Narragansett Bay
*Research Reserve*

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# NERRS Reference Sites Project: Final Report from the Narragansett Bay Research Reserve

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# Overview

## *Rationale and Study Design*

Salt marshes provide valuable habitats for economically important fish, crustacean, and waterfowl species (Daiber 1982). They also protect coastal areas against storm surges and enhance estuarine water quality by intercepting land-based nutrient inputs (Costanza et al. 1997). 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) 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 National Estuarine Research Reserve System (NERRS) and the NOAA Restoration Center entered into a three-year partnership to evaluate the success of numerous restoration projects that were funded with Estuary Restoration Act Funds. The NERRS monitored salt marsh habitats within five reserves to establish baseline reference conditions and simultaneously monitored restoration projects in close proximity to the reserves. The Narragansett Bay (Rhode Island) National Estuarine Research Reserve (NBNERR or Reserve) participated in this partnership, along with the Wells ME, South Slough OR, North Carolina NC, and Chesapeake Bay VA reserves.

At NBNERR, the primary goals of this study were to: 1) develop monitoring protocols, 2) establish monitoring infrastructure at Coggeshall and Nag salt marshes, and 3) conduct initial monitoring. These two marshes were chosen as long-term reference marshes for evaluating how natural salt marshes change over time in response to the large-scale effects of global climate change and sea-level rise, and how the tide-restricted marshes around Narragansett Bay change as they undergo hydrologic restoration. Another goal of this study was to conduct the same ecological monitoring at five marshes that were previously tide-restricted, but have recently been restored (Gooseneck Cove Marsh, Newport; Jacob's Point Marsh, Warren; Potter Pond Marsh, NBNERR; Silver Creek Marsh, Bristol; and Walker Farm Marsh, Barrington). Basic emergent vegetation (e.g., species richness, cover, height, and stem density), hydrologic (water table depth and soil salinity), and sediment (bulk density, percent organic matter) parameters were measured at all sites in this study. National Geodetic Survey (NGS) bench marks were also installed in association with both NBNERR reference marshes to track changes in marsh elevations and to establish vertical control. Each restoration marsh was paired with an appropriate reference marsh and data for each parameter described above were compared within each marsh pair to evaluate restoration performance.

*Study Sites*

Three of the study marshes (Coggeshall Marsh, Nag Marsh, and Potter Pond Marsh) are located in NBNERR on Prudence Island, which lies in the geographic center of Narragansett Bay (Fig. 1). Walker Farm, Jacob's Point, and Silver Creek marshes are all nearby mainland sites that are located in the heavily developed East Bay section of the Bay. Gooseneck Cove lies just outside the mouth of Narragansett Bay along the southern shore of Newport. All marshes lie within 25 km of one another and range from approximately 2-25 ha in size (Table 1). Coggeshall and Nag marshes are two independent reference marshes with natural tidal hydrologies. Potter Pond, Walker Farm, Silver Creek and Gooseneck Cove marshes are all impacted marshes that have undergone tidal restoration (via removal of hydrologic restrictions) within the last 1-8 years. Jacob's Point is unique among the marshes in that it has a downstream, unrestricted reference portion and an upstream tide-restricted portion that has recently been restored. Considering that Jacob's Point consists of two marshes, the NBNERR portion of this study comprised three reference marshes and five restoration marshes (i.e., eight total marshes).

## Coggeshall and Nag Marshes

The Coggeshall and Nag reference marshes are both located within the NBNERR on the glacial outwash-dominated northern end of Prudence Island (Fig. 2). Coggeshall Marsh is a 25-ha marsh located behind a locked gate on the North End Unit of the NBNERR. Tidal exchange between the marsh and Narragansett Bay occurs along a long vegetated marsh edge and via two main tidal creeks (Fig. 3). Nag Marsh is a 15-ha marsh that is the location of one of the NBNERR's System-Wide-Monitoring-Program (SWMP) long-term water quality monitoring stations (Figs. 2 and 4). Tidal exchange between Nag Marsh and Narragansett Bay occurs through a single tidal creek bisecting the marsh. Based on NBNERR SWMP data, spring and neap tide ranges in Nag Marsh are approximately 0.75 m and 0.35 m, respectively. Salinity in Nag Marsh ranges from approximately 11 ppt to 35 ppt, with a mean value of 27 ppt. These data are not available for Coggeshall Marsh, but are expected to be similar to data from Nag Marsh due to the close proximity of the marshes to each other on Prudence Island.

Coggeshall and Nag marshes are both dominated by typical New England salt marsh vegetation species (e.g., *Spartina alterniflora*, *S. patens*, *Distichlis spicata*, *Juncus gerardii*, *Iva frutescens*, etc.) (Figs. 5 and 6). They both contain a network of historic mosquito-ditches, and are generally lacking in marsh pools and the invasive common reed *Phragmites australis* (hereafter referred to as *Phragmites*). Both marshes are surrounded by undeveloped, natural habitat-types and have never had their tidal exchange restricted by an anthropogenic structure. Researchers from Brown University have long used Nag and Coggeshall marshes as primary research locations (e.g., see Donnelly and Bertness 2001, Bertness et al. 2002, Bertness et al. 2008, among others).

Coggeshall Marsh has also previously served as an experimental control for assessing the ecological effects of the restoration of Potter Pond Marsh (Raposa 2008). All of these qualities serve to make both marshes excellent reference sites that are representative of the urbanized, heavily-populated Narragansett Bay.

### Potter Pond

Potter Pond Marsh is a formerly tide-restricted and impounded marsh/tidal pond complex that is located within the NBNERR on Prudence Island (Figs. 1, 7, and 8). Tidal restoration of this site occurred in March 2003 by replacing two sets of undersized or crushed culverts. Extensive details about all aspects of this restoration project can be found in Raposa (2008). Tidal ranges in Potter Pond under restricted conditions averaged 4 cm; they averaged 120 cm after culvert replacement. Emergent marsh vegetation communities were comprised of typical New England salt marsh vegetation (as described for Nag and Coggeshall marshes above) both before and after restoration, although restoration did induce a decrease in height and cover of *Phragmites* in the upper reaches of the site.

### Walker Farm

Walker Farm Marsh is a formerly tide-restricted marsh that is located in Barrington, RI (Figs. 1, 9, and 13). Tidal restoration of this site occurred during the winter of 2005 with the replacement of undersized culverts with new larger culverts and a water control structure. Restoration and long-term monitoring of this site were coordinated by project partner Save The Bay and extensive details about all aspects of this restoration project can be found at http://www.savebay.org/Page.aspx?pid=301. Spring and neap tidal ranges have not been measured for this site; however, it is expected that the tide ranges are similar to what was described for Nag Marsh above. Similarly, salinity levels have not been comprehensively recorded in Walker Farm except as part of the hydrology monitoring conducted during this study (see below). Walker Farm was heavily invaded by *Phragmites* prior to restoration; although this invasive species decreased dramatically after restoration, it remains the dominant species at this marsh. The rest of Walker Farm is composed largely of *S. alterniflora* and, to a lesser extent, *S. patens* and bare ground that is undergoing colonization by *Salicornia* spp.

### Jacob's Point

Jacob's Point Marsh is located in Warren, RI (Figs. 1, 10, and 13). The marsh as a whole is actually comprised of a downstream unrestricted (i.e., reference) marsh and an upstream marsh that was tide-restricted by a dirt footpath. Tidal restoration of the upstream portion of the site occurred during the winter of 2009-10 by replacing two sets of severely undersized culverts; by digging a series of new ditches to facilitate the transport of tidal water in to the upstream marsh; and by spraying and cutting *Phragmites*. Restoration and long-term monitoring of this site were coordinated by

Save The Bay and extensive details about all aspects of this restoration project can be found at http://www.savebay.org/Page.aspx?pid=610. Spring and neap tidal ranges have not been measured for this site; however, it is expected that the tide ranges are similar to what was described for Nag Marsh above. Similarly, salinity levels have not been comprehensively recorded in Jacob's Point except as part of the hydrology monitoring conducted during this study (see below). The downstream marsh is comprised of typical New England vegetation as described above and has some of the most extensive high marsh salt meadow habitat in the upper Narragansett Bay region. The upstream marsh was heavily invaded by *Phragmites* prior to restoration; after restoration *Phragmites* was reduced dramatically and *Salicornia* spp. and *S. alterniflora* began colonizing the newly exposed mud flats.

## Silver Creek

Silver Creek Marsh is a formerly tide-restricted marsh that is located in Bristol, RI (Figs. 1, 11, and 13). Unlike all the other sites, a freshwater stream enters into the head of Silver Creek and results in lower salinity levels throughout much of the upper portions of the marsh. This site was impacted by three tidal restrictions located in series moving upstream into the marsh. Tidal restoration occurred during the winter of 2008-09 with the removal or replacement of each of these restrictions. Restoration and long-term monitoring of this site were coordinated by Save The Bay and extensive details about all aspects of this restoration project can be found at http://www.savebay.org/Page.aspx?pid=609. Spring and neap tidal ranges have not been measured for this site; however, it is expected that the tide ranges are similar to what was described for Nag Marsh above. Similarly, salinity levels have not been comprehensively recorded in Silver Creek except as part of the hydrology monitoring conducted during this study (see below). Emergent marsh vegetation was generally similar before and after restoration and it varied along a head-to-mouth gradient within the marsh. In downstream portions, typical salt marsh vegetation species were present, while most of the upstream portions of the marsh were dominated by *Phragmites*.

## Gooseneck Cove

Gooseneck Cove Marsh is a formerly tide-restricted marsh that is located in Newport, RI (Figs. 1, 12, and 13). This site was impacted by two tidal restrictions; the first one was an old concrete dam located in the lower third of the marsh channel; the second was a set of undersized culverts located towards the upstream distal end of the channel. The dam was removed and the culverts were replaced during the winter of 2008-09. Restoration and long-term monitoring of this site were coordinated by Save The Bay and extensive details about all aspects of this restoration project can be found at http://www.savebay.org/Page.aspx?pid=299. Spring and neap tidal ranges have not been measured for this site; however, it is expected that the tide ranges are similar to what was described for Nag Marsh above. Similarly, salinity levels have not been comprehensively recorded in Gooseneck Cove except as part of the hydrology monitoring conducted during this study (see below). Under tide-restricted conditions, this site was congested with extensive blooms of filamentous green algae throughout much of the main tidal channel; the vast majority of this algae was gone within the first two summers after restoration. In terms of emergent marsh vegetation, Gooseneck Cove is composed of typical New England salt marsh vegetation (both before and after restoration). Relatively small pockets of *Phragmites* were present before restoration, mostly near the upstream head of the marsh or adjacent to residential housing. These *Phragmites* areas remained after restoration, but were beginning to show signs of stress in terms of reduced heights and cover.

## Methods

### *Vegetation*

Permanent emergent vegetation monitoring transects were established in Coggeshall and Nag marshes in 2008 following the NERRS emergent vegetation biomonitoring protocols (Moore and Bulthuis 2003), which in turn are based on the protocols established for use in the National Park Service (Roman et al. 2001). In each marsh, three transects were established that extended from the marsh/upland edge until intersecting with a primary water body (i.e., creek, pool, or pond; Figs. 3 and 4). The beginning location of each transect was randomly chosen using geographic information systems (GIS) software. Vegetation monitoring plots were then located at intervals of at least 10 m along each of the transects. Plots were permanently marked in the field with 1-m PVC stakes and labeled accordingly. The coordinates of each plot in both marshes were recorded using a global positioning system (GPS) receiver, and these point locations were then exported into a shapefile for use in GIS software. Vegetation monitoring transects were established in the six remaining marshes prior to the beginning of this project. All transects and plots were generally established according to the Roman et al. (2001) protocols although more than three transects were established in each marsh; therefore, these same locations were used again in this project (Figs. 7, 9-12). All plots in each marsh were then assigned to one of three marsh zones (low marsh, high marsh, and the upland transition zone) depending on vegetation species present, elevation, and general location of the plot.

Vegetation communities were sampled in each plot at the end of the growing season in each marsh with 1-$m^2$ PVC quadrats. Quadrats were placed at a fixed offset from each stake in an effort to minimize vegetation trampling (following Fig. 10 in Roman et al. 2001). Parameters monitored within each quadrat included species composition, percent cover of each species, and heights and stem densities of target species (e.g., *S. alterniflora*, *S. patens*, *J. gerardii*, and *Phragmites*) when present. Species composition was determined by identifying all species found within each quadrat. If additional species were found while assessing percent cover, they were added to the species composition list. Percent cover was determined using the point-intercept method in conjunction with a 50-point grid (Roman et al. 2001). Stem densities of target species were quantified by placing a 0.0625 or 0.25 $m^2$ sub-quadrat (the larger quadrat was used for *Phragmites* only) in the upper-right corner of each quadrat (i.e., the corner away from the stake, facing the upland) in which these species were present and counting all live and dead stems. Target species height was quantified by measuring the heights of the three tallest stems in the 1-$m^2$ quadrat. Measurements were taken from the base of the stem to the tip of the apical stem or flower (without extending any of the upper leaves). Due to staff and time constraints and to the fact that most data collected from the five non-NBNERR marshes were collected by Save The Bay staff and volunteers (www.savebay.org), all vegetation data were not collected from all sites each year. For example, no data were collected from Jacob's Point (restoration side) or Walker Farm in 2009, while target species heights and stem densities were generally measured in NBNERR marshes, primarily in 2010 (except for *Phragmites*, which was collected from all marshes).

### *Shallow Wells*

Emergent vegetation species in salt marshes are adapted to specific levels of salinity and to the amount of soil saturation. Salinity and water table levels were therefore also monitored at all marshes included in this study. Small PVC wells were installed along one representative vegetation transect in Coggeshall and Nag marshes in 2008 and in Potter Pond in 2009 according to Roman et al. (2001). As with vegetation, wells had been established at Gooseneck Cove, Jacob's Point (both sides), Silver Creek, and Walker Farm by Save The Bay prior to the initiation of this study. They were not established along a single transect in each marsh; instead they were located at multiple points along multiple transects. However, these wells were designed according to Roman et al. (2001) and were therefore used in this study.

Water table levels were monitored in each marsh periodically during the growing season of each year of this project (with exceptions; e.g., see above for vegetation) by measuring the depth to the water table below the marsh surface within each well. Soil salinity was monitored at the same time using a small sipper to extract porewater from the soil adjacent to each well. Extractions were made at a depth of 15-cm; if water could not be extracted at this depth, the sipper was pushed sequentially down to 30 and 45 cm depths; if extractions were still not possible, water was drawn directly from inside the well.

### *Groundwater*

Additional high-frequency water table level and salinity data were also collected in each marsh using Aquatroll 200 automated loggers (In-Situ Inc.) either in 2009 or 2010. In 2009, data were collected from Coggeshall, Nag, Potter Pond, Jacob's Point (reference side) and Walker Farm; in 2010 data were collected from all marshes except Jacob's Point (reference side). During each deployment, one Aquatroll logger was placed into a capped PVC groundwater well in each marsh zone and data were collected every 15 minutes over at least one two-week period that included spring and neap tides during the growing season. At the end of each deployment, the Aquatrolls were retrieved and returned to the NBNERR where the data were downloaded and imported into Microsoft Excel spreadsheets.

### *Soils*

Cores of marsh soils were collected from each marsh and analyzed to determine bulk density (dry weight per volume) and percent organic content. Three replicate cores were collected from each of the five hydrologically altered marshes and the Jacob's Point reference marsh; nine cores were collected from the Coggeshall and Nag reference marshes. A single core was taken from each of the three marsh zones along a randomly selected transect at each marsh (or along all three transects in Coggeshall and Nag). However, since the five off-island marshes were set up by Save The Bay before this project began, cores were taken from among multiple transects to ensure that each zone was sampled. Cores were 3.8 cm in diameter and all attempts were made to extract a core that was 20 cm in depth; in some cases this was not possible due to the conditions of the soils. Cores were placed in baggies, labeled and returned to the laboratory. They were then processed to determine bulk density and percent organic content.

### *Vertical control*

In order to define fine scale elevation changes at reference sites it was first necessary to locate or establish bench marks proximate to the sites of interest with a static defined elevation relative to a national spatial reference system, or geodetic control. A review of tidal and geodetic databases available on-line from NOAA's National Ocean Service (NOS) and the National Geodetic Survey (NGS) was first conducted to determine whether existing bench marks on Prudence Island would be suitable for this purpose. Seventeen geodetic control bench marks, established and/or described between 1843 and 1969, and two tidal bench marks were evaluated.

The majority of geodetic control bench marks that had been established on Prudence Island were considered lost or damaged (Table 2). Of the remaining stations which were considered within reasonable proximity (less than one mile) to reference sites or monitoring stations, only two were found (Nag 1913 and Prudence Use 1909). Nag 1913 was discovered in an established lawn on private property and Prudence Use 1909 was discovered in a closed canopy forest unsuitable for use with satellite based global positioning systems (GPS) technology or traditional leveling methods.

Of the two tidal stations established on Prudence Island, Potter Cove and Navy Pier, only the bench marks associated with the Navy Pier station were located. Both tidal and geodetic elevations were provided for these bench marks; however, the geodetic elevation had been derived from an average of several bench mark elevations relative to the tidal station datum, not by traditional leveling methods, and as a result was not considered to be sufficiently accurate for reference site monitoring.

In 2008, real time kinematic GPS (RTK) was used to determine elevation relative to the North American Vertical Datum of 1988 (NAVD 88) at one previously defined Navy Pier tidal bench mark (845 2555 Tidal 3). An RTK base station was set-up to occupy this site and record approximately seven hours of elevation data derived from the triangulation of multiple satellite transmissions. RTK base stations were also used to collect elevation data from three off-island control sites for a minimum of two hours per site during the same seven hour time period. Simultaneous data collection at control sites with known location (X,Y) and elevation (Z) are used to correct for data fluctuations which occur as the result of atmospheric attenuation and satellite configuration. Control sites included MC SPARRAN 4 (located in North Kingstown), E 28, and H 28 (both located in Portsmouth). Data were then submitted to NGS's On-Line Positioning User Service (OPUS) to determine a solution for the 'unknown' height. Due to an unfortunate act of vandalism, this tidal bench mark had to be reinstalled in 2010 and it was necessary to repeat static data collection and solve for elevation.

Five additional geodetic bench marks were also established for Prudence Island to allow ready access to geodetic control for mapping and monitoring of elevation changes at reference sites and monitoring stations. A number of potential sites were evaluated for ease of access, stability of the substrate, and protection from disturbance. Once selected, each site was permanently marked either through etching or by the installation of a brass disk. In a similar manner to that described above, RTK base stations and an OPUS solution was used to determine elevation at each newly established bench mark relative to a control site. The control site in this instance was the Navy Pier tidal bench mark (845 2555 Tidal 3) for which elevation relative to NAVD 88 has been established.

### *Elevation Data*

A combination of RTK and Leica DNA03 digital level equipment was used to capture elevation measurements in three study marshes on Prudence Island (Coggeshall, Nag, and Potter Pond). Elevations relative to NAVD 88 acquired during this reference site project serve as site descriptors and as baseline data for determining change over time.

In 2009, differential leveling was used to attempt tie-in of two SWMP stations to establish vertical control at these sites for the purpose of evaluating change in sea level. In both instances, leveling to the actual data sonde deployment location was not possible. The T-Wharf station consists of two vertical PVC pipes affixed to a piling on an old Navy era pier. A bolt was placed proximate to the deployment pipes to serve as the start/end point for differential leveling and a nearby benchmark (845 2555 TIDAL 1) provided the second component of the leveling route and elevation relative to the historic tidal datum at this site. The vertical distance from the attached bolt to the water level pressure sensor on the sonde had to be determined by other means. As the sonde is suspended from a rope of fixed length and the position of the water level sensor is at a known position on the sonde it is a simple matter of measuring the full vertical distance using a tape measure and subtracting that distance from the elevation of the fixed bolt on the pier determined by leveling. In a similar manner, differential leveling to the Potter Cove SWMP station occurred between a recently established benchmark (Potter Cove) and a bolt attached to a dock. However the bolt at this site is not proximate (< 0.25 m) to the deployment assemblage due to the dock's construction and difficulty of transit across a non-stationary ramp and float. The mechanism for determining vertical distance between the bolt and the water level pressure sensor in a consistently repeatable way has not yet been determined.

