CHAPTER 7.

Ecological Geography of Narragansett Bay

Kenneth B. Raposa

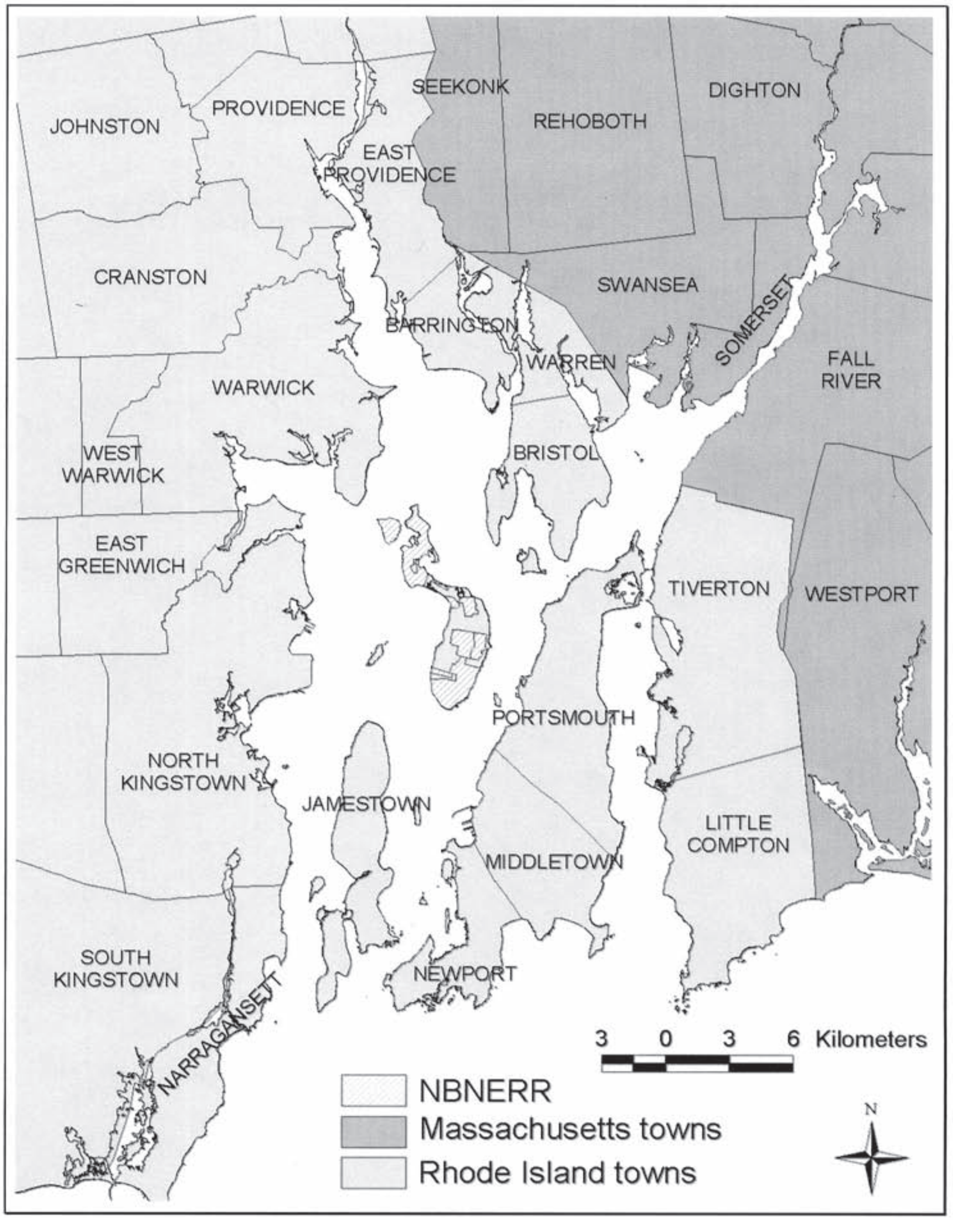

Figure 7.1. Map of Narragansett Bay illustrating the surrounding towns of Rhode Island and southeastern Massachusetts. *Data source: RIGIS*.

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).

