An Ecological Profile of the Narragansett Bay National Estuarine Research Reserve

Edited by Kenneth B. Raposa and Malia L. Schwartz

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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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Narragansett Bay Research Reserve

RI DEM

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OVER 100 YEARS OF EDUCATION, CONSERVATION, & ADVOCACY

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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 Fransisco 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.*

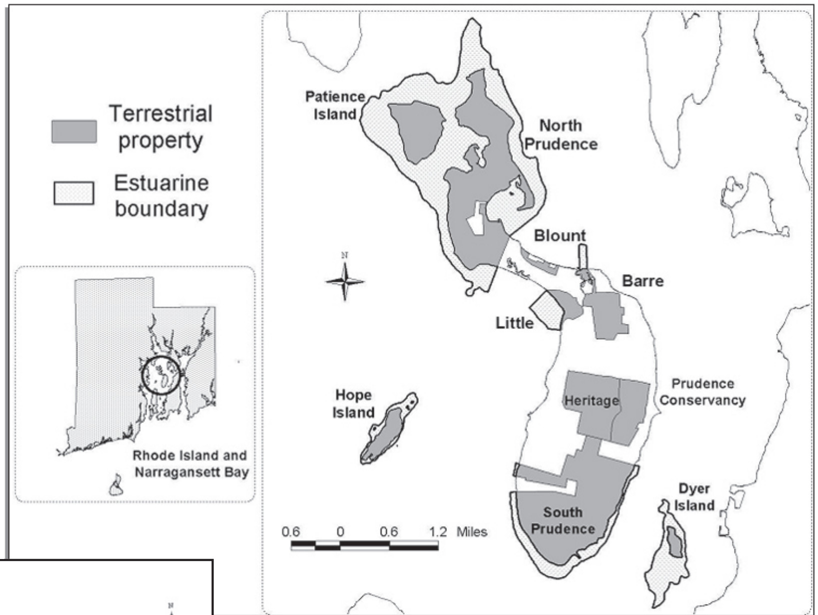

Figure 2.2. Estuarine boundary and terrestrial units of the NBNERR. *GIS data sources courtesy of the Rhode Island Geographic Information System (RIGIS; www.edc.uri.edu/rigis/).*

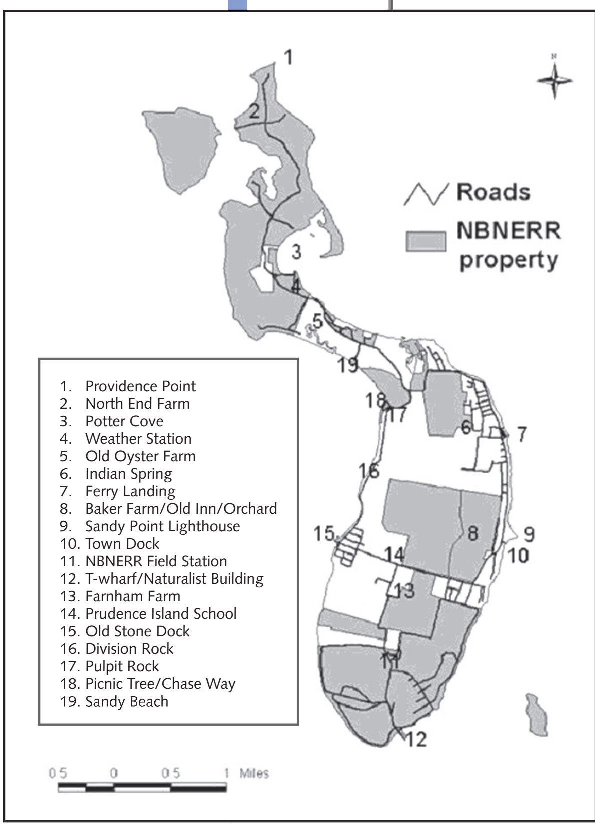

Figure 2.5. NBNERR facilities and other local points of interest on Prudence Island.

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 hierarchal 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

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.*

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*.

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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.

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 Revolutionary 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 successionally 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 cooking 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 Chibachuwesett 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 visitation 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 providing 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.

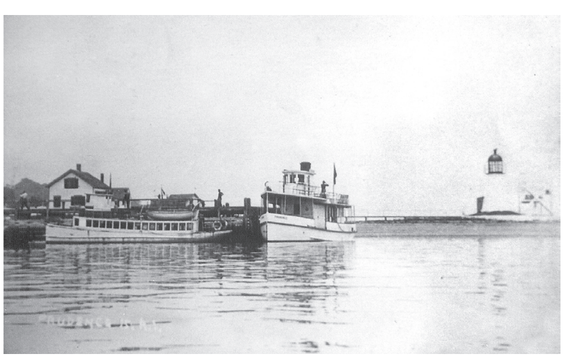

Figure 3.2. Early ferries, shown at the Sandy Point landing, made the development of the eastern shore of the island possible. *Postcard reproduction*.

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

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

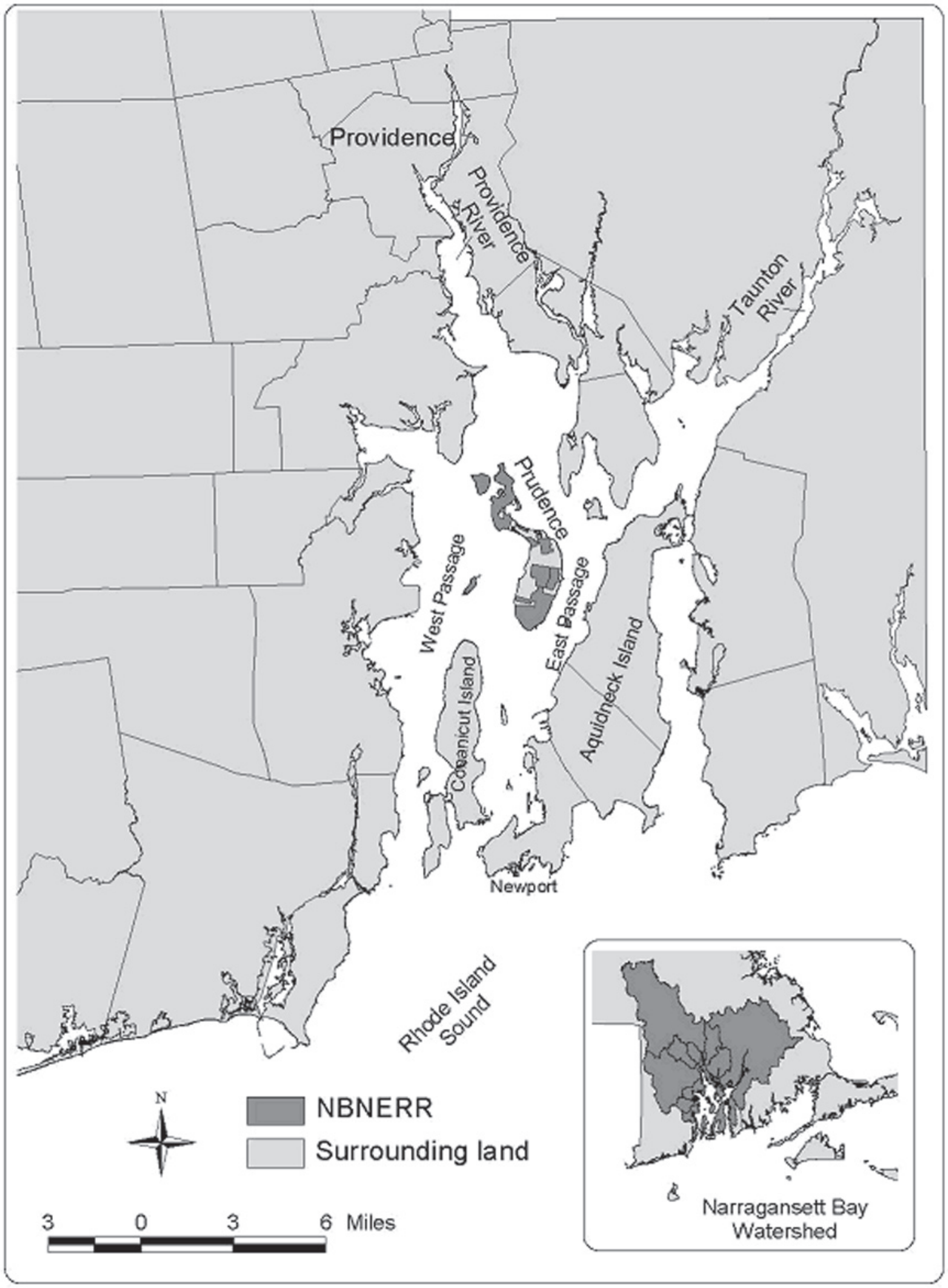

Figure 4.1. Geographic setting of the NBNERR, including the extent of the 4,818 km^2 (1,853-square-mile) Narragansett Bay watershed. *GIS data sources courtesy of RIGIS* (www.edc.uri.edu/rigis/) *and Massachusetts GIS* (www.mass.gov/mgis/massgis.htm).

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.*

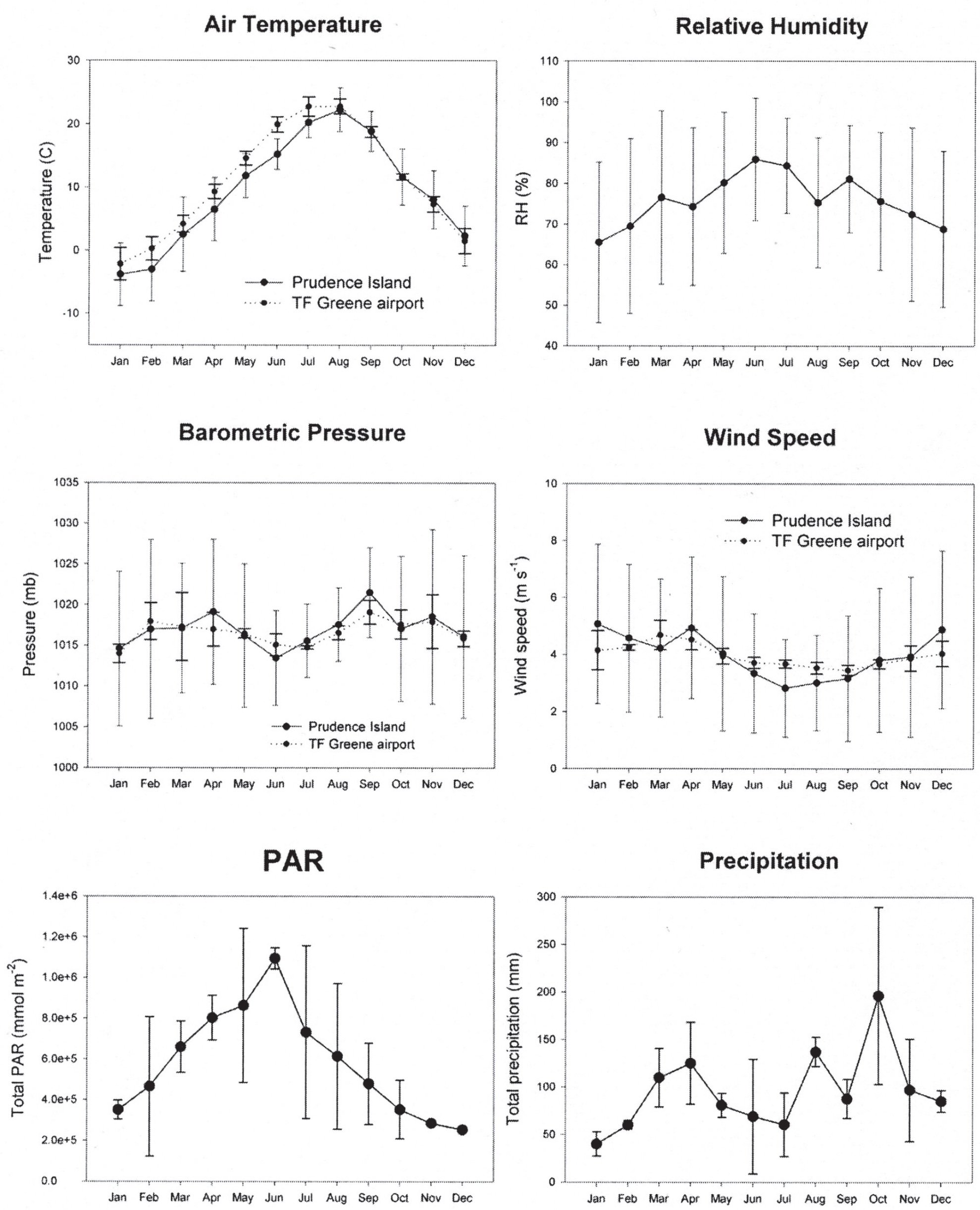

Figure 4.3. Meteorological patterns on Prudence Island and mainland, R.I. Prudence Island data are from 2003–05 from the NBNERR weather station near Potter Cove. Temperature, humidity, pressure, and wind speed plots are monthly averages from 15-minute samples. PAR and precipitation plots are monthly 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.