Elevations at discrete locations along monitoring transects in all three study marshes were collected (all transects in Coggeshall and Nag; transects 4, 6, and 9 in Potter Pond). Elevation of the surface substrate in the center of vegetation plots and at the highest point of groundwater well housings was collected using RTK in 2009 and 2010. Each elevation point was labeled in the dataset by type (e.g. vegetation plot or well) and location (e.g. transect number and position along transect). A combination of differential leveling and intermediate point collection was applied to acquire these discrete elevations in 2009 in Nag marsh only (Fig. 14). Elevation at transitions between cover types along transects (immediately to the left of permanent transect markers when facing upland) were also recorded using RTK in 2010. A two-letter code for each unique cover type was developed and applied to elevation points at transition locations as descriptors during data collection. The codes were generally intended to represent the dominant species, a mix of two dominants, or a topographic feature. Where three or more species occurred, the cover type was described more generally (Table 3). For the purpose of leveling across the marsh surface a special foot for the survey rods was developed to replace the traditional pin which was considered too heavy, unwieldy, and unstable for soft sediment applications. A flat 4 inch square of ½ inch PVC sheet with a 4 inch bolt affixed through the center such that the bolt extended 1 inch below and 2 ½ inches above the surface was used as a pivot point for the rods and appeared to function very well to provide a stable platform for this purpose. In all instances when the RTK unit was in use, the receiver pole (with a flat foot attachment) was held vertical prior to data capture.

Elevation profile data were collected along monitoring transects at 0.25 m intervals in Nag Marsh in 2009 and along all permanent monitoring transects at 1 m intervals in 2010 (all transects in Coggeshall and Nag; transects 4, 6, and 9 in Potter Pond). In 2009, the RTK was set to automatically capture data at fixed intervals while the receiver pole was rolled across the marsh surface on a bicycle-tire foot attachment. This mechanism for data capture proved problematic since it was difficult to maintain the receiver pole in a perfect upright position at all times and the moment of data capture was often unanticipated. In 2010, the RTK receiver pole was set upright (with a flat foot attachment) at estimated distances of one meter and held in a vertical position prior to manual data capture. This method proved more accurate though moderately more time consuming.

In 2009, a two-part effort was made to develop a digital elevation model (DEM) of Nag Marsh and to test the minimal point density requirements for DEM generation. RTK was used to capture elevations at forty-one (of fifty) random points scattered throughout the marsh to provide validation for the anticipated surface elevation product. The receiver pole with a bicycle-tire foot attachment was then wheeled across the marsh surface along approximately parallel routes spaced one meter apart and across the adjacent dune and upper beach along approximately parallel routes spaced 5 meters apart. The RTK was set to automatically capture data at fixed one meter intervals along these routes. The resulting data (totaling 3973 points) was used to generate a DEM with ArcGIS software using inverse distance weighting. The intent was to evaluate the elevations acquired by direct measurement at random points against those at the same location on the DEM acquired by interpolation of points. The density of points was then going to be manipulated by extracting various percentages of the total points to determine the minimum point density required to generate a DEM across a larger geographic area. If successful, this would provide a mechanism for reducing future effort in the development of DEMs.

### *Data Analyses*

For some of the statistical analyses, individual marshes were either placed into general reference, tide-restricted, and restoring marsh groups or into specific restoration/reference marsh pairs. In terms of the generic marsh groupings, reference marshes included Coggeshall, Nag, and Jacob’s Point reference marshes. Tide-restricted marshes included any data from the restoring marshes that were collected prior to the actual marsh restoration (e.g., from Gooseneck Cove in 2008). Restoring marshes included data from any of the restoring marshes that was collected after the actual restoration (e.g., from Gooseneck Cove in 2009 and 2010). Specific marsh pairs were chosen based on factors such as the proximity of the two marshes, marsh sizes, and local professional judgment. The reference/restoration marsh pairs were Potter Pond/Coggeshall, Walker Farm/Nag, Jacob’s Point restoration/Jacob’s Point reference, Silver Creek/Nag, and Gooseneck Cove/Nag. Prior to any analyses, all data were entered into standard data templates generated for use across all reserves participating in this project. NBNERR data were then combined with data from all the other reserves to generate standardized datasets for each monitoring component of this project.

Emergent vegetation parameters that were analyzed included vegetation richness, percent cover, height, and stem densities. Mean overall richness (defined as the total number of vegetation species, including all other abiotic categories) was calculated for individual marshes, marsh groups (reference, tide-restricted, and restoring), marsh zones, and years. Vegetation plot richness (defined as the number of species per quadrat) was statistically compared among years and marshes using two-way ANOVA; if significant differences were found among marshes, post hoc Holm-Sidak multiple comparison procedures were used to directly compare each of the reference/restoration marsh pairs. Mean percent cover of each species was calculated for individual marshes, marsh groups, marsh zones, and years. Percent cover of five dominant species was compared across years and marshes using two-way ANOVA; for each species, if significant differences were found among marshes, post hoc Holm-Sidak multiple comparison procedures were used to directly compare within each of the reference/restoration marsh pairs. Heights of *S. alterniflora* (dominant species), *S. patens* (second dominant species), and *Phragmites* (species of concern) were statistically compared among individual marshes using one-way ANOVA. One-way ANOVA was also used to compare stem densities of *S. alterniflora* (tall form), *S. patens*, *S. alterniflora* (short form), *J. gerardii*, and *Phragmites* among the marshes.

Mean salinity and water table depths (collected with sippers and from shallow wells) were calculated for individual marshes, marsh groups, marsh zones, and years. Each parameter was statistically compared across years and marshes using two-way ANOVA and if significant differences were found among marshes, post hoc Holm-Sidak multiple comparison procedures were used to directly compare within each of the reference/restoration marsh pairs. Hydrology data that were collected with Aquatrolls were used to calculate means and standard errors for surface inundation, groundwater level, and maximum tide height for each reference/restoration marsh pair during each year of this study when data were available. Similarly, means and standard errors for soil bulk density and % organic matter were calculated within each marsh zone in each restoration/reference marsh pair. Both soil parameters were then statistically compared among marshes using one-way ANOVA (within each marsh, individual tests were run for each of the three marsh zones).

Finally, restoration performance index (RPI) scores were generated for each restoration marsh relative to its paired reference marsh (Moore et al. 2009). The RPI enables project managers and the regulatory community to gauge a diverse range of structural and functional parameters indicating relative restoration performance. The RPI achieves this by incorporating a wide variety of monitoring data into its formulation, regardless of the monitoring protocols used, number of variables, or sampling interval, by using calculated mean values and standardizing along a relative index scale from 0-1. The preliminary version of the RPI helps end users calculate the net benefits, present and accrued, of a system undergoing ecological change using monitoring data that they (or others) have collected. The RPI provides (1) a relative index of restoration performance to date, (2) a means of comparing restoration performance at individual sites and across differing sites for local and regional comparisons, and (3) a basis upon which to demonstrate restoration trajectory and ultimately allow for opportunities to improve restoration outcomes (i.e., adaptive management). Because the RPI uses reference marsh data as a baseline for comparison, restoration performance is defined as its trajectory leads toward or intercepts the reference condition. The rate at which the trajectory achieves the desired outcome is expected to be widely variable, and dependent upon a variety of factors, including the factors chosen for measurement. The more factors (i.e., measurable parameters) incorporated into the RPI model, the stronger the predictive value of the output.

The RPI is calculated using the formula:

**$RPI=(T_{present}-T_0)/(T_{ref}-T_0)$**, where $T_0$=initial conditions in the restoring marsh; $T_{ref}$=reference site condition; and $T_{present}$=current conditions in the restoring marsh.

Data weighting for the RPI occurred at 3 different levels for hydrology and 4 levels for vegetation. For hydrology, the RPI weights by (1) marsh zone (low, high, upland transition); (2) parameter (salinity, % inundation, groundwater level, maximum high tide level); and (3) core group (hydrology, vegetation) in this order. For vegetation, the RPI weights by (1) species; (2) marsh zone (low, high, upland transition); (3) parameter (percent cover, species richness); and (4) core group (hydrology, vegetation) in this order. At each level, the RPI only weights by present items. For example, if salinity was inputted for the low and high marsh, but not the upland transition, it would be weighted by 2 marsh zones. Additionally, if only 1 core group was inputted into the RPI instead of 2, it would be weighted by 1 parameters leading to a maximum score of 1 instead of 0.5. Finally, species richness is not weighted by zone nor plant species.

RPI scores range from 0-1, with a score of 1 indicating identical conditions in the restoration and reference marshes for the parameters included in the score. Ideally, RPI scores in a restoring marsh will increase over time and eventually approach or equal 1. In NBNERR, the RPI included vegetation and hydrology parameters, and within these it included vegetation % cover, vegetation richness, salinity, % inundation, groundwater level, and maximum high tide subparameters.

## Results and Discussion

### *Standardized datasets*

Standardized datasets that include data from all five participating reserves were generated for vegetation, shallow well sampling, soils, and elevations. Standardized groundwater datasets were also developed, but these files were kept separately for each site due to file size. For NBNERR, each of these datasets has been submitted to accompany this report.

### *Vegetation*

Fifty-two vegetation species (including other abiotic categories such as water, rocks, bare ground, etc.) were recorded in the Narragansett Bay marshes during the three years of this study (Tables 4 and 5). Overall richness varied among years, marshes, marsh types, and marsh zones. Richness was highest in 2008 (43 categories) compared to both 2010 (35) and 2009 (34). The transition zone had by far the highest richness (44) compared to either the high marsh zone (27) or the low marsh zone (20). Restoring salt marshes had a much higher richness (44) compared to reference and tide-restricted marshes, which were similar to each other (24 and 23, respectively). Richness also varied among the marshes as follows: Silver Creek (24), Walker Farm (22), Jacob's Point Restoration (19), Jacob's Point Reference (18), Potter Pond (17), Gooseneck Cove (14), and Coggeshall and Nag (13 each). Interestingly, the two marshes with the lowest overall richness were the two reference marshes on Prudence Island, while the two highest were restoring marshes closer to the more urbanized and nutrient-rich head of Narragansett Bay. There was a significant difference in plot richness among marshes (F=4.26, p<0.001), but not among years (F=1.57, p=0.21); however, based on Holm-Sidak multiple comparison procedures there were no significant differences between any of the reference/restoration marsh pairs (Table 6).

Based on overall percent cover, the three dominant species in the RI marshes were *S. alterniflora* (17%), *S. patens* (15%), and *D. spicata* (12%) (Table 4). *Phragmites*, *I. frustscens*, *J. gerardii*, and bare ground were each present at mean percent covers greater than 2%. All other species and abiotic categories were present at mean cover values of less than 1%. These data clearly indicate that each of these marshes is generally comprised typical New England salt marsh vegetation (Niering and Warren 1980) and in some cases, *Phragmites*. The only clear patterns in vegetation cover across the three years of this study were a decrease in *Phragmites* cover in 2009 and 2010 and a concomitant increase in the cover of bare ground (Table 4). These changes are a clear response to the restoration of the Gooseneck Cove, Jacob's Point, and Silver Creek marshes, each of which occurred within the timeframe of this study.

Clear differences were observed when comparing vegetation cover across reference, tide-restricted, and restoring salt marsh types (Table 4). For example, *S. alterniflora*, *S. patens*, *D. spicata*, and *J. gerardii* covers were all highest in reference marshes, while *Phragmites* cover was highest in restricted marshes. When directly comparing vegetation cover between tide-restricted and restoring marshes, *S. patens*, *Phragmites*, and open water were more abundant in the former while *S. alterniflora*, bare ground, and *Salicornia* spp. were more abundant in the latter. These patterns clearly reflect predictable vegetation responses to anthropogenic changes in tidal flow to these marshes (Roman et al. 1984). In general, the low marsh zone was overwhelmingly dominated by *S. alterniflora*, while the high marsh zone was dominated by *S. patens*, *D. spicata*, and *S. alterniflora* and the transition zone was dominated by *Phragmites*, *I. frutescens*, and *J. gerardii*. This pattern exemplifies the classic zonation typical of New England salt marshes (Niering and Warren 1980).

Some statistically significant differences in the cover of the five dominant species were found using two-way ANOVA with site and year as factors (Table 6). The covers of *D.*

*spicata, J. gerardii, I. frutescens,* and *S. alterniflora* were each significantly different between two or fewer of the five reference/restoration marsh pairs. However, *P. australis* cover was significantly higher in four of the five restoration marshes compared with their paired reference marshes, and *S. patens* cover was significantly higher in four of the five reference marshes compared with their paired restoration marshes. These results provide statistical backing for the patterns described above, which is primarily that the invasive *Phragmites* displaces native *S. patens* in the high marsh and transition zones of restoration marshes relative to reference marshes.

Heights of *S. alterniflora* (the dominant species at these marshes) differed significantly among the NBNERR marshes based on one-way ANOVA (Fig. 15, top). This species was taller at Walker Farm relative to Coggeshall, Nag, and Potter Pond, and in turn was taller at Potter Pond relative to Coggeshall. When considering *S. patens*, which was the second dominant species among the marshes, there were no significant differences in height among marshes (Fig 15, middle). When considering the heights of *Phragmites* (selected as the species of concern in the NBNERR marshes), it was also found that there were no significant differences in *Phragmites* height among any of the marshes (Fig 15, bottom).

The density of tall-form *S. alterniflora* stems was significantly higher at Walker Farm than at either Nag or Potter Pond (Fig. 16, top). Stem densities of *S. patens* were significantly higher in the Coggeshall and Nag reference marshes than in Potter Pond (Fig. 16, middle). Stem densities of short-form *S. alterniflora* were significantly higher in Coggeshall than in either Nag or Potter Pond (Fig. 16, bottom). Stem densities of *J. gerardii* did not differ among any of the marshes (Fig. 16 continued, top). Finally, stem densities of *Phragmites* were significantly higher in the Jacob's Point restoration marsh than in either the Coggeshall and Nag reference marshes (where *Phragmites* was absent); *Phragmites* stem densities did not significantly differ among any of the other marshes (Fig. 16 continued, bottom). The factors driving any of these differences in stem densities are unknown but it is likely that they include simple site-to-site variability, proximity to (and thus competition from) other vegetation species, and physio-chemical properties of the soil at each site.

### *Shallow Wells*

Using data collected from shallow wells and sippers, it was found that salinity and water table depths varied among marshes, marsh types, marsh zones, and years (Tables 6 and 7). In general, salinity was highest in the low marsh zone and decreased while moving towards the upland. Similarly, water tables below the marsh surface were deepest in the low marsh zone and became shallower while moving towards the upland. These patterns are simply a reflection of the greater effects of tidal waters nearest the marsh edge. Salinity increased each year during this study, but water table depths did not show a consistent pattern. The high salinities in 2010 correspond with uncommonly hot and dry conditions during summer that year that also led to an increased prevalence in salt marsh vegetation die off (Raposa personal observation). Salinity and water table depths were very different in tide-restricted marshes relative to reference and restoring marshes, with restoring marshes clearly representing an intermediate phase between these two types of marshes (Table 7). There were no clear statistical patterns in either salinity or water table depths among the five reference/restoration marsh pairs (Table 6). In summary, the clearest patterns from the shallow water dataset at NBNERR are that porewater salinity and water table levels follow predictable patterns along a transect from the open water/marsh edge to the marsh/upland edge and that restoring marshes function as an intermediate stage between tide restricted and reference marshes.

### *Groundwater*

Using the data collected with Aquatrolls, it is possible to calculate for each zone in each marsh the proportion of the time the marsh surface is inundated (% inundation), the mean groundwater height below the marsh surface, and the maximum tide height. From these data, it is clear that % inundation varied dramatically among marsh zones, among marshes, and even within the same marsh between years (Table 8). This suggests that the variability associated with this parameter varies greatly over space and time and that collecting data for two-week intervals once per year is clearly not enough to draw meaningful conclusions when trying to compare reference and restoration marshes. For example, the low marsh zone in Coggeshall Marsh was inundated 95% of the time in 2009, but only 34% of the time in 2010 based on approximately two-weeks of Aquatroll data each year. Likewise, the transition zone between marsh and upland in Nag Marsh was inundated 92% of the time in 2009, but only 14% of the time in 2010. These examples clearly provide an indication of the variability inherent in these data and suggest that longer datasets need to be collected from each zone in each marsh to allow for more appropriate comparisons among zones and marshes.

In terms of mean groundwater level (relative to the marsh surface), variability seems to be reduced when compared to % inundation (Table 9). For example, when considering data pooled across zones in Coggeshall Marsh, mean groundwater level was -0.08 m (i.e., 8 cm below the marsh surface) in 2009 and -0.16 m in 2010 - a difference of only 8 cm. In addition, the pattern in relative groundwater depths among marsh zones within Coggeshall Marsh was also consistent among the two years. After pooling all data among reference marshes and among restoration marshes, it is clear that mean groundwater levels are similar among both groups of marshes (mean level of -0.048 m in reference marshes and -0.044 m in restoration marshes). This suggests that in Narragansett Bay, mean groundwater levels are very similar between natural reference marshes and marshes that have recently undergone tidal restoration.

Maximum high tide levels also varied among marsh zones, marshes, and between years within the same marsh (Table 10). However, patterns within each marsh generally followed the expected pattern with the highest high tide levels occurring in the low marsh zone and dampening while moving further into the marsh towards the upland. For example, in Coggeshall Marsh in 2009, the maximum high tide level in the low zone was 78 cm, 48 cm in the high marsh zone, and only 10 cm in the transition zone. Maximum high tide levels in reference marshes averaged 29 cm above the marsh surface (individual marsh values ranged from 11 cm to 45 cm), while they averaged 37 cm in restoration marshes (range of 12 cm to 56 cm), indicating that maximum high tide levels are generally similar among the two marsh groups.

### *Soils*

Marsh soil bulk density and organic content varied among each of the NBNERR salt marsh study sites (Table 11, Fig. 17). In the transition zone, neither soil bulk density nor organic content differed significantly among the eight marshes (ANOVA; F=2.07, p=0.25 for bulk density; F=3.26, p=0.14 for organic content). In the salt meadow zone, there was also no significant difference among sites in percent organic matter (F=2.41; p=0.21); there was, however, a significant difference in bulk density (F=14.0; p=0.01); Soil bulk density was significantly higher in the Potter Pond and Silver Creek marshes than in Coggeshall, Nag, and Walker Farm marshes. In the low marsh zone, both bulk density and organic content were significantly different among sites (F=61.67, p=0.001 for bulk density; F=7.87, p=0.03 for organic content). In terms of bulk density, Silver Creek Marsh was significantly higher than all other sites. In terms of organic content, Coggeshall, Nag, Potter Pond and Gooseneck marshes were all significantly higher than Silver Creek Marsh. These results indicate that (at least in the NBNERR region) differences in soil characteristics are primarily site-specific and are not necessarily driven by whether a site is a reference or restoration marsh.

### *RPI analyses*

RPI scores ranged from 0.23 (Gooseneck 2010) to 0.87 (Potter Pond 2010) across two years of analyses in each of the restoration sites (Fig. 18). Mean RPI scores (across years) for each site were Potter Pond (0.78), Silver Creek (0.57), Walker Farm (0.50), Gooseneck (0.50), and Jacob’s Point (0.42). Clearly it is difficult to draw many meaningful conclusions from RPI scores calculated for only two years post-restoration (one year for Jacob’s Point). Continued long-term monitoring is the only way to indicate whether RPI scores for each restoration site improve over time. However, three results from this analysis stand out. Mean RPI scores averaged across years were quite similar for the four marshes that were restored between 2005 and 2010. RPI scores for Potter Pond, which is the site that has been restoring the longest, were easily the highest. Finally, there was a large disparity in RPI scores at Gooseneck Cover Marsh, with a dramatically reduced score in year two post-restoration. The reasons for this are unknown, but illustrate that continued monitoring of this site is highly necessary to ensure that this site follows a positive restoration trajectory.

### *Vertical Control*

Geodetic control was established at six sites on Prudence Island to accommodate mapping and monitoring requirements of reference site monitoring (Fig. 19). The four geodetic control sites established in 2008 are: 845 2555 Tidal 3, Chase Way, Potter Cove, and Long Point. Datasheets with site descriptions, locations, and elevations for the updated tidal bench mark as well as the initial three benchmarks established in 2008 have been submitted to the NGS for inclusion in their database. Following the first field season to utilize leveling and RTK equipment to obtain elevation data at vegetation transects and groundwater wells, it became evident that the number of benchmarks established at Coggeshall and Nag Marshes was potentially limiting. The distance and difficulty of the terrain (associated with tidal creeks, ditches, and substrate characteristics) between benchmarks to the furthest monitoring infrastructure is often too great to allow for a complete circuit (with start and end points at a single benchmark) to occur within a reasonable time frame while also avoiding periods of tidal flooding. Two additional benchmarks were established in 2010 to alleviate this problem. The two geodetic control sites established in 2010 have site name descriptors and are: Nag Marsh and Coggeshall. It is not known whether datasheets for these control points have been submitted for inclusion in the NGS database although location and elevations have been determined.

