NBNERR in Narragansett Bay and at the Sapelo Island NERR in Georgia. A major finding from this work was that top-down forces have a significant effect on salt marsh plant assemblages and on primary production of salt marshes at lower latitudes; in other words, a trophic cascade in these southern marshes was revealed (Silliman and Bertness, 2002). More specifically, Silliman discovered that when top predators in Georgia salt marshes (e.g., the blue crab, *Callinectes sapidus*) were excluded from the marsh, predation pressure on a primary grazer (the snail, *Littorina littorea*) was relieved, resulting in significant effects on the biomass and production of *S. alterniflora*. The same result was not observed further north in the NBNERR where an abundant predator (the mummichog, *Fundulus heteroclitus*) was excluded from Rhode Island salt marsh habitats. Here, top down forces were less important and instead coastal eutrophication is driving shifts in

salt marsh plant assemblages. This work illustrates the power of using multiple NERR sites at different locations and latitudes to investigate the applicability of research results to different areas.

Altieri's research focused primarily on investigating the effects of hypoxia on the blue mussel in Narragansett Bay. One impetus for this research was a large die-off of the mussel in Narragansett Bay that coincided with hypoxic events during the warm summer months of 2001. Events such as this have the potential to severely alter the community structure and function of the benthic communities in estuaries such as Narragansett Bay. Part of Altieri's research examined this in more detail and used laboratory experiments to quantify the tolerance of three important bivalve species to low dissolved oxygen levels. This work found that mortality of blue mussel, quahog, and soft-shelled clam differed in response to varying levels of hypoxia. For example, 50 percent mortality was observed at three, seven, and 19 days for blue mussel, soft-shell clam, and quahog, respectively. This clearly shows that blue mussel is the most susceptible of the three species to hypoxic events in Narragansett Bay, which typically last up to five days. Using field experiments, Altieri further illustrated that hypoxia resulted in reduced blue mussel growth rates, higher mortality among larger individuals, and reduced mussel density and cover (Altieri and Witman, 2006). This in turn resulted in a greater than 75 percent reduction of the planktonic filtration capacity of mussels in Narragansett Bay. Thus, Altieri found that hypoxia greatly impacts the blue mussel and its ability to filter the Bay and ultimately results in a reduced capacity to control future eutrophication and hypoxia.

The next student, Hao-Hsien (Howard) Chang from URI received three years of funding beginning in 2005. Chang's research focused on exploring the effects of winter temperatures in Nar-



Figure 13.3. The NBNERR supports and funds graduate student research through the NERR GRF program. Two of the fellows include (left photo) John Bruno from Brown University, who studied the ecology of cobble beach plant communities; and (right photo) Deborah DiQuinzio from URI, who studied sharp-tailed sparrows (shown here with other URI researchers). Photos from NBNERR photo library.



rangansett Bay on the timing and size of ctenophore (*Mnemiopsis leidyi*) blooms. Ctenophores exhibit top-down control over estuarine processes in Narragansett Bay through direct predation on zooplankton. In recent years, the onset of ctenophore blooms has been occurring earlier, and the bloom size greater, in response to warming water temperatures. It is therefore critical to understand how minimum winter water temperatures affect the timing and size of the blooms of this important estuarine trophic component. Chang explored these relationships through a suite of laboratory and field methods.

The two current fellows are Keryn Bromberg from Brown University and Elizabeth DeCelles from URI. Bromberg's research focuses on determining the effects of anthropogenic stressors on salt marsh plant biodiversity. Forbe habitats—a diverse group of plants in the high salt marsh zone—have largely disappeared from southern New England, and Bromberg is examining the individual and combined effects of climate change and mosquito ditching on this habitat. DeCelles is currently conducting research into the function of tide-restricted and restored salt marshes as foraging habitats for wading birds in Narragansett Bay. DeCelles will also examine regurgitation samples from egrets and cormorants from islands in Narragansett Bay to determine, for the first time, the birds' specific foraging habits in the Bay.

