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 Species Documentation

Technical Report for the Coastal Resources Management Council

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Hope D. Leeson

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Cover Photo: dwarf glasswort *(Salicornia biglovii)*, on exposed sediment, high marsh, Winnapaug Pond, Westerly, Rhode Island, 2018.

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Ninigret Sediment Placement Site Vegetation Surveys and Mapping

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 *(Ammospitza 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 III). Diamondback terrapins *(Malaclemys terrapin)* were studied on all three ponds, as were two species of katydids; specifically, the salt marsh meadow katydid *(Conocephalus spartinae)* and the seaside katydid *(Orchelmum 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 in the state. ***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 physical elevation.

Following the placement of dredge material on top of the marsh surface, re-establishment of vigorous plant cover is essential to 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 on the State of Rhode Island South Shore Management Area, at the Charlestown Breachway (Ninigret) (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 understand 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 these species have adaptations which make them successful at germinating in disturbed soil. Importantly, pioneer species are the 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 be enhanced by deliberately planting salt marsh and dune species into appropriate elevations of the 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 sollicitan)* (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 an additional 46 planted areas, many of which were contiguous with the 2017 plots.

Figure 1. Scribing plots at Ninigret Sediment Placement, 2018

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 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 (Map 6, Appendix II).

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 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 species present 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 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. The six transects had been previously established across the site, per the 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. 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 (L) and Control Site (R).

Results

I Planted Species

Within the 20-acre Ninigret Impact Site, a total of 125 planting plots had been 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**
Ammophila breviligulata	American beach grass	perennial dune grass	loose rhizomatous
Baccharis halimifolia	groundsel tree	maritime shrub	multi-stemmed
Distichlis spicata	salt grass	perennial high marsh grass	loose rhizomatous
Juncus gerardii	salt marsh rush	perennial high marsh rush	v. dense rhizomatous
Iva frutescens	maritime marsh elder	maritime shrub	multi-stemmed
Panicum virgatum	switch panicgrass	perennial grass	cespitose
Solidago sempervirens	seaside goldenrod	perennial herbaceous	cespitose
Spartina alterniflora	smooth cordgrass	perennial low marsh grass	loose rhizomatous
Spartina patens	salt marsh hay	perennial high marsh grass	dense rhizomatous
2018 Species Planted	**Common name**	**Plant Type**	**Growth Habit**
Ammophila breviligulata	American beach grass	perennial dune grass	loose rhizomatous
Juncus gerardii	salt marsh rush	perennial high marsh rush	v. dense rhizomatous
Spartina alterniflora	smooth cordgrass	perennial low marsh grass	loose rhizomatous
Spartina patens	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 7, Appendix II), 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*.

