

Long-term Monitoring Program
Narragansett Bay
National Estuarine Research Reserve



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The Narragansett Bay National Estuarine Research Reserve (NBNERR or Reserve) is one of 28 nationally-coordinated research reserves located throughout the coastal United States. The mission of the National Estuarine Research Reserve System (NERRS) is to practice and promote sound stewardship of coasts and estuaries through innovative research, education, and training using a place-based system of protected areas (NERRS 2005). Each reserve is managed through a federal-state partnership with the federal partner being the Estuarine Reserves Division (ERD) of the National Oceanic and Atmospheric Administration (NOAA). State partners vary by reserve and include state environmental and natural resources agencies, universities, and trusts. As of 2010, the 28 reserves were located across 22 states and Puerto Rico and protect over 1.3 million acres of land and estuarine water in 9 biogeographic regions within the United States (www.nerrs.noaa.gov).

The NBNERR was designated in 1980, making it the seventh reserve in the NERRS. It is located in the geographic center of Narragansett Bay and includes 2542 acres of land on Prudence, Patience, Hope, and Dyer islands (Fig. 1). With jurisdiction of an additional 1908 acres of estuarine water adjacent to its coastal properties, the Reserve encompasses and manages a total of 4450 acres of land and water (NBNERR 2010). The overall mission of the Reserve is to preserve, protect and restore coastal and estuarine ecosystems of Narragansett Bay through long-term research, education and training, which is achieved through the integration of its education, research, stewardship, and training programs (www.nbnerr.org; NBNERR 2010). The overall goal of the Reserve's research program is to support, coordinate, and conduct high-quality research and monitoring in Narragansett Bay. It is currently focused on developing and conducting quantitative ecological monitoring programs in the Reserve and Bay to quantify short-term variability and long-term change in estuarine condition and resources. It also conducts targeted research that complements ongoing monitoring, supports the work of visiting scientists and students at the Reserve, and administers funding to support graduate student research.

Ecological monitoring at NBNERR began in 1995 when the NERR System-wide Monitoring Program (SWMP, pronounced 'swamp') was first implemented. At that point, only abiotic meteorology and water quality parameters were the mandatory SWMP monitoring components. Nutrient and chlorophyll *a* monitoring was added to SWMP in 2002 and, more recently, biological monitoring and land use/habitat change mapping components were launched. Although NBNERR monitoring has historically been driven by SWMP, other additional and complementary monitoring efforts have recently been initiated to address local and national issues. In an effort to bring together these monitoring programs in a comprehensive manner, the Reserve has developed an umbrella framework known as the NBNERR Long-term Monitoring Program (LTMP) (Fig. 2, Table 1). By taking a holistic approach, the LTMP will provide data to help scientists and managers better understand the short- and long-term ecological changes that are occurring in the Reserve and Narragansett Bay in response to climate change, restoration, large-scale policy decisions, and other direct and indirect anthropogenic stressors.

Most, but not all, LTMP monitoring occurs within the boundaries of the Reserve, and efforts are made to integrate this site-based monitoring into broader local and national efforts. At the national level, this includes aligning the LTMP with the NERRS 5-year Research Plan (NERRS 2006), the NERRS SWMP Plan (NERRS 2007, currently under revision), and the NERRS Climate Change Strategy (NERRS 2008), among others. Locally, it includes aligning the LTMP with the NBNERR Site Profile and Management Plans (NBNERR 2009 and 2010, respectively), the Rhode Island Aquatic Invasive Species Plan (RIAISP)

(Aquatic Nuisance Species Task Force 2007), the Bay Window monitoring program (Sherman 2006), and the Rhode Island Bays, Rivers, and Watersheds Plan (RIBRWP) (Colt 2008). In addition, the University of Rhode Island's Coastal Institute has compiled a list of ongoing estuarine monitoring programs in and around the Bay (www.ci.uri.edu/Projects/RI-Monitoring/Docs/RIEMC_Inventory.pdf); this list is consulted when new monitoring components are under consideration for inclusion in the NBNERR-LTMP.

Due to the extensive amount of ongoing monitoring relative to the size of the NBNERR research staff, only a subset of LTMP components are monitored each year. These are determined based on needs, requirements (e.g., SWMP abiotic monitoring is a federal requirement every year), funding, and staffing levels and is generally pre-determined one or more years in advance. When possible, any new component monitored by NBNERR will have a statistically-robust protocol associated with it prior to its inclusion in the LTMP. If a protocol does not already exist in the peer-reviewed scientific literature or at another agency, the necessary pilot data will be collected and then used to develop a new protocol (e.g., Raposa and Dapp 2009, Raposa and Bradley 2010). However, all of this only applies to LTMP components that are monitored directly by NBNERR; other components that are monitored within NBNERR by other partner agencies (Fig. 2) follow their own schedules and protocols.

The goals of this document are to:

- 1) Provide an overview of the NBNERR LTMP;
- 2) Illustrate monitoring components along a profile extending from coastal upland to subtidal estuarine habitats;
- 3) Provide a one-page description of key monitoring components, and;
- 4) Briefly describe additional monitoring components, gaps, and future monitoring directions.