Geodetic control at the three study marshes located on NBNERR properties (Nag Marsh, Coggeshall Marsh, and the Potter Pond restoration site) is considered sufficient to determine fine scale elevation changes at monitoring infrastructure. The current configuration of established benchmarks provides optional ingress and egress from the study sites as necessary to ensure that equipment transit time in itself does not restrict elevation data collection during the relatively short periods when this equipment is made available on loan. The addition of deep rod surface elevation tables (SETs) planned for 2011/2012 will also serve to strengthen the established vertical control network.

Although the established vertical control network was developed to accommodate requirements for this study, the network should be expanded to capture elevation change in additional salt marsh habitat. A modest rise in sea level will place these areas at increasing risk for erosion, storm damage, and vegetation transitions as the result of increased tidal flooding. To capture elevation change within this sensitive habitat the vertical control network on NBNERR properties should include an additional four to seven benchmarks. Initially benchmarks should be installed to establish geodetic control at the northernmost end of the island at Providence Point (requiring two benchmarks) as well as the eastern edge of both Jenny Marsh and Nag Marsh where road displacement will potentially result in temporary marsh expansion. Optionally, if resources permit, the vertical control network should include benchmarks on Patience and Dyer Islands as well as Sheep's Pen Cove.

### *Elevation Data*

SWMP station tie-in to NAVD 88 was not successful due to the nature of the Reserve's deployment structures. At T-Wharf the modest tremor of the Navy era pier forced acceptance of elevation values when error tolerances were exceeded. As the tie-in attempt was conducted under optimal conditions (i.e. no wind and little boat traffic) it was evident that the stability of this structure was not adequate for determining elevations with sub-centimeter accuracy using differential leveling. Access to a stationary reference point at the Potter Cove SWMP station proved problematic. The data sonde is deployed off a floating dock and an approach closer than 10 meters to the deployment assemblage was not possible due to the nature of the dock's construction. No attempt was made to establish vertical control at the Nag Creek SWMP station as that station structure is removed and re-installed annually due to anticipated ice build-up. As a result, a stationary reference point from which to determine vertical distance to the water level sensor is not possible without access to leveling and/or RTK equipment to repeat elevation capture at each installation. In addition, the deployment structure as currently designed is not sufficiently stable to ensure lack of vertical movement between successive deployments.

The method of determining substrate surface elevations in vegetation plots may require modification. Estimating the center point of plots that are offset from transect markers by approximately 1.5 meters laterally and 0.5 meters above the perpendicular (to the transect line) is not consistently repeatable. Given the potential for modest shifts in the positioning of the RTK receiver, inter-annual differences in elevation at plot centers may not reflect actual change as elevations on the marsh surface are extremely variable at fine scales due to presence/absence of wrack material, standing vegetation densities, time of year/tide, etc. The comparatively extreme positional differences between years (ranging from 1.842 to 2.374 meters) at transects 2 and 3 in Nag Marsh (Table 12) are assumed to be a product of using a preliminary OPUS solution at the newly installed (in 2010) Nag Marsh benchmark during receiver base station set-up. Additional static GPS data were collected during point data collection periods to improve the accuracy of position and elevation estimates relative to NAVD 88 but these have not yet been submitted to OPUS. Once final values are acquired, corrections can be applied to the 2010 point data in instances where the Nag Marsh benchmark (vs. the original Chase Way benchmark) was used as the base point.

Cover type transitions along transects are expected to provide the earliest evidence of migration as it occurs on the marsh surface. Vegetation plots, when they occur within large patches of homogeneous cover, will not capture positional shifts at patch boundaries. The coding system should perhaps be further expanded to include more detail regarding all species of vegetation present as well as percent cover or density of dominant species. In particular, more detail may be needed at the upland edge to indicate a clear shift in high marsh species as the results of extended and/or prolonged tidal inundation in this area (Fig. 20).

Elevation profiles along monitoring transects provide a broader context for evaluating potential influences on permanent vegetation plots and groundwater wells. Proximity to tidal creeks and other topographic features can explain the presence of unanticipated species. For instance, the presence of smooth cordgrass (*S. alterniflora*) in the high marsh may be the result of a remnant mosquito ditch which allows tidal inundation along its route in an area that is generally of greater elevation with reduced periods of tidal influence. As expected, a year to year comparison of the elevation data suggests generally higher elevations along the profiles in 2010 over 2009. This is an artifact of the pole being held in a less than a vertical position during data capture in 2009.

The effort required to collect points for the purpose of DEM generation was greatly underestimated. An entire day of effort resulted in coverage of less than ten percent of the planned area (which had included all of Nag Marsh). In addition, the same difficulty with automated point capture using the bicycle-tire wheel was noted during this effort (i.e. difficulty in maintain the receiver pole in a vertical position). Although the resulting DEM provides a good approximation of surface elevations within the reduced project area (Fig. 21) it was not possible to evaluate the minimum point density requirements for lack of independent elevation data. Due to the discrepancy in the planned and actual project area only three random points occurred within the final project boundary. The lack of independent elevation data also made determination of DEM accuracy impossible.

Repetition of profile elevation data capture may reasonably take place at less frequent intervals than cover type transition data capture (planned to coincide with continued periodic reference site monitoring efforts) since substrate elevations are not expected to demonstrate rapid change in this particular setting (i.e. within the interior of the marshes along monitoring transects). Elevation profiles at the land/sea boundary which extend across modest dune or berm features onto the marsh surface would be a more valuable addition to elevation data collection to characterize the reference marshes. The current rate of erosion is entirely unknown along the Reserve's property boundaries and the shoreline has been dramatically altered in past decades by storm events. Even a moderate increase in sea level will place greater stress on natural shoreline features which, although only moderately higher in elevation than the adjacent marsh, provide the only protection from devastating storm damage. Determining beach profile and erosion rates is a high priority for future elevation data capture due to its potential for informing restoration and management decisions in the future.

The acquisition of LiDAR (light detection and ranging) data for the New England states through the USGS National Geospatial Program (scheduled to be available in 2011) may reduce the quantity of elevation data acquisition requirements using RTK. In particular, the effort to generate complete DEMs for the three study marshes will likely be deemed unnecessary as redundant information. Prior to any final determination, the RTK will be used to again collect independent data within the reduced DEM project area in Nag Marsh to evaluate surface models derived from dense RTK points and LiDAR data. If

LiDAR proves to be of comparable accuracy, no additional attempt to generate DEMs using RTK will be made in the near future.

*Restoration Project Evaluations*

### Potter Pond

By all accounts, Potter Pond has been following a solid, positive restoration trajectory during the 8 years since restoration construction. Potter Pond had the highest RPI scores during this study, despite Nag not being an ideal reference site for this restoration. Potter Pond is actually a small tidal pond/fringing marsh complex, while Nag is a true well-defined meadow salt marsh. However, both sites do lie in close proximity to one another. Since restoration, tidal ranges have increased, nuisance macroalgae has almost disappeared entirely, low marsh zone vegetation is colonizing newly exposed mudflats, and *Phragmites* cover and height have been reduced (Raposa 2008). As shown in this study, Potter Pond supports significantly higher covers of both *I. frutescens* and *Phragmites* than Nag Marsh and significantly less *S. patens*. Water table depths were also greater at Potter Pond (reflecting the high groundwater table levels in parts of Nag due to freshwater inflows). This restoration is clearly a success story and will be even more so with a new effort to spray and cut the remaining *Phragmites* in 2011.

### Walker Farm

Walker Farm is another example of an extremely effective salt marsh restoration in Rhode Island. Before it was restored in 2005, Walker Farm was a largely unvegetated stagnant estuarine pond, surrounded by invasive *Phragmites*. After only 5 years of restoration, much of the site has been replaced by emergent salt marsh vegetation with a network of creeks and ditches. *Phragmites* remains as the dominant species (25% cover), but its cover and height are much reduced from tide-restricted conditions. Walker Farm has the second highest vegetation richness, the heights of *S. alterniflora* were significantly higher than at Coggeshall, Nag, and Potter Pond, and stem densities of tall-form S. alterniflora were significantly higher than at Nag and Potter Pond. Walker Farm supported significantly more *Phragmites* and less *D. spicata* and *S. patens* than its reference site (Nag). Water table depths were also greater at Walker Farm (again reflecting site-specific conditions at Nag). The RPI scores for Walker Farm remain around 0.50 (much like the three sites restored in 2009 and 2010) indicating that Walker Farm has only achieved about half of its full restoration potential.

### Gooseneck Cove

Gooseneck Cove was restored in 2009, but based on the first two years of post-restoration monitoring, it is clear that some issues remain. On the positive side, large mats of nuisance macroalgae have largely disappeared from the main tidal channel after only two years (Raposa and Cole personal observation). Among the top six vegetation species, the cover of only *S. patens* differed between Gooseneck Cove and its reference site Coggeshall Marsh (*S. patens* cover was greater at Coggeshall).

However, overall vegetation richness was the third lowest of all the marshes, and while RPI score was high during the first year of restoration, it dropped dramatically during 2010. Further, a large area of the marsh has clearly subsided and is currently converting to shallow open panes (Raposa and Cole, personal observation), which has in part resulted in significantly shallower water table depths. Attempts are currently underway to dig out and clear the ditches to allow this area to drain better, but it is possible that this section of the marsh has sunk too far down and has lost its ability to return to emergent vegetation. Additional monitoring of this site is clearly necessary to track the responses of this subsidence area and to track changes in RPI scores over time.

### Silver Creek

Silver Creek received intermediate RPI scores during the first two years of post-restoration. Its overall vegetation richness was highest among all the sites (this is probably indicative of the freshwater and brackish vegetation communities in portions of the marsh), and *Phragmites* cover and heights were lower after restoration. Silver Creek supported significantly more *Phragmites* than its reference marsh (Nag), and significantly less *S. alterniflora* and *S. patens*. Finally, water table depths were significantly greater in Silver Creek compared to Nag, while the opposite was true for salinities. Longer-term post-restoration monitoring is needed to determine how RPI values change over time, but it is possible that scores will remain relatively low at this site. Silver Creek is nearly completely surrounded by residential development and it also has a freshwater stream entering at the head of the marsh. These conditions will probably make it difficult to control *Phragmites* over the long-term without additional spraying and cutting programs.

### Jacob's Point

Only one year of post-restoration data was collected at Jacob's Point during this study and the first year RPI score was similar to other recently-restored marshes. Overall vegetation richness was also nearly identical to the adjacent reference site. *Phragmites* cover and height was lower after restoration but this was due in part to spraying and cutting efforts. The restoration marsh supported significantly more *Phragmites* and less *D. spicata* than the reference marsh and its salinities were significantly lower. However, the formerly impounded restricted marsh was clearly better drained after restoration and newly exposed areas were heavily colonized by *Salicornia* spp. Uncommon high marsh species were also more conspicuous after restoration; if these trends continue, the restoration side of Jacob's Point may eventually resemble the extensive and diverse salt meadow habitats found on the reference side of the marsh.

### *Summary and Conclusions*

In summary, this project demonstrated that multi-site monitoring using the same or similar protocols can produce quantitative data to evaluate the effects of salt marsh restoration at the local and regional levels. At NBNERR, 5 restoration sites were evaluated by comparing vegetation, hydrology, and soils to paired reference marshes. While the field and analytical methods used here were effective for identifying and defining patterns over space and time, much of this work clearly depends on monitoring consistency and reference site selection. For example, RPI analyses only work if data are collected from the paired restoration and reference marshes each year, and are most appropriate when pre-restoration data are available. In this study, not all parameters were collected from all sites in all years (e.g., hydrology with Aquatrolls; vegetation heights and density). By the third year (2010) all monitoring components were being quantified effectively. This illustrates that it can be difficult to quickly establish a cohesive monitoring program in conjunction with disparate reserves from around the country. However, if this project can in part be considered as a pilot program, then continuing monitoring at these five reserves in the future should be relatively seamless and expanding to additional reserves should be much smoother. In NBNERR, another problem was trying to balance the needs of this project with ongoing monitoring at the four restoration marshes outside NBNERR that were primarily monitored by another agency (Save The Bay) using volunteers; this contributed to a fair amount of the data that were not collected at some marshes in some years.

It was also not easy to pair each restoration marsh with a true reference marsh. For example, Jacob's Point reference and restoration marshes are essentially part of the same marsh complex, and even with unimpeded tidal flow after many years of restoration, the restoring marsh would still be expected to be structurally different from the downstream reference marsh due simply to natural variability from the head to mouth of this marsh. Similarly, Gooseneck was paired with Coggeshall, primarily due to size, but in reality these two marshes are quite dissimilar. Coggeshall sits in the middle of Narragansett Bay and is subject to nutrient inputs from the surrounding estuary that are derived from wastewater treatment facilities located further up in the Bay. In terms of geomorphology, tidal waters enter the marsh via two main tidal creeks and along a long, linear edge with Narragansett Bay. In contrast, Gooseneck Cove sites along the south sore of Newport, RI, outside of Narragansett Bay and tidal waters from RI Sound enter the marsh through a single large channel that bisects the marsh. However, choosing appropriate reference sites is always problematic and the paired reference/restoration sites identified in this project were identified using the best available data and judgment. Based on this pilot work in NBNERR, it is recommended that any additional reserves that undertake similar monitoring carefully select appropriate reference sites and ensure that data from all parameters are collected from all sites every year.

This study also indicates that all parameters may not be useful or appropriate indicators and that monitoring data over a period longer than two years are needed. Overall richness (i.e., the total number of vegetation species in a marsh) may not be a good indicator of restoration performance in part because it is clearly impacted by the type of transition zone that is present in a marsh. For example, the two Prudence Island reference marshes (Nag and Coggeshall) had the lowest overall richness of all marshes and had transition zones comprised of typical salt marsh edge species (e.g., *I. frutescens*, and *J. gerardii*). However, parts of Potter Pond and Walker Farm marshes had transition zones that were essentially upland. The latter habitat supports drastically different vegetation communities from the adjacent marshes and when multiple vegetation plots are located in this zone, richness can increase substantially. Finally, it was clear that one or two years of post-restoration monitoring data are not enough to identify meaningful patterns in restoration trajectories. This was most obvious when considering RPI scores, which are intended to be used over the long-term to determine if a restoring marsh is becoming more similar to its paired reference site. It was not possible to determine this in this study when only one or two years of RPI data were available.

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Table 1.  Basic characteristics of the Rhode Island salt marshes included in this study.

| | Coggeshall | Nag | Potter Pond | Walker Farm | Jacob's Point [1] | Silver Creek | Gooseneck Cove |
|---|---|---|---|---|---|---|---|
| Location | NBNERR, Prudence Island | NBNERR, Prudence Island | NBNERR, Prudence Island | Barrington | Warren | Bristol | Newport |
| Type | Reference | Reference | Tidal restoration | Tidal restoration | Tidal restoration | Tidal restoration | Tidal restoration |
| Size (ha) | 25.5 | 15.3 | 2.3 | 6.5 | 6.7 | 5.6 | 22.8 |
| Dominant vegetation | *Spartina alterniflora* | *Spartina patens* | *Spartina alterniflora/patens* | *S. alterniflora/ Phragmites australis* | *Spartina mix/ Phragmites australis* | *Spartina patens* | *Spartina alterniflora* |
| Hydrologic features | Creeks, pools, ponds | Creeks, ponds | Pond | Creeks | Pools | Creeks, ponds | Channel, pools |

[1] Characteristics are for the tide-restricted portion of Jacob's Point Marsh only.  The entire marsh, including restricted and reference portions, totals 15.4-ha and includes a mix of *Spartina*-dominated habitats, *Phragmites*, and tidal creeks and pools.

Table 2. Geodetic control bench marks on Prudence Island.

| **Designation** | **Latest Report Date** | **Status** |
|---|---|---|
| Barn M Cupola | 1956 | Station lost |
| Bat 1913 | 1943 | Surface and reference marks missing; subsurface mark raised and surrounded by wooden fence |
| Bight 1913 | 1956 | Offshore due to erosion |
| DER 1913 | 1956 | Recovered in good condition but covered by dense vines/underbrush |
| Flagg | 1912 | Reported destroyed 1912 |
| Nag 1913 | 1956 | Recovered in good condition |
| North Point House Chimney | 1956 | Station destroyed |
| Pine Hill 1843 | 1960 | Station recovered but damaged; position needs to be checked |
| Potters Cove Windmill | 1956 | Station destroyed |
| Prudence 1843 | 1869 | Not found, considered lost |
| Prudence 2 1869 | 1897 | Not found, considered lost |
| Prudence 3 1897 | 1912 | Not found, considered lost |
| Prudence 4 | 1968 | Four standard disks in concrete markers |
| Prudence Island Lighthouse | 1956 | Recovered in good condition |
| Prudence Island US Navy Tank | 1969 | Described (but tank no longer exists) |
| Prudence Use 1909 | 1956 | Recovered in good condition |
| Windmill L | 1956 | Station destroyed |

Table 3: Codes applied in combination to represent a cover type transition along monitoring transects.

| Code | Cover Type | Code | Cover Type |
|---|---|---|---|
| as | *Spartina alterniflora / Distichlis spicata* | ms | Spartina mix (*S. alterniflora / S. patens*) |
| cr | common reed (*Phragmites australis*) | mx | mixed species |
| di | *Distichlis spicata* | pn | panne |
| dp | *Distichlis spicata / Scirpus pungens* | sa | *Spartina alterniflora* |
| du | *Distichlis spicata / Juncus gerardii* | sd | *Spartina patens / Distichlis spicata* |
| id | *Iva frutescens / Distichlis spicata* | sp | *Spartina patens* |
| ip | *Iva frutescens / Spartina patens* | ss | scrub-shrub |
| iu | *Iva frutescens / Juncus gerardii* | tc | tidal creek edge |
| iv | *Iva frutescens* | tp | tidal pool |
| md | mosquito ditch | | |

Table 4. Mean percent cover of emergent vegetation species across years, marsh type, marsh zone, and across all available data. Standard errors were omitted for clarity (contact NBNERR to obtain these data if desired). See Appendix A for a list of vegetation species and their six-letter codes.

