

Rhode Island South Coast Habitat and Community Resiliency Project
Botanical Assessment of Sediment Placement Sites on
Ninigret, Quonochontaug, and Winnapaug Ponds
and
Coastal Salt Pond Rare Plant Species Documentation



Technical Report for the Coastal Resources Management Council
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Cover Photo: dwarf glasswort (*Salicornia bigelovii*), on exposed sediment, high marsh, Winnapaug Pond, Westerly, Rhode Island, 2018.

Summary

Rhode Island south coast habitat and community resiliency project; botanical assessment of sediment placement sites on Ninigret, Quonochontaug, and Winnapaug Ponds, and coastal salt pond rare plant species documentation

The technical report, submitted to the Coastal Resources Management Council, is the result of a year-long investigation into botanical conditions on three coastal salt ponds in southern Rhode Island. The focus is vegetative condition observed in the field, as it relates to completed, pending, and anticipated Sediment Placement projects, and salt marsh grass production for future plantings. Four separate but inter-related, sections in the report address different focal areas, which together present a multi-dimensional botanical assessment of condition on the three salt ponds.

Section A addresses the results of re-vegetation conducted on the Ninigret Pond Sediment Placement Impact Site, identifies all colonizing species which arrived at the site independently of the planting effort, and makes recommendations for future planting strategies for future Sediment Placement projects. Planted areas were mapped to provide a metric for increases and decreases in planted area. Site elevation and condition were examined in relation to plant responses and survival success. A number of state listed rare species colonized the site, which was an unexpected positive effect of the disturbance created as a result of the Sediment Placement process.

Areas which received the greatest amount of sediment achieved a maximum vertical height of 0.60m above sea level. These highest areas experienced the greatest rates of survival among planted species, saw moderate increases in vegetation coverage, and were colonized by the greatest diversity of pioneer species. Lowest elevation areas, saw the greatest losses in planted material and vegetation coverage. Colonization by pioneer species at low elevations was limited to those coastal species that are the most salt tolerant. Differences in survival and coverage at low and high elevations appear to be related to soil oxygen and salinity concentrations. Plant responses can be read as indicators of the environmental site conditions, and serve as useful tools for the development of adaptive management strategies.

Recommendations for future planting include conducting planting efforts in two stages and working directly with growers to develop strategies for greatest survival. The first component should focus on plants whose biology and adaptations enable them to be rapid colonizers of environmentally stressful sites. The second phase should entail planting species with slower growth rates, but which are better adapted for long-term site coverage. By informing growers of site conditions and limitations, and including them in the process of assessment after planting, the responses of plants to environmental conditions can be integrated into adaptive management for the site.

Section B included surveys of two future Sediment Placement Impact Sites on Quonochontaug and Winnapaug Ponds. The foremost purpose was to determine if state listed rare species were present at the proposed site locations. Of interest also, was the presence of invasive plant species, and the potential for those species to colonize Sediment Placement Impact Sites. In addition, field surveys were conducted in selected portions of the two ponds to determine the presence of known rare species populations and locate any that had not been previously documented.

No rare species were observed within the immediate areas proposed for sediment placement on either the Quonochontaug or Winnapaug sites. However, populations of rare species were observed in locations adjacent to the sites, and elsewhere within brackish marsh, dune, and woodland habitat located adjacent to both Quonochontaug and Winnapaug Ponds. Invasive species were also identified adjacent to the proposed locations. Monitoring the future Sediment Placement sites for the presence of both rare and invasive colonizers will be aided by documentation of the presence of potential pioneer species growing elsewhere on the salt ponds. The field surveys conducted within habitat adjacent to the two ponds, provides a baseline for future assessments of vegetative condition and responses to change over time.

Section C provides a detailed Floristic Quality Assessments (FQA) of two freshwater wetlands located on each of the ponds that are the focus of future Sediment Placement projects. The two wetlands are considered vulnerable to sea level rise, as they are located at elevations slightly higher than those of the salt marsh, and are contiguous with the marsh systems. The FQA specifically provides a measure of the degree of disturbance at a site, as reflected in the plant species' composition and relative tolerance for disturbance. The presence of rare species indicates uniqueness of habitat, while invasive species provide a reflection of change resulting from land use history, and the influence of surrounding plant communities.

Both freshwater wetlands contained a limited number of state listed rare species, and were vegetated by a greater percentage of native (over non-native) species. Invasive plants were present at both sites, although neither site was dominated by a single invasive plant species. Sea level changes were observed to be impacting the vegetation composition within both wetlands, with plant species tolerant of brackish conditions migrating inland among the freshwater plant communities. Both **Sections B** and **C**, provide a baseline for evaluating change to coastal plant communities along the shorelines of these two ponds.

Section D provides a detailed description of the salt marsh grass, *Spartina alterniflora*, and the procedures to be followed for seed collection and propagation. The text is intended to provide growers with a protocol blue print, providing insight into the life cycle of the species, as it relates to the timing of seed collection, successful seed germination, and propagation. Methods commonly used are documented, as are the experiences of the RINHS Rhody Native™ initiative. Propagation alternatives are presented, based on innovations employed by others working on Sediment Placement revegetation methods tried elsewhere, and for other types of habitat restoration, are recommended for small scale experimentation. Encouraging growers to experiment with innovative propagation methods, can result in the application of their knowledge and experience in plant propagation to the development of adaptive management strategies, and contribute to the success of future Sediment Placement projects.

In conclusion, the report has highlighted the unique qualities and vulnerabilities of the plant communities located on Rhode Island's coastal salt ponds, and provides a baseline for making future assessments. The inter-related nature of the habitats suggests the importance of interpreting the success of Sediment Placement on multiple levels, and monitoring beyond the immediate site impact area for changes in plant community dynamics.

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Introduction

Sea level rise and increased storm intensity have placed coastal features, especially salt marshes along the ocean coast, in increasing danger of disappearance. Ecologists and managers are developing strategies to facilitate salt marsh migration and maintain existing habitat. Raising salt marsh elevation through a process known as Sediment Placement, artificially accelerates accretion rates, the goal of which is to maintain or recover high marsh habitat for use by wildlife, particularly salt marsh sparrow (*Ammospiza caudacuta*), as well as other benefits. Sediment dredged from adjacent navigable channels is deposited on top of salt marsh habitat in layers ranging from 15 to 60 centimeters in depth. The process simulates natural over wash processes and creates short-term novel conditions that have their own ecological consequences, regardless of the outcome of customary deliberate revegetation activities. The process can have especially dramatic consequences for a suite of disturbance dependent plant species, that include a number considered as rare.

In Rhode Island, salt marshes occur in a number of different geographical settings. This report deals primarily with salt marshes associated with coastal salt ponds and tidal streams along the state's Atlantic Ocean shoreline. Some information was gathered at salt marsh sites located within extensive estuarine systems such as in Pettaquamscutt Cove, and in the middle and upper regions of Narragansett Bay, for comparative purposes.

Rare plant and animal species have historically been documented in and adjacent to salt marsh habitat along coastal salt ponds located on the Rhode Island south coast. Prudent management of these habitats necessitates an understanding of the status of these populations. This report encompasses the monitoring of plant communities and rare plant species within and adjacent to salt marsh habitat on Ninigret, Quonochontaug, and Winnapaug Ponds (Map 1; Appendix II). The work was carried out following Sediment Placement on the Ninigret Pond site, and before commencement of projects planned for Quonochontaug and Winnapaug Ponds. Corresponding work conducted through the University of Rhode Island (URI), examines the status of keystone and indicator animal species in salt marshes in Rhode Island (Appendix IV). The presence of Diamondback terrapins (*Malaclemys terrapin*) has been documented on all three ponds, and surveys were conducted to determine the current status of these populations. Additionally, surveys were conducted to better understand the role of two species of katydids, present on salt marshes; specifically, the salt marsh meadow katydid (*Conocephalus spartinae*) and the seaside katydid (*Orchelimum fidicinium*), which according to Greenlaw et al. (2018) and others, form a large portion of the diet of adult salt marsh sparrows.

In cooperation with the state of Rhode Island, the Rhode Island Natural History Survey (RINHS) maintains a list of rare vascular flora found within the state (Enser and RINHS 2016). RINHS also maintains the Natural Heritage Database, which was consulted for rare species population and location data prior to conducting vegetation surveys for this report. The rare status of each species in the state is designated by a letter code. **SE** refers to State Endangered, which is assigned to species in imminent danger of extirpation from RI, with one or two estimated populations remaining. **ST** indicates a species which is likely to become listed as SE in the future, and for which three to five known populations are estimated to occur. **SC** refers to State Concern, which are listed due to various factors of rarity or vulnerability. And **SH** stands for State Historic, and indicates that the species is believed to be extirpated from the state and there are presently no known populations. In this report, rare species status will be listed in parenthesis, after the species' Latin name. Consistent with rare plant species monitoring, data collected through population monitoring is reported to RINHS. As a part of this project, a total of forty-three rare species data forms were completed and submitted for addition to the Natural Heritage Database. Nomenclature used in this report to describe plant species, follows Haines (2011).

Plants are essential, defining elements of salt marshes, and it is the change in plant community composition on the salt marsh platform that is recognized as an indicator of sea level rise, and the rationale behind selection of a marsh site as a candidate for Sediment Placement. The re-establishment of plant cover and diverse salt marsh plant communities are primary goals of Sediment Placement, second only to increasing the vertical elevation.

Following the placement of dredge material on top of the marsh surface, re-establishment of vigorous plant cover is essential for generating the below-ground and above-ground mechanisms that hold sand deposits in place. The cover of plant material, by trapping sediment and through the natural processes of decay and decomposition, adds organic material to the substrate created from Sediment Placement deposits. These biotic processes set in motion the process of plant establishment and community succession, potentially leading to the creation of new high marsh habitat.

Sediment Placement projects in Rhode Island have to date, been undertaken on the U.S. Fish and Wildlife Service, Rhode Island National Wildlife Refuge Complex, at the Sachuest Point NWR (Maidford Marsh) and the John H. Chafee NWR (Pettaquamscutt Cove). The most recent project, and the focus of this report, is located in the State of Rhode Island South Shore Management Area, at the Charlestown Breachway (Ninigret) (for all three locations, see Map 2; Appendix II). The projects have seen varying results for the establishment of plant material, both among the planned deliberate revegetation and the spontaneously established pioneer species. Documentation and assessment of planted species' successes and failures and other data, correlated with pioneer species establishment provides an instructive measure of the conditions created at a site. Evaluating plant responses alongside data collected on physical conditions, can inform planning and development of adaptive management strategies, and improve the efficacy of current and future projects.

To monitor the success of deliberately planted vegetation, and to document the process of plant colonization following Sediment Placement on the marsh surface, the Ninigret Pond Impact Site was extensively surveyed, along with areas of adjacent dune and the designated Ninigret marsh

Control Site (Map 3; Appendix II). Sediment Placement has also been proposed, and is in early planning stages, for areas of salt marsh on Quonochontaug and Winnapaug Ponds (Maps 4 and 5; Appendix II). To provide a botanical perspective on the current state of salt marsh habitat at those sites, salt marsh and other shoreline habitat types along the fringes of those ponds were also surveyed.

Open unvegetated soil, provides suitable substrate for germination of the seed of species adapted to disturbance regimes (Mackey and Currie 2001). The seeds of pioneer species have adaptations which make them important early colonizers of disturbed soil, laying the groundwork for soil stability and future colonization by more permanent perennial species. While pioneer species can facilitate the establishment of these more permanent species, revegetation can also be enhanced by deliberately planting salt marsh and dune species into appropriate elevations on disturbed sites, such as are created at Sediment Placement Impact Sites.

RINHS has been engaged in propagation of local genotypes of local seed since 2010, through its Rhody Native™ initiative. Re-establishment of plant cover through salt marsh species propagated from locally adapted seed material is recognized as desirable by Federal and State agencies to ensure adaptive compatibility with Rhode Island's climate and conditions, and to ensure that the greatest amount of genetic diversity is placed into the planted environment. Codification of seed collection and propagation protocols has been included in this report to provide guidelines for growers looking to enter the niche market of native plant propagation in Rhode Island and nearby regions engaged in similar management strategies. Also included in this report are results and lessons learned from salt marsh grass and herbaceous species propagation, as well as recommendations for future Sediment Placement restoration planting and propagation programs.

A. Assessment of Ninigret Pond Sediment Placement Impact and Control Sites

Mapping of planted areas at Ninigret Impact Site

Methods

During the winter of 2016-17, Sediment Placement was carried out at Ninigret Pond, on salt marsh habitat located west of the Charlestown Breachway (hereafter referred to as the Ninigret Impact Site). Sand and fine sediment was dredged from the breachway, and deposited onto an area of adjacent salt marsh identified as being seriously impacted by sea level rise. At completion, the area ranged in elevation from 15 to 60cm above sea level, with a largely sandy substrate of medium-sized grain, and minimal organic content (Ferguson, *personal communication*). While elevations in the middle of the Impact Site were raised above previous marsh elevations, the peripheral edges were lower, as dredged material tapered to join the elevation of pre-existing shrub habitat. The lower elevations along the periphery of the Impact Site impounded tidal water, creating breeding habitat for the Eastern salt marsh mosquito (*Aedes sollicitans*) (Ferguson, *personal communication*). Consistent with marsh function improvement practices carried out elsewhere in Rhode Island by the non-profit organization Save the Bay, runnels, or small creeks, were excavated into the surface to connect areas of impounded water with existing ditches or creeks, allowing tidal water to flow off of the Impact Site.

In 2017, following the deposition of the dredged material, vegetation within the Ninigret Impact Site was limited to peripheral areas where sediment elevation had been matched to pre-existing marsh elevations. Beginning in the spring of 2017, Save the Bay engaged volunteers to plant a mix of native coastal dune and salt marsh plant species across all elevations of the 20-acre Impact Site. Planting locations were selected based on perceived species elevation preferences in natural salt marsh and dune settings (Ferguson, *personal communication*). The rationale resulted in a mosaic of vegetation plots, where species typically found in dune settings were placed in areas that received approximately 60cm of dredge material, with species more tolerant of daily flooding regimes placed at lower elevations. Spacing between all plants averaged 60cm, and plantings consisted of single-species groupings. Smooth cordgrass (*Spartina alterniflora*) was planted at the lowest elevations, along the leading edge of dredge material, creeks, and runnels. Fencing was placed around areas of smooth cordgrass plantings to discourage grazing by Canada geese (*Branta canadensis*). In March 2018, a small excavator was brought out to the Impact Site to improve runnel construction and raise elevation heights in low areas where tidal water was observed to pool on the surface (Ferguson, *personal communication*). Following the regrading, Save the Bay carried out a second round of planting in April and May 2018. Revegetation occurred along banks of runnels, regraded areas, and locations where prior plantings had not survived. This second planting effort created additional planted areas, many of which were contiguous with the 2017 plots.

Vegetation surveys were conducted beginning in fall 2017, concluding a year later in 2018, with the goal of capturing the process of site colonization, species distribution, and the results of deliberate plant re-establishment. In November 2017, staff members from Save the Bay (STB), the University of Rhode Island's Environmental Data Center (EDC), and Rhode Island Natural History Survey (RINHS) collaborated to digitally map the planted areas. Points were collected



Figure 1. Scribing plots at Ninigret Sediment Placement, 2018

along the perimeter of all planted plots at the site utilizing a *Trimble Yuma* tablet, connected to a *Trimble R1* receiver with an accuracy of 1m. The resulting map defined a total of 79 planted polygons. The mapping process was repeated in June 2018, to record locations of areas planted in April and May of that year. The maps resulting from the June survey depict a total of 46 planted polygons. At the end of the second growing season, a one-year assessment of the 2017 plantings was conducted based on a representative subset of the 79, 2017 polygons. These were mapped in August 2018, with the resulting map showing 38 polygons, which overlay 30 of those defined in 2017 (see Map 8a, b, & c;

Appendix III).

To collect GPS points for delineation of planted plots, the extent of planted vegetation was scribed into the sand substrate by the botanist, who was followed by the GIS mapping assistant who collected GPS points along critical curves in the line. For each plot, the number of points collected varied, and totaled a number necessary to outline the boundaries of the plot. Where rhizomatous tillers of species, such as *Ammophila breviligulata*, radiated out from the plot in distinct lines, the plot boundary was drawn perpendicular to the direction of tiller growth.

From the points collected, plot shapes were digitized in ArcGIS to depict in plan-view, the locations of the planted areas. Data associated with each plot include area (in acres), linear measurements, and all planted and pioneer species present. All plots were identified by a unique number value, as well as by the USDA abbreviation code for each of the planted species located within the plot (for example, SPPA is *Spartina patens*). It should be noted that although some plots are identified by multiple species, the planting strategy placed plants in single-species patches rather than as companion plantings, naturalistic groupings, or other schemes with multi-species adjacency.

Surveys within each plot included a qualitative assessment of the health and degree of establishment success for the planted species. Vegetative growth, observed in above-ground stems and below-ground rhizomes, was evaluated. Evidence of flowering and seed production was noted, as was any evidence of herbivory or parasitism. Spatial distribution of pioneer plant species, established from naturally occurring seed, was documented by collecting presence/absence data for all non-planted species observed within plots.

In the fall of 2018, 30 of the 79, 2017 vegetated plots were selected to be re-surveyed and mapped. Selection of plots was random, with the goal of including representative plots for all species planted across the Impact Site. Individual plant losses within seven of the plots, resulted in discontinuous vegetation coverage, which necessitated the division of these into multiple plots. As a result, a total of 38 mapped polygons were created. As had been done in 2017, the subset survey documented plant species presence (planted and pioneer), evidence of reproduction and survival among planted species, and collection of data points via the *Trimble* tablet for plot digitization. As a result the mapping process produced three sets of data, two of which define the

boundaries of each area planted, and a third which provides a metric for change in plot size between the first and second growing seasons.

In addition to pioneer species colonization within revegetated plots, areas of the Ninigret Impact Site located outside of the plots, also became spontaneously vegetated. To capture the vegetative condition of the site as a whole, presence/absence data was collected in the fall of 2018 along six, 4-meter belt transects (Figure 2). The six transects had been previously established across the site, per a monitoring protocol developed by Charles Roman (James-Pirri 2018), which established a plot-based monitoring system for observing changes in vegetation prior to and after deposition of dredge material.

In October 2018 the URI EDC collected elevation data across the Ninigret site via drone survey (Map 9; Appendix III). The data collected describes the surface elevation of the dredged material in meters above sea level, relative to the North American Vertical Datum of 1988 (NAVD 88) (Bradley, *personal communication*). To determine if a correlation exists between elevation and plant survival and population expansion, this data was compared with the results of changes documented in plot acreage between 2017-18, the condition of the deliberately planted species, and colonization of the plots by pioneer species.

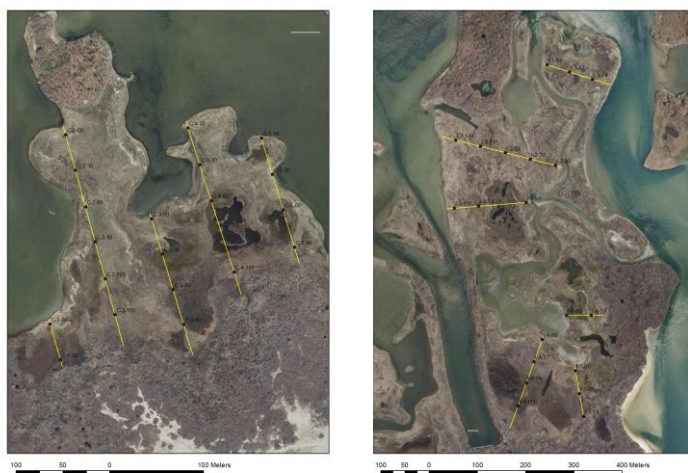


Figure 2. Long-term Monitoring Transect lines, Ninigret Sediment Placement Impact Site (R) and Control Site (L).

Results

I Planted Species

Within the 20-acre Ninigret Impact Site, a total of 125 planting plots were created during the two planting campaigns. Plots consisted primarily of single species patches located at elevations that corresponded to the perceived flooding tolerances of each species. In 2017, the restoration planting included nine species adapted to salt marsh and coastal dune conditions, planted into a combined area of 3.37 acres over 79 plots. The 2018 planting effort was initiated to compensate for species lost over the winter of 2017-18, and to vegetate runnel banks and areas where elevation changes had been made to improve water flow off of the marsh and prevent pooling (Ferguson, *personal communication*). A total of 46 additional plots were created, incorporating four of the nine species planted in 2017. The acreage planted in the second year, totaled 2.25 acres, bringing total acreage of the deliberately vegetated portion of the Ninigret Impact Site to roughly 5 acres. Some overlap occurred between the 2017 and 2018 plot locations.

2017 Species Planted	Common name	Plant Type	Growth Habit
<i>Ammophila breviligulata</i>	American beach grass	perennial dune grass	loose rhizomatous
<i>Baccharis halimifolia</i>	groundsel tree	maritime shrub	multi-stemmed
<i>Distichlis spicata</i>	salt grass	perennial high marsh grass	loose rhizomatous
<i>Juncus gerardii</i>	salt marsh rush	perennial high marsh rush	v. dense rhizomatous
<i>Iva frutescens</i>	maritime marsh elder	maritime shrub	multi-stemmed
<i>Panicum virgatum</i>	switch panicgrass	perennial grass	cespitose
<i>Solidago sempervirens</i>	seaside goldenrod	perennial herbaceous	cespitose
<i>Spartina alterniflora</i>	smooth cordgrass	perennial low marsh grass	loose rhizomatous
<i>Spartina patens</i>	salt marsh hay	perennial high marsh grass	dense rhizomatous
2018 Species Planted	Common name	Plant Type	Growth Habit
<i>Ammophila breviligulata</i>	American beach grass	perennial dune grass	loose rhizomatous
<i>Juncus gerardii</i>	salt marsh rush	perennial high marsh rush	v. dense rhizomatous
<i>Spartina alterniflora</i>	smooth cordgrass	perennial low marsh grass	loose rhizomatous
<i>Spartina patens</i>	salt marsh hay	perennial high marsh grass	dense rhizomatous

Table 1. Native Species Planted at Ninigret Sediment Placement Impact Site; 2017-2018

To evaluate change in plot size between the first and second growing seasons, a subset of 30 of the 79, 2017 plots were selected to be re-surveyed and mapped. The plots selected represented all species planted across the site, with change in plot size serving as a proxy for the success or failure of each species planted. Due to losses of plants within sections of seven plots, plots which had been mapped as a single contiguous unit in 2017, were split into two (in one case three) units. Thus, in actuality 38 plots were defined and surveyed. The acreage mapped showed that overall, there had been a slight reduction in acreage planted. Acreage measured for the combined subset plots in 2018 was 1.47 acres (compared to 1.52 acres in 2017).

To correlate elevation with plant success, the NAVD88 elevation data obtained by URI's EDC drone flights (Map 9), was compared with plot location and plant species data. Elevation points within each of the subset plots, were averaged to arrive at a mean elevation value. Mean elevation values ranged from 0.28m to 0.58m NAVD88. What appeared in the field to be micro-differences in elevation resulting from uneven contouring of dredged material, corresponded to dramatic changes in the status of vegetation, for both the planted and the pioneer species. Even after the 2018 regrading, areas remained where the surface of the sediment at lower elevations showed signs of water pooling, such as the growth of algae. In these areas, planted vegetation was either stunted or had died. Species which had colonized lower elevations were those with annual life cycles, and high tolerances to salinity (halophytes). Overall losses of polygon acreage, were within plots located at lower elevations of the Impact Site.

Qualitative observations regarding species' failure to thrive in lower elevation plots, were striking when compared with planted species survival and growth within higher elevation plots, and when compared to pioneer species diversity and densities in those same plots. Our observations and data suggest that plants placed at low elevations were stressed by either biotic or abiotic conditions, and that they were not affected by these same conditions at higher elevations.

Die-off of the species planted, particularly *Spartina alterniflora* and *Juncus gerardii*, and partial areas of *Distichlis spicata*, were predominantly at elevations below 0.41m NAVD88. The high marsh grass, *Distichlis spicata*, was the only species which expanded below 0.41m, with one plot expanding at elevation 0.36m. However the species also showed reductions in plot acreage both at elevations above that point (0.46m) as well as below it (0.27m), suggesting a narrow tolerance for flooding, or other environmental constraints, such as soil salinity and oxygen. For all other planted species, small increases in acreage were documented above 0.41m, primarily as a result of rhizomatous expansion of the planted grasses, *Ammophila breviligulata* and *Spartina patens*.

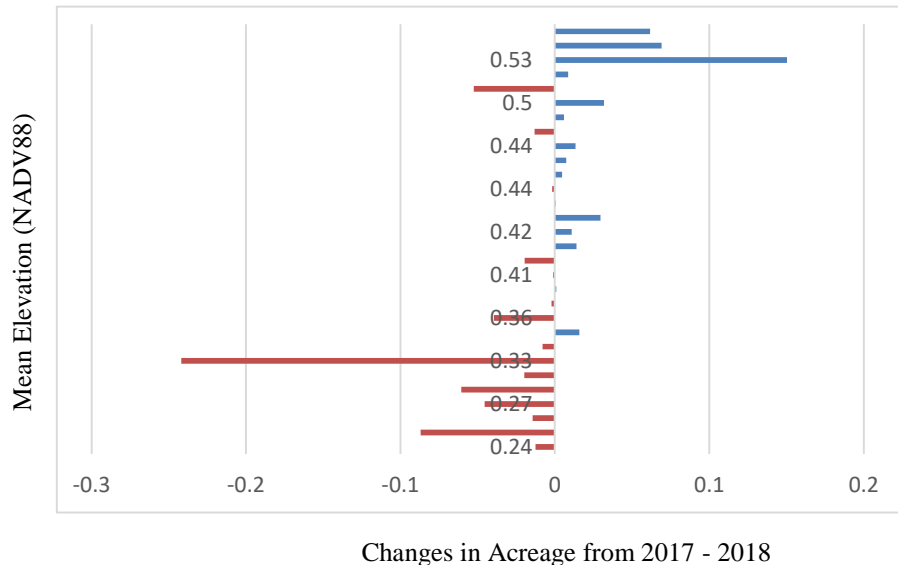


Figure 3. Changes in acreage within re-surveyed plots, arranged by elevation above NAVD88, between 2017 and 2018.

Overall condition of the planted species was assessed in late fall 2017, and again in 2018, with criteria including plant health, evidence of above ground growth, seed production, and horizontal expansion via rhizomatous growth. Following is a summary of observations for each of the species planted.

***Ammophila breviligulata*:** American beachgrass was planted at the highest elevations created by the placement of dredge material, which in 2017 was measured at 60cm above the pre-existing marsh surface (Ferguson, *personal communication*). The URI drone survey recorded elevations for this species ranging from 0.50m to 0.70m NAVD88 by the fall of 2018. At the time of the 2017 fall survey, *Ammophila* appeared well established and had grown to 90cm in height (plant height for typical *Ammophila* nursery plugs, would range from 15-30cm). Spaces in between individual plants were still prominent within the plots. It was estimated that 60 percent of the plants within each plot had flowered and produced seed in their first season of growth. In 2018 an estimated 90% of the 2nd year culms had flowered and produced seed. In 2017 2% of the plants observed showed 8 to 10cm long rhizomes extending from the bases, whereas in 2018 90% of the plants had begun to grow throughout the plots, and in several plots were noted to be accumulating windblown sand within the plot. Robust plants were 1m tall. Rhizomes radiated in all directions, and ranged from 1 to 2m in length. For two of the *Ammophila* plots, rhizomatous

growth accounted for an expansion of 0.06 ac. Overall, expansion of *Ammophila* plots accounted for 86% (0.36ac) of the expansion realized in re-vegetated acreage between the 2017-18 growing seasons.



Figure 4. *Ammophila* plot, expanding rhizomatous tillers; acreage gain, 2018.

Generally *Ammophila* did well; nevertheless, a second planting occurred in 2018 to fill in areas where individual *Ammophila* plants had died, or where other plants, such as *Juncus gerardii* or *Spartina patens* had not survived. Assessment of the 2018 *Ammophila* plantings showed them to be well established by the end of the season, with approximately 40% in seed. The species *Ammophila*, also occurred as a pioneer species in a single plot within the subset of re-surveyed plots, indicating a measure of success for establishment of this species at the site.

***Baccharis halimifolia*:** Groundsel tree was placed in multi-species plots in higher elevation areas, where species like *Ammophila*, *Solidago sempervirens*, and *Spartina patens* had also been planted. The shrubs at the time of planting were roughly 20cm in height, and showed minimal signs of growth over the course of the first growing season. No flowers were observed. In 2017 it was noted that shrubs planted within the lower elevations of the plots had died. By fall 2018 plant height had increased to 45cm. While *Baccharis* was planted into a limited number of plots at Ninigret, the species also became established at the site from seed germinating on the un-vegetated substrate. In 2017, *Baccharis* seedlings were documented in 36% of the plots as pioneer species. However, frequency of occurrence dropped during the following growing season, and seedlings of the species were documented in only 17% of the 2018 planting locations, suggesting that although seed had been able to germinate at the elevations created on the Impact Site, that the species was potentially negatively affected by environmental conditions experienced with increasing root depth. Since planted *Baccharis* did not flower or produce seed in its first growing season, and since the species' seed is wind-dispersed, and the species is a dominant shrub of mesic areas around Ninigret Pond, it is presumed that seed arrived naturally at the Impact Site after sediment was deposited on the surface of the marsh.

***Distichlis spicata*:** Salt marsh rush was planted into a combination of single species plots and within plots also planted with *Juncus gerardii*, *Spartina alterniflora* and *S. patens*. Following planting in 2017, the species responded with rapid rhizomatous growth in four of twelve plots. In 2018 plots that were re-surveyed showed that for this species, growth was most dense in areas of plots located at or near elevations of 0.36m. Loss of plants, stunted growth, and lack of rhizomatous tillering were observed at elevations lower than this.



Figure 5. *Distichlis spicata* colonizing plot, 2018.

Within a single plot herbivory was observed on *Distichlis* leaves.

Within plots planted with *Distichlis* alone, losses amounted to 0.03ac. While growth of this species appeared robust in portions of plots, overall expansion was offset by losses or slow growth in less suitable areas of the plot. A single plot was documented to have increased in overall size. In this location plants were robust and flowering. *Distichlis* was not observed flowering in either season, in any other plot. The plot, located at elevation 0.36m NAVD88, expanded by 0.02ac. Seven to eight rhizomes were noted to radiate out from the base of each plant, measuring 50cm in length, and filling in the empty spaces between plants. *Distichlis* was recorded as a pioneer species within all three vegetation data sets; in seventeen plots (22%) at the end of the 2017 growing season, in ten (21%) of the plots planted in 2018, and in four (27%) of the re-surveyed plots. In all cases, rhizomes of pre-existing plants growing into un-vegetated areas, accounted for the species' presence.

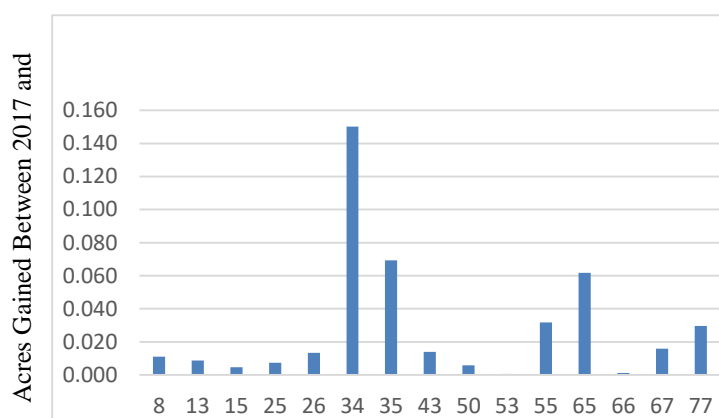


Figure 6. Gains in planted acreage within 30-subset plots, between 2017 and 2018.

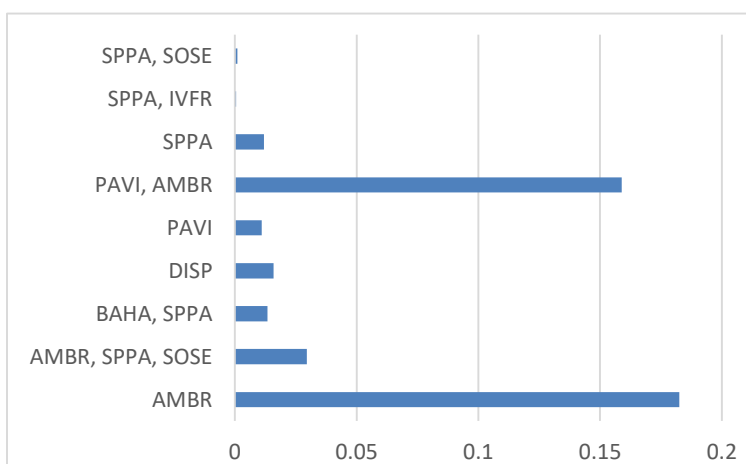


Figure 7. Species plots showing expansion (acres), between 2017 and 2018.

***Juncus gerardii*:** Salt marsh rush was planted in 2017 and 2018, both within single species plots and in combination with plantings of *Spartina patens*. Elevations were slightly higher than those where *Distichlis* was planted (0.39 and 0.41 NADV88 in 2017). By fall 2017 plugs were

observed to have survived their first growing season, but had put on very little vertical growth, and showed no evidence of expansion by rhizomes. By spring 2018 many plants had not survived the winter. Those that remained appeared stunted with minimal rhizomatous growth. Additional plots of *Juncus* were planted in May 2018, but as early as June, it was noted that plant leaves were yellow. In contrast, clumps of *Juncus* that had been dug up from elsewhere on the marsh, and then replanted, had survived and produced seed. *Juncus* was also recorded as a pioneer species in 70% of the 2017 plots. While many were evidently the result of replanted clumps, it was unclear if others resulted from pre-existing growth below the dredge spoils, or from germinated seed. By 2018, the pioneer presence of *Juncus* had dropped and the species was present in 42% of the re-surveyed plots and in 43% of the plots planted in 2018.

Iva frutescens: As with *Baccharis*, high tide bush was planted within a limited number of multi-species plots in 2017. Placement of the species was within plots planted with *Solidago sempervirens* and *Spartina patens*. In 2017 the shrubs were small (20cm) and showed minimal vegetative growth over the course of the growing season. In 2018, plantings of the species had survived and grown to 50cm in height. Approximately 30% of the observed plants were in flower in August, 2018. This species was documented as a pioneer species within plots during both survey years, with frequency of occurrence increasing in 2018. As with *Baccharis*, mature plants of *Iva* surround the Impact Site. Seed of *Iva* falls directly below the plant, with dispersal being primarily through tidal flow. Since planted individuals of *Iva* had not flowered in 2017, it is presumed that pioneer individuals arrived at the site via tidal overwash. In 2017 *Iva* was documented as seedlings in 12% of the plots, and was present in 36% of the re-surveyed plots in 2018. Seedlings were documented in 28% of the 2018 plots. Elevations for planted *Iva*, ranged from 0.42m to 0.47m NAVD88. The species' occurrence as a pioneer corresponded to plots with numerous pioneer species, with seedlings occurring within the same elevation range as the planted individuals, and slightly lower at 0.39m.

Panicum virgatum: Switch-grass was planted within and adjacent to plots planted with *Ammophila*, at elevations between 0.37m and 0.48m NAVD88. At the time of the 2017 fall survey, plants appeared well established and had grown from a typical plug size of 15cm to 1m in height. Flowering and seed set had occurred on 80% of the plants in all plots. Spaces between individual plants were still prominent within the plots, and vegetative growth from the root crown averaged 7 stems. In plots where *Panicum* had been placed at lower elevations within the plot, it was observed that plants had not flowered and overall height was lower. These plots were not re-surveyed in 2018, and survival was not documented. In 2018, within higher plots that were re-surveyed slight acreage increases were documented for all plots that included *Panicum*. Within these plots, 100% of the second year culms flowered and produced seed, and the number of vertical stems increased to an average of 12. *Panicum* has a cespitose growth habit, producing numerous flowering culms (stems) from the root crown. Reproduction is primarily from seed, and in 2018 switch-grass seedlings were observed in two of the re-surveyed plots. Although the source of the seed for these plants is uncertain, naturally occurring stands of *Panicum* were not documented in proximity to the site, suggesting, it is possible the origin could be the planted individuals, which would represent a measure of success for the species at the Ninigret Impact Site.

***Solidago sempervirens*:** Seaside goldenrod was planted high to mid-elevations created at the Impact Site, within plots planted with *Ammophila* and *Spartina patens*. Most successful growth for this species was seen at elevations between 0.45m and 0.57m NAVD88. As with the other species planted at these elevations, plant growth and flower production were interpreted as measures of plant health. By the end of the 2017 growing season the species was well established, with approximately 25% of the plants within each plot flowering and producing seed. At the end of the 2018 growing season, planted *Solidago* had produced a profusion of flowers and plants were robust. *Solidago* seedlings were also recorded as pioneer species in 20% of the plots in the 2017 survey, in 19% of the 2018 plots, and 18% of the re-surveyed subset plots.



Figure 8. *Solidago sempervirens* and *Ammophila*; covering surface of sediment, 2018.

As with *Ammophila* and *Panicum*, the higher elevation areas were successful locations for *Solidago*. Only a single plot planted with *Solidago* (and *Iva*) located at 0.39 NADV88 experienced a slight loss (.002ac) of re-vegetated acreage.

***Spartina alterniflora*:** Plots planted with smooth cordgrass experienced the largest acreage losses across the site during the two seasons of this study. Among the re-surveyed 2017 plots, the loss amounted to 0.47ac, which accounted for 75% of the total losses measured. As with the other herbaceous species planted in 2017, *S. alterniflora* plugs were in their first season of growth, and had not begun to produce rhizomes. Observations of the plantings made in the fall of 2017 indicated that much of what was planted was showing signs of stress, particularly at the lowest elevations along the tidal margin. Growth of plants was minimal and flowering had not occurred. In some areas, clumps of *Spartina* had been dug from elsewhere on the marsh and re-planted into the plots. These were noted to have flowered and produced seed.

Uniquely, mature plants within the genus *Spartina* observed at the Impact Site were infected with the ergot fungus, *Claviceps purpurea*. For *Spartina alterniflora*, approximately 25% of infructescences on the mature plants observed were infected. *Claviceps* is a fungus that parasitizes the seed of many grass species, and has been noted in *Spartina* species (Eleuterius and Meyers 1974; Fisher et al. 2007) in Rhode Island and elsewhere. It has been observed in Rhode Island salt marsh communities most recently in the Maidford Marsh in Middletown (*personal observation*, 2014). *Claviceps* was not observed in fruiting spikelets of *S. alterniflora* in 2018.

S. alterniflora was also planted in May 2018, specifically along runnels created in the same year. In contrast to the 2017 plants, plugs planted in 2018 were in their second year of growth, and were more robust, averaging five stems per plug (as opposed to one or two in 2017), with rhizomes beginning to develop. One area planted in 2018 utilized multi-stem *Spartina* clumps (6-10cm in diameter), dug from the marsh. By the end of the 2018 growing season, some yellowing of leaves had occurred in approximately 30% of all *S. alterniflora* plants placed on the marsh, with some potential losses at lower elevations. Overall rates of survival will only be evident at the start of spring growth in 2019.

Observation of *Spartina alterniflora* in 2018, showed that surviving individual plants had produced rhizomes directed up-slope of the planted area, suggesting that conditions for growth were more suitable at higher elevations. As a result, *S. alterniflora* was recorded as a pioneer species within eleven of the plots planted in 2018, and within four of the re-surveyed plots.

All observations of *S. alterniflora* as a pioneer species, were interpreted as rhizomes extending from of pre-existing colonies into sparsely vegetated plot areas.

There was however, one observation on the Impact Site of *S. alterniflora* as seedlings. In May 2018, following frequent rain events in April, *S. alterniflora* seed was observed to have germinated within a poorly drained area at the site. Although the location presented suitable conditions for seed germination, it was not suitable to support sustained growth of the seedlings. By late-May the seedlings had begun to show signs of stress, expressed by yellowing leaves. Attempts were made to improve drainage in this location, but by late July the seedlings were no longer present on the marsh.



Figure 9. *Spartina alterniflora* plot; acreage loss, 2018.

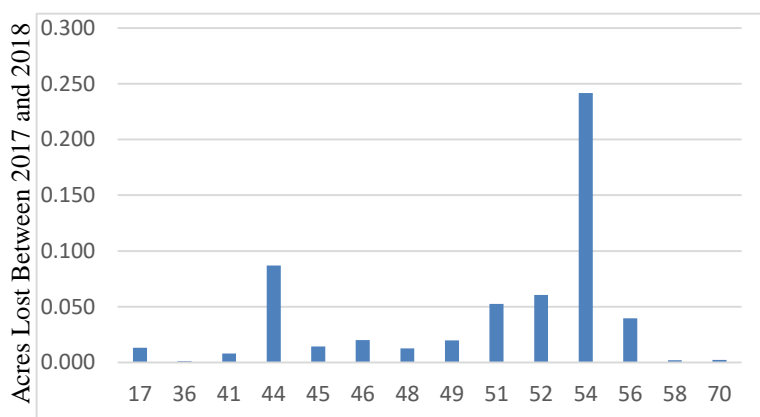


Figure 10. Losses in planted acreage among re-surveyed plots, 2017 - 2018

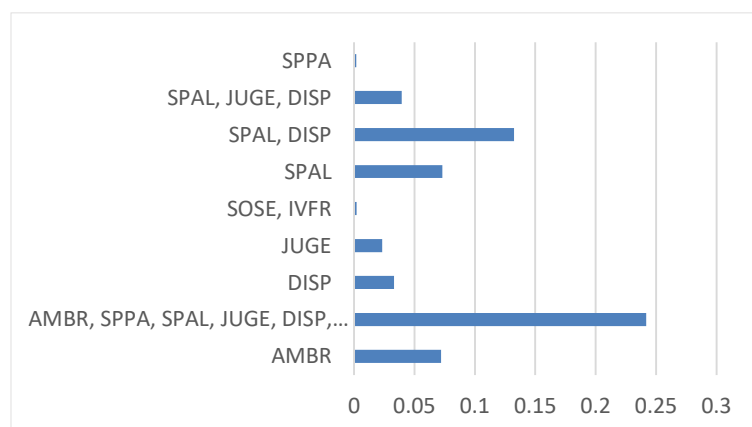


Figure 11. Species plots showing reduction in acres, 2017 - 2018

***Spartina patens*:** Salt marsh hay was planted during both the 2017 and 2018 growing seasons. The majority of the plots (57%) contained only *S. patens*, with the remainder clustered into plots that were also planted with *Solidago*, *Iva* and *Juncus*. At the end of the 2017 growing season, *S. patens* in all plots had flowered and produced multiple stems. Overall plant height within the plots increased from that of a typical nursery plug size of 15cm, to an average of 30cm. As was noted with *S. alterniflora*, flowering spikelets in all plots were infected with the ergot fungus, *Claviceps purpurea*. A total of eight plots containing *S. patens* were re-surveyed in 2018. With the exception of two of the plots, *S. patens* appeared to be thriving. Plants had flowered and set seed. In 2018, the fungus *Claviceps*, was only observed in *S. patens* infructescences in the southern portion of the Impact Site. Elevation of successful plots ranged from 0.40m to 0.64m NAVD88. Within these elevations, plants were vigorously expanding via rhizomatous growth, and filling in the open spaces between plants. Within one plot, at elevation 0.64m, plants were 1m tall and had produced between four and seven infructescences. *S. patens* at this location was actively producing rhizomatous tillers which were filling in the spaces between plants. Of two plots where the species was not thriving, one, located at elevation 0.33m NAVD88, incurred the greatest number of acres lost that were documented within the re-surveyed *S. patens* plots (0.24ac). The other poorly performing plot was located higher, 0.44 NAVD88, with the cause of its failure unclear. Although this second plot showed a reduction in size and poor growth for *S. patens*, the number of pioneer species (16) was greater than those found in all other *S. patens* plots (vs. a mean of 7.8).

S. patens planted in 2018 were located within areas that had been regraded to increase elevation and improve drainage. The plantings were comprised of single species plots, and by the end of the 2018-growing season showed signs of establishment and little sign of stress. Determination of survival and establishment success for these individuals will only be evident at the start of spring growth in 2019.

II Pioneer Species

Although plants of dune and salt marsh communities have high tolerances to salinity, the germination of their seeds is often inhibited by salinity (Baskin and Baskin 2014). Typically, pioneer species can withstand long periods of dormancy, only emerging when environmental conditions are suitable. For halophytes this occurs after periods of high rainfall (Bertness and Hacker 1995). In March and April of 2018, National Oceanographic and Atmospheric Administration (NOAA) rainfall records show that Charlestown, RI received nearly ten inches of rain over the two month period. The appearance of the site in May 2018 indicated that pioneer species seed, lying dormant in the substrate responded with rapid and extensive germination.

Pioneer species contributed substantially to the vegetative diversity at the Ninigret Impact Site, with 90 species observed between 2017 and 2018. While several weed species were observed growing at the base of individual planted species, with roots originating from the soil of nursery plugs, the pioneer species observed were located throughout the Impact Site with germination success corresponding to site elevation and soil saturation. Species documented included a mix of species associated with coastal halophytes, agricultural or human disturbance, with 58% being uniquely associated with coastal habitats. Since dredge material was not tested for the presence of seeds, it is not known which pioneer species might have been present in the sand dredged from the breachway. However given the long dormancy periods capable in many of the species

observed, owed in part to the forced dormancy exerted by salinity (Shumway and Bertness 1992), it is likely that dredged material was responsible for some of the species. Forty-three percent of the coastal species documented are adapted to dispersal by water, and have varying durations of buoyancy in saltwater (Baskin and Baskin 2014; Quirk et al. 2008), suggesting that

either tidal currents washed them onto the surface of the Impact Site after dredged material was deposited, or that they were lying dormant in sand at the bottom of the breachway channel. A small percentage (0.07%) of the documented coastal species are physically adapted to the mechanisms of wind dispersal, and the presence of potential mother plants located with proximity to the site suggests that the seeds of these species arrived after deposition of the dredged material. Another fraction (0.02%) are seeds contained in fruit commonly eaten by migratory songbirds, with the possibility of these too, arriving post deposition.

The remaining 42% of the pioneer species documented at the Impact Site are not coastal specialists, and suggest that a diversity of terrestrial species are washed into Ninigret Pond from freshwater streams and adjacent land, or carried throughout the coastal salt pond community by birds, humans, and wind.



Figure 12. Perennial and annual pioneer species, high elevation at the Ninigret Impact Site, 2018.



Figure 13. Annual halophyte seedlings, low elevation at the Ninigret Impact Site, 2018.

The pioneer species documented, arise from 23 vascular plant families. Families with the greatest number of species (seven or more taxa) were Amaranthaceae, Asteraceae, Cyperaceae, Poaceae, and Polygonaceae. Of the taxa observed, 66% were species native to Rhode Island, with seven considered rare in the state. Thirty-one are introduced species, with five of those being considered invasive. Of the pioneer species documented at Ninigret, 47% were annual or biennial; life forms that represent adaptations to disturbance. Six of the annual species are considered rare in Rhode Island, and 14 (thirteen annual and one biennial) are introduced to this continent from other parts of the world. The remaining 53% of the species have perennial life cycles, which commonly comprise the longer-lived components of habitats in the primary stages of succession. For a complete list of the pioneer species observed at the Ninigret Sediment Placement Impact Site, please refer to Appendix I.

Pioneer species at the site were documented within the re-vegetation plots as well as along the pre-established monitoring transects. Species present within plots were recorded as part of the GIS data set for each vegetated polygon mapped. In 2017, following a single growing season, 41

pioneer species were documented growing within the vegetation plots (of these, five were not observed again in 2018, and presumed to have not survived). During the second growing season, 85 pioneer species were documented (including four species documented uniquely along the transect lines). Between 2017 and 2018, the number of pioneers observed increased among all planted plots, except within areas where *Juncus* was planted.

To illustrate the association between pioneer species and the deliberately planted species, the following figures depict the mean number of pioneer species documented in plots by species planted (Figure 14), and the change in mean from 2017 to 2018 (Figure 15). The highest number of pioneer species corresponds to planted species, which because of their perceived intolerance of salinity and soil saturation, were planted at high elevations. Conversely, the lowest number of pioneers corresponds to species planted in locations of low elevation. The changes (Figure 14) reflect possible synergistic effects of increasingly established plant material, realized as a result of the processes of colonization and succession.

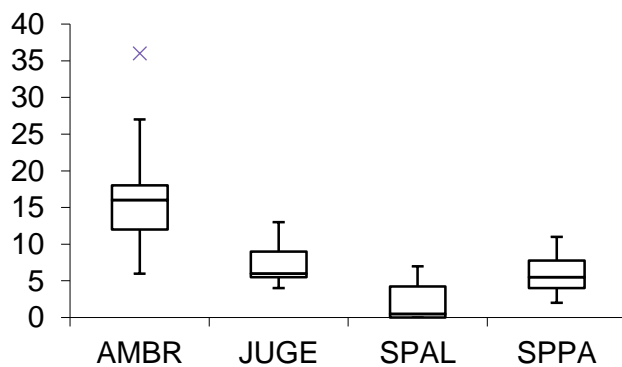


Figure 14. 2018 Planted plots, reflecting mean number of pioneer species present

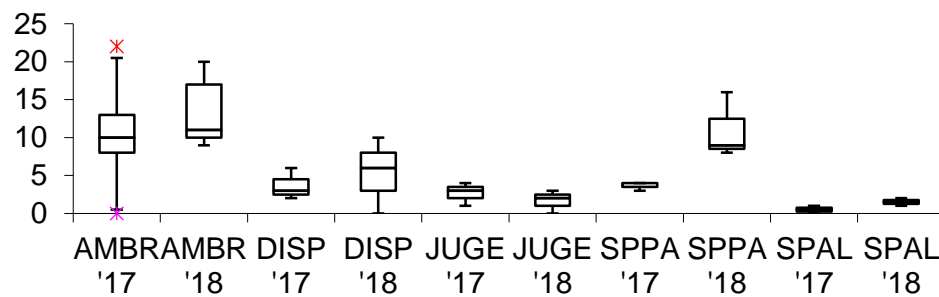


Figure 15. Planted plots, reflecting change in mean for pioneer species (2017-2018)

Among the pioneer species which are native to RI's coastal habitats, 22 have annual (and one biennial) life cycles. The most frequently encountered include oak-leaved goosefoot (*Chenopodium glaucum*) found in 45 plots in 2018; common salicornia (*Salicornia depressa*) found in 25 (2017) and 31 (2018) plots; sea rocket (*Cakile edentula*), which occurred in 12 (2017) and 26 (2018) plots; and fern flatsedge (*Cyperus filicinus*) found in 11 (2017) and 16

(2018) plots. Seedlings of several native shrub species were observed within the plots, including high-tide bush (*Iva frutescens*) occurring in 12 (2017) and 27 (2018) plots; groundsel tree (*Baccharis halimifolia*) 29 (2017) and 14 (2018) plots; and northern bayberry (*Morella caroliniensis*) 1 (2017) and 12 (2018) plots.

Although species diversity among pioneer species was high in 2018, species composition will likely change from year to year, depending on species' suitability to environmental conditions. By August 2018, seedlings of *Morella* that had germinated below .40m NAVD88 had died, potentially reflecting accumulation of salinity in the substrate. The four species which were documented in 2017, but which were absent in 2018 are: field pepperweed (*Lepidium campestre*), English plantain (*Plantago lanceolata*), American plantain (*Plantago rugelli*), pussy willow (*Salix discolor*), and mullein (*Verbascum Thapsus*); all species common to terrestrial, non-coastal habitats. It was reported (Ferguson, *personal communication*) that a garden tomato (*Solanum lycopersicum*) was found during the summer of 2017 growing in the northern-most plot at Ninigret, however no garden tomatoes appeared in 2018. Other pioneer species that are unlikely to survive due to the physical constraints of conditions at the Impact Site are black cherry (*Prunus serotina*), for which a single seedling was observed in 2018, the white poplar hybrid (*Populus x. canescens*), quaking aspen, *Populus tremuloides*) and Bebb's willow, *Salix bebbiana*. all observed on the site in 2017 and 2018.

Table 2 depicts the frequency with which the most common pioneer species occurred in planted plots in 2017 and 2018. Frequencies of 20% or more was used as a benchmark to determine which species were common colonizers of at the Impact Site. Pioneer species diversity at Ninigret was highest within *Ammophila* plots. It was also within these plots that the greatest number of disturbance dependent rare species was found, as well as non-native and invasive species.