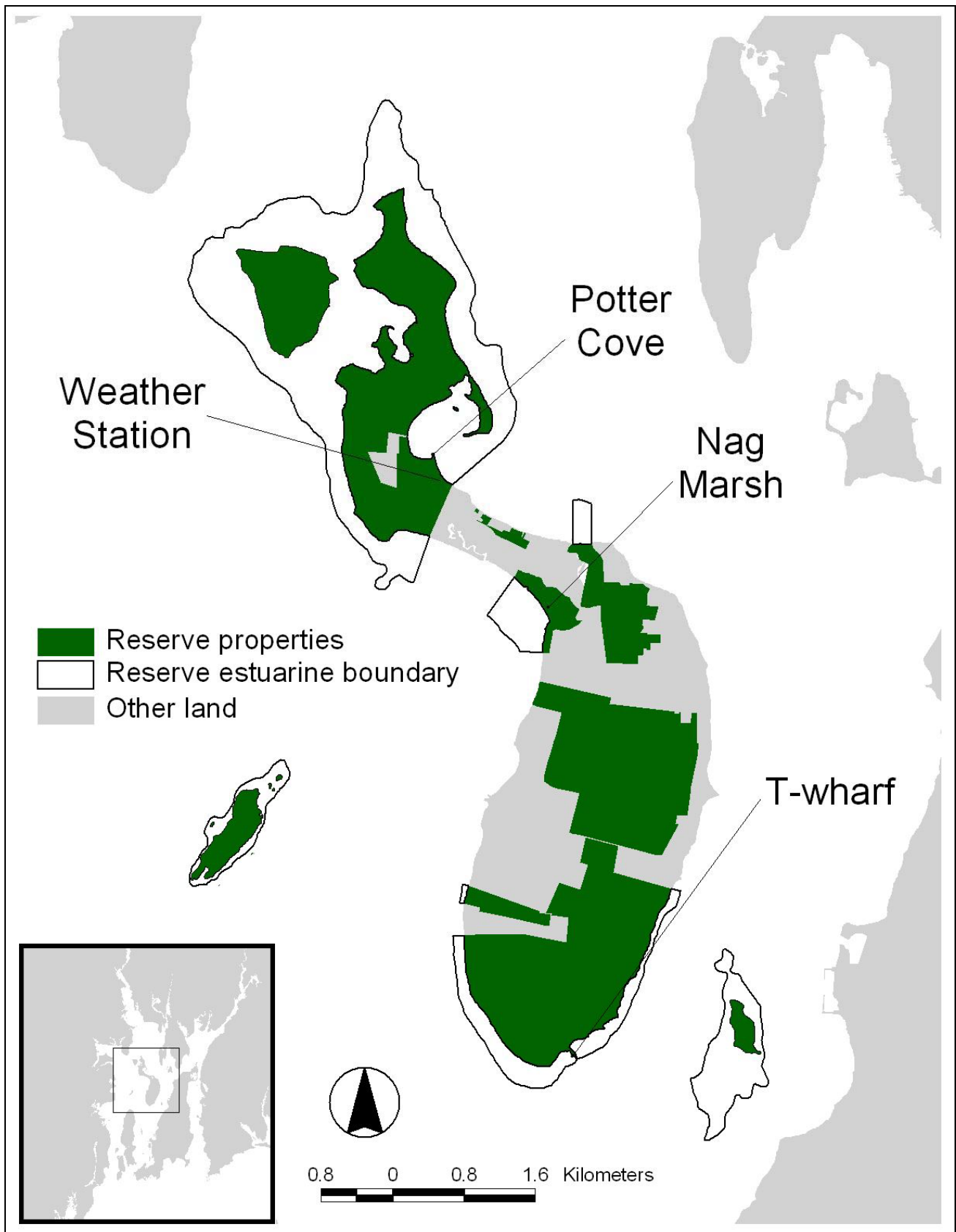


Figure 1. Map of the Narragansett Bay Research Reserve showing the locations of the Reserve’s properties, weather station, and three water quality monitoring sites at Potter Cove, Nag Marsh and T-wharf.