CICEET

The Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) was established jointly between NOAA and the University of New Hampshire for the purpose of funding research at the 27 NERR sites to develop and apply new technologies in estuarine environments. The link between CICEET and the NERR System is logical in that CICEET aims to fund projects that develop technologies essential for managing estuarine environments while the NERR System aims to promote research and monitoring activities that lead to better estuarine resource management. In order to be considered for CICEET funding, all principal investigators must first contact the individual NERR site(s) where they propose to conduct research in order to discuss the project and find ways that the NERR site can assist in study design and implementation. From 1998 through the spring of 2006, 19 research projects at the NBNERR have been funded through the CICEET program at a total funding level of almost \$4.2 million (Table 13.1). Thirteen different principal investigators have

been or are currently conducting the 19 projects, 12 of which are completed, with the remaining seven still ongoing. These projects are predictably diverse and include efforts to develop in situ methods for treating PCBs in marine and freshwater sediments, determine relative eutrophication of coastal embayments using aerial video imagery, and develop a mechanical seeding apparatus for seeding large areas with eelgrass. Details of each research project are not provided here, but Table 13.1 provides current citations and further information on each project can be found at ciceet.unh.edu.

Monitoring

Additional long-term monitoring, both biotic and abiotic, is carried out throughout Narragansett Bay by a variety of agencies and investigators. A summary of monitoring activities in Rhode Island and Narragansett Bay was recently compiled into a database following a Rhode Island monitoring workshop and is listed at www.ci.uri.edu/Projects/mon_ind/RPT_Brief/Brief.html. Table 13.2 shows an abridged list of programs listed in this database that are relevant to the NBNERR, including all programs in Narragansett Bay and upland and freshwater programs that address issues faced by the NBNERR.

Some of these long-term monitoring programs, particularly the ones operated by RIDEM, have stations located within the estuarine boundaries of the NBNERR (Table 13.3). For example, the RIDEM fish trawl survey has 12 stations (out of a total of approximately 265 in Narragansett Bay) located within the Reserve's estuarine boundary. Similarly, the RIDEM juvenile finfish seine survey has two stations located in the NBNERR (out of 20 located around the Bay). Every year since 1964, RIDEM monitors the number of coastal bird nests throughout Rhode Island, and two of these sites are located within the NBNERR. Other notable monitoring programs that have stations within the Reserve are the annual seal counts conducted by Save The Bay, annual waterfowl surveys conducted by EPA, Prudence Island white-tailed deer surveys conducted by RIDEM, and ichthyoplankton surveys conducted by URI and RIDEM.

Additional monitoring programs are now being conducted by the NBNERR (Table 13.3). Notable among these efforts is the ecological monitoring of a recent restoration at Potter Pond salt marsh, along with simultaneous monitoring at Coggeshall salt marsh in the North Prudence Unit that serves as an experimental control. This monitoring began in 2000 before restoration in early 2003, and will continue at varying frequencies, indefinitely. Data

**Table 13.1.** CICEET research projects in the NBNERR.

Principal Investigator	Research Project	Years	Funding
Richard Crawford, WHOI	Assessing relative eutrophication of coastal embayments with calibrated aerial video imagery	1998–ongoing	\$199,722
Taylor Eighmy, UNH	Phosphate-based heavy metal stabilization technologies for contaminated sediments and dredge material	1998–2001	\$251,796
Robert Costanza, University of Maryland	Sediment dynamics in tidal marshes: Functional assessment of accretionary biofilters	1998–2001	\$199,432
Scott Nixon, URI	Density-dependent effect on grazing and success of seed-generated seagrass plants	1998–2001	\$211,462
John King, URI	Developing and applying a new <i>in situ</i> technology for the investigation of episodic contaminant transport events within estuaries	1999–2002	\$260,762
Kevin Gardner, UNH	Development of reuse alternatives for the management of dredged, contaminated sediments	2000–2002	\$220,321
John King, URI	Developing and applying a new <i>in situ</i> technology for the investigation of episodic contaminant transport events within estuaries (II)	2001–2002	\$103,443
Scott Nixon, URI	The mechanical seeding of marine sediments for the restoration of <i>Zostera marina</i> L. habitat	2001–2004	\$204,631
Taylor Eighmy, UNH	Pilot-scale reactive barrier technologies for containment of contaminated sediments and dredged materials	2001–2004	\$378,899
Kevin Gardner, UNH	<i>In situ</i> treatment of PCBs in marine and freshwater sediments using colloidal zero-valent iron	2001–2003	\$219,014
Frederick Short, UNH	Interactive GIS-based site selection model for eelgrass restoration on CD-ROM	2002–2004	\$223,468
David Smith, URI	Microbial source tracking using F-specific coliphages and quantitative PCR	2003–2006	\$173,441
Kevin Gardner, UNH	Polychlorinated biphenyl remediation in sediments: Pilot-scale demonstration	2003–ongoing	\$373,610
Scott Nixon, URI	Field plot demonstration project for large-scale restoration of eelgrass (<i>Zostera marina</i> L.) Using mechanical seeding apparatus	2003–2006	\$115,108
Jose Amador, URI	Evaluation of leachfield aeration technology for improvement of water quality and hydraulic functions in on-site wastewater	2004–ongoing	\$232,294
Thomas Mulcahy, NEIWPC	Presentation of nutrient pollutant load and source estimation model results for enhanced nutrient loading analyses of New England	2004–ongoing	\$159,348
Andrew Hong, University of Utah	<i>In situ</i> sediment ozonator (ISO) for remediation of PCB, PAH, and other recalcitrant chemicals	2004–ongoing	\$229,997
Alfred Hanson, URI	A new autonomous technology for monitoring microbial indicators of fecal contamination in coastal waters	2004–ongoing	\$199,460
Thomas Boving, URI	Field demonstration of wood filter technology for stormwater treatment	2005–ongoing	\$198,178
TOTAL			\$4,154,386