Plot Surveys	2017 N=79	2018 N=84
Pioneer Species	Frequency (%)	
<i>Suaeda maritima</i>	<20	44
<i>Juncus gerardii</i>	70	43
<i>Chenopodium glaucum</i>	0	42
<i>Salicornia depressa</i>	32	37
<i>Chenopodium album</i>	0	36
<i>Cakile edentula</i>	<20	31
<i>Atriplex prostrata</i>	0	32
<i>Iva frutescens</i>	<20	32
<i>Cyperus filicinus</i>	<20	20
<i>Solidago sempervirens</i>	20	20
<i>Baccharis halimifolia</i>	37	<20
<i>Spartina alterniflora</i>	23	<20
<i>Phragmites australis</i>	29	<20
<i>Distichlis spicata</i>	22	<20

In 2017, *Ammophila* plots averaged 6.8 pioneer species (with one plot containing 22 species). In 2018 the mean number of pioneers increased to 17.4, with the greatest number of species encountered being 36. Within the re-surveyed plots the number of pioneer species increased by 47% between the 2017 and 2018 growing seasons.

The mean number of pioneer species to become established in plots which included plantings of *Baccharis* was 5.6, and included *Cyperus filicinus*, *Spergularia marina*, and *Persicaria pensylvanica*; species typically associated with moist sandy soil (Haines 2011). Observations of pioneer species that became established at the Impact Site in association with *Iva* was consistent with pioneer species colonization at a lower elevations, with a mean of only 3.7 in 2017, and 4.0 in the resurveyed plots.

Table 2 Frequency of Pioneer Species found in 20% or more of Ninigret plots

Plots planted with *Distichlis* (also planted at low elevations) were colonized by a relatively small number of pioneer species. In 2017, plots average 2.4 pioneers, and the majority of species are presumed to have been in the locations prior to the addition of dredge material. Novel species were limited to *Salicornia depressa* and *Suaeda maritima*. The most successful *Distichlis* plot, located at elevation 0.36m NAVD88, contained the highest number of species (six). By 2018 that number had risen to ten, and included common sand dune and sand flat species like *Cakile edentula*, *Chenopodium alba*, *Chenopodium glaucum*, *Spergularia maritima*, and *Xanthonium strumarium*.

Juncus plots also became vegetated with low numbers of pioneer species (1.6 on average recorded for both the 2017 and 2018 re-survey), with species primarily limited to *Salicornia*, *Suaeda*, *Atriplex prostrata*, and *Chenopodium glaucum*. In 2018, where *Juncus* plots were located at slightly higher elevations than they had been in 2017, the plots became sparsely colonized by species most often found at mid-elevations within the Impact Site: *Atriplex prostrata*, *Chenopodium alba*, *Iva*, *Baccharis*, and *Morella caroliniensis*, with the number of pioneers averaging 7.4 species.

Consistent with observed associations between seedling recruitment of *Iva* in the presence of *Juncus* (Bertness et al. 1992), pre-existing and transplanted clumps of *Juncus* were present in 85% of the plots where *Iva* occurred as a seedling.

Plots planted with *Spartina alterniflora* were located at the lowest elevations (0.23m – 0.35m NAVD88), and were colonized by the fewest number of pioneer species, with plots averaging just 1.9 species. Species were limited to *Distichlis spicata*, *Juncus gerardii*, and *Salicornia depressa*. With the exception of *Salicornia*, all species were represented by pre-existing plants.

Between the months of May and August 2018, *Salicornia depressa* and *Chenopodium glaucum* were the most frequently encountered pioneer species at or below elevation 0.35m. Observations of the two species located outside of the planted areas were consistent with those made inside the plots. In August, *Chenopodium* had a second round of germination. *Salicornia* located at elevations above 0.30m died, apparently from desiccation. NOAA rainfall records for Charlestown show that 1.32 inches of rain fell in July, with only another 1.54 falling by mid-August. *Salicornia* was the only pioneer species observed, where frequency of occurrence decreased dramatically over the course of the growing season. In June 2018, the species was present in 67% of the plots, but by August *Salicornia* was not alive in any plots.

Rare Pioneer Species

State-listed rare species accounted for 0.07% of the pioneer species documented at the Impact Site. While this circumstance was unexpected, it reflects the significant role that disturbance plays in the ecology of habitats. The rare species found within the Impact Site are, with one exception, species with life cycles that are dependent on disturbance events. The State Concern salt marsh tuber bulrush (*Bolboschoenus maritima*) (SC) has a perennial life cycle, which suggest that *Bolboschoenus* was already present at the site when the dredge material was placed onto the marsh. The bulrush was also found growing at the Impact Site adjacent to species with which it

is normally associated in natural settings: three-square bulrush (*Schoenoplectus pungens*) and soft-stemmed bulrush (*Schoenoplectus tabernaemontani*), further supporting prior presences of the population at Ninigret. The Natural Heritage Database however, includes no record of the species at Ninigret Pond, indicating the value of botanical surveys prior to site work. The remaining six rare species have annual life cycles and would have arrived at the site by seed; either transported in storm surge or tides from other parts of the Ninigret Pond/East Beach complex or, as suggested previously, in sediment dug from the breachway.

Among the rare species found at the Impact Site, only seaside knotweed (*Polygonum glaucum*) (ST) was known from the Ninigret Pond area. The species has been documented on East Beach in varying quantities, since 2013 (Natural Heritage Database 2018). During surveys of habitat adjacent to the Impact Site in 2018, a small population of two plants was located on the beach face directly southwest of the Sediment Placement Impact Site. Both *Bolboschoenus* and *Polygonum* were documented at Ninigret in 2017 and 2018. *Bolboschoenus* was observed in three plots in 2017, and five in 2018, with *Polygonum* being found in six (2017) and eight (2018) plots. Two other species, which occurred relatively frequently in plots and along the pre-established transect lines, but for which there are no Ninigret Pond records, are annual sea-purslane (*Sesuvium maritimum*) (SC), which occurred in six plots, and awned flatsedge (*Cyperus squarrosus*) (SE), found in ten plots. Neither species was recorded during the fall 2017 survey, suggesting that seed may have either been dispersed to the Impact Site on tidal currents during the 2017 growing season, with populations elsewhere on Ninigret Pond, or seed was in breachway sediment and only germinated in response to heavy spring rains in 2018. While in recent years, *Sesuvium* has been documented on Trustom and Quicksand Ponds (S. Kingstown and Little Compton, RI respectively); the closest northeast populations are on Long Island, in New York. No other New England populations are known to occur. As a state endangered species, *Cyperus squarrosus* represents an interesting occurrence in the state. Other previously known populations were located in Warwick, RI (one of which is now historic), occurring on sandy shorelines of glacial moraine kettle hole ponds. Recently, a third population has been documented on a coastal salt pond in Tiverton, indicating that coastal sandy shorelines present suitable habitat for the species, and that similar sites should be surveyed for the species' presence. The remaining three species are all in the goosefoot family (Amaranthaceae), and although they are given rare species status, their actual distribution in Rhode Island is uncertain. Saline orache (*Atriplex subspicata*) (SC) and pit-seeded goosefoot (*Chenopodium berlandieri*) (SC) were documented along the pre-established transect lines. A sub-species of the non-native herbaceous sea-blight (*Suaeda maritima*, with the nomenclature *S. maritima* spp. *richii*) is considered native and rare (SC) in Rhode Island. This species was documented in four plots in 2018. Surrounding habitat was inventoried to determine the presence of nearby populations of all rare species documented at the Ninigret Impact Site. However with the exception of *Polygonum glaucum*, no populations of the other six species were located. Map 10a, in Appendix III depicts locations for state listed rare species present at the Ninigret Impact Site, as well as the invasive species described below.

Non-native Species

Of the non-native species documented at the Impact Site, most are common in terrestrial environments where disturbance is frequent, and are not species regularly observed on coastal beaches or marshes. These include species like dooryard knotweed (*Polygonum aviculare*), crabgrass (*Digitaria sanguinalis*), rabbit's-foot clover (*Trifolium arvense*), white clover (*Trifolium repens*) and two agricultural weeds, quick-weed (*Galinsoga parviflora*) and carpetweed (*Mollugo verticillata*). While many of the non-native species we observed, occurred only in 2018, and only in one plot (for example, *Galinsoga*, *Trifolium arvense*, and *T. repens*), others were more widespread: *Polygonum aviculare* in three plots and *Digitaria* in six. Other non-native annual species found that are common to coastal sites, include herbaceous sea-blight (*Suaeda maritima*), found in 1 plot in 2017, and 37 in 2018; lambs quarters (*Chenopodium album*) which was not seen in 2017, but found in 30 plots in 2018; Mexican tea (*Dysphania ambrosoides*), which was absent in 2017, but present in fifteen plots in 2018.

The five non-native invasive species, observed on the Sediment Placement Impact Site all have perennial life cycles. The species documented, include Asiatic bittersweet (*Celastrus orbiculatus*) found in seven plots in 2018, Japanese knotweed (*Polygonum cuspidatum*) in one plot (2018), rugosa rose (*Rosa rugosa*) in a single location along one of the pre-established transect lines (2018), and a hybrid of the white poplar (*Populus x canescens*) which occurred in eleven (2017) and twelve (2018) plots. The fifth species, common reed (*Phragmites australis*) was present at the fringes of the site prior to deposition of the dredge material, and is actively growing into plots located along the margins of the impact site. In 2017 *Phragmites* was documented in 23 plots, and 14 in 2018, as well as along four of the six pre-established transect lines. Save the Bay staff are actively working to remove *Phragmites* whenever they encounter it. Seedlings of all invasive species encountered, were recorded as present and then pulled. GPS location coordinates were not collected.

Discussion

I Planted Species

Several studies have shown that colonization of coastal salt marsh and dune habitats, and in particular the growth of planted species appropriate to those habitats, is controlled by the environmental parameters presented by soil salinity and oxygen, and the degree of tidal flooding (DeLaune et al. 1983; Cisneros and Zedler 2002; Li et al. 2010). Establishing plant cover on Sediment Placement sites is important for habitat and wildlife functions, and for retaining sediment on the marsh surface. Observation of the growth responses among the species planted at Ninigret, and establishment of pioneer species, present instructive lessons for understanding each species' physiological tolerances to environmental conditions, and response to the absence of competition pressures created by the 'blank slate' of the Impact Site (Ewanchuk and Bertness 2004). Some species experienced significant success in terms of survivorship, flower and seed production, and vegetative reproduction, including *Solidago sempervirens*, *Ammophila breviligulata*, *Spartina patens*, and in part *Distichlis spicata*. Poor success and limited establishment occurred with other species, particularly *Spartina alterniflora*, *Juncus gerardii*, and areas of *Distichlis spicata*.

Of particular note, was the success of seaside goldenrod (*Solidago sempervirens*) which, along with *Ammophila breviligulata*, became well established, expanding its coverage, and producing dense vegetative and reproductive stems during the second growing season at Ninigret. In sand dune settings, where *Solidago* commonly becomes established in openings between *Ammophila* colonies (Lonard et al. 2015), its wide leaves produce dense above-ground growth, which shades the soil surface. The effect of shading being to lower soil temperatures and reduce evaporation rates of soil moisture, thereby minimizing the buildup of salt in the soil (Hacker and Bertness 1995). *Solidago* produces quantities of wind-dispersed seed, which also make the species a good colonizer of bare patches. Including *Solidago* in future restoration plots could assist in short term colonization of Sediment Placement sites, by establishing dense plant cover in the higher elevations, and ameliorating soil salinity levels through the shading of its' dense foliage.

The rapid rhizomatous growth documented within plots of *Ammophila breviligulata*, as well as those of *Distichlis spicata* located at mid-elevations, suggest that because of their natural growth habits, these two species are also well suited to quickly cover Sediment Placement sites. Growth resulting from energy put into lengthening nodal distances within the species' rhizomes is typical of these species' responses to the availability of un-vegetated soil where competition from roots of other species is low, and environmental stresses are high (Bertness 2007). Davy et al. (2011) found that *Distichlis* is tolerant of salinity levels as high as 70ppt. In plantings, rhizomes radiated out from central plugs in all directions, with those of *Distichlis* resembling the spokes of a wheel. The rapid colonizing growth habit was reflected in the data gathered for the 2018 plot comparison, with the largest gains in acreage seen in plots planted with *Ammophila* and *Distichlis*, where underground vegetative stems grew as much as 2.5m in the 2018 season. The ability of these two species to rapidly colonize disturbed sites, suggests the value of their inclusion in future Sediment Placement sites, as ameliorators of the dredge sediment, and placeholders for future marsh species.

For *Spartina alterniflora*, rhizomatous growth also plays a significant role in the species' ability to become established in low marsh habitat and to expand into areas of recent disturbance (Bertness, *personal communication*). As with *Distichlis* and *Ammophila*, *Spartina* puts energy into vegetative growth through large diameter rhizome production with widely spaced nodes. Although planted areas of *S. alterniflora* at Ninigret, showed minimal growth above and below-ground, or had not survived the first growing season, pre-existing colonies of the species located adjacent to, and within areas of shallow dredge deposition, were observed to be growing towards and within un-vegetated (and/or sparsely vegetated) *Spartina* plots in 2018. Pre-existing *Spartina* colonies, appear to be able to grow through sediment layers of 15cm or less (Ernst, *personal communication*). The observed growth in these pre-existing patches of *Spartina* at Ninigret may, in the future, form the basis of plant establishment throughout the lower elevations of the site.

Clonal reproduction is accepted as an important adaptive strategy for salt marsh grasses in low elevations and where conditions are highly stressful to plant growth (Bertness 1994; Teal and Kanwisher 1966). However, seed production, dispersal, and seedling recruitment are important supplements to clonal reproduction, and can represent significant mechanisms for establishment in new locations and bare patches within the matrix of an established salt marsh, (Novy et al. 2008; Metcalf et al. 1986). Novy et al. found that genotypic diversity between individual culms of *Spartina* is high, both within a marsh and between local marshes within a region. Each clonal

patch can occupy an area as small as 100m². Metcalfe et al. (1986) found that *Spartina* seedlings germinated both in the understory of mature stems and in bare patches, but that seedling survival was higher in bare patches, where light availability was greater. At Ninigret, a single patch of *Spartina* seedlings was observed in May 2018, in a low elevation of the Sediment Placement site.



Figure 16. Chlorotic *Spartina alterniflora* seedlings, May 30, 2018.

Possibly due to conditions in the soil, the seedlings failed to survive, growing to height of 4cm before leaves became chlorotic. Chlorosis can be the result of poor drainage or high alkalinity, which causes deficiencies in nutrient uptake (Brian Maynard, *personal communication*).

Despite the importance of sexual reproduction as a mechanism for low marsh colonization by *Spartina alterniflora*, and the ability of the species to rapidly expand through asexual means, Smith and Warren (2012), in review of literature documenting salt marsh restorations, indicate that colonization of restored marsh habitat by *Spartina alterniflora* may

take three or four years, following the initial changes to the system. Biological support for advancing *Spartina* colonies, facilitated by rhizomatous growth and the presence of aerenchyma cells (Teal and Kanwisher 1966), is seen as the main strategy for colonization and tolerance of environmentally stressful conditions. Aerenchyma tissue, present throughout the cell tissue, increases oxygen concentration in the soil around the root zone, enabling rhizomes to rapidly colonize environmentally stressful areas (Howes et al. 1981).

It appears, that since the individual first-year plugs of *Spartina alterniflora* planted at Ninigret in 2017 lacked connection to a clonal community, they were unable to cope with the environmental stresses they experienced. In contrast, the 2018 *Spartina* planting incorporated second-year plugs placed along the sides of drainage runnels. At the end of the growing season, the 2018 plants were showing signs of growth, with rhizome production of 4 to 8cm. The apparent success seen with these plants as opposed to those planted in 2017, could have been due to more established root systems and stem growth at the time of planting, or due to their placement along runnels where soil could become more oxygenated at low tide. The difference in survival between the 2017 and 2018 plantings of *Spartina*, does suggest however, that future Sediment Placement plantings should incorporate older plants with more developed roots as a strategy for overcoming the stress of transplanting and establishment in a situation where each plant must form its own colony. The observation of *Spartina* producing rhizomes upslope of the planted area also suggests that making initial plantings at higher elevations may have increased survivorship. Once these become established,



Figure 17. 2nd-year plugs of *Spartina alterniflora* planted along a runnel in 2018.

colonial growth could advance downslope, as well as in other directions where soil is unvegetated.

While studies of responses of salt marsh vegetation to anoxic conditions in soil are largely restricted to existing marshes, the results are instructive for understanding the limitations of species, such as those planted at the Ninigret Sediment Placement Site. During periods of flooding, oxygen cannot enter pore spaces between soil particles. Available oxygen, dissolved in water, is consumed by plant roots and microbes. Eventually, and if flooding is extended for even a few days (Pezeshki and DeLaune 2012) oxygen is depleted. In the absence of oxygen between soil particles, soil microbes cause the reduction and movement of iron and other minerals (seen as redox concentrations). Visible and odiferous characteristics like orange mottling, gleyed coloration, and the transformation of sulfur to sulfide (which produces the rotten-egg smell of marshes) are indicators



Figure 18. Ninigret sediment, 18 mos. after placement on marsh; depth to ferrous mottles approx.. 4cm; depth to water approx..15cm. (photo taken in 2018).

of anoxic conditions. Soil chemistry measurements, such as redox potential at the Ninigret Impact Site were beyond the scope of this report, nevertheless presence of anoxic soil was indicated by redoximorphic features, such as iron mottling (redox concentrations), black pyrite (iron sulfide, FeS_2) just below the surface, and the smell of hydrogen sulfide that was released upon its exposure (Hurt et al. 2003). Figure 18 shows that sands placed on top of the salt marsh have become stratified since deposition at Ninigret, and reflect prolonged periods of flooding. Howes et al. (1981) measured salt marsh sediment redox potential (Eh) within the root zones of *S. alterniflora*, evaluating levels of oxidized soil in comparison to soil where *S. alterniflora* roots were absent. Their research showed that unvegetated soil was anoxic (-100 mV) below 2cm, measured from the surface. Soil being colonized by *S. alterniflora* was oxygenated to a depth of 15cm with the highest levels (+250 to +425mV) measured within the top 5cm of soil, coinciding with the highest density of roots and rhizomes. Under anoxic conditions, microbes compete with plants for available nitrate (NO_3), further compromising plant survival (Hardy, *personal communication*). Chemical changes, such as increases in soil alkalinity, also occur under conditions of anaerobic respiration, as a result of denitrification or sulfate reduction (Chu et al. 2016). Micronutrients, such as manganese, and iron are less available in soils with high pH values, which could also compromise plant growth (Brown, *personal communication*). Hydrogen sulfide may interfere with nitrogen uptake by the roots of *S. alterniflora* (DeLaune et al. 1983), which would limit the planted seedling's abilities to grow. As a part of their adaptation to salt marsh conditions, halophytes produce a protein called proline, by which they regulate osmotic balance (Levine and Hacker 1998). Nitrogen has been shown to facilitate the production of proline, indicating that without access to biologically active nitrogen, plants could also have reduced tolerance to high concentrations of salinity.

Several studies have looked at symbiotic microbial activity within, the root zone of *Spartina alterniflora*. This is a research topic that is under-explored throughout focal areas of ecological restoration, but one which could significantly affect the outcome of management projects.

Delaune et al. (1983) surmised that hydrogen sulfide could interfere with the process by which microbes act to fix and transform nitrogen. McClung et al. (1983) found that *Spartina alterniflora* roots are colonized by nitrogen-fixing bacteria, which transform nitrogen into forms that can be assimilated by the plants, in exchange for carbon. And recent research (D'Entrement et al. 2018; Burcham et al. 2013) has shown colonization of the salt tolerant arbuscular mycorrhizal fungus, *Funneliformis geosporum* in 9% and 3% (D'Entrement and Burcham, respectively) of the *Spartina alterniflora* roots examined. D'Entrement et al. found concentrations of the mycorrhizal fungus were highest in *S. alterniflora*, in spring when plants were rapidly growing. A mycorrhiza is a symbiotic relationship between fungi and plants, within the plant's root system. Mycorrhizal fungi are capable of breaking down minerals, absorbing elements, producing chemicals, and transporting them directly into the plant cellular system, in exchange for carbon produced by the plant through photosynthesis.

The research showing a presence of these two types of symbiotic microbes at the root zone of *Spartina alterniflora*, suggests that the ability of *Spartina* to survive may be, in addition to its' colonial growth habit and salt tolerance, also be due in part to symbiotic relationships with beneficial bacteria and fungi. The fields of horticulture and agriculture recognize the existence of these types of microbes in relationship with certain plant families, and it is now becoming more widely understood that nearly all plant families (with the exception of Brassicaceae) rely to some extent on either bacteria or fungi (for some species, both) for survival (Koske, *personal communication*). Saline and hydric conditions have long been thought to inhibit the growth of these symbiotic organisms (D'Entrement et al 2018), but their presence detected through the above referenced studies, suggests otherwise.

The long-term residence of the Sediment Placement sand materials, in submerged areas of the coastal salt ponds, and in the absence of association with terrestrial plant species, suggests that dredge sands are unlikely to contain living colonies of the microbes that have been documented within and attached to, the roots of *Spartina*. Other than these references, I have come across no other mention of nitrogen-fixing bacteria or mycorrhiza in association with *S. alterniflora*, and significantly none in the literature on the species' nursery production. Indeed, if associations such as these could improve survivability of *Spartina*, it would be worth further examination (see Section D, Propagation and Production Techniques for more discussion).

It is instructive to compare soils and the course of plant re-establishment between the various Sediment Placement sites in Rhode Island to evaluate responses of plants to environmental conditions. Other project sites include Pettaquamscutt Cove which encompassed 6.6 acres, and was carried out in 2014, and Maidford Marsh, 10 acres, in 2015. Control Sites were identified as part of both projects. Maps 9 and 10 (Appendix II) depict locations for the Impact and Control Sites, for these two projects. Treatment and control plots were examined at both sites in the course of this study as well as by others.

Research conducted in 2018 by Danielle Perry at the Pettaquamscutt Cove Sediment Placement Impact Site (Map 6; Appendix II) measured soil pH levels of between 7.8 and 8.8, compared with that of the Pettaquamscutt Cove Control Site which ranged from pH 4.3 to 6.7 (Perry, *personal communication*), which indicates that at Pettaquamscutt Cove, soil pH had increased to a level where alkalinity could affect plant's abilities to uptake mineral micronutrients. Perry also measured soil salinity at Pettaquamscutt Cove, finding levels of 48-68ppt, as compared to 28-

35ppt at the Control Site (Perry, *personal communication*). The combined effects of salt stress and alkalinity have been found to have strong negative impacts on root growth in *S. alterniflora* seedlings (Li et al. 2010). It is possible that the conditions, documented at Pettaquamscutt Cove also occur at the Ninigret Impact Site and contributed to the inhibited growth of *S. alterniflora* observed.

Perry also collected data at Pettaquamscutt Cove on soil bulk density and organic content at various locations on the marsh. Soil bulk density is dependent on soil organic matter, texture, and density of the soil mineral components, with sand having a high natural density (Arshad et al. 1996). Bulk density can reduce porosity and inhibit the movement of gases within the soil (Bradley and Morris 1990). Perry's data show that bulk density is significantly higher at the Impact Site (1.18 g/cm^3 compared to 0.10 g/cm^3) than at the Control Site. Correspondingly, organic content is significantly lower at the Pettaquamscutt Cove Impact Site (0.5%), compared to 68% at the Control Site. Perry's data also show a slight increase in soil organic content at the Impact Site (to 1.0%) over the course of the growing season, and a corresponding decrease in bulk density (to 1.12 g/cm^3). Although speculative, the physical characteristics of compaction and lack of porosity of the breachway sediment at the Ninigret Impact Site may be inhibiting water percolation through the deposits during periods of low tide, contributing to anoxic conditions at the site.

Incorporation of organic matter into sediment placed in the lowest elevations of Sediment Placement sites could ameliorate some of the environmental stresses experienced by *Spartina* seedlings. O'Brien and Zedler (2006) experimented with various planting techniques for salt marsh restoration in California. Techniques included incorporating composted kelp into the top 30cm of the marsh surface, variable spacing between seedlings (10, 30, and 90cm), planting in multi-species clusters, and creating tidal creeks between planted areas. The most significant results in the study were realized from the application of composted kelp, and secondarily from plant spacing between seedlings at no more than 10cm. The composted kelp, which was a commercially produced product, containing perlite in addition to kelp, was shown to significantly increase soil organic matter, increase both total and inorganic nitrogen, and to decrease bulk density. Transplant survivorship increased and stem density and overall height of *Spartina foliosa* (a west coast species) increased (O'Brien and Zedler 2006). In future Sediment Placement plantings, it may be worthwhile to experiment with techniques such as this to increase soil organic content, as a means towards increasing soil porosity and increasing oxygen levels in dredge sediment placed at lower elevations. Marine algae raked off of recreational beach surfaces, is a potential source of local marine organic material that could be composted and incorporated into the dredge material as a part of the Sediment Placement process.

The positive effect, realized by O'Brien and Zedler (2006), with their tight planting clusters (10cm) may have resulted from the increase in canopy cover within the planting plot, causing a reduction in evapotranspiration, and minimizing increases in salinity. O'Brien and Zedler's findings are consistent with that of Bertness and Hacker (1994), who showed that when *Juncus gerardii* was removed from the understory of *Iva frutescens*, soil salinity levels more than doubled (25ppt to 55ppt). While O'Brien and Zedler (2006) showed no significant change in survivability where seedlings were planted in distinct 5-species clusters, Bruno et al. (2017) did find that for the salt marsh aster, *Symphyotrichum tenuifolium*, there can be a facilitative effect realized by salt marsh grasses and rushes (particularly by *Juncus gerardii*) during the seedling

stage of the aster. The benefit for *Symphyotrichum* being possibly due to a decrease in soil salinity through coverage of the substrate by a network of aboveground stems. Additionally, rare plant restoration work conducted by the New England Wildflower Society (Bill Brumback, *personal communication*) has had greater success when multiple species, that are naturally found growing together in a habitat, are seeded together and then planted out as a population cluster.



Figure 19. Transplanted *Juncus gerardii* in flower with *Atriplex* sp. growing in the shelter of the colony, 2018.

Although it is not known what mechanisms have caused these plantings to be more successful than prior efforts of single species plantings, it suggests that species growing together may facilitate positive interactions within the community (Shumway 1995; Hacker and Gaines 1997; Bruno et al 2017). Examples of mutualisms and commensalisms appear frequently in environments with periodic disturbances, or have high levels of environmental stress, where associated species can facilitate the success of the community as a whole (Hacker and Gaines 1997), although the relationships between facilitation and competition can vary between species in salt marsh communities depending on annual changes in soil salinity (due to rainfall patterns) and temperature (Bertness and Ewanchuk 2002).

In salt marsh communities, *Spartina patens* and *Juncus gerardii* are species with slower, and more dense underground clonal growth. Rhizome diameter and nodal distances are smaller than that of the previously discussed species, and form a more dense mat of roots. The dense growth contributes to the competitive advantage these high marsh species have over rapid colonizers like, *Spartina alterniflora* and *Distichlis spicata*, enabling them to successfully compete for underground space and resources (Bertness 2007; Hacker and Bertness 1995). However, at higher elevations such as back dunes and sand deposits along brackish tidal lagoons and rivers, *S. patens* has been observed to take on morphological characteristics similar to those of the rapid colonizers (*personal observation and communication*, Donnelly; Miller). In dune settings, nodal distances within *S. patens* rhizomes is greater than those where plants are found growing in high marsh conditions, as is the overall height of the plant (*personal observation and Donnelly*, unpublished data). At the Ninigret Impact Site, plots planted with *S. patens* at higher elevations, exhibit these morphological changes in the species' growth habits. Within plots located at 0.44 NAVD88, *S. patens* had grown to 1m in height, and had four to seven fruiting spikes. Plants had grown vigorously, producing long rhizomes which extended in straight lines away from plant centers. Although this morphology has not been studied in the field, it has been observed in locations around Rhode Island, New York, and New Jersey where the species has



Figure 20. *Spartina patens* (Fall, 2017), exhibiting tall growth habit at elevation 0.44m NAVD88.

been observed to exhibit a wide tolerance for drought conditions (*personal observation and communication*, Donnelly; Miller). Chris Miller, of the U.S. Department of Agriculture, Plant Materials Center in Cape May, New Jersey, has produced seedlings of *Spartina patens* for planting in sand dune restoration projects in Mid-Atlantic states for the last 18 years. He has noted that when compared to adjacent plantings of *Ammophila*, that *S. patens* has been better at accumulating sand than *Ammophila*, and has become increasingly popular for dune restoration (Miller, *personal communication*). Grace Donnelly, a Cytogeneticist with an interest in the genus, *Spartina*, has been documenting variations in growth habit of *S. patens* along the Rhode Island coast since observing phenotypic differences among populations in 2014. The success of *S. patens* at the Ninigret Impact Site, and the potential for its stems to accumulate sand, suggest that continued use of the species at mid-elevations at future Sediment Placement sites could be beneficial for the establishment of high marsh habitat as sea levels continue to rise.

Growth of *S. patens*, planted within plots located at elevations below 0.44m NAVD88, was less vigorous than those above this elevation, and many plants placed below 0.37m NAVD88 failed to survive. Plots below this elevation also had few pioneer species, and those present were only the most salt tolerant species (*Salicornia*, *Cakile*, *Chenopodium*, *Suaeda*). It is possible that below 0.44m NAVD88, salinity levels and reduced oxygen present too great a stress for the survival of *S. patens* without the supportive effect of clonal structure to transfer oxygen as needed, shade the soil and prevent the accumulation of salts due to evaporation. As with *Spartina alterniflora*, *S. patens* has also been found to form symbiotic associations with arbuscular mycorrhizal fungus (AMF).

The research of D'Entrement et al. (2018) showed colonization of the salt tolerant AMF, *Funneliformis geosporum* in *Spartina patens* roots. In fact it was as significantly higher (68%) than those found in *S. alterniflora*. Also, in contrast to the timing of maximum colonization of *S. alterniflora* roots, concentrations of AMF in *S. patens* were highest in late summer and fall when plants were actively storing carbohydrates for winter dormancy. Gemma and Koske (1997) found the AMF *Gigaspora margarita* also within roots of *S. patens*. The research suggests that for *Spartina patens*, there is a high probability of improved growth when the plant is associated AMF symbionts. This is a poorly understood area within horticultural circles and because of its potential contribution to salt marsh restoration practice, it should be an area for future research.

The ergot fungus observed in seeds of *Spartina alterniflora* and *S. patens* is the result of *Claviceps purpurea*, which infects the seed of grasses during the flowering stage, and feeds on carbohydrates produced in the maturing ovaries (Eleuterias and Meyers, 1974). While plants are not significantly affected, the fungal infection causes seed to be sterile. Within the Ninigret Impact Site, fungal infections of *Claviceps* on both species of *Spartina*, were observed less frequently in 2018 than in 2017. While the fungus is not detrimental to the vegetative parts of grasses, or to rhizomatous growth, heavy infestations (>20% of inflorescences) do result in lower seed production and seed weight (Fisher et al. 2007). Dispersal of sporophytes is by insects and wind, with survival from year to year dependent on overwintering in soil. Heaviest infections of salt marsh grasses, *Spartina patens*, *S. alterniflora*, and *S. pectinata*, have been observed where the grasses are growing in dredge spoils or man-made beaches. Possibly due to aeration and drying at the soil surface, the conditions presented by marsh restoration with dredge spoils appear to be ideal for sporophyte germination, with exposure to wind contributing to dispersal (Eleuterias and Meyers, 1974). In 2014 *Spartina alterniflora* stands in the southern portion of Maidford Marsh Impact Site in Middletown, RI, (Map 7; Appendix II) were heavily infected

with *Claviceps* (*personal observation*). This half of the marsh was restored in 2004 from previous use as a landfill. Soil composition was predominantly fine sands mixed with fine organic matter, conditions which could contribute to fungal success.

Aside from reducing the ability of *Spartina* populations to reproduce through seed, a reduction in the availability of *Spartina* seed could negatively impact the vigor of the salt marsh meadow katydid (*Conocephalus spartinae*), which feeds on the seeds and flowers of *S. alterniflora* (Wason and Pennings 2008). The degree of fungal infection may vary from year to year. In years where infection is widespread, not only could katydid populations be affected, but the impact could also be seen in populations of salt marsh sparrows, which during the breeding period feed on katydids and other marsh insects (Greenlaw et al. 2018).

In natural marsh settings, rhizomatous growth of *Juncus gerardii* is characterized by compact, intertwined roots of small diameter (Bertness 2007; *personal observation*). *Juncus* has a low tolerance for salinity, compared with other salt marsh species, and has been shown in several studies (Crain et al. 2004; Ewanchuk and Bertness 2004; Hacker and Bertness 1995) to be excluded from lower elevations of salt marsh habitat due to this intolerance. Studies have also shown that *Juncus* seed dominates the seed bank of salt marsh soils, producing thousands of seedlings in a given year (Shumway and Bertness 1992). Despite this, no seedlings of *Juncus* were observed as pioneer species within the Ninigret Impact Site revegetation plots. Potential reasons for the absence of *Juncus*, as a pioneer species seedling at Ninigret, relate in part to the species' position in natural marsh settings, and also to the conditions required for its' seed germination. As a high marsh species, distribution of ripened seed would be primarily within areas receiving irregular flooding, with limited opportunity for seed dispersal to lower marsh elevations. In addition, seed germination of *Juncus* is inhibited by salinity (Hacker and Bertness 1995; Shumway and Bertness 1992), so any seed that is dispersed to lower and more saline elevations, would not be likely to germinate. *Juncus* seed typically germinates in unvegetated sandy areas of the high marsh following spring rains (Bertness 1991). *Juncus* growing naturally within the Ninigret Impact Site, was located along the margins of the project area, beneath stands of *Iva frutescens*. Any seed produced by these dense colonies would have been unlikely to reach the sparsely vegetated low elevations of the Impact Site, where salinity levels would likely inhibit seed germination.

At Ninigret, planted *Juncus* plots were located at a mean elevation of 0.34m NAVD88, while some in slightly higher areas (0.36m and 0.41m) showed minimal establishment and production of stems and rhizomes. Overall plant height remained short, and many individual seedlings had not survived into the second growing season. The growth response observed within the plots could reflect stress in response to the conditions at the locations where the species was planted. While although elevations where *Juncus* is naturally found growing along the margins of the Ninigret Impact Site, are lower (0.27m – 0.34m) than those where the species was planted, those colonies were well established prior to current sea level elevations, and receive inputs of freshwater from surrounding non-tidal areas. Their continued success could be attributed to the physical mass of the plant colony and the biological role it plays. As with salt marsh grasses, the advantage of the colony for *Juncus* is in the collective ability to modify growing conditions and transfer nutrients and oxygen. In addition, in many areas along marsh margins, freshwater seeps out onto the marsh as groundwater or surface runoff during rain events, further ameliorating

conditions for *Juncus*. It may be that for restoration plantings, *Juncus* is better suited to locations along the marsh margin where these conditions prevail.

As with *S. alterniflora*, patches of *Juncus* were dug from back regions of the marsh where runnels were created within the Ninigret Impact Site. The clumps, measuring 12-20cm in diameter, were planted alongside planted plots of *Juncus gerardii* as a way of increasing plant numbers within the plots. In 2017 and 2018, the clumps of *Juncus* transplants appeared healthy and had produced seed. Since growth for this species is naturally slow due to its biology and the stored reserves in the root mass (Pennings et al. 2005), plant condition in 2018 could represent a delayed stress response due to the slow growth rate of *Juncus*. The 2019 growing season should determine the degree of success for transplants of this species, and could be instructive for future plantings at Sediment Placement sites for realizing the role and potential value of intact clonal sections for revegetation.

Salt marsh shrub species typically occupy the highest elevations on the marsh. The plots which include planted individuals of *Iva frutescens* and *Baccharis halimifolia* are located between approximately 0.42 and 0.47 NAVD88, and are among the plots which lost coverage between the 2017 and 2018 growing seasons. Although, within these plots survival of the planted shrubs was high, and individuals put on growth and flowered, their long term survival will not be clear for a few growing seasons and will be affected by the level and duration of tidal flooding at the site, and the degree to which the root systems are impacted by flooding (Bertness et al. 1992). Thursby and Abdelrhman (2004) determined that robust *Iva*, measured on salt marshes within Narragansett Bay, received tidal flooding at root depth for only 6-7% of total time during the growing season. Where flooding was within 5cm of the surface for 30% of the total time, *Iva* was absent. Lack of oxygen, due to prolonged periods of flooding for durations between these two scenarios, was attributed to stunted growth of *Iva* (Thursby and Abdelrhman 2004). *Iva* can only survive where roots, the bulk of which are located within 5-10cm of the soil surface (Bertness unpublished data), are not exposed to long periods of flooding (Bertness et al. 1992). Survival of *Iva* at low elevations appears to result from its association with *Juncus gerardii* (Shumway and Bertness 1992). *Juncus* increases oxygen levels in the soil (Metcalf et al. 1986; Bertness and Hacker 1994; Hacker and Bertness 1995) by passing oxygen across cell walls of aerenchyma tissue in the roots.



Figure 21. Dr. Steve Alm and Becky Grumbrewicz collecting insects within the *Iva*-*Juncus* zone, Ninigret Impact Site, 2018.

The ability of the dense, turf-like growth of *Juncus* to ameliorate soil salinities is thought to be responsible for plant species diversity in high marsh elevations, which critically supports a diversity of marsh insect food webs (Hacker and Bertness 1996). As a part of this report, Becky Grumbrewicz' work on salt marsh katydid distribution (see Appendix 1), indicates that *Iva frutescens* could provide important habitat for over-wintering and young instar katydids, during the months before they venture out onto the salt marsh. Distance, from the *Iva* border also appears to influence katydid location on the marsh, with the mean number of katydids being captured within 5m of the *Iva* border. Since katydids form a major portion of the diet of adult salt marsh sparrows,

Grumbrewicz recommends including *Iva* as an integral part of revegetation in future applications of Sediment Placement sites on Rhode Island salt marshes. The synergistic effect of *Juncus* oxygenating the marsh soil, appears to facilitate the growth of *Iva* in lower elevation zones, and would suggest that for *Iva* to be a successful component of salt marsh restoration, future plantings should consider elevations that receive a minimal amount of flooding to the root zone (in the top 5-10cm of the marsh surface) and co-planting with *Juncus* as an understory species.

In developing revegetation plans for future Sediment Placement projects, *Juncus gerardii* should be recognized for its ability to play a key role in setting the stage for a diverse salt marsh plant community. While not a species whose benefit is in early colonization and revegetation of bare soil, the role of *Juncus* is to slowly establish dense coverage. Once established, *Juncus gerardii* forms dense vegetative mats, which enables the species to compete for space where environmental conditions are suitable (Bertness 1991). As discussed, the effects for species such as *Symphyotrichum tenuifolium* and *Iva frutescens*, can be positive, with *Juncus* acting largely to ameliorate growing conditions through a reduction of evaporation and as a result, lowering the potential for the accumulation of salinity in the soil. Taking into account the species' slow growth, and intolerance for flooding duration and salinity, plantings should be well established before placing them on the marsh, and placed in locations where surface flooding occurs irregularly, and daily soil inundation is below the top 5-10cm of the marsh surface. Planting tight clusters, with plants spaced 10cm apart, could facilitate the formation of what would function as a dense mat, by covering a greater percentage of the soil surface with vegetation in the planted area. In addition, planting *Juncus* at the base of *Iva* would mimic natural marsh conditions, and could improve growth and survival for both species. Although important initial goals for revegetation, are the quick establishment of plant cover, it is also important to set in place species whose role will come into play in later successional stages. For species like *Juncus*, and *Iva*, creating compact clusters may be of greater value than diffuse coverage.

II Pioneer Species

Natural disturbance is an important factor affecting population dynamics and species diversity in coastal ecosystems (Lonard et al. 2015). The Ninigret Sediment Placement Impact Site has simulated conditions which could be realized by a stochastic event, such as a major hurricane that causes sand over wash onto the top of a salt marsh platform. Recruitment of pioneer species to sites following disturbance events can be limited by a combination of biotic and abiotic factors (Rand 2000; Lindig-Cisneros and Zedler 2002; Keer and Zedler 2002; Davy et al. 2011), and the species diversity and canopy complexity can influence further recruitment to the site, as well as influence suitability of the site for wildlife species (Lindig-Cisneros and Zedler 2002; Keer and Zedler 2002). The pioneer species documented within the first two growing seasons at the Ninigret Impact Site are representative of species in the Rhode Island flora, adapted to colonizing soils comprised largely of sands and fine gravel and which typically germinate in gaps within vegetated systems. Species observed at the site include those typically found growing along freshwater, brackish, and coastal salt pond sandy shorelines, within sand dunes, and in the disturbed soils of agricultural sites, roadsides, and old field margins as well as those found exclusively on bare soil in the tidal margins of salt marshes, or within wrack lines and salt

scrub habitat. The current vegetative community at the Ninigret Impact Site represents not any single one of the surrounding habitats but an amalgamation of all of them.

Long term dormancy of seed, plays a critical role in maintaining plant populations, particularly in habitats that are characterized by environmental stresses. The presence of dormant seed in soil ensures persistence and regeneration of populations when conditions for germination become favorable (Kahn and Ungar 1995). Halophytes are adapted to survival in saline conditions, a key component of which is a species' germination response to the concentration of salt in water as spring-time temperatures increase. And it is salt, that plays a significant role in maintaining the seeds of halophytes in a perpetual state of enforced dormancy. Saline conditions inhibit the germination of halophytes, and it is only upon exposure to freshwater from rainfall, that germination occurs (Hacker and Bertness 1995; Ungar 2001). As a result, the distribution of species along a salinity gradient is not only a reflection of the varying responses and tolerances of mature plants to salinity, but also a response to saline conditions at the time germination (Rand 2000). These responses have been observed at the Ninigret Impact Site, and are presumed to have significantly influenced seed germination in pioneer species, including the documented rare species, which allowed these populations to replenish seed bank stores through the production of seed in 2018.

Potential sources of seed for the species which spontaneously germinated at the site include dormant seed held within sands along the breachway floor, which was deposited onto the marsh, and the plant communities surrounding Ninigret Pond, from which seed would be carried to the site by birds, mammals, wind or tidal currents. In addition to seeds having a degree of tolerance to salinity at germination, the frequency of annual halophytes (*Atriplex*, *Cakile*, *Iva*, *Chenopodium*, *Salicornia*, and *Suaeda*) as the first colonizers, is also a reflection of the species' adaptive strategies to annual life cycles, such as the production of numerous small-sized seed and rapid reproductive life cycles (Lindig-Cisneros and Zedler 2002; Ungar 2001). By the second growing season, some combination of the dominant halophytes was growing in all plots. In the lower elevation plots, disturbance adapted colonizing halophytes were largely responsible for what vegetation matrix there was. While small in stature and temporal in nature, these species are embryonic colonizers, setting the stage for future vegetation by more permanent species.

While seed availability influences species composition, the conditions into which the seeds land also appears to play a role in determining germination and community composition. Though halophytes are adapted to survive in saline conditions, saline conditions inhibit their germination, and it is only upon exposure to freshwater from rainfall, that germination occurs (Hacker and Bertness 1995; Ungar 2001). Annual species, with only one season to carry out their reproductive potential, are particularly vulnerable when harsh environmental conditions limit germination. Their seeds therefore tend to be adapted to remain dormant and accumulate in the seed bank. In 2018, rainfall amounts for Charlestown, RI, during the months between March and June, totaled 37.00cm with the bulk 24.92cm falling during March and April (NOAA, accessed 2/27/2019). This flush of fresh water in spring was likely a critical factor in the germination of the diverse plant species recorded at the site.

Rand (2000) determined that post-dispersal factors predominate in determining patterns of plant recruitment. Consistent with the research of Davy et al. (2011) the distribution and diversity of pioneer species correlated with elevation variations at the Ninigret Impact Site, with species

diversity increasing at elevations of 0.44NAVD88 and higher. As many as 36 pioneer species were recorded in polygons located at the highest elevations, compared to polygons with no species present at the lowest elevations. While tidal sorting and wind dispersal may account for initial distribution patterns, environmental factors of salinity and soil oxygen availability, and competition from established vegetation can determine both germination and survival of seedlings. Salinity inhibits seed germination and can negatively impact seedling survival (Ungar 1988; Shumway and Bertness 1992). Low availability of oxygen due to flooded conditions can be a factor in the failure of seedlings to germinate (van der Valk 1981). Occlusion of light, due to coverage by wrack or sediment, can cause seeds to fail to germinate when light is a necessary factor in bringing seeds out of dormancy (Baskin and Baskin 2014). And suppression, by species that are competitive dominants within a marsh zone, can negatively impact survival of seedlings (Rand 2000). The exposed soil of the Sediment Placement site provides a soil surface where dominant marsh species are absent and which, because of exposure to wind and tidal flow, were not observed to accumulate wrack.



Figure 22. *Suaeda maritima* at Ninigret Sediment Placement, September, 2018

In frequency of occurrence, annual halophytes predominated at low to mid-elevations at the Ninigret Impact Site, and were observed in 20% or more of the areas surveyed. Due to tolerances to soil salinity (Shumway and Bertness 1992; Shumway and Bertness 1994), and possibly due to their greater access to oxygen through shallow root systems (*personal observation*), annual halophytes were the only species capable of germinating and surviving in all but the very lowest elevations. The three most common species to colonize the site from seed were *Suaeda maritima*, *Chenopodium glaucum*, and *Salicornia*

depressa, which is consistent with reports of the species colonizing bare patches in other salt marsh habitat and marsh restoration sites (Ellison 1987; Crain et al. 2004; Davy et al. 2011; Smith and Warren 2012). A study conducted on a developing salt marsh in England, found that at the lowest elevations, bare ground predominated, and that *Salicornia* and *Suaeda* were the most frequently occurring species (Davy et al. 2011). Davy's research showed that at elevations where redox potential was between 100 and 200mV, vegetation other than *Salicornia*, was absent. Soils where the redox potential is below 100mV, is considered anoxic (Davy et al. 2011).

At the Ninigret Impact Site, *Suaeda* was present within 44% of the polygons surveyed in 2018. Growth of the species was tallest (up to 60cm) and most dense at elevations between 0.40m and 0.45m NAVD88. At these elevations, the species added complexity of canopy structure to the planted plots. The species is intolerant of conditions where drainage is poor and soil oxygen is low (Davy et al. 2011; Tessier et al. 2000). Davy et al. (2011) found that where soil redox potential was below 200mV, that *Suaeda* was absent. At the Ninigret Impact Site, *Suaeda* coverage was sparse and of a low stature, where it had colonized elevations below 0.40m. *Chenopodium glaucum* was observed at Ninigret as an early (May) seedling to emerge throughout the site. The species was present in 42% of the plots surveyed in 2018. By early summer, *Chenopodium* occurred at low to mid-elevations and put out a second round of germination in August following rain events. Observation of this species would suggest that seed

is plentiful in the coastal salt pond system, and that germination is triggered when significant rainfall causes soil salinity levels to fall.

Salicornia depressa is widely considered a rapid colonizer of low marshes with a tolerance for salinities as high as 80ppt, and for sulphide concentrations in the soil at the root level (Crain et al. 2004; Davy et al. 2011). At Ninigret, *Salicornia* was present throughout low to mid-elevations, growing in 32% of the plots in 2017 and 37% in 2018. The species was also observed growing on bare soil within mature stands of *Spartina alterniflora* at the edges of the Sediment Placement site. However, out of all of the pioneer species observed at the Ninigret Site, *Salicornia* was the only pioneer species to experience significant decreases in coverage over the course of the 2018 growing season.

Where *Salicornia* had colonized mid-elevation areas (0.34m NAVD88) early in the season, it was dead during the mid-August surveys. Some mortality was also observed during this interval among other halophytic colonizers *Spergularia maritima* and *Suaeda maritima*, although none suffered as extensively as *Salicornia*, possibly due to these species' tolerance for non-hydric soils. Unusually dry weather may have affected the survival of *Salicornia*. At the time of our survey in late August, the upper soil layers were noticeably dry and during the month of July, Charlestown received 3.35cm of rain, and only another 3.91cm by August 17.

At higher elevations within the Impact Site, a greater number of species were present as colonizers, although each was present in lower frequencies than the species previously discussed. The greater diversity of species also resulted in a diversity of structural forms, with forbs, sedges, grasses, vines, and woody tree and shrub species introduced to these zones as colonizers. These elevations provided suitable conditions for the germination and survival of many of the rare species found at the Ninigret Impact Site, as well as many of the non-native and invasive species observed. Of the total species inventory, the majority are species commonly associated with dune and terrestrial systems where neither salinity nor soil oxygen present strong negative influences. The success of the planted species at these higher elevation polygons, contributed to the recruitment of diverse pioneer species observed. High stem density in these plots could have had the effect of shading the soil and reducing evaporation of water, as well as that of slowing tidal flow during storm over-wash events. Dense stem coverage could have slowed water flow, allowing seeds carried in the tidal water, to settle out onto the substrate within the vegetated areas.

Of the species planted at the site, several also appeared independently as pioneers, germinating from dispersed seed, including the salt scrub species, *Baccharis* and *Iva*. The seed of a third coastal shrub species, bayberry (*Morella caroliniensis*) also germinated within the planted plots. All three species dominate the shrub communities surrounding Ninigret Pond. Seed distribution has been shown to have a strong correlation to adult plant patterns of distribution (Rand, 2000). Pioneer species seedlings then, are likely the result of seed being transported through various means, from elsewhere on Ninigret Pond. *Iva* seedlings were recorded across all elevations in polygons planted with *Ammophila*, *Distichlis*, *Spartina patens*, as well as within naturally occurring remnant clusters of *S. alterniflora*. Although as shrubs, the species represents a longer-lived elements of the community, the *Iva* seedlings (as well as those of *Baccharis* and *Morella*) are potentially temporary colonizers of the exposed sand substrate. For example, there were losses of *Morella* observed at the end of the 2018 growing season, where seed of the species had successfully germinated in the sandy substrate at mid-elevations, with the same potential fate for

Iva. It is possible that mortality occurred as root growth extended down to reach regularly flooded depths of soil where salinity levels were toxic. Survival of all shrub seedlings over time will be determined by the level and duration of tidal flooding at the site (Bertness et al. 1992). *Iva* can only survive where their roots, the bulk of which are located within 5-10cm of the soil surface (Bertness *unpublished data*), and are not exposed to long periods of flooding (Bertness et al. 1992). Of the three salt marsh shrub species observed, *Iva* typically occupies the lowest elevation zone of the scrub-shrub habitat, with *Baccharis* and *Morella* increasing in frequency at higher elevations.

Conclusions

Initial colonization of the site by pioneer species has been rapid (particularly when compared to the two other Sediment Placement sites in Rhode Island). Colonization and succession are largely dependent on the availability of seed from a diverse set of coastal species, coupled with the species inherent tolerances to salinity and anoxic conditions. Seed dispersal to Sediment Placement sites can be facilitated by tidal flow, wind, and the presence of dormant seed in dredged material. Seed germination will be successful for those species that arrive at locations within a site where conditions that influence the cessation of dormancy are present. While these factors are outside of the realm of control by site managers and planners, site conditions can be shaped in ways that facilitate colonization by pioneer species. Although long-term pooling on the surface of the dredged sediment is not desirable, topography can be sculpted to create micro-habitats to provide variations in elevation across the surface. Deliberate revegetation of mid to high elevations created within a Sediment Placement site is another mechanism for jump-starting the process of site colonization. Utilizing species with rapid rhizomatous characteristics, that are adapted to colonizing bare patches within dune and salt marsh plant communities, puts in place species that can stabilize sediment and further accumulate sands. The biology and growth habits of rapid colonizers also will begin to ameliorate the harsh environmental conditions created by the process of Sediment Placement, facilitating the establishment of a more diverse suite of species.

Locations on the Ninigret Impact Site, which have become vegetated predominantly by pioneer species, should be seen as successful, in that the conditions at those elevations have provided suitable sites for a suite of embryonic marsh building species. Over time, these plant communities can be expected to change and be colonized by the characteristic, rapid salt marsh colonizers, *Distichlis spicata* and *Spartina alterniflora*. These species, present at the Ninigret Impact Site as a result of revegetation efforts, are strategically located at the fringes of the pioneer-colonized areas. Locations within planted plots of both *Distichlis* and *Spartina* were documented to lose acreage as a result of plant death. However, as surviving individuals become established, they will form the extensive rhizomatous support systems needed to grow into lower elevations and interior regions, which have been initially too harsh for seedling survival.