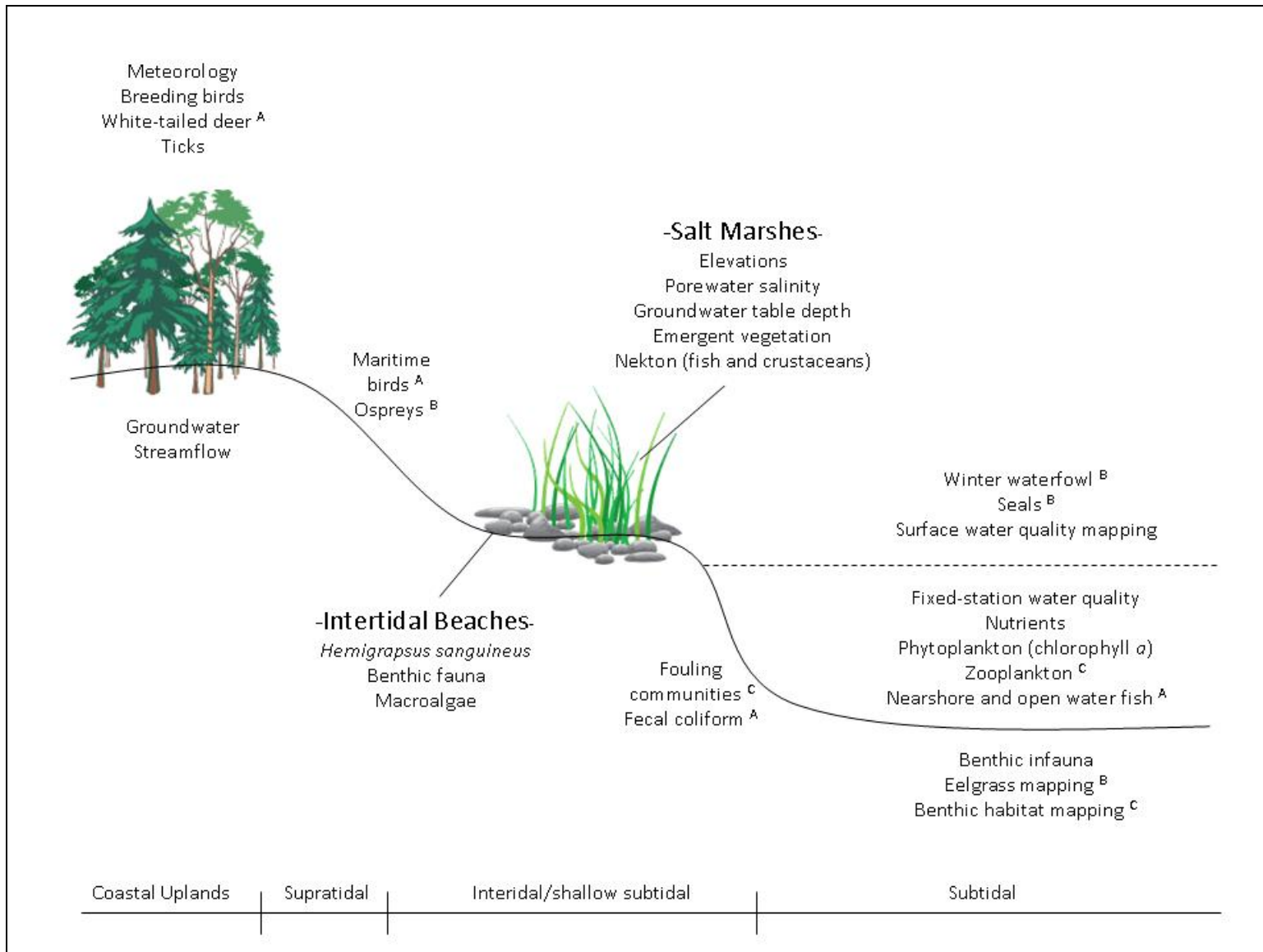


Figure 2. Ongoing and potential new long-term monitoring components within the NBNERR visualized along a profile from coastal upland to subtidal estuarine habitats. A=key monitoring component collected by another group/agency; B=monitored collaboratively between NBNERR and others; C=potential new NBNERR monitoring component.

Table 1. Timeline for the NBNERR LTMP showing the components that are monitored within each zone, and the years in which they have been monitored. Components that will be monitored in 2011 are projections only. This table only includes monitoring that is coordinated and conducted by NBNERR staff. X=monitoring conducted within NBNERR; x=monitoring conducted outside NBNERR. Bold and Italics indicate those monitoring components that are required as part of SWMP.

Zone	Component	1995-1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Coastal Upland	Breeding Birds						X	X	X	X	X	X		X	X
	Groundwater									X	X	X	X	X	X
	Meteorology				X	X	X	X	X	X	X	X	X	X	X
	Stream Flow									X	X	X	X	X	X
	Ticks												X	X	X
Intertidal	Ospreys												X	X	X
Supratidal	Intertidal beach invertebrates										X	X/x	X	X/x	X
Shallow Subtidal	Macroalgae												X	X	X
	Salt Marsh elevations												X	X	
	Salt marsh hydrology											X/x	X/x	X/x	
	Salt marsh nekton			X			X	X	x	X	x	x	x	x	X/x
	Salt marsh vegetation			X			X	X				X/x	X/x	X/x	X
Subtidal	Benthic infauna													X	X
	Nutrients					X	X	X	X	X	X	X	X	X	X
	Phytoplankton (Chlorophyll <i>a</i>)					X	X	X	X	X	X	X	X	X	X
	SAV (eelgrass)									X/x			X		X/x
	Water Quality	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Water Quality Mapping (Dataflow)										x	x		x	x

SWMP METEOROLOGY AND WATER QUALITY

A fundamental component of any comprehensive estuarine monitoring program is the collection of physical, chemical, and geological abiotic data. Many of these parameters provide a direct link between external forcing factors (e.g., global climate change, watershed development patterns, etc.) and ecosystem processes and estuarine biology. It would not be possible to explain biological patterns observed from monitoring without simultaneously monitoring the potential causative abiotic factors. In recognition of this, the NBNERR has been monitoring a suite of meteorological and estuarine water quality parameters in Narragansett Bay for over 15 years.

The Reserve's meteorological and water quality monitoring is conducted as part of SWMP, which is the signature program of the NERRS. The SWMP was established to collect a broad suite of water quality and meteorological parameters for tracking short-term variability and long-term changes in estuarine environments. It is being implemented at each reserve where abiotic, biological, and land use/habitat change monitoring are core components of the program. The abiotic component includes the collection of 1) water quality data from at least four stations per reserve, 2) meteorological data from at least one weather station per reserve, and 3) monthly nutrient and chlorophyll data from the same water quality stations.