| | Year | | | Type | | | Zone | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2008 | 2009 | 2010 | Reference | Restricted | Restoring | Low | High | Transition | |
| SPAALT | 15.39 | 18.96 | 17.73 | 19.92 | 12.17 | 16.35 | 41.37 | 15.22 | 1.28 | 17.23 |
| SPAPAT | 16.44 | 16.37 | 13.82 | 24.36 | 14.17 | 8.54 | 3.88 | 31.94 | 4.83 | 15.48 |
| DISSPI | 10.01 | 13.95 | 12.17 | 18.53 | 7.83 | 7.49 | 2.98 | 21.85 | 6.82 | 11.89 |
| PHRAUS | 13.99 | 4.88 | 7.11 | 0.16 | 20.39 | 13.30 | 3.53 | 1.20 | 24.98 | 8.96 |
| IVAFRU | 4.55 | 5.14 | 4.72 | 4.52 | 3.95 | 5.13 | 0.02 | 2.06 | 12.89 | 4.78 |
| JUNGER | 3.15 | 5.43 | 4.26 | 6.07 | 3.15 | 2.71 | 0.00 | 2.64 | 10.32 | 4.19 |
| Bare Ground | 1.24 | 2.85 | 3.98 | 0.92 | 0.05 | 4.80 | 3.46 | 0.72 | 2.38 | 2.67 |
| SALEUR | 1.19 | 0.41 | 0.72 | 0.34 | 0.46 | 1.28 | 2.13 | 0.47 | 0.20 | 0.80 |
| Water | 0.77 | 0.91 | 0.70 | 0.00 | 2.29 | 1.05 | 0.01 | 0.06 | 0.09 | 0.78 |
| Other | 0.91 | 0.57 | 0.71 | 0.01 | 1.75 | 1.11 | 0.37 | 0.01 | 2.14 | 0.75 |
| SALSP | 0.75 | 0.90 | 0.11 | 0.28 | 0.00 | 0.94 | 1.19 | 0.42 | 0.28 | 0.56 |
| SOLSEM | 0.50 | 0.36 | 0.62 | 0.20 | 0.19 | 0.84 | 0.02 | 0.58 | 0.79 | 0.50 |
| ATRPAT | 0.44 | 0.11 | 0.76 | 0.04 | 0.03 | 0.92 | 0.08 | 0.31 | 1.05 | 0.46 |
| BACHAM | 0.10 | 0.41 | 0.59 | 0.00 | 0.00 | 0.76 | 0.02 | 0.31 | 0.78 | 0.36 |
| SCIAME | 0.40 | 0.27 | 0.33 | 0.38 | 0.85 | 0.18 | 0.00 | 0.00 | 1.12 | 0.34 |
| ASITEN | 0.13 | 0.41 | 0.38 | 0.39 | 0.31 | 0.23 | 0.00 | 0.55 | 0.24 | 0.30 |
| TYPLAT | 0.28 | 0.14 | 0.37 | 0.00 | 0.85 | 0.35 | 0.21 | 0.00 | 0.72 | 0.27 |
| LIMNAS | 0.31 | 0.29 | 0.09 | 0.52 | 0.07 | 0.02 | 0.17 | 0.39 | 0.07 | 0.22 |
| ACERUB | 0.28 | 0.00 | 0.29 | 0.00 | 0.00 | 0.43 | 0.00 | 0.00 | 0.68 | 0.20 |
| QUESP | 0.28 | 0.00 | 0.29 | 0.00 | 0.00 | 0.43 | 0.00 | 0.00 | 0.68 | 0.20 |
| PLAMAR | 0.10 | 0.23 | 0.17 | 0.41 | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 0.16 |
| GERMAR | 0.12 | 0.22 | 0.14 | 0.35 | 0.12 | 0.01 | 0.00 | 0.39 | 0.00 | 0.16 |
| PARQUI | 0.00 | 0.46 | 0.05 | 0.00 | 0.00 | 0.31 | 0.00 | 0.25 | 0.16 | 0.15 |
| LONSP | 0.09 | 0.20 | 0.12 | 0.00 | 0.25 | 0.21 | 0.00 | 0.00 | 0.43 | 0.13 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PLUPUR | 0.26 | 0.00 | 0.07 | 0.00 | 0.00 | 0.24 | 0.00 | 0.00 | 0.39 | 0.12 |
| Wrack | 0.13 | 0.12 | 0.06 | 0.20 | 0.00 | 0.06 | 0.15 | 0.03 | 0.18 | 0.10 |
| CALSEP | 0.02 | 0.25 | 0.07 | 0.00 | 0.00 | 0.21 | 0.10 | 0.00 | 0.25 | 0.10 |
| Rock | 0.10 | 0.09 | 0.06 | 0.22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.28 | 0.09 |
| MALSP | 0.21 | 0.00 | 0.00 | 0.00 | 0.63 | 0.00 | 0.00 | 0.00 | 0.25 | 0.08 |
| PANVER | 0.13 | 0.04 | 0.02 | 0.14 | 0.00 | 0.02 | 0.00 | 0.03 | 0.18 | 0.07 |
| TOXRAD | 0.00 | 0.01 | 0.15 | 0.00 | 0.00 | 0.12 | 0.00 | 0.00 | 0.20 | 0.06 |
| ASTSUBU | 0.01 | 0.00 | 0.14 | 0.00 | 0.00 | 0.11 | 0.00 | 0.00 | 0.17 | 0.05 |
| ELEPAL | 0.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.00 | 0.00 | 0.14 | 0.04 |
| PITCAP | 0.08 | 0.00 | 0.00 | 0.00 | 0.24 | 0.00 | 0.00 | 0.00 | 0.09 | 0.03 |
| LTYSAL | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 | 0.06 | 0.10 | 0.00 | 0.00 | 0.03 |
| RUMSP | 0.00 | 0.01 | 0.05 | 0.00 | 0.00 | 0.05 | 0.00 | 0.02 | 0.05 | 0.02 |
| TYPANG | 0.06 | 0.00 | 0.00 | 0.00 | 0.19 | 0.00 | 0.00 | 0.00 | 0.07 | 0.02 |
| SUELIN | 0.01 | 0.04 | 0.01 | 0.01 | 0.00 | 0.03 | 0.00 | 0.02 | 0.04 | 0.02 |
| SCIMAR | 0.05 | 0.00 | 0.00 | 0.00 | 0.12 | 0.01 | 0.00 | 0.04 | 0.01 | 0.02 |
| POLPUN | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.03 | 0.00 | 0.01 |
| MENARV | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.03 | 0.05 | 0.00 | 0.00 | 0.01 |
| MYRPEN | 0.03 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.01 |
| CELORB | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.03 | 0.01 |
| PHYAME | 0.02 | 0.00 | 0.00 | 0.00 | 0.03 | 0.01 | 0.00 | 0.00 | 0.03 | 0.01 |
| ELEPAR | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.00 | 0.00 | 0.01 |
| THETHE | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 |
| POLSAG | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| HIBMOS | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| AMBTRI | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| SALVIR | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| JUNVIR | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| SYMFOE | 0.01 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |

Table 5. Mean percent cover of emergent vegetation species in each of the eight NBNERR salt marshes. Data were pooled across the three years of this study. Standard errors were omitted for clarity (contact NBNERR to obtain these data if desired). See Appendix A for a list of vegetation species and their six-letter codes.

| | Coggeshall | Gooseneck Cove | Jacob's Point (reference) | Jacob's Point (restoration) | Nag | Potter Pond | Silver Creek | Walker Farm |
|---|---|---|---|---|---|---|---|---|
| SPAALT | 30.35 | 31.60 | 6.17 | 0.00 | 22.67 | 16.40 | 5.91 | 17.33 |
| SPAPAT | 20.13 | 7.11 | 24.05 | 14.95 | 28.16 | 7.87 | 15.69 | 3.44 |
| DISSPI | 7.67 | 6.48 | 37.78 | 5.70 | 10.59 | 7.81 | 14.12 | 0.35 |
| PHRAUS | 0.00 | 4.91 | 0.81 | 31.22 | 0.00 | 9.87 | 14.60 | 25.05 |
| IVAFRU | 5.17 | 0.00 | 6.84 | 1.86 | 2.03 | 9.46 | 8.83 | 0.00 |
| JUNGER | 6.14 | 0.69 | 9.44 | 4.38 | 3.55 | 4.26 | 3.72 | 0.35 |
| Bare Ground | 1.65 | 6.25 | 0.00 | 0.38 | 1.07 | 5.27 | 1.83 | 3.44 |
| SALEUR | 0.00 | 1.34 | 1.02 | 1.03 | 0.01 | 0.02 | 0.15 | 4.44 |
| Other | 0.02 | 0.00 | 0.02 | 3.35 | 0.00 | 0.00 | 2.78 | 1.35 |
| Water | 0.00 | 4.31 | 0.00 | 0.30 | 0.00 | 0.00 | 1.40 | 0.00 |
| ATRPAT | 0.00 | 0.00 | 0.13 | 0.95 | 0.00 | 0.13 | 1.55 | 1.65 |
| SOLSEM | 0.03 | 0.00 | 0.57 | 0.00 | 0.00 | 0.00 | 2.06 | 1.72 |
| SCIAME | 0.00 | 0.00 | 0.00 | 2.51 | 1.06 | 0.00 | 0.00 | 0.00 |
| SALSP | 0.11 | 0.00 | 0.00 | 0.00 | 0.70 | 2.62 | 0.00 | 0.00 |
| ACERUB | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.33 |
| QUESP | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.33 |
| ASITEN | 0.00 | 0.11 | 1.17 | 0.00 | 0.01 | 0.00 | 0.98 | 0.00 |
| BACHAM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.12 | 0.00 | 0.00 |
| TYPLAT | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.05 | 0.00 |
| LIMNAS | 1.13 | 0.11 | 0.30 | 0.00 | 0.16 | 0.01 | 0.02 | 0.00 |
| PLUPUR | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 1.30 |
| PLAMAR | 0.00 | 0.00 | 1.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| GERMAR | 0.00 | 0.14 | 0.87 | 0.00 | 0.19 | 0.00 | 0.00 | 0.00 |
| PARQUI | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.12 | 0.00 |
| MALSP | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LONSP | 0.00 | 0.62 | 0.00 | 0.00 | 0.00 | 0.29 | 0.00 | 0.00 |
| CALSEP | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.71 | 0.07 |
| Wrack | 0.24 | 0.00 | 0.00 | 0.00 | 0.33 | 0.15 | 0.00 | 0.00 |
| Rock | 0.67 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| PANVER | 0.03 | 0.00 | 0.41 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 |
| ELEPAL | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.47 |
| TOXRAD | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 0.42 | 0.00 |
| ASTSUBU | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.37 | 0.02 |
| PITCAP | 0.00 | 0.00 | 0.00 | 0.38 | 0.00 | 0.00 | 0.00 | 0.00 |
| TYPANG | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 |
| SCIMAR | 0.00 | 0.00 | 0.00 | 0.19 | 0.00 | 0.00 | 0.00 | 0.05 |
| LTYSAL | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 |
| RUMSP | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 |
| POLPUN | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.14 |
| SUELIN | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 |
| PHYAME | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.05 |
| MENARV | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.00 |
| MYRPEN | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CELORB | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| HIBMOS | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 |
| POLSAG | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 |
| THETHE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 |
| ELEPAR | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 |
| AMBTRI | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 |
| SYMFOE | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| JUNVIR | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 |
| SALVIR | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Table 6. Results of two-way ANOVA tests comparing the percent cover of five dominant vegetation species, vegetation plot richness, and hydrologic parameters from shallow wells among pairs of restoration and reference marshes. Significant ANOVA results are indicated by REF (indicating the parameter was significantly higher in the reference marsh) or REST (higher in the restoration marsh). Ds=*Distichlis spicata*, If=*Iva frutescens*, Jg=*Juncus gerardii*, Pa=*Phragmites australis*, Sa=*Spartina alterniflora*, Sp=*Spartina patens*, Rich=vegetation plot richness, Sal=salinity from shallow well sampling, Wt=water table depth from shallow well sampling.

| Marsh comparison | | Parameter | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Restoring | Reference | Ds | If | Jg | Pa | Sa | Sp | Rich | Sal | Wt |
| Gooseneck | Coggeshall | x | x | x | x | x | REF | x | REST | REF |
| Jacob's Point (rest) | Jacob's Point (ref) | REF | x | x | REST | x | x | x | REF | x |
| Potter Pond | Nag | x | REST | x | REST | x | REF | x | x | REST |
| Silver Creek | Nag | x | x | x | REST | REF | REF | x | REF | REST |
| Walker Farm | Nag | REF | x | x | REST | x | REF | x | x | REST |

Table 7. Salinity and water table depths from shallow well and sipper measurements. Data are provided for individual marshes, marsh types, marsh zones, and years and are expressed as means (standard error).

| | | Salinity (ppt) | Water Table (cm) |
|---|---|---|---|
| Marsh | Coggeshall | 26.75 (0.94) | 9.24 (1.32) |
| | Gooseneck Cove | 29.85 (0.65) | 2.71 (0.58) |
| | Jacob's Point (Ref) | 27.82 (0.60) | 8.65 (1.00) |
| | Jacob's Point (Rest) | 11.28 (0.91) | 6.60 (1.06) |
| | Nag | 23.14 (0.66) | 2.72 (0.42) |
| | Potter Pond | 23.82 (2.21) | 16.15 (3.59) |
| | Silver Creek | 17.27 (0.80) | 15.80 (0.84) |
| | Walker Farm | 19.97 (0.66) | 8.83 (0.83) |
| Type | Reference | 25.96 (0.43) | 6.80 (0.57) |
| | Restoring | 22.17 (0.49) | 8.96 (0.54) |
| | Restricted | 13.99 (0.84) | 11.14 (1.36) |
| Zone | Low | 27.99 (0.53) | 3.77 (0.39) |
| | High | 24.76 (0.45) | 7.12 (0.49) |
| | Transition | 15.59 (0.55) | 13.83 (0.83) |
| Year | 2008 | 18.30 (0.68) | 11.24 (0.97) |
| | 2009 | 22.57 (0.50) | 5.87 (0.55) |
| | 2010 | 24.99 (0.52) | 8.86 (0.57) |

Table 8. Percent inundation for each reference and restoration marsh pair based on data collected with Aquatrolls. Low=low marsh zone, High=high marsh/salt meadow zone, Trans=transition zone, X=mean, SE=standard error.

|  |  |  | % INUNDATION |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | 2008 |  |  |  | 2009 |  |  |  | 2010 |  |  |  |
| Reference | Restoration | Zone | Ref X | Ref SE | Rest X | Rest SE | Ref X | Ref SE | Rest X | Rest SE | Ref X | Ref SE | Rest X | Rest SE |
| Coggeshall | Gooseneck Cove | Low | . | . | . | . | 95.42 | . | . | . | 34.37 | . | 39.46 | . |
|  |  | High | . | . | . | . | 17.72 | . | . | . | 29.73 | . | 19.21 | . |
|  |  | Trans | . | . | . | . | 1.20 | . | . | . | 0.00 | . | 100.00 | . |
|  |  | Pooled | . | . | . | . | 38.11 | . | . | . | 21.37 | . | 52.89 | . |
| Jacob's Point (REF) | Jacob's Point (REST) | Low | . | . | . | . | 100.00 | . | . | . | . | . | 48.99 | . |
|  |  | High | . | . | . | . | 12.47 | . | . | . | . | . | 14.93 | . |
|  |  | Trans | . | . | . | . | 99.93 | . | . | . | . | . | 10.65 | . |
|  |  | Pooled | . | . | . | . | 70.80 | . | . | . | . | . | 24.86 | . |
| Nag | Potter Pond | Low | . | . | . | . | 32.69 | . | 47.50 | . | 19.70 | . | 85.76 | . |
|  |  | High | . | . | . | . | 57.20 | . | 77.53 | . | 4.57 | . | 89.31 | . |
|  |  | Trans | . | . | . | . | 91.77 | . | . | . | 14.39 | . | 3.31 | . |
|  |  | Pooled | . | . | . | . | 60.55 | . | 62.52 | . | 12.89 | . | 59.46 | . |
| Nag | Silver Creek | Low | . | . | . | . | 32.69 | . | . | . | 19.70 | . | 99.70 | . |
|  |  | High | . | . | . | . | 57.20 | . | . | . | 4.57 | . | 5.42 | . |
|  |  | Trans | . | . | . | . | 91.77 | . | . | . | 14.39 | . | 4.08 | . |
|  |  | Pooled | . | . | . | . | 60.55 | . | . | . | 12.89 | . | 36.40 | . |
| Nag | Walker Farm | Low | . | . | . | . | 32.69 | . | 12.49 | . | 19.70 | . | 70.31 | . |
|  |  | High | . | . | . | . | 57.20 | . | 26.62 | . | 4.57 | . | 10.41 | . |
|  |  | Trans | . | . | . | . | 91.77 | . | 0.00 | . | 14.39 | . | 38.02 | . |
|  |  | Pooled | . | . | . | . | 60.55 | . | 13.04 | . | 12.89 | . | 39.58 | . |

Table 9. Mean water table level for each reference and restoration marsh pair based on data collected with Aquatrolls. Negative values indicate depths below the marsh surface. Low=low marsh zone, High=high marsh/salt meadow zone, Trans=transition zone, X=mean, SE=standard error.

| | | | GROUNDWATER LEVEL (m) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2008 | | | | 2009 | | | | 2010 | | | |
| Reference | Restoration | Zone | Ref | Ref | Rest | Rest | Ref | Ref | Rest | Rest | Ref | Ref | Rest | Rest |
| | | | X | SE | X | SE | X | SE | X | SE | X | SE | X | SE |
| Coggeshall | Gooseneck Cove | Low | . | . | . | . | 0.10 | 0.00 | . | . | 0.02 | 0.00 | 0.04 | 0.00 |
| | | High | . | . | . | . | -0.01 | 0.00 | . | . | -0.09 | 0.00 | -0.04 | 0.00 |
| | | Trans | . | . | . | . | -0.34 | 0.00 | . | . | -0.42 | 0.00 | 0.14 | 0.00 |
| | | Pooled | . | . | . | . | -0.08 | 0.00 | . | . | -0.16 | 0.00 | 0.05 | 0.00 |
| Jacob's Point (REF) | Jacob's Point (REST) | Low | . | . | . | . | 0.02 | 0.00 | . | . | . | . | 0.04 | 0.00 |
| | | High | . | . | . | . | -0.02 | 0.00 | . | . | . | . | -0.02 | 0.00 |
| | | Trans | . | . | . | . | 0.13 | 0.00 | . | . | . | . | -0.06 | 0.00 |
| | | Pooled | . | . | . | . | 0.04 | 0.00 | . | . | . | . | -0.02 | 0.00 |
| Nag | Potter Pond | Low | . | . | . | . | 0.03 | 0.00 | -0.01 | 0.00 | -0.05 | 0.00 | 0.04 | 0.00 |
| | | High | . | . | . | . | 0.03 | 0.00 | 0.01 | 0.00 | -0.08 | 0.00 | 0.04 | 0.00 |
| | | Trans | . | . | . | . | 0.01 | 0.00 | . | . | -0.09 | 0.00 | -0.33 | 0.00 |
| | | Pooled | . | . | . | . | 0.03 | 0.00 | 0.00 | 0.00 | -0.07 | 0.00 | -0.08 | 0.00 |
| Nag | Silver Creek | Low | . | . | . | . | 0.03 | 0.00 | . | . | -0.05 | 0.00 | 0.22 | 0.00 |
| | | High | . | . | . | . | 0.03 | 0.00 | . | . | -0.08 | 0.00 | -0.10 | 0.00 |
| | | Trans | . | . | . | . | 0.01 | 0.00 | . | . | -0.09 | 0.00 | -0.26 | 0.00 |
| | | Pooled | . | . | . | . | 0.03 | 0.00 | . | . | -0.07 | 0.00 | -0.05 | 0.00 |
| Nag | Walker Farm | Low | . | . | . | . | 0.03 | 0.00 | -0.05 | 0.00 | -0.05 | 0.00 | 0.01 | 0.00 |
| | | High | . | . | . | . | 0.03 | 0.00 | -0.01 | 0.00 | -0.08 | 0.00 | -0.08 | 0.00 |
| | | Trans | . | . | . | . | 0.01 | 0.00 | -0.31 | 0.00 | -0.09 | 0.00 | -0.01 | 0.00 |
| | | Pooled | . | . | . | . | 0.03 | 0.00 | -0.12 | 0.00 | -0.07 | 0.00 | -0.02 | 0.00 |

Table 10. Maximum high tide level for each reference and restoration marsh pair based on data collected with Aquatrolls. Low=low marsh zone, High=high marsh/salt meadow zone, Trans=transition zone, X=mean, SE=standard error.

| | | | MAX HIGH TIDE LEVEL (m) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2008 | | | | 2009 | | | | 2010 | | | |
| Reference | Restoration | Zone | Ref X | Ref SE | Rest X | Rest SE | Ref X | Ref SE | Rest X | Rest SE | Ref X | Ref SE | Rest X | Rest SE |
| Coggeshall | Gooseneck Cove | Low | . | . | . | . | 0.76 | . | . | . | 0.45 | . | 0.50 | . |
| | | High | . | . | . | . | 0.48 | . | . | . | 0.20 | . | 0.35 | . |
| | | Trans | . | . | . | . | 0.10 | . | . | . | -0.32 | . | 0.59 | . |
| | | Pooled | . | . | . | . | 0.45 | . | . | . | 0.11 | . | 0.48 | . |
| Jacob's Point (REF) | Jacob's Point (REST) | Low | . | . | . | . | 0.31 | . | . | . | . | . | 0.84 | . |
| | | High | . | . | . | . | 0.35 | . | . | . | . | . | 0.54 | . |
| | | Trans | . | . | . | . | 0.32 | . | . | . | . | . | 0.28 | . |
| | | Pooled | . | . | . | . | 0.33 | . | . | . | . | . | 0.56 | . |
| Nag | Potter Pond | Low | . | . | . | . | 0.53 | . | 0.16 | . | 0.24 | . | 0.42 | . |
| | | High | . | . | . | . | 0.50 | . | 0.15 | . | 0.12 | . | 0.41 | . |
| | | Trans | . | . | . | . | 0.29 | . | . | . | 0.07 | . | 0.13 | . |
| | | Pooled | . | . | . | . | 0.44 | . | 0.15 | . | 0.14 | . | 0.32 | . |
| Nag | Silver Creek | Low | . | . | . | . | 0.53 | . | . | . | 0.24 | . | 0.61 | . |
| | | High | . | . | . | . | 0.50 | . | . | . | 0.12 | . | 0.29 | . |
| | | Trans | . | . | . | . | 0.29 | . | . | . | 0.07 | . | 0.26 | . |
| | | Pooled | . | . | . | . | 0.44 | . | . | . | 0.14 | . | 0.39 | . |
| Nag | Walker Farm | Low | . | . | . | . | 0.53 | . | 0.18 | . | 0.24 | . | 0.16 | . |
| | | High | . | . | . | . | 0.50 | . | 0.17 | . | 0.12 | . | 0.10 | . |
| | | Trans | . | . | . | . | 0.29 | . | -0.06 | . | 0.07 | . | 0.11 | . |
| | | Pooled | . | . | . | . | 0.44 | . | 0.10 | . | 0.14 | . | 0.12 | . |