The success of the deliberately planted plots located within the higher elevations of the Ninigret Impact Site, have more obviously been successful, as documented by slight increases in acreage at those elevations. By planting several species which are rapid colonizers of dune systems, *Ammophila breviligulata*, *Solidago sempervirens*, and the more recently appreciated *Spartina patens*, these locations have become densely vegetated and have, in some locations, begun

accumulating wind-blown sand. As a result of the higher elevation and open areas between planted individuals, a diverse set of pioneer species have become established, including several state-listed rare species. While these areas at present do not represent a typical salt marsh plant community, they are expected to evolve to resemble one over time. Species planted at higher elevations, such as *Spartina patens*, *Iva frutescens*, and *Baccharis halimifolia*, represent slower-growing components of a high marsh community. Their establishment at early stages of the revegetation process, puts them in place to colonize future conditions.

Disturbance through the deposition of sediment on the marsh surface, presents a not-uncommon circumstance along the New England coast. As storm intensities increase as a result of changes in climate norms, we can expect that disturbances from sedimentation will be more common. The process of Sediment Placement functionally changes a salt marsh in a similar way. The goal of revegetation following Sediment Placement should be to facilitate the dynamic natural process of colonization and succession (Smith and Warren 2012). Since zonation of plant species in salt marsh habitats is a reflection of influences on their growth and seed germination by variable environmental conditions, particularly salinity, soil anoxia, and elevation above tidal inundation (Davy et al. 2011; Crain et al. 2004; Bertness and Ewanchuk 2002), these factors are instructive for future projects.

Revegetation planning for future Sediment Placement sites should perhaps be staged in multiple phases. The focus, during the Sediment Placement and grading phase, should be in preserving existing patches of *Spartina alterniflora* along the marsh edges and creating micro-habitats for pioneer species. Recognition that existing patches of *Spartina* represent viable first colonizers with greater tolerances for the stresses of salinity, flooding, and low oxygen, than seedling plugs, should improve the rate of establishment of plant cover along the marsh edge. Ensuing focal points should be placed on staged deliberate planting. In the first growing season species should be limited to those with rapid colonizing abilities. For example, in mid-to low-elevations where soil appears to drain daily, plant *Distichlis spicata*, and *Spartina alterniflora*, and in mid-to high-elevations plant *Ammophila breviligulata*, *Spartina patens*, and *Solidago sempervirens*. During the second growing season, after the hydrology and limitations of the site are better understood based on observation of both the planted and pioneer vegetation responses, planting should focus on 1) a more strategic placement of rapid colonizers to utilize their abilities to grow into stressful (poorly draining) areas once seedlings become established in less stressful areas, and 2) selection of suitable locations for tightly planted clusters of multi-species plots, to promote the establishment of slower growing species like *Juncus gerardii*, *Iva frutescens*, and *Spartina patens*. These locations should be either along the marsh fringes where freshwater is available from the surrounding habitat, or at mid-elevations in interior portions of the Impact Site, where salinity levels may not be as high due to the ability of the soil to drain at low tide, or where pioneer vegetation has become established and shades the soil surface.

Due to the nature of the Sediment Placement process, the structure of the dredge material is dependent on the material and soil particle size of the channel from where the material is dredged. Sediment on the three Rhode Island sites has ranged from fine sand (Pettaquamscutt Cove) to that of medium-coarse grain size (Ninigret Pond), and on all three sites, lacked organic matter (*personal observation*). Density of soil (measured as bulk density) will effect root growth of seedlings and possibly percolation of water through the substrate. Soils at low and mid-

elevations can, because of the degree of density and lack of organic matter, become anoxic, and can accumulate salts during months where rainfall is minimal. Germinating seeds and seedlings are particularly sensitive to conditions of low oxygen and high salinities. Species commonly dominating low elevations in salt marshes grow within supportive colonies, rarely becoming established as seedlings. This suggests that for Sediment Placement sites, more attention must be paid to monitoring conditions which, though within the range for established salt marsh plants, are outside the envelope for the same species as seedlings.

High elevation soil can be expected to be well aerated and present suitable germination conditions to a diversity of species. Rapidly colonizing species and salt marsh shrubs planted into these elevations will promote the process of accretion, and limit establishment of non-native and invasive species. The function of the higher elevation zones within Sediment Placement sites should be viewed as place-holders for future salt marsh. In the short term, these elevations have been shown to provide valuable temporary habitat for a number of rare species whose life cycles are attuned to disturbance just above tidal inundation levels. Several of the rare species documented, for example at the Ninigret Impact Site, are not only rare in Rhode Island, but also throughout New England. Proliferation of these species, even if short-lived, replenishes the seed bank, increasing the species' potentials for germinating in the future when similarly suitable conditions arise.

Successful establishment of vegetation can be enhanced in several ways. Experimental directions encountered as a result of research for this report, are presented here for consideration. Decreases in soil density are achieved through increases in soil organic matter. If soil density can be decreased through the addition of organic matter, there will be a greater availability of oxygen, and an increase in nutrients. The addition of composted organic matter has resulted in some successes for salt marsh restoration on the west coast, and should be tried on an experimental basis in Rhode Island. Dense plantings provide greater aerial coverage of soil and potentially less evaporation of freshwater held in the soil. Unpredictable synergistic effects can occur as well, when plants of different species are planted together. These effects can occur above-ground, with a diversity of structural forms and abilities to shade soil, as well as below-ground through a diversity of root structures and abilities to oxygenate soil. Planting species within miniature colonies that mimic natural species co-occurrences should be a part of future plantings, particularly as mentioned above, for the slower growing marsh species. Experimentation in the propagation of plants, especially *Spartina* species, for Sediment Placement revegetation should incorporate the addition of microbes (both nitrogen fixing and arbuscular mycorrhizae), to determine if benefits can be realized from these approaches. Propagation contracts should also allow for sufficient time for seedlings to develop more extensive root systems prior to planting, as this may also improve survivorship.

Vegetation Management Recommendations for Future Sediment Placement		
Condition	Response	Species to Consider
High Soil Bulk Density	<ul style="list-style-type: none"> Add organic content Incorporate composted marine algae Minimize compaction and trampling 	All species
Low Redox Potential	<ul style="list-style-type: none"> Plant rapidly colonizing, rhizomatous species Incorporate nurse plants Monitor decomposition of covered salt marsh 	<i>Spartina alterniflora</i> , <i>Distichlis spicata</i>
High Soil Salinity	<ul style="list-style-type: none"> Focus planting strategy on 1st establishing rapid colonizers Incorporate nurse plants Decrease plant spacing 	<i>Spartina alterniflora</i> , <i>Distichlis spicata</i> , <i>Ammophila breviligulata</i> , <i>Spartina patens</i> (high elevations), <i>Solidago sempervirens</i>
Flooding Duration at Root Zone	<ul style="list-style-type: none"> Monitor tidal flooding below the soil surface 	<i>Iva frutescens</i> , <i>Juncus gerardii</i> , <i>Spartina patens</i> , <i>Baccharis halimifolia</i>
Absence of Naturally Occurring Microbial Life	<ul style="list-style-type: none"> Add nitrogen-fixing bacteria to nursery plants Add arbuscular mycorrhizae to nursery plants 	<i>Spartina alterniflora</i> , <i>Spartina patens</i>
Actions	Response	Species to Consider
Monitor Seed Bank Potential	<ul style="list-style-type: none"> Monitor seed dispersal on sediment surface Evaluate seed bank potential of dredge material Evaluate tidal flow for deposition and relocation of seed 	Annual Halophytes, Rare species, Early Colonizers
Increase Rapid Colonization	<ul style="list-style-type: none"> Preserve Existing <i>Spartina alterniflora</i> where possible Create micro-habitats Plant <i>Spartina alterniflora</i> at higher elevations Utilize plants with rapidly expanding growth habits 	<i>Spartina alterniflora</i> , <i>Distichlis spicata</i> , <i>Ammophila breviligulata</i> , <i>Spartina patens</i> (higher elevations), <i>Solidago sempervirens</i>
Plant Later Successional Plant Communities	<ul style="list-style-type: none"> Plant slower growing species in tight, incubator clusters Plant naturalistic combinations of species 	<i>Juncus gerardii</i> , <i>Iva frutescens</i> , <i>Spartina patens</i> (mid elevations), <i>Symphyotrichum tenuifolium</i>
Improve Wildlife Conditions	<ul style="list-style-type: none"> Increase structural diversity Increase shrub component Incorporate shrub habitat contiguous to low marsh zones Promote a diverse high marsh plant community 	<i>Iva frutescens</i> , <i>Juncus gerardii</i> , <i>Panicum virgatum</i> , <i>Solidago sempervirens</i>

Table 3. Recommendations for future Sediment Placement Projects

B. Plant Community Assessments for Ninigret, Quonochontaug, and Winnapaug Ponds, and Future Sediment Placement Sites

Introduction

Several Rhode Island, state-listed rare plant species have been documented within salt marsh and adjacent habitats, on Ninigret, Quonochontaug, and Winnapaug Ponds (Maps 10, 11, and 12; Appendix III). To assess the current state of rare species presence, and to catalog floristic compositions within the coastal habitats surrounding these coastal salt ponds, meander surveys were conducted throughout the growing season on selected habitats. These surveys were untimed. Meander surveys are often used for determining population location for state listed rare species and invasive non-native species and for monitoring habitat biodiversity (Stahl, G. 2003). The methodology targets habitats where rare species are known to occur and ecotones between plant communities. All species encountered are recorded, providing presence-only observation data. Abundance codes are then assigned to each species based on distribution within the habitat type. A complete list of all vascular plant species encountered can be found in Appendix I.

Documentation of existing floristic conditions on salt marshes and surrounding habitat, prior to the placement of sediment over salt marsh habitat to raise vertical elevation, provides valuable data for interpreting post-Sediment Placement conditions, and is essential for better understanding the processes needed for successful salt marsh re-establishment. To this end, the location selected for the 2019 Sediment Placement on Quonochontaug Pond and the proposed future locations for Winnapaug Pond were extensively surveyed in the spring, summer, and early fall months to document plant species presence in the impact areas and surroundings. This floristic survey was done in addition to data collected by the University of Rhode Island Environmental Data Center (EDC) along vegetation transects within the proposed Sediment Placement Impact Sites. The EDC survey, carried out as part of monitoring plans approved for the project, are primarily aimed at quantifying the course of the restoration in gross, area-wide terms, and was not designed to provide fine-scale information on the trajectory of individual species, nor to detect all the examples of rare, invasive, or otherwise noteworthy plants. The floristic survey completed for this report, on the other hand, was intended specifically to provide a botanical perspective on existing plant communities, and to ensure that rare species populations in the Sediment Placement locations are detected.

Fine-grained floristic surveys can also produce valuable evidence for the operation of long-term trends such as sea level rise. Freshwater wetlands adjacent to the coast are vulnerable to stresses brought on by climate change. By virtue of their horizontal proximity to coastal habitats, and vertical elevation relative to sea-level, the potential exists for over wash and flooding during storm events and shifts in species composition due to increasing salinity levels introduced as a result of rising seas (Osland et al. 2016). Evidence of species shifts have been observed within brackish/freshwater ecotones (*personal observation*; Kutcher 2018) at elevations of 0.60m above sea level along the coast. In addition to the meander surveys, and to document changes occurring on Quonochontaug and Winnapaug Ponds, two systematic floristic assessments were conducted following the Floristic Quality Assessment (FQA) protocol (Kutcher and Forester 2017). Locations selected for FQA were low elevation freshwater wetlands with hydrologic connections to the salt marsh habitat of each pond (Maps 11a and 12a; Appendix III). The data collected provide a baseline for the present state of the floristic composition of these vulnerable

habitats, and builds on data collected in 2017 by RINHS on freshwater wetlands adjacent to coastal habitats (Kutcher 2018).

In addition to rare plant species being present on these coastal salt ponds, several observations of the State-Endangered (SE) diamondback terrapin (*Malaclemys terrapin terrapin*) have been recorded on Winnapaug, Quonochontaug, and Ninigret Ponds (RI Natural Heritage Database 2018). Maps depicting these locations are included in the report on diamondback terrapins in Appendix IV. The species is found only in brackish water and typically nests in open gaps in sand dune habitat (Provensal, *personal communication*). RINHS database records for terrapin sightings on Ninigret Pond date back to 1982, with no recent observations. Records for Quonochontaug and Winnapaug Ponds span the years between 2007 and 2013, with an observation of six terrapin made on Winnapaug Pond adjacent to the Lathrop Property (potential Sediment Placement site) in 2018 (Bradley and Claver, *personal communication*). As a part of

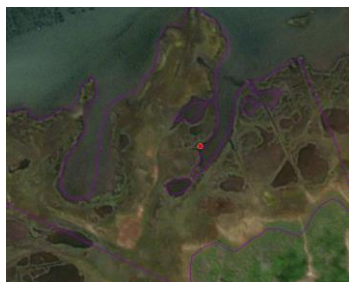


Figure 23. Diamondback terrapins (6 sighted) on Winnapaug Pond 2018, adjacent to the Lathrop Property (red dot, photo to R)

this report students in the laboratory of Dr. Laura Meyerson at URI, conducted surveys for diamondback terrapin on all three ponds in 2018. Plant community data, which forms the bulk of this report, is also relevant to ongoing research by Meyerson, into habitat preferences for diamondback terrapin. The data contributes to a body of spatial data being collected on environmental conditions at known terrapin nesting sites in coastal waters throughout the northeast (Meyerson, *personal communication*).

The spatial data so far, show that water bodies with a predominance of sandy substrates correlate highly with nesting sites. Both Quonochontaug and Winnapaug Ponds rank above the mean when evaluated for the percentage of sandy soil shorelines (Provensal, *personal communication*), and it is possible that the species could utilize Sediment Placement sites on these ponds as nesting sites (Paton, *personal communication*). Preliminary data for the Habitat Suitability Index being compiled by Meyerson, are included in Appendix IV.

Coastal salt pond Plant Community Surveys

Methods

Untimed meander surveys were conducted on Quonochontaug and Winnapaug Ponds in areas of proposed Sediment Placement, and in adjacent habitats. The technique was also applied to the Ninigret Pond Sediment Placement Control Site (see Methods in section A for details). Location data was collected with a hand-held Garmin GPS unit for rare species populations, populations of other infrequently encountered species, and for non-native invasive plant species. Invasive species data were limited to instances where, because of location, the species represented a potential impact to Sediment Placement site re-vegetation, or because the species' distribution in coastal habitats is not well documented. Abundance codes (Table 5) were then assigned to each species by habitat type on each pond. Broadly, the habitat types surveyed included: salt marsh (high marsh and low marsh), brackish marsh, salt scrub, tidal creek, coastal salt pond, forested swamp (red maple swamp), open mineral soil wetlands (shrub swamp and emergent marsh), coastal grasslands (maritime beach strand and maritime herbaceous dune), coastal shrubland

(maritime shrubland), maritime woodland, and ruderal grassland/shrubland (old field). Ecological communities described in this report are according to those described in *Rhode Island Ecological Communities Classification* (Enser et al. 2011). Survey locations were limited to properties along each of the pond shorelines, where permission could be obtained to access the site.

For each state-listed rare species population encountered, the population size and condition was documented and the associated plant species identified, and community characterized. A RINHS Rare Species Data form was filled out for each species, with data submitted to both RINHS and the New England Wildflower Society (New England Plant Conservation Program).

Abundance Code		Description
A	Abundant	Plants are dominant and a representative feature of the habitat
C	Common	Locally abundant or frequently encountered
O	Occasional	Occasionally encountered or locally common, absent across much of habitat
U	Uncommon	Infrequently encountered
R	Rare	Very few plants (includes state-listed rare species)

Table 4. Meander Survey Abundance Codes

Findings

Ninigret Pond East Beach and Sediment Placement Control Site

The Ninigret Pond survey was limited to East Beach, along beach strand, and within herbaceous dune, located south of the Sediment Placement Impact and Control Sites, the Control Site itself, and the glacial moraine island located immediately north of the Control Site. The survey was limited to these areas primarily to monitor the area for known State listed rare species occurrences, and to determine if any of the rare species which had been documented as pioneers within the Sediment Placement Impact Site, were present along this coast line and could have served as possible seed sources.

During this survey, five state listed rare species populations were documented. Populations for two of the species were previously known to occur in the locations where they were found. Sea-beach knotweed (*Polygonum glaucum*) is a State Threatened (ST) annual species typically found on maritime beach strands above the reach of most storm surges. Plants have been documented on East Beach in previous years, with the most recent observation being in 2013 (RI Natural Heritage Database 2018). It is possible that seeds of these plants are the source of those that germinated on the Ninigret Impact Site. A second species, which occupies similar habitat as the knotweed, but which had not been previously documented on East Beach, was seaside sandwort (*Honkenya peploides*). Seaside sandwort is a species of State Concern (SC), known from other

beach faces in Westerly, South Kingstown, and New Shoreham (RI Natural Heritage Database 2018).

Both *P. glaucum* and *H. peploides* are annual species, with seeds being dispersed during storm events. Population locations, as well as sizes, can vary from year to year. Both species however, have affinities for the open sand of beach strands, just above the wrack lines that define the high tide margins. On East Beach in 2018, the species were located southwest of the Ninigret Impact Site on land owned by RIDEM growing at the upper edge of the beach strand in an area traveled by four-wheel drive vehicles. Due to the steepness of the beach at Ninigret, the upper edge of the beach strand, appears to be most often selected for four-wheel drive vehicle travel (*personal observation*), with tire tracks passing within centimeters of the populations of both species. Disturbance to the surface of the sand, by pedestrians and vehicles is evident, and is compromising the sustainability of these species. When soft sands are disturbed, the plant roots become dislodged and desiccate.



Figure 24. *Honkenya peploides* seedling growing at the edge of a tire track on East Beach, 2018.

The Ninigret Sediment Placement Control Site was also surveyed for rare species (Map 10a; Appendix III). The survey included the glacial moraine island located along the northern margin of the salt marsh, as previously, two rare perennial wildflower species had been documented in this location (RI Natural Heritage Database 2018). The vegetation community on the glacial moraine island is a maritime woodland, dominated by sassafras (*Sassafras albidum*), with open areas vegetated primarily by goldenrods (*Solidago spp.*) and cow-parsnip (*Heracleum maximum*). Rare species present include a previously documented population of the state-listed lance-leaved figwort (*Scrophularia lanceolata*) (SC) and a previously undocumented population of downy wild rye (*Elymus villosus*) (SC). While the elevation of this rocky ‘island’ would suggest security for these species from a sea-level rise standpoint, a previously documented species located in the same habitat (wild coffee, *Triosteum perfoliatum*; SC) is no longer found in the woodland understory implying that perhaps present conditions are affecting species composition. All three species require an open woodland canopy to provide enough light to produce flowers and set seed. The two extant species are in fact growing in canopy openings within the woodland. In the case of *Triosteum*, white-tailed deer (*Odocoileus virginianus*) browse on their stems and flowers (Paton, *personal communication*), and could also have adversely impacted the population at this location.

Within the upper reaches of the salt marsh, a previously unrecorded rare spikesedge was identified growing in the understory of a dense stand of the invasive common reed, *Phragmites australis*. The sedge, beaked spikesedge (*Eleocharis rostellata*), has a colonial growth habit and is found in brackish marshes, often in sea-level fens or in association with groundwater seepage. The species had been identified prior to the Sediment Placement work but had not been recognized as a rare species. Beaked spikesedge had also not previously been documented on Ninigret Pond, and although the status is SC, our understanding of the species’ actual distribution is incomplete due both to sparse survey coverage and confusion of identification. Recent monitoring of known populations of *E. rostellata* elsewhere in RI, have resulted in the realization

that in the past some populations were incorrectly identified. Other populations (one previously documented at the north end of Quonochontaug Pond) no longer exist. While extensive at this location, beaked spikesedge occupies a 3-5 meter wide band across the top of the marsh. It grows in association with other species commonly found on salt marshes often growing in association with freshwater seepage. These include, salt marsh arrow-grass (*Triglochin maritima*) and soft-stemmed bulrush (*Schoenoplectus pungens*). One portion of the population abuts a remnant freshwater shrub swamp, that transitions abruptly into high marsh on its north side. The following species are present at the edge of brackish marsh: winterberry, *Ilex verticillata*; marsh fern, *Thelypteris palustris*; tussock sedge, *Carex stricta*; blue-flag iris, *Iris versicolor*. Gumbrewitz reported capturing a stonefly (Plecoptera) in this location. Stoneflies are typically associated with perennial freshwater flow (Alm, *personal communication*), further supporting the botanical evidence of groundwater flow from the dune into the marsh system at this location.

There were five other state-listed rare species among the plants that colonized the Ninigret Impact Site and that have not yet been documented elsewhere on Ninigret Pond. All are annual species adapted to disturbance regimes, with seed dispersal dependent on storm surge, tidal flooding, or inadvertent transportation by birds or mammals. It is possible that seeds of these species (as well as other colonizers of the Impact Site) were present as dormant seeds in dredge spoils taken from the Charlestown Breachway. These species, with their state statuses, are:

Saline orache, *Atriplex subspicata* (SC)

Pit seeded goosefoot, *Chenopodium berlandieri* (SC)

Awed flatsedge, *Cyperus squarrosus* (SE)

Annual sea purslane, *Sesuvium maritimum* (SC)

Herbaceous sea-blight, *Suaeda maritima* ssp. *richii* (SC)

Of these rare species, the occurrence of awed flatsedge was the most unexpected. Only two other extant populations for the species are known to be located in Rhode Island (see previous discussion in Section A, Pioneer Species). The species is present throughout New England (Haines 2011), and is state-listed in Maine (SC), New Hampshire (SE) and RI (SE). The New England Wildflower Society has established protocols for the collection and long term storage of rare species seed throughout New England. The population of awed flatsedge may be a candidate for seed collection and banking through this program. As with all other rare species documented in this report, annual population surveys should be made and additional areas along the shore of Ninigret Pond should be searched to determine the species' complete distribution.

Quonochontaug Pond 2019 Sediment Placement Impact Site

The 2019 Sediment Placement Impact Site (Map 4, Appendix II), located to the east and west of the Quonochontaug Breachway (Eastern and Western Impact Sites) was surveyed three times during the 2018 growing season to determine if any state listed rare species would be impacted by the deposition of dredge material on top of salt marsh. This survey was conducted as a part of

a larger survey conducted in selected habitats on and adjacent to Quonochontaug Pond, to assess plant community and rare species status.

In 2018, no rare plant species were observed within the proposed impact areas east or west of the breachway. Several species, however, were observed in habitat adjacent to the areas, but would not be immediately impacted by the addition of dredge material on the marsh surface (Map 11; Appendix III). The meander survey located state-listed bracted orache (*Atriplex glabriuscula*) (SC), growing within the wrack line along the area of transition between high marsh and *Iva frutescens* dominated salt scrub habitat. Having an annual life cycle, the species has the potential to appear in unpredictable locations from year to year, depending on seed transport via tidal and storm flooding the previous fall, or germination conditions in wrack each spring. As a result, the species could appear as a pioneer species within the Quonochontaug Sediment Placement Site. A population of a second species (Scotch lovage, *Ligusticum scoticum*) (SC) was located along the ecotone between high marsh and salt scrub habitat immediately east of the Sediment Placement Site, in an area of freshwater seepage on the Charlestown Land Trust's property, known as the Hathaway Preserve. This slow-growing, perennial species is also found growing in similarly patterned vegetation communities elsewhere along the southern shore of Quonochontaug Pond. The species occupies a narrow band of conditions at the top of marsh habitat, where available light and hydrologic conditions are suitable, and is vulnerable to sudden increases in salinity and in the duration and regularity of the tidal flooding regime. A third rare species observed, known as velvety rosette panicgrass (*Dicanthelium scoparium*,) (SC), was observed growing among the mosaic of old field habitat that has formed along the berm located along the western bank of the breachway. While several other rare species were found within interior portions of the Hathaway Preserve, and are discussed in detail in the following section regarding Quonochontaug Pond findings. No other rare species were in immediate proximity of the proposed Sediment Placement Impact Site.

Although not considered rare in Rhode Island, there were several species of interest growing within and adjacent to the Sediment Placement Impact Site: these include widgeon grass, (*Ruppia maritima*), an aquatic submergent species, saltmarsh arrow-grass (*Triglochin maritima*), and perennial glasswort (*Salicornia ambigua*). Widgeon grass is an important food for waterfowl, and is present in two locations within the Sediment Placement Site, the tidal creek bordering the eastern-most edge of the Eastern Impact Site and the ponded area located in the southern portion of the Western Impact Site. Saltmarsh arrow-grass is occasionally found along high marsh margins, in association with freshwater inflow from groundwater seeps. This population is located on the Hathaway Preserve where freshwater flows into the salt marsh. Perennial glasswort is infrequently encountered on salt marshes in Rhode Island, and although it is likely present elsewhere on Quonochontaug Pond, it was only observed in this one location. The population, covers approximately 70 square feet is located at the northwestern tip of the sandy berm that fringes the western most portion of the Sediment Placement Site.

The non-native invasive species porcelain berry (*Ampelopsis glandulosa*) was observed in two locations around the periphery of the Eastern Impact Site. A population exists within the Hathaway Preserve in salt scrub habitat immediately abutting the salt marsh (Map 11), with the second growing among *Phragmites* at the southern end of the Impact Site. While scientific literature does not address salinity tolerances for this species, it is found primarily in coastal



Figure 25. Porcelain berry growing among *Phragmites* along margin of Quonochontaug Sediment Placement Impact Site (East), 2018.

communities of Rhode Island, and has been found growing in maritime grassland at Napatree Point in Watch Hill, RI (State of Napatree 2015). In addition, several populations of Asiatic sand sedge (*Carex kobomugi*) were located west of the Impact Site, in areas of extensive sand over wash. Previously, the species was known from Ninigret Pond at East Beach. Given the exposed soil that will result from Sediment Placement at this site, the proximity of these two invasive species could present opportunities for both *Carex* and *Ampelopsis* to become established over the next few years. GPS coordinates were collected for both species, with locations mapped as a part of this report (Map 11). As is common throughout coastal habitats, particularly in areas of past disturbance and areas of freshwater inflow, the non-native genotype of common reed (*Phragmites australis*) is present throughout the margins of salt marsh on Quonochontaug Pond. The species presence along the perimeters of the East and West Impact Sites suggests opportunity for the species to colonize the Sediment Placement area, either through vegetative expansion of the existing population, or through seed germination. Although not commonly observed, *Phragmites* seedlings have been observed on exposed sand on Quicksand Pond in Little Compton, RI (Leeson 2007). A fourth species, with the potential to be present at higher elevations in early stages of Sediment Placement colonization, is the non-native Montauk daisy (*Nipponthamum nipponicum*). Although RINHS did not recognize Montauk daisy as an invasive species in 2013 (RINHS 2013), the fall blooming chrysanthemum was found growing on two of the small rock islands located to the north of the Quonochontaug Sediment Placement Site. The species appears to have some salinity tolerance and was present in a single location at the Ninigret Sediment Placement Site in 2018.



Figure 26. Quonochontaug Sediment Placement Impact Site (east side of breachway)

The proposed Sediment Placement Impact areas are predominantly vegetated by *Spartina alterniflora* varying in height from 15 to 120cm. Common glasswort (*Salicornia depressa*) was frequently recorded as present in the lower elevations of the marsh, growing on bare soil in the understory of *S. alterniflora*. Areas of higher elevation had a greater diversity of species, with patches and margins of tidal creeks vegetated by stands of spike-rush (*Distichlis spicata*), mixed with perennial salt marsh aster (*Symphyotrichum tenuifolium*), black rush (*Juncus gerardii*), and *Salicornia depressa*. Exposed sediment along the fringes of *Distichlis* patches were vegetated by two less commonly encountered perennial salt marsh species: seaside plantain (*Plantago maritima*) and sea lavender (*Limonium caroliniense*). In anticipation of Sediment Placement, GPS points were taken to mark the location of higher elevation communities to see if they would emerge through the sand layer deposited over their root systems. *Spartina patens* occupies the highest topographic areas where *Distichlis* is found growing, and along marsh edges growing with *Juncus* and *Iva frutescens*. The transition zones, between high marsh and salt scrub habitat

are marked by an accumulation of wrack, which provides opportunities for seed germination, particularly of the annual species whose seed is circulated throughout the system on tidal flow and storm surges. Three species of goosefoot were noted in this zone, *Atriplex acadiensis*, *A. glabriuscula* (SC) (as discussed above), and *A. prostrata*, along with the non-native sea-blight, *Suaeda maritima*.

The berm located along the western side of the present-day breachway, is a mosaic of open, old field habitat, interspersed with patches of maritime shrub and early successional maritime woodland species such as seaside goldenrod (*Solidago sempervirens*), switchgrass (*Panicum virgatum*), velvety rosette panicgrass (*Dicanthelium scoparium*) (SC), black raspberry (*Rubus alleghaniensis*), northern bayberry (*Morella caroliniense*), winged sumac (*Rhus copallinum*), quaking aspen (*Populus tremuloides*), and black cherry (*Prunus serotina*). The western portion of the Sediment Placement Site includes a sandy beach along its north side, which supports a diversity of annual and perennial species more common to beach strands and herbaceous dunes, like sea rocket (*Cakile edentula*), hastate-leaved orache (*Atriplex prostrata*), lambsquarters (*Chenopodium album*), and seaside goldenrod (*Solidago sempervirens*). The marsh fringe bordering the far western side of the area (along what appears to be an historic breachway) is vegetated by a number of pioneer species, both native (evening primrose, *Oenothera biennis* and seaside sandmat, *Euphorbia polygonifolia*) and non-native (curly dock, *Rumex crispus*) that are infrequently encountered along salt marsh margins. It is also in this area where the perennial glasswort (*Salicornia ambigua*) population is located (Map 11a).

State Listed Rare Species	Common Name
<i>Atriplex glabriuscula</i> SC	bracted orache
<i>Cyperus odoratus</i> SC	fragrant flatsedge
<i>Dicanthelium scoparium</i> SC	velvety rosette panicgrass
<i>Ligusticum scoticum</i> SC	Scotch lovage
<i>Scrophularia lanceolata</i> SC	lance-leaved figwort
Infrequently Encountered Species	Common Name
<i>Plantago maritima</i>	seaside plantain
<i>Salicornia ambigua</i>	perennial glasswort
<i>Triglochin maritima</i>	salt marsh arrow-grass
Non-native Invasive Species	Common Name
<i>Ampelopsis glandulosa</i>	porcelain berry
<i>Carex kobomugi</i>	Asiatic sand sedge
<i>Phragmites australis</i>	common reed
<i>Polygonum cuspidatum</i>	Japanese knotweed

Table 5. Quonochontaug Pond, plant species of interest

As was realized at the Ninigret Sediment Placement Site, both rare and commonly occurring marsh and dune pioneer species present in and around the impact site, such as *Atriplex glabriuscula* (SC), *Suaeda maritima*, and *Solidago sempervirens* have the potential, by virtue of

their ecology and seed dispersal mechanisms, to populate exposed sands within Sediment Placement Impact areas during future growing seasons. The same can be true for salt tolerant, perennial species including those non-native species that are considered invasive.

Quonochontaug Pond, Maritime Shrub Dune, Salt marsh, and Maritime Woodlands

In addition to the vegetation survey conducted within the Quonochontaug Sediment Placement Impact Site, surveys were conducted elsewhere within habitat surrounding Quonochontaug Pond. These surveys concentrated on salt marsh and maritime shrub dune habitats of the barrier beach, particularly along the ecotone between the high marsh and salt scrub habitat. Surveys also included maritime woodland and open rocky habitat found on glacial moraine islands located on the marsh and within the open water areas of the pond. Survey areas were selected based on proximity to the anticipated Impact Site, locations with a known presence of rare species, and on the potential for the habitat to support rare species. Surveys were limited to locations where permission was granted to access properties. In addition to locating rare species populations, survey goals included observations that could inform the Sediment Placement monitoring process including identification of possible sources of pioneer species. Additional surveys, using the Floristic Quality Assessment methodology, were made of forested swamp located on the Charlestown Land Trust's Hathaway Preserve.

During this survey, ten state listed rare species populations were documented. Of these, two were previously documented with recent observations in the RI Natural Heritage Database and eight other species located in habitat adjacent to the pond, were new records for the Database. Map 11 (Appendix III) depicts GPS coordinate locations for species of interest documented on Quonochontaug Pond.

Back-dune habitat within western regions of the barrier beach was previously known to support two state-listed rare species, the state endangered Nantucket shad (*Amelanchier nantucketensis*) and state concern field wormwood (*Artemisia campestris*). Populations of both species were located and documented (Map 11). Nantucket shad grows within maritime shrub habitat on both the south and north sides of the sand trail, along with bayberry (*Morella caroliniense*), non-native Japanese black pine (*Pinus thunbergii*) and wrinkled rose (*Rosa rugosa*). Field wormwood is tolerant of the hot and dry conditions of open, exposed sand. It grows north of the sand trail within open gaps in the shrub community, along with species like wooly beach-heather (*Hudsonia tomentosa*), Gray's flatsedge (*Cyperus grayii*), and silvery-flowered sedge (*Carex argyrantha*). Additional species found in the back dune of the barrier beach, which are infrequently encountered in RI are beach plum (*Prunus maritima*) and star-like false Solomon's seal (*Maianthemum stellatum*).

Wide swaths of the beach were washed over during Hurricane Sandy in 2012, particularly in areas in the middle and eastern portions of the barrier beach. It is in these areas that the invasive Asiatic sand sedge (*Carex kobomugi*) was encountered (Figure 28; Map 11). Deep sand in these areas remains largely un-vegetated, with a high percentage of dead Japanese pine. Aeolian

movement, as well as drying, may be helping to prevent establishment of colonizing species. Sand that was washed across the dune was deposited in the northern reaches of the barrier beach (west of Noyes Island), into coastal shrub habitat populated by freshwater wetland species, like sweet pepperbush (*Clethra alnifolia*) and winterberry, and the state listed hairy-stemmed gooseberry (*Ribes hirtellum*) (SC). Owing to groundwater seepage into the marsh, this habitat presents an abrupt ecotone along the high marsh regions of the salt marsh. Growing just above the high marsh wrack line are several patches of the state listed Scotch lovage (*Ligusticum scoticum*) (SC), where the species straddles the border between a shrub swamp and high marsh habitat.



Figure 27. *Carex kobomugi*, Weekapaug Beach, 2018

As with the glacial moraine island in Ninigret Pond, the larger islands on Quonochontaug Pond support maritime woodland habitat (Maps 11 and 11a), and include lance-leaved figwort (*Scrophularia lanceolata*) (SC) in the understory (three island locations), as well as occasionally encountered species like trout lily (*Erythronium americanum*), turk's cap lily (*Lilium superbum*), American basswood (*Tilia Americana*), and the non-native broad-leaved helleborine (*Epipactis helleborine*). Habitat on the smallest islands was vegetated with a mix of annual and perennial forbs, while interior portion of the larger islands was vegetated by tall shrubs and trees. Species encountered frequently included bayberry, winged



Figure 28. Maritime woodland on glacial moraine island (Noyes Is.) in Quonochontaug salt marsh

sumac (*Rhus copallinum*), sassafras (*Sassafras albidum*), and shad (*Amelanchier canadensis*). Less frequently encountered species include swamp milkweed (*Asclepias incarnata*), sleepy catch-fly (*Silene antirrhina*), and annual wooly bean (*Strophostyles helvola*). The non-native Montauk daisy (*Nipponanthemum nipponicum*), was encountered twice on open rock islands, located north of the Quonochontaug Sediment Placement site. This species, while not listed on RINHS lists of known invasive species, has been spreading throughout coastal dunes on the south coast of the state (*personal observation*).

Several locations of freshwater in-flow are present along the pond. Brackish marsh associated with those in-flow locations at the western and northwestern end of the pond are vegetated by dense stands of *Phragmites australis*. Permission to access these wetlands was not granted, and so the areas were not surveyed for rare species. The freshwater area flowing into the northeastern cove of the pond was previously known to support populations of the rose-gentian (*Sabatia stellaris*) (ST) and beaked spike sedge (*Eleocharis rostellata*) (SC). However, a combination of anthropogenic impacts such as shoreline clearing and dock construction as well as colonization of the location by *Phragmites australis* have significantly altered conditions in these locales. Neither the *Sabatia* nor the *Eleocharis* had been observed since the mid-1900's and a survey for the populations in 2018 again failed to locate them.

The forested swamp located northwest of the intersection of Old West Beach Road and West Beach Rd. on the Hathaway Preserve was the site of the Floristic Quality Assessment survey. A total of five rare species were present within freshwater areas of the Hathaway Preserve (Map 11a). These included collared dodder (*Cuscuta indecora*) (SE), fragrant flatsedge (*Cyperus odoratus*) (SC), Wright's panicgrass (*Dicanthelium wrightianum*) (SC), and hairy stem gooseberry (*Ribes hirtellum*) (SC). Although the fragrant flatsedge is presently listed as State Concern, it has been recommended that the species status be changed to State Endangered, as it appears this may be the only population of the species in Rhode Island (Enser, *personal communication*). As was discussed in the previous section, a population of *Ligusticum scoticum* (SC) was also documented growing along the marsh edge, east of the Quonochontaug Sediment Placement area. Additional species encountered at the site, while not considered rare, are infrequently encountered in Rhode Island wetlands. These include marsh mermaidweed (*Proserpinaca palustris*) and lowland yellow loosestrife (*Lysimachia hybrida*).

The transition zone between the Hathaway Preserve wetland and high marsh on Quonochontaug Pond is one where the effects of sea level rise, can be clearly seen. Wetland shrubs and trees, typical of freshwater conditions, such as highbush blueberry (*Vaccinium corymbosum*) and red maple (*Acer rubrum*), are located along the margin of the marsh. At this topographic position, woody vegetation is dying or showing signs of stress, likely as a result of increased salinity at the root zone. Salt marsh shrubs, *Iva frutescens* and *Baccharis halimifolia* have migrated into the understory, representing the first stages of the transition from shrub swamp to salt scrub habitat. The area currently supports a small population (four plants) of *Ligusticum scoticum* in the herbaceous understory, surrounded by brackish herbaceous species such as *Schoenoplectus pungens*.

Along the north side of the pond, on private property located northeast of Quahog Point, a large population of the state listed Indian grass (*Sorghastrum nutans*) (SC) has been maintained by a private landowner with an interest in native plant communities, since 1960. The property is mowed biennially to keep woody plants from becoming dominant, and invasive species are pulled by hand. Otherwise the site is allowed to grow in an unmanaged state. The property also supports a population of the infrequently encountered pale blue iris (*Iris prismatica*) within the freshwater wetland that fringes the brackish marsh at the pond edge. For a complete list of the species observed on Quonochontaug Pond, see Appendix I.

Winnapaug Pond Proposed Sediment Placement Impact Sites

On the south shore of Winnapaug Pond, two potential sites under consideration for future Sediment Placement have been identified (Map 5, Appendix II). The sites, known as the Ray and Lathrop properties, are located on land protected under the auspices of the Weekapaug Foundation for Conservation. The sites were surveyed during the late summer of 2018 to determine if any state listed rare species or other noteworthy botanical resources would be impacted by the deposition of dredge material on top of saltmarsh, as well as to assess adjacent areas that could contribute to the natural process of site colonization by pioneer species. As with the Quonochontaug Pond survey, the investigation was conducted as a part of a larger survey of selected habitats on and adjacent to Winnapaug Pond, to assess plant community and rare species status.

The Rhode Island Natural Heritage Program Database operated by RINHS documents past observations of four rare plant species on the combination of the Lathrop and Ray properties. For two of the species, sea milkwort (*Lysimachia maritima*) from the Lathrop property and pine barren sand-plant (*Minuartia caroliniana*) from the Ray property, the observations are historic and the species have a status of SH, being considered to have been extirpated from Rhode Island. A third listed species previously found on the Lathrop property, and having a status of State Concern, is the spring ladies'-tresses (*Spiranthes vernalis*). Prior to 1978, it had been documented adjacent to upper portions of the marsh, along the southern side of the Lathrop property. The population has not been observed in prior surveys and was not found in 2018 either. The increasing salinity of groundwater adjacent to the high marsh habitat would not be tolerated by this orchid which is usually found growing in freshwater conditions. A population of a few plants of *Atriplex glabriuscula* (SC) was encountered at the southwest end of the Ray Property. The annual life cycle of this species gives it the potential to appear in unpredictable locations from year to year, depending on seed transport on tidal currents and in wrack in the fall of the year.

Several non-listed but nonetheless noteworthy plant species were also found on the Ray and Lathrop properties (Map 12; Appendix III). Two species, dwarf glasswort (*Salicornia bigelovii*) and seaside gerardia (*Agalinus maritima*) were only observed on Winnapaug Pond (out of the three coastal salt ponds surveyed in 2018). Seaside gerardia, though apparently of limited distribution at these sites, is known from other saltmarshes around the state; however, the populations of dwarf glasswort on Winnapaug Pond were the only populations observed throughout the 2018 season and the distribution of the species elsewhere in the state is unknown. While three of the four locations where dwarf glasswort was observed were within the areas proposed for Sediment Placement, the species has an annual life cycle, similar to that of *Atriplex glabriuscula*, which makes it difficult to predict where it will grow from year to year. However, for this species, scientific literature (Davy et al. 2011) suggests that the species has a high tolerance for salinity, and that it is only found in high marsh locations growing on exposed substrate. In the event that Sediment Placement is carried out in these locations on Winnapaug Pond, dwarf glasswort may be a colonizing pioneer species of highly saline locations. In addition to collecting GPS coordinates for the above species, data was also collected for populations of *Salicornia ambigua*, on the Ray property, and *Triglochin maritima* on both the Ray and Lathrop properties. While neither of these latter two species are considered rare, their infrequent distribution is of botanical interest and suggests a greater affinity for certain physical parameters.

Low elevations of the marsh on the Lathrop property show signs of deterioration, with tidal water pooled on the surface. The overall topography is fairly uniform, with areas of higher elevation located in association with tidal creeks and ditches. It is possible that at one time, these elevation variances could have provided habitat for the State Historic sea milkwort, which is historic known elsewhere to occupy regions of the marsh similar to that of dwarf glasswort (Davy et al. 2011).

State Listed Rare Species	Common Name
<i>Atriplex glabriuscula</i> SC	bracted orache
<i>Lysimachia maritima</i> SH	sea milkwort
<i>Minuartia caroliniana</i> SH	pine barren sand-plant
<i>Sabatia stellaris</i> ST	annual rose-gentian
<i>Spiranthes vernalis</i> SC	spring ladies'-tresses
Infrequently Encountered Species	Common Name
<i>Agalinus maritima</i>	seaside gerardia
<i>Plantago maritima</i>	seaside plantain
<i>Salicornia ambigua</i>	perennial glasswort
<i>Salicornia bigelovii</i>	dwarf glasswort
<i>Triglochin maritima</i>	salt marsh arrow-grass
Non-native Invasive Species	Common Name
<i>Centaurea nigrescens</i>	short-fringed knapweed
<i>Phragmites australis</i>	common reed

Table 6. Winnapaug Pond, Species of Interest

While the lowest elevations of the Ray Preserve also show evidence of impacts of sea level rise, the site is topographically varied, apparently owing to over wash during major hurricane events. The sandy nature of the soil, both in the highest upland elevations and in high marsh and salt scrub areas of the northern portions of the marsh, presents unique botanical opportunities for species colonization. These conditions once supported the state listed pine barren sand-plant. Unvegetated sandy soil within high marsh habitat, presently supports seaside plantain, both the perennial and dwarf glassworts, and saltmarsh gerardia.

Maritime herbaceous dune habitat is an uncommon feature along the barrier beach and shoreline of Winnapaug Pond. Remnant patches, such as is present on the Ray Property, are increasingly rare and diminishing in size (Kneiper, *personal communication*). These habitats present a unique set of conditions which promote the growth of soil lichens and pioneer species of vascular plants that are early colonizers of open, unvegetated sand. A relative lack of human-generated disturbance at the Ray Property site, has allowed for the proliferation of three species of soil lichen, *Cladonia grayi* (Gray's cupped lichen) and *Cladonia subtenuis* (reindeer lichen), as well as *Placyinthiella uliginosa* (tar spot lichen) (Kneiper, *personal communication*). Due to the fragility of lichen that cover the sand surface, communities such as this are easily threatened by the damages of foot traffic. The open nature of such areas, is appealing to humans as it provides an easy avenue through which to access the salt marsh. In fact, a pathway has already been established through the herbaceous dune as an access to salt marsh being considered for Sediment Placement. Loss of such sites contributes to community-wide declines in both species diversity and abundance. Maintaining a reservoir of diversity ensures that when dunes



Figure 29. Delicate soil lichens encrusted on sand surface, Ray Property, Winnapaug Pond

within the surrounding area are damaged by storms, lichen spore and vascular plant seed is present in the ecosystem and can recolonize the damaged sites. Soil lichens maintain the surface integrity of fragile soils by blanketing them and anchoring the sand, protecting the soils against both water and wind erosion. Lichens are also a component in the marsh ecosystem, and play a role in the ecosystem food web. In soils, lichens form microhabitats that modify soil surface temperatures and humidity, allowing microorganisms and a myriad of insects and spiders to thrive in these habitats (Kneiper, *personal communication*). Any measure that can promote the maintenance of dune locations where lichen species are present should be seriously considered.

In addition to the flat topography of the maritime dune, the Ray Property includes areas of elevated topography, possibly formed by historic hurricane events. The soil within the higher elevation hummocks is comprised primarily of sand. Vegetation at present is characteristic of maritime shrubland with a canopy of *Amelanchier*. The northern-most of these hummocks, which juts out into the marsh, contains a coyote (*Canis latrans*) den dug into the sandy soil. Upland mounds located within wetlands, such as is present on the Ray Property, represent important denning and resting sites for coyotes. Two other den sites were noted on Winnapaug pond, one each to the east and west of the Ray den. While dens are only used during pupping season (mid-April to mid-June or July), they are located within core areas of coyote ranges, and represent occupation of the surrounding area by a resident pack (Mitchell, *personal conversation*). According to Mitchell, maintaining the health of a resident pack is the best defense against intrusion by problem coyotes, and avoiding impacts to the area of the property will minimize disturbance of the den site. Coyotes play an important role in salt marsh ecology, maintaining balances within a biota that has evolved to expect a large canid predator, with primary prey including meadow voles and Canada geese (Mitchell, *personal conversation*).

As with Quonochontaug Pond, the margins of the Winnapaug salt marsh are heavily vegetated by the non-native genotype of common reed (*Phragmites australis*). This condition was observed particularly in areas of past disturbance from storm surge over wash and areas where freshwater inflow is either naturally occurring or generated by storm water discharge. As with the Quonochontaug Sediment Placement site, the species presence along the perimeters of both the Ray and Lathrop properties presents opportunities for *Phragmites* to colonize unvegetated Sediment Placement sites through vegetative expansion or seed germination. A second invasive species to be aware of as a potential colonizer of Sediment Placement Sites on Winnapaug Pond, is the invasive perennial, short-fringed knapweed (*Centaurea nigrescens*). A population of this species was encountered in sand dune habitat located along the north side of Atlantic Avenue, across from the Misquamicut State Beach parking lot (Map 12a). *Centaurea* is an aggressive colonizer of sandy habitats, where it often displaces both rare and common, native pioneer species growing on sandy soil. While this location is relatively distant from either the Lathrop or Ray properties, seeds of *Centaurea* are wind dispersed. In the event of Sediment Placement being carried out on either property, *Phragmites* and *Centaurea* should be looked out for and managed as a part of the monitoring process.

Winnapaug Pond, Maritime Shrub Dune, Shrubland and Woodland, and Sea Level Fen

Winnapaug Pond is unique, as compared with Ninigret and Quonochontaug Ponds, as it largely exists separated from the dune strand and maritime dune habitats by residential and commercial development. In addition, maritime shrubland and woodland areas, which appear to be the result of sand over wash from historic hurricane events, jut out into the marsh as upland peninsulas, or

hummocks. In addition to the salt marsh surveys, these upland hummocks were surveyed for the presence of rare species, as was an upland area created out of breachway dredge material located along the western side of the Weekapug Breachway. On the north shore of Winnapaug Pond, marsh surveys were limited to habitat within the Audubon Society of Rhode Island's Lathrop Preserve. It should be noted here that there are two distinct Winnapaug Pond properties, which carry the name of Lathrop (The Lathrop Property was discussed in the previous section). The Lathrop Preserve (Audubon Society of Rhode Island) is known for its rare community type, known as a sea level fen (Enser et al. 2011). Additionally, freshwater wetland habitat associated with this property was surveyed utilizing the FQA method (see FQA below).

The RI Natural Heritage Database includes records for rare plant species populations on Winnapaug Pond. Four of these species were discussed above, as their population locations coincided with the potential Sediment Placement sites on the Lathrop and Ray Properties (south side of Winnapaug Pond). In addition to these, populations of *Artemisia campestris*, *Sabatia stellaris*, and *Liatris novae-angliae* have in the past also been documented along the southern side of Winnapaug Pond. Additionally a population for mock bishop's-weed *Ptilimnium capillaceum* was known from the north side of the pond.

Locations for *Artemisia*, *Liatris*, and *Sabatia stellaris* were extant in 1978. However by 2002, only one species, rose gentian (*Sabatia stellaris*) was extant. Approximately 300 plants were observed growing along the southern edge of the marsh, to the west of property owned by the Town of Westerly. The *Sabatia* population was not located during the 2018 survey. Searches by others, also for recently monitored populations of *Sabatia stellaris* elsewhere in RI, failed to relocate populations, and this species may have been extirpated from the state (Enser, *personal communication*). A concerted effort should be undertaken to look for surviving populations.

The 2018 survey on Winnapaug Pond located an additional population for the state endangered Nantucket shad (*Amelanchier nantucketensis*), which had previously only been known from Quonochontaug Pond. Mock bishop's weed (*Ptilimnium capillaceum*) (SC) was observed on the Lathrop Preserve (Map 12a). The species is tolerant of brackish conditions, and was found growing in the understory of common reed in the area of transition from freshwater to brackish conditions. A third species, Indian grass (*Sorghastrum nutans*) (SC) was also located by survey; however it appears likely (Ferguson, *personal communication*) that this species was planted as a component of a conservation seed mix to stabilize soil after construction activities. This population of *Sorghastrum* is located on a berm which was constructed over a storm drainage system, that was installed to the north of the Misquamicut State Beach parking lot (Map 12a). The storm drain conveys freshwater runoff from the parking lot into Winnapaug Pond. The SC species, (*Sorghastrum nutans*), is commonly used in conservation seed mixes for areas with sandy or droughty soil, with seed predominantly sourced from mid-western ecotypes.

Both the historic and extant rare species documented on Winnapaug Pond, are associated with either sandy upland habitats (*Artemisia* and *Liatris*), or with brackish marshes that have sandy substrates (*Sabatia* and *Lysimachia*). In addition to these rare species, areas of sandy marsh substrate support uncommonly encountered species of botanical interest such as salt marsh sand spurry (*Spergularia maritima*), perennial salt marsh aster (*Symphotrichum tenuifolium*), dwarf glasswort (*Salicornia bigelovii*), and perennial glasswort (*Salicornia ambigua*). Perennial glasswort was encountered more often on Winnapaug than on Quonochontaug, and in several

locations, the species was found growing along the edges of sandy hummocks located within the marsh in association with *Iva frutescens*.

The higher sandy hummocks within the marsh support species typical of maritime herbaceous dune and maritime shrubland habitat, like shad (*Amelanchier canadensis*), northern bayberry (*Morella caoliniensis*), black cherry (*Prunus serotina*), highbush blueberry (*Vaccinium corymbosum*), black chokeberry (*Aronia melanocarpa*), western poison ivy (*Toxicodendron rydbergii*), and northern arrowwood (*Viburnum dentatum*). Western poison ivy is a common component of maritime dune systems, where the species tends to grow in a shrub-like habit, rather



Figure 30. Shad in bloom on a sandy upland knoll, Winnepaug Pond

than the vine habit of poison ivy (*Toxicodendron radicans*). Where the hydrology of these hummocks is mesic, the non-native invasive shrub, glossy buckthorn (*Frangula alnus*) is found. This species is becoming increasingly common along the south coast of Rhode Island, and was found throughout areas on Winnepaug Pond where the combination of canopy cover and hydrology provided suitable habitat. Among sand hummocks at the eastern end of the pond, Nantucket shad (*Amelanchier nantucketensis*) (SE) was found, along with drought tolerant species that are more typical of inland sandy habitats: wild indigo (*Baptisia tinctoria*), Canada frostweed (*Crocianthemum canadensis*), and grove sandwort (*Moehringia lateriflora*).