NBNERR began collecting water quality parameters from Potter Cove in 1995, from T-wharf in 1996, and from Nag Marsh in 2002 (Fig. 1). These stations were selected to represent a gradient in habitat types, from salt marsh (Nag Marsh), to shallow cove (Potter Cove) to open water (T-wharf). The T-wharf site includes a surface and a bottom station in order to examine patterns in stratification. Water temperature ($^{\circ}\text{C}$), salinity (ppt), dissolved oxygen (% saturation, and mg L^{-1}), pH, turbidity (NTU), and chlorophyll a ($\mu\text{g L}^{-1}$) data are collected at each station every 15 minutes. Meteorological data have been collected at NBNERR since 2001 from a weather station located near the Potter Cove water quality monitoring station (Fig. 1). Air temperature ($^{\circ}\text{C}$), relative humidity (%), wind speed (m s^{-1}), wind direction (degrees), barometric pressure (mb), precipitation (mm), and photosynthetically active radiation (PAR, mmol m^{-2}) data are collected every 5 seconds. Nutrient and chlorophyll data collections began at NBNERR in 2002. The two sub-components of this program include a monthly grab sampling program at each of the four water quality stations and a diel monitoring program each month at the T-wharf Bottom station (since switched to Potter Cove in 2011). All collected samples are analyzed for concentrations of PO_4 , NH_4 , NO_2 , NO_3 , NO_2+NO_3 , DIN, SiO_4 , and chlorophyll a .

SWMP data from all NERR sites, including NBNERR, are included in the national Integrated Ocean Observing System (IOOS; www.ocean.us/ioos_system) and represent the only nationally-coordinated set of estuarine water quality and weather data with real-time capabilities included in this system. They are also part of the Hydrometeorological Automated Data System (HADS; www.nws.noaa.gov/oh/hads/), which provides near real-time data to the nation's Hydrologic Services program. NBNERR SWMP data are an integral part of the fixed-site water quality monitoring network component of the Narragansett Bay Window (Sherman 2006, Stoffel and Kiernan 2009). NBNERR SWMP data continually provide an invaluable resource for researchers (e.g., Altieri and Witman 2006, Calabretta and Oviatt 2008, Codiga et al. 2009), and are used by the RIDEM Office of Water Resources to identify and define impaired waters in the Bay based on dissolved oxygen criteria (Stoffel, personal communication). Near-real time NBNERR SWMP data and annual reports beginning in 2007 are posted on www.nbnerr.org. SWMP Data from all NERR sites are also posted and available for download on www.nerrs.noaa.gov and www.cdmo.baruch.sc.edu/.

High-resolution spatial mapping of water quality parameters is an ongoing need in Narragansett Bay. At present, water quality conditions in the Bay are monitored annually by a multi-institutional collaborative team under the umbrella program known as the Narragansett Bay Window (Sherman 2006). Three integral components of the Bay Window are the fixed-site water quality monitoring network, the mobile Mariner Shuttle surveys, and the Insomniac surveys. The fixed-site network includes 13 water quality monitoring stations (including the Potter Cove and T-wharf SWMP sites) located throughout Narragansett Bay (Deacutis and Kiernan 2006). The Mariner Shuttle program uses a ship-towed shuttle that is equipped with water quality sensors and has the ability to undulate between surface and bottom waters (Berman et al. 2006). The Insomniac program collects vertical water quality profiles at dozens of stations in upper Narragansett Bay during summer to examine dissolved oxygen patterns (Deacutis and Kiernan 2006). Although these programs each contribute to an increased understanding of Narragansett Bay water quality conditions, there remains a need for a spatially robust water quality monitoring and mapping program in the Bay's numerous shallow coves and embayments (Oviatt and Kiernan, personal communication). The dataflow monitoring component of the LTMP seeks to address this need.

Dataflow originated as a high-resolution spatial water quality mapping program in portions of Chesapeake Bay in 1992 (e.g., Smail et al. 2005). It is essentially a flow-through water quality monitoring system that can be mounted on a small boat and used to map surface water quality parameters at speeds of up to 20 knots or more. The system is equipped with a YSI 6000-series datalogger to measure water quality and a GPS to simultaneously measure spatial location for each data point (Raposa and Durant 2008). The same dataloggers are used throughout the Bay Window fixed-site network, which facilitates data integration among the two programs.

In 2007, NBNERR piloted the use of dataflow in Greenwich Bay, which is a sub-estuary of Narragansett Bay (Raposa and Olmeta 2008). Based on this successful pilot and on discussions with local scientists and managers, NBNERR adopted an informal plan to use dataflow to map selected shallow coves and embayments throughout Narragansett Bay on a rotating inter-annual basis. In 2008, the Reserve used dataflow to map summer water quality conditions in both Greenwich Bay and Wickford Harbor (Raposa and Durant 2008). Dataflow cruises did not occur in 2009 while a new version was built, but the program resumed again in 2010 in the Sakonnet River. Four to six dataflow cruises are generally undertaken each summer, with each cruise following a pre-determined cruise track throughout the study area. Surface water quality data are collected every four seconds throughout the duration of each cruise. Approximately six stops are made during each cruise in order to collect additional ancillary data including secchi depth, chlorophyll, and light extinction. These high-resolution spatial water quality data are then used to develop maps of water quality conditions throughout the study areas and can be used to identify spatial patterns in surface water quality.

The dataflow monitoring component of the LTMP is particularly useful for examining the effects of recent large-scale regulatory activities. For example, the ongoing nutrient input reduction effort is expected to affect ecosystem processes throughout the Bay, but its effects on shallow coves and embayments will remain largely unknown due to a lack of monitoring data. Dataflow will address this gap. Dataflow is included in annual reports to the RIBRWP (Rhode Island Environmental Monitoring Collaborative 2009) and is informally included within the Narragansett Bay Window program. At this time, technical reports from the 2007 and 2008 dataflow cruises are posted on www.nbnerr.org.