collected include water quality (using the same methods as described for the SWMP), vegetation (emergent and macroalgae), nekton, and birds. From 2003 to 2005, the NBNERR also conducted weekly driving surveys for target wildlife species, including large mammals, reptiles, raptors, and winter waterfowl, with the goal of quantifying the species composition, relative and seasonal abundances, and distribution of these species to promote more informed stewardship and management decisions (Raposa and Rehor, 2004). Other recent NBNERR efforts on Prudence Island include monitoring of breeding songbirds, spotted salamander egg masses, the distribution and area of fringing salt marshes, osprey and barn swallow nesting success, and upland vegetation communities in multiple habitats in the South Prudence pine barrens.

Research

As described above, the NBNERR was established to provide an ideal setting for conducting coastal and estuarine research, and it provides support in a variety of ways to fulfill this function. Until recently, the Reserve only supported research efforts that were conducted within the 5.4 m depth boundary of the Reserve around Prudence, Patience, Hope, and Dyer islands. A broader, more holistic

approach that focuses on all of Narragansett Bay and its watershed was adopted to expand the amount of research conducted and supported by the NBNERR in Narragansett Bay. It is hoped that the new approach will better incorporate the NBNERR into the local and regional scientific community and more effectively promote quality research in Narragansett Bay and its watershed.

As with monitoring, research in the NBNERR is conducted by both visiting researchers and by the NBNERR itself, and it addresses a wide variety of topics (Fig. 13.4). Much of the work by visiting researchers has been funded and promoted by the NERR GRF program and CICEET. However, the NBNERR has also attracted visiting researchers that have not received funding from these programs. This includes researchers from Brown University, URI, EPA, the Smithsonian Institution, the Lloyd Center, Roger Williams University, the University of Houston, and Save The Bay, among many others. As is the case with research funded through CICEET, there are too many projects conducted by visiting researchers to describe each one here. However, Appendix 13.1 provides basic information on these research efforts, many of which are detailed in the appropriate sections elsewhere in this document.

In the future, the NBNERR research and monitoring program will continue to include projects conducted by staff as well as visiting researchers. On the terrestrial side, there will be an enhanced



Table 13.2. Monitoring programs conducted in and around Narragansett Bay, including upland programs relevant to the resources of the NBNERR. Most data are from a Rhode Island monitoring database located at www.ci.uri.edu/Projects/mon_ind/RPT_Brief/Brief.html.