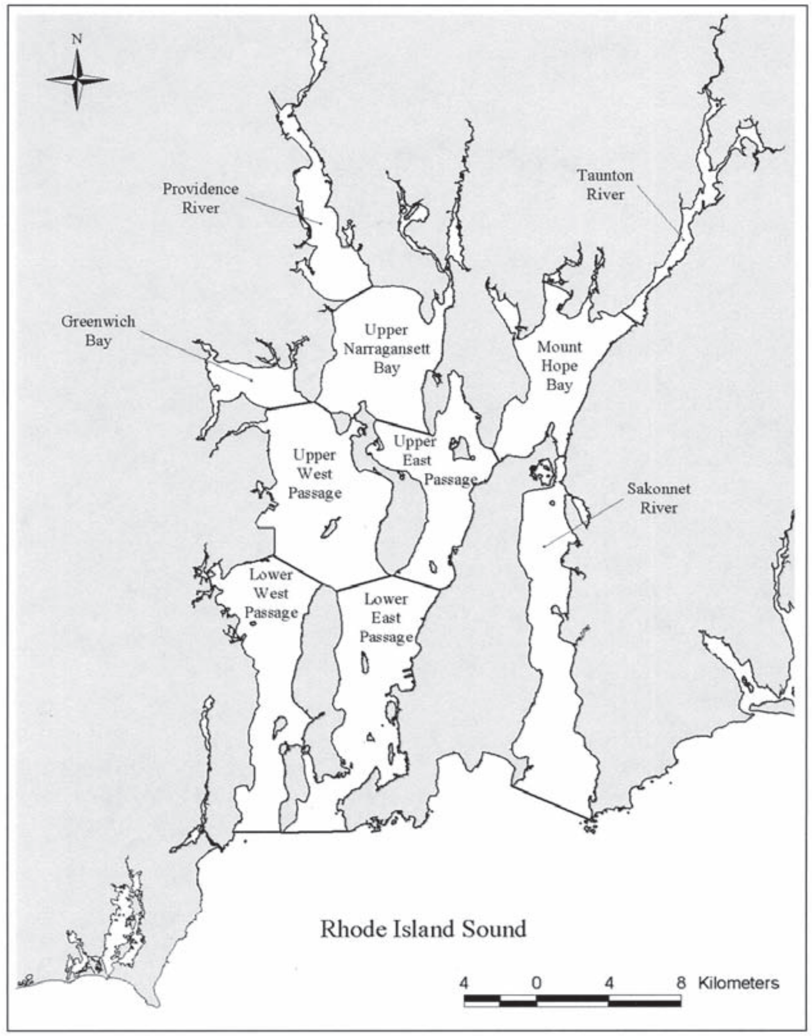

Figure 7.2. Commonly recognized subdivisions within Narragansett Bay. *Data sources: RIGIS and Lee et al. (2000).*