Eelgrass (*Zostera marina* L.) is a species of submerged aquatic vegetation (SAV) that grows in shallow coves and embayments in temperate estuaries around the world. Eelgrass removes dissolved nutrients from the water column and sediments and can help reduce water column turbidity (Dennison et al. 1993). Eelgrass beds help stabilize sediments and limit erosion by reducing wave action and currents (Fonseca et al. 1982, Harlin et al. 1982, Fonseca et al. 1983, Fonseca 1996). Eelgrass is also an important forage and refuge habitat for many commercially important fin and shellfish such as scallops and juvenile flounder (Dennison et al. 1993, Raposa and Oviatt 2000). Despite these benefits, eelgrass is threatened by human-related problems including disease, mechanical disturbance, and nutrient-enrichment and water clarity issues related to watershed land-use practices (Short and Wyllie-Echeverria 1996, Duarte 2002).

In recognition of the values it provides and the threats it faces, eelgrass has been deemed a critical marine resource and is currently protected by both Federal (Clean Water Act; 33 U.S.C. 26 section 1251 et seq) and Rhode Island legislation (RI Coastal Resource Management Program). In Narragansett Bay, additional protection is provided by the Reserve, which prohibits anchoring and shellfishing in eelgrass beds within the Reserve's boundaries. Unfortunately, only 1.6 km² (approximately 400 acres) of eelgrass currently remain in the 342 km² Narragansett Bay (i.e., approximately 0.5% of the Bay area) (Chinman and Nixon 1985, Bradley et al. 2007), but trends in eelgrass between the most recent Bay-wide surveys in 1996 and 2006 remain unclear (Bradley et al. 2007). Additional mapping and monitoring in the future will therefore help identify how eelgrass in Narragansett Bay is changing over time in response to watershed-based anthropogenic impacts, climate change, and other local management and regulatory activities.

A variety of tools and methods are available for monitoring eelgrass, but each has its associated set of benefits and drawbacks. A new hierarchical strategy for monitoring eelgrass in northeast US estuaries has been developed (Neckles et al. unpublished data) and this same strategy is now recommended by the Rhode Island SAV Mapping Task Force (Raposa and Bradley 2009). The three components of this approach include large-scale mapping using aerial photography (Tier 1), a rapid mapping assessment using underwater video (Tier 2), and site-specific underwater monitoring using divers, transects, and quadrats that is analogous to Seagrassnet (Tier 3). While NBNERR will continue to promote and assist with Tier 1 aerial-photograph mapping throughout the Bay and support Save The Bay-based Tier 3 monitoring at T-wharf, the focus of its eelgrass mapping program will be on the Tier 2 rapid assessment procedure. This was successfully piloted in 2009 in Quonochontaug Pond (Raposa and Bradley 2010) and is planned for a similar pilot effort at the Reserve in 2011 to adapt these methods for use in Narragansett Bay. Once the pilot within the Reserve is completed, this Tier 2 monitoring approach will be developed into the long-term quantitative eelgrass monitoring component within the NBNERR-LTMP, and it will complement future Tier 1 and Tier 3 efforts.

Eelgrass mapping remains a top priority for Narragansett Bay scientists and managers (Raposa and Bradley 2009). It is listed as a core indicator in the Narragansett Bay Estuary Program's Status and Trends Report (NBEP 2009) and is a primary focus of ongoing SWMP biological monitoring (Moore 2010). While NBNERR will assist with any future efforts to map eelgrass throughout Narragansett Bay, the rapid assessment project that will begin in 2011 will provide a localized annual or biannual dataset of eelgrass distribution and cover to better track responses of this resource to various agents of change. Results from the 2006 Bay-wide mapping effort are posted on www.nbnerr.org, and all data from the new rapid assessment program will be posted on this website as well.

BENTHIC INFAUNA

Benthic infaunal communities play an important role in the ecology of marine and estuarine environments by affecting water and sediment quality. These organisms aid in the recirculation of nutrients, and they mix, sort, and oxygenate bottom sediments via burrowing and feeding activities. Benthic infaunal organisms are relatively sedentary which minimizes their ability to avoid deteriorating conditions within the water column and bottom sediment. These characteristics led the US Environmental Protection Agency (EPA, <http://www.epa.gov/bioiweb1/html/marinetidal.html>) to consider macrobenthic organisms (metazoans >500 µm in size) as bioindicators of the health of aquatic environments.

Several studies on benthic infauna have been conducted in Narragansett Bay (Rudnick et al. 1985, Frithsen 1989, Ellis 2002, Calabretta and Oviatt 2008). However, qualitative and quantitative studies of the benthic infauna around Prudence Island have not been conducted and long-term benthic monitoring in the Bay is lacking. The Reserve's new benthic infaunal monitoring program described here will fill these gaps. The goal of this program is to characterize the benthic macrofauna and meiofauna communities at three locations around Prudence Island as the initial first step for developing a long-term biological monitoring component that will be included in the NBNERR-LTMP. When fully functional, this monitoring component will allow the Reserve to:

- 1) Quantify population and community metrics (e.g., density, biomass, diversity, richness, etc.) of the benthic infaunal community around Prudence Island and track them over time;
- 2) Compare these metrics along a gradient in estuarine habitat types, and;
- 3) Provide data for assessing the long-term changes in benthic communities in response to large-scale anthropogenic nutrient reductions in the Bay, climate change, and other factors.