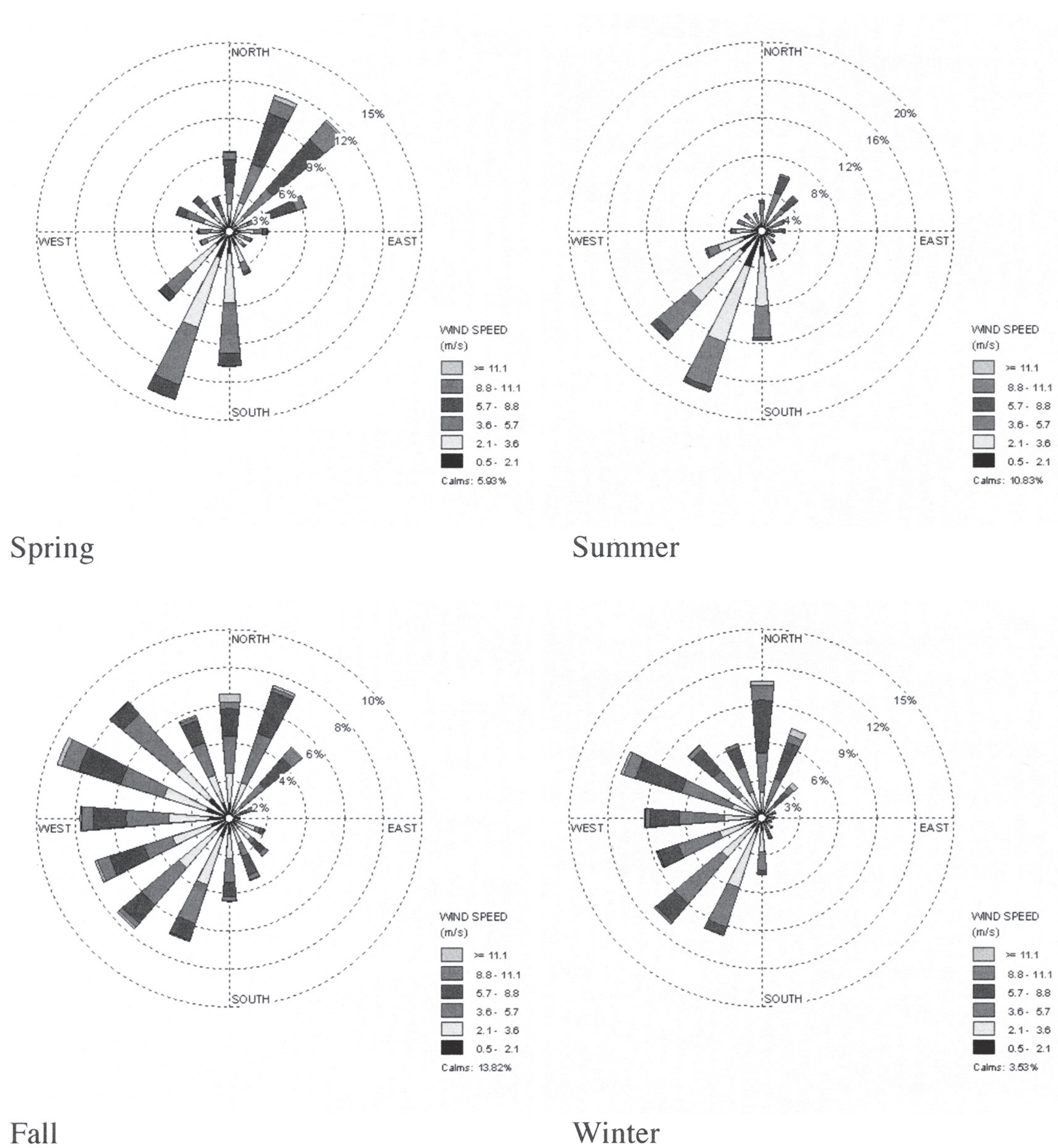

Figure 4.4. Seasonal wind roses from the NBNERR weather station located near Potter Cove on Prudence Island. Data are from 2003–05. All wind rose figures were created using the WRPLOT View software package (©1998–2004 Lakes Environmental Software).

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

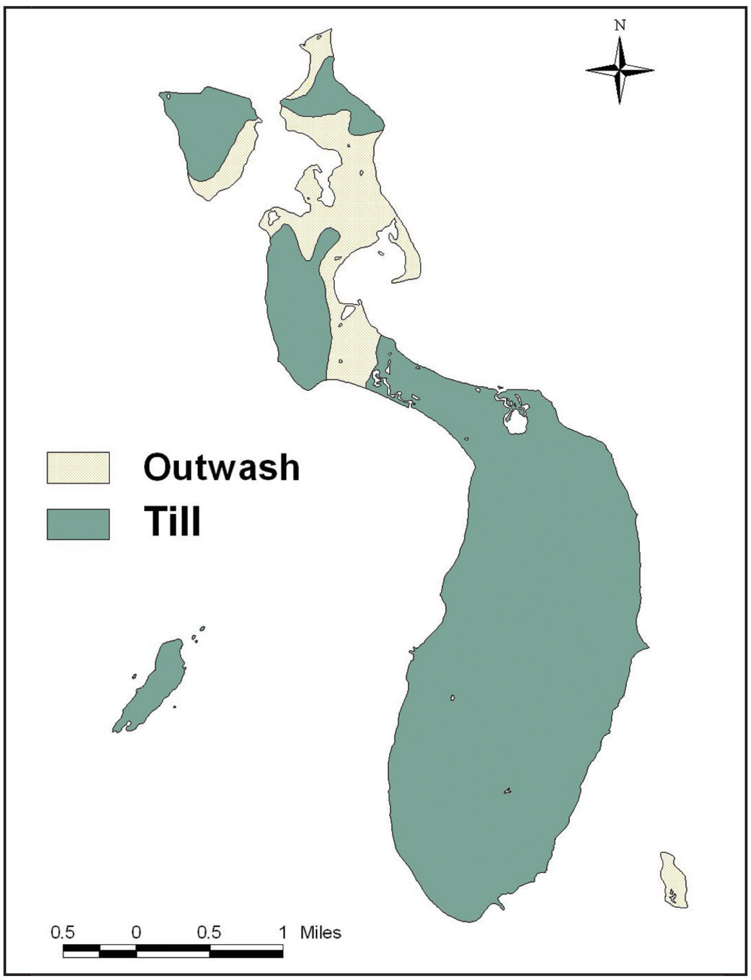

Figure 4.6. Glacial deposits overlying bedrock on Prudence, Patience, Hope, and Dyer islands. *GIS data sources courtesy of RIGIS.*

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		

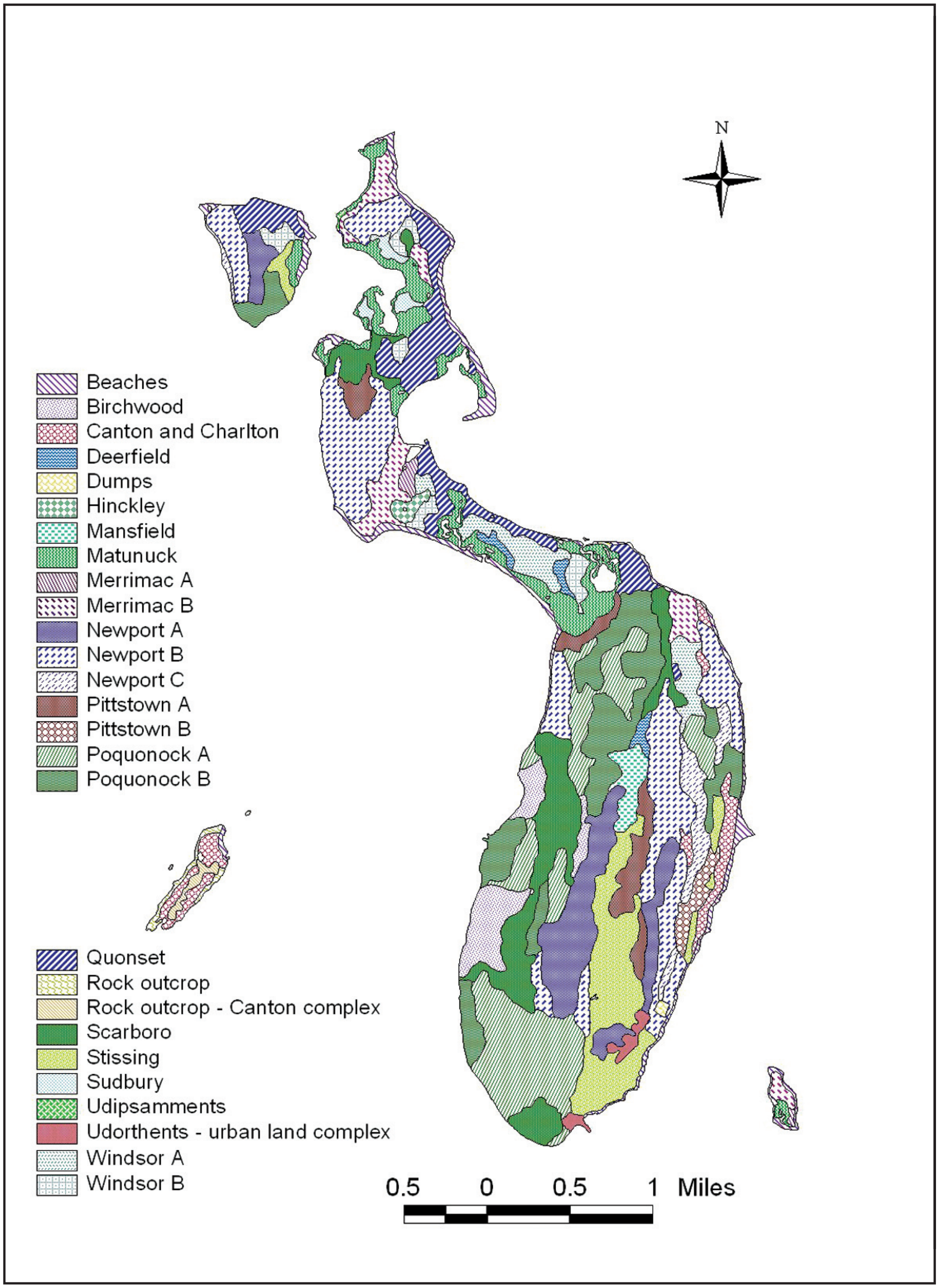

Figure 4.7. Soil types found on Prudence, Patience, Hope, and Dyer islands. *GIS data sources courtesy of RIGIS*.