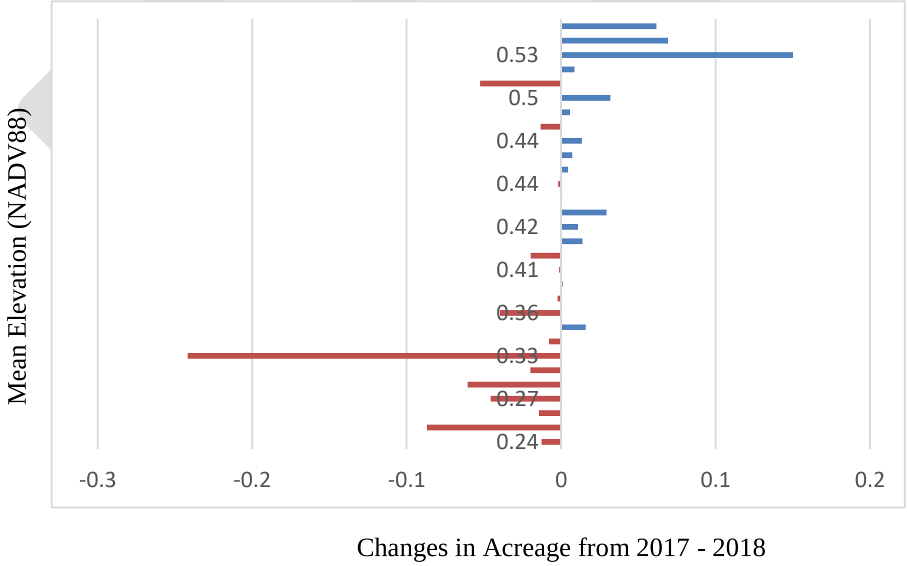

Figure 3. Changes in acreage within resurveyed plots, arranged by elevation above NAVD88 at the Ninigret Impact Site 2017 – 2018

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 spoil, 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.

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

Figure 5. Distichlis spicata colonizing plot.

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.

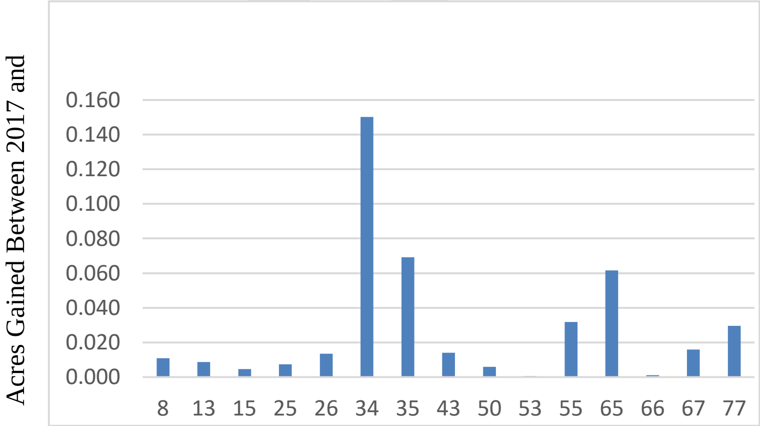

Figure 6. Gains in planted acreage among 30-subset plots-Ninigret Sediment Placement Impact Site 2017 – 2018

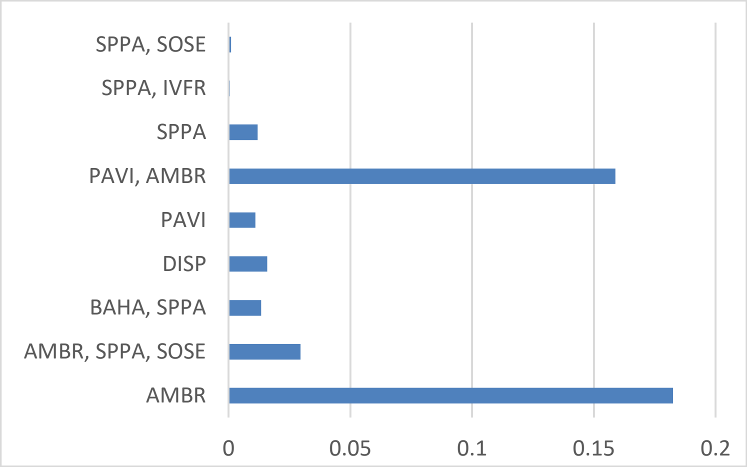

Figure 7. Species Plots Showing Expansion (Acres) Between 2017 and 2018

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*, the seed of *Iva* is wind-dispersed and the species is present throughout the transition zone from high marsh to scrub-shrub habitat. Since plants had not flowered in 2017, it is presumed that pioneer individuals of *Iva* arrived at the site as wind-blown seed. 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 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 in the highest 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

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 years 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 be have flowered and produced seed. In addition, 25% of the infructescences on these mature *S. alterniflora* plants were noted to be infected with the ergot fungus, *Claviceps purpurea*. *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). 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.

Figure 9. Spartina alterniflora plot; acreage loss

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.