Agency	Monitoring Program
Barrington Land Conservation Trust	Diamondback terrapin population study
Brown University	Barrington River and Palmer River monitoring
EPA	Coastal 2000/EMAP Winter waterfowl monitoring
EPA Atlantic Ecology Division (AED)	Aircraft remote sensing for chlorophyll a Amphipod population studies
Jamestown Land Trust	Breeding and migratory bird monitoring
Narragansett Bay Commission	Providence, Seekonk, and Ten Mile rivers water quality monitoring Regional river fecal monitoring
NBEP (multiagency)	Volunteer dissolved oxygen night survey
NBNERR	SWMP water quality monitoring SWMP nutrient monitoring SWMP meteorological monitoring
NOAA	National Status and Trends Program PORTS
NOAA Fisheries	NOAA Restoration Center programs
NOAA Fisheries; NOAA Cooperative Marine Education and Research Program (CMER); Rhode Island Sea Grant	Lobster tagging program
NOAA; NBNERR; EPA; RIDEM; URI Pokanoket Watershed Alliance	Narragansett Bay Window monitoring
RIDEM	Runnins River monitoring Rhode Island shellfish disease survey American shad and river herring monitoring Air quality monitoring Aquatic furbearer surveys Artificial substrate monitoring Biotoxin shellfish poisoning sampling Maritime bird nest count monitoring Baseline water quality monitoring in Rhode Island Coastal pond finfish monitoring Freshwater fish surveys Gill net pelagic fish monitoring Sport fish trawl monitoring Juvenile finfish seine monitoring Lobster fishery monitoring Rapid bioassessment protocol monitoring Shellfish growing area monitoring Shellfish shoreline monitoring Summer Canada geese monitoring Upland game monitoring Waterfowl surveys
RIDEM; URI GSO	Ichthyoplankton monitoring
R.I. Department of Health	Beach water quality monitoring Drinking water monitoring Coastal lagoon water quality monitoring
Rhode Island Sea Grant	Impacts of ctenophores on ichthyoplankton
Rhode Island Sea Grant; Brown University	Salt marsh plant community status and monitoring
Rhode Island Sea Grant; RIDEM	Larval lobster settlement index
Rhode Island Sea Grant; CMER	Lobster shell disease program
Rhode Island Sea Grant (multiagency lead)	Rapid assessment survey for marine bioinvasives
Rhode Island Surfrider Foundation Save The Bay	Rhode Island coastal beach water quality monitoring Salt marsh, eelgrass, herring run, horseshoe crab, seal, and other monitoring
The Nature Conservancy—Rhode Island	Rhode Island odonata atlas
URI; RIDEM	Galilee salt marsh restoration and bird monitoring Pond breeding amphibian monitoring
URI; ASRI	Fall migratory bird monitoring in Kingston
URI Cooperative Extension	URI Watershed Watch (surface water quality)
URI Geosciences (multiagency lead)	Long-term beach profile monitoring
URI Natural Resources Science	Water table levels in southern Rhode Island forested wetlands
URI GSO	Narragansett Bay benthic infauna monitoring Pollution, circulation, and habitat monitoring in coastal ponds Water column nutrients Narragansett Bay phytoplankton monitoring
U.S. Fish & Wildlife Service; URI	Avian productivity and survivorship monitoring
U.S. Army Corps of Engineers	Disposal area monitoring system
U.S. Department of Agriculture APHIS	CAPS survey to detect invasive species
U.S. Geological Survey	National water quality assessment program
WHOI Sea Grant	Rocky shore intertidal crab monitoring



Table 13.3. Monitoring programs conducted by the NBNERR or within the NBNERR by other agencies.

Agency	Monitoring Program
EPA AED	Aircraft remote sensing for chlorophyll <i>a</i> Winter waterfowl monitoring Coastal 2000/EMAP
NOAA	PORTS
NOAA Fisheries	NOAA Restoration Center programs—oyster restoration
NBNERR	SWMP water quality monitoring SWMP nutrient monitoring SWMP meteorological monitoring Salt marsh monitoring Wildlife driving surveys Salamander monitoring Spotted salamander egg mass monitoring Upland vegetation monitoring Osprey and barn swallow monitoring Land cover mapping
RIDEM	Maritime bird nest count monitoring Freshwater fish surveys Sport fish trawl monitoring Juvenile finfish seine monitoring Upland game monitoring (deer) Breeding bird and owl surveys
RIDEM; URI GSO	Ichthyoplankton monitoring
Rhode Island Sea Grant; Brown University	Salt marsh plant community status and monitoring
Save The Bay	Salt marsh, eelgrass, herring run, horseshoe crab, seal, and other monitoring
The Nature Conservancy—Rhode Island	Rhode Island Odonata atlas

focus on examining the ecology of the Reserve's islands from an ecosystem perspective—important in light of ongoing and future land management practices as well as the emergence of a new top predator (coyote; Chapter 6) on Prudence Island. Some specific terrestrial needs at the Reserve include more frequent monitoring of white-tailed deer populations, upland vegetation, and tick populations, and research into the ecology and effects of coyote immigration. There is also a need to monitor hydrologic parameters on Prudence Island, including wetland water levels, groundwater, and stream flows, and to understand the effects of increasing residential development and subsequent water demand on these parameters (although the NBNERR stewardship program has begun to address these needs).