Along the south coast of Winnepaug Pond, are two locations of maritime herbaceous dune habitat, possibly the only remaining examples of this habitat on the pond. One is located on the Ray Property, and was discussed previously (see discussion on Sediment Placement locations). The second is located at the western end of the pond, to the north of the Misquamicut State Beach parking lot, and represents an historic population location for field wormwood (*Artemisia campestris*). Plant species found at the site include a rarely encountered species in RI natural systems, creeping juniper (*Juniperus horizontalis*), as well as maritime herbaceous dune colonizers, sand joint-weed (*Polygonum articulatum*), beach pinweed (*Lechea maritima*), wooly beach-heather (*Hudsonia tomentosa*), Gray's flatsedge (*Cyperus grayii*), silvery-flowered sedge (*Carex argyrantha*), and reindeer lichen (*Cladonia subtenuis*).

As with the Ray Property, this site presents conditions that are unique along salt marsh margins, and in addition provides potential nesting habitat for diamondback terrapin (*Malaclemys terrapin*). Although, not confirmed as nesting sites, the western end of Winnepaug Pond corresponds with the greatest proportion of, on the water terrapin sightings (RI Natural Heritage Database 2018). Meyerson (*personal communication*) has created a database for locations of diamondback terrapin nesting sites along the northeastern shoreline of the United States. Data collected from New Jersey, north to Massachusetts, show that nests are predominantly located in the coarse sand and sand of open maritime dune habitats, such as those found north of Misquamicut State Beach and on the Ray property. For the full report on the 2018 diamondback terrapin survey and the species' nesting site Habitat Suitability Index, see Appendix IV.

The northern shoreline of Winnapaug Pond lies immediately south of the Charlestown glacial moraine. Groundwater seepage flows from the moraine, feeding a sea level fen, as well as brackish marsh and fresh water wetland habitat types located within the RI Audubon Society's Lathrop Preserve. Freshwater flow onto the marsh has created a wide area of brackish marsh along the margin of the pond. This area provides habitat for a unique assemblage of plant species. Of note were several shrub species that while common or locally common within the coastal plain, are usually absent from salt marsh shrub habitats. These species were black huckleberry (*Gaylussacia baccata*), inkberry (*Ilex glabra*), and poison sumac (*Toxicodendron vernix*). And although common reed (*Phragmites australis*) dominates the majority of the brackish zone, openings where the reed is more sparse a remnant understory of native brackish species exists. A species of State Concern, Atlantic mock Bishop weed (*Ptilimnium capillaceum*) is one such species, along with one-glumed spike sedge (*Eleocharis uniglumis*), sweetgrass (*Anthoxanthum nitens*), button sedge (*Carex bullata*), and camphor-weed (*Pluchea odorata*). Although not listed as rare in RI, an uncommon brackish marsh forb, Pacific silverweed (*Argentina egedii*) was documented growing among *Spartina patens*, in sandy marsh substrate within 1m of the pond edge (Map 12a). The location on the marsh is unusual, as the species has a low tolerance for salinity (Davy et al. 2011). The location of the *Argentina* population is a strong indication that freshwater outflow, associated with the fen hydrology, is responsible. *Argentina*, while listed as fairly common in Massachusetts, is known from one county in Connecticut (Haines 2011) and there are no documented accounts of the species in Rhode Island, other than the one documented on Winnapaug Pond in 2018.

Within the Lathrop Preserve, the strong freshwater influx flowing from groundwater sources in the glacial moraine, has historically been the dominant determinant of the sea level fen and brackish marsh plant communities, for which the site is known. Potentially as a result of sea level rise, these habitats can clearly be seen in transition. The freshwater wetland systems, of the sea level fen, shrub swamp and red maple swamp, are being transformed into communities vegetated by plants tolerant of brackish conditions. Herbaceous wetland species associated with freshwater, like boneset (*Eupatorium perfoliatum*) and long sedge (*Carex folliculata*), are interspersed among the brackish herbaceous species, such as salt marsh rush (*Juncus gerardii*), and camphor weed (*Pluchea odorata*). The common freshwater wetland shrub, highbush blueberry (*Vaccinium corymbosum*) and upland red cedar (*Juniperus virginiana*) are in decline and dying, with salt marsh shrubs (*Baccharis halimifolia* and *Iva frutescens*) growing around them. Freshwater wetland habitat that extends north, out of the brackish marsh, was surveyed utilizing the FQA survey method and is described below. For a complete list of the species observed on Winnapaug Pond, see Appendix I.



Figure 31. Remains of red cedar with hightide bush in understory, Lathrop Preserve, Winnapaug Pond.

C. Floristic Quality Analysis of Two Vulnerable Coastal Freshwater Wetlands

Introduction

Freshwater wetlands adjacent to the coast are vulnerable to stresses brought on by climate change. By virtue of their horizontal proximity to coastal habitats, and vertical elevation relative to sea-level, the potential exists for over wash and flooding during storm events. As a result, the potential exists for changes in species composition due to waterlogging and increased salinity in the root zone, introduced as a result of rising seas (Osland et al. 2016). Evidence of species shifts has been observed within brackish/freshwater ecotones (*personal observation*; Kutcher 2017) at elevations of 0.60m above sea level along the coast. Common shrub species in decline at this elevation, are highbush blueberry, red cedar (*Juniperus virginiana*), and winterberry (*Ilex verticillata*). Halophytic species, including common reed (*Phragmites australis*), that are commonly seen as colonizers among dead shrub species, are common three-square (*Schoenoplectus pungens*), hightide bush (*Iva frutescens*), and groundsel tree (*Baccharis halimifolia*).

To quantify the present condition of botanical communities within freshwater wetlands along Quonochontaug and Winnapaug Ponds, and to document any degradation that might be occurring, due to sea level rise or other causes, a biological assessment was undertaken using a method called the Floristic Quality Assessment (FQA). The FQA method was originally developed as a tool to evaluate a site's conservation value, based on the presence of a known set of plant species (Swink and Wilhelm 1979). Increasingly FQA has been applied, integrating targeted vegetation surveys, to freshwater wetlands to assess condition and restoration success (Deberry et al. 2015; Bried et al. 2013). Evaluation of vegetation within the site relies on a ranking system based on the level of tolerance individual plant species have to human disturbance, called Coefficients of Conservatism (CC's). CC's are usually assigned by a team of botanists, familiar with the flora of a region, as described by Swink and Wilhelm (1979) and Wilhelm and Masters (1995). The FQA method has been evaluated and tested in Rhode Island, against other biological assessment methods, for its value in determining freshwater condition (Kutcher and Forrester 2017; Peach-Lang *unpublished data*), and on vulnerable coastal wetlands (Kutcher 2018). Analysis of data collected for this report is compared to FQA analyses conducted on similar coastal freshwater wetlands by RINHS in 2017 (Kutcher 2018). The FQA provides a benchmark for the status of coastal wetlands, and documents the shift in species composition taking place on Winnapaug and Quonochontaug Ponds.

The freshwater wetlands selected for interpretation through FQA, are located on Winnapaug and Quonochontaug Ponds, on preserved land, with most recent land use histories of grazing by livestock (Maps 11a and 12a; Appendix III). Each is hydrologically connected to its respective coastal salt ponds and marshes. The wetland systems are characterized as Palustrine Forested wetlands, with areas of red maple swamp, shrub swamp, and seasonally flooded emergent marsh (RIECC 2011). On the horizontal plane, the two wetlands are located within 300m of the coastal salt ponds, and are vertically situated less than 3.0m above the North American Vertical Datum (NAVD88). Their topographic positions suggest vulnerability to potential impacts of sea level rise, as well as salt-water influx and over wash resulting from storm surge in major hurricane events. The wetland located on Quonochontaug Pond is located between the barrier beach and coastal salt pond, immediately east of the Quonochontaug Sediment Placement Impact Site. The

Winnapaug wetland, lies on the north side of the coastal salt pond, at the base of the Charlestown Moraine and includes a sea level fen, identified as a rare habitat type by the RI Natural Heritage Program.



Figure 32. Outline of two FQA vulnerable coastal wetlands. Hathaway (left), and Lathrop (right) Preserves.

Methods

The FQA methodology followed for this report was based on the protocol used by Kutcher (2018) for evaluation of vulnerable coastal wetlands and Kutcher and Forester (2017) to evaluate the efficacy of the method on non-coastal freshwater wetlands, and derived from original work by Swink and Wilhelm (1979). The methodology is based on floristic surveys, which are then quantified through the assignment of quality scores derived from the combination of each species' perceived aerial cover and its assigned Coefficient of Conservatism. CC's for species found within Rhode Island's flora were assigned by Richard Enser (*unpublished data*). Ranking and assignment of CC's was based primarily on species' sensitivity to disturbance and secondarily, to the degree of affinity to certain environmental conditions (Enser, *personal communication*). CC values range from 0 to 10, with all non-native species assigned a value of zero. Plants intolerant of human disturbance factors, or unique to specific habitat types, are assigned CC's with higher value (five to ten), with generalist species, or those with a greater tolerance of disturbances, receiving a value below five (Kutcher and Forrester 2017).

FQA surveys were conducted in the freshwater wetlands on Winnapaug and Quonochontaug Ponds in August of 2018. Both wetlands surveyed for this report contained extensive and dense shrub swamp habitat entwined with greenbrier (*Smilax rotundifolia*) and poison ivy (*Toxicodendron radicans*). Travel within the wetlands was extremely slow, so the decision was made to modify the field methods from those described by Kutcher and Forrester (2017), to those used by Kutcher on vulnerable coastal wetlands (Kutcher 2018). Three transects were designated across the short dimensions of each wetland and mapped on aerial photographs of the sites. All vascular plant species observed within a 4m wide swath along the length of the transect (belt transect) were recorded. The goal was to create as complete a picture as possible of the wetland's flora, and to estimate the coverage of each species. Species observed along each transect were identified to species in the field, or were collected for later identification if that was not possible. Plants that could not be identified to the species level were not included in the assessment. At the completion of each transect, aerial coverage was estimated for each species encountered using cover class ranges of either scarce (<10%), common (10-60%), or dominant (>60%). After all three transects were surveyed, an average cover class was estimated for each

species, based on the values assigned for each transect and its' coverage in the wetland as a whole.

As described by Kutcher (2018), the vegetation data collected from each wetland was then applied to three floristic metrics, including Mean CC (MCC), Weighted Mean CC (WMCC), and percent native (%N).

$$MCC = \frac{\sum CC}{S} \quad WMCC = \frac{\sum (CC \times P)}{\sum P} \quad \text{and} \quad \%N = \frac{N}{S}$$

Where CC = coefficient of conservatism for all vascular plant species identified during the survey; N = number of native plant species recorded; S = total number of plant species recorded (including non-native); and P = the midpoint value of the overall cover class range assigned to each plant species during the survey, i.e. scarce = 0.05, common = 0.35, and dominant = 0.80.

Results

The Winnapaug Pond site, known as the Lathrop Preserve, measures roughly 11 acres in size, with a vertical elevation ranging from 0.60m to 1.21m above sea level. The wetland transitions into salt marsh all along its southern edge, with the transition to a halophyte-dominated system occurring in locations as close as 30m from the shore of the coastal salt pond. Several ditches carry fresh water from the wetland interior, across the salt marsh, and into the coastal salt pond. Additionally, fresh water sheet flow, from forested portions of the site, passes through brackish marsh, and eventually filters into Winnapaug Pond.

The Quonochontaug site, known as the Hathaway Preserve, is 9 acres in size, with an elevation range of 0.60m to 1.5m above sea level. The majority of the wetland is located 91m from the pond margin, and is contained, more or less, within an isolated basin. Historically, berms were created along the western margin of the wetland, perhaps to contain drinking water for livestock. A seasonal stream flows from the northwest portion of the wetland directly into Quonochontaug Pond. The transition to halophytic vegetation along this stream occurs about 25m from the coastal salt pond shoreline.

Cumulative data for the sites surveyed, resulted in observation of 131 species. Of these, 115 are native in origin, and 16 are non-native. A total of 14 halophytes were recorded as present growing among freshwater vegetation. The sites contained five state listed rare species, with four found on the Hathaway Preserve, and one at Lathrop. Both sites are dominated by thickets of tall shrub species, with red maple (*Acer rubrum*) present in the overstory. Across both sites, the dominant shrub species were winterberry (*Ilex verticillata*) and swamp azalea (*Rhododendron viscosum*). Greenbrier and poison ivy ranged from common to dominant, with cinnamon fern (*Osmundastrum cinnamomeum*) being the most common understory species. A total of nine invasive species were encountered across both wetlands, with the majority being scarce in coverage. Only common reed, found on both sites, and glossy buckthorn (*Frangula alnus*), found only on the Lathrop Preserve, were more widespread.

The median Coefficient of Conservatism of species observed within the wetlands was 3, with 56% of the species at the Hathaway Preserve and 53% of the Lathrop species receiving this value, indicating that more than half of the wetland species associated with these wetland

systems are common to wetlands across the state and have a relatively high tolerance for disturbance. In addition, a third of the species (35% at Lathrop and 32% at Hathaway) are considered less tolerant of disturbance and have affinities for more narrow habitat characteristics. Collectively these portions of each site's flora were assigned CC values of five or more. State listed rare species are included among the species receiving higher CC values, as are several species which, although not considered rare, have less frequent distributions across the state. Included in this group are also species tolerant of brackish conditions. For a complete list of species found within each of the vulnerable coastal wetland sites, refer to Appendix I. State listed rare species are discussed above in the discussions of habitat on Quonochontaug and Winnapaug Ponds. Tables 7 and 8 below, summarize the rare and uncommon species observed at each of the two FQA sites.

Charlestown Land Trust – Hathaway Preserve	
State Listed Rare Species	Common Name
<i>Cuscuta indecora</i> SE	collared dodder
<i>Cyperus odorata</i> SC	fragrant flatsedge
<i>Dicanthelium writianum</i> SC	Wright's panicgrass
<i>Ligusticum scoticum</i> SC	Scotch lovage
<i>Ribes hirtellum</i> SC	hairy-stem gooseberry
Infrequently Encountered Species	Common Name
<i>Proserpinaca palustris</i>	marsh mermaidweed
<i>Lysimachia hybrida</i>	yellow loosestrife

Table 7. Species of Interest, Hathaway Preserve, Quonochontaug Pond

A sea level fen, located on the Lathrop Preserve, is recognized by state and national entities, as a rare community type. Sea level fens are described as peatland communities that occupy habitat defined by freshwater seepage onto a salt marsh (NatureServe Explorer 2009). In Rhode Island this community type has been documented in less than six locations. Sea level fens are vulnerable to the impacts of sea level rise, due to their low elevation and association with marine systems. Within the United States, this community is restricted to the mid and north Atlantic coastal plain. Typical indicator species for the community are beaked spikesedge (*Eleocharis rostellata*) and twig rush (*Cladium mariscoides*). Past botanical surveys at the Lathrop Preserve had mistakenly identified the spikesedge present at the site as *E. rostellata*. A 2017 survey for the New England Wildflower Society, Northeast Plant Conservation Program, determined that the species had been misidentified, and was instead one-glumed spikesedge (*E. uniglumis*) (Mangels, *personal communication*), a species tolerant of brackish conditions (Haines 2011). Several species present on the site, while not typical of sea level fen communities, are species not usually encountered along coastal salt ponds. These include black huckleberry (*Gaylussacia baccata*), inkberry (*Ilex glabra*), maleberry (*Lyonia ligustrina*), poison sumac (*Toxicodendron vernix*), long sedge (*Carex folliculata*) and Turk's cap lily (*Lilium superbum*).

Audubon Society of Rhode Island – Lathrop Preserve	
State Listed Rare Species	Common Name
<i>Ptilimnium capillaceum</i> SC	Mock Bishop's weed
Infrequently Encountered Species	Common Name
<i>Argentina egedii</i>	Pacific silverweed
<i>Eleocharis uniglumis</i>	One-glumed spikesedge
<i>Ilex glabra</i>	inkberry
<i>Lilium superbum</i>	Turk's cap lily
<i>Lyonia ligustrina</i>	maleberry
<i>Toxicodendron vernix</i>	poison sumac

Table 8. Species of Interest, Lathrop Preserve, Winnapaug Pond

Total species richness (S) for the sites were Lathrop 84 and Hathaway 96, with native richness (N) respectively being 77 and 82, placing these wetlands at the higher end of the spectrum when compared with other vulnerable freshwater coastal wetlands surveyed as a part of the RINHS 2017 study (Kutcher 2018). These values reflect the diversity of habitat types, and consequent niche opportunities for a diversity of species located within each of the wetland sites evaluated for this report. In addition to red maple swamp, both sites included areas dominated by shrub swamp, interspersed with lower elevations characterized as emergent marsh. The percentage of native species at Hathaway falls in line with the mean value for all freshwater coastal wetlands surveyed in 2017 (85.4%); Lathrop is slightly higher at 91.6%. Richness for non-native species ranged from 14 species at Hathaway, to seven species at Lathrop, resulting in a mean of ten, which is slightly higher than the mean calculated for the set of coastal wetlands surveyed in 2017.

Recent forest clearing within habitat adjacent to the Lathrop Preserve wetland has resulted in colonization of the area by the invasive species, glossy buckthorn as well as other native species. Within both sites, dense stands of *Phragmites* were present. The mean of the WMCC and MCC values for the Hathaway and Lathrop Preserves are consistent with those calculated for the 2017 sites. WMCC values for Lathrop were 3.5 and 3.2 for Hathaway, resulting in a mean of 3.3 for the two sites. The MCC values for Lathrop were 3.7 and for Hathaway 3.4, with a total mean of 3.5. The mean WMCC value for the vulnerable coastal wetlands surveyed in 2017 sites was 3.4, and the mean of the MCC values was 3.3.

Unlike the 2017 surveys of freshwater coastal wetlands, the Quonochontaug and Winnapaug wetlands were not assessed using the Rhode Island Rapid Assessment Method (RIRAM) for the prevalence and impact of human disturbances in the surrounding areas (for details of RIRAM see Kutcher, 2012). Never the less, the WMCC and percentage of native species data can be overlain onto a graph taken from Kutcher's 2018 report (Figure 33), which compares FQA values of coastal freshwater wetlands with those of the RIRAM Reference Set (Kutcher 2018). The data show that the floristic quality of the Quonochontaug and Winnapaug wetlands is consistent with the WMCC values derived from the vulnerable coastal wetlands surveyed in 2018. When the WMCC values are compared with the 2017 reference data set, the assessment values fall slightly

above the WMCC values seen among the most disturbed group of freshwater reference wetlands. This is the result of more than 50% of the plant species at both sites having CC's of 3, or below, which indicates that more than half of the species present are tolerant of disturbance.

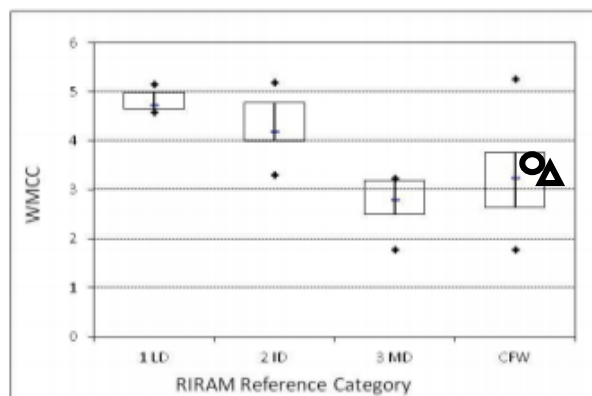


Figure 33. Box plots depicting the distributions of floristic index and RIRAM values among RIRAM-based reference designations of freshwater wetland conditions for 20 reference wetlands, compared with 16 vulnerable coastal freshwater wetlands; boxes represent interquartile ranges, crosses represent minimum and maximum values, and dashes represent median values; 1LD = least disturbed, 2ID = intermediately disturbed, and 3MD = most disturbed; CFW = vulnerable coastal freshwater wetlands (from Kutcher, 2018). Hathaway (black triangle) and Lathrop (circle outline) Preserve coastal freshwater wetlands are overlain for reference.

Discussion

The vegetative condition of the Quonochontaug and Winnapaug freshwater wetlands assessed in 2018 was similar to conditions found during a RINHS Floristic Quality Assessment of sixteen vulnerable coastal wetlands in 2017 (Kutcher 2018). As was demonstrated for the 2017 coastal wetlands, the presence of predominantly disturbance adapted species, and species with broad distribution within the state's freshwater wetlands, suggests a degree of anthropogenic disturbance, either through sea level rise, nutrient input to the coastal salt ponds, or direct disturbance to the soil and vegetation. Despite the fact that human disturbance factors were not evaluated as a part of this report, indications from the mean and weighted mean CC values indicate that disturbance of one or several types has contributed to the plant species composition at both sites. Before being preserved, which allowed vegetation transitions to progress without human interference, prior land use on the sites were agricultural, for livestock grazing and as woodlots. In addition to family histories of the two sites, evidence of past silviculture practices include stone walls, ditches, and berms. Stone walls at both sites delineate boundaries between mesic or upland soils from poorly drained soils, limiting access of livestock to the wettest areas. Freshwater is directed off of inland portions of the Lathrop Preserve wetland via several north-south ditches which conduct water from within forested habitat, across salt marsh, and into Winnapaug Pond. On the Hathaway Preserve, a soil berm built around the western margin of the wetland, possibly served to retain fresh drinking water for livestock.

Historic accounts of land use across New England are consistent with observations from the Lathrop and Hathaway Preserves. Research into land use history across New England, indicates that 75% of pasturage was located in poorly drained soil, and that mesic and poorly drained sites



Figure 35. Red maple and cinnamon fern in forested wetland; both common wetland species with CC's of 3. Lathrop Preserve, Winnapaug Pond.

were favored for woodlots (Foster 1992). The prevalence of species like *Ilex verticillata*, *Vaccinium corymbosum*, *Rosa palustris*, *Smilax rotundifolia*, and *Acer rubrum* indicate that primary succession stages were dominated by sprouting species, with disturbance-adapted life history traits (Foster et al. 2003). The broad, multi stemmed habit of the tall shrubs present on the sites indicate past access to sunlight when canopy cover was minimal. Red maples at both sites were multi-stemmed, indicating that they had been cut in the past; likely for firewood. In recent history, the Lathrop Preserve was a potential site for housing development, with trees cut and soil manipulated along the northern side of the wetland. The presence of mature stands glossy buckthorn (*Frangula alnus*) within the previously clear-cut area suggests colonization by this invader took place at that time. Elsewhere within the site, *Frangula* is present as young plants, in the early stages of site colonization.

Environmental stresses, stemming from salinity influx are reflected in the transitional nature of the vegetation along the brackish/freshwater ecotone. Signs of salt-water stress include the overlap of brackish marsh species with those typical of freshwater wetland conditions, along with the dead and dying woody vegetation of species characteristic of freshwater wetlands. Woody vegetation, with its' deep root system, would be the first species to show impacts of salinity in the soil horizon, and appear to serve as indicators of the chemical change, with dead stems remaining upright while the understory vegetation below them shifts to form a new community type.

Within the Lathrop Preserve, *Phragmites australis* dominates the wettest portions of the brackish marsh, and extends inland among tall shrubs. At the Hathaway Preserve, *Phragmites* distribution is more patchy, and limited to the wettest portions of the site. As freshwater wetlands, located along nutrient rich coastal salt ponds, these habitats are inherently vulnerable to invasion by *Phragmites* (Silliman and Bertness 2004). Groundwater flowing toward the coastal lagoons reduces salinity to levels that are tolerable for native freshwater and brackish marsh species, as well as *Phragmites*, while nutrients (predominantly growth-limiting nitrogen) flowing into the pond from surrounding residential and commercial properties, tip the balance of competition in favor of the rapid rhizomatous expansion of *Phragmites*. Because of the tall stature of the plant, *Phragmites* is also successful at competing with native brackish species of lower stature, for aboveground light (Minchinton and Bertness 2003).

Although future vegetation composition is impossible to predict, the topographic positions of these two coastal wetlands would seem to offer possibilities for salt marsh migration as sea levels continue to rise. Surroundings at present include areas of open emergent wetland, which frequently support a diversity of habitat specific species in both freshwater and brackish systems. At present species with narrow tolerances to environmental conditions, or poor competitive abilities, represent one third of the species in the plant communities (35% and 32%) at each preserve. For highly specialized species, however, narrow tolerances to conditions and disturbance puts them, as well as the habitats they occupy, at risk of colonization from species

with greater tolerances and competitive advantages. *Phragmites*, for example has a broad salinity tolerance, ranging from between 10 and 25ppt (Smith and Warren 2012) and somatic competitive advantages both above and below ground (Minchinton and Bertness 2003), in particular with an ability to rapidly colonize disturbed habitat through rhizomatous growth. The threat of *Phragmites* at both study sites is exemplified by its presence in freshwater and brackish conditions, as well as its ability to expand inland within the canopy of tall shrubs. The competitive advantages of generalist species, such as *Phragmites*, suggests that over time, and in response to continued sea level rise, these species will occupy a greater percentage of the brackish and freshwater plant communities, and overall wetland species diversity and richness may trend towards greater simplification.



Figure 36. Highbush blueberry with *Juncus gerardii* understory, Hathaway Preserve, Quonochontaug Pond.

D. Propagation and Production Techniques for smooth cordgrass (*Spartina alterniflora*)

Introduction

Spartina alterniflora has been planted in salt marsh restorations along the east and gulf coasts of the United States, since 1980. Planting goals for these tidal community restorations, have been for *Spartina* to function as an ecosystem engineer in the process by stabilizing shorelines and creating low marsh habitat (Novy et al. 2008). Propagation methods for the production of *Spartina* restoration material, have included both seed and asexual propagation methods. It is generally accepted at present, that seed production from regionally collected wild seed is preferred to achieve a biologically diverse population (Lindig-Cisneros and Zedler 2002; Novy et al. 2008; Smith and Warren 2012). Genetically diverse populations of *Spartina*, are predicted to have greater potential for population resiliency over time. Research has also shown that genetically diverse populations of *Spartina* support a greater diversity of dependent faunal species (Novy et al. 2008), which has benefits beyond the initial goals of soil stabilization.

Salt marsh restorations in Rhode Island have utilized *Spartina alterniflora* propagated from seed collected in Rhode Island and elsewhere along the Atlantic coast. For initial small scale restorations, carried out by the non-profit organization Save the Bay, seed was collected locally and propagated in partnership with high schools (Ferguson, *personal communication*). In other cases, both seed and plant material, was obtained from Pinelands Nursery, located in New Jersey. The RINHS Rhody Native™ initiative has also propagated *Spartina alterniflora*, as well as other salt marsh grasses, perennials, and shrubs, from locally collected seed, and the program contributed plants to both the Maidford Marsh and Ninigret Sediment Placement projects. However, since Sediment Placement projects require large quantities of seedlings, contracting with a nursery production facility has been required to produce the volume needed.

The Maidford Marsh and Pettaquamscutt Cove Sediment Placement Impact Sites were planted with a mix of two salt marsh species: *Distichlis spicata* and *Spartina alterniflora*. In 2016, the Rhody Native initiative contributed 3,500 *Distichlis* and 1,500 *Spartina* seedlings to the Maidford Marsh site. The overall planting (which spanned two years) required a total of 38,000 seedlings, split between the two species. For the Pettaquamscutt Cove site 35,000 seedlings of the two species were planted in a single season. The majority of the Maidford Marsh, and 100% of the Pettaquamscutt Cove, seedlings were propagated in New Jersey, from Rhode Island collected seed. The Ninigret Sediment Placement Site, utilized a mix of Rhode Island and out of state material, and required 6,000 plugs of *Distichlis spicata*, 13,200 plugs of *Spartina alterniflora*, 16,000 plugs of *Spartina patens*, 7,000 of *Juncus gerardii*, 40,375 *Ammophila breviligulata*, 2,000 *Panicum virgatum*, 256 *Solidago sempervirens*, as well as 448 plants of *Baccharis halimifolia* and *Iva frutescens* combined. In addition, Rhody Native propagated 140 *Baccharis* for the project. The total number of plants, planted in 2017 and 2018 for the Ninigret Impact Site was 85,419. Of the total, 25,844 were propagated from seed collected in Rhode Island, which were then propagated in New Jersey. The *Ammophila* was propagated on Cape Cod, in Massachusetts from vegetative culms of the Cape Cod ecotype, resulting in 66,219 of the plants being genetically regional. The remaining plants (19,200) were propagated from seed collected in New Jersey, and propagated by Pinelands Nursery. Aside from the portion of seed collected through the Rhody Native initiative and Save the Bay, the majority of seed collected in Rhode Island was part of a large scale, multi-year, seed collection effort conducted by the New

England Wildflower Society in partnership with the Mid-Atlantic Regional Seed Bank. This seed was collected and made available for propagation as a result of federal funds allocated to states for salt marsh and dune restoration following the impact of Hurricane Sandy in 2011.

At present the capacity for large scale native plant production in the Eastern United States, resides largely in the mid-Atlantic region. While small nurseries specializing in native plant production are present in New England, some produce only a limited number of species through vegetative reproduction or through seed sourced not entirely from regional populations. While others, which have the expertise and ability to produce genetically diverse plant material, lack production facilities needed for large scale restoration projects. However, the need for quantities of salt marsh (and other native) species, sourced from regional seed for regional habitat restoration represents an opportunity for industry growth in New England. To facilitate the production of local ecotypes from seed, state and federal agencies involved in these large scale restoration projects, may need to partner with regional growers to support seed collection efforts.

Development of a local capacity to produce salt marsh restoration species, and increasing dialogue between resource managers and growers, could lead to plants being better suited to particular site conditions. In addition plants propagated locally, would experience less stress due to shorter transportation distances, which could contribute to higher survivorship. In addition to increases in the success of projects in Rhode Island and New England, there would be substantial reductions in the amount of energy spent shipping locally collected seed to a nursery located 300 miles away, and then shipping plants back the same distance.

As most local growers are not familiar with the requirements of native plant production intended for restoration, they must be introduced to potential opportunities and provided with protocols to follow. In addition, there needs to be communication between growers and managers regarding the need for restoration plant material, in order for growers to consider taking on new production methods. The following description of the propagation requirements for the salt marsh grass, *Spartina alterniflora*, attempts to codify various protocols and information from scientific research, and relates our experiences at RINHS with growing the species. Incorporated here are the propagation protocols established by the USDA Plant Materials Centers, the Center for Plant Restoration at the University of Southern Mississippi Gulf Coast Research Laboratory, Greenbelt Native Plant Center of the New York City Department of Parks and Recreation, and production protocols for *Spartina alterniflora*, compiled by Rhode Island's Save the Bay for their partners at local high schools.

Spartina Life Cycle and Seed Collection

Spartina alterniflora has a natural distribution that extends along the eastern and gulf coasts, from Newfoundland to Florida and Texas (Gleason and Cronquist 1991). Peak flowering times have been documented in correlation to day length, with populations in lower latitudes flowering earlier and longer than those in northern latitudes (Fang 2002; Novy et al. 2008). Flowering periods extend over a 3 month time period, which in Rhode Island begins in early July (in Narragansett Bay) and ends in late-September (within coastal salt ponds), with peak flowering across the state concentrated between late July and early September (Donnelly, *personal communication*; *personal observation*). Variations in timing between populations located in

Narragansett Bay and those along the south coast, are potentially due to delayed warming along the south coast in early spring. For example, in 2018 flowering dates observed in Ninigret, Quonochontaug and Winnapaug Ponds, began in early August and continued until mid-September, and in 2017, I observed *S. alterniflora* in bloom in Warwick and Barrington, in late July.



Figure 37. (L) *Spartina alterniflora* in flower, August 15, 2018 on Ninigret Pond. (R) Ripe seed heads on October 30, 2013 at the Maidford Marsh.

Flowering sequence within the culm, begins at the tip and progressing down to the base (Fang et al. 2004).

Fertilization of seed is via wind-borne pollen, with cross-pollination being the primary mode of fertilization due to timing of the exertion of male and female floral parts (Fang et al. 2004). Plants flowering during the peak time period have a greater chance of being cross pollinated, and Fang (2002)

found higher germination rates from seed produced by plants that flowered during peak times.

Maturation time from flower to seed dispersal appears to be about 60 days in Rhode Island, although Fang (2002) documented 84 days in Louisiana where the growing season is longer and shattering does not occur until late November. It may be that our ecotype is adapted to the constraints of a shorter growing season. Seeds along the Rhode Island south coast, begin to ripen in early October, and can be collected up until shattering is complete in mid to late October. Late September collection dates have been documented by Ferguson in Narragansett Bay, and Donnelly has documented seed shattering as late as mid-October on the Seekonk River.

I have collected seed in South Kingstown and Westerly in mid-October, and in Middletown in late October. Year to year seasonal variability can be expected to influence the timing of seed ripeness, and seed collectors should monitor the flowering time of targeted seed donor populations, to determine peak flowering time, from which the best time frame for seed collection can be calculated.

Seed is ripe when it is beginning to shatter, or fall easily from the stem. Stem color is an indicator of the state of dryness that needs to take place before seeds will separate from the rachis. Stems with some green along the rachis, have not yet dried sufficiently, and will not readily release seeds. The state of readiness can be tested by taking the base of the rachis between two fingers, and running the finger nails from the bottom to the tip of the culm. Ripe seed will naturally fall off. If the majority of seeds are released, collection can be made by seeking out stems of a similar color, and cutting the stem just below the



Figure 38. Shattered seed of *Spartina alterniflora* at Maidford Marsh (October 30, 2013).

rachis. Since strong winds, especially those from storms accompanied by cold weather, actively disperses seeds, collection should be timed before a major storm event, to prevent losses from dislodged seeds.

Selection of collection areas should be made in locations across the marsh, as not all areas are equally productive, and genetic composition can vary within the population. I have observed that culms containing the highest proportion of seed are located along the margins of the population, as along transition zones and leading edges of the marsh. Broome et al. (1974) observed similar circumstances, concluding that the oldest and most dense portions of the population are the least productive. These observations may also relate to the degree of soil oxygenation, where interior marsh substrates may be slower to drain (Davy et al. 2011). Collecting seed throughout the marsh ensures that the greatest degree of genetic variability, contained within the population, will be collected. Novy et al. (2008) found that there was a higher degree of genetic variability between individual stems of *Spartina alterniflora* collected within a single marsh, than between stems collected from multiple marshes. Novy et al. collected *Spartina alterniflora* seed from marshes located from Narragansett, RI to Jamaica Bay, NY, and examined the population genetics of each collection. Their data revealed that marshes within their study area were relatively similar to each other. The data also showed that the genetic variability seen within marshes along the east coast reflected the regional genetics of the species. They concluded that for *S. alterniflora*, seed collection need not be marsh specific to be considered local, but that it should be regional. Novy et al. define regional, broadly, with all of New England encompassing a single region. Additionally, as a result of the high degree of genetic variability between stems that were collected as close as 10m apart, Novy et al. (2008) also concluded that clonal production within marshes is limited to patches, possibly as small as 100m². The implication for seed collection, is that randomly collecting stems, from throughout productive regions of the marsh, will increase the potential of obtaining a broad spectrum of the population's genetic variability.

The collection size will be determined by the following growing season's need for, or the nursery facility's capacity to grow and maintain, *Spartina* seedlings. Seed cannot be stored for subsequent years, for unlike most halophytes, *Spartina alterniflora* is not adapted to long periods of dormancy. Within each *Spartina* spike are 12-15 spikelets. Each spikelet, may contain a single seed, and there are approximately 174,000 spikelets per pound (Bush 2002). Although I could not find data which quantified percentage of non-viable (empty) seed, Biber and Caldwell (2008) commented that "Although *S. alterniflora* appears to produce a significant number of seeds, most spikelets are empty, or contain a damaged or sterile caryopsis". Our collections have shown that less than one-half of the seeds collected are mature and viable.

To avoid introducing pathogens into a nursery production facility, stems that show signs of rust, which is a fungus that appears as reddish colored spots on the leaves of *Spartina*, should be avoided. In addition, *Spartina alterniflora* is prone to the ergot fungus (*Claviceps purpurea*) infected culms should



Figure 39. Ergot fungus (*Claviceps purpurea*), with characteristic sticky exudate, in spikelet of *Spartina alterniflora*.

also be avoided (for details see Discussion under Section A). Not only will the culms be devoid of viable seed, but collection of the fungus would also risk contamination of the propagation site.

Seed Storage and Germination Requirements

Seed of *Spartina alterniflora* is recalcitrant, which means that viability will be lost if the seeds dry, and the moisture content of the endosperm falls below 40% (Cohn and Chappell 2007). During the collection process, cut stems should be placed directly into plastic bags to prevent drying. To avoid over-heating seeds, the bags should be kept cool, and out of direct sunlight. The Green Belt Native Plant Center (unpublished data) recommends allowing seed to after-ripen on the rachis in a cold dry state for two months prior to threshing. After-ripening allows seeds to complete the maturation process before introducing them to conditions that will eventually promote germination. Storage can be in burlap or plastic, under cold conditions (2-4 degrees C). However the Center for Plant Restoration and Coastal Plant Research (2012), recommends processing seed immediately to avoid the potential for drying. We have allowed seeds to after-ripen in plastic bags placed in a refrigerator for 30 days before separating spikelets from the rachis. Threshing, can be accomplished with threshers designed for small grain production, or for small quantities, by rubbing spikes across the surface of a rubber stair-tread mat (placed within a box) or over a one-quarter inch hardware cloth screen. Ripe spikelets will separate easily from the rachis, and can then be sorted to remove stem debris.

Although time consuming, spikelets can be further sorted at this point to separate mature seed from those that are immature or empty (sterile) to reduce the volume of non-viable seed. Seeds placed on top of a florescent light box will show endosperm color and fullness of the spikelet. We found it easier to distinguish ripe endosperms when the spikelets were wet, after soaking in freshwater for 24 hours. In general among plant species, as seeds ripen, the color changes from white or green, to brown or black. For *Spartina alterniflora*, darker seed color indicates seed ripeness.

In 2015 we separated light colored seed from dark (black) colored seed, and stored each separately. Empty spikelets were discarded. Light colored, immature seed comprised 10% of the seed collected, with dark colored mature seed constituting 30% of the collection.

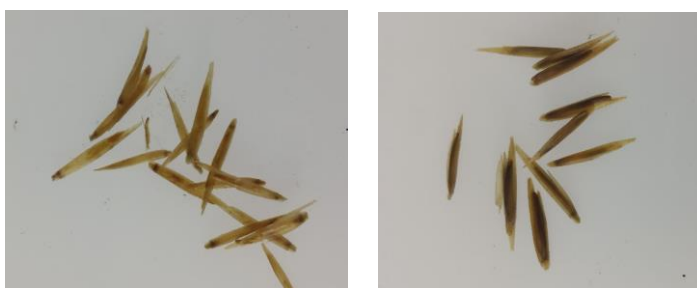


Figure 40. *Spartina alterniflora* caryopsis. Sterile seed (L), Fertile seed (R)

Following cleaning, seed should be placed into glass or plastic containers filled with water, and refrigerated at 2-4 degrees C for a minimum of 60 days. *Spartina* spikelets will initially float inside the jar. Flotation is a mechanism for seed dispersal on tidal currents. In salt marsh settings, filled spikelets eventually sink, or are washed ashore. Quirk et al. (2009) found that *S. alterniflora* seeds, are buoyant when first dispersed, but sink after 24 days. Stratification (or exposure to wet and cold conditions) mimics winter dormant conditions, and is required to bring the seed of many plant species out of

dormancy, and to promote germination (Baskin and Baskin 2014). The length of time needed for cold stratification varies with each species. *Spartina alterniflora*, requires a minimum of 60 days.

Recommendations for the chemistry of water in which the seeds are stored vary, ranging from concentrations above that of sea water, to entirely fresh. We have used freshwater and concentrations of 10% salt with equal effects. Pinelands Nursery stores seed in a 40% solution of saltwater with several rinses over the course of the stratification period to prevent the solution from becoming anaerobic (Knezick, *personal communication*). Fang (2002) recommends concentrations as low as 0.4%, and The Center for Plant Restoration and Coastal Plant Research (2012) recommends freshwater. Shumway and Bertness (1992) found germination rates as low as .05% at concentrations of 30% salinity, indicating that soaking seed in higher concentrations of salt, could keep seeds in a state of temporary forced dormancy. High salinity may also prevent the growth of molds, although we have not experienced any growth of micro-organisms in our jars.

Accounts in protocols and scientific literature regarding the length of time for seed to be soaked in cold water vary in relation to realized rates of germination. Biber and Caldwell (2008) tested viability of seed after storage for varying durations in cold and wet (stratification) storage. They achieved the highest germination rates from seeds that were stored for 90 and 120 days (35%), and saw declines in viability at greater lengths of time. After 12 months of storage, germination rates had dropped to 1%, and no seed was viable after 15 months. Biber and Caldwell's results indicate that it is the cumulative effect of the cold and soaking conditions that influences germination, and that after a certain point, seeds begin to deteriorate.

We have stored seed for 90 to 120 days and achieved 80% germination (after sorting out immature and non-viable seed). In 2014, seed that had been stored for as much as 150 days, was sown with germination rates realized of approximately 60% (Meyerson, *personal communication*). The degree of variation between our results and that of others, could be that our numbers reflect percentages based only on dark colored, mature seed.

It is not stated in the research of others, whether non-viable or immature seed was removed prior to propagation. Despite this, all accounts recognize an overall low level of fertility within the rachis (56% of our collected seed in 2015 was sterile), and Fang (2002) states there is a need for identification of uniquely fertile plants, producing large numbers of viable seed for restoration plantings.

According to Fang (2002), higher germination rates appear to be correlated with flowering date, seed set, and seed weight, as well as plant height. Fang found that plants which flowered during peak time producing a greater number of seeds with better rates of germination. In addition, Fang made collections across various seed maturation dates, and from plants growing within a range of heights and with varying panicle lengths. He found that seed set in plants that flowered early ranged from 0-29%, and that seed set among plants flowering at peak time increased, and ranged from 46 – 71%. Collection timed as close to the shattering stage has also been noted to produce the best germination rates (Broome et al, 1974), possibly due to the extended ripening time allowed for all seeds within the rachis. For our collections, made in mid-October, just as seeds were shattering, we saw germination rates that ranged from 69% to 80%.

Seeds of *Spartina alterniflora* can germinate in light or in the absence of light. The Center for Plant Restoration (2012) floats seeds in glass jars of freshwater under 60-100 watt florescent light bulbs, at temperatures of 25-35 degrees C. They find seed will germinate in seven to ten days, and can then be planted into containers for growing out, after they reach 1.3cm in length. Alternatively, seeds can be surface sown, at a rate that places seeds roughly 1cm apart, and covering with 5mm of soil. Water tight trays placed under the seed trays, should be kept filled with freshwater, and plastic domes should be used over the trays to keep humidity levels high. It is recommended that freshwater be used to stimulate germination after seeds are sown. Shumway and Bertness (1992) found germination rates to be highest for *S. alterniflora* at salinity concentrations of 0 and 15%.

Germination of *S. alterniflora* seed can take place within 3-14 days. Temperatures in our greenhouse conditions fluctuate between 20 and 27 degrees C between night and day during the month of February, when there are about ten and one-half hours of natural daylight. The length of time from sowing to germination has ranged from as few as three days, to ten days. The relatively short amount of time that it takes *Spartina* to come out of dormancy in response to warmth, light, and freshwater is possibly an adaptation to the flushing conditions presented by spring rains, which has the effect of lowering salinity levels on the marsh surface. Biber and Caldwell (2008) suggest that when seed has been sufficiently stratified, the pale plumule (rudimentary shoot) becomes visible, and can be used as an indication of seed readiness. They observed seed in this state to germinate after a few days of exposure to light. In 2018, we observed a similar indication of seed readiness. A glass jar of seed, stored in freshwater, was left overnight in the greenhouse. After being exposed to 12 hours of daylight, the plumule turned green. However, despite this early step in the germination process, leaf shoots took seven days to emerge.

Propagation and Cultivation

Our growing methods entailed sorting viable from non-viable seed just prior to sowing. After utilizing the florescent light box method in 2015, and finding it very time consuming, we decided to try a different method of separating sterile spikelets from those that appeared fertile in 2018. For many plant species, fertility of seed can be inferred by the relative weight of viable seed versus that of seed which is sterile. Soaking seeds in freshwater is often used as a method of separating the two, as viable seed has a heavier endosperm and usually sinks in water, whereas lighter weight, empty seed will float. Based on past experience with seed sorting, we decided to utilize the differential weight and flotation characteristics of filled versus empty spikelets, as a more efficient method for separating out non-viable *Spartina alterniflora* seed. A large potting trough was filled with freshwater, into which the seed was immersed. Light weight, empty spikelets floated to the top and were discarded. Dark seed containing mature embryos, sank to the bottom and were collected for sowing. The method was successful for sorting out non-viable seed, and took a fraction of the time required for the florescent light box method. We also surmised that since seed had been stratified in a 10% saline solution, that immersion in freshwater at this point had the added benefit of rinsing salts out of the spikelets; a process which improves germination rates.

Recently germinated *Spartina* seedlings require 2-3 weeks to develop the waxy cuticle that prevents desiccation (Biber and Caldwell 2008). Soil within germination flats must be kept saturated, and humidity levels high around the newly emerging leaves for two weeks after germination, and then gradually acclimatized to ambient humidity. As most seed germination in nursery settings takes place under plastic domes to maintain high humidity, this is an easy condition to maintain. Surface watering, until germination occurs also aids in keeping seeds wet, and aids in flushing any residual salts. After germination it is recommended that watering take place from below the seed tray, to prevent algae from forming on the surface of the soil.

Spartina alterniflora seedlings require fertilization with high proportions of nitrogen, however the Greenbelt Native Plant Center (unpublished protocol) stresses that fertilization should only begin once the roots have reached 4cm in length, which is around six to seven weeks. A balanced high nutrient formula (10-10-10) is recommended to be applied monthly at this point. Materne (2001) also recommends a high nitrogen, slow release fertilizer (15 – 30%N), be applied to seedlings just prior to transplant on saturated and anaerobic soils.

Although flooded and saturated growing conditions are important to maintain during propagation, it is equally important that the soil medium has good drainage characteristics to maintain soil oxygen levels. Typically 2:1 mixes of peat to sand, and sand to medium-fine soilless potting mixtures are commonly used. We have experimented with variable rates of soil medium drainage, water retention, and particle size, and their effects on seedling growth. The fastest initial growth rates of seedlings realized has been in a mix with medium-high drainage, moderately coarse particle size, and medium-low water retention. Slowest growth rates were measured in seedlings grown in 100%, medium-fine grained sand, with a high drainage capacity, as well as those grown in a very fine particle size soil mixture, with low drainage and high water retention. Table 10 outlines experimental soil mediums and initial seedling growth during the first two weeks after shoot emergence.

Rhode Island Natural History Survey, Rhody Native™ <i>Spartina alterniflora</i> Propagation					
Date Sown	Soil Mixture	Drainage	Particle Size	Water Retention	Stem Height at 2 weeks
2/6/2015	2:1 Ratio Sand, Metro Mix 510™	Medium	Medium	Medium High	5cm
2/7/2015	100% Moderately fine-grained Sand	High	Medium	Low	3cm
3/12/2018	100% Coconut Coir, Sphagnum Peat Mixture	Low	Fine	High	4cm
2/14/2019	1:1:1 Ratio Sand, Metro Mix 852™ and Coconut Coir, Sphagnum Peat	Medium High	Med-Coarse	Medium Low	6cm

Table 9. Soil ratios used by RINHS for *Spartina alterniflora* production

RINHS Propagation Experiences (2015)

The Rhody Native initiative has propagated a number of coastal plant species common to salt marsh and dune habitats. The bulk of our plant material is sold for habitat restoration projects around the state, and to nearby locations in Massachusetts and Connecticut. Plants are grown primarily in landscape plug trays. Our experimentation with growing *Spartina alterniflora* and other salt marsh graminoids, has been small in scale relative to the quantity needed for each restoration, due to limited space and operation capacity. However, as previously stated, there is opportunity for nursery growers in Rhode Island to expand their operations to include genetically appropriate restoration plant material. For all species, growers require at least a year's lead time to collect seed and propagate seedlings. For shrub species, which are slower growing from seed, a minimum of two years is necessary. In 2014, RINHS was contracted to grow a limited amount of salt marsh grasses for an upcoming Sediment Placement Site. In preparation, reproductive populations of the two species: *Distichlis spicata* and *Spartina alterniflora* were located and permission for seed collection was requested from the landowner. Below are accounts from our work, detailing the processes we used for the propagation of *Spartina alterniflora*.

Ripe seed was collected from southern Rhode Island on October 20, and stored in plastic bags under refrigeration for one month, to allow seed to continue ripening. After allowing seed to after-ripen, the culms were rubbed across the surface of a one-quarter inch screen of hardware cloth to separate spikelets from the spikes located along the rachis. No further cleaning was done to isolate the seed from its protective outer layers. Seed was then placed into glass jars and covered with fresh (non-chlorinated) tap water, and refrigerated at 4 degrees C. for three months. In February 2015, seed was taken out of the jars and sorted on a florescent light table to remove empty spikelets. We found spikelets to be of three types: empty and sterile; light colored and immature; dark colored and mature. All types were weighed, and we determined that 56% of the total collection was non-viable. The remaining seed was made up of 10% immature seed and 33% mature seed. To test if the lighter colored seed was in fact immature, and to see if it had any potential for germination, we sowed the two colors of seed in separate trays. To determine the effect of different seeding soil mediums, we compared two types. In mid-February, 85g of imbibed seed was sown into 4 x

6in seeding trays. One set was planted into a 2:1 mixture of the commercial growing medium Metro Mix 510™ and sand. The second set was planted into trays of 100% moderately fine-grained sand. The seeding trays were placed into non-draining seed flats, covered with plastic dome tops, and kept flooded at all times while seeds germinated and seedlings became established. Water was fresh, and non-chlorinated. Seed

trays were exposed to ambient light conditions, which at that time of year was 10.5 daylight hours. Temperatures within the heated greenhouse fluctuated from 20 to 27 degrees C, during night and day. Germination of seeds occurred after seven days, and by ten days, most of the seed



Figure 41. *Spartina alterniflora*, germination in sand (L) and potting mix (R). Trays in front (R), sown with immature seed.

had germinated. Germination rates for mature seed was estimated at 80% for the seeds sown into the Metro Mix substrate and 40% for those sown into sand. For both soil medium sets, mean germination rates for immature seed was 15%.

Fourteen days after germination, the dome tops were removed and flats were allowed to drain down before additional freshwater was added. At this point, the seedlings growing in pure sand became chlorotic. It is recommended that fertilizer only be applied after roots have grown to 4cm in length, so none was added at this point. Woodhouse and Knutson (1984) found that freshly deposited sand substrates are usually deficient in nitrogen and phosphorus. The Metro Mix seedlings remained green and continued to grow in height. When seedlings had developed their second set of true leaves (at four weeks), all seedlings were transplanted into 8 x 15cm tree tubes in a 2:1 mixture of peat and sand. Tree tubes, with 2cm wide open spaces at the bottom, were used to allow for rhizomatous tiller production. The seedlings that were removed from the 100% sand soil medium were noted to have poor root development. Seedlings transplanted from the Metro Mix substrate had well developed roots that measured in lengths equal to their stem height. At this point we began a regime of weekly feeding with a balanced nutrient mix. After transplanting, half of the pots were placed into an Ebb and Flow™ hydroponic grow table, with flooding set at 6 hour intervals to mimic tidal cycles. The other half were kept in non-draining seed flats (5cm height) and watered as needed to allow drainage and refill. Both sets received only fresh non-chlorinated water.

Light for both conditions was ambient in a heated greenhouse with daytime temperatures set to 25 degrees C, and nighttime to 20 degrees C. After 4 weeks of growing under these conditions, measurements of stem height and leaf width were taken to compare growth both within and outside of the ebb and flow conditions. Transplants from the sand medium regained their color and grew as vigorously as the Metro Mix transplants. Mean stem height was slightly higher on plants grown in the ebb and flow table (9.9cm) compared with those grown in flats (8.7cm). Differences between mean leaf width were insignificant (0.31cm for those in the flood table vs. 0.28cm for those in the flats). Under both conditions, plants had begun to produce tillers through the open-celled bottoms of the containers.

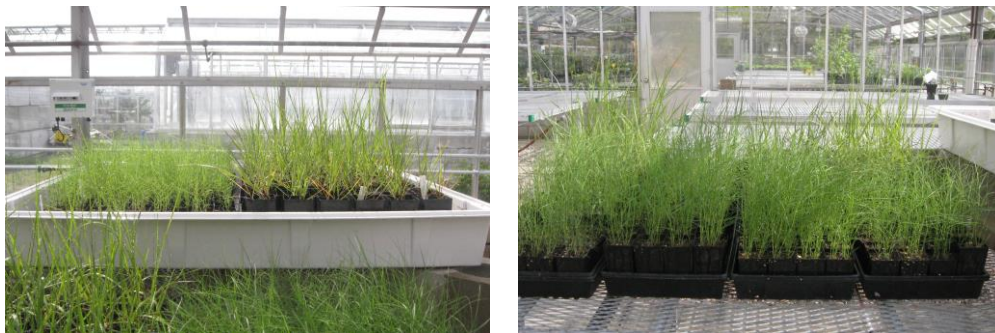


Figure 42. *Spartina alterniflora* and *Distichlis spicata* after 90 days of growth (2015); Ebb and Flow Table (L); Flooded flats (R).