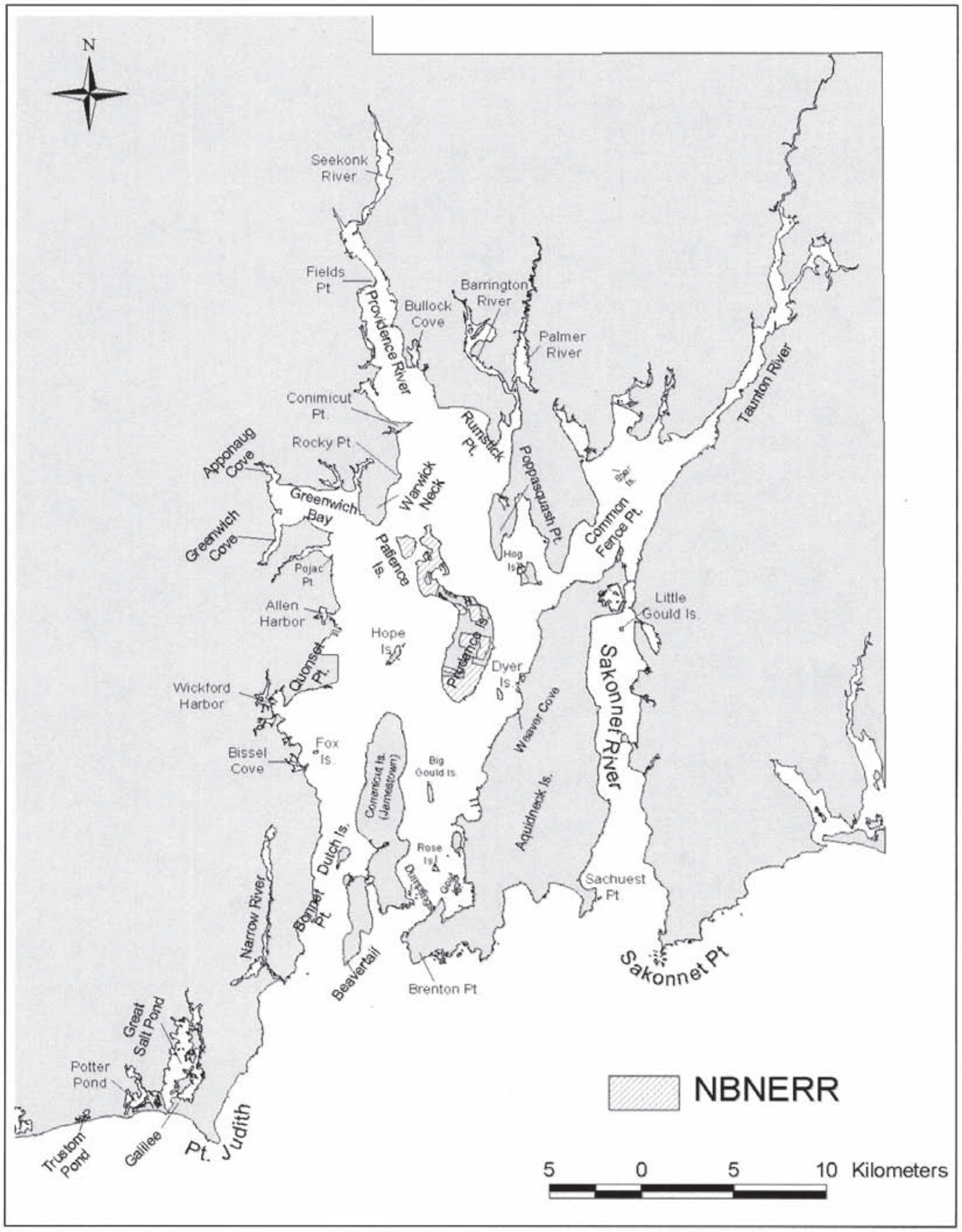

Figure 7.3. Common landmark features in Narragansett Bay, including islands, points, rivers, coves, and embayments. *Data source: RIGIS*.