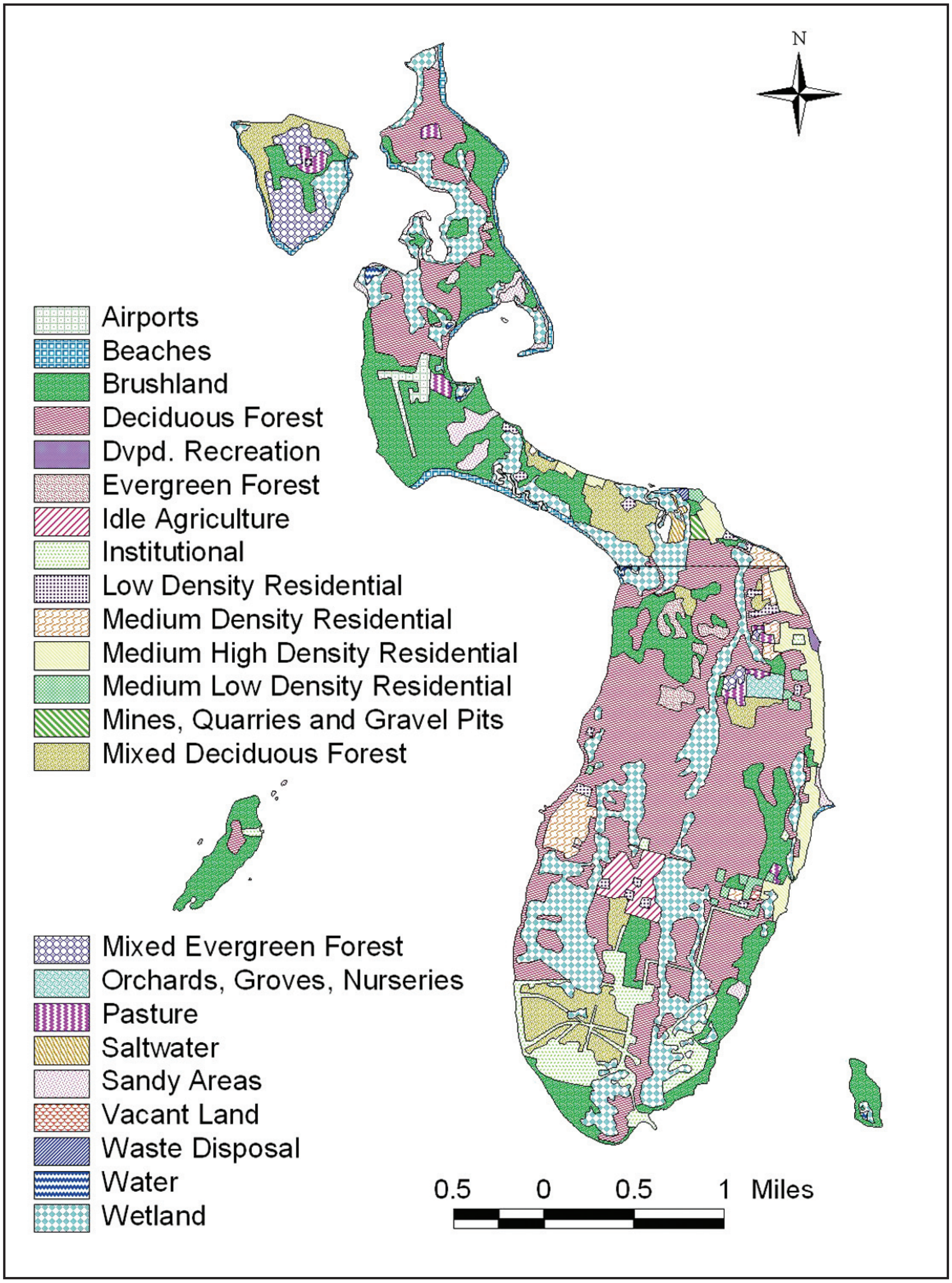

Figure 4.9. Land cover in 1995 on Prudence, Patience, Hope, and Dyer islands. *GIS data sources courtesy of RIGIS*.

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					Patience	Hope	Dyer
	North Prudence Unit	Mid Prudence Units	South Prudence Unit	Total NBNERR on Prudence	Total 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

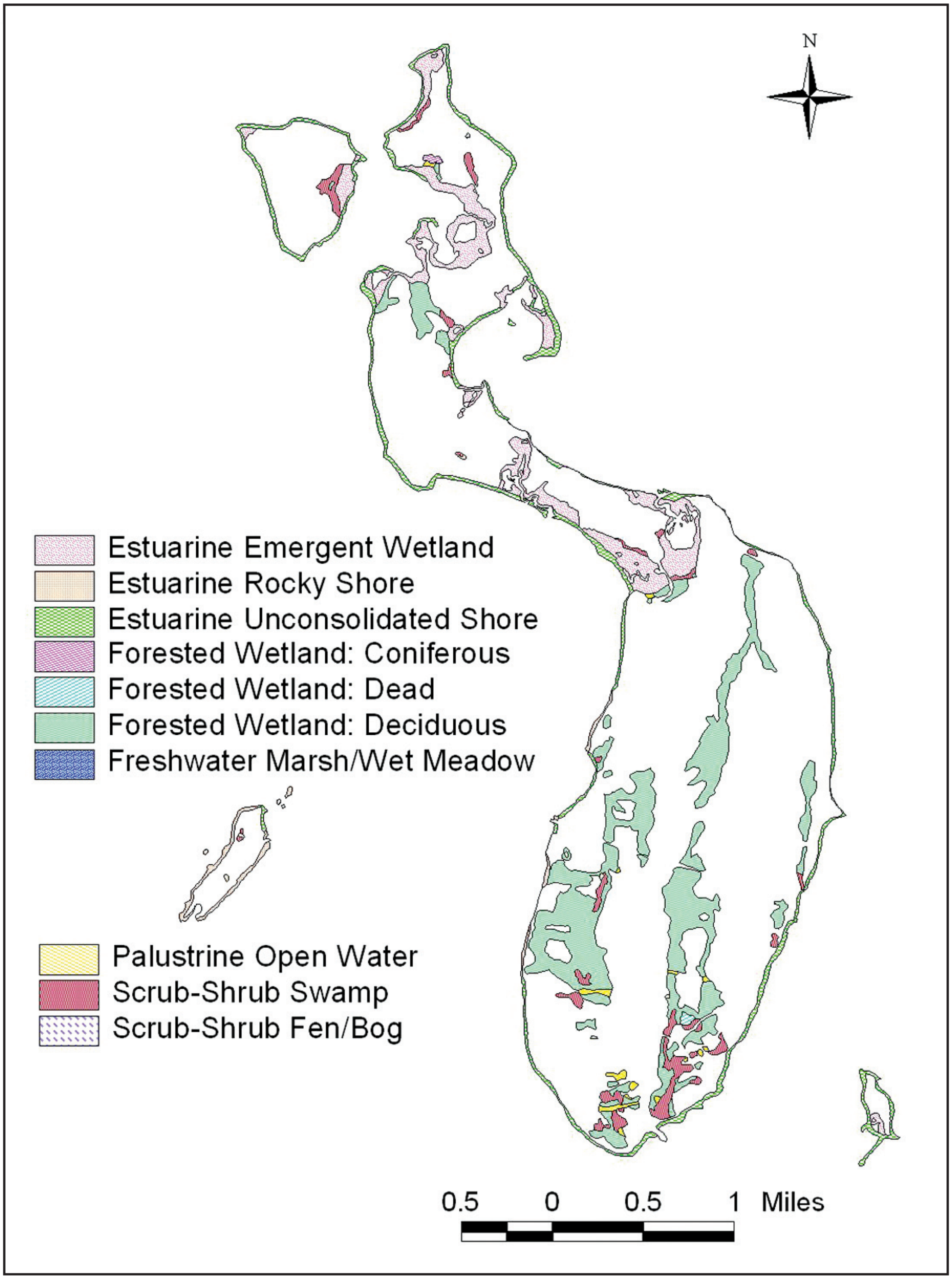

Figure 4.11. Wetlands on Prudence, Patience, Hope, and Dyer islands. *GIS data sources courtesy of RIGIS*.

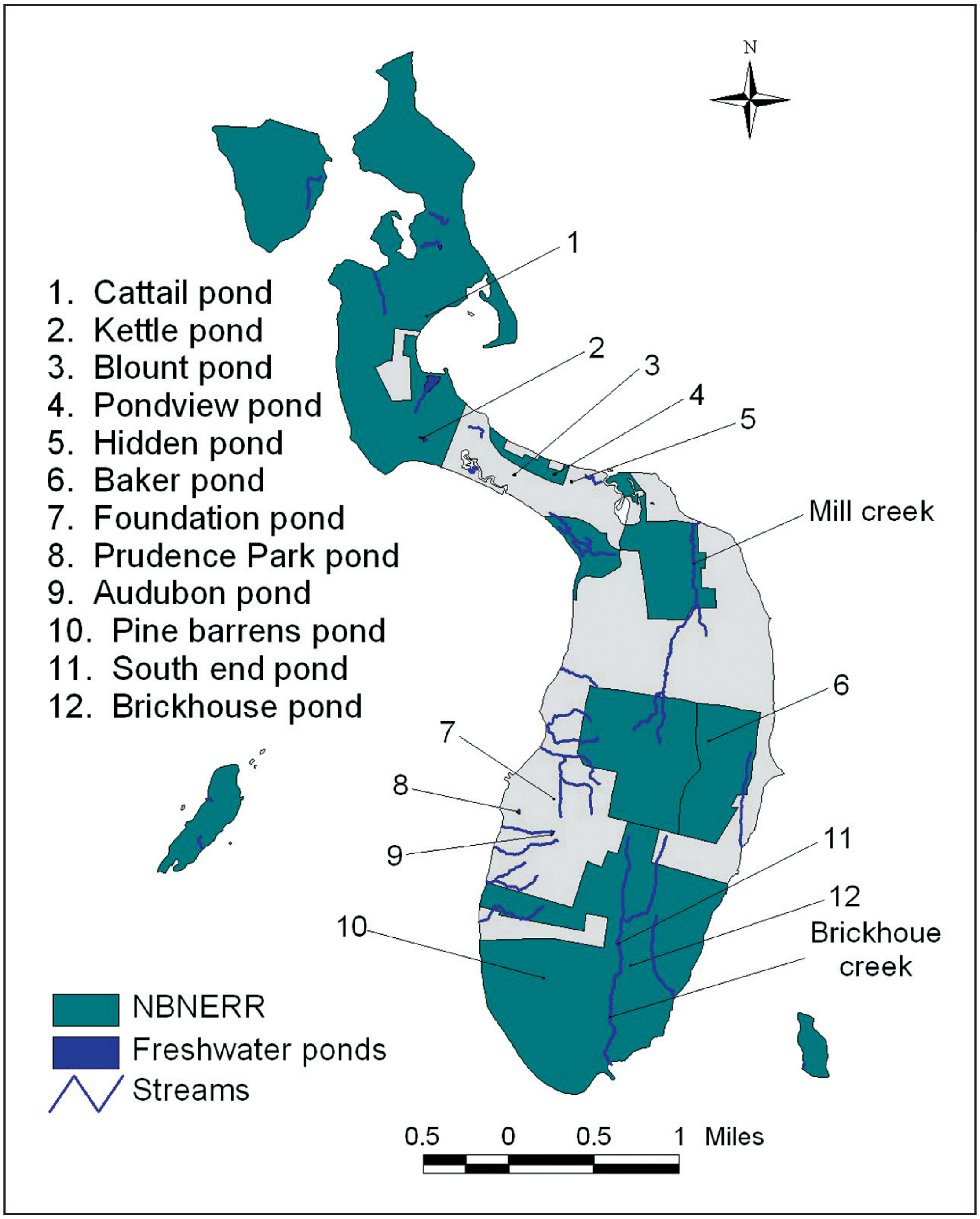

Figure 4.12. Freshwater ponds and streams on Prudence, Patience, Hope and Dyer islands. All pond names are colloquial; ponds were unofficially named by island residents or Reserve staff. *GIS data sources courtesy of RIGIS.*

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.

	Prudence					Patience	Hope	Dyer
Wetland class	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	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.

a.

b.

c.

d.

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.*

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).