At 90 days 1,000 *Spartina alterniflora* seedlings were transplanted to 15cm deep, open trays, and placed into an outdoor, unheated hoop house with 50% shade cover, and allowed to tiller within the trays. Soil mixture was 2:1 peat to sand, and tray bottoms were covered with 3ml plastic to

keep soil moist at all times. Plants over-wintered under these conditions. The following spring, six weeks before the *Spartina* seedlings were to be planted onto the salt marsh, we began the process of acclimating the seedlings to low concentrations of salinity. Salinity doses were increased by 5% each week. Since seedlings had vigorously formed rhizomes under these growing conditions, they were removed from the soil medium just prior to planting, and divided into bare-root bundles. Bundles were soaked in 25% saline solution, combined with a mixture of fish emulsion and a mycorrhizal additive, and delivered to USFWS for transport to the Maidford Marsh Sediment Placement Impact Site.

RINHS Propagation Experiences (2018)

In preparation for this report, a limited amount of seed was collected on October 16, 2017 from two salt marshes located along the south coast. For this particular year, as a result of the combined early maturation of seeds and prevalence of fall storms, the majority of seed had already shattered at the time of collection. Never the less, a sufficient amount was available for testing additional growing methods. Collected seed was treated as before, and placed into glass jars with fresh water and refrigerated at 4 degrees C for four months. In March 2018, the stratified seed was sorted to remove empty and light colored spikelets, using the flotation method described earlier. After experiencing the time consuming process of transplanting individual grass seedlings from the open seed trays in 2014, we decided to eliminate a transplanting step and sowed a set number of seeds directly into two different sizes of seed plug trays. Three seeds were sown directly into single 4cm wide cells in 50-cell plug trays, and covered with 5mm of soil medium. The soil medium used was a fine textured coconut coir and sphagnum peat seed mixture, manufactured by GreenTree™. We had been successfully using this mixture for all of our seed germination in 2018, and decided to also test it on salt marsh grasses. The intent behind selecting two different size plug trays, was to experiment with different methods of root and rhizome production.

Seeds from both marsh collections were divided equally and sown into the two plug tray sizes. The depth and style of the two plug tray sizes were: 1) deep landscape plugs (13cm) and 2) short germination plugs (4.5cm). For both styles, each tray contained 50-cells. As in 2014, water tight flats were placed beneath the planting trays, and trays were covered with plastic dome tops. For both plug tray styles, the water tight flats were 2cm deep. Flats were kept flooded at all times, and although soil in plug cells was saturated, it was allowed to drain down. This differed from the 2014 germinating conditions, in that seeds were not maintained in a flooded state until germination. Germination rates realized in both plug tray sizes, varied between the two marsh collections, with one collection being 81%, and the other 69%.

Despite initially high germination rates and growth of seedlings, all became chlorotic and stopped growing after 45 days. At that point we began applications of a weak fertilizer treatment for two weeks. When plants failed to respond we switched to a high nitrogen fertilizer for two more weeks. Plants continued to be chlorotic, with 60% eventually dying. We determined that the fine textured soil, with its high capacity to retain moisture, provided insufficient drainage, and that low soil oxygen levels prevented seedlings from taking up nutrients. Coincidentally, we observed what we thought to be a similar phenomenon occurring at the Ninigret Sediment

Placement Impact Site, where *S. alterniflora* seedlings that had germinated at a low elevation within the site, gradually become chlorotic over the course of a month, and eventually died (See Discussion, Section A).



Figure 43. *Spartina alterniflora* plugs (deep) after 90 days (2018).

After 90 days, we measured stem height and root length to compare growth that had occurred prior to the plants becoming chlorotic, and found that root length correlated with the depth of the cells. Mean root length in the deep plugs was 15.6cm versus a mean of 4.08cm in the short plugs. Stem height did not appear to correlate to plug size, with the mean height of stems in the deep trays being 4.08cm, and the mean height of the stems in the short trays being 3.78cm. Aside from the different rates of germination recorded between the two marsh collection sites, overall growth and survival was not significantly different. Observation of *S. alterniflora* root depth in natural marsh settings (Bertness and Shumway 1992; Davy et al. 2011) has shown highest root density at 5cm below the marsh surface, with maximum depths of 15cm.

We surmised that the extent of root growth, observed in our two tray depths, related to the level at which soil conditions were continually flooded. The 2cm trays placed below the seeding trays, were kept flooded at all times, which kept soil moisture levels high throughout the plug, and saturated within lower portions of the plug.

Our rationale for using the deep landscape plugs, was to allow for greater root system production, and for the potential creation of rhizomes. Our intent was to compare the survival rates of plants with longer, and potentially more developed roots, with those grown in the shorter plug sizes. Seedlings of *S. alterniflora*, planted at the Ninigret site were grown in the shorter plug size, measuring 4.5cm x 4cm. Plug trays of this size facilitate a quick turnaround of plant material for the nursery. In addition, the short time that seedlings are kept in containers prevents roots from becoming bound up tightly within the cells, which can then slow the establishment phase of the transplant. The disadvantage of this however, is that the small size and shallow depth creates a smaller root system and doesn't promote the production of rhizomes (Center for Plant Restoration 2012). By utilizing a soil mix with a higher drainage capacity and larger particle size, it is possible that growing seedlings in deep landscape plugs could prove to be a valid production method, by creating an easily planted plug with a more developed root system. However, as our experiences show, prior understanding of the depth of permanent below-soil flooding at the planting elevation, and drainage capacity of the soil, are important factors to consider when determining which growing methods and root depth would be most suited for the marsh conditions.

Since *S. alterniflora* relies on the support of the rhizomatous colony to advance into environmentally stressful conditions, we also hypothesized that if seedlings could be produced in a manner that facilitated the creation of a rhizomatous root mass, survival rates after transplanting would be higher. Our intent for the small plugs was to transplant seedlings grown in these shallow plugs into a mix of soil medium and coir mat within an open flat to promote rhizomatous growth. The concept behind utilizing coir mat, was to provide a surface for

rhizomes to grow around, to create a *Spartina* mat. We theorized that the organic structure, comprised of the root systems of many *Spartina* seedlings, and the organic material of the coir, could facilitate movement of oxygen through the soil, and improve survival for seedlings planted into Sediment Placement substrates.



Figure 44. Preparation of choir mat (L); *Spartina alterniflora* colonizing mat (R)

At 90 days, all seedlings remaining alive were transplanted into open 21 x 11 x 3inch trays without drainage holes. A 2:1 peat, sand mixture was layered with coir mat. Seedlings were planted in rows within the tray, with the expectation that they would form rhizomatous tillers along the coir fabric. Unfortunately, overall survival of the seedlings was poor due to the stress experienced during the previous two months. 90% of the seedlings did not survive after being transplanted, leaving us unable to measure the efficacy of the coir-mat growing method.

RINHS Propagation Experiences (2019)

In October 2018, a small collection of seed was made to further test the *Spartina* mat growing method. Seed was treated as before, but was stored in a 10% saline solution. After 4 months of cold wet stratification, seeds were separated using the floatation method, sown into 21 x 11 x 3inch trays with drainage holes, covered with clear plastic dome tops, and placed into 2cm deep non-draining flats. The soil mix was a composite of 1:1:1 Metro Mix 852™, the GreenTree fine textured seed mix and sand. The 852 formulation of Metro Mix has a high drainage capacity, with low water retention, and is coarsely textured by small pieces of bark. The goal of the blend was to create a well-drained mixture, that contained organic matter and coarse material to allow for oxygenation, along with medium fine textured particles to facilitate seed germination through good soil to seed contact. Seeds were broadcast across the surface, with spacing between seeds at about 1cm. Seeds were then covered with 5mm of the soil mixture and watered in with freshwater. Germination occurred within three days of sowing, and continued for seven days, with a realized rate of germination estimated at 75%. After two weeks of growth, seedlings were 7cm in height. Plastic domes were removed after one week due to the height of the stems. Soil in the open trays was kept moist at all times, though allowed to drain down. Fresh water was added daily to the lower tray, after standing dry for 12 hours.

To continue experimentation with creating a *Spartina* mat for planting into marsh restoration sites, the 2019 seedlings will be transplanted into the choir mat setting. Seedlings will be combined with the surviving 2018 seedlings, in a 2:1 peat to sand mixture, to promote rhizomatous root growth around the choir mat, creating a dense root and rhizome layer that is 5cm deep.

Spartina alterniflora is considered a facultative halophyte, in that seed of the species germinates at higher rates in the absence of salt (Shumway and Bertness 1992) and has higher nursery survival rates and growth at low salinity levels (Witje and Gallagher 1996). Sudden transplant into saline environments, while not toxic to the plants due to the genetically coded mechanisms that allow for the species tolerance to salt (Brown, *personal communication*), does however represent a stress which can slow the establishment time of seedlings, at a time when maximum growth is needed.

Protocols for *Spartina* propagation recommend acclimating seedlings to increasing concentrations of salt in the final month of propagation, but recommendations vary. The Center for Plant Restoration (2012) suggests that if salinity levels at the planting location are above 15ppt, that plants be gradually acclimatized to 10ppt. The Green Belt Native Plant Center recommends increasing salinity every 4-5 days by 5ppt to arrive at 25ppt. Save the Bay's protocol suggests starting at 6-8 weeks (2 months prior to planting) and to increase salinity by 5ppt every week to arrive at 25ppt. While Pinelands Nursery acclimates *Spartina* to between 25 and 30ppt, heavy rains can often dilute the percentage in their outdoor growing tanks (Knezick, *personal communication*).

Scientific literature also reports varying growth responses for *Spartina* at salinity differences under which both established plants and nursery transplants are growing. Low levels of salinity (between 5 and 15ppt) has been shown to stimulate shoot growth and to improve establishment rates for plants grown in saline conditions when they are transplanted into marsh settings, when compared to plants grown solely in freshwater (Li et al. 2009; Carrion 2017). In some cases, nursery growers take advantage of this, as under freshwater conditions both above and below-ground growth is increased, and nursery survival rates are higher (Carrion et al., *unpublished data*). In natural marsh settings, Fang (2002) found the highest growth rate of *Spartina alterniflora* was at salinities of 20ppt, with the upper limit of tolerance being 60ppt. He found that marshes with 75ppt contained no *Spartina alterniflora*. However, Hwang et al. (2004) found that *Spartina alterniflora* grown in higher concentrations of salt (25 – 40ppt) underwent irreversible structural changes in response to high salinity levels, that plants grown in lower concentrations did not exhibit. Their research suggests that these permanent adaptive responses offers plants greater resiliency to varying levels of salinity. Since mean salinity levels at the Pettaquamscutt Sediment Placement Impact Site ranged from 48ppt in May of 2018 to 65ppt in September (see Discussion, Section A), it appears that acclimating *Spartina* seedlings to higher levels of salinity during propagation stages may improve survival at Sediment Placement sites, particularly if permanent adaptive responses for resiliency to varying levels of salinity, are initiated.

In addition to salt, seawater contains trace elements that are essential to plant growth (calcium, magnesium, potassium, zinc, and molybdenum), and research by Flowers (2015) and others has shown these to be beneficial to plant growth and salinity tolerance. Trace elements, such as potassium and calcium play important roles in regulating salt uptake and increasing salinity tolerance by halophytes, while others assist in the uptake of nutrients, and can reduce transplant stress responses (Maynard, *personal communication*). The significance of the presence of trace minerals suggests that salinity acclimatization should include minerals in addition to sodium chloride. These can be found in synthetic sea water, created for maintenance of saltwater aquaria.

In 2019, we will begin salinity acclimation upon transplanting the *Spartina* seedlings into the mat formation conditions. To simulate all of the minerals in seawater, we will utilize the synthetic sea water mix called Instant Ocean™. *Spartina alterniflora* seedlings will be acclimated to 15ppt initially, with the expectation of achieving higher growth rates. Based on the research of Hwang et al. (2004), and to initiate greater tolerance to the potential for high salinity at the Sediment Placement Site, we will increase salinity concentration to 35ppt, one month prior to planting.

To successfully install the *Spartina* mats into Sediment Placement Impact Sites, some experimentation with planting methods will be necessary. Planting method considerations include securing the mat in place, so they are not washed away or displaced by the daily ebb and flow of tides. Also of consideration is the ease of planting. Volunteers are comfortable with the practice of digging a small hole and placing a seedling extracted from a plug tray into the hole. In 2015, they found planting bare-root material was not as straight forward, and more time consuming, due to the horizontal nature of the plant material. Potential methods may include cutting *Spartina* mats prior to transporting to the site, to provide volunteers with mats measuring 13cm x 28cm. Volunteers would then dig a slightly larger area, that was 5 to 7cm deep. *Spartina* mats could then be laid into the holes, just below the surface, and covered with the sand material that was dug from the hole, ensuring that vegetative stems be kept upright, above the sediment surface. Spacing between mat segments should be 30cm, to allow space for seedlings to advance rhizomes into unvegetated soil, while establishing initial coverage of the soil surface. The hypothesis on which this method is based, is that planting intertwined mats of vegetation, will simulate the natural establishment of a nascent *Spartina* colony growing out onto new marsh surface. The goal is to increase survival of the seedlings by increasing soil oxygen levels through the presence of a greater volume of roots. The additional organic matter gained from the choir mat, may facilitate the conduction of atmospheric oxygen to pore spaces within the soil.

In addition to experimenting with the production of *Spartina* mats, we will investigate the potential for positive effects to be gained from multi-species plantings. As with the intertwined *Spartina* mats, most plant communities are a formation of multiple, intertwined species. Examples of mutualisms and commensalisms appear frequently in environments with periodic disturbances, and those with high levels of environmental stress. Under stressful conditions, associated species often facilitate the success of the community as a whole (Hacker and Gaines 1997). Combinations of naturally occurring species growing at multiple canopy levels within salt marsh habitat, has been shown to benefit the growth and survival of species (Bertness and Hacker 1994; Hacker and Gaines 1997; O'Brien and Zedler 2006; Bruno et al. 2017). In 2018, in addition to collecting seed of *Spartina alterniflora*, we also collected the seed of several other salt marsh species, including *Juncus gerardii*, *Cakile edentula*, *Plantago maritima*, *Salicornia depressa*, and *Symphyotrichum tenuifolium*. In 2019, we are experimenting with seeding combinations of annual and perennial species together, to determine if there are any beneficial synergistic effects that can be observed when these groups are planted out onto the marsh.

Specifically, we will sow the annual species, *Salicornia depressa*, within the flats of *Spartina alterniflora*. *Salicornia depressa* is considered a rapid colonizer of bare soil in low marsh areas, with a high tolerance for salinity and soils with a low redox potential (Davy et al. 2011). Observations of *Salicornia* growing within the understory of *S. alterniflora* in the low marsh

suggested the potential for a positive effect for *Spartina*, resulting from the accumulation of salts in *Salicornia* leaves, as well as increased oxygen within the top 5cm of the soil.

We will also work with some of the slower growing high marsh species, with the goal of developing methods for improving survival and establishment of species which, over the long term, will provide biological diversity on the marsh. Bruno et al. (2017), found that for the salt marsh aster (*Symphyotrichum tenuifolium*) there can be a facilitative effect realized by salt marsh grasses and rushes (particularly by *Juncus gerardii*) during the seedling stage of the aster; the synergistic effect being to reduce soil salinity through coverage of the substrate by a network of aboveground stems. In light of this research we will experiment with combinations of the high marsh species we have collected. Combinations of containers sown with suites of marsh species will be offered to Save the Bay for planting at Sediment Placement Sites to determine if multiple species plantings can have greater survivability than species planted singly.

Conclusion

The process of growing salt marsh plants for Sediment Placement conditions presents both a challenge and an opportunity for growers, and investigations like these should be on-going. Success within the plant material component of the Sediment Placement projects, should be seen as the result of a partnership between growers and environmental scientists. The placement of sediment over salt marsh habitat has been seen in Rhode Island to present novel conditions at each location, with the potential for the resulting conditions to vary significantly from those for which many of the propagation protocols were developed. Variability in sediment texture and grain size, elevation and drainage patterns, are seen both between and within sites. The effect of these factors on soil oxygen and salinity levels, influences plant species colonization and survival, which are in turn key indicators of site conditions. Plants function not only as coverage for the sediment placed on the site, but also as indicators of how and where adjustments, through adaptive management, should be made. By including growers in the discussion for site management, an appreciation for site conditions and limitations can be applied to their understanding of plant responses to stresses, enabling them to modify plant production methods. Growers could potentially propagate restoration plant material in ways that would seek to improve the plant responses to stress, producing plants with the highest potential for survival.

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Appendix I

Coastal Salt Pond Botanical Surveys

**Pioneer Species Present at Ninigret Sediment Placement Impact Site
2017 - 2018 RINHS Inventories**

Family	Species Name	USDA Species Code	Common Name	Life Cycle: Annual (A) Biennial (B) Perennial (P)	State-listed Rare Species Conservation Status	Native (N)	Introduced (I)	Invasive*	2017 N Plots (2017 Polygons)	2018 N Plots (2017 Polygons)	2018 N Plots (2018 Polygons)	2018 N Transects
Aizoaceae (Stone Plant Family)												
	<i>Sesuvium maritimum</i>	SEMA	annual sea-purslane	A	State concern	N			0	1	5	2
Amaranthaceae (Goosefoot Family)												
	<i>Atriplex acadiensis</i>	ATAC	maritime orache	A		N			0	0	5	0
	<i>Atriplex cristata</i>	ATCR	seabeach orache	A		N			0	1	2	2
	<i>Atriplex prostrata</i>	ATPR	hastate-leaved orache	A		N			0	4	23	3
	<i>Atriplex subspicata</i>	ATSU	saline orache	A	State concern	N			0	0	0	1
	<i>Chenopodium album</i>	CHAL	lambsquarters	A			I		0	5	25	2
	<i>Chenopodium berlandieri</i>	CHBE	pit seeded goosefoot	A	State concern	N			0	0	0	1
	<i>Chenopodium glaucum</i>	CHGL	oak-leaved goosefoot	A		N			0	7	28	5
	<i>Dysphania ambrosioides</i>	DYAM	Mexican tea	A			I		0	8	7	4
	<i>Salsola kali</i>	SAKA	salt wort	A			I		7	4	4	4
	<i>Salicornia depressa</i>	SADE	common salicornia	A		N			25	0	31	2
	<i>Suaeda linearis</i>	SULI	annual sea-blight	A		N			8	6	1	0
	<i>Suaeda maritima</i>	SUMA	herbaceous sea-blight	A			I		1	9	28	6
	<i>Suaeda maritima ssp. richii</i>	SUMAR	herbaceous sea-blight	A	State concern	N			0	0	4	4
Asteraceae (Aster Family)												
	<i>Ambrosia artemissifolia</i>	AMAR	ragweed	A		N			0	3	2	0
	<i>Artemisia vulgaris</i>	ARVU	mugwort	P			I		2	0	2	0
	<i>Baccharis halimifolia</i>	BAHA	groundsel tree	P		N			29	9	6	4
	<i>Bidens frondosa</i>	BIFR	Devil's beggar-ticks	A		N			0	0	1	0
	<i>Erechtites hieraciifolius</i>	ERHI	American burnweed	A		N			0	0	6	1
	<i>Euthamia graminifolia</i>	EUGR	grass-leaved flat top goldenrod	P		N			0	1	1	0
	<i>Galinsoga parviflora</i>	GAPA	quick-weed	A			I		0	0	1	0
	<i>Iva frutescens</i>	IVFR	high tide bush	P		N			12	14	13	5
	<i>Nipponanthemum nipponicum</i>	NINI	Nippon daisy	P			I		0	2	0	0
	<i>Pluchea odorata</i>	PLOD	camphor-weed	P		N			1	1	0	0
	<i>Solidago altissima</i>	SOAL	tall goldenrod	P		N			0	0	1	0
	<i>Sonchus arvensis</i>	SOAR	field sow-thistle	A			I		1	1	2	0
	<i>Solidago sempervirens</i>	SOSE	seaside goldenrod	P		N			16	7	9	3
	<i>Symphyotrichum tenuifolium</i>	SYTE	perennial saltmarsh aster	P		N			0	1	0	3
	<i>Taraxicum officinale</i>	TAOF	dandelion	P			I		0	1	0	0
	<i>Xanthium strumarium</i>	XAST	cockle-bur	A		N			1	2	7	0
Brassicaceae (Mustard Family)												
	<i>Cakile edentula</i>	CAED	sea rocket	A		N			12	13	13	2
	<i>Lepidium campestre</i>	LECA	field pepperweed	A			I		1	0	0	0
	<i>Lepidium virginicum</i>	LEVI	poor-man's pepperweed	A		N			2	5	3	3
	<i>Raphanus raphanistrum</i>	RARA	wild radish	B			I		0	0	2	0
Caryophyllaceae (Pink Family)												
	<i>Spergularia marina</i>	SPMA	saltmarsh sand spurry	A		N			0	9	7	4
Celastraceae (Staff-tree Family)												
	<i>Celastrus orbiculatus</i>	CEOR	Oriental Bittersweet	P			I	Yes	0	3	4	0
Convolvulaceae (Morning Glory Family)												
	<i>Calystegia sepium</i>	CASE	hedge false bindweed	A		N			0	0	2	0
Cyperaceae (Sedge Family)												
	<i>Bolboschoenus maritimus</i>	BOMA	saltmarsh tuber bulrush	P	State Concern	N			3	0	5	1
	<i>Cyperus filicinus</i>	CYFI	fern flatsedge	A		N			11	15	1	3
	<i>Cyperus grayi</i>	CYGR	Gray's flatsedge	P		N			0	2	2	0
	<i>Cyperus squarrosus</i>	CYSQ	awned flatsedge	A	State Endangered	N			0	8	2	1
	<i>Cyperus strigosus</i>	CYST	straw-colored flatsedge	A		N			0	0	0	2
	<i>Schoenoplectus pungens</i>	SCPU	three-square bulrush	P		N			4	0	4	3
	<i>Schoenoplectus tabernaemontana</i>	SCTA	soft-stemmed bulrush	P		N			1	1	1	1
Euphorbiaceae (Spurge Family)												
	<i>Euphorbia polygonifolia</i>	EUPO	seaside sand-mat	A		N			0	7	4	0

**Pioneer Species Present at Ninigret Sediment Placement Impact Site
2017 - 2018 RINHS Inventories**

Family	Species Name	USDA Species Code	Common Name	Life Cycle: Annual (A) Biennial (B) Perennial (P)	State-listed Rare Species Conservation Status	Native (N)	Introduced (I)	Invasive*	2017 N Plots (2017 Polygons)	2018 N Plots (2017 Polygons)	2018 N Plots (2018 Polygons)	2018 N Transects
Fabaceae (Bean Family)												
	<i>Lathyrus japonicus</i>	LAJA	beach pea	P		N			5	5	0	1
	<i>Strophostyles helvola</i>	STHE	annual wooly bean	A		N			0	1	0	0
	<i>Trifolium arvense</i>	TRAR	rabitt's-foot clover	A			I		0	0	1	0
	<i>Trifolium repens</i>	TRRE	white clover	P			I		1	1	0	0
Juncaceae (Rush Family)												
	<i>Juncus gerardii</i>	JUGE	black rush	P		N			55	16	20	5
Juncaginaceae (Arrow-grass Family)												
	<i>Triglochin maritima</i>	TRMA	saltmarsh arrow-grass	P		N			1	0	0	1
Lamiaceae (Mint Family)												
	<i>Teucrium canadense</i>	TECA	American germander	P		N			0	1	0	1
Molluginaceae (Carpetweed Family)												
	<i>Mollugo verticillata</i>	MOVE	green carpetweed	A			I		0	1	4	2
Myricaceae (Bayberry Family)												
	<i>Morella caroliniensis</i>	MOCA	northern bayberry	P		N			1	6	6	1
Onagraceae (Evening Primrose Family)												
	<i>Oenothera biennis</i>	OEBI	evening primrose	B		N			10	9	4	2
Plantaginaceae (Plantain Family)												
	<i>Plantago lanceolata</i>	PLLA	English plantain	P			I		1	0	0	0
	<i>Plantago major</i>	PLMA	common plantain	P			I		0	0	1	0
	<i>Plantago rugelii</i>	PLRU	American plantain	P		N			1	0	0	0
Poaceae (Grass Family)												
	<i>Agrostis gigantea</i>	AGGI	redtop bentgrass	P			I		0	1	0	1
	<i>Ammophila breviligulata</i>	AMBR	American beachgrass	P		N			0	1	0	4
	<i>Digitaria ischaemum</i>	DIIS	smooth crabgrass	A			I		1	1	6	0
	<i>Digitaria sanguinalis</i>	DISA	hairy crabgrass	A			I		0	2	0	0
	<i>Distichlis spicata</i>	DISP	saltgrass	P		N			17	4	10	4
	<i>Elymus virginicus</i>	ELVI	eastern wild-rye	P		N			0	1	0	0
	<i>Eragrostis pectinacea</i>	ERPE	tufted lovegrass	A		N			4	6	0	2
	<i>Eragrostis spectabilis</i>	ERSP	purple lovegrass	P		N			1	1	0	0
	<i>Festuca rubra</i>	FERU	red fescue	P			I		0	0	2	0
	<i>Panicum dichotiflorum</i>	PADI	fall panicgrass	A		N			0	0	0	3
	<i>Panicum virgatum</i>	PAVI	switchgrass	P		N			1	2	0	2
	<i>Phragmites australis</i>	PHAU	tall reed	P			I	Yes	23	7	7	4
	<i>Puccinellia fasciculata</i>	PUFA	saltmarsh alkali grass	A			I		0	0	1	0
	<i>Spartina alterniflora</i>	SPAL	smooth cordgrass	P		N			18	4	11	3
	<i>Spartina patens</i>	SPPA	saltmarsh hay	P		N			13	6	5	5
Polygonaceae (Buckwheat Family)												
	<i>Fallopia cristata</i>	FACR	crested bindweed	A		N			0	0	1	0
	<i>Persicaria lapathifolia</i>	PELA	dock-leaved smartweed	A		N			0	4	2	0
	<i>Persicaria maculosa</i>	PEMA	lady's-thumb smartweed	A			I		1	1	3	0
	<i>Persicaria pensylvanica</i>	PEPE	Pennsylvania smartweed	A		N			0	4	1	1
	<i>Polygonum aviculare</i>	POAV	dooryard knotweed	A			I		0	1	2	3
	<i>Polygonum cuspidatum</i>	POCU	Japanese knotweed	P			I	Yes	0	0	1	0
	<i>Polygonum glaucum</i>	POGL	seaside knotweed	A	State Threatened	N			6	5	3	2
	<i>Rumex crispus</i>	RUCR	curly dock	P			I		0	1	1	1
	<i>Rumex persicarioides</i> var. <i>persicarioides</i>	RUPE	American golden dock	A		N			0	0	2	0
Plumbaginaceae (Leadwort Family)												
	<i>Limonium carolinianum</i>	LICA	sea-lavender	P		N			1	0	0	0
Rosaceae (Rose Family)												
	<i>Prunus serotina</i>	PRSE	black cherry	P		N			0	0	1	0
	<i>Rosa rugosa</i>	RORU	rugosa rose	P			I	Yes	0	0	0	1
Salicaceae (Willow Family)												
	<i>Populus x. canescens</i>	POCA	white poplar hybrid	P			I	Yes	11	6	4	1
	<i>Populus tremuloides</i>	POTR	quaking aspen	P		N			0	3	2	0
	<i>Salix bebbiana</i>	SABE	Bebb's willow	P		N			0	2	2	1
	<i>Salix discolor</i>	SADI	pussy willow	P		N			8	0	0	0
Scrophulariaceae (Figwort Family)												
	<i>Verbascum thapsus</i>	VETH	mullein	B			I		1	0	0	0

Coastal Salt Pond Vascular Plant Species
Ninigret, Quonochontaug, and Winnapaug Ponds, 2018

Family	Species Name	USDA Species Code	Common Name	State-listed Rare Species Conservation Status	Native (N)	Introduced (I) Invasive*	Life Cycle: Annual (A) Biennial (B) Perennial (P)	Distribution Ninigret (Sediment Placement/C out/rd)	Distribution Quonochontaug	Distribution Winnepaug	Habitat Description
<p>Abundance Code A = Dominant or representative feature of habitat C = Locally abundant or frequently encountered O = Occasionally encountered or locally common U = Infrequently encountered, large population of R spp. R = Very few plants, single population</p>											
Adoxaceae (Moschatel Family)											
	<i>Sambucus nigra</i>	SANI	black elderberry		N		P		R		QP population on Bill's Island, mesic maritime woodland
	<i>Viburnum dentatum</i> var. <i>lucidum</i>	VIDEL	smooth arrowwood		N		P	O	C	C	QP upland old field habitat west of breachway, hydric areas of maritime shrubland,
	<i>Viburnum dentatum</i> var. <i>venosum</i>	VIDEV	northern arrowwood		N		P			R	WP upland old field habitat west side of breachway
Aizoaceae (Stone Plant Family)											
	<i>Sesuvium maritimum</i>	SEMA	annual sea-purslane	State concern	N		A	R			Ninigret Sed.Pl. Impact Site
Alismataceae (Water-plantain Family)											
	<i>Sagittaria latifolia</i>	SALA	common arrowhead		N		P			R	At edge of fill in clear cut portion of ASRI Lathrop Preserve
Amaranthaceae (Goosefoot Family)											
	<i>Atriplex acadiensis</i>	ATAC	maritime orache		N		A		R	R	QP Sed Pl. site occ. In wrack line at top of marsh; WP among Iva at top of marsh
	<i>Atriplex cristata</i>	ATCR	seabeach orache		N		A	R			Ninigret Sed. Pl. Impact Site
	<i>Atriplex glabrescens</i>	ATGL	bracted orache		N		A		R		QP Sed. Pl. site occ. In wrack line at top of marsh
	<i>Atriplex patula</i>	ATPA	spinescale atriplex		N		A			U	<50 plants east of Ray Property, with Iva, J. gerardii
	<i>Atriplex prostrata</i>	ATPR	hastate-leaved orache		N		A	C	C	C	common throughout in wrack lines along marsh; NP Sed. Pl. & QP Sed. Pl. Impact Sites
	<i>Atriplex subspicata</i>	ATSU	saline orache	State concern	N		A	R			Ninigret Sed. Pl. Impact Site
	<i>Chenopodium album</i>	CHAL	lambquarters			I	A	C	C	C	common in sandy areas along marsh wrack line
	<i>Chenopodium berlandieri</i>	CHBE	pit seeded goosefoot	State concern	N		A	R			Ninigret Sed. Pl. Impact Site
	<i>Chenopodium glaucum</i>	CHGL	oak-leaved goosefoot		N		A	C			Ninigret Sed. Pl. Impact Site comm. Throughout
	<i>Dysphania ambrosioides</i>	DYAM	Mexican tea			I	A	C			Ninigret Sed. Pl. Impact Site
	<i>Salsola kali</i>	SAKA	salt wort			I	A	U		R	Ninigret Sed. Pl. Impact Site; WP in wrack along top of marsh
	<i>Salicornia ambigua</i>	SAAM	perennial glasswort		N		P		R	O	QP w. side of breachway Sed. Pl. site, at ne edge of old breachway; WP northern end of Ray Property along Iva island in marsh, and occ. Throughout marsh
	<i>Salicornia bigelovii</i>	SABI	dwarf glasswort		N		A			U	Lathrop Property (prop. Sed. Pl. site) 3 locations in high marsh, 1 location east of Ray Property
	<i>Salicornia depressa</i>	SADL	common salicornia		N		A	A	A	A	common throughout high and low marsh
	<i>Suaeda linearis</i>	SULI	annual sea-blight		N		A			R	WP at top of marsh in wrack line
	<i>Suaeda maritima</i>	SUMA	herbaceous sea-blight			I	A	A	O	C	QP Sed. Pl. east side, In wrack at top of marsh; NP Sed. Pl. Impact site; WP top of marsh in wrack
	<i>Suaeda maritima</i> ssp. <i>richii</i>	SUMAR	herbaceous sea-blight	State concern	N		A	U		R	NP Sed. Pl. Impact Site; WP island in marsh adj to Atlantic Ave.
Anacardiaceae (Cashew Family)											
	<i>Rhus copallinum</i>	RUCO	winged sumac		N		P	C	C	C	throughout margins of woodlands; shrub dune; islands in QP, ASRI Lathrop
	<i>Toxicodendron radicans</i>	TORA	poison ivy		N		P	C	A	C	Noyes Island (QP), Bill's Island (QP), Hathaway Pres.; NP Sed. Pl. Control site island; WP maritime woodland, sand peninsulas, ASRI Lathrop Pres.
	<i>Toxicodendron rydbergii</i>	TORY	western poison ivy		N		P		C	C	QP & WP fringes of woodland/transition to maritime shrub habitat
	<i>Toxicodendron vernix</i>	TOVE	poison sumac		N		P			R	FWW above high marsh ASRI Lathrop Preserve
Apiaceae (Carrot Family)											
	<i>Aralia nudicaulis</i>	ARNU	wild sarsaparilla		N		P		R		QP Hathaway Pres., in mesic maritime woodland
	<i>Heracleum maximum</i>	HEMA	American cow-parsnip		N		P	U	U		NP Sed. Pl. Control site, openings in maritime woodland on island; mesic areas of rock islands in marsh
	<i>Ligusticum scoticum</i>	LISC	Scotch lovage	State concern	N		P		U		Hathaway Pres. and Quonnie Beach, in assoc. with freshwater inflow
	<i>Prillimium capillare</i>	PTCA	Atlantic mock Bishop weed	State concern	N		A			R	ASRI Lathrop Preserve, in assoc. with freshwater inflow
	<i>Sium suave</i>	SISU	hemlock water parsnip		N		P		U		QP Hathaway Preserve emergent marsh
Apocynaceae (Dogbane Family)											
	<i>Asclepias incarnata</i>	ASIN	swamp milkweed		N		P		U		QP On open rock islands
	<i>Asclepias syriaca</i>	ASSY	common milkweed		N		P	U	U		NP Sed. Pl. Control site, openings in maritime woodland on island; QP Hathaway Preserve, edge of high marsh in areas of FW outflow, emergent marsh
Aquifoliaceae (Holly Family)											
	<i>Ilex crinata</i>	ILCR	Japanese holly			I	P		R		QP Hathaway Preserve FWW red maple swamp
	<i>Ilex glabra</i>	ILGL	inkberry		N		P			R	FWW above high marsh ASRI Lathrop Preserve
	<i>Ilex opaca</i>	ILOP	American holly		N		P	U	U	U	mesic maritime woodlands throughout, fww Hathaway and ASRI Lathrop
	<i>Ilex verticillata</i>	ILVE	winterberry		N		P	A	C	C	shrub swamps throughout maritime dunes, FWW
Araceae (Arum Family)											
	<i>Arisaema triphyllum</i>	ARTR	jack-in-the-pulpit		N		P		R		Bill's Island (QP), Hathaway Preserve FWW red maple swamo
	<i>Lemna minor</i>	LEMI	common duckweed		N		A		U		QP Hathaway Preserve emergent marsh
	<i>Symplocarpus foetidus</i>	SYFO	skunk cabbage		N		P		O	O	FWW, red maple swamp Hathaway Preserve, ASRI Lathrop Preserve

Coastal Salt Pond Vascular Plant Species
Ninigret, Quonochontaug, and Winnapaug Ponds, 2018

Family	Species Name	USDA Species Code	Common Name	State-listed Rare Species Conservation Status	Native (N)	Introduced (I) Invasive*	Life Cycle: Annual (A) Biennial (B) Perennial (P)	Distribution Ninigret (Sed. Pl./Control)	Distribution Quonochontaug	Distribution Winnapaug	Habitat Description
								Abundance Code A = Dominant or representative feature of habitat C = Locally abundant or frequently encountered O = Occasionally encountered or locally common U = Infrequently encountered, large population of R spp. R = Very few plants, single population			
Asteraceae (Aster Family)											
	<i>Achillea millefolium</i>	ACMI	common yarrow		N		P		O	O	QP upland old field habitat west of breachway; WP on dredge spoils along west side of breachway, sand overwash area opp. Misquamicut Beach
	<i>Ambrosia artemisiifolia</i>	AMAR	ragweed		N		A	U	O		QP On open rock islands
	<i>Artemisia campestris</i>	AMCA	field wormwood	State concern	N		P		O		QP open portions of maritime herbaceous dune
	<i>Artemisia stelleriana</i>	AMST	beach wormwood			I	P		O		dune and open portions maritime herbaceous dune
	<i>Artemisia vulgaris</i>	ARVU	ragwort			I	P	C	O	C	maritime dune along sand trails; WP on top of fill for storm drain at Misquamicut Beach
	<i>Baccharis halimifolia</i>	BAHA	groundel tree		N		P	A	A	A	throughout maritime shrub zone at top of salt marsh
	<i>Bidens frondosa</i>	BIFR	Devil's beggar-ticks		N		A		U	U	QP, WP open areas of FWW red maple swamp
	<i>Bidens tripartita</i>	BITR	three-lobed beggar-ticks		N		A		R		QP open areas of FWW red maple swamp
	<i>Centaurea nigrescens</i>	CENI	short-fringed knapweed			I*	P			R	WP sand overwash opposite Misquamicut Beach
	<i>Erechtites hieracifolius</i>	ERHI	American burnweed		N		A	C	O	U	throughout open areas of maritime dune, sand overwash areas, woodland edges
	<i>Erigeron canadensis</i>	ERCA	Canada fleabane		N		A	O	O	U	through in open sandy areas of maritime dune and overwash
	<i>Eupatorium perfoliatum</i>	EUPE	common boneset		N		P			R	ASRI Lathrop Preserve emergent marsh understory of open shrub swamp above high marsh
	<i>Eurybia divaricata</i>	EUDI	white wood aster		N		P		R		Hathaway Preserve, mesic maritime woodland understory
	<i>Euthamia graminifolia</i>	EUGR	grass-leaved flat top goldenrod		N		P	C	C	O	mesic sandy areas throughout maritime dunes, maritime shrub adj. to high marsh
	<i>Galinsoga parviflora</i>	GAPA	quick-weed			I	A	R			Ninigret Sed. Pl. Impact Site
	<i>Iva frutescens</i>	IVFR	high tide bush		N		P	A	A	A	common throughout high marsh habitat, islands in marsh
	<i>Mikania scandens</i>	MISC	climbing hempvine		N		P		U		QP Hathaway Preserve emergent marsh
	<i>Nabalus trifolius</i>	NATR	three-leaved rattlesnake root		N		P		R		QP Hathaway Preserve FWW red maple swamp
	<i>Nipponanthemum nipponicum</i>	NINI	Nippon daisy			I	P		U		QP On open rock islands
	<i>Pluchea odorata</i>	PLOD	camphor-weed		N		P	O	O	C	Occ. In high marsh habitat; Ninigret Sed. Pl. Impact Site - possibly present prior to Sed. Pl.
	<i>Pseudognaphalium obtusifolium</i>	PSOB	blunt-leaved rabbit tobacco		N		A	C	C	C	open maritime dune throughout; WP upland old field habitat west side of breachway
	<i>Rudbeckia hirta</i>	RUHI	black-eyed Susan		N		P			O	WP on top of fill for storm drain at Misquamicut Beach (planted as cons. seed?)
	<i>Solidago aestivalis</i>	SOAE	swamp wrinkled goldenrod				P	U		U	WP ASRI Lathrop Preserve in openings in FWW red maple swamp; NP Sed. Pl. Control site island; WP sand overwash island at s. side of marsh
	<i>Solidago altissima</i>	SOAL	tall goldenrod		N		P	U			Ninigret Sed. Pl. Impact Site
	<i>Sanchus arvensis</i>	SOAR	field sow-thistle			I	A	R	R		Ninigret Sed. Pl. Impact Site; QP Sed. Pl. at edge of parking
	<i>Solidago gigantea</i>	SOGI	giant goldenrod		N		P			R	WP ASRI Lathrop Preserve in openings in FWW red maple swamp
	<i>Solidago rugosa</i>	SORU	wrinkled goldenrod		N		P	C	C	C	Hathaway Preserve, maritime shrub habitat immed. Adj. to high marsh
	<i>Solidago sempervirens</i>	SOSE	seaside goldenrod		N		P	C	C	C	common throughout high marsh and salt shrub habitat
	<i>Symphoricarum novi-begii</i>	SYBE	New York aster		N		P	U	O	U	wet areas of maritime dune throughout; Open areas of FWW within red maple swamp Hathaway & ASRI Lathrop Preserves
	<i>Symphoricarum tenuifolium</i>	SYTE	perennial salt marsh aster		N		P	O	C	C	QP Sed. Pl. site, WP common in high marsh throughout; NP Sed. Pl. Impact Site - possibly present prior to Sed. Pl.
	<i>Taraxicum officinale</i>	TAOF	dandelion			I	P	R			Ninigret Sed. Pl. Impact Site
	<i>Xanthium strumarium</i>	XAST	cockle-bur		N		A	U		R	NP Sed. Pl. Impact Site ; WP top of marsh in wrack line of sandy areas
Berberidaceae (Barberry Family)											
	<i>Berberis thunbergii</i>	BETH	Japanese barberry			I*	P		R		occ. In understory of red maple swamp, Hathaway Pres.
Brassicaceae (Mustard Family)											
	<i>Alitaria petiolata</i>	ALPE	garlic mustard			I*	B		U		FWW red maple swamp Hathaway Property
	<i>Cakile edentula</i>	CAED	sea rocket		N		A	C	O	O	common in sandy areas along marsh wrack line
	<i>Lepidium campestre</i>	LECA	field pepperweed			I	P	U			Ninigret Sed. Pl. Impact Site
	<i>Lepidium virginicum</i>	LEVI	poor-man's pepperweed		N		P	C	O	O	NP, QP, WP in open areas of maritime dune
	<i>Raphanus raphanistrum</i>	RARA	wild radish			I	B	U		U	NP Sed. Pl. Impact Site; WP in wrack at top of marsh
Campanulaceae (Harebell Family)											
	<i>Triodanis perfoliata</i>	TRPE	Venus' looking-glass		N		A	R	R		QP On open rock islands; NP Sed. Pl. Control site in open area of maritime woodland
Caprifoliaceae (Honeysuckle Family)											
	<i>Lonicera morrowii</i>	LOMO	Morrow's honeysuckle			I*	P	C	C	C	QP Hathaway Preserve, maritime shrub habitat adj. to high marsh, maritime dune habitat throughout, occ. In maritime dune and salt scrub habitat
Caryophyllaceae (Pink Family)											
	<i>Cerastium fontanum</i>	CEFO	mouse-eared chickweed			I	P		R		Hathaway Preserve, opening in maritime woodland adj. to marsh
	<i>Honkenya peploides</i>	HOPE	seaside sandwort	State concern	N		A	R			NP on beach face at top of sand trail
	<i>Moehringia luteiflora</i>	MOLA	grove sandwort		N		P		U	U	QP & WP sand overwash areas in openings in maritime woodland
	<i>Silene antirrhina</i>	SIAN	sleepy catchfly		N		A		R		QP On large open rock island
	<i>Spergularia marina</i>	SPMA	salt marsh sand spurry		N		A	O	U	O	NP Sed. Pl. Impact site, QP, WP in open flats in marsh
Celastraceae (Staff-tree Family)											
	<i>Celastrus orbiculatus</i>	CEOR	Oriental Bittersweet			I*	P	C	C	C	throughout at edges of FWW, maritime woodland
Cistaceae (Rockrose Family)											
	<i>Crocotanthemum canadense</i>	CRCA	Canada frostweed		N		P			U	WP upland old field habitat west side of breachway & on T. of Westerly parcel
	<i>Hudsonia tomentosa</i>	HUTO	woolly beach-heather		N		P	O	C	U	NP, QP, WP in open areas of maritime dune; WP upland old field habitat west side of breachway, opposite Misquamicut Beach
	<i>Lechea maritima</i>	LEMA	pinweed		N		P	C	C	O	NP, QP, WP in open areas of maritime dune; WP upland old field habitat west side of breachway
Clethraceae (White Alder Family)											
	<i>Clethra alnifolia</i>	CLAL	sweet pepper-bush		N		P	C	C	C	QP understory on Noyes Island, NP, QP backdune maritime woodlands, dense ASRI Lathrop red maple swamp

Coastal Salt Pond Vascular Plant Species
Ninigret, Quonochontaug, and Winnapaug Ponds, 2018

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Colchicaceae (Colchicum Family)											
	<i>Udularia sessilifolia</i>	UVSE	sessile-leaved bellwort		N		P		R		maritime shrub habitat in assoc. with freshwater inflow, top of marsh Hathaway Preserve
Comandraceae (Bastard-toadflax Family)											
	<i>Comandra umbellata</i>	COUM	bastard-toadflax		N		P		R		QP On open rock islands
Convolvulaceae (Morning Glory Family)											
	<i>Calystegia sepium</i>	CASE	hedge false bindweed		N		A	U	O	U	common in FWW adjacent to high marsh; QP Hathaway Preserve in emergent marshes
	<i>Cuscuta indecora</i>	CUIN	collared dodder	State Endangered	N		A		R		FWW, emergent marsh Hathaway Preserve
Cornaceae (Dogwood Family)											
	<i>Nyssa sylvatica</i>	NYSY	black gum		N		P		O	U	QP & WP - FWW, red maple swamp Hathaway & ASRI Lathrop Preserves, FWW red maple swamp; QP Noyes Island, maritime dune maritime woodland
Cupressaceae (Cypres Family)											
	<i>Juniperus horizontalis</i>	JUHO	creeping juniper		N		P			R	WP sand overwash opposite Misquamicut Beach (planted?)
	<i>Juniperus virginiana</i>	JUVI	eastern red cedar		N		P	C	C	C	common throughout maritime dune, along high marsh, and FWW margins throughout maritime dune, open rock islands, salt marsh scrub, sandy overwash, edges of maritime woodland
Cyperaceae (Sedge Family)											
	<i>Bolboschoenus maritimus</i>	BOMA	salt marsh tuber bulrush	State Concern	N		P	U			Ninigret Sed. Pl. Impact Site - possibly present prior to Sed. Pl.
	<i>Carex argyrantha</i>	CAAR	silvery-flowered sedge		N		P		O	R	QP in open areas of maritime dune; WP maritime herbaceous dune opposite Misquamicut Beach
	<i>Carex bullata</i>	CABU	button sedge		N		P			C	ASRI Lathrop Pres., in shrub swamp adjacent to high marsh
	<i>Carex comosa</i>	CACO	longhair sedge		N		P			R	ASRI Lathrop Pres., in shrub swamp adjacent to high marsh
	<i>Carex debilis</i>	CADE	white edge sedge		N		P		O	O	Hathaway & ASRI Lathrop Pres., understory of FWW red maple swamps
	<i>Carex folliculata</i>	CAFO	long sedge		N		P		R		maritime shrub habitat in assoc. with freshwater inflow, top of marsh Hathaway Preserve
	<i>Carex intumescens</i>	CAIN	greater bladder sedge		N		P		U	U	QP, WP open areas of FWW red maple swamp
	<i>Carex kobomugi</i>	CAKO	Asiatic sand sedge			I*	P	C	O		dune strand and along sand trail
	<i>Carex muehlenbergii</i>	CAMU	Muehlenberg's sedge		N		P	R			NP Sed. Pl. Control site, openings in maritime woodland on island
	<i>Carex pensylvanica</i>	CAPE	early sedge		N		P		O	C	shrub understory in sandy overwash, understory of maritime woodland
	<i>Carex scoparia</i>	CASC	broom sedge		N		P		C	C	ASRI Lathrop Pres. open areas of shrub swamp adjacent to high marsh (WP), Hathaway Pres. in emergent marsh (QP)
	<i>Carex stricta</i>	CAST	upright sedge		N		P		O	O	open areas of shrub swamp adjacent to high marsh (WP), in wetmeadows (QP)
	<i>Carex swanii</i>	CASW	Swan's sedge		N		P		O		QP emergent marsh areas
	<i>Carex utriculata</i>	CAUR	Northwest Territory sedge		N		P			C	WP ASRI Lathrop Preserve above brackish marsh in shrub swamp
	<i>Cyperus filicinus</i>	CYFI	fern flatsedge		N		A	C	O	O	common in open sandy fww transition areas btwn. High marsh and maritime shrubland
	<i>Cyperus gravi</i>	CYGR	Gray's flatsedge		N		P		U	R	QP, WP in open areas of maritime dune, maritime herbaceous dune opp. Misquamicut St. Beach
	<i>Cyperus odoratus</i>	CYOD	fragrant flatsedge	State Endangered	N		A		R		FWW, emergent marsh Hathaway Preserve
	<i>Cyperus squarrosus</i>	CYSQ	awned flatsedge	State Endangered	N		A	C			NP Sed. Pl. Impact Site
	<i>Cyperus strigosus</i>	CYST	straw-colored flatsedge		N		A	O		O	NP Sed. Pl. Impact Site; WP occ. Along wet meadow along Atlantic Ave.
	<i>Eleocharis palustris</i>	ELPA	common spikesedge		N		P		U		FWW, emergent marsh Hathaway Preserve
	<i>Eleocharis rostellata</i>	ELRO	beaked spikesedge	State Concern	N		P	U			brackish marsh, NP Sed. Pl. Control Site (USFWS)
	<i>Eleocharis uniglumis</i>	ELUN	on-glumed spikesedge		N		P			U	brackish marsh/Sea-Level Fen transition area, ASRI Lathrop Preserve
	<i>Schoenoplectus pungens</i>	SCPU	three-square bulrush		N		P	O	O	O	common in brackish marsh throughout in areas assoc with freshwater inflow; NP Sed. Pl. Impact Site - possibly present prior to Sed. Pl.
	<i>Schoenoplectus tabernaemontana</i>	SCTA	soft-stemmed bulrush		N		P	U			NP Sed. Pl. Impact Site - possibly present prior to Sed. Pl.
	<i>Scirpus cyperinus</i>	SCCY	wool-grass		N		P			R	WP ASRI Lathrop Preserve in openings in FWW red maple swamp
Dryopteridaceae (Woodfern Family)											
	<i>Dryopteris carthusiana</i>	DRCA	spinulose woodfern		N		P		R		FWW, red maple swamp Hathaway Preserve
Elaeagnaceae (Oleaster Family)											
	<i>Elaeagnus umbellata</i>	ELUM	autumn olive			I*	P			U	WP upland old field habitat west side of breachway
Equisetaceae (Horsetail Family)											
	<i>Equisetum arvense</i>	EQAR	field horsetail		N		P			U	WP ASRI Lathrop Preserve open area FWW red maple swamp
Ericaceae (Heath Family)											
	<i>Gaylussacia baccata</i>	GABA	huckleberry		N		P			U	FWW above brackish marsh ASRI Lathrop Preserve (sea level fen)
	<i>Lyonia ligustrina</i>	LYLI	male-berry		N		P		U	O	open areas of shrub swamp adjacent to high marsh (WP), in shrub swamp (QP)
	<i>Rhododendron viscosum</i>	RHVI	swamp azalea		N		P		X	X	Hathaway & ASRI Lathrop Preserves, shrub swamp adj. to high marsh
	<i>Vaccinium corymbosum</i>	VACO	highbush blueberry		N		P	O	C	A	Throughout hydric areas of maritime dune, maritime shrub habitat, mesic maritime woodland, Fww (Lathrop & Hathaway Preserves)
Euphorbiaceae (Spurge Family)											
	<i>Euphorbia polygonifolia</i>	EUPO	seaside sand-mat		N		A	U	U	R	Occ. On open sand throughout maritime dunes and occ. In sand overwash areas on marsh
Fabaceae (Bean Family)											
	<i>Apios americana</i>	APAM	ground nut		N		P			R	WP ASRI Lathrop Preserve above brackish marsh in shrub habitat
	<i>Baptisia tinctoria</i>	BATI	wild indigo		N		P			R	WP upland old field habitat west side of breachway
	<i>Lathyrus japonicus</i>	LAJA	beach pea		N		P	U	C	U	throughout maritime dune habitat
	<i>Lespedeza capitata</i>	LECA	tall bush-clover		N		P			U	WP upland old field habitat west side of breachway
	<i>Strophostyles helvola</i>	STHE	annual wooly bean		N		A	R	R		NP Sed. Pl. Impact Site; QPSed. Pl. site, west along shrub edge, QP on open rock islands
	<i>Trifolium arvense</i>	TRAR	rabbits-foot clover			I	A	R			Ninigret Sed. Pl. Impact Site
	<i>Trifolium repens</i>	TRRE	white clover			I	P	R			Ninigret Sed. Pl. Impact Site
Fagaceae (Beech Family)											
	<i>Quercus velutina</i>	QUVE	black oak				P		C	C	WP upland old field habitat west side of breachway, QP Noyes Island; WP margins of FWW at ASRI Lathrop Preserve