Table 11. Soil bulk density and % organic matter for each reference and restoration marsh pair. Low=low marsh zone, High=high marsh/salt meadow zone, Trans=transition zone, X=mean, SE=standard error.

| | | | BULK DENSITY 2008-2010 | | | | - | % ORGANIC MATTER 2008-2010 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference Marsh | Restoration Marsh | Marsh Zone | REF - X | REF - SE | REST - X | REST - SE | | REF - X | REF - SE | REST - X | REST - SE |
| Coggeshall Marsh | Gooseneck Cove Marsh | Low | 0.133 | 0.023 | 0.100 | . | | 41.637 | 2.636 | 52.330 | . |
| | | High | 0.153 | 0.013 | 0.190 | . | | 43.497 | 4.090 | 38.310 | . |
| | | Trans | 0.670 | 0.106 | 0.060 | . | | 7.417 | 2.028 | 62.690 | . |
| | | POOLED | 0.319 | 0.093 | 0.117 | 0.038 | | 30.850 | 6.059 | 51.110 | 7.064 |
| Jacob's Point Reference Marsh | Jacob's Point Restoration Marsh | Low | 0.170 | . | . | . | | 41.860 | . | . | . |
| | | High | 0.200 | . | . | . | | 39.260 | . | . | . |
| | | Trans | . | . | 0.060 | . | | . | . | 70.610 | . |
| | | POOLED | 0.185 | 0.015 | 0.060 | . | | 40.560 | 1.300 | 70.610 | . |
| Nag Marsh | Potter Pond Marsh | Low | 0.137 | 0.015 | 0.130 | . | | 43.767 | 3.957 | 56.790 | . |
| | | High | 0.130 | 0.012 | 0.280 | . | | 55.957 | 8.118 | 76.470 | . |
| | | Trans | 0.320 | 0.164 | 0.850 | . | | 30.340 | 12.663 | 36.730 | . |
| | | POOLED | 0.196 | 0.057 | 0.420 | 0.219 | | 43.354 | 5.817 | 56.663 | 11.472 |
| Nag Marsh | Silver Creek Marsh | Low | 0.137 | 0.015 | 0.810 | . | | 43.767 | 3.957 | 6.500 | . |
| | | High | 0.130 | 0.012 | 0.300 | . | | 55.957 | 8.118 | 26.170 | . |
| | | Trans | 0.320 | 0.164 | 0.670 | . | | 30.340 | 12.663 | 10.720 | . |
| | | POOLED | 0.196 | 0.057 | 0.593 | 0.152 | | 43.354 | 5.817 | 14.463 | 5.979 |
| Nag Marsh | Walker Farm Marsh | Low | 0.137 | 0.015 | 0.120 | . | | 43.767 | 3.957 | 44.630 | . |
| | | High | 0.130 | 0.012 | 0.110 | . | | 55.957 | 8.118 | 57.430 | . |
| | | Trans | 0.320 | 0.164 | 0.460 | . | | 30.340 | 12.663 | 16.080 | . |
| | | POOLED | 0.196 | 0.057 | 0.230 | 0.115 | | 43.354 | 5.817 | 39.380 | 12.222 |

Table 12: Point location and elevation at groundwater wells and vegetation plots along Nag Marsh transects and difference in position and elevation between years.

| | | 2009 | | | 2010 | | Positional | Elevation |
|---|---|---|---|---|---|---|---|---|
| Point | Northing | Easting | Elevation | Northing | Easting | Elevation | Difference (m) | Difference (m) |
| tr1gw1 | 60120.9829 | 114771.2471 | 0.586518 | 60120.9889 | 114771.2358 | 0.612372 | 0.013 | -0.02585 |
| tr1gw2 | 60109.1203 | 114780.1482 | 0.481343 | 60109.1131 | 114780.1462 | 0.490752 | 0.007 | -0.00941 |
| tr1gw3 | 60097.1698 | 114789.0952 | 0.653134 | 60097.1837 | 114789.0975 | 0.670510 | 0.014 | -0.01738 |
| tr1gw4 | 60085.2557 | 114798.3829 | 0.668903 | 60085.2895 | 114798.3649 | 0.670085 | 0.038 | -0.00118 |
| tr1gw5 | 60073.4661 | 114807.6410 | 0.634630 | 60073.4784 | 114807.6465 | 0.650069 | 0.013 | -0.01544 |
| tr1gw6 | 60059.5007 | 114818.1804 | 0.701908 | 60059.5043 | 114818.2035 | 0.694934 | 0.023 | 0.00697 |
| tr1gw7 | 60047.6263 | 114827.5219 | 0.764045 | 60047.6530 | 114827.5380 | 0.760240 | 0.031 | 0.00380 |
| tr1gw8 | 60037.2114 | 114835.4357 | 0.836201 | 60037.2487 | 114835.4552 | 0.818575 | 0.042 | 0.01763 |
| tr1vp1 | 60121.8911 | 114769.3494 | 0.533541 | 60121.6590 | 114769.5133 | 0.561813 | 0.284 | -0.02827 |
| tr1vp2 | 60109.7202 | 114778.4988 | 0.532933 | 60109.7306 | 114778.1152 | 0.582696 | 0.384 | -0.04976 |
| tr1vp3 | 60097.7682 | 114787.2527 | 0.576123 | 60097.4539 | 114787.2909 | 0.593625 | 0.317 | -0.01750 |
| tr1vp4 | 60085.8235 | 114796.4584 | 0.612111 | 60085.7470 | 114795.9488 | 0.623873 | 0.515 | -0.01176 |
| tr1vp5 | 60074.1439 | 114805.7506 | 0.552624 | 60074.3828 | 114805.1912 | 0.563419 | 0.608 | -0.01080 |
| tr1vp6 | 60060.3503 | 114816.4913 | 0.603119 | 60060.2426 | 114815.8291 | 0.641800 | 0.671 | -0.03868 |
| tr1vp7 | 60048.2901 | 114825.4575 | 0.670051 | 60048.1589 | 114824.9623 | 0.665558 | 0.512 | 0.00449 |
| tr1vp8 | 60038.0319 | 114833.5705 | 0.736380 | 60037.9151 | 114833.0041 | 0.735434 | 0.578 | 0.00095 |
| tr2vp1 | 60270.4220 | 114609.5982 | 0.386935 | --- | --- | --- | --- | --- |
| tr2vp2 | 60281.3561 | 114611.4275 | 0.593430 | 60283.1231 | 114612.4554 | 0.629652 | 2.044 | -0.03622 |
| tr2vp3 | 60294.2358 | 114613.6385 | 0.616026 | 60295.8316 | 114614.6145 | 0.665603 | 1.871 | -0.04958 |
| tr2vp4 | 60303.1526 | 114615.0037 | 0.595116 | 60305.2939 | 114616.0179 | 0.632210 | 2.369 | -0.03709 |
| tr2vp5 | 60313.8587 | 114616.6018 | 0.581778 | 60315.7446 | 114617.7408 | 0.611785 | 2.203 | -0.03001 |
| tr2vp6 | 60324.7450 | 114618.2383 | 0.641001 | 60326.7522 | 114619.3939 | 0.694679 | 2.316 | -0.05368 |
| tr2vp7 | 60335.6080 | 114619.7655 | 0.695635 | 60337.5688 | 114621.1043 | 0.699463 | 2.374 | -0.00383 |
| tr2vp8 | 60345.4950 | 114621.3043 | 0.756849 | 60347.0945 | 114622.5234 | 0.758020 | 2.011 | -0.00117 |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| tr3vp1 | --- | --- | --- | 60301.2650 | 114473.3939 | 0.666110 | --- | --- |
| tr3vp2 | 60308.6207 | 114476.2095 | 0.625698 | 60310.3453 | 114477.1826 | 0.671842 | 1.980 | -0.04614 |
| tr3vp3 | 60318.6226 | 114480.8819 | 0.630650 | 60320.4957 | 114481.8632 | 0.679041 | 2.115 | -0.04839 |
| tr3vp4 | 60328.6515 | 114485.4299 | 0.641943 | 60330.4258 | 114486.3976 | 0.675431 | 2.021 | -0.03349 |
| tr3vp5 | 60338.7636 | 114489.9230 | 0.450403 | 60340.6197 | 114490.9916 | 0.612565 | 2.142 | -0.16216 |
| tr3vp6 | 60348.5023 | 114494.6349 | 0.487910 | 60350.4257 | 114495.6960 | 0.547508 | 2.197 | -0.05960 |
| tr3vp7 | 60358.4420 | 114499.2970 | 0.629069 | 60360.0543 | 114500.2089 | 0.622180 | 1.852 | 0.00689 |
| tr3vp8 | 60368.7557 | 114503.8930 | 0.745791 | 60370.2959 | 114504.9039 | 0.804294 | 1.842 | -0.05850 |

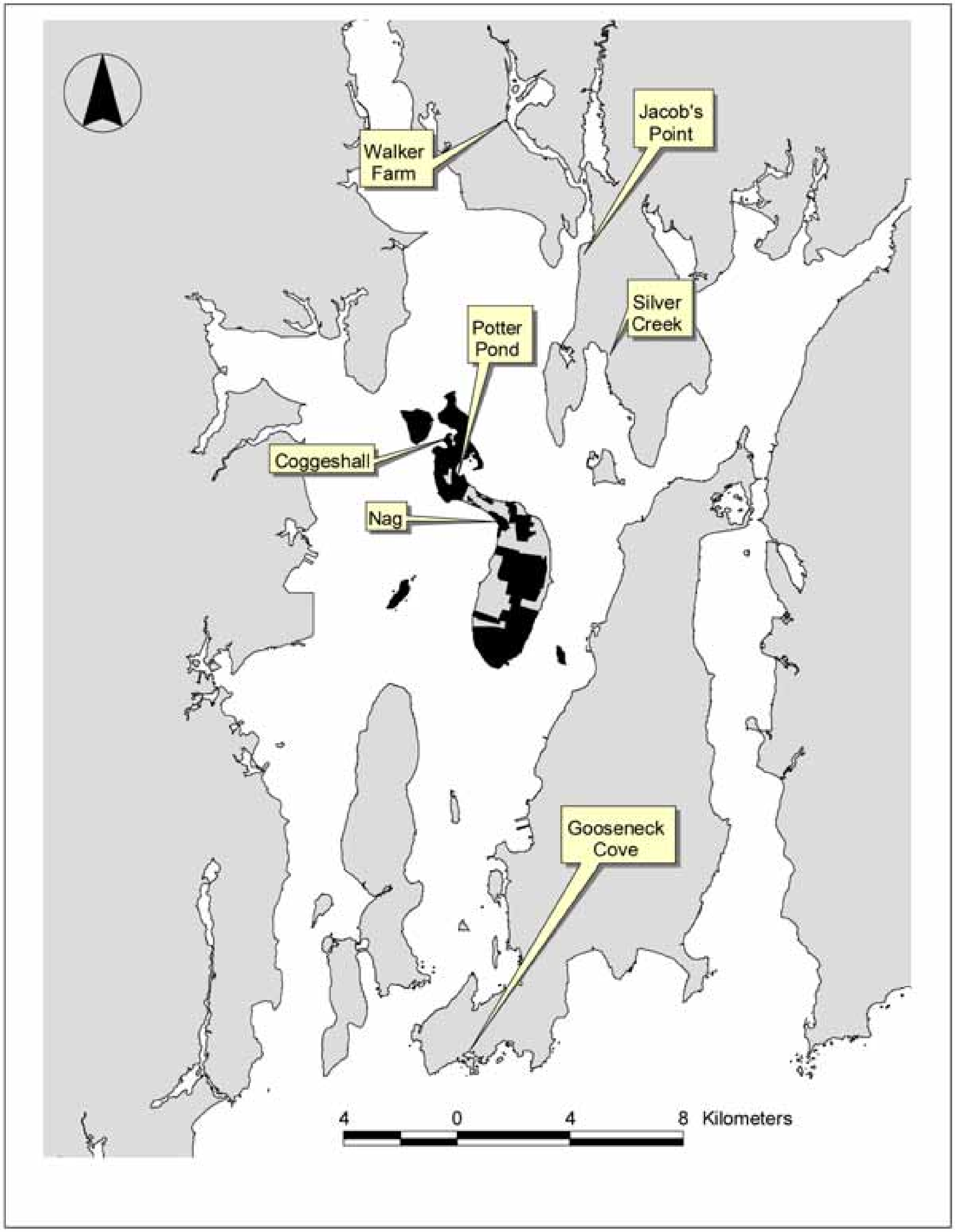


Figure 1. Map of Narragansett Bay showing the locations of the reference and restoration marshes included in this study. Land within the Narragansett Bay National Estuarine Research Reserve is indicated in black.

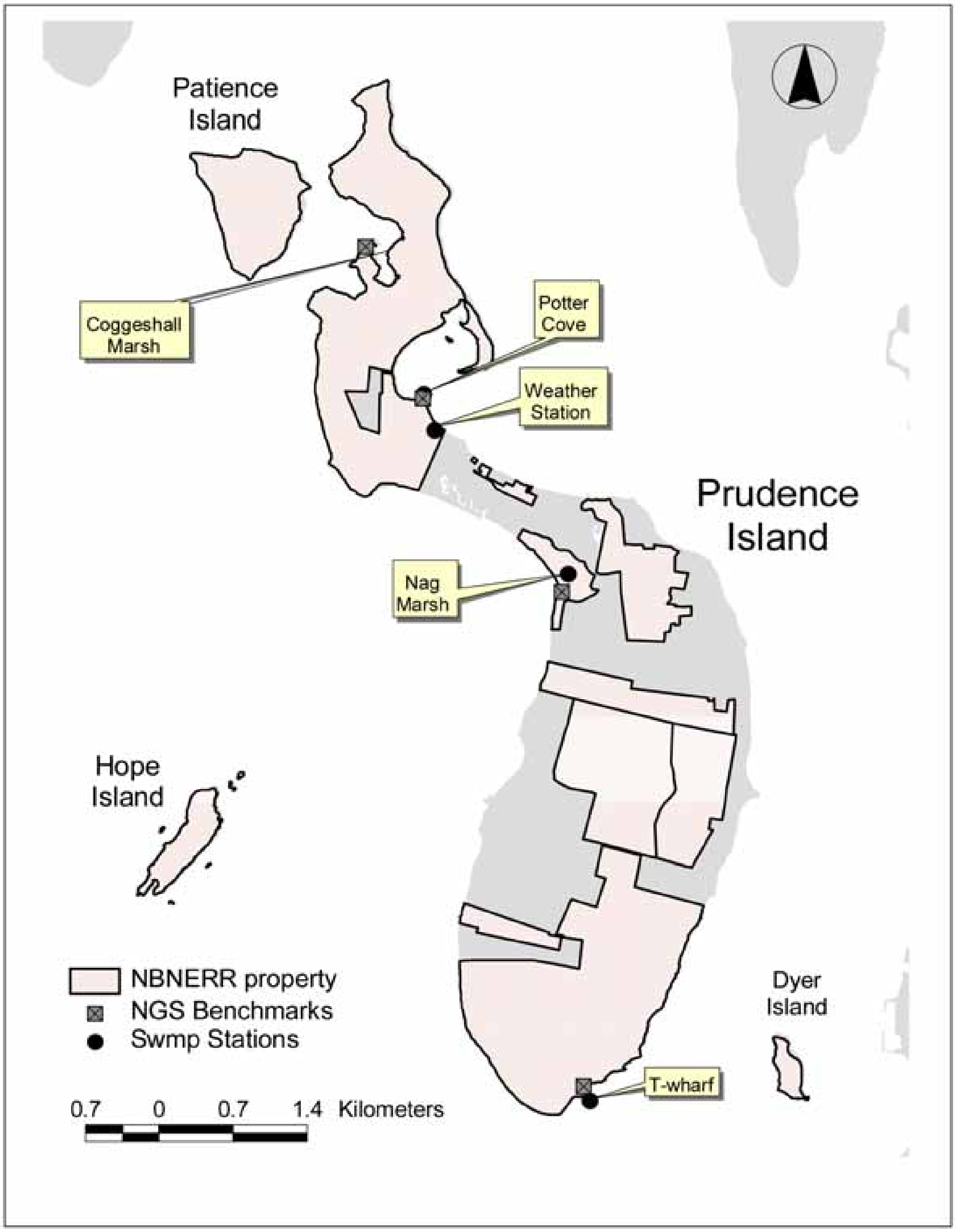


Figure 2. Map of Prudence Island and the Narragansett Bay National Estuarine Research Reserve showing the locations of the Coggeshall and Nag reference salt marshes. Locations of the three SWMP water quality stations, SWMP weather station, and four National Geodetic Survey bench marks are also indicated.

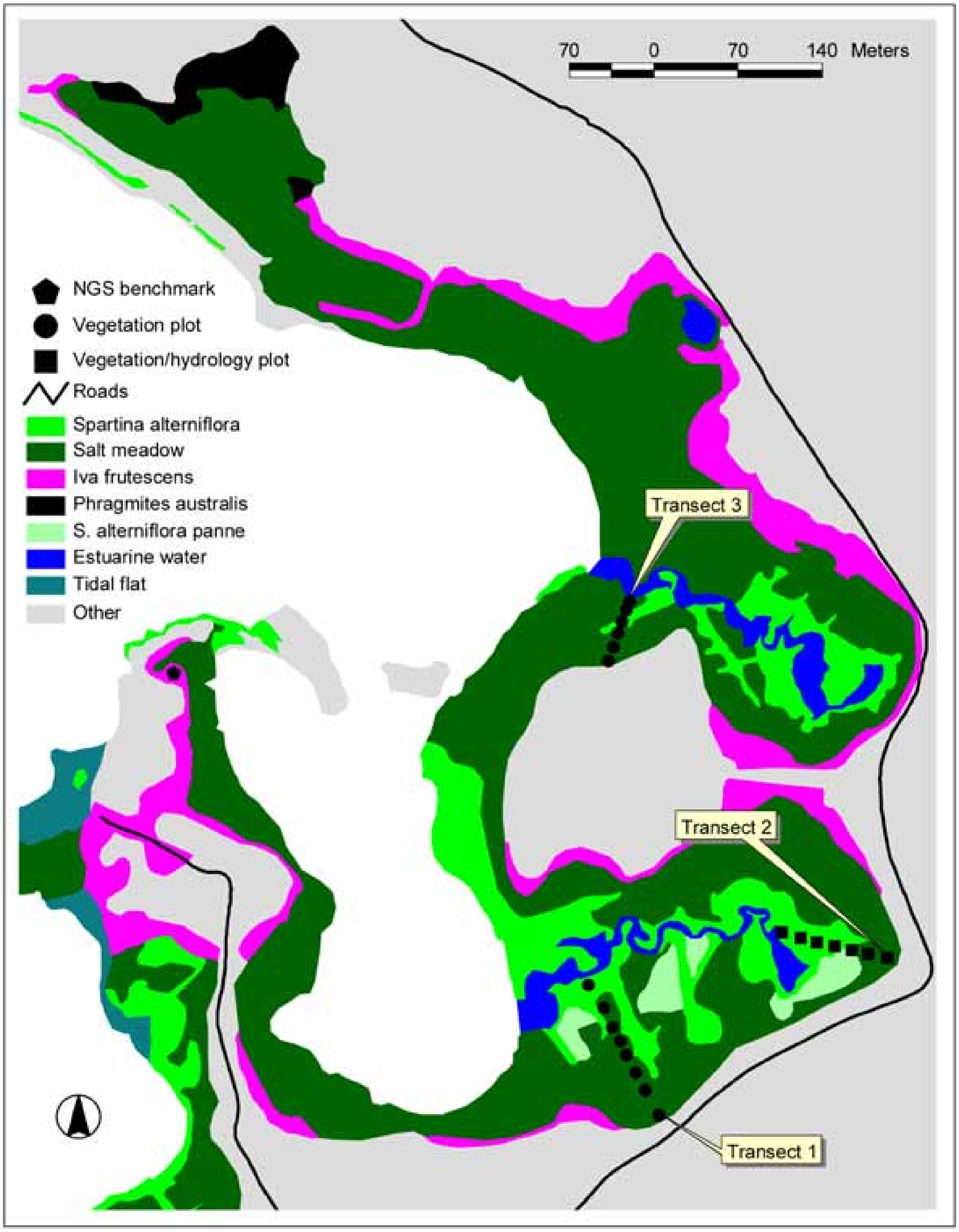


Figure 3. Map of Coggeshall Marsh showing the locations of vegetation and hydrology monitoring plots and an NGS bench mark overlaid on a habitat map of the marsh. Habitats were mapped and classified according to Kutcher et al. 2004.