In estuarine habitats of the Reserve, a continued focus on understanding how salt marsh systems and processes are responding to local and large-scale human-related changes is essential. In addition, the NBNERR must begin a comprehensive baseline monitoring program in its salt marshes, which are in a relatively natural state in comparison to many marshes in Narragansett Bay. There is a continuing need for baseline ecological data (e.g., vegetation, nekton, water quality, birds) from unrestricted (i.e., no barriers to tidal flow) salt marshes in New England, and the NBNERR is in prime position to address this need. Two additional estuarine research needs of particular importance to the Reserve are the mapping of subtidal soils and habitat types and the monitoring and quantification of ephemeral drift macroalgal populations in Narragansett Bay.

More specific research and monitoring needs in both terrestrial and estuarine habitats at the NBNERR include:

Terrestrial

- Detailed maps of ponds, streams, and vernal pools in NBNERR and on Prudence Island
- Effects of invasive species on forested wetland habitats in NBNERR
- Ecological effects of restoration of pine barren habitats
- Additional surveys of Lepidoptera on Prudence, Patience, Hope, and Dyer islands
- Inventory of invertebrate faunal groups on Prudence, Patience, Hope, and Dyer islands
- Institutionalization of NBNERR long-term tick monitoring, and reestablishment of human serological testing for tick-borne diseases
- Herpetofaunal use of Patience, Hope, and Dyer islands
- Breeding bird surveys on Patience, Hope, and Dyer islands
- Syntheses of existing data from NBNERR breeding bird monitoring program, including comparisons with other nearby stopover sites (e.g., Block Island, R.I.)
- Ecology of white-tailed deer (*Odocoileus virginianus*) and the ecological effects of recent reductions in deer abundance on Prudence Island
- Top-down ecological effects of the emergence of coyotes (*Canis latrans*) as a top predator on Prudence Island



- Ecological effects of NBNERR land management practices, such as controlled burns, woodcutting, and invasive species control, on invertebrate species of concern (e.g., tiger beetles), herpetofauna, mammals, and other flora and fauna
- Mapping and monitoring of rare plant and invasive species distributions
- Complete species inventories of individual Reserve parcels

Estuarine

- Ecosystem responses to nutrient reduction efforts in Narragansett Bay, including effects on phytoplankton dynamics
- Enhanced spatial resolution of ongoing water quality monitoring programs in the Bay
- Additional mapping and monitoring of eelgrass cover, distribution, and health over time in Narragansett Bay
- Ecological effects of efforts to transplant and restore eelgrass to the Bay
- Ecological effects of efforts to restore tidal flow to salt marshes
- Restoration of shallow pool habitats to ditched salt marshes in Rhode Island, and effects of pool restoration on fishes and estuarine birds
- Fisheries use of eutrophic areas of upper Narragansett Bay, and effects of recurring hypoxia on fish populations in Greenwich Bay and other impacted areas
- Ecology of abundant estuarine birds, such as cormorants, gulls, terns, and shorebirds in Narragansett Bay
- Factors affecting recent declines in nesting wading birds at heronries in the Bay

- Syntheses of NBNERR SWMP data, including water quality, meteorological, and nutrient data
- Ecological impacts of estuarine invasive species in Narragansett Bay
- Ecological responses to large-scale changes in climate, such as warming water temperature and sea-level rise
- Identification and modeling of primary factors that affect fisheries, productivity, and water quality

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a.



b.



c.

Figure 13.4. The NBNERR attracts and supports researchers from throughout the Rhode Island scientific community and beyond. Some examples include (a) Brown University (Mark Bertness); (b) URI (Grace Klein-MacPhee (center)); (c) EPA (James Latimer); and NBNERR staff (Matthew Rehor) (bottom photo, page 163). *Photos from NBNERR photo library.*



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Appendix 13.1. NBNERR Research and Survey Projects

Research and survey projects conducted in or by the NBNERR, excluding GRF and CICEET research. This includes projects conducted entirely in the NBNERR and those that were larger in extent but included stations within the NBNERR. All known projects at the NBNERR are listed, but those resulting in a publication in a peer-reviewed scientific journal are italicized and cited.