Coastal Salt Pond Vascular Plant Species
Ninigret, Quonochontaug, and Winnapaug Ponds, 2018

Family	Species Name	USDA Species Code	Common Name	State-listed Rare Species Conservation Status	Native (N)	Introduced (I) Invasive*	Life Cycle: Annual (A) Biennial (B) Perennial (P)	Distribution Ninigret (Sed. Pl./Control)	Distribution Quonochontaug	Distribution Winnepaug	Habitat Description
								Abundance Code A = Dominant or representative feature of habitat C = Locally abundant or frequently encountered O = Occasionally encountered or locally common U = Infrequently encountered, large population of R spp. R = Very few plants, single population			
Grossulariaceae (Current Family)											
	<i>Ribes hirtellum</i>	RIHI	hairy-stem gooseberry	State Concern	N		P		R		Hathaway Preserve and Quonnie Beach, FWW, shrub swamp
Haloragaceae (Water-milfoil Family)											
	<i>Proserpinaca palustris</i>	PRPI	marsh mermaid-weed		N		A		R		QP Hathaway Preserve emergent marshes
Hypericaceae (St. John's-wort Family)											
	<i>Hypericum mutilum</i>	HYMU	dwarf St. John's-wort		N		A		R		QP Hathaway Preserve emergent marsh
	<i>Triadenum virginicum</i>	TRVI	Virginia marsh St. John's-wort		N		A	U	O	U	NP, QP, WP at top of high marsh in assoc with fw inflow, open areas of FWW ASRI Lathrop & Hathaway Preserves
Iridaceae (Iris Family)											
	<i>Iris prismatica</i>	IRPR	slender blue iris		N		P		U		brackish marsh, north side of QP
	<i>Iris versicolor</i>	IRVE	harlequin blue-flag iris		N		P		U		maritime shrub habitat in assoc. with freshwater inflow, top of marsh Hathaway Preserve
Juncaceae (Rush Family)											
	<i>Juncus antheratus</i>	JUAN	Weigand's rush		N		P		R		maritime shrub habitat in assoc. with freshwater inflow, top of marsh Hathaway Preserve
	<i>Juncus canadensis</i>	JUCA	Canada rush		N		P		U	O	emergent marshes within FWW on Hathaway and ASRI Lathrop Preserve
	<i>Juncus dichotomus</i>	JUDI	forked rush		N		P		R		island south of Bill's Is. (QP) at top of high marsh, in assoc. with freshwater
	<i>Juncus effusus</i>	JUEF	soft rush		N		P		C	O	Open FWW within red maple swamp Hathaway & ASRI Lathrop Preserves
	<i>Juncus gerardii</i>	JUGE	black rush		N		P	A	A	A	common throughout high marsh habitat; Ninigret Sed. Pl. Impact Site - possibly present prior to Sed. Pl.
	<i>Juncus pylaei</i>	JUPY	Pyle's rush		N		P		O		maritime shrub habitat in assoc. with freshwater inflow, top of marsh Hathaway Preserve
	<i>Juncus tenuis</i>	JUTE	path rush		N		P		U		QP On open rock islands
	<i>Luzula luculoides</i>	LULU	oak-forest woodrush			I	P		R		Hathaway Preserve, maritime woodland adj. to marsh
Juncaginaceae (Arrow-grass Family)											
	<i>Triglochin maritima</i>	TRMA	salt marsh arrow-grass		N		P	O	U	O	WP Ray & Lathrop Properties (WP Sed. Pl. prop. Sites), QP Hathaway Preserve; NP Sed. Pl. Control site in upper reaches of salt scrub habitat ; NP Sed. Pl. Impact Site - possibly present prior to Sed. Pl.
Juglandaceae (Walnut Family)											
	<i>Carva glabra</i>	CAGL	pignut hickory		N		P		U		Maritime woodland, Noyes Island (QP)
Lamiaceae (Mint Family)											
	<i>Lycopus uniflorus</i>	LYUN	northern bugleweed		N		A		R		QP Hathaway Preserve emergent marsh
	<i>Lycopus virginicus</i>	LYVI	Virginia water-horehound		N		A			U	WP ASRI Lathrop Preserve openings in FWW red maple swamp
	<i>Scutellaria galericulata</i>	SCGA	marsh skullcap		N		P		R		QP Hathaway Preserve emergent marsh
	<i>Teucrium canadense</i>	TECA	American germander		N		P	C	C	C	common in upper reaches of salt scrub habitat throughout; FWW emergent marsh Hathaway Preserve; QP open rock islands; NP Sed. Pl. Impact site
Lauraceae (Laurel Family)											
	<i>Sassafras albidum</i>	SAAL	sassafras		N		P		C	C	margins of FWW, red maple swamp Hathaway Preserve; marsh island opposite Hathaway Preserve, dying; QP & WP rock islands
Liliaceae (Lily Family)											
	<i>Eritronium americanum</i>	ERAM	American trout-lily		N		P		U		extensive groundcover, Noyes Island (QP)
	<i>Lilium superbum</i>	LISU	Turk's-cap-lily		N		P		R	R	Bill's Island (QP); WP ASRI Lathrop Preserve
Lythraceae (Loosestrife Family)											
	<i>Lythrum salicaria</i>	LYSA	purple loosestrife			I*	P			R	WP ASRI Lathrop Preserve opening in FWW red maple swamp
Malvaceae (Mallow Family)											
	<i>Hibiscus moscheutos</i>	HIMO	marshmallow		N		P			U	WP ASRI Lathrop Preserve high marsh
	<i>Tilia americana</i>	TIAM	American basswood		N		P		R		Noyes Island (QP), Bill's Island (QP)
Molluginaceae (Carpetweed Family)											
	<i>Mollugo verticillata</i>	MOVE	green carpetweed			I	A	U			Ninigret Sed. Pl. Impact Site
Myricaceae (Bayberry Family)											
	<i>Comptonia peregrina</i>	COPE	sweet-fern		N		P			U	WP upland old field habitat west side of breachway
	<i>Morella carolinensis</i>	MOCA	northern bayberry		N		P	C	C	C	common throughout upper marsh edge/transition zone; NP, QP, WP in maritime dune, QP on rock islands, salt scrub habitat throughout
Myrsinaceae (Marlberry Family)											
	<i>Lysimachia hybrida</i>	LYHY	lowland yellow-loosestrife		N		A		U		QP Hathaway Preserve FWW red maple swamp
	<i>Lysimachia terrestris</i>	LYTE	earth loosestrife		N		P		R	U	open areas of shrub swamp adjacent to high marsh (WP), margins of emergent marsh (QP)
Oleaceae (Olive Family)											
	<i>Ligustrum vulgare</i>	LIVU	European privet			I*	P		R		island south of Bill's Is. (QP)
Onagraceae (Evening Primrose Family)											
	<i>Circaea canadensis</i>	CICA	broad-leaved enchanter's nightshade		N		A	R			NP Sed. Pl. Control site, openings in maritime woodland on island
	<i>Ludwigia palustris</i>	LUPA	marsh seedbox				A		U		QP Hathaway Preserve emergent marsh
	<i>Oenothera biennis</i>	OEBI	evening primrose		N		B	O	O	U	QP On open rock islands, QP & WP upland old field habitat west of breachways; maritime dune habitat throughout; Ninigret Sed. Pl. Impact Site
Onocleaceae (Sensitive Fern Family)											
	<i>Onoclea sensibilis</i>	ONSE	sensitive fern		N		P		U		maritime shrub habitat in assoc. with freshwater inflow, top of marsh Hathaway Preserve
Orabanchaceae (Broom-rape Family)											
	<i>Agalinis maritima</i>	AGMA	salt marsh agalinis		N		P			U	RIDEM prop at Misquamicut Beach, Ray Property & Lathrop Property (prop. Sed. Pl. sites)
	<i>Agalinis purpurea</i>	AGPU	purple agalinis		N		P			R	2 locations in high marsh
Orchidaceae (Orchid Family)											
	<i>Epipactis helleborine</i>	EPHE	broad-leaved helleborine			I	P		R		edge of Atl Ave in wet meadow/roadside ditch
											island south of Bill's Is. (QP)

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Osmundaceae (Royal Fern Family)											
	<i>Osmunda regalis</i>	OSRE	royal fern		N		P		U	O	maritime shrub habitat in assoc. with freshwater inflow at top of marsh, FWW understory Hathaway & ASRI Lathrop Preserves
	<i>Osmundastrum cinnamomeum</i>	OSCI	cinnamon fern		N		P		C	C	maritime shrub habitat in assoc. with freshwater inflow at top of marsh, FWW understory Hathaway & ASRI Lathrop Preserves
Pinaceae (Pine Family)											
	<i>Pinus thunbergii</i>	PITH	Japanese black pine			I	P	C	C	U	planted throughout maritime dunes; WP upland old field habitat west side of breachway
Plantaginaceae (Plantain Family)											
	<i>Plantago lanceolata</i>	PLLA	English plantain			I	P	R			Ninigret Sed. Pl. Impact Site
	<i>Plantago major</i>	PLMA	common plantain			I	P	R			Ninigret Sed. Pl. Impact Site
	<i>Plantago maritima</i>	PLMAR	seaside plantain		N		P		U	O	WP Occ. in high marsh habitat often with Agalinus; QP Sed. Pl. Impact site, Hathaway Pres. On boulders in marsh
	<i>Plantago rugelii</i>	PLRU	American plantain		N		P	R			Ninigret Sed. Pl. Impact Site
Poaceae (Grass Family)											
	<i>Agrostis gigantea</i>	AGGI	redtop bentgrass			I	P	R			Ninigret Sed. Pl. Impact Site
	<i>Agrostis hyemalis</i>	AGHY	winter bentgrass		N		P		O	U	WP, QP top of high marsh
	<i>Agrostis perennans</i>	AGPE	autumn bentgrass		N		P		U	U	QP upland old field habitat west of breachways; WP upper edge of sandy areas along marsh
	<i>Agrostis stolonifera</i>	AGST	creeping bentgrass			I	P		O		Hathaway Preserve, emergent marsh along seasonal ponds
	<i>Ammophila brevifigulata</i>	AMBR	American beachgrass		N		P	A	A	A	dune throughout, sandy margins of upper salt marsh
	<i>Andropogon virginicus</i>	ANVI	broom-sedge		N		P			O	WP ASRI Lathrop Preserve clear cut area
	<i>Anthoxanthum nitens</i>	ANNI	sweetgrass		N		P			R	WP ASRI Lathrop Preserve, brackish marsh
	<i>Dicanthelium linearifolium</i>	DILI	linear-leaved panicgrass		N		P		U		QP Bill's Island and lg. rock island
	<i>Dicanthelium scoparium</i>	DISC	velvety rosette panicgrass	State Historic	N		P		U		QP. Breachway berm (west side) Old field mosaic of herbaceous species and woody shrubs
	<i>Dicanthelium wrightianum</i>	DIWR	Wright's panicgrass	State Concern	N		P		U		QP Hathaway Preserve, edge of emergent marsh
	<i>Digitaria ischaemum</i>	DIIS	smooth crabgrass			I	A	U		R	NP Sed. Pl. Impact site; QP in sand overwash areas adj to parking lots
	<i>Digitaria sanguinalis</i>	DISA	hairy crabgrass			I	A	R			Ninigret Sed. Pl. Impact Site
	<i>Distichlis spicata</i>	DISP	saltgrass		N		P	A	A	A	common throughout high marsh habitat
	<i>Echinochloa walteri</i>	ECWA	coast cocksbur grass		N		A		C		FWW, emergent marsh Hathaway Preserve
	<i>Elymus villosus</i>	ELVI	downy wild-rye	State Concern	N		P	R			NP Sed. Pl. Control site, mesic maritime woodland on rock island
	<i>Elymus virginicus</i>	ELVI	eastern wild-rye		N		P	R			Ninigret Sed. Pl. Impact Site
	<i>Eragrostis pectinacea</i>	ERPE	tufted lovegrass		N		A	U			Ninigret Sed. Pl. Impact Site
	<i>Eragrostis spectabilis</i>	ERSP	purple lovegrass		N		P	U	U	U	NP Sed. Pl. Impact site; QP & WP upland old field habitat west of breachways, upper edge of sandy areas along marsh
	<i>Festuca ovina</i>	FEOV	sheep fescue			I	P			C	WP upland old field habitat west side of breachway, open areas of sand overwash islands
	<i>Festuca rubra</i>	FERU	red fescue			I	P	R			Ninigret Sed. Pl. Impact Site
	<i>Festuca subverticillata</i>	FESU	nodding fescue		N		P	R			NP Sed. Pl. Control site, openings in maritime woodland on island
	<i>Glyceria obtusa</i>	GLOB	Atlantic mannagrass		N		P		C	O	Open FWW within red maple swamp Hathaway & ASRI Lathrop Preserves
	<i>Glyceria striata</i>	GLST	fowl mannagrass		N		P			U	Open FWW within red maple swamp ASRI Lathrop Preserve
	<i>Leersia virginica</i>	LIVI	whitegrass		N		P		O		QP Hathaway Preserve emergent marsh
	<i>Panicum capillare</i>	PACA	witch panicgrass		N		A		O		QP Hathaway Preserve emergent marsh
	<i>Panicum clandestinum</i>	PACL	deers-tongue		N		P		O	C	Bill's Island (QP); WP on top of fill for storm drain at Misquamicut Beach (planted as cons. seed?)
	<i>Panicum dichotiflorum</i>	PADI	fall panicgrass		N		P	U			Ninigret Sed. Pl. Impact Site
	<i>Panicum virgatum</i>	PAVI	switchgrass		N		P	C	C	C	QP On open rock islands, QP & WP upland old field habitat west of breachways; maritime dune habitat and transition to brackish marsh habitat throughout
	<i>Phalaris arundinacea</i>	PHAR	reed-canary grass			I*	P		U	O	WP ASRI Lathrop & Hathaway Preserves in openings in FWW red maple swamp
	<i>Phragmites australis</i>	PHAU	common reed			I*	P	A	A	A	common throughout openings in FWW red maple swamp, and high marsh habitat in assoc. with freshwater inflow, septic systems, and disturbance
	<i>Poa palustris</i>	POPA	fowl bluegrass		N		P	U	U		NP Sed. Pl. Control site, mesic area of NP Sed. Pl. Control site, rock island; QP Hathaway Preserve emergent marsh
	<i>Puccinellia fasciculata</i>	PUFA	salt marsh alkali grass			I	A	R			NP Sed. Pl. Impact Site
	<i>Schizachyrium scoparium</i>	SCSC	little bluestem		N		P			U	WP upland old field habitat west side of breachway
	<i>Sorghastrum nutans</i>	SONU	Indian grass	State Concern	N		P		U	U	QP old field north shore of pond; WP on top of fill for storm drain at Misquamicut Beach (planted as cons. seed?)
	<i>Spartina alterniflora</i>	SPAL	smooth cordgrass		N		P	A	A	A	common throughout; NP Sed. Pl. Impact Site - possibly present prior to Sed. Pl.
	<i>Spartina patens</i>	SPPA	salt marsh hay		N		P	C	A	A	common throughout; NP Sed. Pl. Impact Site - possibly present prior to Sed. Pl.
	<i>Spartina pectinata</i>	SPPE	prairie cordgrass		N		P	U	U	U	QP maritime shrub habitat in assoc. with freshwater inflow, top of marsh Hathaway Preserve; NP, WP highest marsh areas

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Polygonaceae (Buckwheat Family)											
	<i>Fallopia cristata</i>	FACR	crested bindweed		N		A	R	U		NP Sed. Pl. Impact site; QP On open rock islands, maritime dune
	<i>Fallopia scandens</i>	FASC	climbing bindweed		N		A			U	along Atlantic Ave. in shrubs where marsh abuts roadway
	<i>Persicaria hydropiperoides</i>	PEHY	false water-pepper smartweed		N		A		O		QP Hathaway Preserve emergent marsh
	<i>Persicaria lapathifolia</i>	PELA	dock-leaved smartweed		N		A		O		mesic open areas of rock islands (QP)
	<i>Persicaria longisteta</i>	PELO	Oriental lady's thumb smartweed			I	A		U		QP Hathaway Preserve emergent marsh
	<i>Persicaria maculosa</i>	PEMA	lady's-thumb smartweed			I	A	O			NP Sed. Pl. Impact Site
	<i>Persicaria pennsylvanica</i>	PEPE	Pennsylvania smartweed		N		A	O			NP Sed. Pl. Impact Site
	<i>Persicaria punctata</i>	PEPU	dotted smartweed		N		A		O	U	emergent marshes within FWW on Hathaway and ASRI Lathrop Preserve
	<i>Persicaria sagittata</i>	PESA	arrow-leaved tearthumb		N		A			U	WP ASRI Lathrop Preserve openings in FWW red maple swamp
	<i>Polygonum articulatum</i>	POAR	sand joint-weed		N		P	U	O	U	NP, Qp, WP in open areas of maritime dune; WP sand overwash opposite Misquamicut Beach
	<i>Polygonum aviculare</i>	POAV	dooryard knotweed			I	A	U			NP Sed. Pl. Impact Site
	<i>Polygonum cuspidatum</i>	POCU	Japanese knotweed			I*	P	C			NP Sed. Pl. Impact site; NP in maritime dune, along sand trail
	<i>Polygonum glaucum</i>	POGL	seaside knotweed	State Threatened	N		A	U			NP on beach face at top of sand road
	<i>Rumex acetosella</i>	RUAC	sheep sorrel			I	P	R		U	WP upland old field habitat west side of breachway, sand overwash area opp. Misquamicut Beach; NP backdune
	<i>Rumex crispus</i>	RUCR	curly dock			I	P	O	U		NP Sed. Pl. Impact Site; QP. On large open rock island and Hathaway Preserve emergent marshes
	<i>Rumex persicarioides</i> var. <i>persicarioides</i>	RUPE	American golden dock		N		A	R			NP Sed. Pl. Impact Site
Plumbaginaceae (Leadwort Family)											
	<i>Linum catharticum</i>	LICA	sea-lavender		N		P	O	O	O	QP Sed. Pl. site, common throughout high marsh habitat on all ponds
Rhamnaceae (Buckthorn Family)											
	<i>Frangula alnus</i>	FRAL	glossy buck-thorn			I*	P	U		C	WP upland old field habitat west side of breachway, and occ in understory of maritime woodland on islands in marsh; NP maritime dune; WP ASRI Lathrop Preserve open area FWW red maple swamp
Rosaceae (Rose Family)											
	<i>Amelanchier canadensis</i>	AMCA	eastern shadbush		N		P	C	C	C	dry knolls within marsh, rock islands, maritime woodland throughout; Edge of maritime shrub zone along salt marsh, throughout mesic areas of maritime woodlands
	<i>Amelanchier nantucketensis</i>	AMNA	Nantucket shadbush	State Threatened	N		P		U	R	QP maritime dune shrub habitat; WP dredge spoil area west of breachway, overwash islands at south end of marsh
	<i>Argentina egedii</i>	AREG	Pacific silverweed		N		P			U	WP ASRI Lathrop Preserve, brackish marsh, edge of salt marsh
	<i>Aronia floribunda</i>	ARFL	purple chokeberry		N		P		O		QP Hathaway Preserve, edge of brackish marsh in areas of FW outflow
	<i>Aronia melanocarpa</i>	ARME	black chokeberry		N		P	C	C	C	maritime dune shrub swamps, dense on WP ASRI Lathrop Preserve; maritime dune throughout, sandy margins of brackish marsh
	<i>Prunus maritima</i>	PRMA	beach plum		N		P		O		QP throughout shrub habitat in maritime dune
	<i>Prunus serotina</i>	PRSE	black cherry		N		P	O	O	O	seedling at NP Sed. Pl. Impact Site; Throughout mesic areas of maritime woodland adj. to high marsh, sQP & WP upland old field habitat west of breachways, upper edge of sandy areas along marsh
	<i>Rosa multiflora</i>	ROMU	multiflora rose			I*	P		O	O	NP, QP Hathaway & WP ASRI Lathrop Preserves, shrub swamp adj. to brackish marsh
	<i>Rosa rugosa</i>	RORU	wrinkled rose			I*	P	C	C	C	maritime dune shrub habitat throughout; NP, QP Hathaway & WP ASRI Lathrop Preserves, shrub swamp adj. to high marsh
	<i>Rosa palustris</i>	ROPA	swamp rose		N		P	U	C	C	wetland shrub habitat throughout; NP, QP Hathaway & WP ASRI Lathrop Preserves, shrub swamp adj. to high marsh
	<i>Rosa virginiana</i>	ROVI	Virginia rose		N		P	C	C	C	QP On open rock islands; maritime dune habitat throughout; WP upland old field habitat west of breachway
	<i>Rubus alleghaniensis</i>	RUAL	Alleghany blackberry		N		P	O	O	C	maritime dune shrub habitat throughout; QP & WP upland old field habitat west of breachways; shrub swamp adjacent to high marsh
	<i>Rubus flagellaris</i>	RUFL	prickly dewberry		N		P	U	O	C	QP On open rock islands; NP, QP, WP maritime dune & sand overwash areas
	<i>Rubus hispidus</i>	RUHI	swamp dewberry		N		P		O	C	Hathaway & ASRI Lathrop Preserves, understory of FWW red maple swamp
	<i>Rubus phoenicolasius</i>	RUPH	wineberry			I*	P		U		Hathaway Preserve, in understory of FWW red maple swamp
	<i>Spiraea tomentosa</i>	SPTO	steepbush		N		P		R		QP Hathaway Preserve shrub margins of emergent marsh
Rubiaceae (Madder Family)											
	<i>Galium palustre</i>	GAPA	marsh bedstraw		N		A		U		QP sand flat along old breachway
	<i>Galium tinctorium</i>	GATI	stiff marsh bedstraw		N		A		O	O	FWW above high marsh Hathaway & ASRI Lathrop Preserves
	<i>Galium trifidum</i>	GATR	three petal bedstraw		N		A		O		QP Hathaway Preserve emergent marsh
Ruppiaceae (Ditch-grass Family)											
	<i>Ruppia maritima</i>	RUMA	widgeon grass		N		P		O		QP in large salt marsh creek, opposite Bill's Island, QP Sed. Pl. site in marsh pool west of breachway
Ruscaceae (Butcher's Broom Family)											
	<i>Maianthemum canadense</i>	MACA	Canada mayflower		N		P	C	C	C	Mesic understory of maritime woodlands Hathaway & ASRI Lathrop Preserves (QP & WP), rock islands and sand overwash areas (NP, QP, WP)
	<i>Maianthemum stellatum</i>	MAST	star-like false Solomon's seal		N		P		C		several large patches in understory of maritime dune shrub habitat

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Salicaceae (Willow Family)											
	<i>Populus x. canadensis</i>	POCA	white poplar hybrid			I*	P	O			NP Sed. Pl. Impact Site
	<i>Populus tremuloides</i>	POTR	quaking aspen		N		P	O	R		NPSed. Pl. Impact site; QP west side of breachway, dredge spoil area
	<i>Salix bebbiana</i>	SABE	Bebb's willow		N		P	U			NP Sed. Pl. Impact Site
	<i>Salix cinerea</i>	SACI	European gray pussy willow			I*	P	O	C	C	QP upland old field habitat west of breachway; common throughout shrub swamp margins
	<i>Salix discolor</i>	SADI	pussy willow		N		P	O			NP Sed. Pl. Impact Site
Sapindaceae (Soap-berry Family)											
	<i>Acer platanoides</i>	ACPL	Norway maple			I*	P		U		QP Bill's Island
	<i>Acer rubrum</i>	ACRU	red maple		N		P	C	C	C	common in maritime dune woodlands, rock islands, maritime woodland along salt marsh edge, red maple swamp Hathaway Preserve & ASRI Lathrop Preserve
Scrophulariaceae (Figwort Family)											
	<i>Scrophularia lanceolata</i>	SCLA	lance-leaved figwort	State Concern	N		P	U	O		NP Sed. Pl. Control site - openings in mesic maritime woodland on island; QP mesic red maple areas of rock islands in marsh
	<i>Verbascum thapsus</i>	VETH	mullein			I	B			U	WP upland old field habitat west side of breachway
Smilacaceae (Catbrier Family)											
	<i>Smilax rotundifolia</i>	SMRO	greenbrier		N		P	C	A	C	Noyes Island (QP), Bill's Island (QP), Hathaway Preserve (QP), ASRI Lathrop Preserve (WP) NPSed. Pl. Control site island; WP maritime woodland, sand overwash islands
Solanaceae (Nightshade Family)											
	<i>Solanum dulcamara</i>	SODU	climbing nightshade			I	A		O		QP Hathaway Preserve emergent marsh, Mesic transition areas of rock islands
Thelypteridaceae (Marsh fern Family)											
	<i>Thelypteris palustris</i>	THPA	marsh fern		N		P	R	O	O	Ninigret Control Site, Forested wetland Hathaway & ASRI Lathrop
Typhaceae (Cat-tail family)											
	<i>Spartanium americana</i>	SPAM	American bur-reed		N		P		C		QP Hathaway Preserve emergent marshes
	<i>Typha angustifolia</i>	TYAN	narrow leaved cat-tail		N		P		C	C	Shrub swamp adj. to high marsh Hathaway & ASRI Lathrop Preserves
	<i>Typha latifolia</i>	TYLA	common cat-tail		N		P	O		O	emergent marshes, maritime dune NP and ASRI Lathrop Preserve
Vitaceae (Grape Family)											
	<i>Ampelopsis glandulosa</i>	AMGL	porcelain berry			I*	P		C		QP Sed. Pl. site edge of salt marsh adj. to houses (salt scrub and ruderal marsh), and Hathaway Preserve in assoc. with freshwater inflow, in shrub swamp & red maple swamp margins of maritime woodland, FWW, maritime dune scrub shrub, sand hummock islands throughout
	<i>Parthenocissus quinquefolia</i>	PAQU	Virginia creeper		N		P	C	C	C	hydric areas of maritime dune, maritime shrub habitat, mesic maritime woodland, red maple swamp (Lathrop & Hathaway Preserves) throughout
	<i>Vitis labrusca</i>	VILA	fox grape		N		P	C	C	C	
Zosteraceae (Eel-grass Family)											
	<i>Zostera marina</i>	ZOMA	eel-grass		N		P	C	C	C	submerged beds throughout coastal lagoons

FQA Vegetation Survey for Vulnerable Coastal Wetlands
Hathaway Preserve, Quonochontaug Pond
Lathrop Preserve, Winnapaug Pond

Family	Species Name	USDA Species Code	Common Name	State-listed Rare Species Conservation Status	Native (N)	Introduced (I) Invasive*	Life Cycle: Annual (A) Biennial (B) Perennial (P)	Present in Forested Wetland Hathaway Preserve	Present in Forested Wetland Lathrop Preserve
Adoxaceae (Moschatel Family)									
	<i>Viburnum dentatum</i> var.	VIDEL	smooth arrowwood		N		P	yes	yes
Alismataceae (Water-plantain Family)									
	<i>Sagittaria latifolia</i>	SALA	common arrowhead		N		P		yes
Anacardiaceae (Cashew Family)									
	<i>Rhus copallinum</i>	RUCO	winged sumac		N		P		yes
	<i>Toxicodendron radicans</i>	TORA	poisin ivy		N		P	yes	yes
	<i>Toxicodendron rydbergi</i>	TORY	western poisin ivy		N		P		yes
	<i>Toxicodendron vernix</i>	TOVE	poison sumac		N		P		yes
Apiaceae (Carrot Family)									
	<i>Aralia nudicaulis</i>	ARNU	wild sarsaparilla		N		P	yes	
	<i>Ligusticum scoticum</i>	LISC	Scotch lovage	State concern	N		P	yes	
	<i>Ptillimnium capillaceum</i>	PTCA	Atlantic mock Bishop weed	State concern	N		A		yes
	<i>Sium suave</i>	SISU	hemlock water parsnip		N		P	yes	
Apocynaceae (Dogbane Family)									
	<i>Asclepias incarnata</i>	ASIN	swamp milkweed		N		P	yes	
Aquifoliaceae (Holly Family)									
	<i>Ilex crinata</i>	ILCR	Japanese holly			I	P	yes	
	<i>Ilex glabra</i>	ILGL	inkberry		N		P		yes
	<i>Ilex opaca</i>	ILOP	American holly		N		P	yes	yes
	<i>Ilex verticillata</i>	ILVE	winterberry		N		P	yes	yes
Araceae (Arum Family)									
	<i>Arisaema triphyllum</i>	ARTR	jack-in-the-pulpit		N		P	yes	
	<i>Lemna minor</i>	LEMI	common duckweed		N		A	yes	
	<i>Symplocarpus foetidus</i>	SYFO	skunk cabbage		N		P	yes	yes
Asteraceae (Aster Family)									
	<i>Baccharis halimifolia</i>	BAHA	groundsel tree		N		P	yes	yes
	<i>Bidens frondosa</i>	BIFR	Devil's beggar-ticks		N		A	yes	
	<i>Bidens tripartita</i>	BITR	three-lobed beggar-ticks		N		A	yes	yes
	<i>Erechites hieraciifolius</i>	ERHI	American burnweed		N		A	yes	
	<i>Eupatorium perfoliatum</i>	EUPE	common boneset		N		P		yes
	<i>Eurybia divaricata</i>	EUDI	white wood aster		N		P	yes	
	<i>Euthamia graminifolia</i>	EUGR	grass-leaved flat top goldenrod		N		P	yes	yes
	<i>Iva frutescens</i>	IVFR	high tide bush		N		P		yes
	<i>Mikania scandens</i>	MISC	climbing hempvine		N		P	yes	
	<i>Nabalus trifoliatu</i>	NATR	three-leaved rattlesnake root		N		P	yes	
	<i>Pluchea odorata</i>	PLOD	camphor-weed		N		P		yes
	<i>Solidago aestivalis</i>	SOAE	swamp wrinkled goldenrod		N		P		yes
	<i>Solidago gigantea</i>	SOGI	giant goldenrod		N		P		yes
	<i>Solidago rugosa</i>	SORU	wrinkled goldenrod		N		P	yes	yes
	<i>Solidago sempervirens</i>	SOSE	seaside goldenrod		N		P		yes
	<i>Symphyotrichum novi-begii</i>	SYBE	New York aster		N		P	yes	yes
Berberidaceae (Barberry Family)									
	<i>Berberis thunbergii</i>	BETH	Japanese barberry			I*	P	yes	
Caprifoliaceae (Honeysuckle Family)									
	<i>Lonicera morrowii</i>	LOMO	Morrow's honeysuckle			I*	P	yes	

FQA Vegetation Survey for Vulnerable Coastal Wetlands
Hathaway Preserve, Quonochontaug Pond
Lathrop Preserve, Winnapaug Pond

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Caryophyllaceae (Pink Family)									
	<i>Cerastium fontanum</i>	CEFO	mouse-eared chickweed			I	P	yes	
	<i>Moehringia leteriflora</i>	MOLA	grove sandwort		N		P	yes	
Celastraceae (Staff-tree Family)									
	<i>Celastrus orbiculatus</i>	CEOR	Oriental Bittersweet			I*	P	yes	yes
Clethraceae (White Alder Family)									
	<i>Clethra alnifolia</i>	CLAL	sweet pepper-bush		N		P	yes	yes
Convulvulaceae (Morning Glory Family)									
	<i>Calystegia sepium</i>	CASE	hedge false bindweed		N		A	yes	
	<i>Cuscuta indecora</i>	CUIN	collared dodder	State Endangered	N		A	yes	
Cornaceae (Dogwood Family)									
	<i>Nyssa sylvatica</i>	NYSY	black gum		N		P	yes	yes
Cupressaceae (Cypres Family)									
	<i>Juniperus virginiana</i>	JUVI	eastern red cedar		N		P	yes	yes
Cyperaceae (Sedge Family)									
	<i>Carex bullata</i>	CABU	button sedge		N		P		yes
	<i>Carex comosa</i>	CACO	longhair sedge		N		P		yes
	<i>Carex debilis</i>	CADE	white edge sedge		N		P	yes	yes
	<i>Carex folliculata</i>	CAFO	long sedge		N		P		yes
	<i>Carex intumescens</i>	CAIN	greater bladder sedge		N		P	yes	yes
	<i>Carex pensylvanica</i>	CAPE	early sedge		N		P	yes	yes
	<i>Carex scoparia</i>	CASC	broom sedge		N		P	yes	yes
	<i>Carex stricta</i>	CAST	upright sedge		N		P	yes	yes
	<i>Carex urticulata</i>	CAUR	Northwest Territory sedge		N		P	yes	
	<i>Cyperus filicinus</i>	CYFI	fern flatsedge		N		A		yes
	<i>Cyperus odoratus</i>	CYOD	fragrant flatsedge	State Endangered	N		A	yes	
	<i>Eleocharis palustris</i>	ELPA	common spikesedge		N		P	yes	
	<i>Eleocharis uniglumis</i>	ELUN	on-glumed spikesedge		N		P		yes
	<i>Schoenoplectus pungens</i>	SCPU	three-square bulrush		N		P	yes	yes
	<i>Scirpus cyperinus</i>	SCCY	wool-grass		N		P		yes
Dryopteridaceae (Woodfern Family)									
	<i>Dryopteris carthusiana</i>	DRCA	spinulose woodfern		N		P	yes	
Equisetaceae (Horsetail Family)									
	<i>Equisetum arvense</i>	EQAR	field horsetail		N		P		yes
Ericaceae (Heath Family)									
	<i>Gaylussacia baccata</i>	GABA	huckleberry		N		P		yes
	<i>Lyonia ligustrina</i>	LYLI	male-berry		N		P		yes
	<i>Rhododendron viscosum</i>	RHVI	swamp azalea		N		P	yes	yes
	<i>Vaccinium corymbosum</i>	VACO	highbush blueberry		N		P	yes	yes
Euphorbiaceae (Spurge Family)									
	<i>Euphorbia polygonifolia</i>	EUPO	seaside sand-mat		N		A		
Fabaceae (Bean Family)									
	<i>Apios americana</i>	APAM	ground nut		N		P		yes
Fagaceae (Beech Family)									
	<i>Quercus velutina</i>	QUVE	black oak				P		yes

FQA Vegetation Survey for Vulnerable Coastal Wetlands
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Lathrop Preserve, Winnapaug Pond

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Grossulariaceae (Current Family)									
	<i>Ribes hirtellum</i>	RIHI	hairy-stem gooseberry	State Concern	N		P	yes	
Haloragaceae (Water-milfoil Family)									
	<i>Proserpinaca palustris</i>	PRPI	marsh mermaid-weed		N		A	yes	
Hypericaceae (St. John's-wort Family)									
	<i>Hypericum mutilum</i>	HYMU	dwarf St. John's-wort		N		A	yes	
	<i>Triadenum virginicum</i>	TRVI	Virginia marsh St. John's-wort		N		A	yes	yes
Iridaceae (Iris Family)									
	<i>Iris prismatica</i>	IRPR	slender blue iris		N		P		
	<i>Iris versicolor</i>	IRVE	harlequin blue-flag iris		N		P	yes	
Juncaceae (Rush Family)									
	<i>Juncus canadensis</i>	JUCA	Canada rush		N		P	yes	yes
	<i>Juncus effusus</i>	JUEF	soft rush		N		P	yes	yes
	<i>Juncus pylaei</i>	JUPY	Pyle's rush		N		P	yes	
	<i>Luzula luzuloides</i>	LULU	oak-forest woodrush			I	P	yes	
Lamiaceae (Mint Family)									
	<i>Lycopus uniflorus</i>	LYUN	northern bugleweed		N		A	yes	
	<i>Lycopus virginicus</i>	LYVI	Virginia water-horehound		N		A		yes
	<i>Scutellaria galericulata</i>	SCGA	marsh skullcap		N		P	yes	
	<i>Teucrium canadense</i>	TECA	American germander		N		P	yes	
Lauraceae (Laurel Family)									
	<i>Sassafras albidum</i>	SAAL	sassafras		N		P	yes	
Liliaceae (Lily Family)									
	<i>Lilium superbum</i>	LISU	Turk's-cap-lily		N		P		yes
Lythraceae (Loosestrife Family)									
	<i>Lythrum salicaria</i>	LYSA	purple loosestrife			I*	P		yes
Malvaceae (Mallow Family)									
	<i>Hibiscus moscheutos</i>	HIMO	marshmallow		N		P		yes
Myricaceae (Bayberry Family)									
	<i>Morella caroliniensis</i>	MOCA	northern bayberry		N		P	yes	yes
Myrsinaceae (Marlberry Family)									
	<i>Lysimachia hybrida</i>	LYHY	lowland yellow-loosestrife		N		A	yes	
	<i>Lysimachia terrestris</i>	LYTE	earth loosestrife		N		P	yes	yes
Onagraceae (Evening Primrose Family)									
	<i>Ludwigia palustris</i>	LUPA	marsh seedbox				A	yes	
Onocleaceae (Sensetive Fern Family)									
	<i>Onoclea sensibilis</i>	ONSE	sensetive fern		N		P	yes	yes

FQA Vegetation Survey for Vulnerable Coastal Wetlands
Hathaway Preserve, Quonochontaug Pond
Lathrop Preserve, Winnapaug Pond

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Osmundaceae (Royal Fern Family)									
	<i>Osmunda regalis</i>	OSRE	royal fern		N		P	yes	yes
	<i>Osmundastrum cinnamomeum</i>	OSCI	cinnamon fern		N		P	yes	yes
	<i>Agrostis gigantea</i>	AGGI	redtop bentgrass			I	P		
	<i>Agrostis hyemalis</i>	AGHY	winter bentgrass		N		P	yes	yes
	<i>Agrostis stolonifera</i>	AGST	creeping bentgrass			I	P	yes	
	<i>Andropogon virginicus</i>	ANVI	broom-sedge		N		P		yes
	<i>Anthoxanthum nitens</i>	ANNI	sweetgrass		N		P		yes
	<i>Dicanthelium wrightianum</i>	DIWR	Wright's panicgrass	State Concern	N		P	yes	
	<i>Echinochloa walteri</i>	ECWA	coast cocksbur grass		N		A	yes	
	<i>Glyceria obtusa</i>	GLOB	Atlantic mannagrass		N		P	yes	yes
	<i>Glyceria striata</i>	GLST	fowl mannagrass		N		P		yes
	<i>Leersia virginica</i>	LIVI	whitegrass		N		P	yes	
	<i>Panicum capillare</i>	PACA	witch panicgrass		N		A	yes	
	<i>Phalaris arundinacea</i>	PHAR	reed-canary grass			I*	P	yes	yes
	<i>Phragmites australis</i>	PHAU	common reed			I*	P	yes	yes
	<i>Poa palustris</i>	POPA	fowl bluegrass		N		P	yes	
Polygonaceae (Buckwheat Family)									
	<i>Persicaria hydropiperoides</i>	PEHY	false water-pepper smartweed		N		A	yes	
	<i>Persicaria longiseta</i>	PELO	Oriental lady's thumb smartweed			I	A	yes	
	<i>Persicaria punctata</i>	PEPU	dotted smartweed		N		A	yes	yes
	<i>Persicaria sagittata</i>	PESA	arrow-leaved tearthumb		N		A		yes
	<i>Rumex crispus</i>	RUCR	curly dock			I	P	yes	
Rhamnaceae (Buckthorn Family)									
	<i>Frangula alnus</i>	FRAL	glossy buck-thorn			I*	P		yes
Rosaceae (Rose Family)									
	<i>Amelanchier canadensis</i>	AMCA	eastern shadbush		N		P	yes	yes
	<i>Argentina egedii</i>	AREG	Pacific silverweed		N		P		yes
	<i>Aronia floribunda</i>	ARFL	purple chokeberry		N		P	yes	
	<i>Aronia melanocarpa</i>	ARME	black chokeberry		N		P		yes
	<i>Prunus serotina</i>	PRSE	black cherry		N		P	yes	yes
	<i>Rosa multiflora</i>	ROMU	multiflora rosa			I*	P	yes	yes
	<i>Rosa palustris</i>	ROPA	swamp rose		N		P	yes	yes
	<i>Rubus alleghaniensis</i>	RUAL	Alleghany blackberry		N		P	yes	yes
	<i>Rubus hispidus</i>	RUHI	swamp dewberry		N		P	yes	yes
	<i>Rubus phoenicolasius</i>	RUPH	wineberry			I*	P	yes	
	<i>Spiraea tomentosa</i>	SPTO	steeplebush		N		P	yes	
Rubiaceae (Madder Family)									
	<i>Galium tinctorium</i>	GATI	stiff marsh bedstraw		N		A	yes	yes
	<i>Galium trifidum</i>	GATR	three petal bedstraw		N		A	yes	
Ruscaceae (Butcher's Broom Family)									
	<i>Maianthemum canadense</i>	MACA	Canada mayflower		N		P	yes	

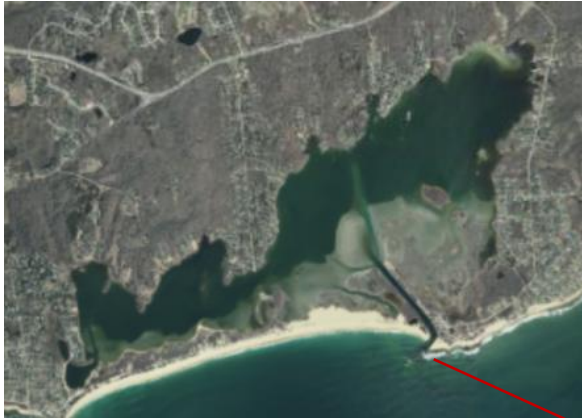
FQA Vegetation Survey for Vulnerable Coastal Wetlands
Hathaway Preserve, Quonochontaug Pond
Lathrop Preserve, Winnapaug Pond

Family	Species Name	USDA Species Code	Common Name	State-listed Rare Species Conservation Status	Native (N)	Introduced (I) Invasive*	Life Cycle: Annual (A) Biennial (B) Perennial (P)	Present in Forested Wetland Hathaway Preserve	Present in Forested Wetland Lathrop Preserve
Salicaceae (Willow Family)									
	<i>Salix cinerea</i>	SACI	European gray pussy willow			I*	P	yes	yes
Sapindaceae (Soap-berry Family)									
	<i>Acer rubrum</i>	ACRU	red maple		N		P	yes	yes
Smilacaceae (Catbrier Family)									
	<i>Smilax rotundifolia</i>	SMRO	greenbrier		N		P	yes	yes
Solanaceae (Nightshade Family)									
	<i>Solanum dulcamara</i>	SODU	climbing nightshade			I	A	yes	
Thelypteridaceae (Marsh fern Family)									
	<i>Thelypteris palustris</i>	THPA	marsh fern		N		P	yes	yes
Typhaceae (Cat-tail family)									
	<i>Sparganium americana</i>	SPAM	American bur-reed		N		P	yes	yes
	<i>Typha angustifolia</i>	TYAN	narrow leaved cat-tail		N		P	yes	yes
	<i>Typha latifolia</i>	TYLA	common cat-tail		N		P		yes
Vitaceae (Grape Family)									
	<i>Ampelopsis glandulosa</i>	AMGL	porcelain berry			I*	P	yes	
	<i>Parthenocissus quinquefolia</i>	PAQU	Virginia creeper		N		P	yes	
	<i>Vitis labrusca</i>	VILA	fox grape		N		P	yes	yes

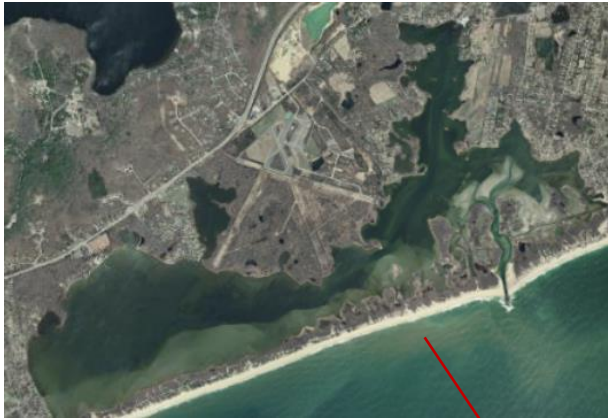
Appendix II

Location Maps

Southern Rhode Island, Coastal Salt Ponds



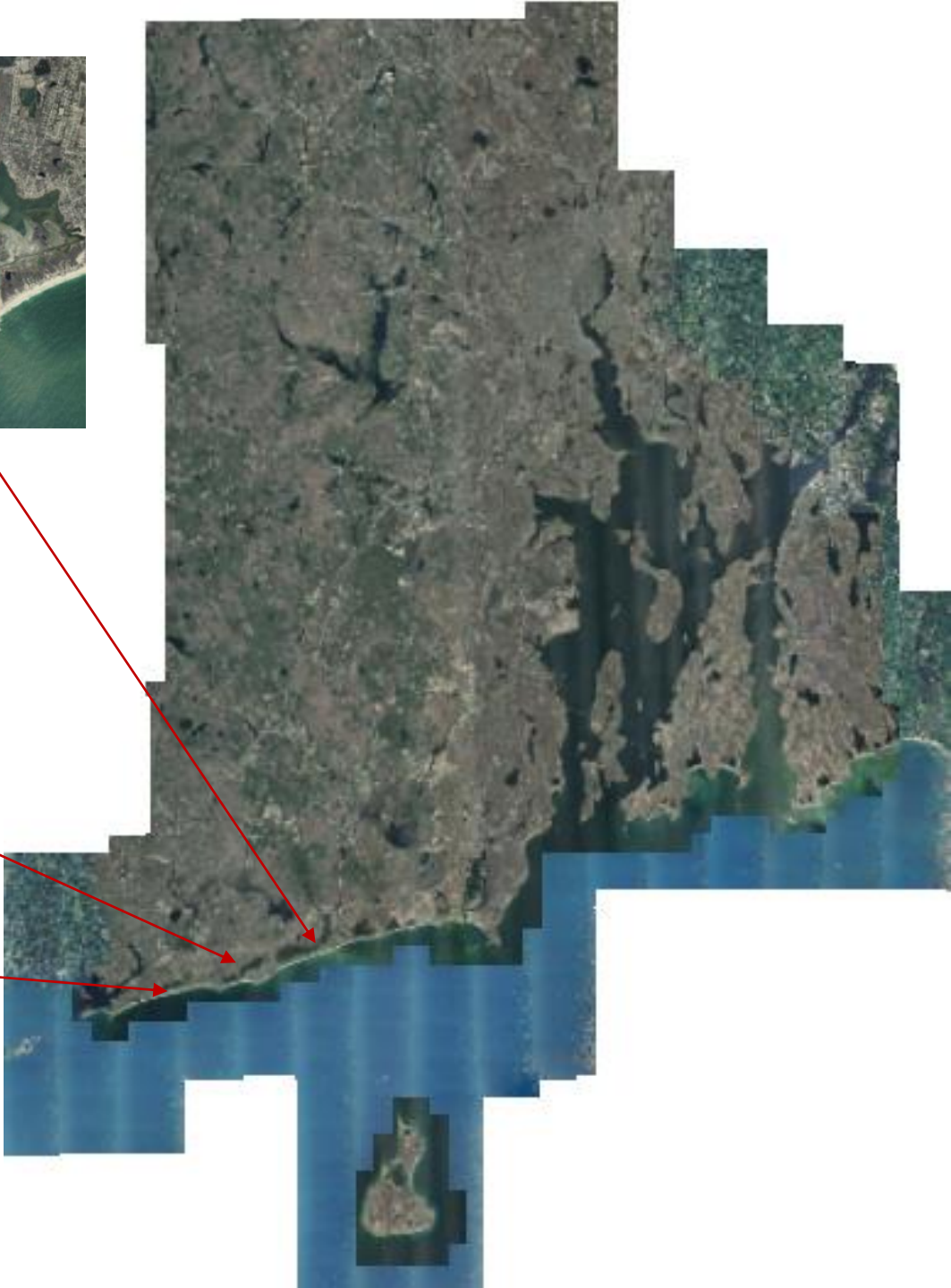
Quonochontaug Pond,
Charlestown and Westerly, RI



Ninigret Pond, Charlestown, RI

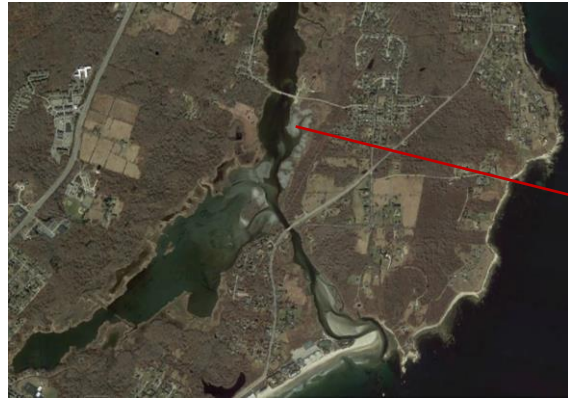


Winnapaug Pond, Westerly, RI



Map 1, Coastal Salt Pond Locations

Sediment Placement Locations in Rhode Island, 2018



Pettaquamscutt Cove, Narragansett, RI



Maidford Marsh, Middletown, RI



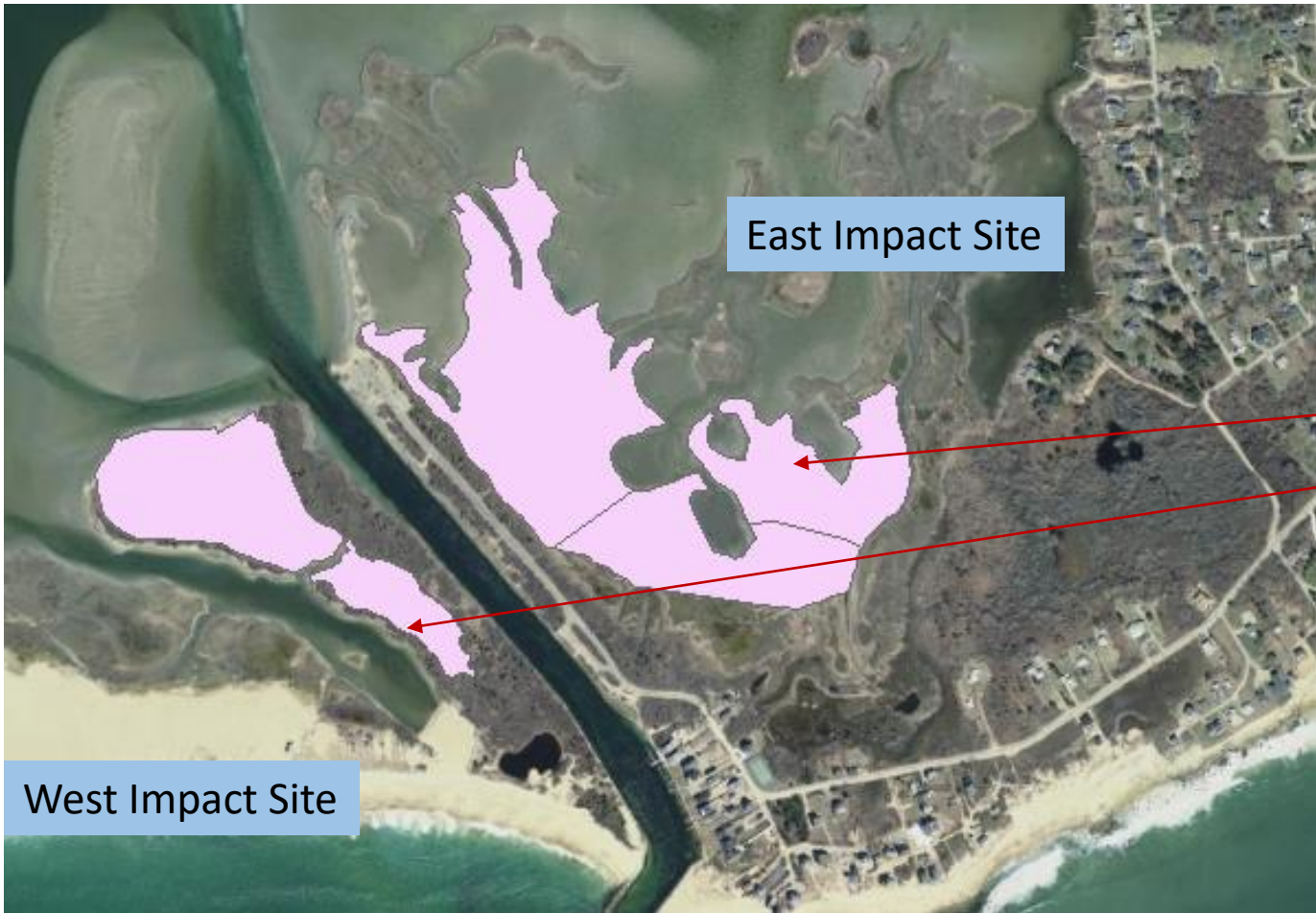
Ninigret, Charlestown, RI





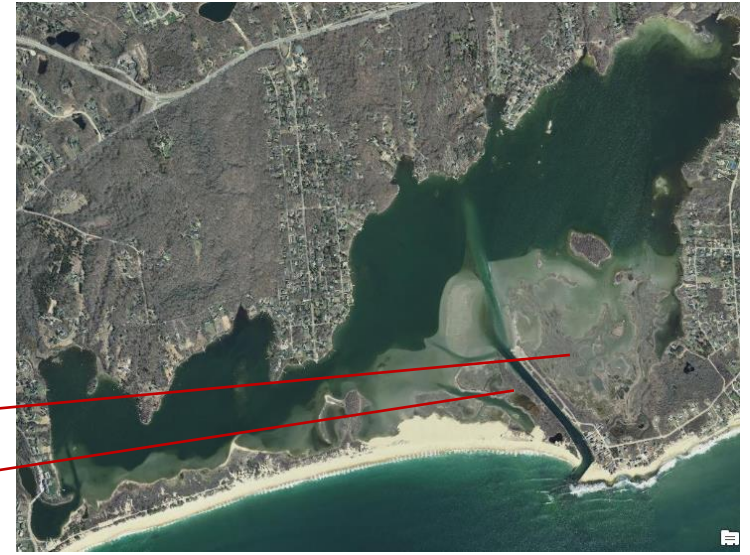
**Ninigret Pond Sediment Placement
Impact and Control Sites**