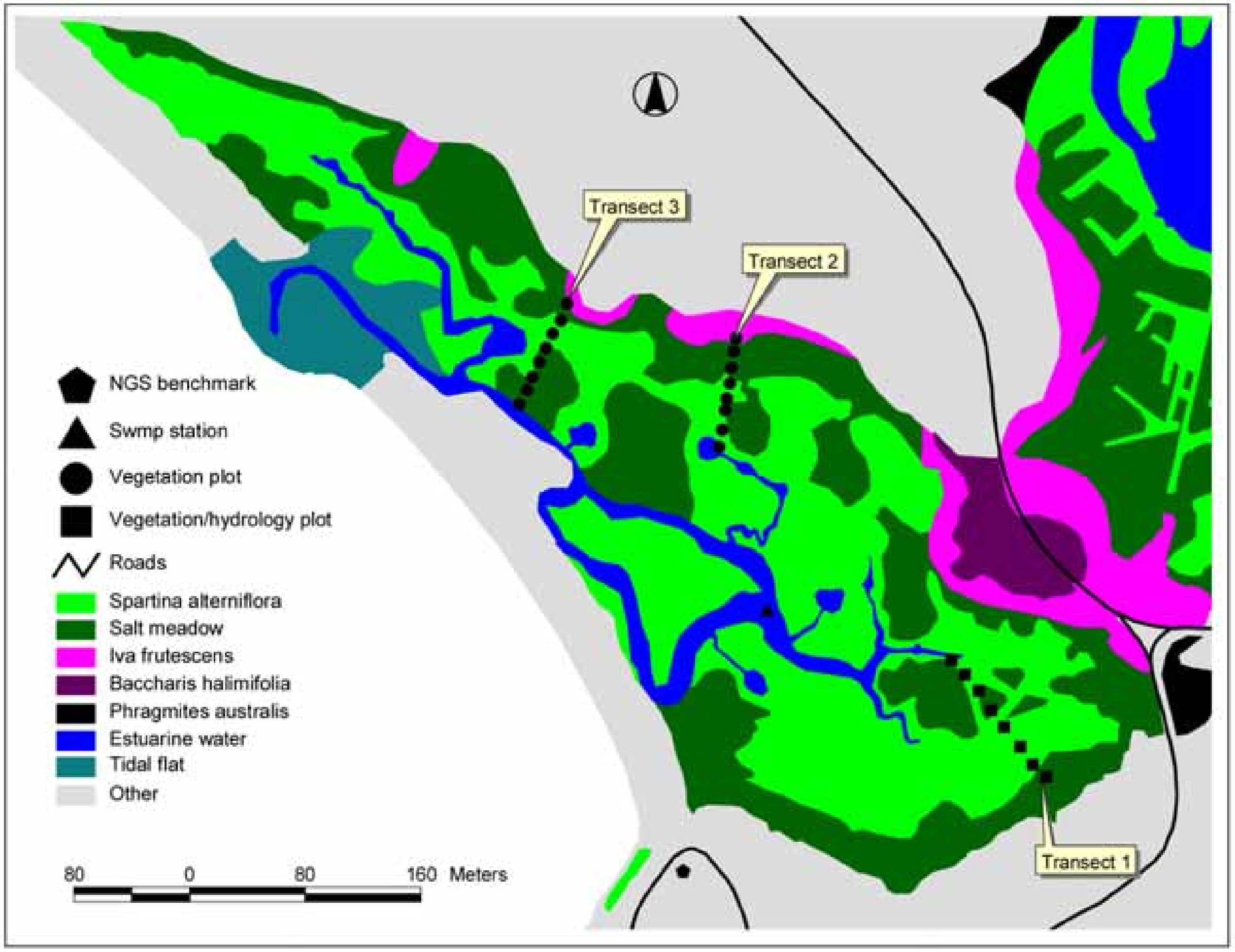


Figure 4. Map of Nag Marsh showing the locations of vegetation and groundwater monitoring plots, a SWMP station, and an NGS bench mark overlaid on a habitat map of the marsh. The study marsh is bounded to the northeast by a dirt road that passes through an *Iva frutescens/Baccharis halimifolia* shrubland. Habitats were mapped and classified according to Kutcher et al. 2004.

Figure 5.  Photographs of Coggeshalll Marsh.  The top picture shows extensive *Spartina patens* habitat; the bottom shows extensive short-form *S. alterniflora* high marsh.

Figure 6. Photographs of Nag Marsh. The top picture shows a kayaker approaching the SWMP station in the main creek in winter; the bottom shows lush summer vegetation while looking south towards the creek mouth and dune.

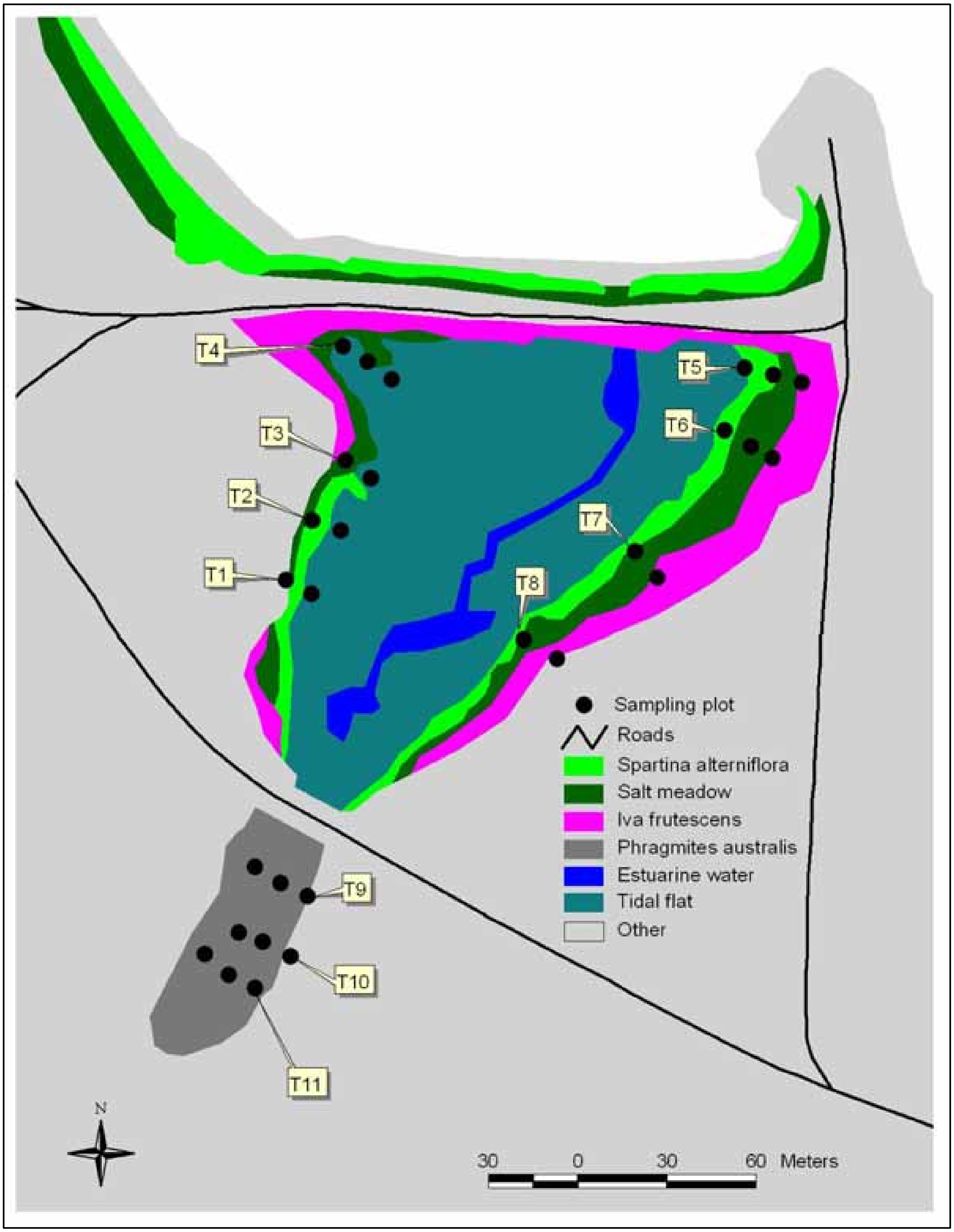


Figure 7. Map of Potter Pond Marsh showing major habitats and the locations of the 11 sampling transects and plots. Vegetation was sampled at all plots; hydrology was sampled along transect 6 only.

Figure 8. Two photographs taken from the same permanent photo-station in Potter Pond Marsh. The top photo was taken in 2004 during the second year of post-restoration. The bottom one, taken 6 years after tidal restoration, clearly shows expansion of low marsh *S. aleterniflora*.

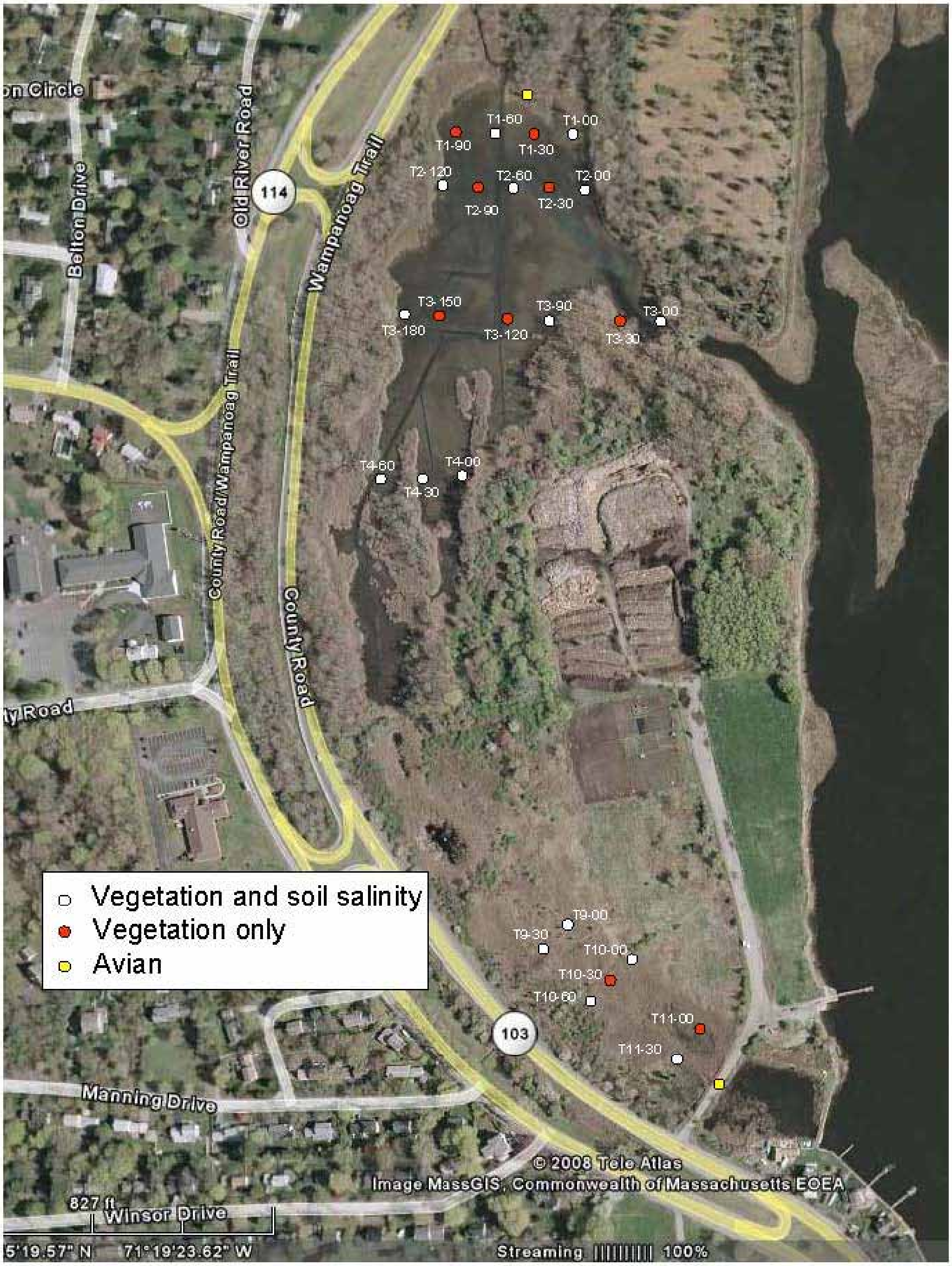


Figure 9. Map of Walker Farm Marsh showing the locations of vegetation and hydrology monitoring transects and plots. Map provided by Dr. Marci Cole of Save The Bay.

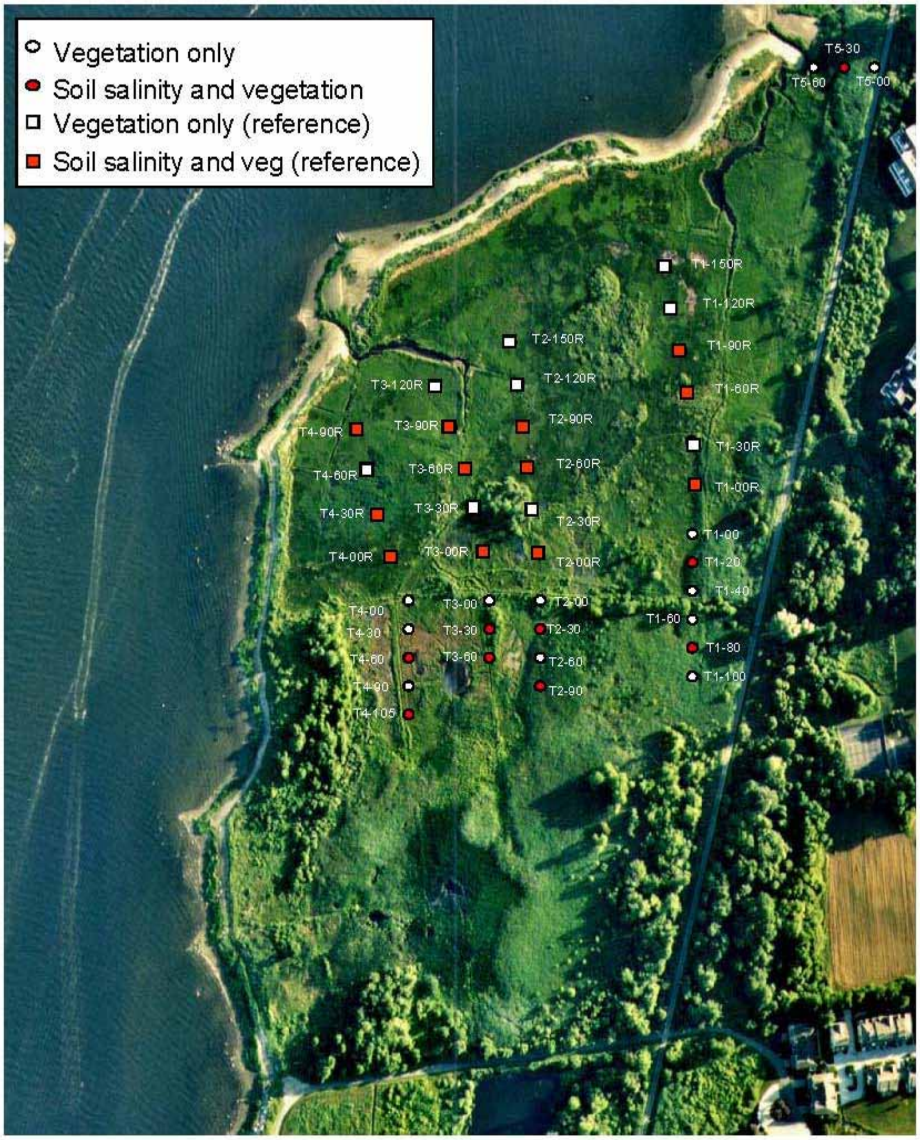


Figure 10. Map of Jacob's Point Marsh showing the locations of vegetation and hydrology monitoring transects and plots. The restoration (bottom half of the marsh) and reference (top half) sides of Jacob's Point are both shown. Map provided by Dr. Marci Cole of Save The Bay.

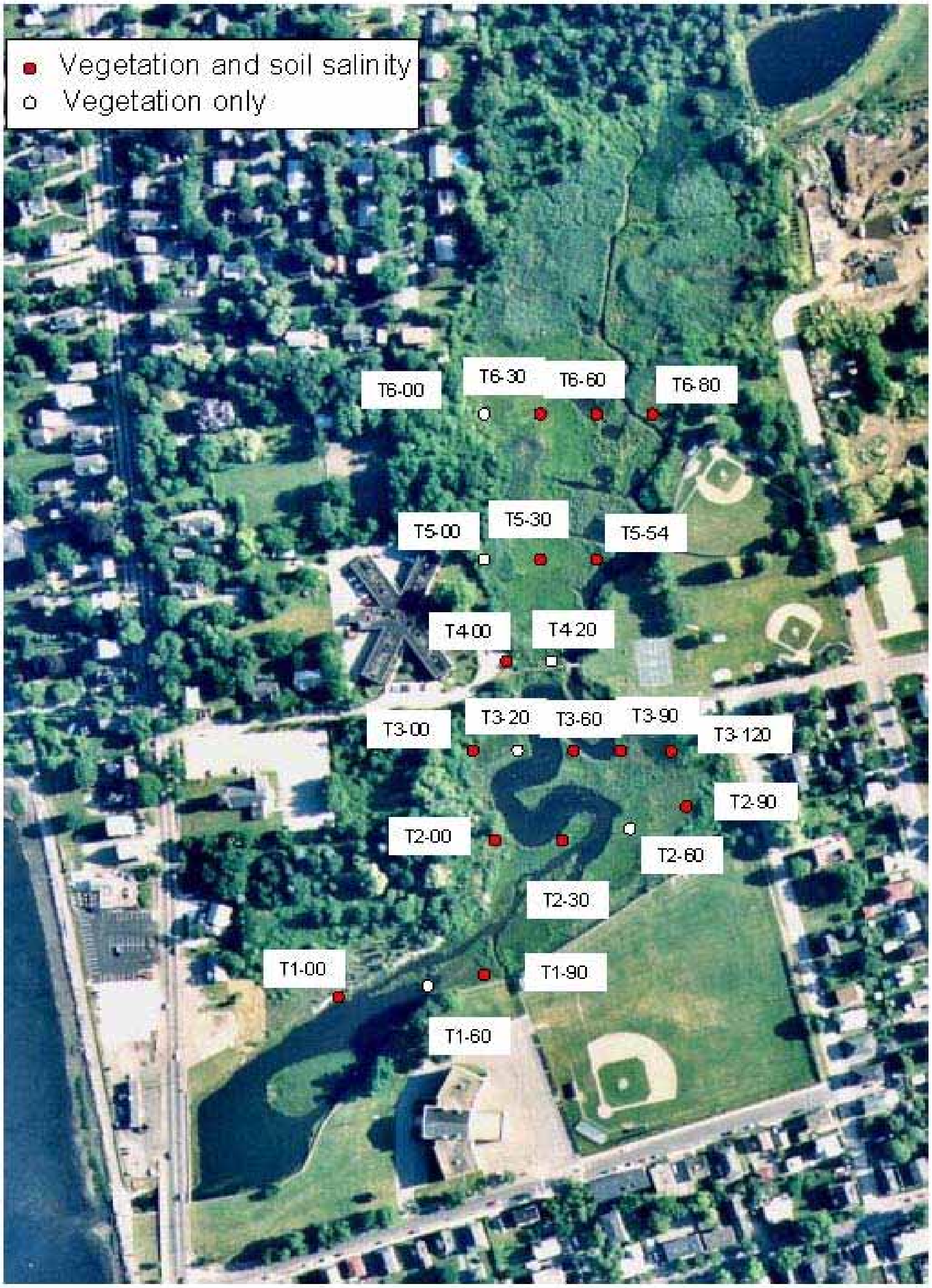


Figure 11. Map of Silver Creek Marsh showing the locations of vegetation and hydrology monitoring transects and plots. Map provided by Dr. Marci Cole of Save The Bay.