Principal Investigator	Affiliation	Research Project/Publication	Project Years
Adamowicz, S.	URI	New England salt marsh pools: Analysis of geomorphic and geographic parameters, macrophyte distribution, and nekton use	1999–2000
Alberti, M.	URI	Evaluation of community assemblages and habitat use by odonate nymphs in highly anthropogenic wetland systems on Prudence Island and Block Island, R.I.	2004–2005
Anderson, J. et al.	Connecticut Agricultural Experiment Station	<i>Prevalence of Borrelia burgdorferi and Babesia microti in mice on islands inhabited by white-tailed deer</i>	1984–1987
Armstrong, P.	Harvard School of Public Health	Pathogen diversity at the tick-human interface	1998
Auker, L.	URI	The effects of the invasive colonial tunicate <i>Didemnum</i> sp. on native species in Narragansett Bay	2005
Bertness, M. and Pennings	Brown University	Climate-driven processes and patterns in northern Atlantic salt marshes	1998–2003
Bertness, M. et al.	Brown University	<i>Anthropogenic modification of New England salt marsh landscapes</i>	2002
Bertness, M. et al.	Brown University	Will eutrophication help marshes keep up with sea level rise?	2003–ongoing
Bertness, M. et al.	Brown University	<i>Salt marshes under seige</i>	2004
Bertness, M. et al.	Brown University	The role of climate in regulating the primary productivity, abundance, and distribution of salt marsh plants	2005–ongoing
Bricker-Urso, S. et al.	URI	<i>Accretion rates and sediment accumulation in Rhode Island salt marshes</i>	1989
Bromberg, K. and M. Bertness	Brown University	Elucidating the history of human modification of New England salt marshes and the consequences of human disturbance on services provided by salt marshes	2005–ongoing
Bruno, J.	University of North Carolina-Chapel Hill	Metapopulation dynamics of the cobble beach plant community	1997–2005
Carroll, M.	URI	<i>Distribution of Ixodes dammini (Acari: Ixodidae) in residential lawns on Prudence Island, Rhode Island</i>	1991
Casagrande, R.	URI	Evaluation of native and exotic <i>Phragmites australis</i> and associated herbivores	2003–2006
Cicchetti, G.	EPA AED	Contributions of estuarine habitats to the ecological function and integrity of a small cove	1999–2001
Craig, N.	URI	Growth of the bivalve <i>Nucula annulata</i> in nutrient-enriched environments	1994
Crain, C.M. and M.D. Bertness	Brown University	<i>Ecosystem engineering across environmental gradients: Implications for conservation and management</i>	2006
Crain, C.M. et al.	Brown University	<i>Physical and biotic drivers of plant distribution across estuarine salinity gradients</i>	2004
Davis, J. et al.	EPA AED	<i>Denitrification in fringing salt marshes of Narragansett Bay, Rhode Island, USA</i>	2004
Donnelly, J. and M. Bertness	Brown University	<i>Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise</i>	2001
Dorf, B. and C. Powell	URI and RIDEM	<i>Distribution, abundance, and habitat characteristics of juvenile tautog (Tautoga onitis, family Labridae) in Narragansett Bay, Rhode Island, 1988–1992</i>	1988–1992
Dyrman, S. and B. Palenik	Scripps Institution of Oceanography	<i>Phosphate stress in cultures and field populations of a dinoflagellate Prorocentrum minimum detected by a single-cell alkaline phosphate assay</i>	1999
Ebel, G. et al.	Harvard School of Public Health	<i>Enzootic transmission of deer tick virus in New England and Wisconsin sites</i>	2000
Emery, N. et al.	Brown University	<i>Competition and salt-marsh plant zonation: Stress tolerators may be dominant competitors</i>	2001
Enser, R.W.	R.I. Natural Heritage Program	The breeding birds of Prudence Island	1990
Fonseca, M.	NOAA-Beaufort, NC	<i>World Prodigy</i> eelgrass planting project: Narragansett Bay, RI	1996–2000
Fraher, J.	URI	Atmospheric wet and dry deposition of fixed nitrogen to Narragansett Bay	1991
Halpin, P.	Brown University	Patterns and determinants of intertidal habitat use in the mummichog, <i>Fundulus heteroclitus</i>	1991–1994
Ho, C.	University of Houston	Using the NERR system to explore plant-herbivore interactions: Latitudinal variation and impacts of climate change	2004–2006
Hu, R.	URI	Identification of the wasp parasitoid of the deer tick, <i>Ixodes dammini</i> , in Rhode Island and its implication in the control of Lyme disease	1990
Hyland, K.	URI	Ticks and tick-borne diseases in Rhode Island: Assessment of risks and other epizootiologic considerations	1989/1990
Jivoff, P.	Smithsonian Institution	Factors regulating the local and regional distribution of green crabs along eastern North America	2001–002