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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 prickley 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, gamma 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 platenoides*) 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

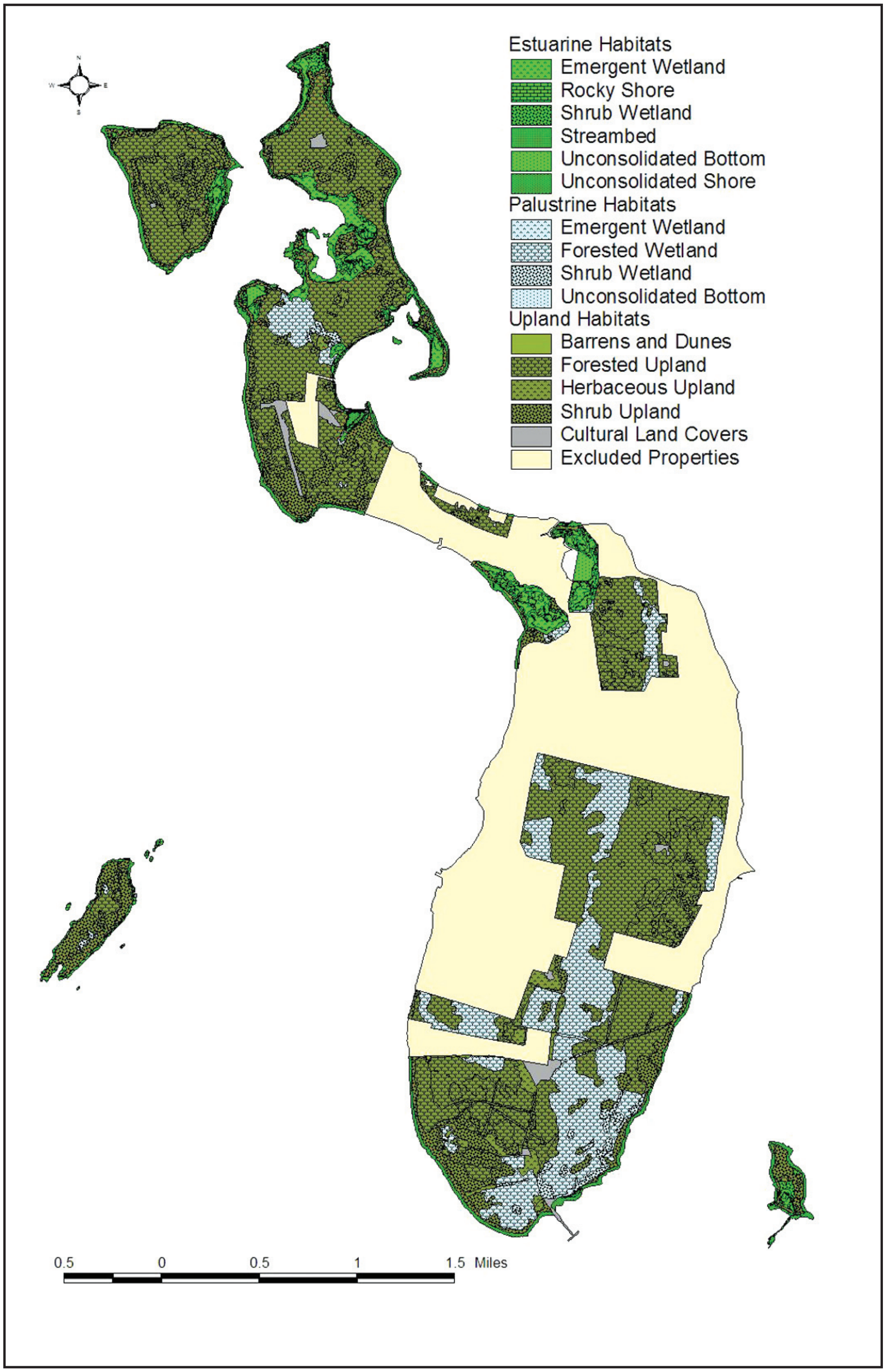


Figure 5.3. Habitats of the NBNERR ordered by system and class. *Source: Kutcher et al., 2004*.

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 Scarboro 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 (*Centauria 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 then 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. capallinum*), bayberry, greenbrier, or beach rose. They also commonly include stunted black cherry (*Prunus serotina*), stunted eastern red cedar (*Juniperus virginiana*), fox grape (*Vitus 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. Shaugnessy 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).

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*

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 influenced by direct coastal effects, invasion by bittersweet 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

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

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,

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.

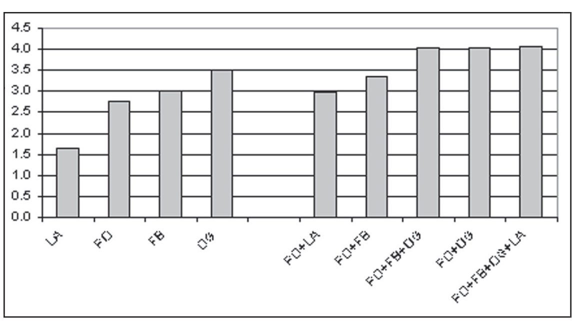


Figure 5.9. Shannon-Wiener indices of species diversity of habitats and habitat combinations of the Atlantic coastal pine barrens of the NBNERR South Prudence Unit. LA = European larch forest, PO = pine-oak forest, FB = linear shrubby firebreak, OG = open grassland. *Source: Kutcher and Raposa, 2005.*

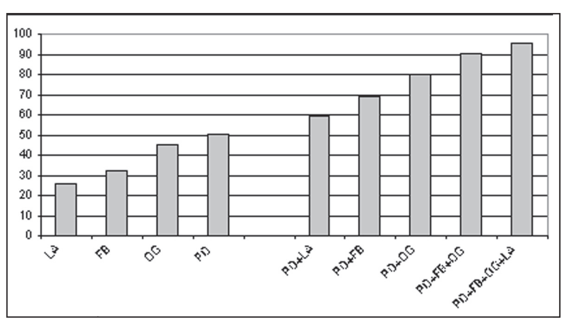
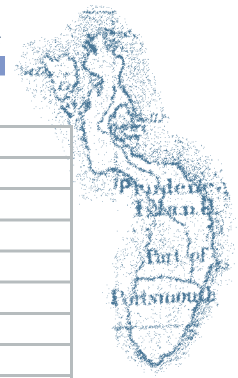


Figure 5.10. Jackknife estimate of richness of habitats and habitat combinations of the Atlantic coastal pine barrens of the NBNERR South Prudence Unit. LA = European larch forest, PO = pine-oak forest, FB = linear shrubby firebreak, OG = open grassland. *Source: Kutcher and Raposa, 2005.*

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



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

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

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

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

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

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CHAPTER 6.

Terrestrial Fauna

Kenneth B. Raposa

Photo by Robin Weber

a.

b.

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

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, *Zanclognatha martha* (pine barrens *Zanclognatha* 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 macrolipidoptera, 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 diseases 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	*Ambystoma maculatum*	Spotted salamander	6
	Bufo fowleri	Fowler's toad	6
	Chelydra serpentina	Common snapping turtle	2
	Chrysemys picta picta	Eastern painted turtle	2
	Clemmys guttata	Spotted turtle	2
	Coluber constrictor	Northern black racer	2
	Eurycea bislineata	Northern two-lined salamander	2
	Hemidactylium scutatum	Four-toed salamander	2
	Lampropeltis triangulum	Eastern milk snake	1
	Opheodrys vernalis	Eastern smooth green snake	4
	Plethodon cinereus	Northern redback salamander	5
	Pseudacris crucifer crucifer	Northern spring peeper	2
	Terrapene carolina	Eastern box turtle	5
	Thamnophis sauritus	Eastern ribbon snake	2
	Thamnophis sirtalis	Eastern garter snake	6
Hope Island	*Opheodrys vernalis*	Eastern smooth green snake	1
	Storeria dekayi	Northern brown snake	1
	Thamnophis sirtalis	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-

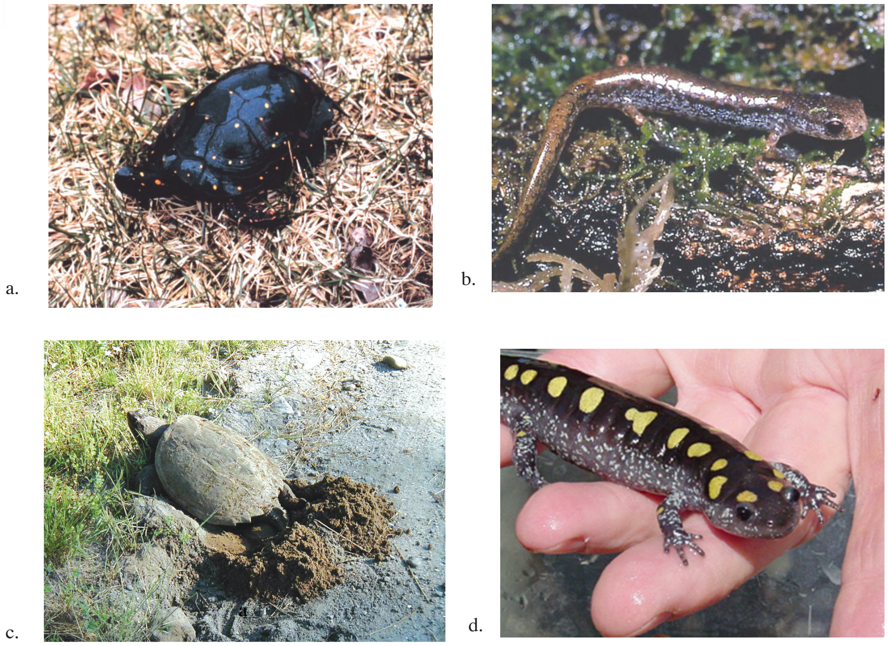

Figure 6.3. Several amphibians and reptiles found on Prudence Island include: (a) spotted turtle *(Clemmys guttata)*; (b) Northern redback salamander *(Plethodon cinereus)*; (c) snapping turtle *(Chelydra serpentina)*; and (d) spotted salamander *(Ambystoma maculatum). Photo from NBNERR photo library.*

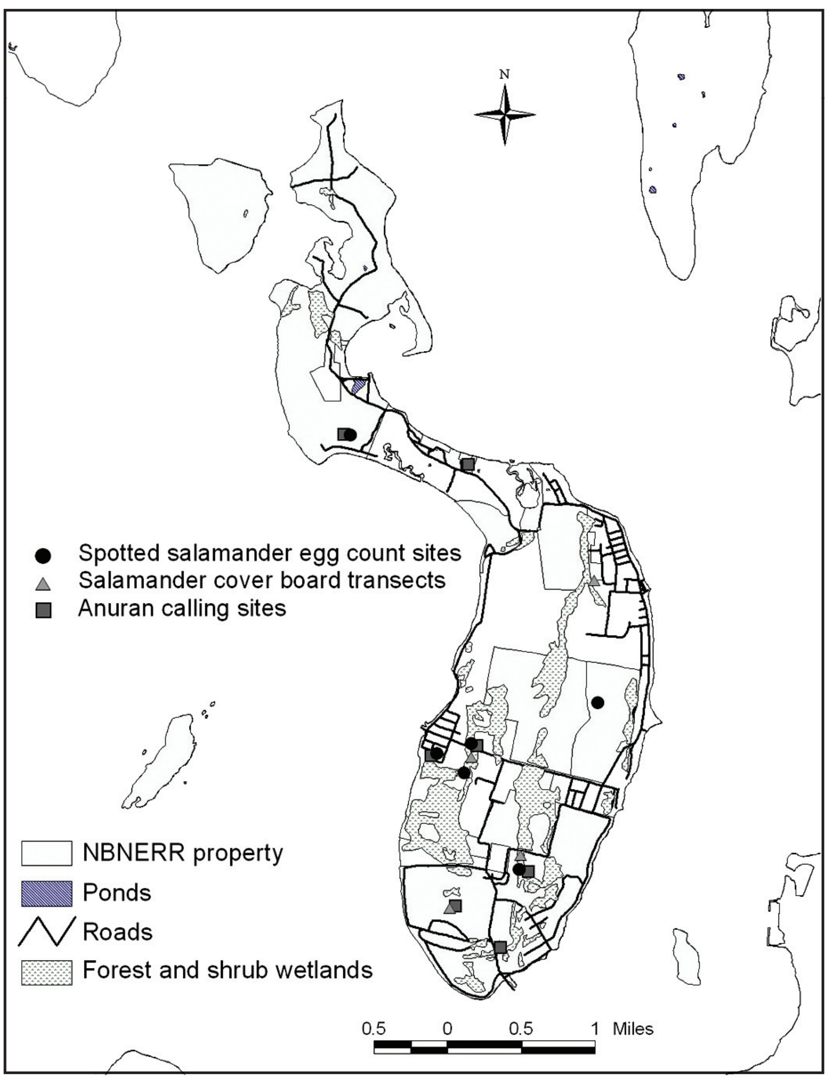

Figure 6.4. Locations of amphibian surveys, including spotted salamander egg mass counts, salamander cover board transects, and anuran calling surveys. *Data from Raposa and Rehor, 2003. GIS pond and wetland data courtesy of RIGIS.*

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

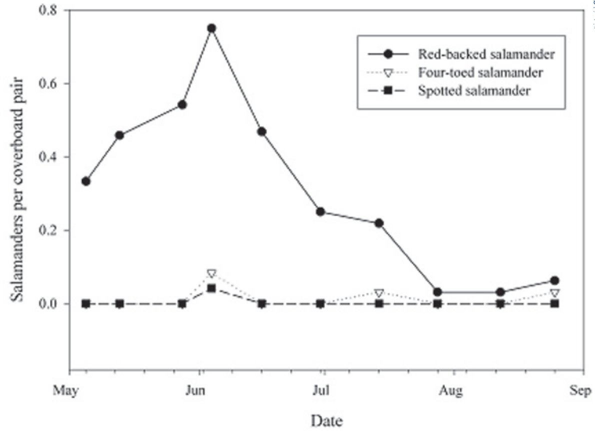

Figure 6.5. Abundance of salamanders found under paired coverboards during 2003 on Prudence Island. *Data from Raposa and Rehor, 2003.*

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).