As part of the pilot program, benthic infaunal communities and associated sediments around Prudence Island are being sampled seasonally at the Potter Cove, Nag Marsh, and T-Wharf SWMP stations. At present, samples have already been collected in each of the four seasons in 2010 and in the winter of 2011. During each sampling event, three locations at each station are randomly selected a priori using geographic information systems (GIS). At each location, infaunal and sediment cores are collected to a depth of approximately 10 cm with small hand-held coring devices, returned to the laboratory, preserved with formalin and stained with Rose Bengal. Sediment samples are then processed to quantify grain size composition and organic content. Infaunal samples are separated into 0-2 cm and 2-10 cm intervals (to separate out opportunistic surface fauna), sieved into four size fractions (<45 µm, 45-300 µm, and 300-500 µm, and >500 µm), and sorted. All benthic fauna are then identified to the lowest possible taxonomic level and counted.

This monitoring component directly addresses goals and objectives in the NERR SWMP Plan (NERRS 2007), the 2006-2011 NERR Research and Monitoring Plan (NERRS 2006), and the 2010-2015 NBNERR Management Plan (NBNERR 2010). The initial surveys will provide valuable baseline reference data for future use at the SWMP stations and other sites around Narragansett Bay. In addition, by monitoring the ecology and composition of the benthic communities around Prudence Island over the long term it might be possible to link any alterations to benthic community structure with changes in nutrient concentrations, climate change (i.e. water temperature changes), and other anthropogenic factors. Technical reports and benthic monitoring data will ultimately be posted for viewing and downloading on the Reserve's website at www.nbnerr.org.

Salt marshes provide valuable habitats for economically important fish, crustacean, and waterfowl species; protect coastal areas against storm surges and floods; and enhance estuarine water quality by intercepting land-based nutrient inputs (Dean 1979, Brush et al. 1986, Able et al. 1988, Heck et al. 1995, Howes et al. 1996). Unfortunately, these and other ecosystem services were compromised when extensive areas of marsh along the coastal United States were either outright destroyed or otherwise degraded by humans dating back to colonial times. For example, Bromberg and Bertness (2005) have documented that 37% of original salt marshes have been lost throughout the New England region, with the highest rate of loss (53%) along the heavily-developed Rhode Island coast. More recently, an increased awareness of the values that salt marshes provide has resulted in a subsequent increase in the number of efforts to restore degraded marshes. Many restoration projects unfortunately suffer from a lack of quantitative ecological monitoring, and equally problematic is the general lack of data from reference salt marshes to which data from restoration sites can be compared. To help address these needs, the NBNERR has been intermittently monitoring salt marsh structural parameters for a decade beginning with its assessment of the Potter Pond salt marsh restoration (Raposa 2009). More recently, the Reserve entered into a 3-year project with 4 additional reserves to conduct coordinated salt marsh monitoring at a national scale. These prior efforts now provide the foundation on which the salt marsh monitoring component of the NBNERR-LTMP will be built.

The LTMP salt marsh component will include the monitoring of numerous marsh-related parameters. These include nekton (fishes and decapod crustaceans), vegetation, hydrology, and elevations. Quantitative monitoring protocols for each of these parameters are well-defined and some have been in use over broad geographic areas for years (e.g., Raposa and Roman 2001, James-Pirri et al. 2007). For the LTMP, these parameters will be monitored in both Coggeshall and Nag salt marshes in order to establish these sites as the premier long-term salt marsh monitoring sites in Narragansett Bay. Monitoring will also be conducted at additional newly-restored marshes both within and outside the Reserve in order to assess the long term effects of tidal restoration. The specific parameters that will be monitored and the monitoring frequency for each will be determined based on the needs of each site. Thus, over time the LTMP salt marsh monitoring component will set up Reserve marshes as long-term reference sites that can be used to 1) evaluate how natural salt marshes are changing over time in response to the large-scale effects of global climate change and sea-level rise, and 2) evaluate the ecological changes at restoring marshes around Narragansett Bay as they recover from tidal restrictions.

The NBNERR-LTMP salt marsh component will provide long-term ecological data for salt marshes within and around the Reserve and will enable scientists and managers to assess how these marshes are changing over time in response to climate change, restoration, and other natural and anthropogenic stressors. Salt marsh monitoring is now operational within the NERR biomonitoring program, is a key component of the NERR Sentinel Site vision (Saumweber et al. 2010), and is listed in the RIBRWP (Colt 2008); the NBNERR-LTP will thus address needs and link with each of these broader plans. Published data from this monitoring component can be found in Raposa (2009) and Raposa and Weber (2009; posted on www.nbnerr.org). This same website will soon host another report summarizing three years of monitoring (2008-2010) as well as available salt marsh monitoring data collected by the Reserve in Narragansett Bay.

At low and moderate biomass levels, macroalgae can provide excellent habitat for juvenile nekton and forage for waterfowl (Smith et al. 1985, Raposa and Oviatt 2000). However, excessive nutrient inputs can lead to equally excessive nuisance macroalgal blooms that can blanket shorelines, emit foul odors, and lead to locally hypoxic and anoxic conditions. Because of this, macroalgal blooms can also be used as an indicator of estuarine eutrophication (Nedwell et al. 2002). In Narragansett Bay, nuisance macroalgal blooms are common during the summer months and are primarily driven by nutrient pollution as a result of excessive discharges from waste water treatment facilities (WWTFs) (Granger et al. 2000). Upgrades to 11 Rhode Island WWTFs are ongoing and will eventually reduce summer nitrogen inputs from these facilities to the Bay by approximately 50% by 2014. It is expected that these reductions will subsequently reduce macroalgae cover and biomass in the Bay, but this can only be verified with quantitative macroalgal monitoring conducted before and after the reductions are completed.