Appendix 13.1. Continued

Kerber, J. and B. Leudtke	Brown University and University of Massachusetts-Boston	Technical report on a prehistoric survey of Prudence Island, RI	1981
Klein-MacPhee, G. and E. Durbin	URI	An ichthyoplankton survey of Narragansett Bay with emphasis on the NERR	1990–91
Krause, P. et al.	University of Connecticut School of Medicine	<i>Increasing health burden of human babesiosis in endemic sites</i>	2003
Kutcher, T.	URI, NBNERR	Habitat classification and inventory for the Narragansett Bay National Estuarine Research Reserve	2003–2004
Kutcher, T. and K. Raposa	NBNERR	An analysis of the vegetative composition of an Atlantic coastal pitch pine barren	2005
Latimer, J. and J. Quinn	EPA, URI	Organic contaminant flux to Narragansett Bay from wet deposition samples collected at Prudence Island meteorological station	1991–92
Latimer, J.	URI	Wet deposition of organic contaminants to the coastal marine environment	1994
Mather, T. and M. Mather	Harvard School of Public Health	<i>Intrinsic competence of three ixodid ticks (Acari) as vectors of the Lyme disease spirochete</i>	1990
McKinney, R.	EPA, URI	Assessing the effects of habitat alteration on wildlife: Utilization of coastal habitats by wintering waterfowl in Narragansett Bay	2002–ongoing
McLaughlin, M.	URI	Using GIS and hedonic analysis to measure the social benefits of improving environmental quality along the Providence River corridor	1996
Mello, M.	The Lloyd Center	Survey of Lepidoptera on Prudence Island, Rhode Island	2002
Meng, L. and C. Powell	EPA AED, RIDEM	<i>Linking juvenile fish and their habitats: An example from Narragansett Bay, Rhode Island</i>	1988–1996
Meng, L. et al.	EPA AED, RIDEM	<i>Using winter flounder growth rates to assess habitat quality across an anthropogenic gradient in Narragansett Bay, Rhode Island</i>	1998
Meng, L. et al.	EPA AED	Aquatic stressors justification for winter flounder habitat alteration—population response demonstration project	2002
Meng, L. et al.	EPA AED	<i>Nekton habitat quality at shallow water sites in two Rhode Island coastal systems</i>	2004
Nomann, B.	Brown University	The importance of plant-bacterial interactions for New England salt marsh dynamics	2004
Norris, A.	Roger Williams University	Nocturnal behavior of the harbor seal (<i>Phoca vitulina</i>) from Prudence Island, Rhode Island	2003–2004
Osenkowski, J.	URI	Avian community dynamics on and adjacent to Prudence Island, RI	1999
Oviatt, C. and S. Whitehouse	URI	The role of <i>Crangon septemspinosa</i> in Narragansett Bay Estuarine Sanctuary and the impact of pollution from the upper Narragansett Bay on the structure and function on the benthic infauna-Crangon demersal fish food chain	1987–88
Paton, P. et al.	URI	Avian community dynamics in the salt marshes of the Narragansett Bay National Estuarine Research Reserve, with emphasis on the salt marsh sharp-tailed sparrow (<i>Ammodramus caudacutus</i>)	1997–1999
Pennings, S. et al.	University of Houston	<i>Latitudinal differences in plant palatability in Atlantic coast salt marshes</i>	2001
Pennings, S.	University of Houston	Latitudinal variation in plant-herbivore interactions in coastal salt marshes	2002–2005
Rand, T.	Brown University	Interactive effects of multiple ecological factors on the distribution of halophytic forbs in New England salt marshes	1996–2000
Rand, T.	Brown University	<i>Effects of environmental context on the susceptibility of Atriplex patula to attack by herbivorous beetles</i>	1999
Raposa, K. and M. Chintala	NBNERR, EPA AED	Comparing Breder traps and bottomless lift nets for sampling nekton on vegetated salt marsh surfaces	2001–02
Raposa, K. and R. Weber	NBNERR	Water quality patterns among different salt marshes in Narragansett Bay, R.I.	2003–04
Raposa, K. and T. Kutcher	NBNERR	Habitat and home range of eastern box turtles on Prudence Island, Rhode Island	2005–06
Raposa, K. et al.	NBNERR	Using a survey to gauge public opinion on the status of the Prudence Island, R.I., deer herd	2003–04
Raposa, K. et al.	NBNERR	Ecological responses to restoration of Potter Pond salt marsh	2000–ongoing
Raposa, K. et al.	NBNERR, EPA AED	Bird and nekton use of salt marshes along a human-disturbance gradient	2005–ongoing
Richardson, K. and N. West	URI	Land cover/use study using Landsat Multispectral Scanner and Thematic Mapper data unsupervised classification	1988
Satchwill, R. et al.	RIDEM	Preliminary assessment of biological and physical characteristics of the Narragansett Bay Estuarine Sanctuary	1982–83
Schroeder, C.	URI	Population status and distribution of the harbor seal in Rhode Island waters	1996–1999