Map 3, Ninigret Sediment Placement Location and Control Site



East Impact Site

West Impact Site



**Quonochontaug Pond Sediment Placement
East and West Impact Sites**

**Winnapaug Pond Potential
Sediment Placement
Impact Sites**





**Pettaquamscutt Cove
Sediment Placement
Impact and Control Sites**

Map 6, J.H. Chafee National Wildlife Refuge, Pettaquamscutt Cove Sediment Placement Locations



**Maidford Marsh
Sediment Placement
Impact and Control Sites**

Map 7, Sachuest Point National Wildlife Refuge, Maidford Marsh Sediment Placement Location

Appendix III

Coastal Salt Pond

Sediment Placement Sites

Survey Results



Ninigret Pond Sediment Placement Impact Site Planted Areas, Fall 2017


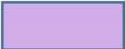
Legend

 2017, Planted Polygons

**Ninigret Pond Sediment Placement Impact Site
Re-surveyed Subset of 2017 Planted Areas**




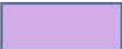
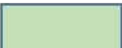
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-  2017, Planted Polygons
-  2017, Re-surveyed Polygons

Ninigret Pond Sediment Placement Impact Site Outline of All Planted Areas, 2017-2018



Legend

-  2017, Planted Polygons
-  2017, Re-surveyed Polygons
-  2018, Planted Polygons

**Ninigret Pond Sediment Placement Impact Site
2018 Elevations in Meters, above NAVD88**



Map 9, Elevations Ninigret Sediment Placement Impact Site
Imagery and Data: URI EDC Drone Flight, 2018

Ninigret Pond (Southern Portion) State-listed Rare Species and Species of Interest Locations, 2018



Legend

- ▲ Rare_Species_Coastal_Lagoons_2018
- Invasive_Species_Coastal_Lagoons_2018
- ◆ Species_of_Interest_Coastal_Lagoons_2018

Map 10, Species of Interest Ninigret Pond
Imagery: URI EDC Drone Flight, 2018 and World Imagery

**Ninigret Sediment Placement
Impact Site and Control Site
State-listed Rare Species and Species of
Interest Locations, 2018**



Legend

- ▲ Rare_Species_Coastal_Lagoons_2018
- Invasive_Species_Coastal_Lagoons_2018
- ◆ Species_of_Interest_Coastal_Lagoons_2018

Map 10a, Species of Interest Ninigret Pond
Sediment Placement Impact and Control Sites
Imagery: URI EDC Drone Flight, 2018 and World Imagery

Quonochontaug Pond (Southeast Portion) State-listed Rare Species and Species of Interest Locations, 2018



Legend

- ▲ Rare_Species_Coastal_Lagoons_2018
- Invasive_Species_Coastal_Lagoons_2018
- ⬠ Species_of_Interest_Coastal_Lagoons_2018

Map 11, Species of Interest Quonochontaug Pond
Sediment Placement Impact Sites and Hathaway Preserve
Imagery: World Imagery

Quonochontaug Pond (Southwest Portion) State-listed Rare Species and Species of Interest Locations, 2018

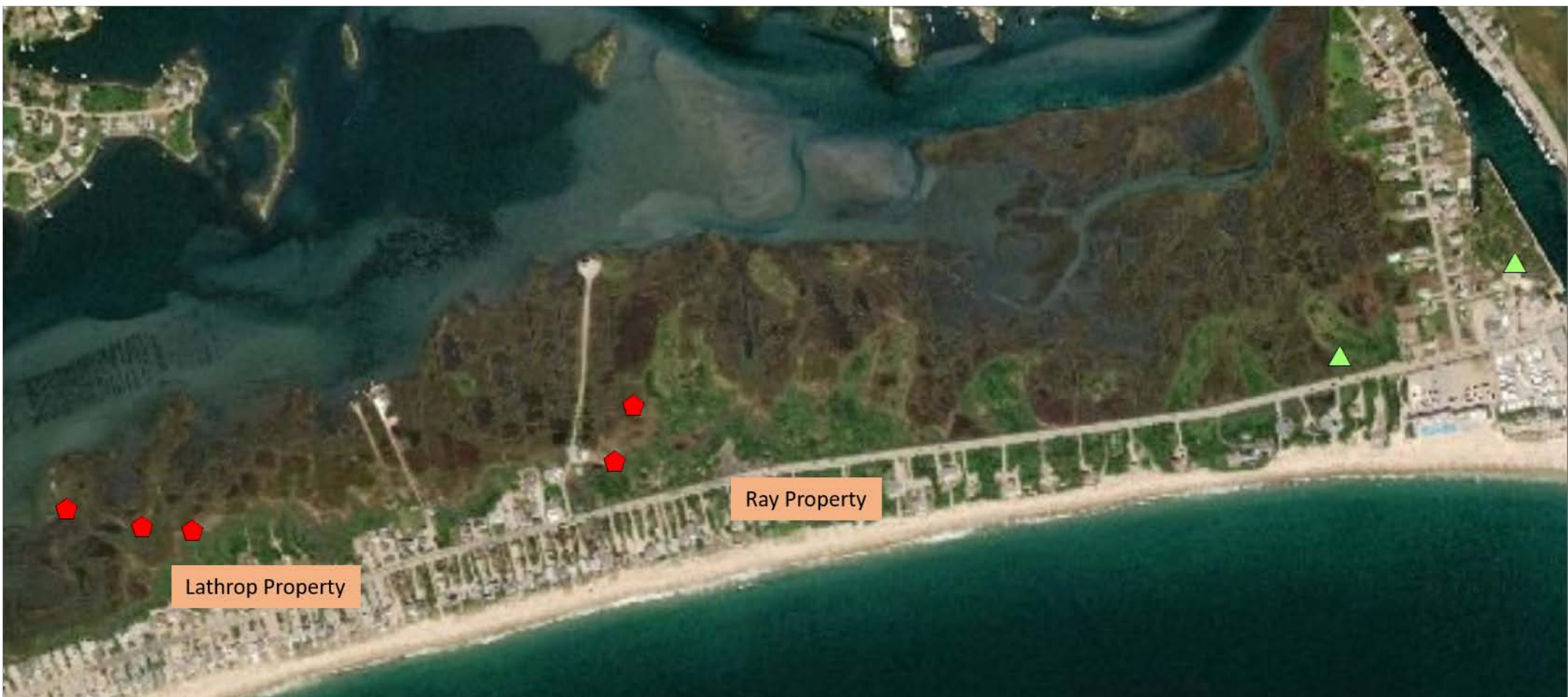


Legend

- ▲ Rare_Species_Coastal_Lagoons_2018
- Invasive_Species_Coastal_Lagoons_2018
- ⬠ Species_of_Interest_Coastal_Lagoons_2018

Map 11a, Species of Interest Quonochontaug Pond
Imagery: World Imagery

**Winnapaug Pond (Southeast Portion)
State-listed Rare Species and Species of
Interest Locations, 2018**



Legend

- ▲ Rare_Species_Coastal_Lagoons_2018
- Invasive_Species_Coastal_Lagoons_2018
- ⬠ Species_of_Interest_Coastal_Lagoons_2018

Map 12, Species of Interest Winnapaug Pond
Potential Sediment Placement Impact Sites
Imagery: World Imagery

Winnapaug Pond (Southwest Portion) State-listed Rare Species and Species of Interest Locations, 2018



Legend

- ▲ Rare_Species_Coastal_Lagoons_2018
- Invasive_Species_Coastal_Lagoons_2018
- ⬠ Species_of_Interest_Coastal_Lagoons_2018

Map 12a, Species of Interest Winnapaug
Pond and Lathrop Preserve
Imagery: World Imagery

Appendix IV

Studies of Additional Taxa

- i. The Saltmarsh Sparrow; Extinct in 50 Years?
Summer 2018
- ii. RINHS – Report for Diamondback Terrapin Internship
Summer 2018
- iii. Diamondback Terrapin Habitat Suitability Index Tables

The Saltmarsh Sparrow; Extinct in 50 Years?

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The saltmarsh sparrow, *Ammodramus caudacuta*, is a small avian tidal-marsh species found along the Atlantic coast (Fig. 1). Due to human disturbance and sea level rise in its habitat, it is predicted to go extinct within the next 50 years (Correll et al. 2017). To combat sea level rise which drowns chicks in nests, and restore subsiding salt marshes, Rhode Island CRMC has opted to apply dredgings, called thin layer deposition (TLD) up to 60 cm thick on marshes (Fig. 2). After dredging deposition, plugs of smooth cordgrass, *Spartina alterniflora* and American beach grass, *Ammophila breviligulata*, etc. are planted to stabilize the soil and begin plant recolonization (Fig. 2). All plant species planted in 2017 and 2018 at the Ninigret TLD site are listed in Table 1.

The sparrow's diet consists mainly of insects and marine invertebrates, a large portion being long-horned grasshoppers known as katydids (Greenlaw et al. 2018, Post et al. 1983, Post and Greenlaw 2006). Two Rhode Island species are the saltmarsh meadow katydid, *Conocephalus spartinae* (Fig. 3) and the seaside meadow katydid, *Orchelimum fidicinium* (Fig. 4). These species feed on marsh grasses and seeds and therefore have a negative impact on salt marsh plant productivity (Bertness et al. 1987; Bertness and Shumway 1992). They also play an important role in sustaining sparrow populations. Little is known how TLD might affect salt marsh insect populations. Therefore, it is important to research the impact thin layer deposition may have on katydid populations as well as what plant species are needed to restore marshes after thin layer deposition. Early season insect sampling indicated that the katydids were closely associated with the salt tolerant woody shrub, maritime marsh elder, *Iva frutescens* (Fig. 5). We designed our katydid sampling in smooth cordgrass and saltmarsh rush, *Juncus gerardii*, at approximately 5 and 10 m from marsh elder to see if there was an association. If marsh elder is critical in the life cycle of katydids, it should be one of the species planted when TLD is used to restore a salt marsh.

Our objectives were to determine: 1) how populations of katydids and other insects change over time in disturbed and undisturbed salt marshes, 2) if marsh elder is important for oviposition and sustainability of katydid populations, and 3) suggest options to sustain katydid populations to improve salt marsh sparrow breeding success and therefore survival.

Materials and Methods.

Field Sites. Three field sites were used in this study: 1) an undisturbed, inland marsh along Narrow River (Fig. 6), 2) an undisturbed coastal marsh on Ninigret Pond (Fig. 7), and 3) a coastal marsh on Ninigret Pond that had undergone thin layer deposition (Fig. 7).

Insect Collection and Handling. Insects were collected using a 38 cm diameter sweep net in two plant types: *Spartina alterniflora* and *Juncus gerardii* (Fig. 8). We took 20 sweeps in 6 m transects in each of the plant types x 4 replicates for each at approximately 5 and 10 m from the

nearest patch of *Iva frutescens*. Sweep net captures from each transect were transferred into 3,785 ml Ziploc bags, frozen, sorted, counted, weighed and identified to order, family or species depending upon the group.

Egg Laying Sites. To find out where katydids lay their eggs, an *ex situ* experiment was designed to simulate a marsh environment. Plugs of *S. alterniflora* and *I. frutescens* were set up in a 36-liter pot and enclosed with insect netting. Seven females and 8 males of *Conocephalus spartinae* were added to the enclosure. After 57 days the soil was sifted, and the plants were inspected for evidence of oviposition and eggs. One of the two females and one male still alive at that time was dissected to see the size and color of eggs.

Statistical Analysis. Arthropod counts and biomass for each distance from *I. frutescens* were analyzed by ANOVA followed by Tukey's HSD mean separation test (SAS, version 9.4).

Results.

A total of 21,448 individuals were collected across all field sites (Fig. 9). The largest numbers of individuals were collected in the orders Diptera (flies), Homoptera (planthoppers) and Hemiptera (true bugs) (Fig. 9). The mean total number of all specimens was not significantly different between sites ($F = 1.56$, df 5,15, $P < 0.23$) (Fig. 10). Dominant orders in biomass included Diptera, Homoptera, Hemiptera, and Orthoptera (katydids) (Fig. 11). The mean total biomass of all specimens was significantly greater at the Narrow River 5 m distance from *I. frutescens* site ($F = 9.08$, df 5,15, $P < 0.001$) (Fig. 12).

The mean number of katydids was always higher at the 5 m distance from *Iva frutescens*, however, it was only statistically significantly different ($F = 21.19$, df 5,15, $P < 0.001$) at the Narrow River control site (Fig. 13). The same was true for the total biomass of katydids ($F = 13.88$, df 5,15, $P < 0.001$) (Fig. 14).

The number of katydids collected at the Narrow River control site remained relatively constant throughout the summer (Fig. 15). The number of katydids at the Ninigret control and thin layer deposition sites however dropped to zero on the August 3rd and 16th sampling dates.

The results of the caged katydid experiment revealed two lepidopteran larvae in *I. frutescens* twigs and six leafhopper nymphs in *Spartina alterniflora*. We did not find any katydid eggs in the enclosure plant material or soil. Eggs of a dissected female *C. spartinae* katydid were 4 mm in length and yellow in color (Fig. 18).

Discussion.

During the breeding period, sparrows feed almost exclusively on amphipods, larval flies, marsh grasshoppers, lycosid spiders, moths and caterpillars, beetles, homopterans, hemipterans and snails (Greenlaw et al. 2018). Adult dipterans, homopterans, hemipterans and orthopterans were dominant orders in biomass in our collections. The energy cost in capturing adults in these orders may prevent them from being important in the diets of salt marsh sparrows. Further research should be conducted on these potential food sources for salt marsh sparrows.

There appears to be an association between the katydids and *Iva frutescens*. Katydids may need higher elevation and dryer soil or protective woody vegetation such as *I. frutescens* in which to lay their eggs. We suspect as eggs hatch in the spring, the young nymphs migrate out from the *Iva* and eventually late instars and adults move further out onto the salt marsh. Although these data are preliminary, we would recommend planting *Iva frutescens* on the higher areas of thin layer deposition sites.

There were significantly more katydids and a greater biomass of arthropods at the Narrow River control site. This site appeared to have more salt marsh sparrows than the Ninigret control site and thin layer deposition sites. The katydid population remained relatively constant at the Narrow River control site, which would provide sparrows with rich food source. Further research comparing the Narrow River site with other control sites should help elucidate the arthropods and plants needed to sustain larger populations of salt marsh sparrows.

Although omnivorous, *O. fidicinium* and *C. spartinae* have been observed to have inflexible diets that require them to consume plant material, i.e. *S. alterniflora*, along with other protein-rich prey (Marczak et al. 2013). Research on nitrogen eutrophication of New England salt marshes suggests that such nutrient enrichment will lead to increased herbivory by insect consumers, which already suppress Narragansett Bay salt marsh primary productivity by 50-70% (Bertness et al. 2008). Such detriment by top-down consumers can lead to further disruption of other organisms in marsh food webs (Jiménez et al. 2012, Stiling et al. 1991).

O. fidicinium feeds primarily on marsh leaves, and *C. spartinae* on seeds and flowers. Their relative abundance varies across latitudes (Wason and Pennings 2008), which presents further pressure to study these species more to examine their net effects on marsh grasses, given continuous changes in global warming, grass propagation success and sparrow viability. Management of their populations is needed to provide forage for sparrows, but also to sustain marsh productivity. We did not see significant plant damage at the sites we sampled. Therefore, further research is highly encouraged to investigate the influence of katydids on marsh food webs and their manipulation to improve restoration success of disturbed salt marshes by anthropogenic factors like eutrophication.

It is important to preserve the sparrow's habitat since all organisms depend on healthy ecosystems like marshes for productivity and protection. The loss of a species indicates weakening of these systems that undermines aesthetic, ecological, educational, and scientific values for humans and ecosystems alike by food web disruption.

Acknowledgements

We thank ornithologist Steve Reinert for assistance with understanding saltmarsh sparrow life history and forage activity. We also thank Dr. Mark Bertness for insight on marsh ecology, and Jennifer White and Nick Ernst from the U.S. Fish and Wildlife Service for their cooperation throughout this project.

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Table 1. All plant species planted at the Ninigret TLD site in 2017 and 2018.

2017	Common name
<i>Ammophila breviligulata</i>	American beach grass
<i>Baccharis halimifolia</i>	eastern false willow
<i>Distichlis spicata</i>	salt grass
<i>Juncus gerardii</i>	saltmarsh rush
<i>Iva frutescens</i>	maritime marsh elder
<i>Panicum virgatum</i>	switch panicgrass
<i>Solidago sempervirens</i>	seaside goldenrod
<i>Spartina alterniflora</i>	smooth cordgrass
<i>Spartina patens</i>	saltmarsh hay
2018	
<i>Ammophila breviligulata</i>	American beach grass
<i>Juncus gerardii</i>	saltmarsh rush
<i>Spartina alterniflora</i>	smooth cordgrass
<i>Spartina patens</i>	saltmarsh hay



Fig. 1. The saltmarsh sparrow, *Ammospiza caudacuta* (photo The Cornell Lab of Ornithology).



Fig. 2. Thin layer deposition with *S. alterniflora* plugs (photo S. Alm).



Fig. 3. The saltmarsh meadow katydid, *Conocephalus spartinae* (photo Songs of Insects by Elliott and Hershberger).



Fig. 4. The seaside meadow katydid, *Orchelimum fidicinium* (photo bugguide.net).



Fig. 5. Maritime marsh elder, *Iva frutescens* (photo S. Alm).



Fig. 6. Narrow river control site (red rectangle).



Fig. 7. Ninigret control (left yellow rectangle) and 2017 Ninigret thin layer deposition (right yellow rectangle) sites.

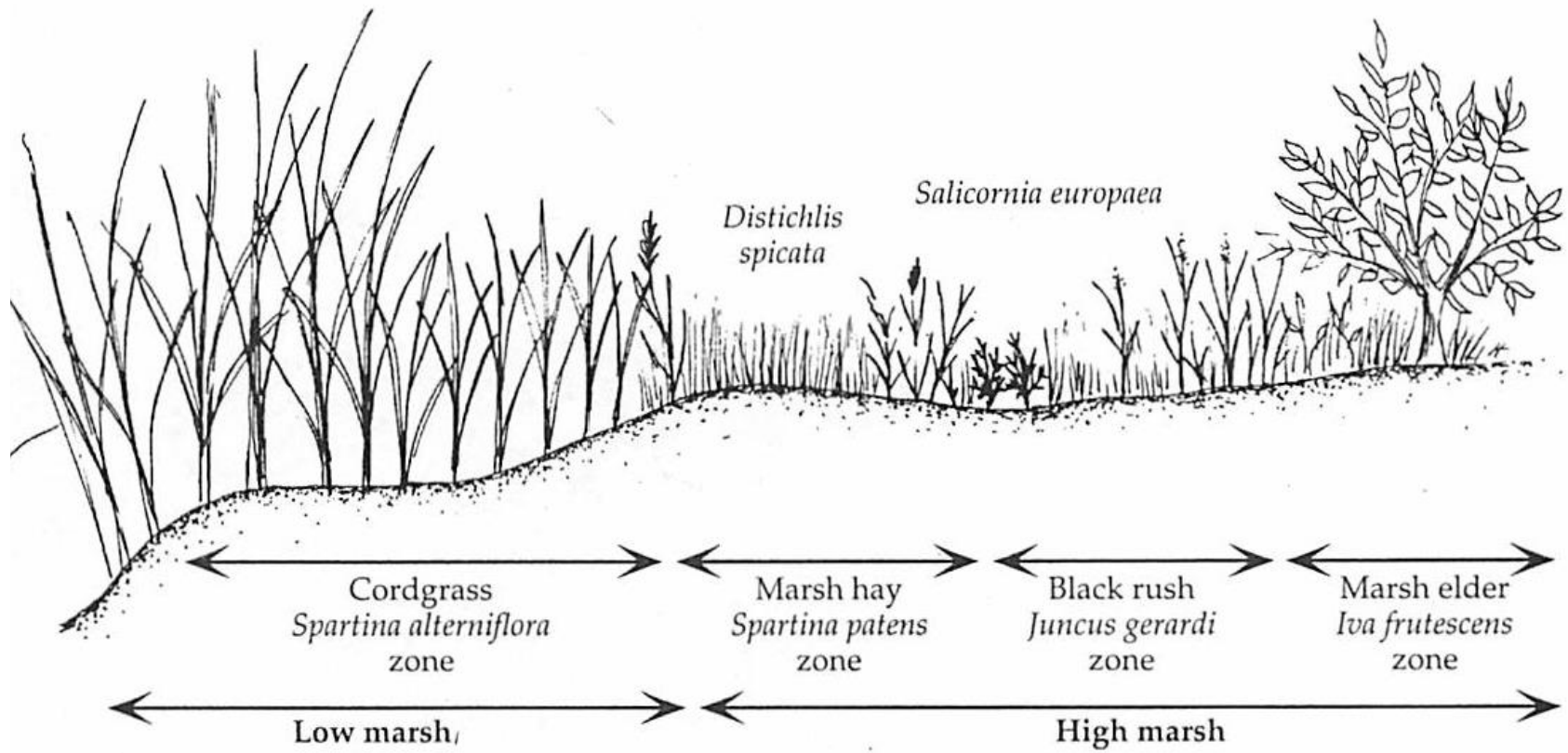


Fig. 8. Plant zonation in a New England salt marsh (Bertness 2007).

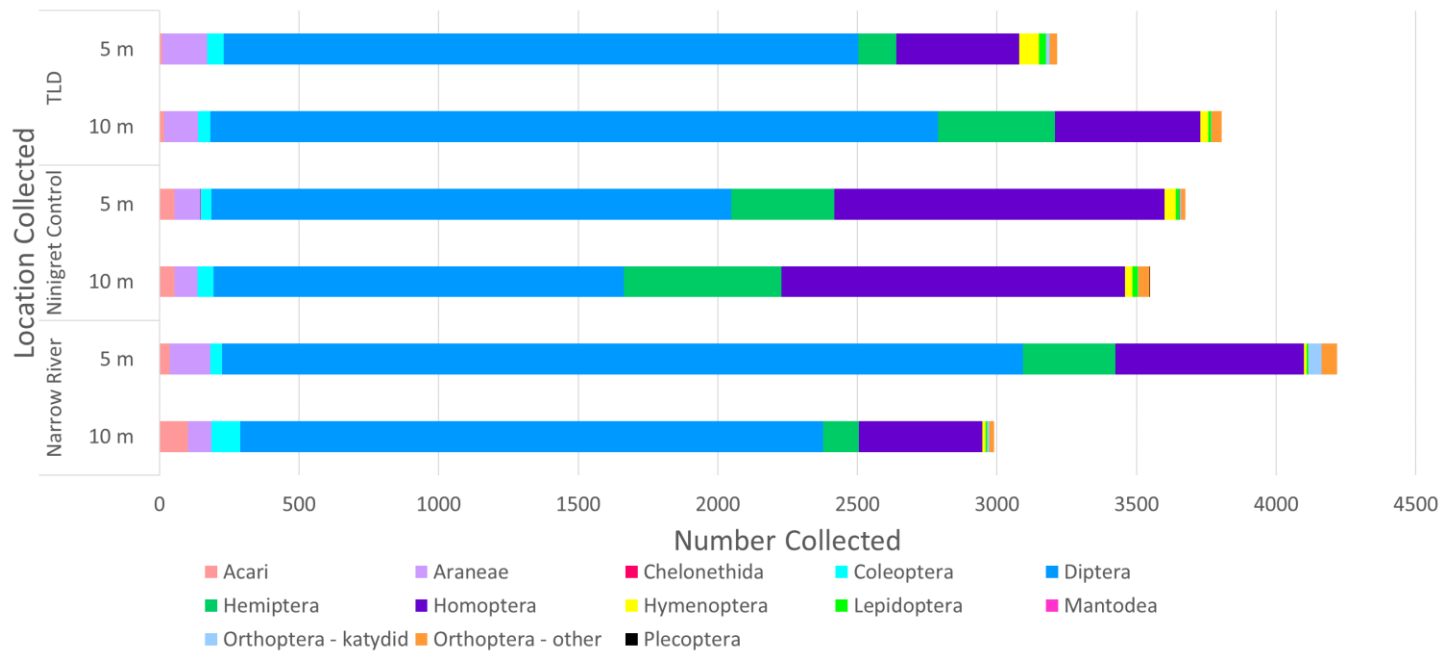


Fig. 9. Total number of specimens collected at each site.

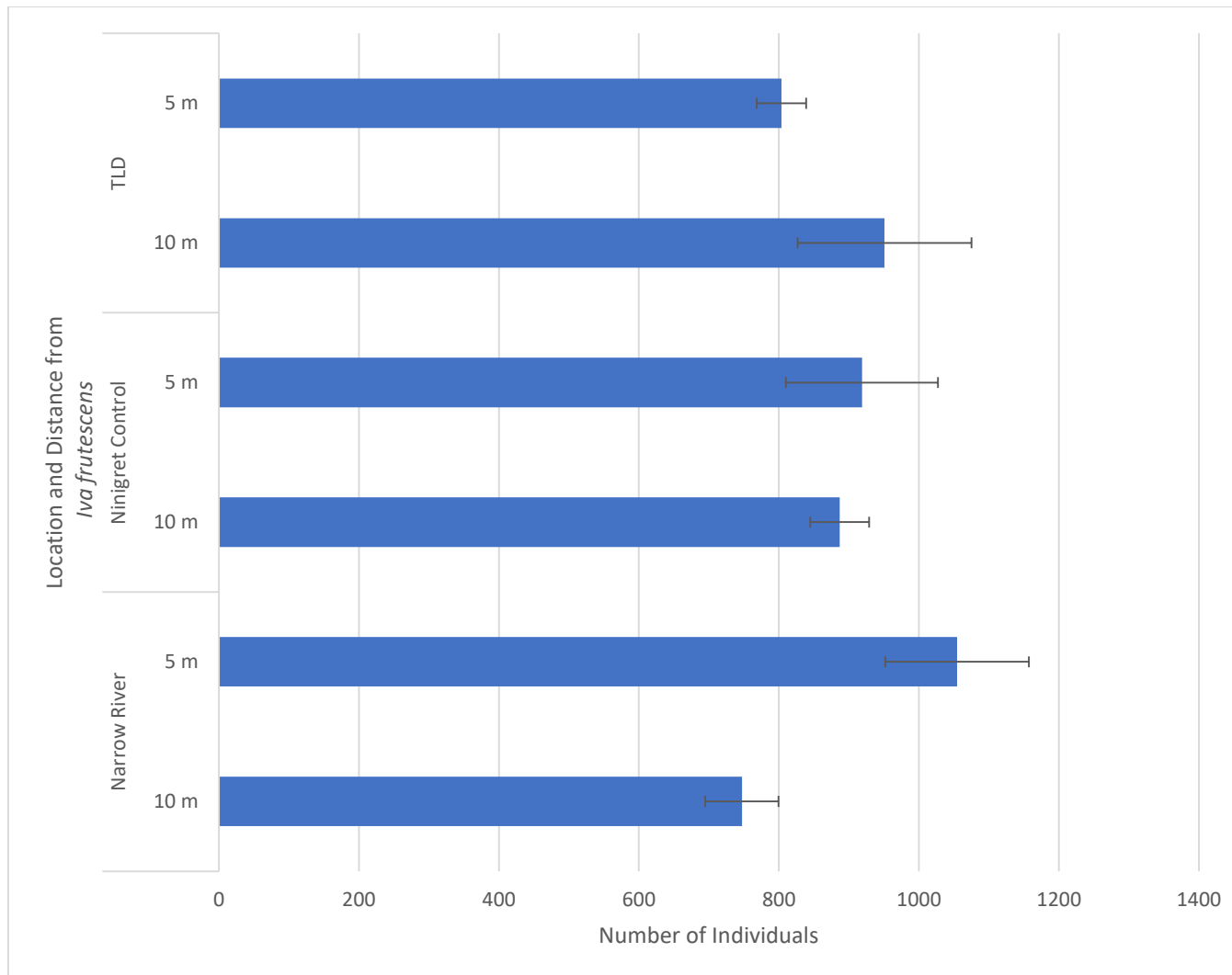


Fig. 10. Mean \pm SE total number of specimens collected at each site. Not significant ($F = 1.56$, $df\ 5,15$, $P = 0.23$)

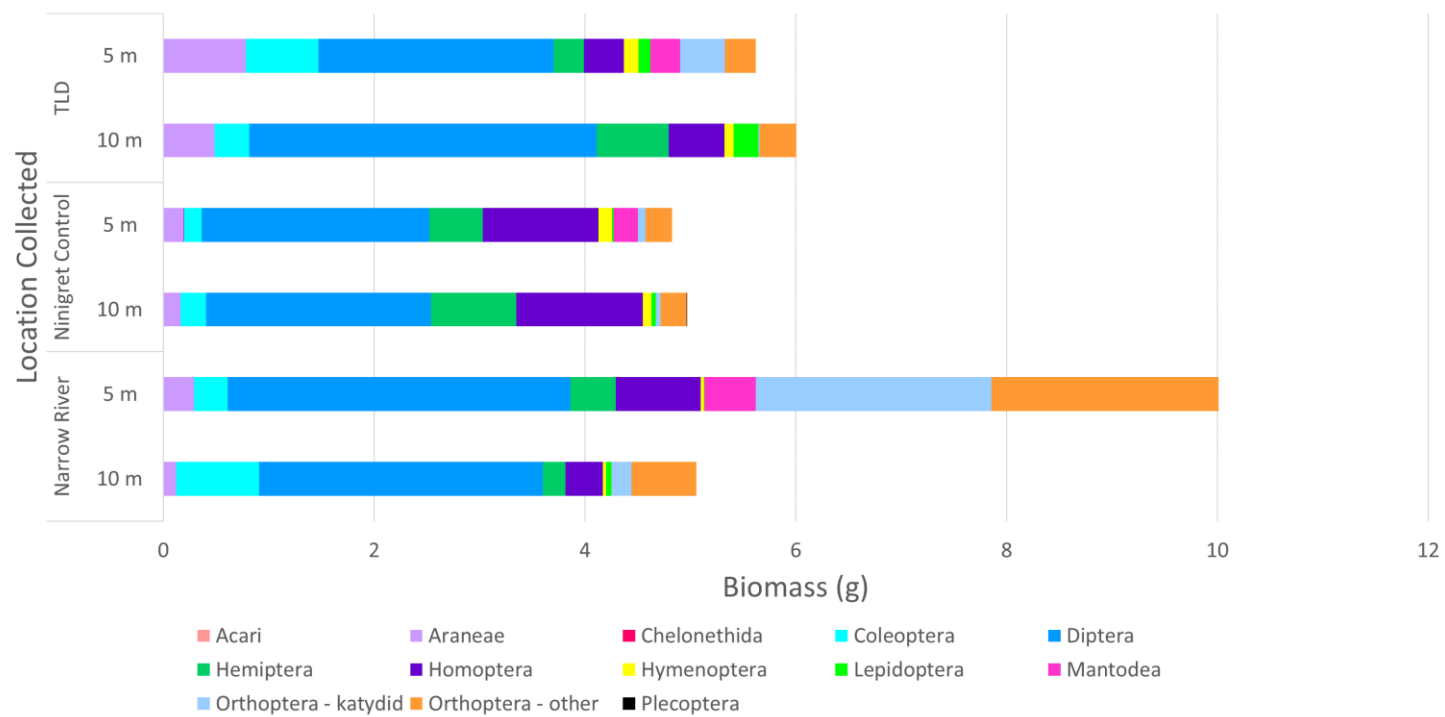


Fig. 11. Total biomass (g) collected at each site.

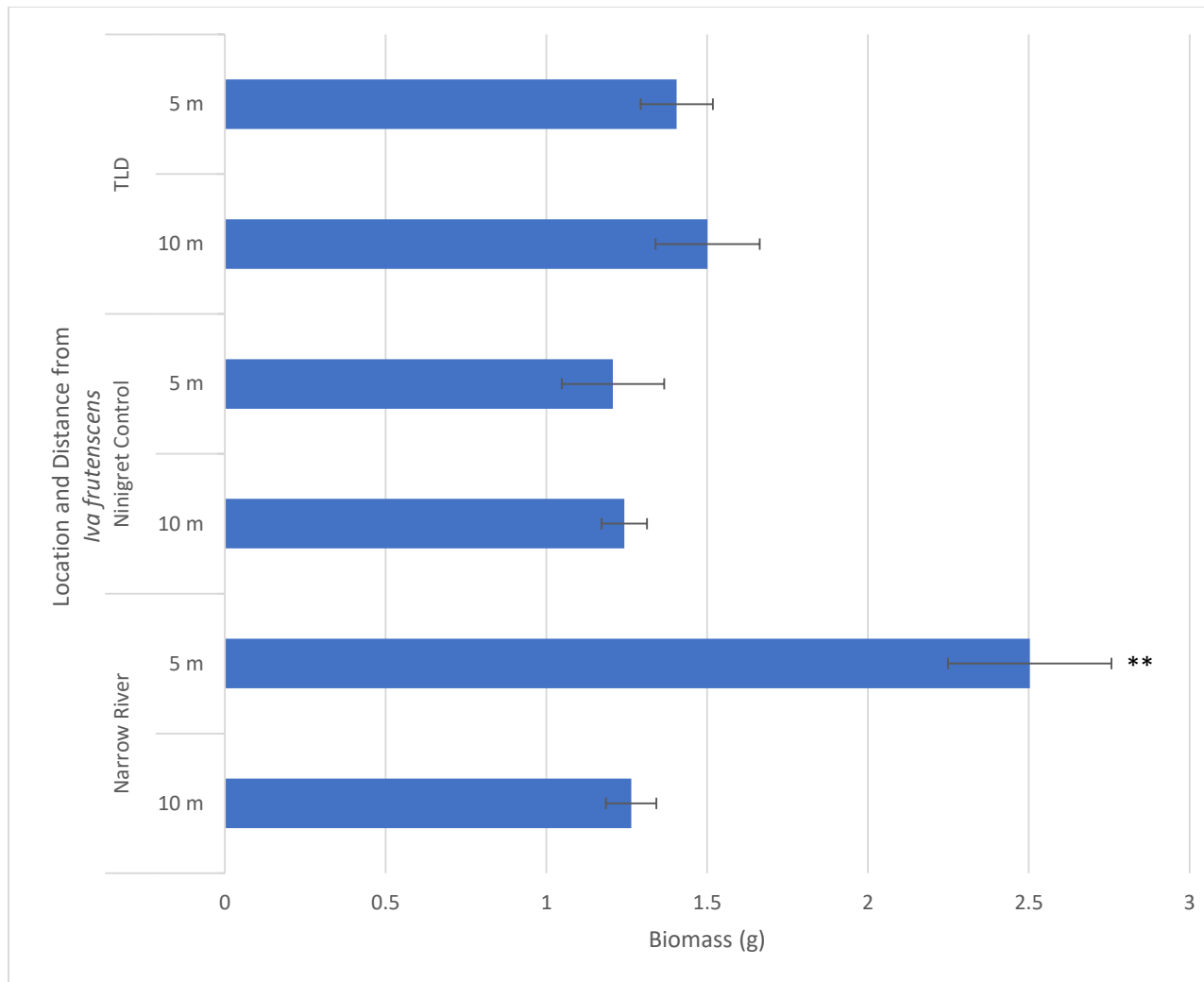


Fig. 12. Mean \pm SE total biomass (g) collected at each site. ** Highly significant ($F = 9.08$, $df\ 5,15$, $P < 0.001$)

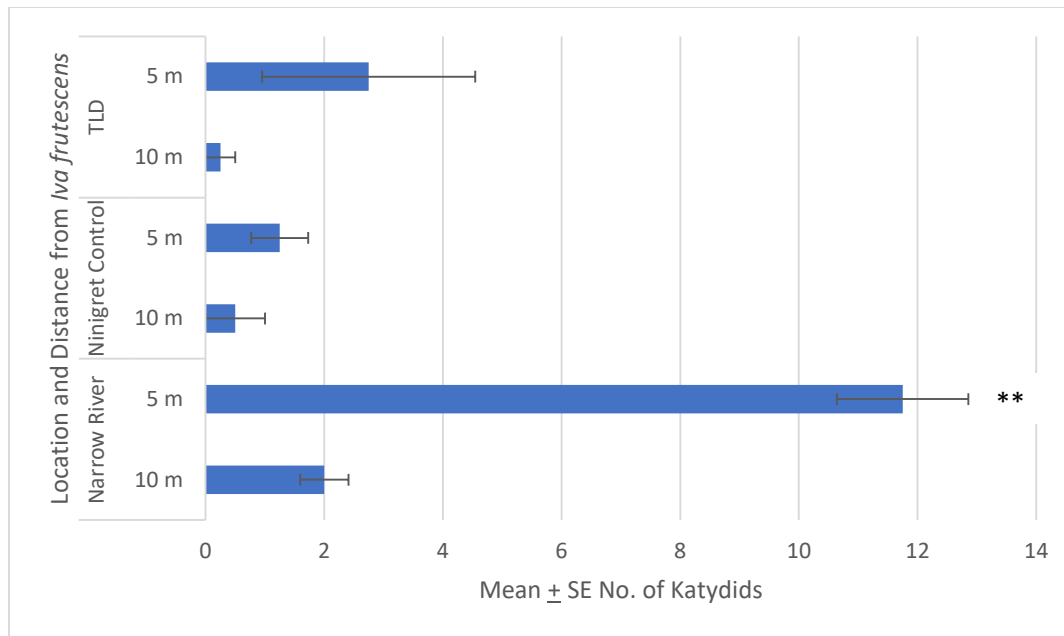


Fig. 13. Mean \pm SE number of katydids at each site. ** Highly significant ($F = 21.19$, $df\ 5,15$, $P < 0.001$).

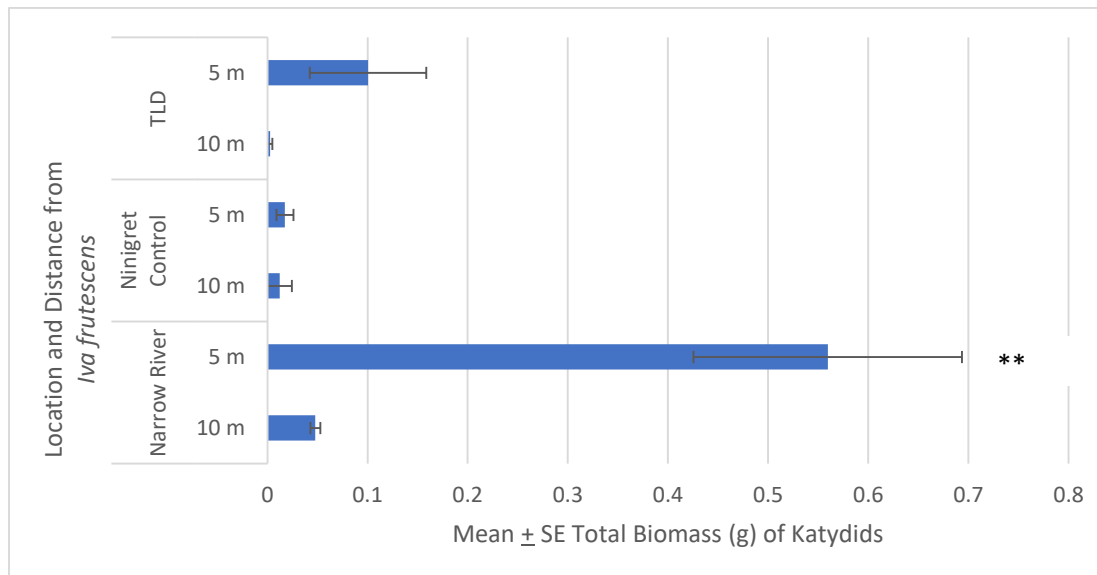


Fig. 14. Mean \pm SE total biomass (g) of katydids. ** Highly significant ($F = 13.88$, $df\ 5,15$, $P < 0.001$).

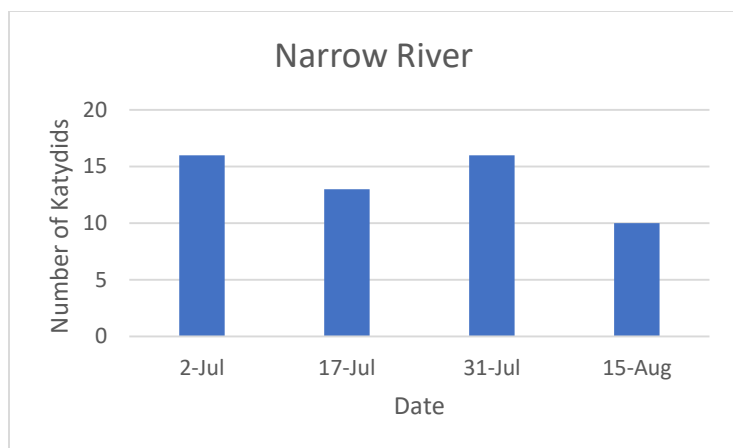


Fig. 15. Number of katydids collected over the summer at the Narrow River control site, 2018

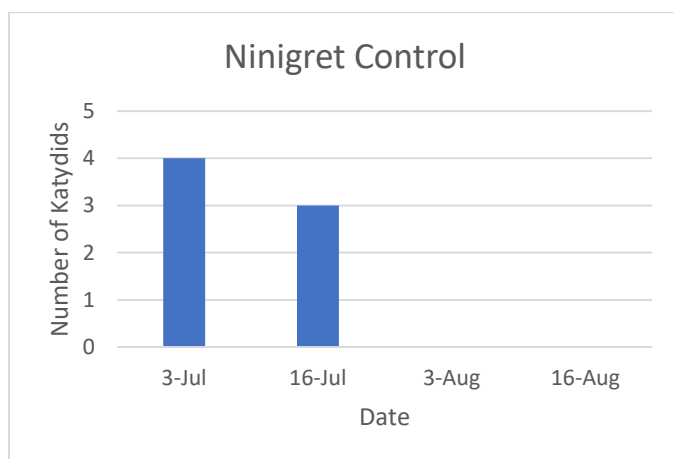


Fig. 16. Number of katydids collected over the summer at the Ninigret control site, 2018

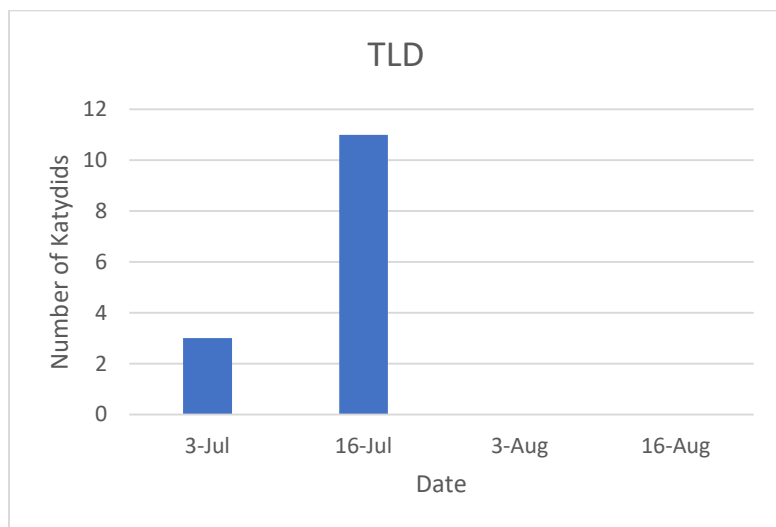


Fig. 17. Number of katydids collected over the summer at the thin layer deposition (TLD) site, 2018.

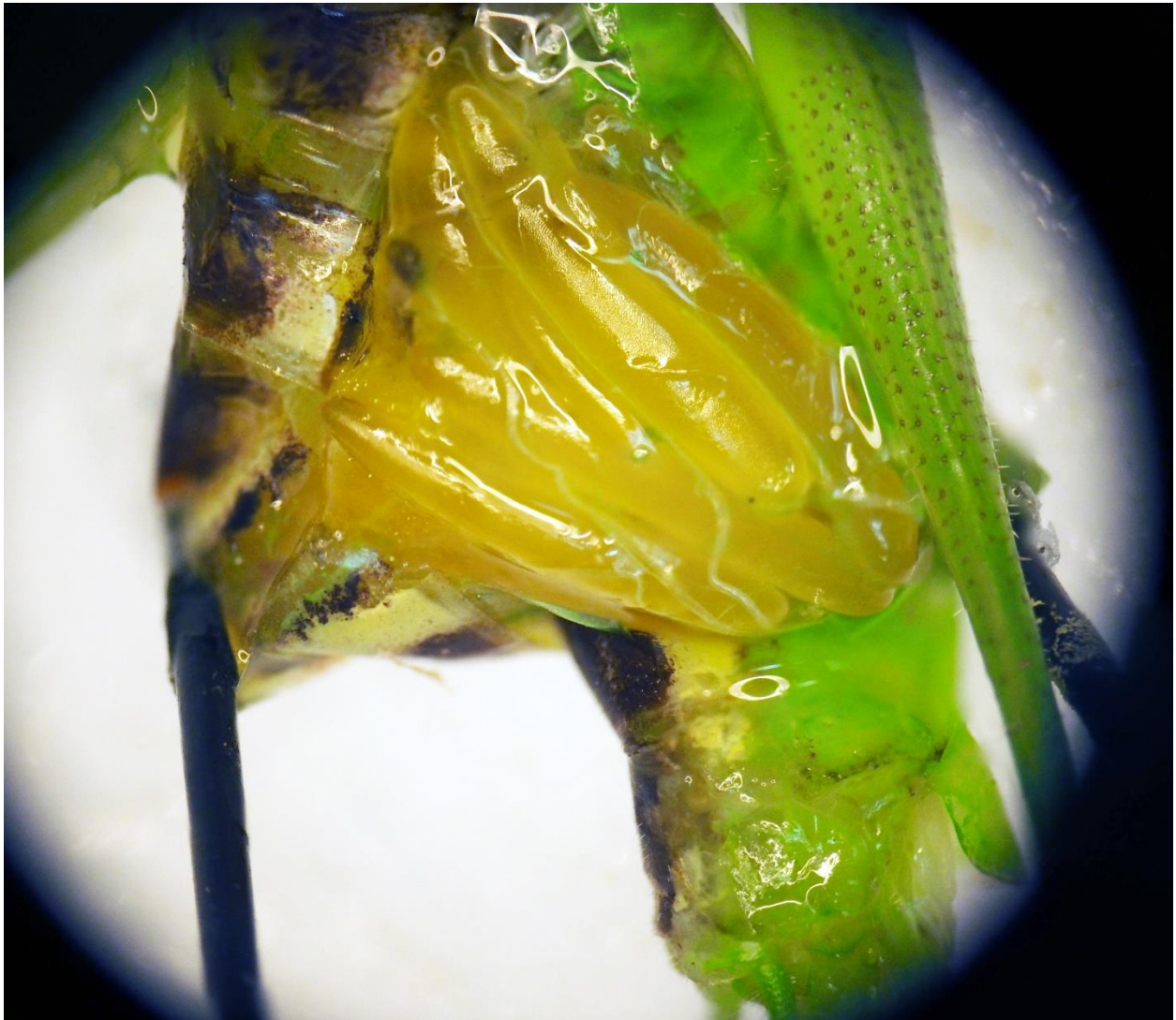


Fig. 18. Eggs of *Conocephalus spartinae* (approximately 4 mm long) (photo Matt Requistina).



**Rhode Island Natural History Survey
Diamondback Terrapin Internship, Summer 2018
Nicole Provensal**

Introduction:

The Diamondback Terrapin (*Malaclemys terrapin*) is the only species of turtle that inhabits brackish coastal tidal marshes from Cape Cod, to the Gulf of Mexico. The terrapin is a medium sized turtle, with males ranging from 3.5-4.5" in length, and females ranging from 6.0-9.0" in length. They spend their entire lives in the water, except for when females come up on land to lay their eggs. The terrapin was once considered common, but was historically overharvested for use in turtle soup, and are now listed as state-endangered in many of the states that they inhabit. Other factors, such as loss of nesting habitat due to anthropogenic factors and climate change, predators, and the pet trade, have also contributed to terrapin population declines throughout their range (Brennessel, 2006).

The subspecies of terrapin found within Rhode Island is the Northern Diamondback Terrapin (*Malaclemys terrapin terrapin*), whose range extends from Cape Cod to North Carolina. The terrapin is considered a state-endangered species in the state of RI, where there are currently only two known nesting sites: Rocky Hill School in East Greenwich and Hundred Acre Cove in Barrington. The Barrington site, which has been overseen by Charlotte Sornberger for the last 29 years, has been known in RI for having the most protected nests and highest hatching rate every year. More recently, in 2016, terrapins were also seen nesting on the beach of the Rocky Hill School in East Greenwich, RI. For the past two years, Dr. Laura Meyerson, a professor from the University of Rhode Island, has been in charge of monitoring efforts at this site with the help of university students and full support from the Rocky Hill School. Terrapins have been reportedly sighted at other locations within RI, including the Providence River and in the salt ponds in Westerly. The only other documentation of terrapin nesting within RI is on Prudence Island (Kenny Raposa, personal communication) and at Napatree Point (Kevin Rogers, personal communication).

This summer I split time between the Rocky Hill School location, assisting with nest monitoring and protection, and the salt ponds in Westerly trying to detect possible terrapin nesting sites. I also visited other out-of-state nesting sites, including South Wellfleet Bay Sanctuary in Cape Cod, MA and a couple sites throughout Buzzards Bay, MA, to learn more about terrapin nesting habits and the work being done to protect their nests. It is important to identify and monitor nesting sites, as well as begin to communicate with other researchers working with terrapins, so we can further coordinate conservation efforts to preserve the species.

Internship goals assigned were as follows:

1. Salt marsh restoration planning for Ninigret, Quonochontaug, and Winnapaug will have the benefit of the best, most up-to-date knowledge of terrapin distribution, ecology, and habitat use
2. Identify possible management adaptations that can optimize habitat value of already restored areas of salt marsh within Ninigret

3. In future projects, planners will be better able to balance other project goals with potential negative impacts in terrapins and better plan to maximize habitat value of restored salt marshes
4. Identify additional avenues for research on terrapins and salt marsh restoration

Site descriptions:

Table 1. Site description, land use, and soil data from RIGIS for each Westerly Terrapin site.			
<u>Location</u>	<u>Description</u>	<u>Land Use</u>	<u>Soils Present</u>
Ninigret	Brackish marsh, mudflat bare, salt shrub, <i>Phragmites</i> , natural pool, high marsh (<i>S.alterniflora</i>)	Brushland, vacant land, beach, deciduous forest, developed recreation, mixed forest sandy area	UD, BhA, ShA, Tb, Mk, Sa, FtA
Winnapaug	High marsh (<i>S.alterniflora</i> , <i>S. patens</i> and <i>D. spicata</i>), low marsh, mudflat bare, <i>Phragmites</i> , low marsh, salt shrub	Wetland, brushland, commercial	Mk, Su, Sa, ShA, FtA, WNaO, ChC
Quonochontaug	Mudflat bare, high marsh (<i>S. alterniflora</i> , <i>S. patens</i> , and <i>D. spicata</i>)	Beach, wetland/sandy area	FtA, WMgO

Site 1: Ninigret

Ninigret is the largest of the salt ponds studied. It is located in Charlestown, RI and is linked to the ocean via the Charlestown Breachway (Figure 1). Surrounding land includes public beaches, Ninigret National Wildlife Refuge, sand flats, low and high salt marsh (including large areas undergoing restoration), and residential properties. Ninigret is separated from Block Island Sound by a barrier beach system that includes East Beach, and also contains a portion of the Ninigret Wildlife Sanctuary. This strip of land contains coastal strand, foredune, dune, and backdune (Audubon, “Ninigret Pond and Conservation Areas”). Public access areas include Charlestown Breachway, East Beach, and Ninigret Wildlife Refuge. The pond is heavily utilized for recreational activities such as shell-fishing and boating. Large stretches of sandy beach exist and may provide suitable nesting habitat for terrapins; however, the last reported sighting of terrapins here was in 1982.