Despite its ecological importance and problematic distribution throughout much of Narragansett Bay, very few algae survey or monitoring efforts currently exist in the Bay. One exception is the ongoing monthly aerial surveys of macroalgal distribution and cover across much of the western shoreline and upper Bay regions, conducted by the Narragansett Bay Estuary Program (NBEP) and partners since 2006 (<http://www.nbep.org/bay-science-macro.html>). These data provide a larger-scale view of algae and can be used to make maps of the distribution of algal groups, but they do not provide smaller-scale quantitative data for a specific site or species. The Rapid Macroalgal Assessment (RMA) component of the NBNERR-LTMP is a new macroalgae monitoring program in the Bay that seeks to address this gap.

The RMA monitoring component was developed for the NBNERR-LTMP to provide fast, reliable, and quantitative data on algal composition, distribution, and cover around Prudence Island, where the Reserve is based. This component was initiated as a pilot project in 2009, and was slightly refined and improved in 2010. The RMA was initially based on methods that were adapted from Lyons et al. (2009) on Cape Cod, MA. At NBNERR, five macroalgal surveys were conducted between June and October in both 2009 and 2010. Sampling was conducted at 31 points along the entire coast of Prudence Island, with these points representing the midpoints of 1-km stretches of shoreline. At each point, the abundance of macroalgae was evaluated on a scale of 0-5 in both subtidal and intertidal zones. Algae that was present was identified to the lowest possible taxonomic group and preferably to species. A field guide to the common macroalgal species found around Prudence Island was drafted in 2010 and will aid in identification and monitoring consistency in future years. During the winter of 2010/2011, the Reserve will analyze the first two years of data in order to refine and improve the quantitative macroalgae monitoring protocol moving forward.

The RMA component of the NBNERR-LTMP addresses issues raised in a number of systems-level plans and strategies. Although the RMA does not target invasive species, it is poised to capture them if any new invaders reach Prudence Island. It therefore links with the RIAISP (Aquatic Nuisance Species Task Force 2007), which in turn is included in the RIBRWP (Colt 2008). Finally, if the NBEP aerial surveys can be extended to include Prudence Island, the RMA could be an effective groundtruthing component of those flights and help to link the two datasets. The RMA is an easy, rapid, and quantitative monitoring component of the NBNERR-LTMP and it could easily be adopted by other groups to expand this kind of monitoring in Narragansett Bay.

While sandy beaches, rocky intertidal zones, and salt marshes are all conspicuous intertidal habitats in New England, they each comprise a relative small portion of Narragansett Bay's shoreline. Instead, most of the Bay's shoreline is dominated by stretches of unconsolidated beaches that are made up of glacially deposited boulders, cobble, gravel, and other smaller-sized particles (Bruno 2000).

Unconsolidated beaches are valuable as refuge and forage habitats for both estuarine and terrestrial fauna, and this value is often enhanced when patches of fringing *Spartina alterniflora* beds colonize cobble zones. Unconsolidated beaches intermixed with fringing *Spartina* beds make up virtually the entire shoreline of Prudence Island, where most of the Reserve is located. Exceptions include small areas of fully-developed meadow salt marsh on the northern half of the island and bedrock outcroppings along the southern end. The prevalence of this valuable yet relatively understudied habitat clearly indicates that more research and monitoring should focus on unconsolidated beaches. The NBNERR has therefore added the monitoring of invertebrate communities within unconsolidated beaches to its LTMP as a first step.

At present, this component of the NBNERR-LTMP includes the concurrent monitoring of the invasive Asian shore crab (*Hemigrapsus sanguineus*) and cobble beach invertebrate communities (although macroalgae in intertidal beaches is also monitored via a separate component of the LTMP – see p. 13). The Asian shore crab was first discovered off the coast of New Jersey in 1988 (McDermott 1991) and has since become common along the east coast of the United States. It is ubiquitous along unconsolidated beaches comprised of cobble and boulders and now represents over 98% of all crabs in this habitat in Narragansett Bay (Rohr and Raposa unpublished data). It is a voracious omnivore and can impact juvenile mussels and other shellfish where it is abundant (Ledesma and O'Connor 2001, Tyrrell et al. 2006). Moreover, despite it being one of the most common and recognizable invasive species in Narragansett Bay, there are currently no ongoing efforts to monitor this species, except by the NBNERR as part of the LTMP. For these reasons, this LTMP component couples Asian shore crab monitoring with intertidal beach invertebrate monitoring to better understand the effects of this invasive crab on intertidal beach resources. The *H. sanguineus* component of the LTMP began in 2007 with a gear and protocol development phase. By 2008, annual monitoring began and was coupled with a Bay-wide survey to examine patterns on a larger scale. By 2010, annual monitoring was streamlined to conducting monthly quadrat surveys at four sites in NBNERR from June through October when crabs are most abundant. Invertebrate sampling, which began in 2009, uses a smaller quadrat embedded into the *Hemigrapsus* quadrat to quantify all terrestrial and aquatic invertebrates.