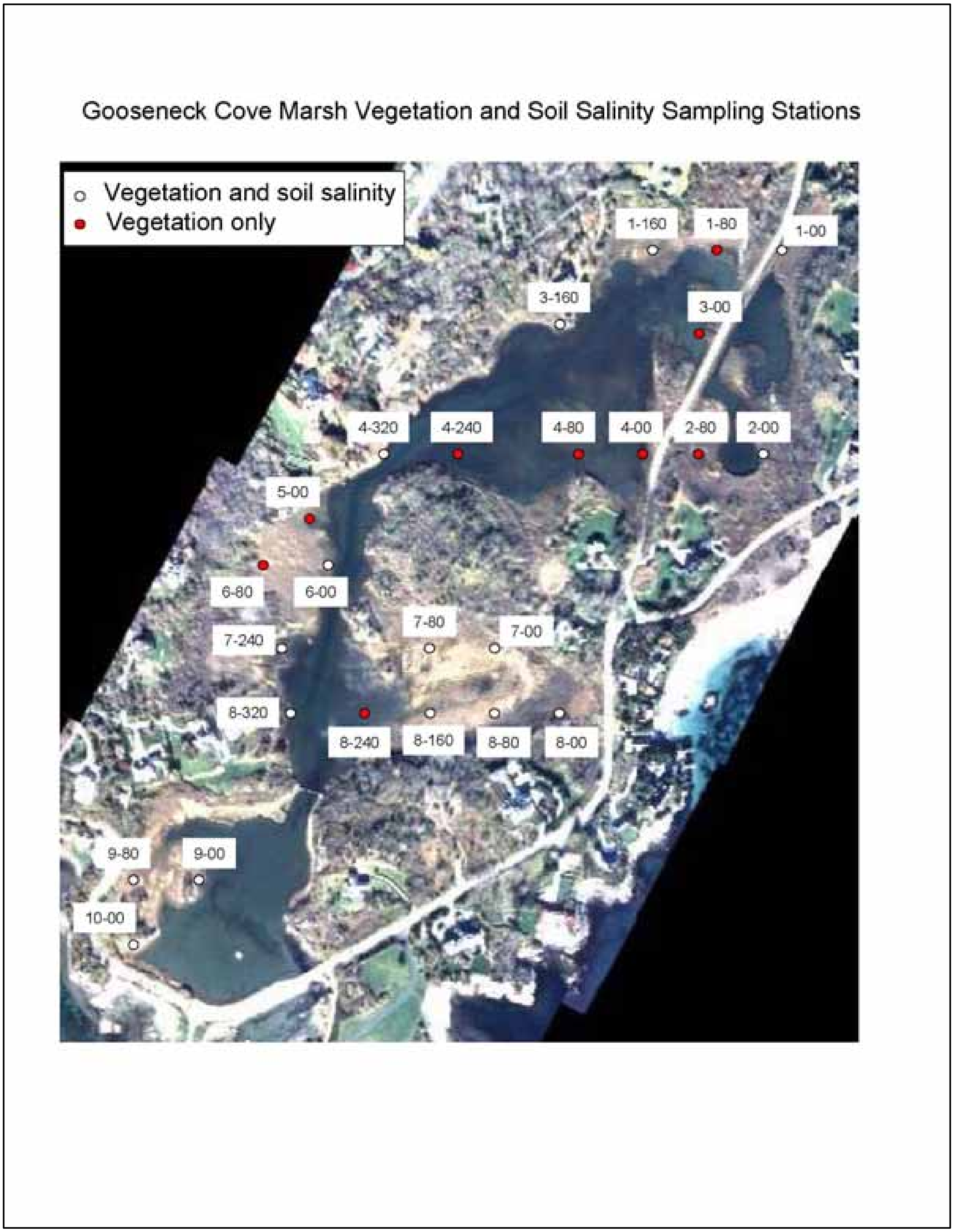


Figure 12. Map of Gooseneck Cove Marsh showing the locations of vegetation and hydrology monitoring transects and plots. Map provided by Dr. Marci Cole of Save The Bay.

Figure 13. Photos of the four Save The Bay restoration sites. Top left: Gooseneck Cove, showing a sunken, degraded portion of the marsh after restoration. Top right: Jacob's Point, showing one of the new culverts leading into the restoring marsh. Bottom left: Silver Creek after restoration. Bottom right: Walker Farm after restoration.

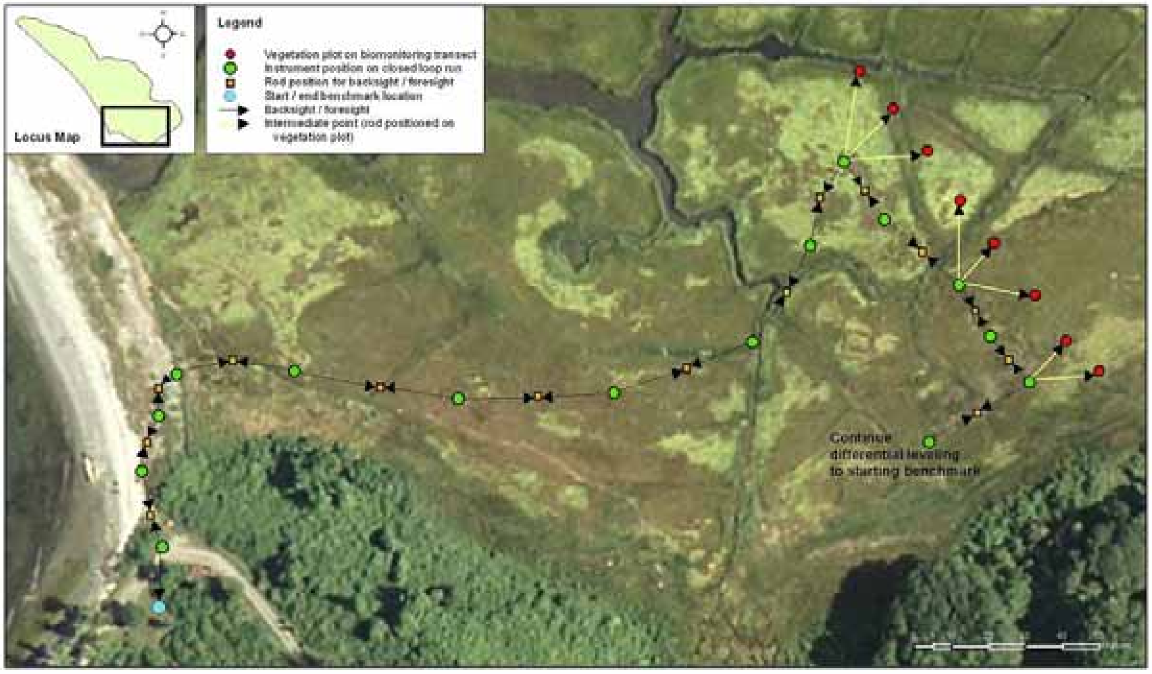


Figure 14: Example of combined differential leveling and intermediate point collection to determine elevations at vegetation plots and groundwater wells in Nag Marsh (2009).

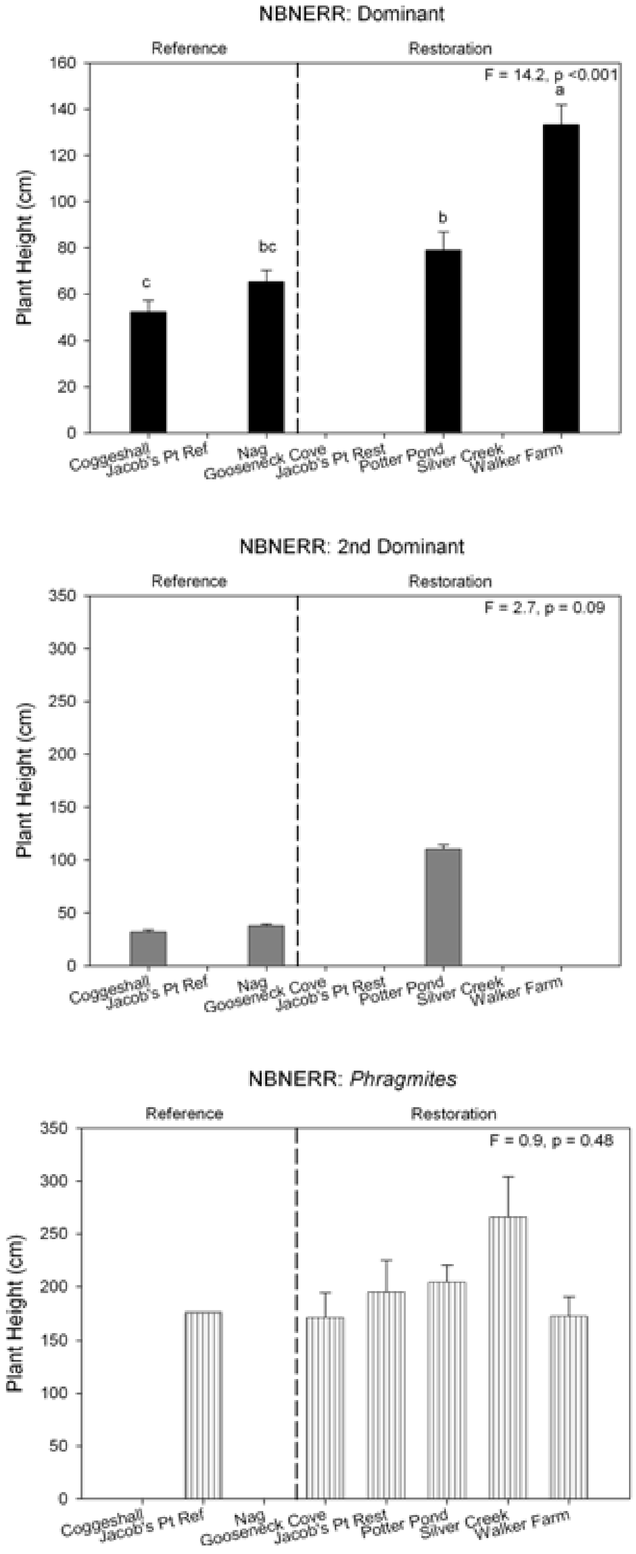


Figure 15. Heights of *S. alterniflora* (dominant), *S. patens* (2nd dominant), and *Phragmites* in the eight study salt marshes. Reference sites are on the left of the vertical dash; restoration sites are on the right. Densities were compared among all marshes using ANOVA.

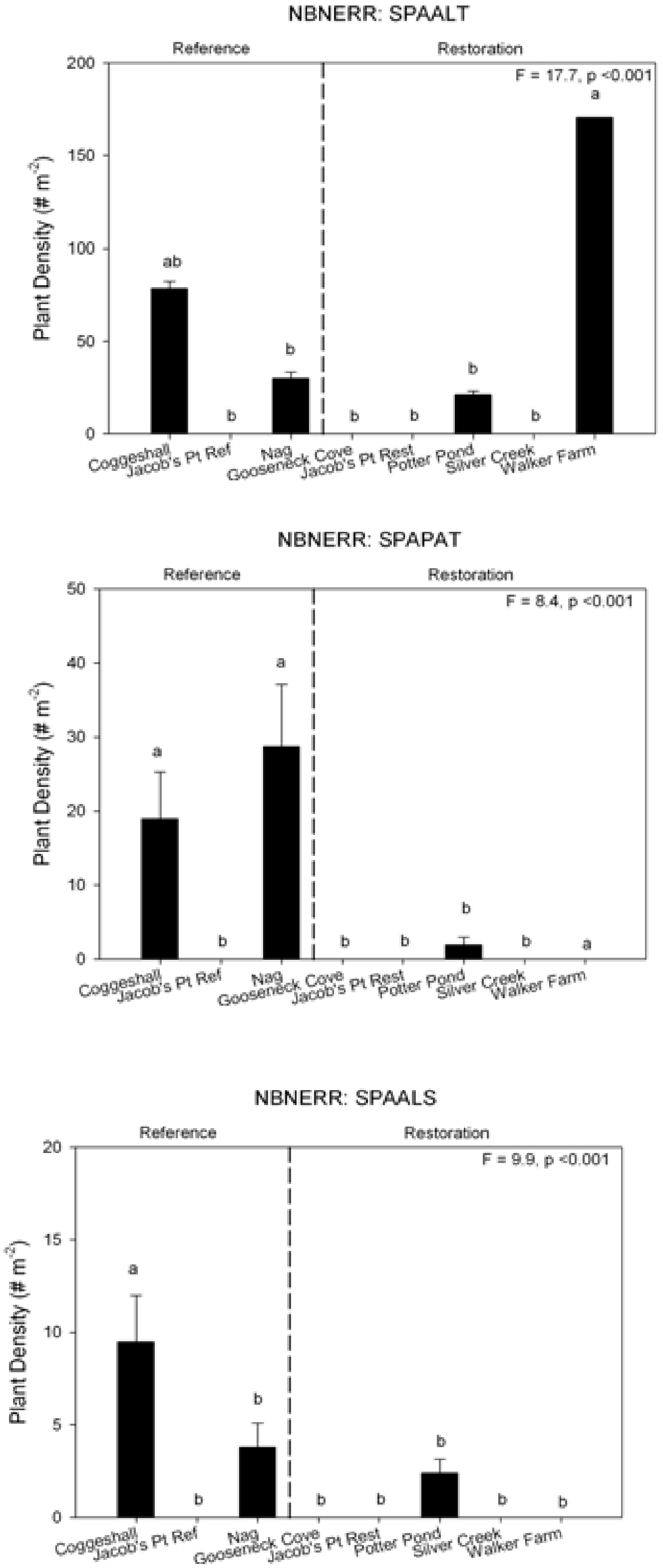
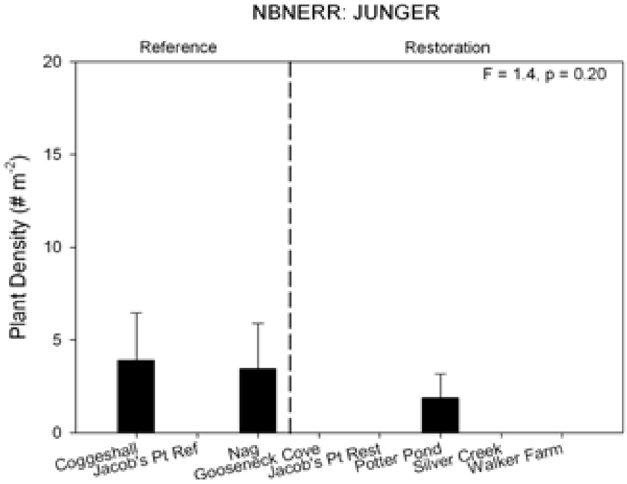


Figure 16. Stem densities of *S. alterniflora* (tall form), *S. patens, and S. alterniflora* (short form) in the eight study marshes. Reference sites are on the left of the vertical dash; restoration sites are on the right. Densities were compared among all marshes using ANOVA.



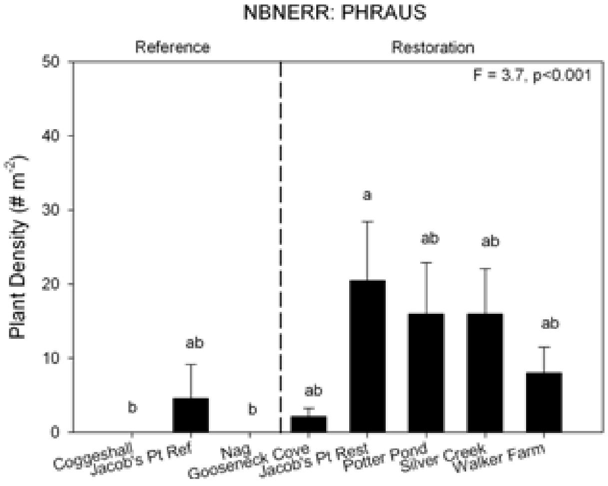


Figure 16, continued. Stem densities of *J. gerardii* and *Phragmites*.

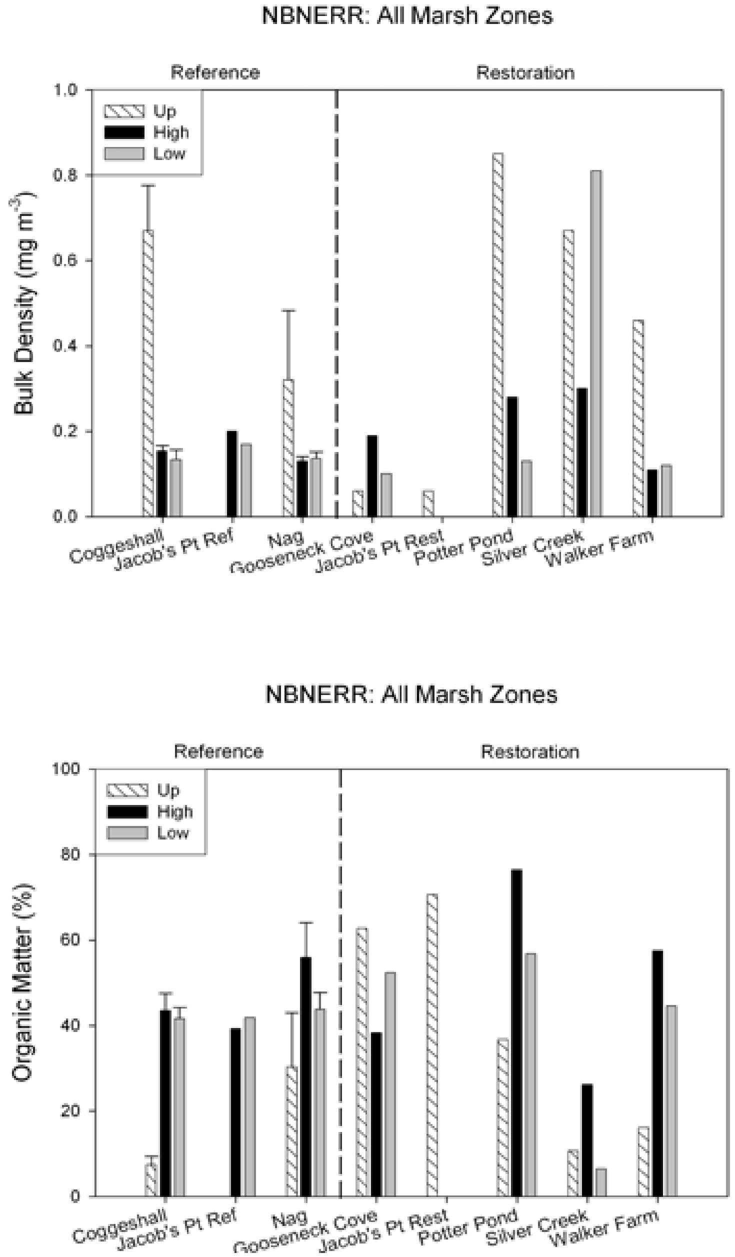


Figure 17. Bulk density (mg $m^{-3}$) (top) and organic content (%) (bottom) of soils in each marsh zone in each of the eight study marshes. Reference sites are all located to the left of the vertical dashed line; restoration sites are located to the right.