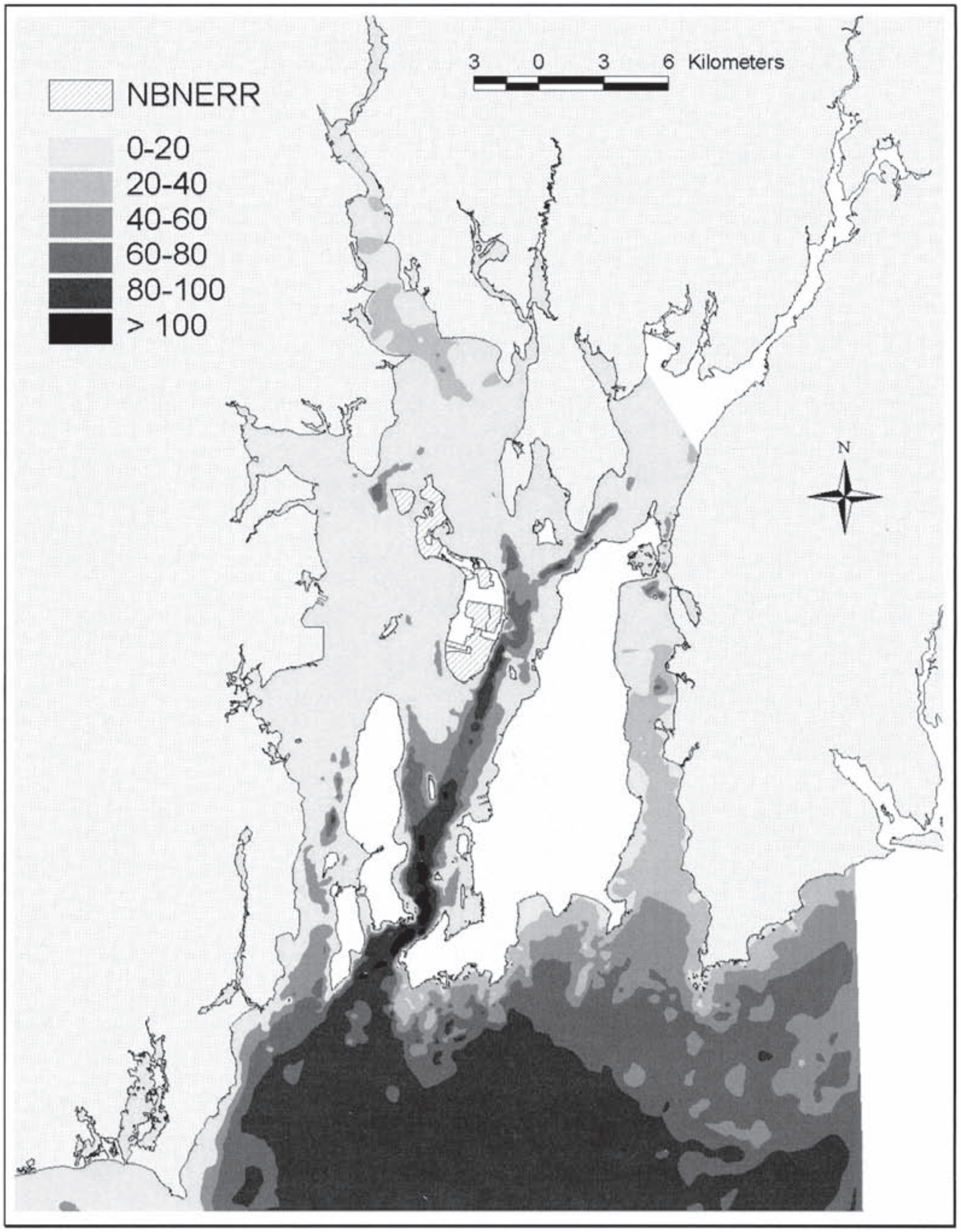

Figure 7.4. Narragansett Bay bathymetric map, with depth intervals illustrated in feet. The deeper East Passage is clearly visible along the eastern side of Prudence Island and the NBNERR. *Data source: RIGIS*.