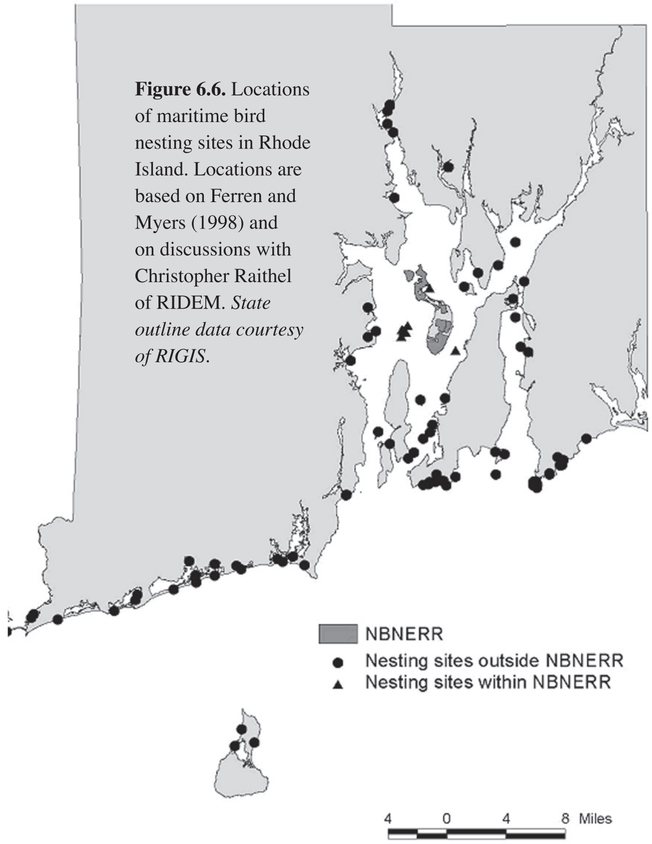

Figure 6.6. Locations of maritime bird nesting sites in Rhode Island. Locations are based on Ferren and Myers (1998) and on discussions with Christopher Raithel of RIDEM. *State outline data courtesy of RIGIS.*

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 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.

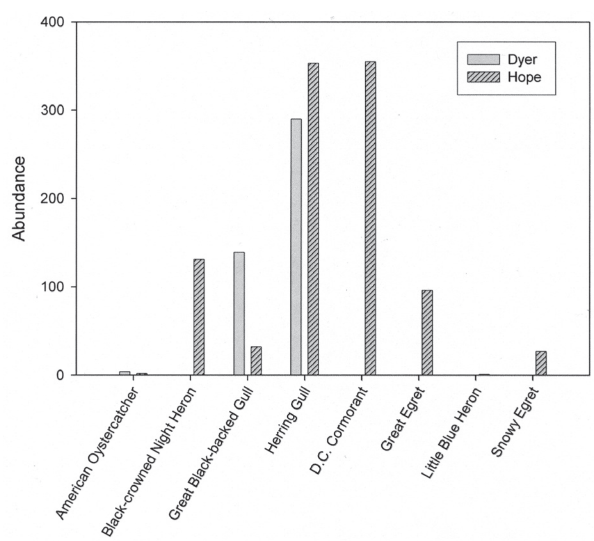

Figure 6.7. Abundance of maritime nesting birds on Dyer and Hope islands in the NBNERR in 2003. Data are from the long-term maritime nesting bird monitoring program, provided by RIDEM.

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.*

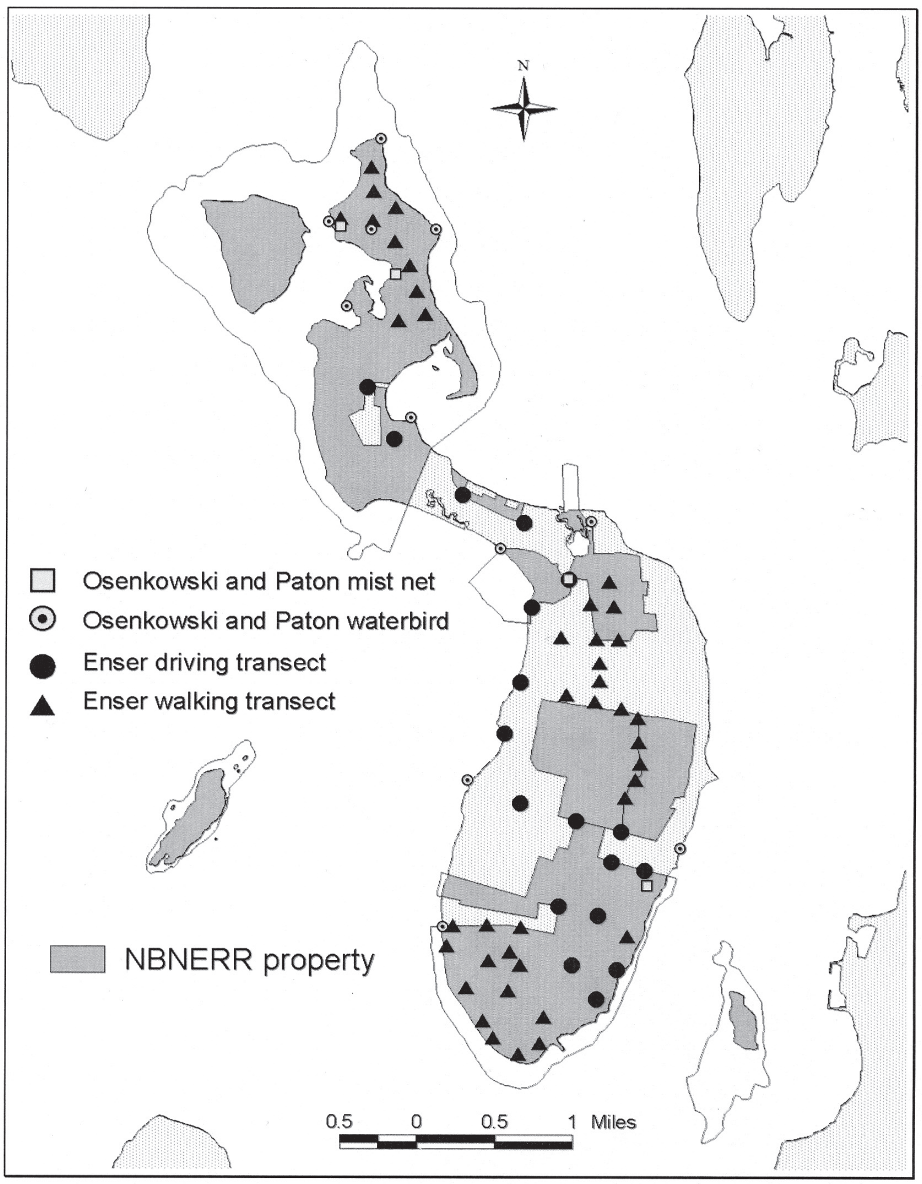

Figure 6.9. Locations of all bird sampling stations on Prudence Island described in Enser (1990) and Osenkowski and Paton (2000). Station locations were approximated based on information and figures provided in the original reports.

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.*

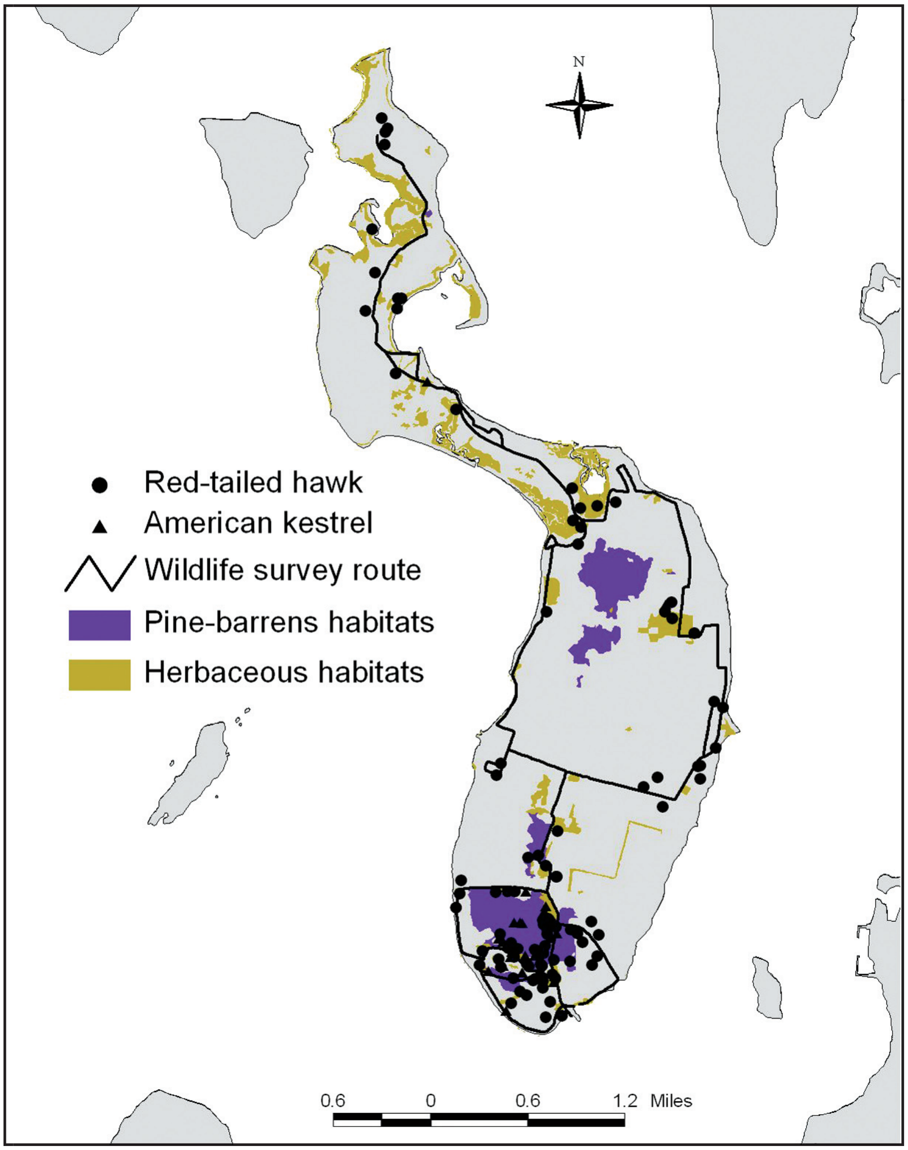

Figure 6.11. Locations of red-tailed hawk and American kestrel observed during the 2003–2004 NBNERR wildlife driving surveys (Raposa and Rehor, 2004) in relationship to pine barrens and herbaceous (including upland grasslands and meadows and estuarine salt marshes) habitats.