The goals of this LTMP monitoring component are to 1) quantify the density and demographic characteristics of Asian shore crab populations in the NBNERR over time, 2) quantify physical factors at each crab sampling site to help explain any observed patterns in crab distribution and density, and 3) explore relationships between Asian shore crabs and beach invertebrate communities, with an emphasis on identifying any potential impacts of crabs on commercially important bivalve species. This work builds on similar invasive crab monitoring elsewhere in the NERRS (Riggs 2003), addresses critical needs outlined in the RIAISP (Aquatic Nuisance Species Task Force 2007), and is included in annual monitoring reports to the RI Bays, Rivers, and Watershed Coordination Team (e.g., RI Environmental Monitoring Collaborative 2009). Moving forward, it is envisioned that this work might also grow into a collaboration between the NBNERR research and education sectors that is similar to the Washington State University's Beach Watchers program (<http://www.beachwatchers.wsu.edu/regional/index.php>).

In addition to the seven monitoring components described above, numerous other components are also being monitored either as part of the NBNERR-LTMP or in general association with the Reserve. In coastal upland habitats this includes breeding birds (monitored by NBNERR since 2003), white-tailed deer (monitored by the Rhode Island Department of Environmental Management [RIDEM] since 1977), ticks (monitored by NBNERR since 2009), and groundwater table levels and streamflow (monitored by NBNERR since 2006). In supratidal and nearshore habitats, RIDEM has been monitoring populations of maritime nesting birds throughout coastal Rhode Island, including in the NBNERR, since 1964 (Ferren and Myers 1998). The Reserve has also been assisting RIDEM and the Audubon Society of RI with annual osprey monitoring since 2003 and RIDEM with fecal coliform monitoring since 2008. In the open waters of the Bay, additional monitoring components include winter waterfowl, shallow- and open-water fish, and seals. The NBNERR has monitored winter waterfowl abundances each year since 2005 as part of a Bay-wide effort coordinated by the Environmental Protection Agency's Atlantic Ecology Division (<http://www.epa.gov/emap/aed/html/research/fowl/>). The RIDEM has been monitoring fish and select crustaceans in shallow-water habitats with its long-term seining program since 1990 and in deeper open water with its trawling program since 1979; both programs have multiple stations located within the NBNERR. Finally, NBNERR and Save The Bay began coordinating at least one Bay-wide seal survey each year in 2010. This is accomplished by simultaneously surveying all known seal haul-out locations on a single date and this includes 4 sites in the NBNERR (Raposa and Dapp 2009). Details on each of these additional monitoring components will soon be posted on the Reserve's website (www.nbnerr.org).

Future directions include refining and improving existing monitoring protocols, improved planning of which components will be monitored in out years, and filling monitoring gaps by adding new components to the NBNERR-LTMP. Potential improvements to existing monitoring protocols that are currently under consideration include statistically determining a reduced sample size to improve the efficiency of macroalgae monitoring, improving the standardization of benthic epifauna and infauna sampling on unconsolidated beaches, and finalizing comprehensive guides to the macroalgae and beach invertebrates of the NBNERR to assist new staff with field identifications in future years.

Potential new monitoring components under consideration include benthic habitat mapping, zooplankton, settling plates for fouling communities, and additional salt marsh parameters that are outlined in the new NERR-SWMP plan. Benthic habitat mapping within the Reserve has been an ongoing priority for well over a decade (Deacutis, personal communication) and would also contribute to the newly emerging mapping toolkit of the revised SWMP plan. Zooplankton is a key trophic component of any phytoplankton-based estuary (like Narragansett Bay) and is an obvious gap in the NBNERR-LTMP. Zooplankton has been historically monitored by URI-GSO, though only at one station, and only up until 2005; subsequently, zooplankton has been listed by URI-GSO as a top priority for future monitoring in the Bay (<http://www.ci.uri.edu/Projects/RI-Monitoring/Docs/Narragansett%20Bay%20Monitoring.pdf>). Settling plates are a commonly used method for quantifying populations and communities of fouling organisms on hard substrates and are useful for tracking invasions of non-native species (Harris and Dijkstra 2007). This method has been recommended as a long-term monitoring tool for use throughout the NERRS (Wasson et al. 2002), although this idea has not yet come to fruition. Settling plates are not currently used in Narragansett Bay, nor are invasive estuarine species (aside from *H. sanguineus*) consistently monitored with a

quantitative protocol in the Bay; adding this component to the NBNERR-LTMP would address these gaps. A number of key indicators of salt marsh condition are listed in an internal NERRS proposal to develop NERR salt marshes into Sentinel Sites for detecting long-term ecological changes due to multiple stressors (Saumweber et al. 2010). These include installing surface elevation tables, monitoring porewater, and analyzing sediments; adding some or all of these marsh parameters would greatly improve the salt marsh component of the NBNERR-LTMP.

The refinements to existing components and additions of new monitoring components and parameters as described above will clearly improve the NBNERR-LTMP. The regular publication of reports and manuscripts to the NBNERR Technical Reports Series (<http://www.nbnerr.org/techreports.htm>) and peer-reviewed scientific journals, combined with regular postings of monitoring data to a revised NBNERR website will greatly improve the visibility of the LTMP as well. The NBNERR-LTMP is clearly a work in progress. However, data for some of its components date back over 15 years, the number of monitoring components has rapidly expanded in recent years, and when fully operational the LTMP will represent one of the most comprehensive long-term ecological monitoring programs in Narragansett Bay.

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