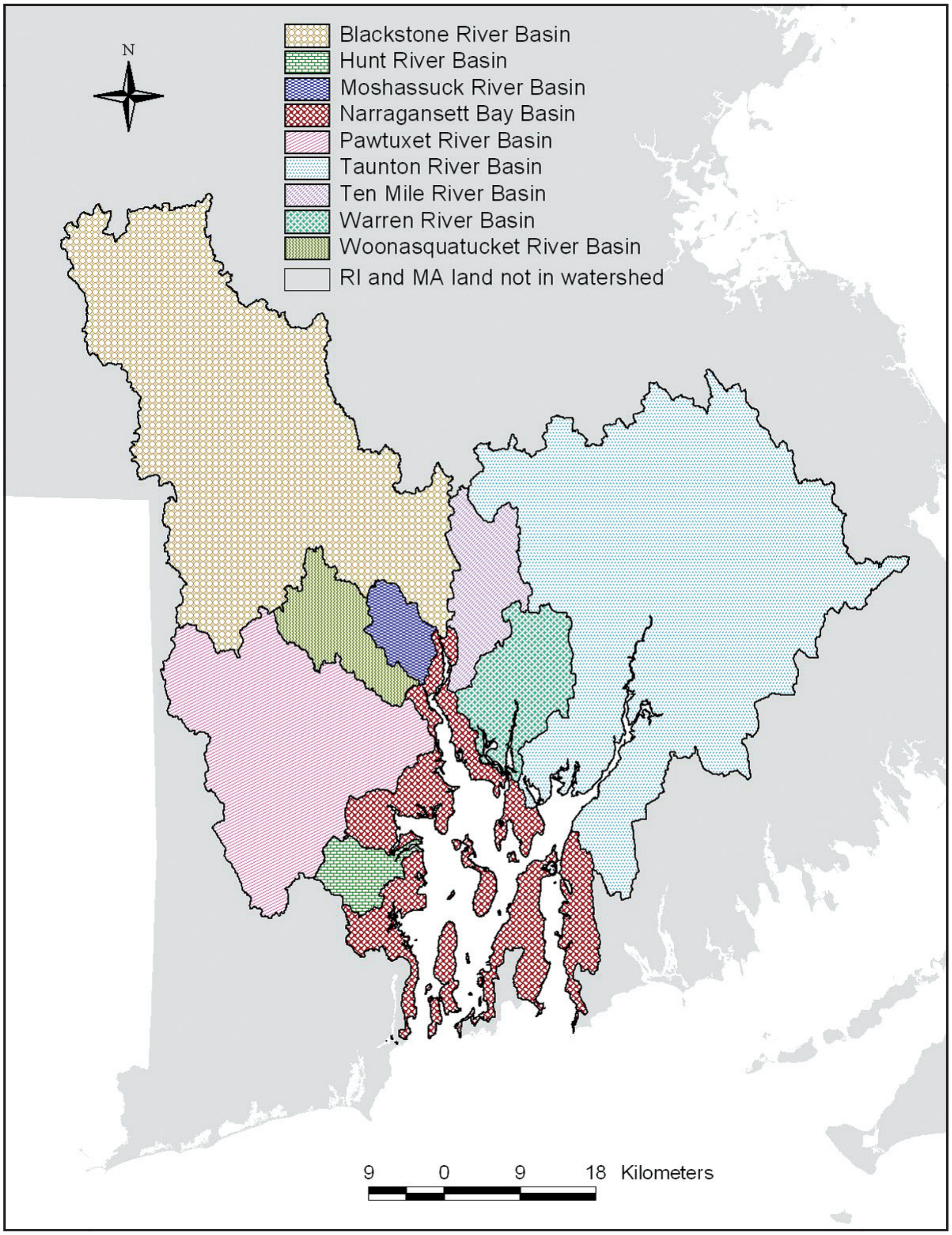

Figure 7.5. The watershed and subwatershed basins of Narragansett Bay. Data sources: RIGIS and Massachusetts GIS (www.mass.gov/mgis/massgis.htm).

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.