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 herodius*), 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-

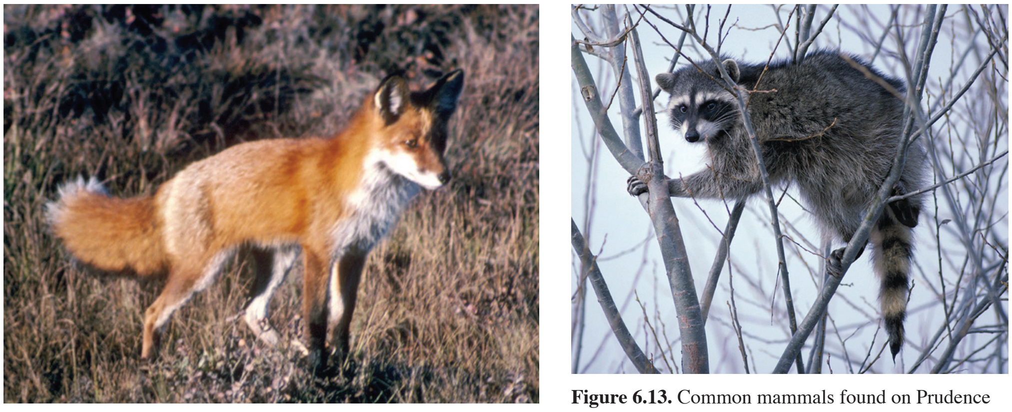

Figure 6.13. Common mammals found on Prudence Island include: (a) red fox and (b) raccoon. *Photo from U.S. Fish & Wildlife Service photo library.*

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

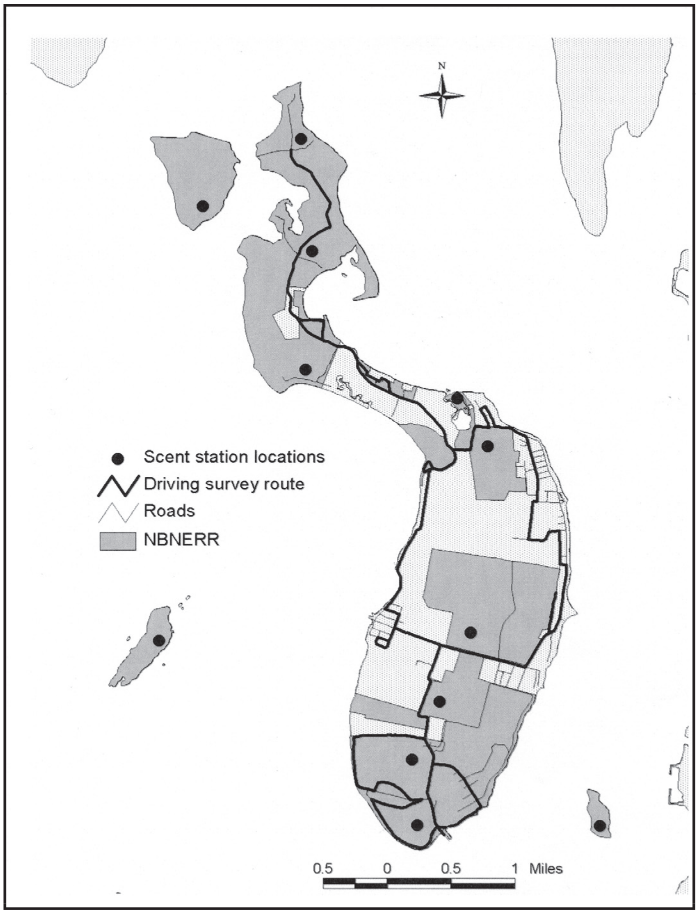

Figure 6.14. Locations of scent stations on each of the NBNERR islands and the driving survey route on Prudence Island.

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.

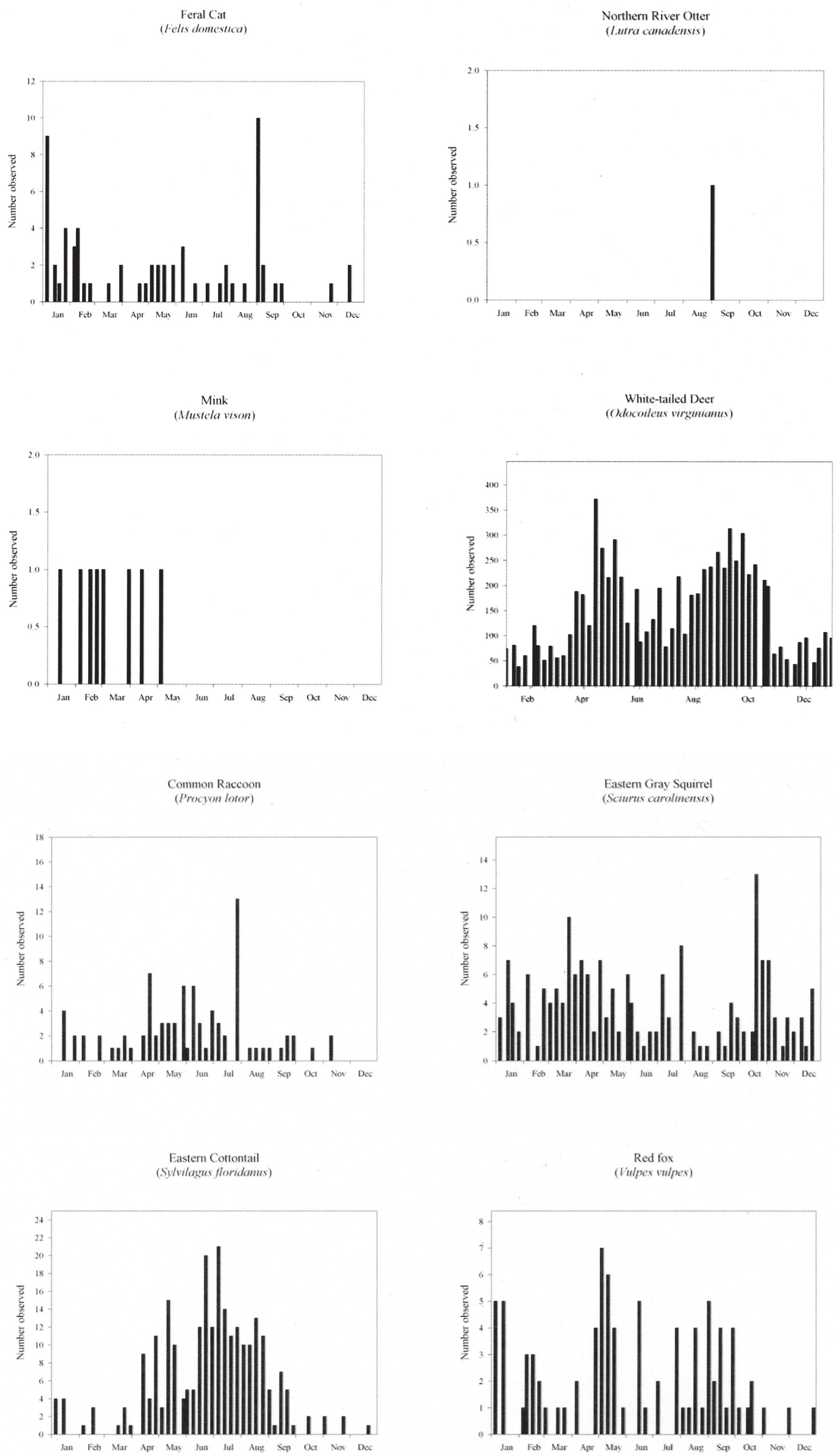

Figure 6.15. The number of sightings of mammal species over time on Prudence Island in 2003. All sighting data are from wildlife driving surveys conducted by the NBNERR (Raposa and Rehor, 2004).

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.*

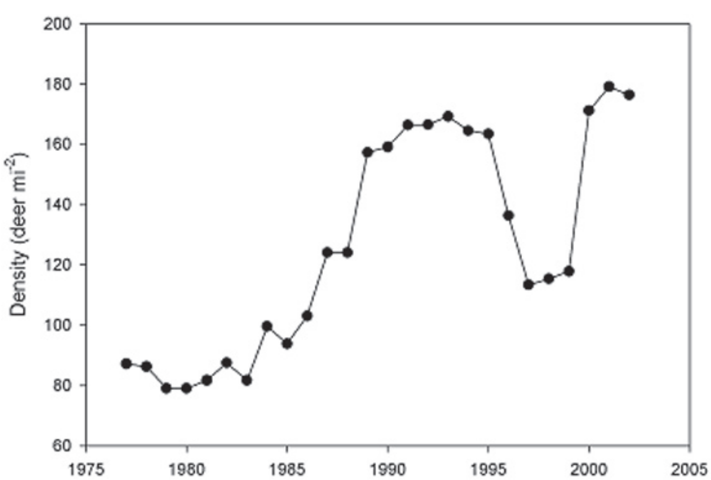

Figure 6.18. Density of white-tailed deer on Prudence Island from 1979–2002. Density values were calculated by dividing the size of the total population by the area of Prudence Island (14.4 km^2). *Deer population data through 1999 are from Gibson and Suprock (2000); data from 2000 through 2002 are from Gibson (personal communication).*

Appendix 6.I 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 1985	Maclachlan 1981	Enser 1990	Paton and Osenkowski 2000	Paton and Osenkowski 2000	Paton et al. 2000	Ferren and Myers
			Patience	Prudence	Prudence	Prudence w/s	Prudence s/f	Prudence (banding)	PPHD
Anatinae	*Aix sponsa*	wood duck			B				
	Anas acuta	Northern pintail				3			
	Anas americana	American wigeon				11			
	Anas platyrhynchos	mallard		*	B	8	2		
	Anas rubripes	American black duck		B	B	1392	159		
	Anas strepera	gadwall					26		
	Aythya marila	greater scaup				3			
	Aythya sp.	scaup sp.				2			
	Branta bernicla	brant				775	1		
	Branta canadensis	Canada goose		*	B	369	96		
	Bucephala albeola	bufflehead				204	55		
	Bucephala clangula	common goldeneye				1932	505		
	Bucephala islandica	Barrow's goldeneye				3	2		
	Clangula hyemalis	long-tailed duck				3			
	Cygnus olor	mute swan			B	2			
	Lophodytes cucullatus	hooded merganser				5	10		
	Melanitta fusca	white-winged scoter		*		46	387		
	Melanitta nigra	black scoter				1			
	Melanitta perspicillata	surf scoter				2			
	Mergus serrator	red-breasted merganser				592	92		
Phasianidae	*Phasianus colchicus*	ring-necked pheasant		B	9				
Odontophoridae	*Colinus virginianus*	common bobwhite			2				
Gaviidae	*Gavia immer*	common loon		*		19	1		
Podicipedidae	*Podiceps auritus*	horned grebe				369	105		
	Podiceps grisegena	red-necked grebe				3			
Phalacrocoracidae	*Phalacrocorax auritus*	double-crested cormorant		*		7	552		x
	Phalacrocorax carbo	great cormorant				113	2		
	Phalacrocorax sp.	cormorant sp.				14	1		
Ardeidae	*Ardea alba*	great egret		*		4	89		x
	Ardea herodias	great blue heron		*		4	4		
	Bubulcus ibis	cattle egret							x
	Butorides striatus	green heron		*	B				
	Egretta caerulea	little blue heron		*			4		x
	Egretta thula	snowy egret		*			127		x
	Egretta tricolor	tricolored heron					2		
	Nycticorax nycticorax	black-crowned night heron		*			1		x
		egret sp.					1		
Threskiornithidae	*Plegadis falcinellus*	glossy ibis		*			17		x
Accipitridae	*Accipiter cooperii*	cooper's hawk				1			
	Accipiter striatus	sharp-shinned hawk		*		4		1	
	Buteo jamaicensis	red-tailed hawk		B		8			
	Buteo platypterus	broad-winged hawk		*					
	Circus cyaneus	northern harrier		*		2			
	Pandion haliaetus	osprey		*			4		
Falconidae	*Falco sparverius*	American kestrel		B	B	2			
Haematopodidae	*Haematopus palliatus*	American oystercatcher					8		x
Charadriidae	*Charadrius semipalmatus*	semipalmated plover		*			12		
	Charadrius vociferus	killdeer			B				
	Pluvialis squatarola	black-bellied plover		*			1		
		plover sp.					1		
Scolopacidae	*Actitis macularia*	spotted sandpiper		*			4		
	Arenaria interpres	ruddy turnstone		*			27		
	Calidris alba	sanderling		*		26			
	Calidris minutilla	least sandpiper					13		
	Catoptrophorus semipalmatus	willet					2		
	Scolopax minor	American woodcock			B				
	Tringa melanoleuca	greater yellowlegs		*			1		
Laridae	*Larus argentatus*	herring gull		*		1182	1300		x
	Larus atricilla	laughing gull		*			95		
	Larus delawarensis	ring-billed gull					22		
	Larus marinus	great black-backed gull		*		375	330		x
	Larus philadelphia	Bonaparte's gull		*		24	9		
	Larus sp.	gull sp.					2295		
	Sterna albifrons	least tern		*			16		x
	Sterna dougallii	roseate tern					2		

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

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

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CHAPTER 7.