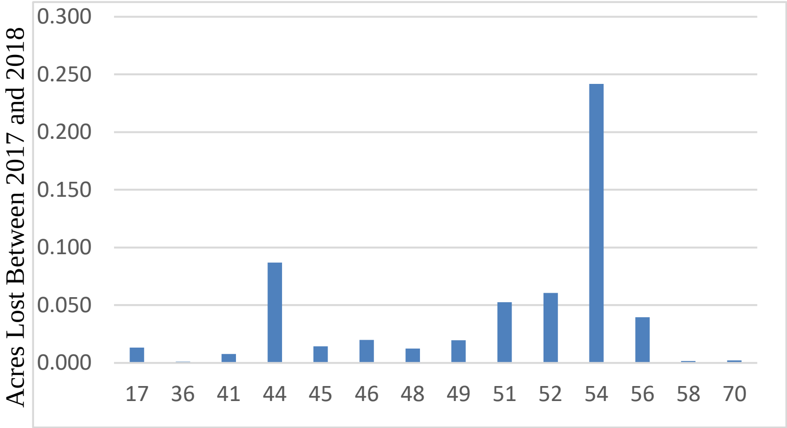

Figure 10. Losses in planted acreage among re-surveyed plots at the Ninigret Impact Site 2017 – 2018

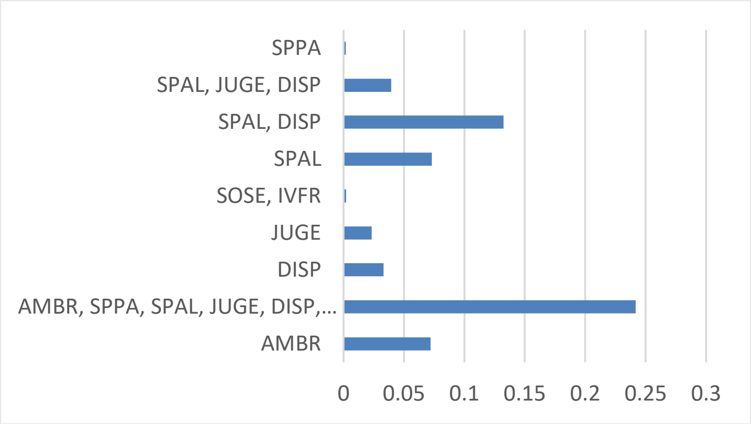

Figure 11. Species Plots Showing Reduction in Acres, Between 2017 and 2018

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* was still thriving, 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, and it seems possible that they also arrived 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.

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

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 polygons 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.

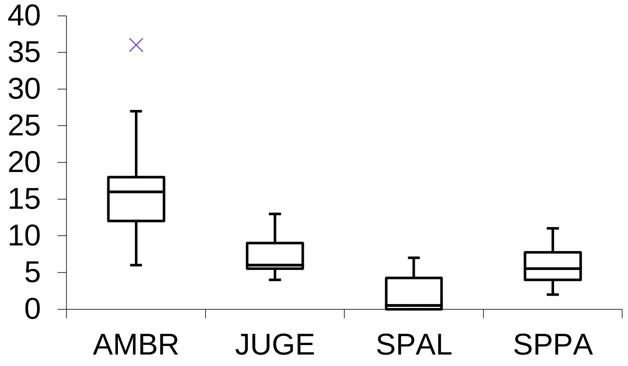

Figure 14. 2018 Planted species with mean number of pioneer species

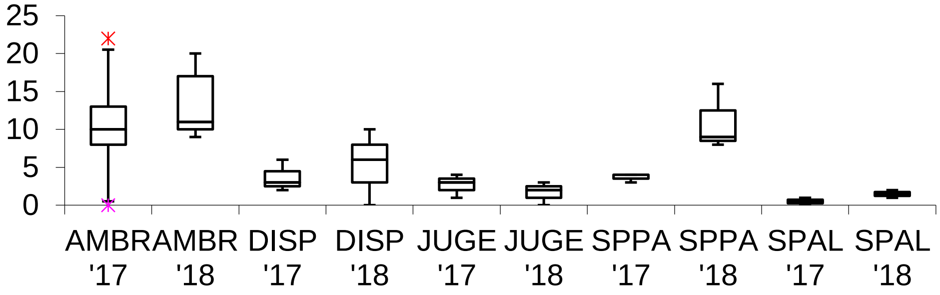

Figure 15. 2017 Planted species with change in mean number of pioneer species (2017-18)