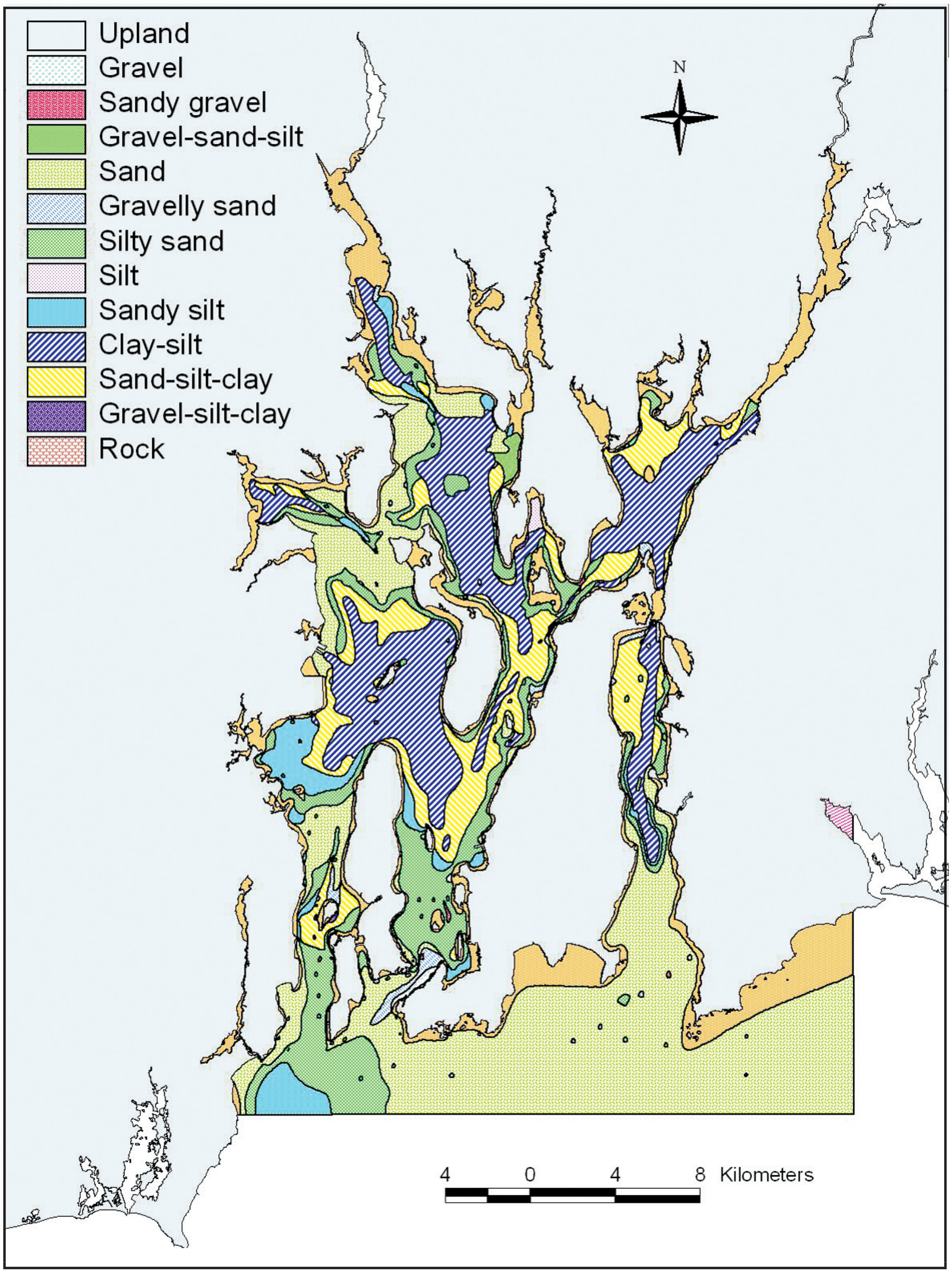

Figure 7.6. Sediments of Narragansett Bay. All sediment data are from McMaster (1960). Unclassified areas were either not sampled or not coded during the study. Note the dominance of clay-silt sediments in the mid- and upper Bay regions, and the coarser sediments lower in the Bay. Data sources: RIGIS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

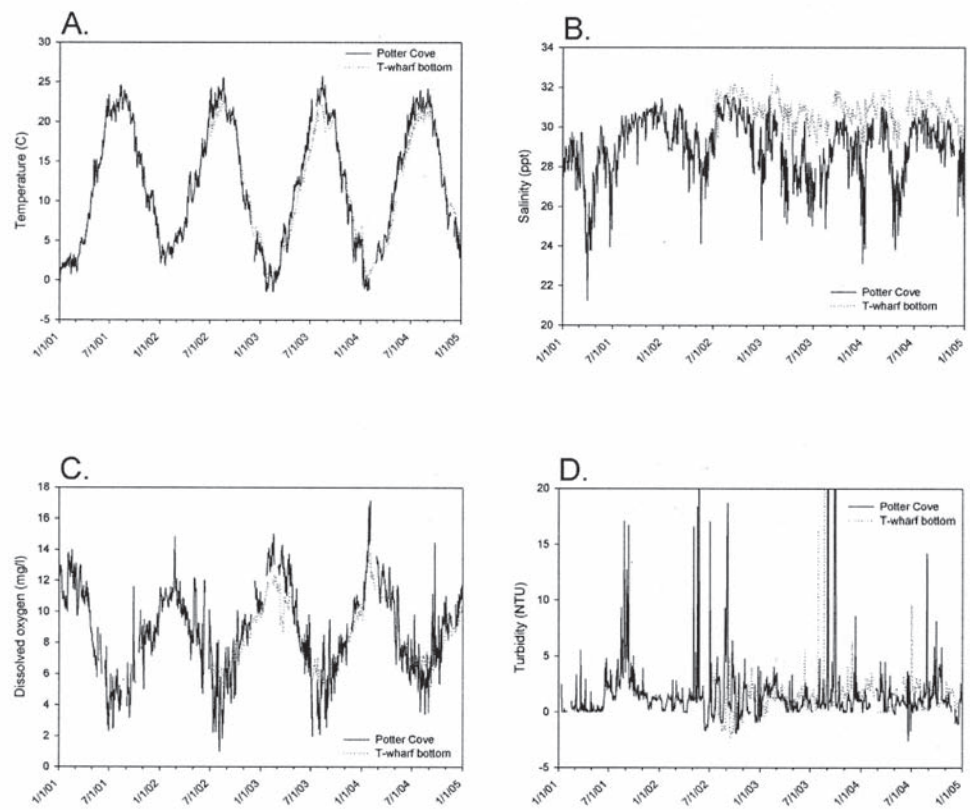

Figure 7.7. Time series of water-quality parameters in Narragansett Bay. All data were taken from the NBNERR SWMP stations at T-wharf and Potter Cove between January 2001 and December 2004. At both stations, readings were taken from approximately 1 m off the bottom. A. temperature; B. salinity; C. dissolved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