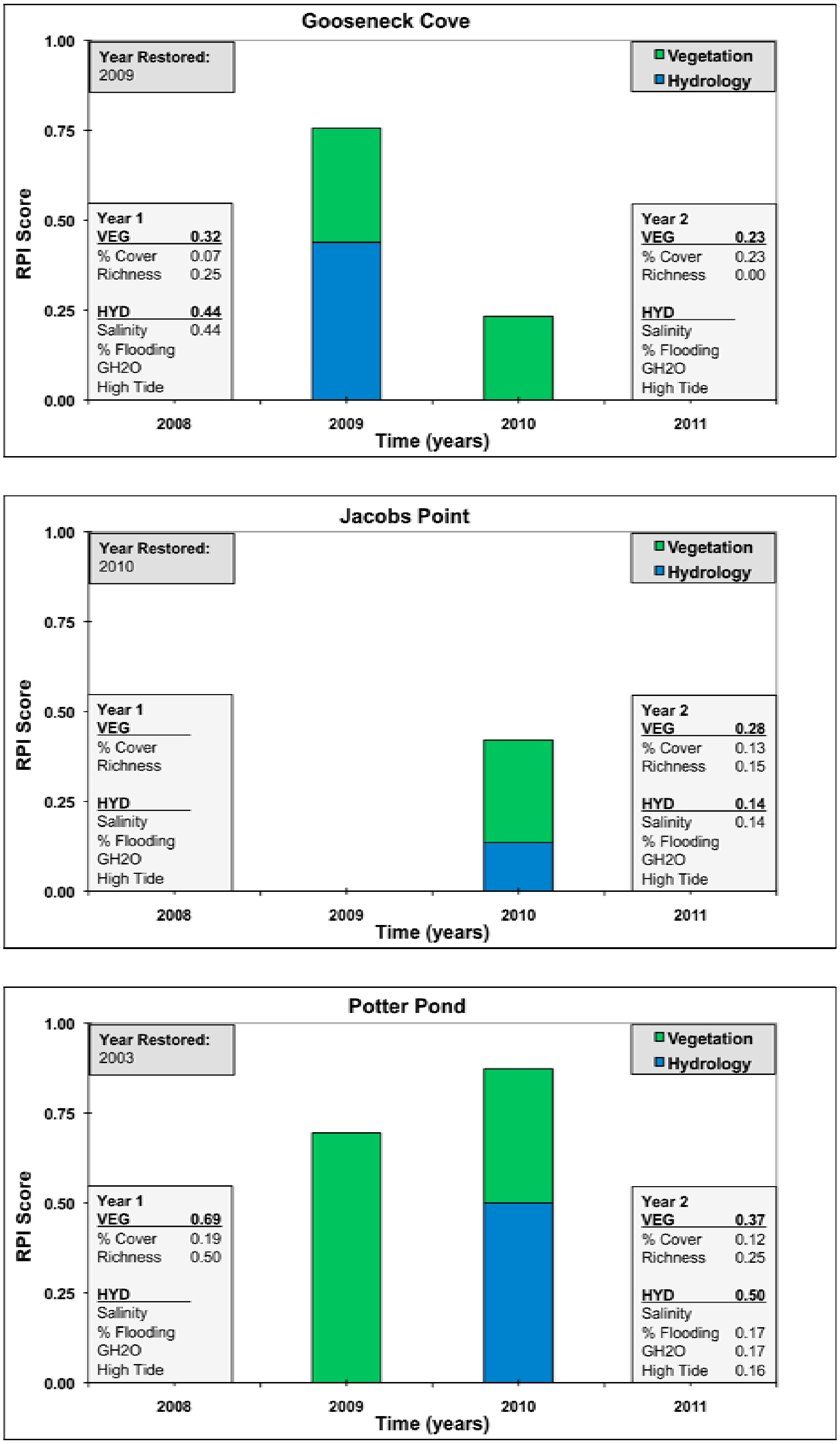
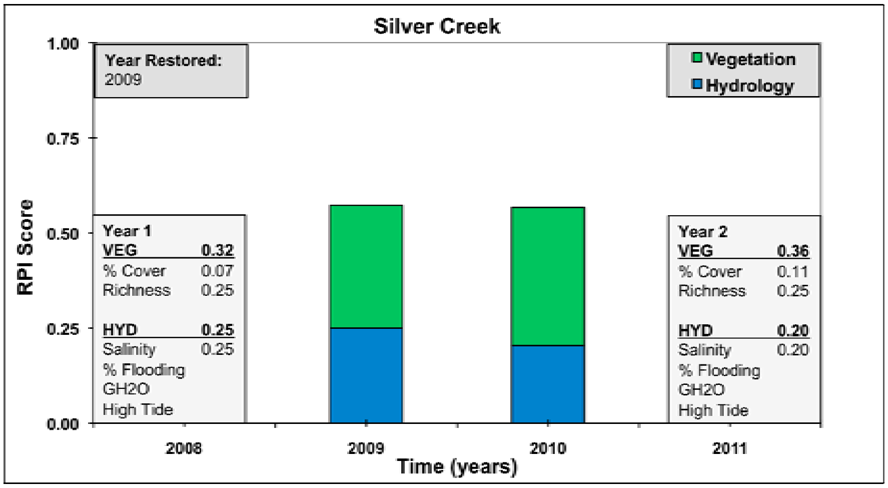


Figure 18. RPI scores for each of the restoration salt marshes in Narragansett Bay, RI in 2009 and 2010.



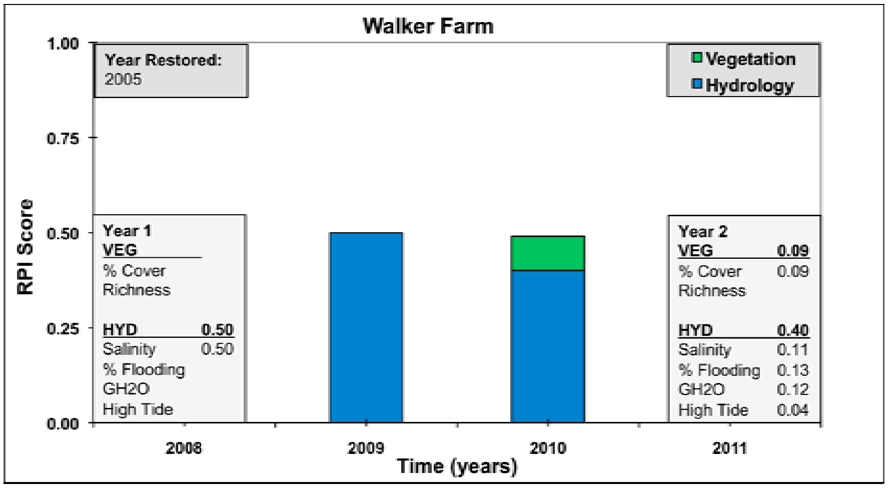


Figure 18, continued.

Figure 19. Vertical control points and bench marks on Prudence Island.

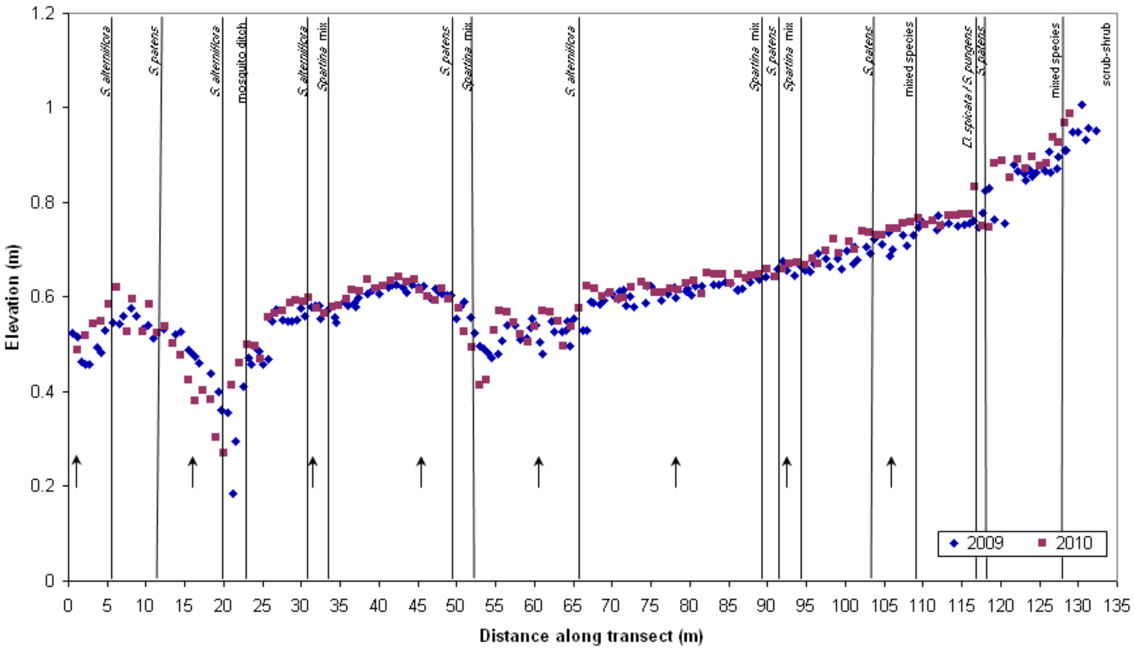


Figure 20: Profiles at discrete intervals along Nag Marsh (transect 1) in 2009 and 2010 and recorded transition locations (2010) by cover type. Up arrows indicate approximate locations of vegetation plots.

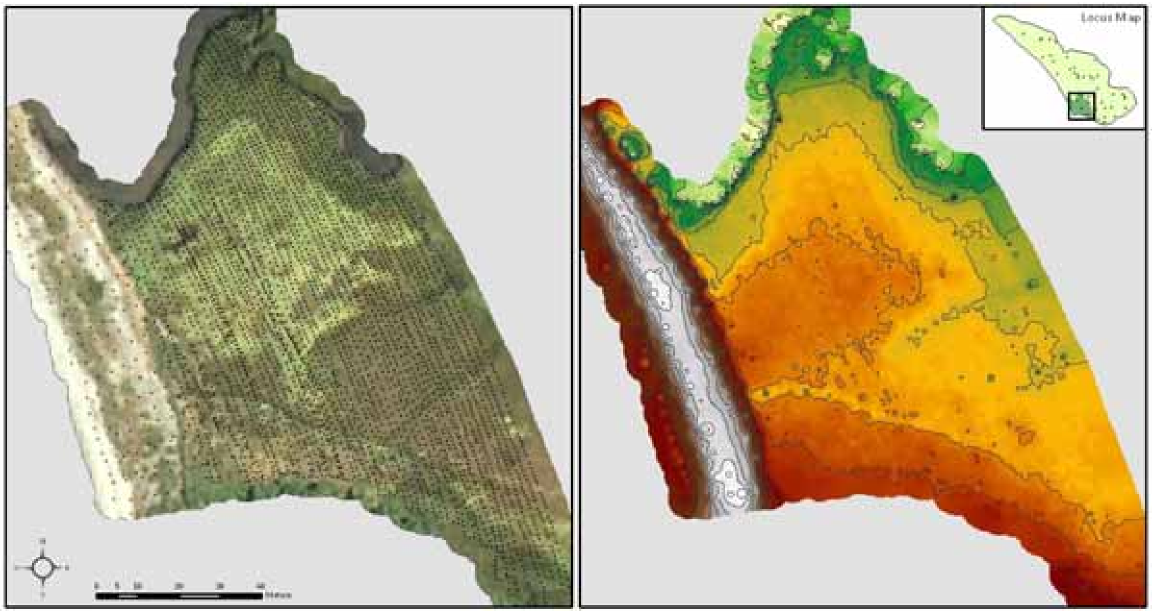


Figure 21: Dense point collection pattern in a subset of Nag Marsh and the derived DEM and elevation contours at 0.1 meter intervals. The final project area is bounded to the south by upland vegetation, to the west by open water, to the north by a tidal creek, and to the east by additional salt marsh. Acquired independent elevation data point locations are displayed in the locus map inset.

**Appendix A**. Codes for emergent vegetation species at all five Research Reserves.

| Code | Scientific Name | Common Name/s |
|---|---|---|
| ACERUB | *Acer rubrum* | red maple |
| ACHMIL | *Achillea millefoleum* | Yarrow |
| AGRSTO | *Agrostis stolonifera* | creeping bentgrass (exotic) |
| ALNRUB | *Alnus rubra* | red alder |
| AMBTRI | *Ambrosia trifida* | ragweed |
| ANGSP | *Angelica Sp.* | angelica |
| ARGEGE | *Argentina egedii* | pacific silverweed |
| ASTSUBS | *Aster subspicatus* | Douglas aster |
| ASTSUBU | *Aster subulatus* | eastern annual saltmarsh aster |
| ATHFIL | *Athyrium filix-femina* | lady fern |
| ASTTEN | *Aster tenuifolium* | perennial saltmarsh aster |
| ATRPAT | *Atriplex patula* | fat hen/marsh orach/spear saltbush |
| BACHAL | *Baccharis hamlimifolia* | groundsel bush/cotton bush |
| BORFRU | *Borrichia frutescens* | sea ox-eye |
| CALNUT | *Calamagrostis nutkaensis* | Pacific reed grass |
| CALHET | *Callitriche heterophylla* | water starwort |
| CALSEP | *Calystegia sepium* | morning glory |
| CALSTA | *Callitriche stagnalis* | common water starwort |
| CARLYN | *Carex lyngbyei* | Lyngby's sedge |
| CAROBN | *Carex obnuta* | slough sedge |
| CARPAL | *Carex paleacea* | salt marsh sedge |
| CARTRE | *Carex tremuloides* | marsh straw sedge |
| CELORB | *Celastrus orbiculatus* | oriental bittersweet |
| CIRVUL | *Cirsium vulgare* | bull thistle |
| COTCOR | *Cotula coronopifolia* | brass buttons |
| CUSSAL | *Cuscuta salina* | salt marsh dodder |
| CYPSTR | *Cyperus strigosus* | strawcolored flatsedge |
| DESCAE | *Deschampsia caespitosa* | tufted hairgrass |
| DISSPI | *Distichlis spicata* | salt grass/spike grass |
| ECHWAL | *Echinochloa walteri* | coast cockspur grass |
| ELEPAL | *Eleocharis palustris* | creeping spike rush |
| ELEPAR | *Eleocharis parvula* | dwarf spike rush |
| EREMIN | *Erechtites minima* | fireweed |
| ELEIND | *Eleusine indica* | Indian goosegrass |
| FESSP | *Fescue Sp.* | fescue grass |
| FESRUB | *Festuca rubra* | red fescue |
| GALAPA | *Galium aparine* | cleavers |
| GALTIN | *galium tinctorium* | dye bedstraw |
| GAUMAR | *Gaux maritima* | sea milkwort |
| GERMAR | *Geralia maritima* | seaside Gerardia |
| GLAMAR | *Glaux maritima* | milkwort |
| GRIINT | *Grindelia integrifolia* | gumweed |

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|---|---|---|
| HERLAN | *Heracleum lanatum* | cow parsnip |
| HIBMOS | *Hibiscus moscheutos* | Swamp rosemallow |
| HOLLAN | *Holcus lanata* | common velvet grass |
| HORBRA | *Hordeum brachyantherum* | meadow barley |
| HYDSP | *Hydrocotyle sp.* | pennywort |
| ILEVOM | *Ilex vomitoria* | Yaupon holly |
| IMPCAP | *Impatiens capensis* | jewelweed |
| IVAFRU | *Iva frutescens* | Jesuit's bark |
| JAUCAR | *Jaumea carnosa* | fleshy jaumea |
| JUNBAL | *Juncus balticus* | baltic rush |
| JUNBUF | *Juncus bufonious* | toad rush |
| JUNEFF | *Juncus effusus* | common rush |
| JUNGER | *Juncus gerardi* | black grass |
| JUNROM | *Juncus romerianus* | Black needlerush |
| JUNSP | *Juncus sp.* | rush |
| JUNVIR | *Juniperus virginiana* | eastern red cedar |
| LATSP | *Lathyrus sp.* | pea |
| LEEVIR | *Leersia virginica* | whitegrass |
| LILOCC | *Lilaeopsis occidentalis* | western lilaeopsis |
| LIMNAS | *Limonium nashii* | sea lavender |
| LIMAQU | *Limosella aquatica* | mudwort |
| LONINV | *Lonicera involucre* | twinberry |
| LONSP | *Lonerica sp.* | honeysuckle species |
| LOTCOR | *Lotus corniculatus* | bird's-foot trefoil |
| LYSAME | *Lysichiton americanum* | skunk cabbage |
| LYTSAL | *Lythrum salicaria* | purple loostrife |
| MAIDIL | *Maianthemum dilatatum* | false lily of the valley |
| MALFUS | *Malus fusca* | Pacific crabapple |
| MALSP | *Malva sp* | mallow species |
| MENARV | *Mentha arvensis* | wild mint |
| MYRCER | *Myrica cerifera* | southern wax myrtle |
| MYRPEN | *Myrica pensylvanica* | bayberry |
| OENSAR | *Oeanthe sarmentosa* | water parsley |
| PANVER | *Panicum virgatum* | switchgrass |
| PARQUI | *Parthenocissus quinquefolia* | virginia creeper |
| PHAARU | *Phalaris arundinacea* | reed canary grass |
| PHRAUS | *Phragmites australis* | common reed |
| PHYAME | *Phytolacca americana* | pokeweed |
| PICSIT | *Picea sitchensis* | Sitka spruce |
| PLAMAR | *Plantago maritima* | seaside plantain |
| PLUCAM | *Pluchea camphorata* | camphorweed |
| PLUPUR | *Pluchea purpurescens* | saltmarsh fleabane |
| POLSAG | *Polygonum sagittatum* | arrow-leaved tearthumb |

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|---|---|---|
| POLMUN | *Polystichum munitum* | sword fern |
| POLPUN | *Polygonum punctatum* | dotted smartweed |
| PTEAQU | *Pteridium aquilinum* | bracken fern |
| PTICAP | *Ptilimnium capillaceum* | mock bishop's weed |
| PUCMAR | *Puccinellia maritime* | goose grass |
| QUESP | *Quercus sp.* | oak species |
| RANSCL | *Ranunculus sceleratus* | cursed buttercup |
| RIBDIV | *Ribes divaricatum* | spreading gooseberry |
| ROSRUG | *Rosa rugosa* | rose hip |
| RUBURS | *Rubus ursinus* | pacific blackberry |
| RUMCON | *Rumex conglomeratus* | dock |
| RUMCRI | *Rumex crispus* | curly dock |
| RUMSP | *Rumex sp.* | dock |
| SALEUR | *Salicornia europaea* | common glasswort |
| SALSP | *Salicornia sp.* | salicornia sp. |
| SALVIR | *Salicornia virginica* | American glasswort |
| SALISP | *Salix sp.* | willow |
| SCIAME | *Scirpus americanus* | Olney three square |
| SCICER | *Scirpus cernuus* | low clubrush |
| SCIMAR | *Scirpus maritimus* | salt marsh bulrush |
| SCIMIC | *Scirpus microcarpus* | small-fruited bulrush |
| SCIROB | *Scirpus robustus* | saltmarsh bulrush |
| SCIVAL | *Scirpus validus* | soft-stemmed bulrush |
| SOLSEM | *Solidago sempervirens* | seaside goldenrod |
| SORHAL | *Sorghum halepense* | Johnsongrass |
| SPAAME | *Sparganium americanum* | American bur-reed |
| SPAALT | *Spartina alterniflora* | saltwater cordgrass/smooth cordgrass |
| SPAALS | *Spartina alterniflora short form* | saltwater cordgrass short form/smooth cordgrass short form |
| SPACYN | *Spartina cynosuroides* | big cordgrass |
| SPAPAT | *Spartina patens* | salt hay grass/salt meadow cordgrass |
| SPAPEC | *Spartina pectinata* | prairie cordgrass |
| SPECAN | *Spergularia canadensis* | sandspurry |
| STECAL | *Stellaria calycantha* | northern starwort |
| SUELIN | *Sueda linearis* | sea blite |
| SYMFOE | *Symplocarpus foetidus* | skunk cabbage |
| THETHE | *Thelypteris thelypteroides* | marsh fern |
| TOXRAD | *Toxicodendron radicans* | poison ivy |
| TRIWOR | *Trifolium wormskjoldii* | springbank clover |
| TRICON | *Triglochin concinnum* | dwarf arrowgrass |
| TRIMAR | *Triglochin maritimum* | seaside arrowgrass |
| TYPANG | *Typha angustifolia* | narrowleaf cattail |
| TYPLAT | *Typha latifolia* | Cattail |
| VACOVA | *Vacinnium ovatum* | evergreen huckleberry |

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|---|---|---|
| VICNIG | *Vicia nigricans* | black vetch |
| ZOSJAP | *Zostera japonica* | Japanese eelgrass |