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 plaintain *(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. 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 (%)	
Suaeda maritima	<20	44
Juncus gerardii	70	43
Chenopodium glaucum	0	42
Salicornia depressa	32	37
Chenopodium album	0	36
Cakile edentuala	<20	31
Atriplex prostrata	0	32
Iva frutescens	<20	32
Cyperus filicinus	<20	20
Solidago sempervirens	20	20
Baccharis halimifolia	37	<20
Spartina alterniflora	23	<20
Phragmites australis	29	<20
Distichlis spicata	22	<20

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

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.

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 then 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 below elevation 0.35m. Observations of the two species outside of the planted areas were consistent with inside 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 maritma)* 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 *Boloboschoenus* 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), where they occurred on the sandy shores 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 each documented in a single location along the pre-established transect lines. A sub-species of the non-native herbaceous sea-blight *(Suaeda 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 the rare species documented at the Ninigret Impact Site. However with the exception of *Polygonum glaucum* no additional populations of the other six species were located. Map 8, in Appendix II 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. Similarly, all seedlings of invasive species encountered, were recorded as present and then pulled.

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 responseto 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 2nd 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 which is 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 leaf foliage.

The rapid rhizomatous growth documented within plots of *Ammophila breviligulata* as well as those of *Distichlis spicata* which were 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 place-holders 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 (Nick Ernst, *personal communication*). The observed growth in these remaining, unplanted patches of *Spartina* at Ninigret may, in the future, form the basis of plant establishment throughout the lower elevations of the site. At future Sediment Placement sites, adding sediment in front of the existing edge of the marsh, and minimizing coverage of existing *S. alterniflora*, may result in better establishment and colonization at low elevations.

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

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 100m^2. 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. 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*).

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

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. Although rhizomatous growth was evident, it was not vigorous. 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, colonial growth could advance in multiple directions where soil is un-vegetated.

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 and 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 sulfer to sulfide (which produces the rotten-egg smell of marshes) are indicators 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 profoundly 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 produces 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.

Figure 18. Ninigret sediment, 18 mos. after placement on marsh; depth to ferrous mottles approx.. 4cm; depth to water approx.. 15cm.

Several studies have looked at symbiotic microbial activity at, and within, the root zone of *Spartina alterniflora*. This is 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, but it is becoming more widely realized 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 C, *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 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 a strong negative impact on the root growth of *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.

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

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. 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).


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

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 *S. patens* has been observed, at higher elevations such as back dunes and sand deposits along brackish tidal lagoons and rivers, to take on morphological characteristics similar to that of the rapid colonizers (*personal observation* and *communication*, Donnelly; Miller; Weigand). In dune settings, nodal distances within *S. patens* rhizomes is greater than those of plants of the species 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, 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 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 the clonal colony 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 infestation (>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, 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 have contributed 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 yet and will be a factor of 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 Abdelrhaman (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 Abdelrhaman 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 (Metcalfe 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 Gumbrewicz collecting insects within the Iva-Juncus zone, Ninigret Impact Site

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 tenuiflium* and *Iva frutscens*, 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, to 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 the germination of species, including the documented rare species, and 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, 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 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 23. 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 at low 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 stands of *Spartina alterniflora* that fringed the edges of the Sediment Placement site. However, out of all of the pioneer species observed at the Ninigret Site, *Salicornia* was the only species which experienced 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..

a greater number of species were present as colonizers, although each was present in lower frequencies. The greater diversity of species resulted in a diversity of plant habitus, or ecological and structural forms, with forbs, sedges, grasses, vines, and woody tree and shrub species present in these zones. 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 combined effect of shading the soil and slowing tidal flow during storm over-wash events. Dense stem coverage could also have contributed to reduced soil salinity and allowed seeds, carried in tidal water, to settle out onto the substrate within the vegetation and germinate.