Appendix 13.1. Continued



Sedor, K.	Rhode Island Sea Grant, RIDEM	An investigation of the hydrology and hydraulics of the Nag Creek salt marsh system Prudence Island, Rhode Island	1994–1995
Shaughnessy, G. and F. Golet	RIDEM, URI	Inventory of upland and wetland habitats of the Narragansett Bay Estuarine Sanctuary	1983
Short, F. et al.	UNH	Eelgrass in estuarine research reserves along the East Coast, USA Part 1: Declines from pollution and disease	1993
Short, F. et al.	UNH	Eelgrass in estuarine research reserves along the East Coast, USA Part 2: Management of eelgrass meadows	1993
Smayda, T.	URI	Characterization of plankton dynamics and environmental properties within the Narragansett Bay Estuarine Sanctuary	1986–87
Stachiw, M.	R.I. Historical Preservation Commission	Historic sites archaeological survey of Patience and Prudence islands, Rhode Island	1981
Stabach, J.	URI	Salt marsh pool restoration	2004
Tallman, J.	URI	Assessing the value of shellfish aquaculture gear as fish habitat	2005
Telford, S. and P. Krause	Harvard School of Public Health; University of Connecticut School of Medicine	Epidemiological study of Prudence Island residents for Lyme disease, babesiosis, and ehrlichiosis	1994–2005
Thursby, G.	EPA AED	Development of a coastal wetland plant condition index	1999–2001
Tyrrell, T. et al.	URI	The economic importance of Narragansett Bay	1994
Tyrrell, T. and M. McLaughlin	URI	The economic contribution of water quality in the Narragansett Bay: Phase II downtown Providence development	1995
Urish, D.	URI	Groundwater availability on Prudence Island, Town of Portsmouth, Rhode Island	1992
Urish, D. et al.	URI	The ecological impact of the Prudence Island landfill on the Nag Creek marsh system	1992–93
Urso, S. and S. Nixon	URI	The impact of human activities on the Prudence Island Estuarine Sanctuary as shown by historical changes in heavy metal inputs and vegetation	1984
van de Koppel et al.	Brown University	<i>Scale-dependent interactions and community structure on cobble beaches</i>	2006
Van Wesenbeeck	Brown University	Landscape patterns in species interactions among halophytic plants	2005
Vigness-Raposa, K.	URI	Landcover map of Prudence Island, Rhode Island, from Landsat imagery	2004
Vigness-Raposa, K.	URI	The relationship of landscape composition to the distribution of birds on Prudence Island	2004
Wigand, C. et al.	EPA AED	<i>Denitrification enzyme activity of fringe salt marshes in New England (USA)</i>	2004
Wigand, C. et al.	EPA AED	<i>Response of Spartina patens to nitrogen and phosphorous additions in a field manipulative experiment</i>	2004
Zhioua, E.	URI	Biological control of the lone star tick, <i>Amblyomma americanum</i> , using entomopathogenic fungi	1997–2001