Ecological Geography of Narragansett Bay

Kenneth B. Raposa

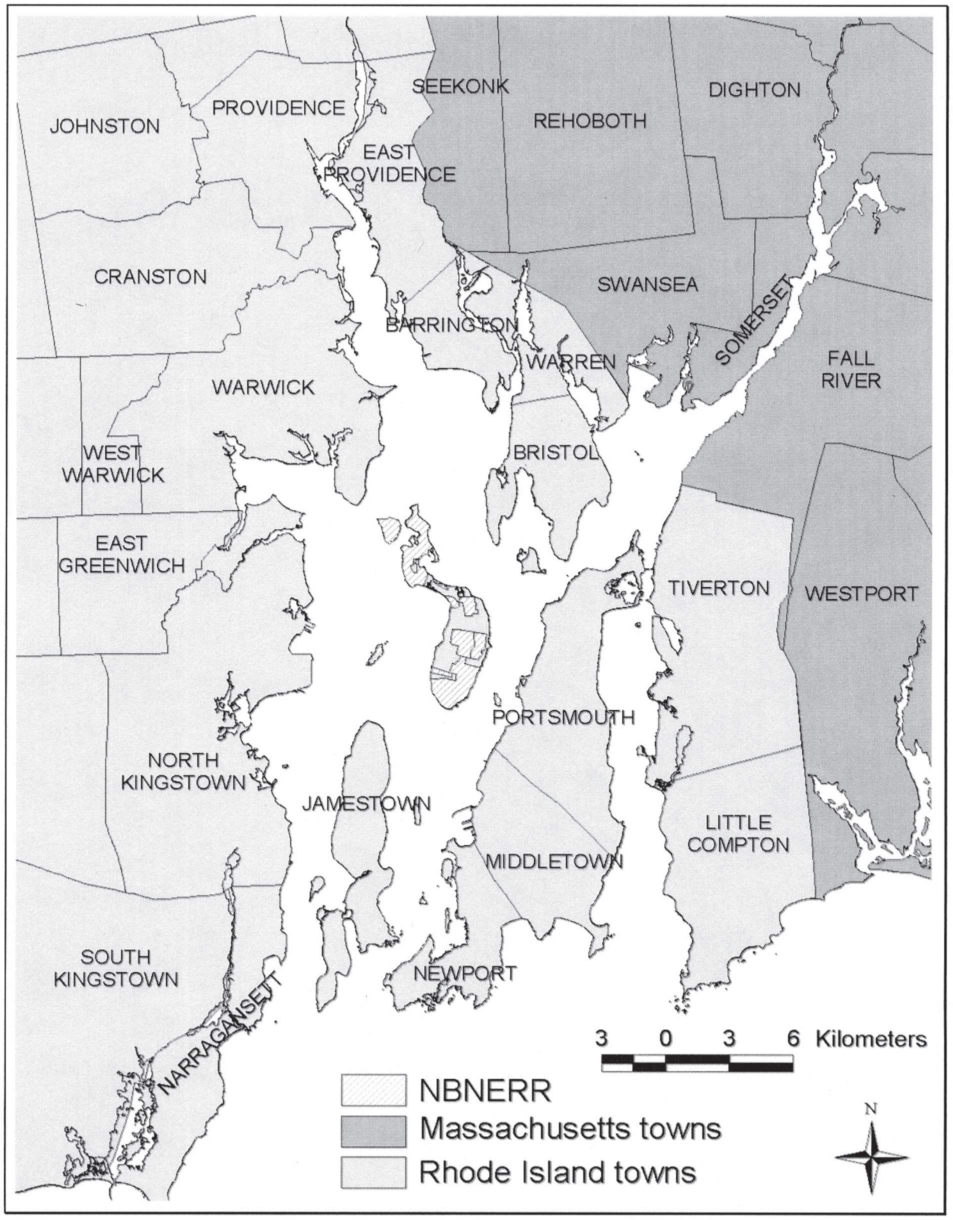

Figure 7.1. Map of Narragansett Bay illustrating the surrounding towns of Rhode Island and southeastern Massachusetts. *Data source: RIGIS*.

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 km^2 (147 $miles^2$). 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 km^2 (Pilson, 1985), 39 percent of which is in Rhode Island and 61 percent in neighboring Massachusetts (Fig. 7.5). The watershed contains 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).

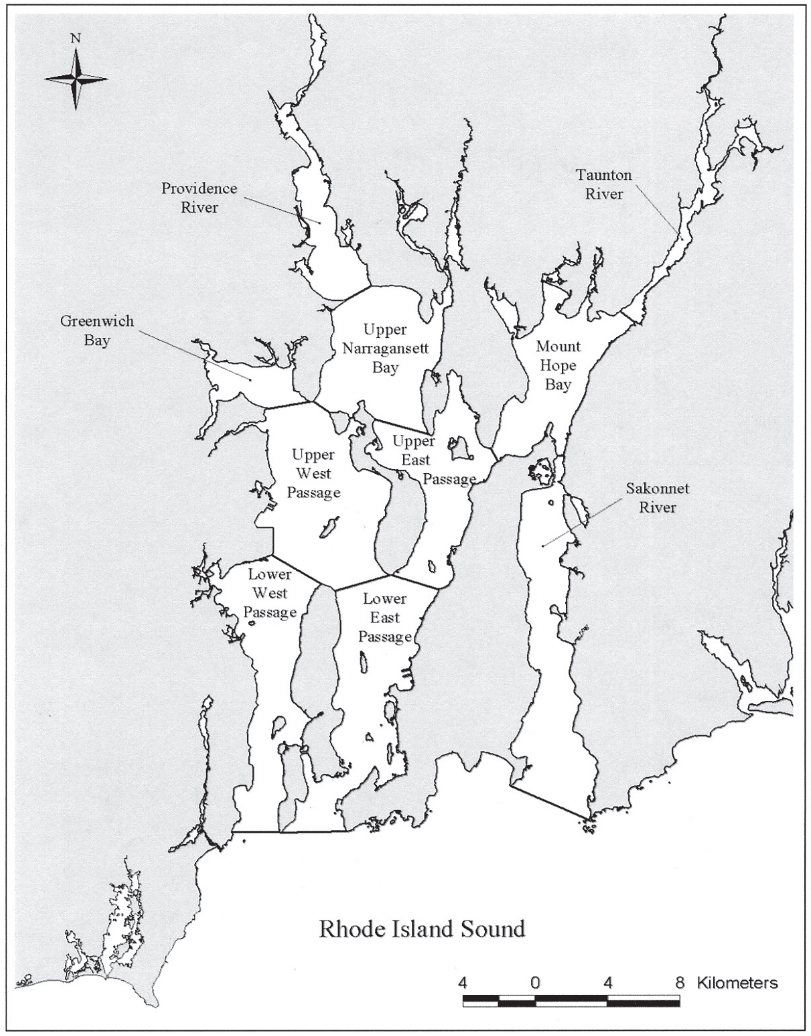

Figure 7.2. Commonly recognized subdivisions within Narragansett Bay. *Data sources: RIGIS and Lee et al. (2000).*

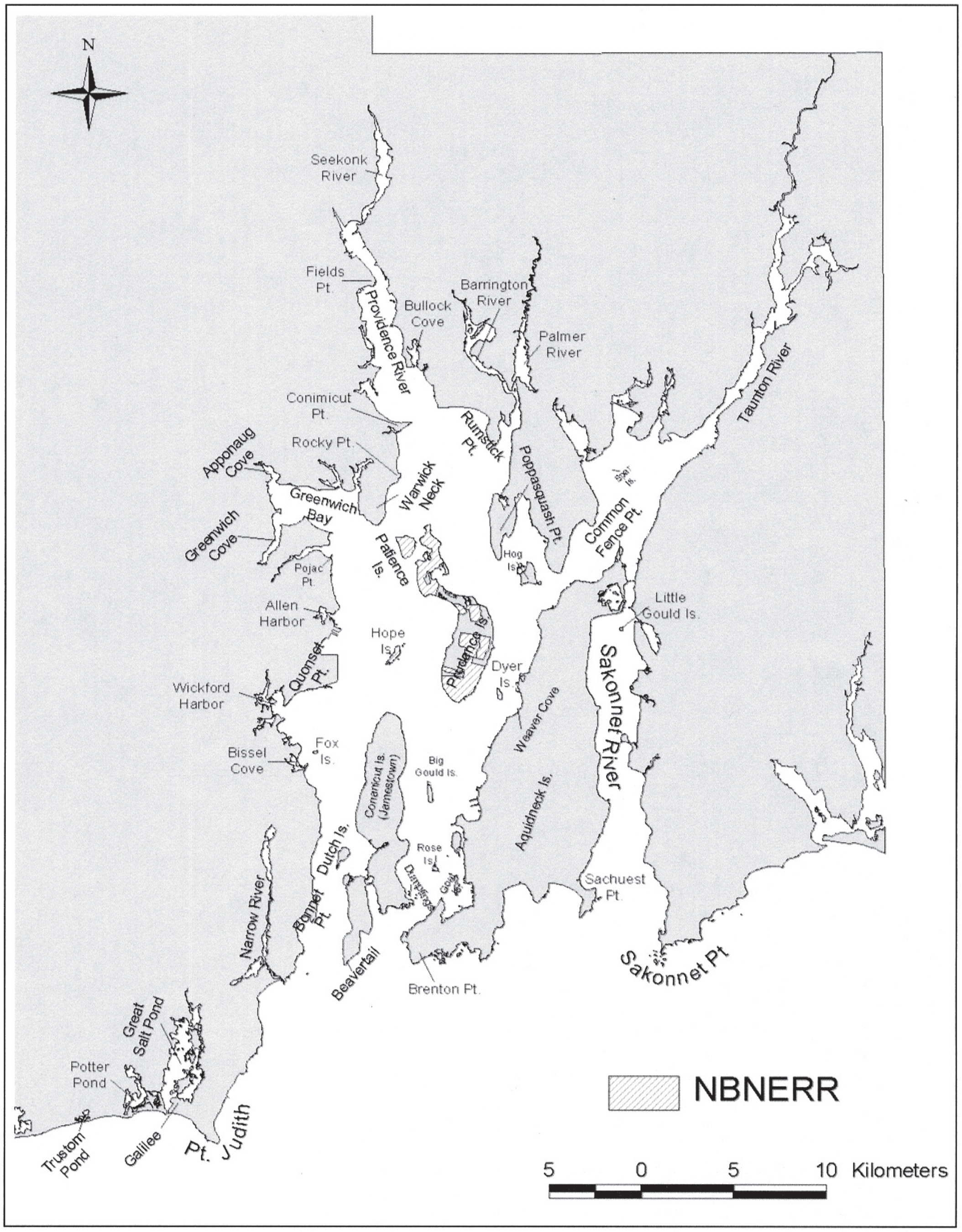

Figure 7.3. Common landmark features in Narragansett Bay, including islands, points, rivers, coves, and embayments. *Data source: RIGIS.*

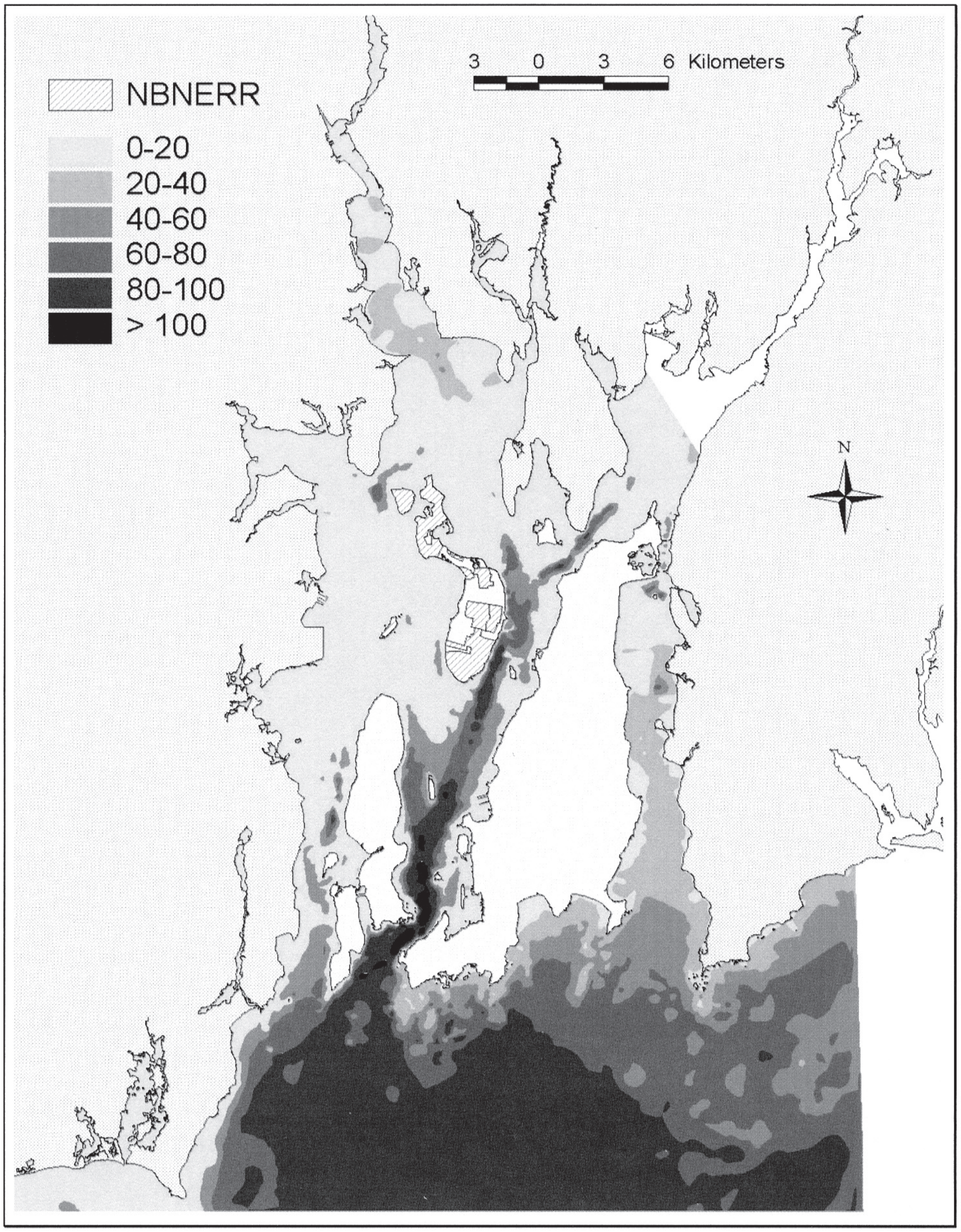

Figure 7.4. Narragansett Bay bathymetric map, with depth intervals illustrated in feet. The deeper East Passage is clearly visible along the eastern side of Prudence Island and the NBNERR. *Data source: RIGIS*.