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 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 unpredictable synergistic effects can occur 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. Propagation of plants, especially *Spartina* species, for Sediment Placement revegetation should incorporate the addition of microbes (both nitrogen fixing and arbuscular mycorrhizae), and allowed to develop more extensive root systems prior to planting, to determine if survival rates can be improved.

Vegetation Management Recommendations for Future Sediment Placement

Condition	Response	Species to Consider
High Soil Bulk Density	• Add organic content • Incorporate composted marine algae Minimize compaction and trampling	All species
Low Redox Potential	• Plant rapidly colonizing, rhizomatous species • Incorporate nurse plants • Monitor decomposition of covered salt marsh	*Spartina alterniflora*, *Distichlis spicata*
High Soil Salinity	• Focus planting strategy on rapid colonizers • Incorporate nurse plants • Decrease plant spacing	*Spartina alterniflora*, *Distichlis spicata*, *Ammophila breviligulata*, *Spartina patens* (high elevations), *Solidago sempervirens*
Flooding Duration at Root Zone	• Monitor tidal flooding below the soil surface	*Iva frutescens*, *Juncus gerardii*, *Spartina patens*, *Baccharis halimifolia*
Absence of Naturally Occurring Microbial Life	• Add nitrogen-fixing bacteria to nursery plants • Add arbuscular mycorrhizae to nursery plants	*Spartina alterniflora*, *Spartina patens*
Actions	**Response**	**Species to Consider**
Monitor Seed Bank Potential	• 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	• Preserve Existing *Spartina alterniflora* where possible • Create micro-habitats • Plant *Spartina alterniflora* at higher elevations • Utilize plants with rapidly expanding growth habits	*Spartina alterniflora*, *Distichlis spicata*, *Ammophila breviligulata*, *Spartina patens* (higher elevations), *Solidago sempervirens*
Plant Later Successional Plant Communities	• Plant slower growing species in tight, incubator clusters • Plant naturalistic combinations of species	*Juncus gerardii*, *Iva frutescens*, *Spartina patens* (mid elevations), *Symphyotrichum tenuifolium*
Improve Wildlife Conditions	• Increase structural diversity • Increase shrub component • Incorporate shrub habitat contiguous to low marsh zones • Promote a diverse high marsh plant community	*Iva frutescens*, *Juncus gerardii*, *Panicum virgatum*, *Solidago sempervirens*

Table 3. Recommendations for future Sediment Placement Projects

B. Plant Community Assessments for Ninigret, Quonochontaug, and Winnapaug Ponds, and Future Thin Layer Deposition 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 8, 11, and 12 in Appendix II). 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 II.

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 to 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. To document changes occurring on Quonochontaug and Winnapaug Ponds, in addition to the meander surveys, 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. 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 III. 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 range from 2007 to 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 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 on-going 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 Winnapuag Ponds rank above the mean when evaluated for the percentage of sandy soil shorelines (Provensal, *personal communication*). Preliminary data for the Habitat Suitability Index being compiled by Meyerson, are included in Appendix III.