Figure 1. Map of Ninigret pond, including boat access points, terrapin sighting records and a thin layer deposition site. Figure provided by Hope Leeson.

Site 2: Quonochontaug

Quonochontaug pond, located between Winnapaug and Ninigret, is the deepest and most saline salt pond located in both Charlestown and Westerly, RI and connects to the ocean with the Quonochontaug Breachway (Figure 2). The pond is surrounded by salt marsh, red maple swamps, private residential property and private beach. It is the least developed of the salt ponds in Westerly (Salt Pond Coalition).



Figure 2. Map of Quonochontaug pond, including boat access points, sighting records, and thin layer deposition site. Figure provided by Hope Leeson.

Site 3: Winnapaug

Winnapaug pond is the smallest and most developed of the three survey sites in Westerly, RI. It is surrounded by both public and private land, and the landscape consists of salt marshes, woods, grassy areas, and residential and commercial land (Figure 3) (Salt Marsh Coalition). Winnapaug pond is located directly adjacent to Misquamicut State Beach and Atlantic Avenue, which are both heavily utilized during the summer months. The pond itself is also heavily utilized by humans for activities such as kayaking, jet-skiing, and shell-fishing. Small patches of what appears to be suitable nesting habitat may exist at different points on the pond. Terrapins have reportedly been spotted there as recently as June/July 2018, but not much about this population is known and research is ongoing.

Figure 3. Map of Winnapaug pond including boat access points, sighting records, and a thin layer deposition site. Figure provided by Hope Leeson.



Protocol: Ninigret

This site was visited throughout June-August 2018, with the most monitoring hours taking place between 0800 and 1500. On the southern side of the pond, around East Beach, a single person walked the edge of the pond, stopping about every 300m to do head counts for 30 minutes (Figure 4). On the northern side of the pond, in Ninigret National Wildlife Refuge, a single person conducted single point head-counts, only where access to the pond was feasible (Figure 4). A single kayak survey was conducted to attempt to detect the presence of terrapins, but none were seen.



Figure 4. Line- and point-transects that were surveyed along Ninigret pond.

Protocol: Quonochontaug

Surveys at Quonochontaug were severely limited to the lack of access to the pond due to private property, lack of public parking, and deep water (Figure 5). Each point was surveyed for 1 hour on two separate dates between the hours of 0900 and 1200 and 1200 and 1500.



Figure 5. Points surveyed at Quonochontaug pond.

Protocol: Winnapaug

This site was visited throughout June-August 2018, with the most monitoring hours taking place between 0800 and 1500. A single person walked the edge of the pond stopping about every 300m to do head counts for about 30 minutes (Figure 6). Longer-timed head counts were also conducted at single points at areas where terrapins had been recently seen; these head counts lasted 1-2 hours. Surveys on the eastern side of the pond were limited by private property and deep water.



Figure 6. Line-transect surveys done at Winnapaug pond.

Results:

Table 2. Head-count, time and tide data from surveys. (Nini = Ninigret, Winn = Winnapaug, Quon = Quonochontaug)						
<u>Date</u>	<u>Location</u>	<u>Time In</u>	<u>Time Out</u>	<u>High Tide</u>	<u>Low Tide</u>	<u>Head Count</u>
6/26	Nini	0830	1530	0801	1412	0
6/29	Nini	0800	1200	0955	1610	0
7/2	Winn	0900	1400	1150	0554	1
7/10	Winn	0800	1300	0622	1222	0
7/11	Nini	0900	1300	0719	1319	0
7/16	Nini	0800	1300	1151	0546	0
7/20	Winn	0900	1400	1553	0933	0
7/21	Nini (kayak)	0900	1400	0410	1027	0
7/23	Quon	0900	1200	0602	1214	0
7/27	Winn	0930	1200	0855	1454	0
7/27	Quon	1200	1500	0855	1454	0

Challenges:

Throughout the course of the summer, obstacles and restrictions prevented thorough kayak and land surveys in some areas within the salt ponds. The most inhibiting factor was limited access to sites, especially Quonochontaug. During the summer months, the only public parking available, for Quonochontaug, was at the Quonnie boat ramp located at the end of West Beach Road in the Eastern side of the breachway. Access to the perimeter of the pond was impossible at this location due to deep water. Due to this, head-count surveys were limited to a very small

area at this pond. Kayak surveys were also limited throughout the summer because it is dangerous to conduct kayak surveys alone.

Overall, the scope of the area was too great for a single person to safely and effectively monitor, as any signs of terrapins could have been missed.

Recommendations:

While there were limitations to this project, adjustments can be made to improve the quality of the surveys for upcoming years:

1. More people: additional individuals to assist with the monitoring is necessary, because the survey area was so large. Having a minimum of two individuals is required for kayak surveys, which would make the surveys much more feasible and reliable; however, if extensive nest monitoring and protection is desired, then many more researchers would be required. For example, at the Rocky Hill School site in East Greenwich, they tried to have 5 people out at a time, for 12 hours a day, for 5 weeks. This translates to over 2,000 person hours per season.
2. Trail cams: they could be set-up in areas identified as suitable nesting habitat for terrapins, which would increase the likelihood of detecting nesting and reduce the number of person hours required. Trail cams, such as the Bushnell 11987 series, work well and are relatively inexpensive. Trail cameras should be locked and placed off the beaten path to prevent theft and checked once a week to switch out SD cards and download data.
3. Motorboat: some areas of the ponds, specifically Ninigret, would be much easier to access with a motorboat. Kayaking on Ninigret is very time consuming to cover even a small area of the pond.
4. Parking permits: additional parking permits or allowances to cover parking would be helpful and increase accessibility to the ponds, especially Quonochontaug pond. A privately-owned beach has offseason public parking available; however, in the summer, which is peak nesting season, the parking is reserved for members.
5. Gather more data: other surveys that would contribute to this project include of vegetation surveys, and soil grain size analysis. Other data, such as slope and aspect, could also be collected and analyzed in ArcMap. These data sets could be used to determine suitable habitat and pinpoint ideal nesting locations, which would narrow down the study areas.
6. Signage: once nesting habitat is detected, placing signs asking public to stay away and keep their dogs away could increase the number of nesting terrapins and increase survivability.

7. Citizen science: involvement of citizen science could be started by creating a webpage for people to report possible terrapin sightings in the area. Other public engagement efforts could include holding neighborhood meetings, and partnering with local schools and scouting troops.

Current and Future Work:

Research is currently taking place to create a new habitat suitability index (HSI) for the Northern Diamondback Terrapin. Known nesting sites from Cape Cod to New Jersey are being included in this effort, and data such as land cover, soil grain size, anthropogenic factors, aspect and slope, are being analyzed. I have included some preliminary results and maps (figure 7) showing the RI soil sample locations, land cover data, and slope information. Once the HSI is completed, it will be more feasible to identify and prioritize possible nesting sites for monitoring at the Westerly salt ponds, and efforts can be focused at these locations.

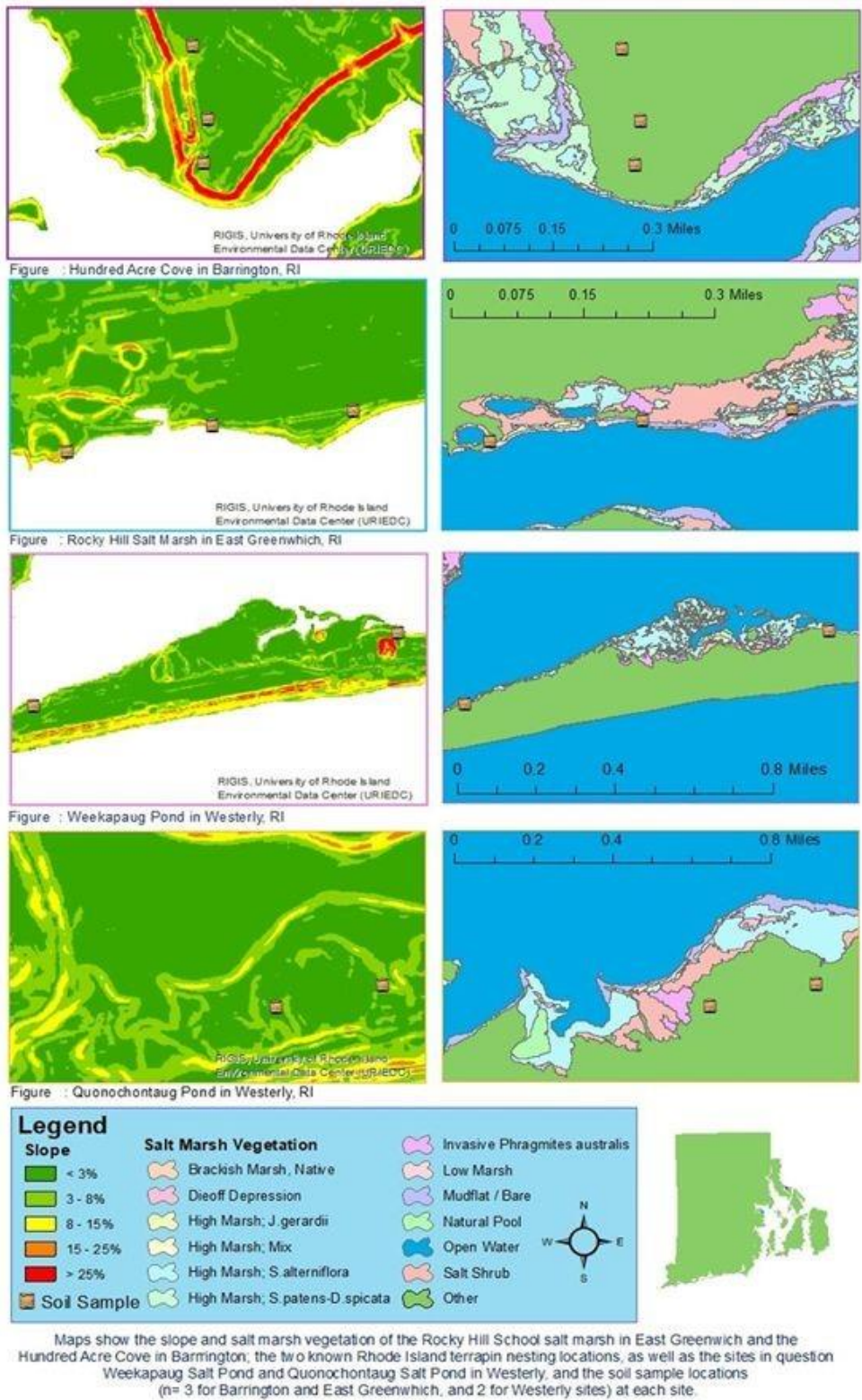


Figure 7. Preliminary slope and vegetation data of the Rhode Island soil sample locations at known and suspected nesting sites.

References:

Brennessel, B. (2006). *Diamonds in the Marsh A Natural History of the Diamondback Terrapin*

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(n.d.). Retrieved from <http://www.saltpondscoalition.org/PageWinnapaug.html>

Appendices:

- I. Protocols
 - A. Kayak Survey
 - B. Vegetation Analysis
 - C. Soil Grain Size Analysis

Appendix IA: Kayak Survey Protocol

Diamondback Terrapin Kayak Survey Protocols Introduction:

Integrated kayak survey

The kayak survey protocol is designed to gather an estimated population size using visual surveys on the water. The goal is after multiple surveys with accurate data collected over many years. The early years will give estimates on population densities and over time will give an estimated population number for a given site. The survey is a hybrid between point count and transects surveys. Where the point stations have a predetermined distance, and that distance between the points is where the transect takes place. For example, let's say the site is large enough that the point station survey points are spaced 250 m apart from each other, this would allow a 250 m transect survey to run between the points. GPS is required to maintain accurate course along routes, they will need to be completed at least 3 times. Therefore, accuracy is important to have reliable data. There will most likely be slight variations in the route, +/- 5 m left or right along routes can be accepted, along with 5-10m drift margins for the point station. Estimating distance the districts the head are away from the current position. Is important to do so as accurate as possible. Recording the distance of the head in bins (i.e. 0-10m, 11-20m, 21-30m, 31-40m, 41-50m). Would be an accurate way to estimate this. The set distance of point stations can be modified based on the sizes of the site along with bin sizes if needed. Each point station stop will be conducted for 5 minutes, and observers will count heads and record the distance in bins. Observers will have to be comfortable estimating distance, and use of rangefinders can aid in training the eye to measure distance; only works on physical objects, not water. The data collected can be used to map the distribution of terrapins in the water and analysis of the data is necessary to learn more about the threatened species, such as whether the population is increasing or declining over time. The protocol will be used by investigators from the University of Rhode Island at the Potowomut salt marsh, in East Greenwich. The protocol is designed to also be applied at other sites that the Diamondback Terrapins inhabit.

Materials:

- Kayak with paddle
- Personal flotation device/ life jacket
- Transect Data Sheets (rite in the rain with pencil)
- GPS device (etrek or better)
- Appropriate clothing and footwear
- Field journal for other/daily observation.
- Cell phone for emergencies and for photo (at your own risk) Dry bag to keep belongings safe.

Survey

Prior to going out on the water, the set distance between point stations must be determined. Marking GPS location on a map and using a GPS to get to starting point is recommended. A minimum of two researchers must go out together for safety purposes and to have a 360 degree view angle from each point station site. Researchers need to track their movement with a GPS unit to know when they reach certain distances. The travel between two point station is where the transect takes place.

When researchers are at the first point station, they will need to set-up by filling in the data sheet with the metadata and get their equipment ready (i.e. binoculars). The survey should start when all party members are ready. The survey needs to be conducted with as little disturbance as possible. Each researcher will cover a 180 degree view angle each; therefore, they must be set up facing opposite directions. (picture could be add). Survey should take 5 mins. All heads seen need to be recorded on the data sheet as tallies in the correct bin distance (i.e. 0- 10m, 11-20m, 21-30m, 31-40m, 41-50m) ; making sure not to double counts heads.

After the first point station is complete, the travel to the next point station is where the transect takes place.(i.e. 0- 10m, 11-20m, 21-30m, 31-40m, 41-50m). The route is also predetermined, starting is the first point location then the most direct route to the next predetermined point station. Use of GIS or Google Earth is needed to pre-determine transect start points, length, and route. During transects researchers will be scanning 50 meters in a 180-degree field of view looking forward, over the front of the kayak. Travel along the plotted course with GPS tracking location and try to not be disruptive when paddling. Count the number of heads seen and record them in bin ranges (i.e. 0- 10m, 11-20m, 21-30m, 31-40m, 41-50m) away from transect. Only head spotted during the transect within 50 meter are recorded. Once you arrive at the next point station repeat that 5 min survey. Data sheets need to completed by the end of each survey. Which consists of a start point station, transects, and end point station.

Multiple integrated kayak surveys can accomplished in one day but cannot repeat the same survey twice in one day. Instead, repeat completed locations on different days at least 3 times throughout the summer. More point station an be add within a transect, instead of having only start and end points, there could be middle point if planned right (changes the data table based on number of points).

The end goal is to sample a large percentage of the water way accurately. With the first few year determining densities of the population, and over time estimate the sites population. Therefore, consistency and accuracy are important when conducting these surveys.

Procedure Instructions:

Kayak survey Overview:

- Predesignate a point stations location and transect route using GIS or Google Earth.
- Be in groups of two observers (minimum) in Kayaks.

- Use binoculars to scan for Diamondback Terrapins at 50 meters in a 180-degree field of view for each person. Bring rangefinder if needed.
- Transect part survey 180m ahead in distance to second point station.
- Record all head seen within a 5 mins time frame in bins, give time for set up.
- Record all heads on transect in bins.
- Point station locations, track movement traveled during transect with GPS.
- Mark rough location of terrapin on data sheet. (Bottom of Protocol)
- Fill in data sheet correctly and fully
- Enter & Analyze data in Excel Spreadsheet.

Data analysis: (not completed yet, more info on stats program used.)

Using the data collected (i.e. size of area surveyed and number of terrapins seen), we can begin to estimate terrapin population density within the Potowomut salt marsh. However, to more accurately estimate terrapin population density the kayak survey would need to be conducted throughout the future to get as much data as possible. Population density would be (# of terrapin/area surveyed).

With accurate area estimates surveyed and the number of terrapins seen during those surveys, would estimate densities of terrapins with more years of research would be the start to estimating population size.

Data Sheet:

Date: _____ Observers: _____

Time start: _____ Time end: _____ Total time: _____

Start GPS Point N. _____ W. _____

GPS # _____ Cloud Cover: _____ % Temperature: _____ (°F)

End GPS Point

N. _____ W. _____

Tide: _____ (high, mid, or low)

Terrapins (Tally system)

Terrapin heads	0-10 m	11-20 m	21-30 m	31-40 m	41-50 m
Start point station					
Tansect ____ meters					
End point station					
Total					

Additional Notes:

Scan date:

Scanned by:

Appendix I B. Vegetation Analysis Protocol Vegetation Monitoring Protocol at the Rocky Hill School

Modified from Charley Roman's

'Monitoring Vegetation in Salt Marshes' for the National Park Service, 2010

Selecting Monitoring Sites and Establishing Vegetation Plot

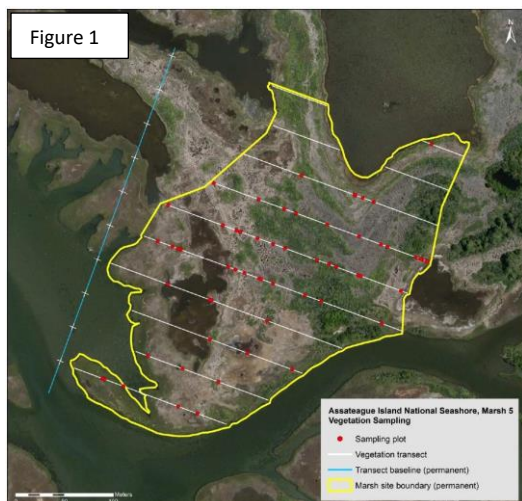
The monitoring site occurring within the salt marsh habitat is identified and delineated using GIS. Delineation is based on geographic features such as tidal creeks, salt marsh upland borders, ditches, and bay front. Permanent monitoring sites are chosen randomly from the entire set of delineated monitoring sites. Delineated site boundaries are permanent, ensuring that the sampled area of each site remains the same from year to year.

Establishing Transects and Plots

To establish transects, GIS with a recent aerial image is used. A baseline is drawn along one edge of each monitoring site so that ten transects oriented perpendicular to this baseline follow the natural elevation gradient from estuarine edge, or low salt marsh, to the upland edge. The baseline is then divided into 1-meter increments, and the start of the first transect is randomly selected along the baseline. Based on the initial random placement of the first transect, nine additional transects are systematically and evenly placed from this point in either direction. For example, if the baseline is 100 m and the random starting point of the first transect is 75, transects would be located at 85, 95, 65, 55, 45, 35, 25, 15, and 5 m. The distance between transects depends on the length of the baseline.

Orientation of transects is guided by the following rules:

- The ten transects traverse the main elevation gradient (e.g., low to high marsh) (Figure 1).



- Transects extend from the seaward permanent boundary to the permanent boundary toward the upland.
- If a tidal creek bisects the marsh, transects should run perpendicular to the creek (i.e., cross the creek rather than running parallel to it).
- If the marsh is grid ditched, orient transects so they do not run parallel to the ditches. This is done to prevent an overabundance of vegetation plots from being located in the same type of habitat such as low marsh near ditch edges.

Once transects are established, the lengths of the ten transects are added together to create one total length.

This single length is divided into 1-meter segments, and 35-50 points are chosen randomly along this length. Ten additional random points are chosen as possible replacement plots, if needed. These points are used if one of the original random points falls in an area that is not suitable for salt marsh vegetation sampling (e.g., falls in a forested upland, cannot be safely accessed). Plots are then placed at these points (Figure 1). The point selected in GIS indicates the location of the bottom left-hand corner of each plot. The field crew must be exceptionally careful of trampling vegetation in adjacent plots when plots are close together. If trampling does occur, the plot should be deleted from the data set of the year that trampling occurred. The plot can be re-sampled during the subsequent sample year. With this design, the plots are randomly located and spatially distributed across the marsh. Both transects and plots are established as permanent and are re-visited in the following sampling year. With this design, the plots are randomly located and spatially distributed across the marsh. Both transects and plots are established as permanent and are re-visited in the following sampling year.

Definition of GPS/GIS terminology:

Coordinates are a set of numbers describing your exact location on the earth's surface. Latitude and longitude are one example of a coordinate system.

A horizontal datum is used as a reference point for determining a specific location on the earth's surface in a coordinate system such as latitude and longitude, or UTM. For example, the coordinates of a particular sampling station will be based on its location relative to a specific reference point, or datum. The NCBN uses NAD 83 (North American Datum 1983) as the datum when conducting salt marsh monitoring.

A waypoint is a coordinate that is either recorded with a GPS or uploaded to the GPS, and represents the location of a sampling station or other feature (i.e., marsh access points).

WAAS (Wide Area Augmentation System) is an array of satellites and ground stations that provide GPS signal corrections. WAAS does not help the GPS unit determine your location, but rather it helps to make the position calculation more accurate.

Configuring the Handheld GPS Unit

- Use the User's Manual to navigate the menu options. Verify the following:
- Units for distance, speed, etc. are set to metric units (meters, meters / sec).
- Compass heading is set to 'true'.
- WAAS is enabled.

- Route preference is set to 'off road'. If 'off road' is not selected, the GPS will try to navigate to the site and sampling stations using roads, which is not helpful in a salt marsh.

Preparing for Field Sampling

- Check battery levels—at least 8 hours before use, ensure that batteries are fully charged.
- Always have at least two sets of fully charged batteries as a backup in the field.
- Upload waypoints (coordinates for sampling stations) to GPS units and confirm they have uploaded properly (ie, plot IDs match up with maps, all points have loaded)
- Print site maps with site access points and vegetation plots labeled.

Using the Handheld GPS unit to Navigate to Known Locations

- The GPS unit is used to navigate to known locations (i.e., previously uploaded or saved waypoints).
- Turn on GPS, and allow it to acquire signals from available satellites. Wait until the GPS status indicates '3D differential' (depends on the model).
- Select the waypoint to which you would like to navigate.
- The GPS will indicate the direction and distance to the waypoint.
- Many GPS units will 'beep', indicating that you have 'arrived' at the sampling location.

Saving Waypoints to the Handheld GPS unit in the Field

It is occasionally necessary to save a waypoint location in the field (e.g., if you need to mark a site access point, etc). In addition to saving waypoints to the GPS unit, the waypoint ID and coordinates must be recorded on a waterproof field sheet. This prevents loss of data in the event of equipment malfunction. For the salt marsh monitoring protocols, saving waypoints is most often used when conducting a marsh reconnaissance to determine suitable sampling locations or site access points.

To save a waypoint:

- Consult the User's Manual for specific instructions for saving waypoints.
- For increased accuracy it is best to 'average' your location. Consult the User's Manual for specific instructions for 'averaging' your location. This is time consuming (on the order of several minutes), and is only necessary when high accuracy is required-- such as when saving actual sample locations that need to be revisited.
- Record waypoint number, coordinates, and estimated horizontal error on the field sheet.

Navigating to vegetation plots

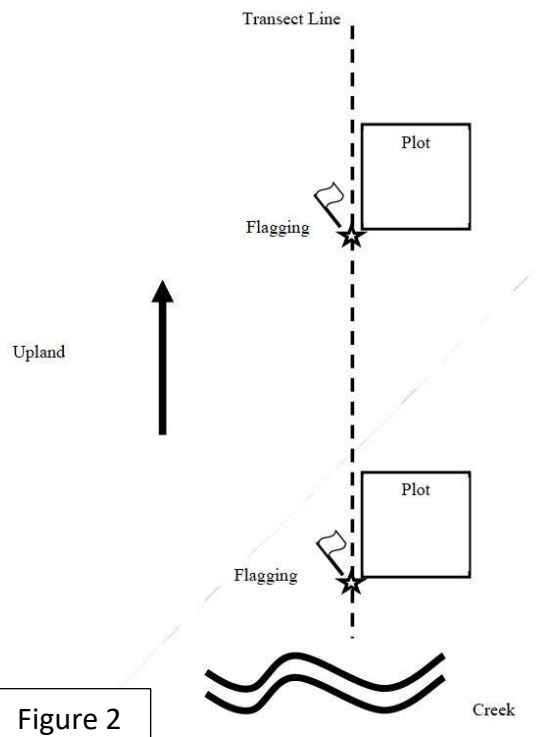
- Locate the beginning of each transect. This is done with the aid of maps of the site in addition to GPS coordinates generated from GIS programs.
- Navigate to each plot along the transect using the GPS coordinates.
- Plots are located to the right of transects and oriented towards the upland end of the transect (Figure 2). When navigating to plots, it is critical to always walk to the left of the transect to avoid trampling plots.
- If transects or plots are located immediately adjacent to one another, take extreme care not to trample adjacent plots when navigating to plots. Use a map of the site with the locations of the vegetation plots on it to help ensure you are not trampling plots.
- It is acceptable for a plot to be partially or completely located in a pool, creek, or ditch. The percent cover of water is estimated accordingly.
- UTM coordinates of every plot should be taken with a GPS and recorded on the field sheet.
- It is highly recommended that the elevation of each vegetation plot be recorded in each sampling year. Information on elevation is extremely valuable to interpret any changes in vegetation communities of the plots that may be resultant from changes in hydroperiod.
- As soon as possible, a GIS map should be plotted with the station locations and verified for accuracy.

Sampling Methods

This protocol is designed to monitor changes in vegetation species composition and percent cover within each monitoring site. The identity of each cover type (live and dead vascular plants by species, macroalgae, bare ground, standing water, wrack/litter, trash, rock, other) and an estimate of the percent cover of each type must be determined within each 1-m² plot. Two methods of estimating percent cover, the visual cover estimate and the point intercept estimate, are used.

Supplies

- Clipboard
- Flags and black permanent markers for marking vegetation plots



- GPS unit and compass
- Quadrants
- Clipboard
- Blank Vegetation Monitoring Field Sheet & Blank

Field Sheets

To ensure that data sets remain complete, accurate, and up to date as possible, it is imperative that all field data are recorded on appropriate field sheets during each sampling event. Any unknown specimens are identified as soon as possible upon return to the laboratory and the correct identification indicated on the field sheets. Any edits, changes or corrections to the data are noted on the field sheet and include the data and initial of the person making the change. All the GPS coordinates are entered into GIS to verify location of sampling stations.

Data Entry and Verification

Data sheets are scanned and uploaded into the Rocky Hill School Google Drive promptly after data collection. Field data will be submitted under **Diamondback Terrapin Project > Data > Scanned Data Sheets** as well as submitted manually in the cumulative data files under the corresponding subject matter within the Google Drive.

Determining Cover Class

- Navigate to the beginning of the first transect as described above (Navigating to vegetation plots).
- Navigate to the first plot on that transect. To prevent trampling of plots, it is important that the field crew stay to the left of the transect (plots are oriented on the right side of transect facing the upland) as they are navigating to plots.
- Use a PVC quadrat or four dowels to define the 1-m² plot.
- Facing the upland, place the quadrat to the right of the transect with the lower left hand corner of the quadrat at the plot's coordinates, next to the plot marker (if used) (Figure 2).
- Record the plot ID according to the naming convention in the current NCBN Salt Marsh Monitoring database on the field sheet. Complete all fields on the field sheet as described below (Data Recorded at each Vegetation Plot).
- List all species that are present within the 1-m² plot on the field sheet for that plot.
- List all other cover types present within the plot, such as "water", "bare ground", "standing dead", "wrack or litter," and others.

- The two technicians stand over the plot and silently estimate the percent cover category (see Visual cover estimate categories below) of each individual species or cover type.
- Once each technician has come to an estimate, they speak the estimate out loud. If the estimates are the same then the visual cover class is written on the field sheet. If the estimates differ, then the samplers re-evaluate the cover class estimate until they agree on one cover class category for the species or other cover type.
- The method is repeated for all species and cover types within the plot.
- If the plot is located in a pool or ditch, record the appropriate percentage of water. A plot can have 100% water (e.g., Braun-Blanquet score of 6) if it is entirely within a pool, creek, ditch, or bay front. The type of water (pool, creek, ditch, panne, rivulet, or bay must be recorded). If a plot has permanent standing water that is covering a bare mud bottom, this is simply recorded as water. There is no need to record bare ground.
- If macroalgae or submerged aquatic vegetation is present in a plot in a standing water habitat, then both the plant and water are recorded.
- If a plot is at the edge of a marsh pool (water), and vegetation (e.g., *Spartina alterniflora*) overhangs the water, then both *S. alterniflora* and water should be recorded.
- The “bare” cover category is only used when there is no other canopy cover. Bare ground is recorded when either the entire plot or any part of the plot that is completely bare (e.g., plot located entirely or partially in a mudflat, dry creek bottom, unvegetated panne).

Visual Cover Estimate Method

The visual cover estimate is an estimate of the percent cover of vegetation cover classes within a 1-m² vegetation plot. This protocol uses the Braun-Blanquet method to estimate percent cover in vegetation plots. This method requires training to familiarize the technician with estimating percent cover by visualization. It is recommended that the same team of technicians estimate all plots to reduce error among samplers.

Visual cover estimate categories

The following cover class categories are used to determine percent cover for individual cover types within the vegetation plot. It is extremely

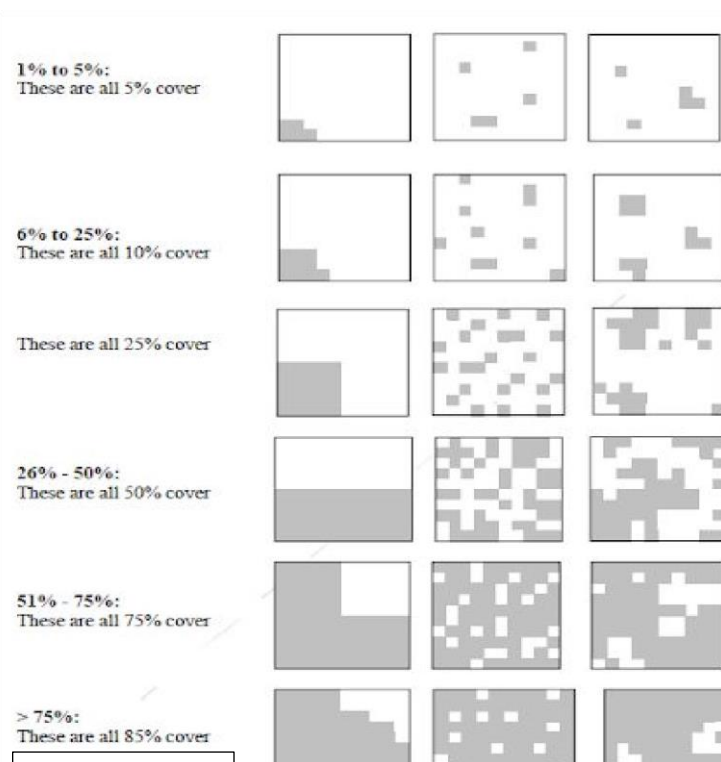


Figure 3

important that technicians using the visual estimate cover method are able to arrive at the same cover class category repeatedly. This protocol uses the Braun-Blanquet cover scale. In statistical analyses the Braun-Blanquet data are analyzed as ordinal data (e.g., 0 to 6 scale for categories). Schematic representation of Braun-Blanquet cover categories are shown in Figure 3.

0: absent (indicating the absence of a species or other cover type is usually only necessary during data analyses).

1: Less than 1% (usually only 1 specimen or seedling in plot)

2: 1% to 5% cover

3: 6% to 25% cover

4: 26% to 50% cover

5: 51% to 75% cover

6: 76% to 100% cover

Height of Species of Interest

Height of species of interest such as the common reed (*Phragmites australis*) and salt marsh cordgrass (*Spartina alterniflora*) should be measured within vegetation plots where it occurs. Height can indicate the vigor of the species and response to changes in hydrology. The tallest stems are measured, thus avoiding any bias in selecting stems that may occur if stems are haphazardly selected to derive an average stem height.

- Height (cm) is measured when the plants are at peak biomass (e.g., at the end of the growing season) and when plants have produced or should have produced a seed head. It is possible that an inflorescence may not be present if plants are stressed, in this case height is still measured.
- Height is measured from the ground to the tallest portion of the plant, such as the leaves (when stretched out over the top of the inflorescence) or the top of the inflorescence. If inflorescence is not present then height is measured by stretching the leaves to their full extent.
- Height of the 5 tallest stems of *Phragmites* and *S. alterniflora* in the plot is measured.
- If there are less than 5 stems of the target species, then only the tallest stem (1 stem) is measured.

Data Recorded at each Vegetation Plot

For each vegetation plot, the following information must be recorded on the field sheet. Verify that the field sheet is filled out completely before moving to the next plot.

- Date of sample collection (month, day, year)
- Crew: initials of people conducting the work
- Coordinates of plot in UTM (meters) and horizontal error for the GPS
- Site Code: RHS1
- Plot ID: Unique plot number: Site code + V + 4 digit plot number. For example, RHS1V0616 indicates a plot located at RHS marsh 1, where 'V' signifies a vegetation plot, and '0610' indicates plot number 6 in sampling year 2016.
- Presence of fiddler crabs, fiddler crab burrows, ribbed mussels: record a check mark to indicate presence.
- Height of 5 tallest *Spartina alterniflora* and /or *Phragmites australis* plants measured in centimeters (cm)
- Species or cover type: species name of each plant species or another cover category (water, bare, etc.). Full species name is written on the field sheet. For frequently observed species such as *Spartina alterniflora* and *Spartina patens*, species may be abbreviated to *S. alterniflora*, *S. patens*.
- Cover classes: record the cover class of each cover type (plant species, water, bare, etc.)
- Indicate (Y/N) if species was flowering
- If water was present, record the type of water body (pool, creek, ditch, panne, rivulet, or bay).

Before moving to the next plot, confirm that all fields on the field sheet have been completed. Upon return to the office, all field sheets must be checked to ensure they include all information. If any information is missing every attempt should be made to complete the missing information. The person completing the missing information must initial and date the change and/or addition. If voucher specimens are taken for unknown or difficult to identify species, the person verifying the identification must date and initial the changes on the field sheet.

Appendix I C. Soil grain size analysis Grain size analysis protocol for diamondback terrapin nesting habitat

Goal – determine organic matter using LOI, %sand and %silt/clay in soils collected from nesting sites of DBT. % Sand will be divided into > 2mm (gravel), 5 classes within sand.

Step 1: Determining organic matter (p. 132 and p 368) Loss on ignition):

p. 132 of Burt 2004 soil survey laboratory methods manual (see reference from Amber's email)

1. Record weight of all soil in bag once air dried. Record.
2. Sieve entire soil sample in bag through 2mm sieve
3. Pre-heat drying oven to 105° C
4. Record air dry weight of > 2mm fraction (gravels) and < 2mm fraction
5. Subsample 20g from < 2mm fraction
6. Mark crucible with grease pencil and record weight of empty crucible on spreadsheet
7. Put 10-20g subsample in crucible, weigh again and record weight
8. Put in 105° C oven overnight or 16 hours – make sure dries to constant weight
9. Once dry to constant weight, place in desiccator to cool 15-20 minutes (or else weight will fluctuate).
10. Record oven dry weight of soil and crucible. Do this quickly and keep sample out in the air for as short a time as possible because the sample will rapidly absorb moisture. Once recorded, sample does not have to be in desiccator.
11. Repeat above for all samples that will be included in this run.
12. Place crucibles in cold muffle furnace and raise temperature to 550° .
13. Run for at least 5 hours in muffle furnace.
14. Let furnace cool for 1 hour before removing crucibles to desiccator. Be sure to protect hands and use tongs to prevent burning your hands.

Step 2: Particle Size Analysis (p 55) – this will be done in soil lab up at Coastal Institute

1. Calgon method

Step 3: Loss on Ignition

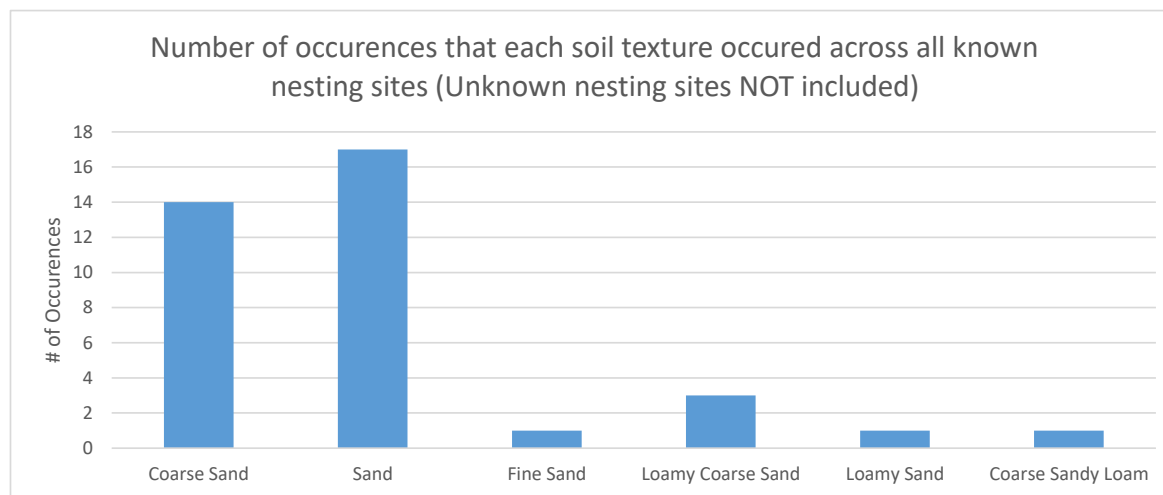
Uses samples from step 1

Diamondback Terrapin Habitat Suitability Index
Northeast Data Collection, Soil Texture
Dr. Laura Meyerson, URI 2018

Table 2. Soil texture of samples across different sites. (Source: NRCS Soil Texture Calculator)

State	Site ID	Soil Texture
CT	CT_1	Coarse Sand
CT	CT_2	Sand
CT	CT_3	Sand
RI	RI_1	Sand
RI	RI_2	Sand
RI	RI_3	Sand
RI	RI_10	Sand
RI	RI_11	Sand
RI	RI_12	Loamy Sand
RI	RI_13	Sand
RI	RI_14	Sand
MA	MA_1	Coarse Sand
MA	MA_2	Coarse Sand
MA	MA_3	Coarse Sand
MA	MA_4	Sand
MA	MA_5	Coarse Sand
MA	MA_6	Coarse Sand
MA	MA_7	Sand
MA	MA_9	Sand
MA	MA_10	Coarse Sand
MA	MA_11	Coarse Sand
MA	MA_12	Sand
MA	MA_13	Coarse Sand
MA	MA_14	Coarse Sand
NJ	NJ_1	Loamy Coarse Sand
NJ	NJ_2	Loamy Coarse Sand
NJ	NJ_3	Coarse Sand
NJ	NJ_4	Fine Sand
NJ	NJ_5	Coarse Sand
NJ	NJ_6	Loamy Coarse Sand
NJ	NJ_7	Coarse Sandy Loam
NY	NY_1	Sand
NY	NY_2	Coarse Sand
NY	NY_3	Coarse Sand
NY	NY_4	Sand
NY	NY_5	Sand
NY	NY_6	Sand

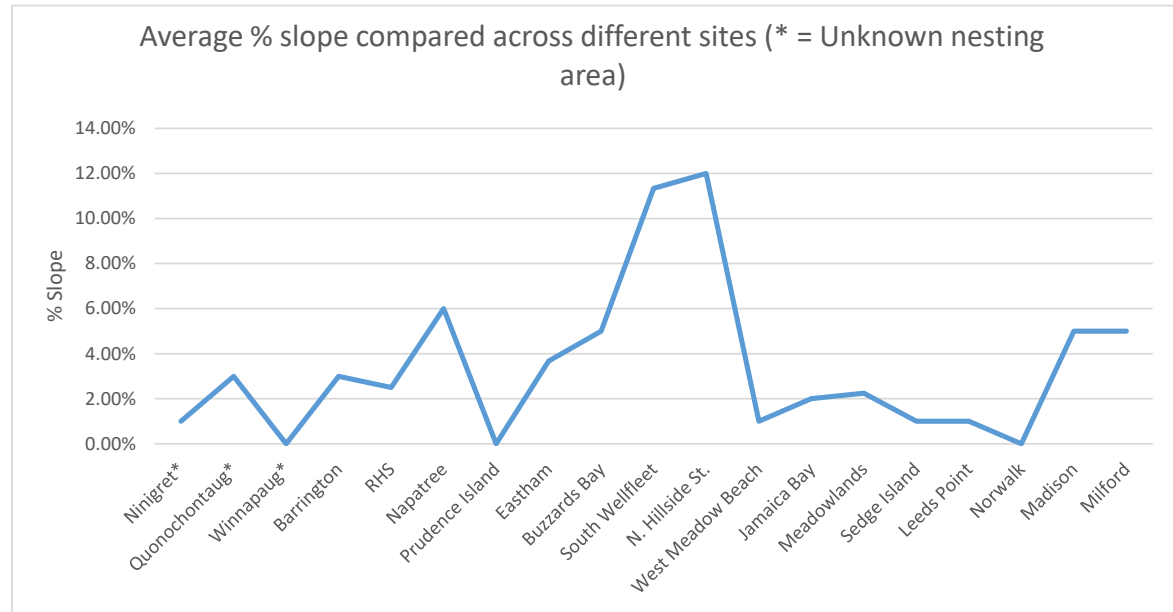
Soil Texture	# of Occurrences
Coarse Sand	14
Sand	17
Fine Sand	1
Loamy Coarse Sand	3
Loamy Sand	1
Coarse Sandy Loam	1



Diamondback Terrapin Habitat Suitability Index
Northeast Data Collection, Slope
Dr. Laura Meyerson, URI 2018

Table 4. Slope for each known nesting site. (Source: NRCS Web Soil Suvey)

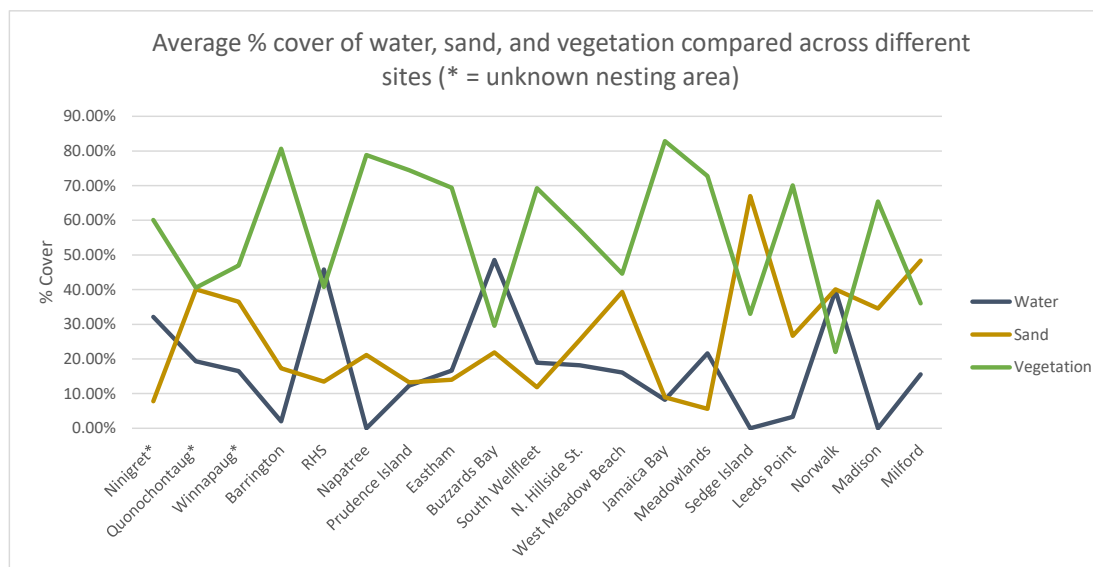
State	Site	Average Slope
RI	Ninigret*	1.00%
RI	Quonochontaug*	3.00%
RI	Winnapaug*	0.00%
RI	Barrington	3.00%
RI	RHS	2.50%
RI	Napatree	6.00%
RI	Prudence Island	0.00%
MA	Eastham	3.67%
MA	Buzzards Bay	5.00%
MA	South Wellfleet	11.33%
MA	N. Hillside St.	12.00%
NY	West Meadow Beach	1.00%
NY	Jamaica Bay	2.00%
NJ	Meadowlands	2.25%
NJ	Sedge Island	1.00%
NJ	Leeds Point	1.00%
CT	Norwalk	0.00%
CT	Madison	5.00%
CT	Milford	5.00%



Diamondback Terrapin Habitat Suitability Index
Northeast Data Collection, Land Cover
Dr. Laura Meyerson, URI 2018

Table 1. Land cover percentage separated into water, sand, and vegetation.
Percentages are averaged from all the samples per site. (Source: Google Earth Engine, Landsat 8 Imagery, 30x30m pixels)

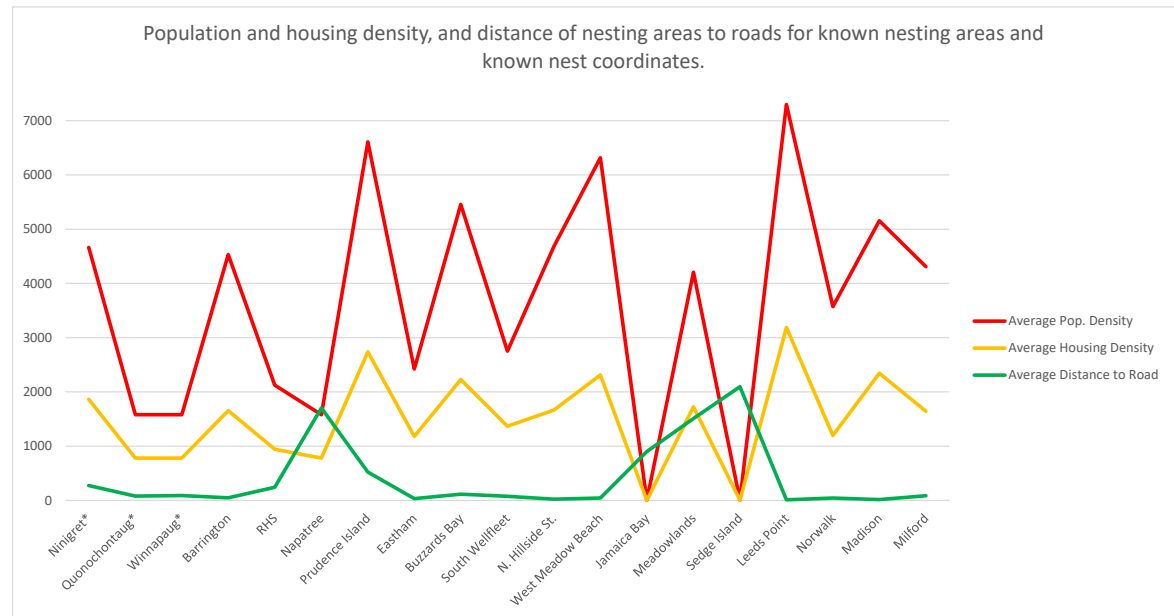
State	Site	Average % Landcover		
		Water	Sand	Vegetation
RI	Ninigret*	32.13%	7.79%	60.08%
RI	Quonochontaug*	19.31%	40.11%	40.58%
RI	Winnapaug*	16.50%	36.52%	46.98%
RI	Barrington	2.01%	17.31%	80.68%
RI	RHS	45.79%	13.48%	40.73%
RI	Napatree	0.00%	21.14%	78.86%
RI	Prudence Island	12.29%	13.29%	74.42%
MA	Eastham	16.62%	14.00%	69.38%
MA	Buzzards Bay	48.56%	21.87%	29.58%
MA	South Wellfleet	18.90%	11.83%	69.27%
MA	N. Hillside St.	18.20%	25.49%	57.21%
NY	West Meadow Beach	16.11%	39.32%	44.57%
NY	Jamaica Bay	8.24%	8.92%	82.84%
NJ	Meadowlands	21.60%	5.62%	72.78%
NJ	Sedge Island	0.00%	66.99%	33.01%
NJ	Leeds Point	3.29%	26.66%	70.05%
CT	Norwalk	39.70%	40.08%	22.02%
CT	Madison	0.00%	34.57%	65.43%
CT	Milford	15.57%	48.38%	36.04%



**Diamondback Terrapin Habitat Suitability Index
Northeast Data Collection, Anthropogenic Factors
Dr. Laura Meyerson, URI 2018**

Table 5. Data of various anthropogenic factors that effect nesting areas. (Source: US Census)

State	Site ID	Average Pop. Density	Average Housing Density	Average Distance to Road
RI	Ninigret*	4665	1862	274.837
RI	Quonochontaug*	1578	780	78.513
RI	Winnapaug*	1578	780	87.6795
RI	Barrington	4531	1655	46.8283
RI	RHS	2126	942	241.2596
RI	Napatree	1578	780	1705.267
RI	Prudence Island	6611	2737	520.831
MA	Eastham	2421	1179	32.5216
MA	Buzzards Bay	5455.2857	2228.2857	115.5729
MA	South Wellfleet	2750	1366	76.768
MA	N. Hillside St.	4681	1665	20.587
NY	West Meadow Beach	6315	2313	43.196
NY	Jamaica Bay	0	0	901.144
NJ	Meadowlands	4205.5	1723.25	1508.8665
NJ	Sedge Island	5	3	2095.63
NJ	Leeds Point	7299	3189	9.778
CT	Norwalk	3572	1199	43.882
CT	Madison	5154	2343	13.287
CT	Milford	4308	1642	85.946



Diamondback Terrapin Habitat Suitability Index
Northeast Data Collection, Aspect
Dr. Laura Meyerson, URI 2018

Table 3. Aspect data of known nesting sites.
 (Source: NOAA Data Access Viewer)

State	Site ID	Aspect	Direction
CT	CT_1	14.49	N
CT	CT_2	44.47	NE
CT	CT_3	124.07	SE
RI	Site 1	127.49	SE
RI	Site 2	200.09	S
RI	Site 3	140.09	SE
RI	Site 4	357.3	N
RI	Site 5	195.6	S
RI	Site 6	344.64	N
RI	Site 7	181.1	S
RI	Site 8	338.64	N
RI	RI_1	138.15	SE
RI	RI_2	261.54	W
RI	RI_3	269.65	W
RI	RI_13	279.55	W
RI	RI_14	297.05	NW
MA	MA_1	99.27	E
MA	MA_2	68.01	E
MA	MA_3	283.36	W
MA	MA_4	234.23	SW
MA	MA_5	247.36	SW
MA	MA_6	0.968	N
MA	MA_7	235.44	SW
MA	MA_8	204.28	SW
MA	MA_9	306.95	NW
MA	MA_10	103.42	E
MA	MA_11	3.81	N
MA	MA_12	99.711	E
MA	MA_13	250.209	W
MA	MA_14	290.597	W
NJ	NJ_1	56.22	NE
NJ	NJ_2	321.18	NW
NJ	NJ_3	286.17	W
NJ	NJ_4	219.44	SW
NJ	NJ_5	17.45	N
NJ	NJ_6	329.98	NW
NJ	NJ_7	202.507	SW
NY	NY_1	129.08	SE
NY	NY_2	175.89	S
NY	NY_3	296.496	NW
NY	NY_4	303.578	NW
NY	NY_5	24.204	NE
NY	NY_6	311.624	NW

Direction	# of Occurrences
N	7
NE	3
E	4
SE	5
S	4
SW	6
W	7
NW	7