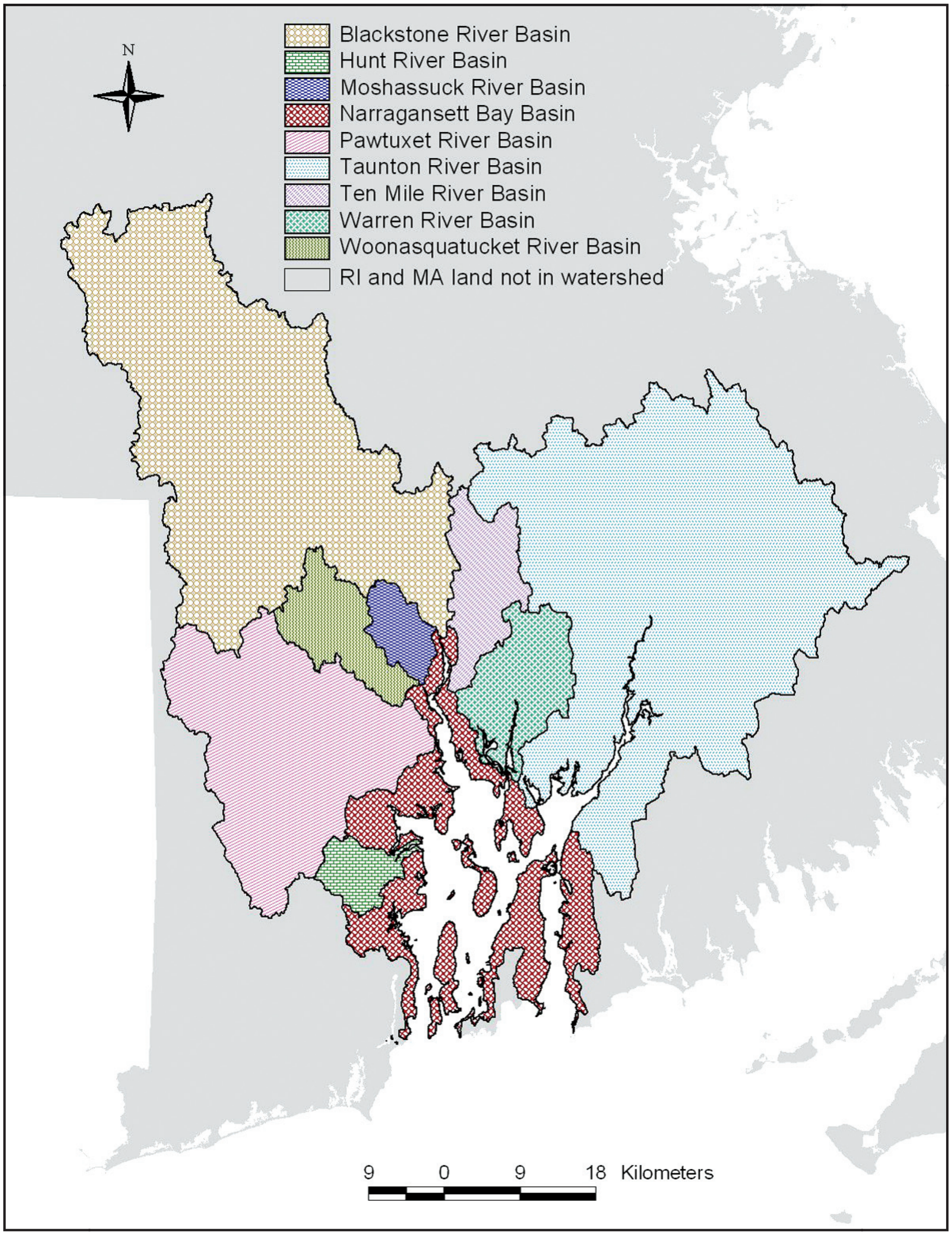

Figure 7.5. The watershed and subwatershed basins of Narragansett Bay. Data sources: RIGIS and Massachusetts GIS (www.mass.gov/mgis/massgis.htm).

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 course 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.

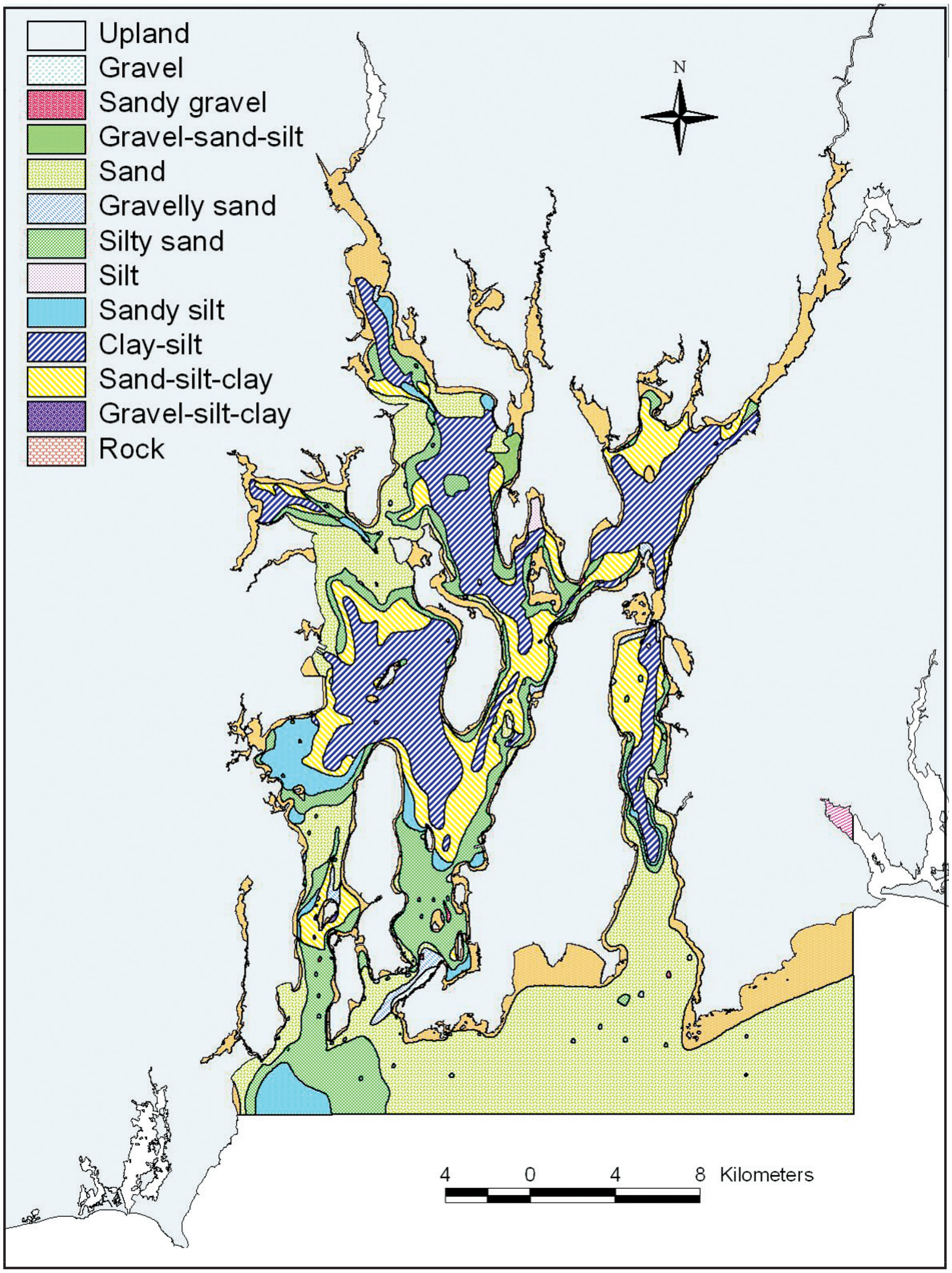

Figure 7.6. Sediments of Narragansett Bay. All sediment data are from McMaster (1960). Unclassified areas were either not sampled or not coded during the study. Note the dominance of clay-silt sediments in the mid- and upper Bay regions, and the coarser sediments lower in the Bay. Data sources: RIGIS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

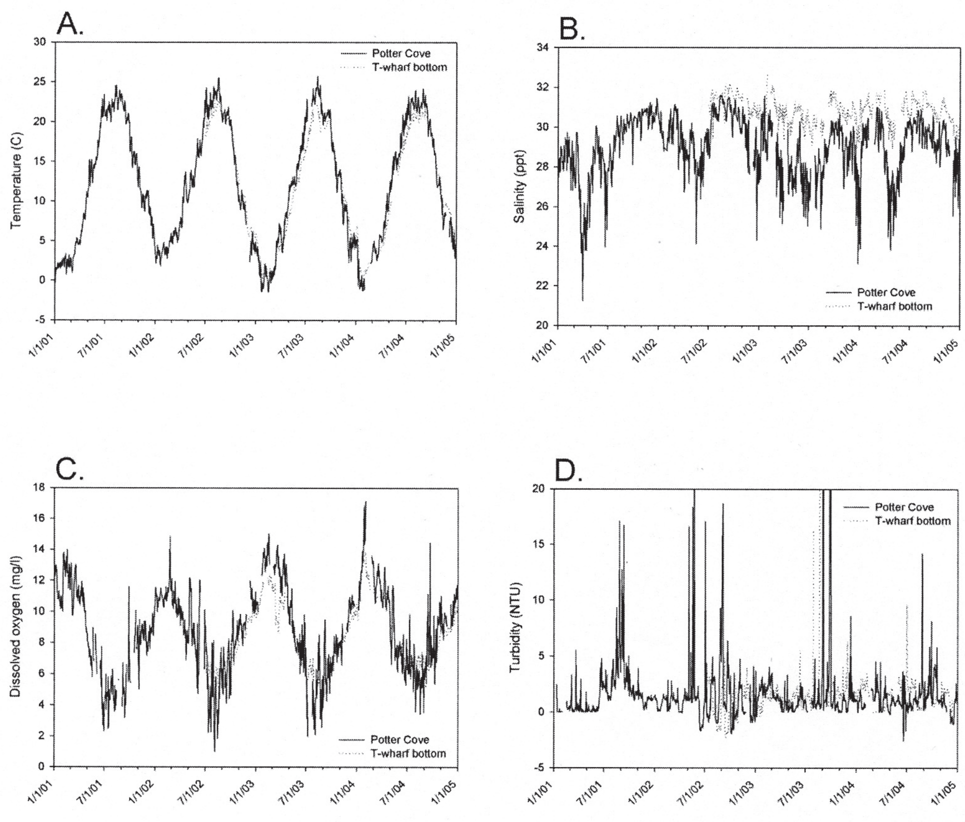

Figure 7.7. Time series of water-quality parameters in Narragansett Bay. All data were taken from the NBNERR SWMP stations at T-wharf and Potter Cove between January 2001 and December 2004. At both stations, readings were taken from approximately 1 m off the bottom. A. temperature; B. salinity; C. dissolved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