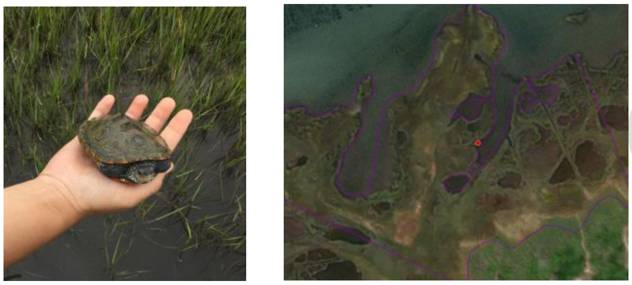

Figure 24. Diamondback terrapins (6 sighted) on Winnapaug Pond 2018, adjacent to the Lathrop Property (red dot, photo to R)

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 25. Honkenya peploides seedling growing at the edge of a tire track on East Beach

The Ninigret Sediment Placement Control Site, including the glacial moraine island located at the north end of the marsh, was surveyed for rare species. In past years, two rare perennial wildflower species had been documented on the rock island (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 known population of the SC lance-leaved figwort *(Scrophularia lanceolata)* and a previously undocumented population of downy wild rye *(Elymus villosus)*, also listed as 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 a long-term shift is already affecting the island habitat. 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*), which 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 pattern and is found in brackish marshes, often in sea-level fens or in association with groundwater seepage. The species had been identified along pre-established transects 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 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*).

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)

Awned 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 awned flatsedge was the most unexpected. The only other extant population for the species in Rhode Island is located on the sandy shore of a glacial kettle-hole pond in Warwick. 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 awned 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, 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 and 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 spoils on the marsh surface. The meander survey located a state-listed, Species of Concern (SC) bracted orache *(Atriplex glabriascula)*, 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 SC species (Scotch lovage, *Ligusticum scoticum*) 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, where available light and hydrologic conditions are suitable, and is vulnerable to sudden increases in the duration and regularity of the tidal flooding regime. The third rare species, also of SC status, is velvety rosette panicgrass (*Dicanthelium scoparium*,). It 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 Sediment Placement site and the ponded area located in the southern portion of the site to the west of the breachway. 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.

Figure 26. Porcelain berry growing among Phragmites along margin of Quonochontaug Sediment Placement Impact Site (east).

Several populations of the non-native invasive species porcelain berry *(Ampelopsis glandulosa)* were located to the east of the Sediment Placement site on the Hathaway Preserve in salt scrub habitat immediately abutting the salt marsh. While scientific literature does not address salinity tolerances for this species, it is found primarily in coastal 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 the species to become more broadly established over the next few years. GPS coordinates were collected for both species, with locations mapped as a part of this report. 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. The species presence along the perimeters of the Quonochontaug Sediment Placement Site 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 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 27. 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 the 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. glabriascula* (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)*, a state listed (SC) grass, velvety rosette panicgrass (*Dicanthelium scoparium*), 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 west 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 poligonifolia*) 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.

State Listed Rare Species	**Common Name**
Atriplex glabriascula SC	bracted orache
Cyperus odoratus SC	fragrant flatsedge
Dicanthelium scoparium SC	velvety rosette panicgrass
Ligusticum scoticum SC	Scotch lovage
Scrophularia lanceolata SC	lance-leaved figwort
Infrequently Encountered Species	**Common Name**
Plantago maritima	seaside plantain
Salicornia ambigua	perennial glasswort
Triglochin maritima	salt marsh arrow-grass
Non-native Invasive Species	**Common Name**
Ampelopsis gladulosa	porcelain berry
Carex kobomugi	Asiatic sand sedge
Phragmites australis	common reed
Polygonum cuspidatum	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 glabriascula* (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. Figure 26 depicts GPS coordinate locations for species of interest documented on Quonochontaug Pond.

Back-dune habitat 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. Nantucket shad grows within maritime shrub habitat on both the south and north sides of the sand trail (see Figure 26), 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). 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 habitat populated by freshwater wetland species, like sweet pepperbush *(Clethra alnifolia)* and winterberry, and state listed Species of Concern, hairy-stemmed gooseberry *(Ribes hirtellum)*. 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

Figure 28. Carex kobomugi, Weekapaug Beach, 2018

marsh wrack line are several patches of the state listed Scotch lovage *(Ligusticum scoticum)* (SC). The species straddles the border between a shrub swamp and high marsh habitat,.

Figure 29. Maritime woodland on glacial morraine island (Noyes Is.) in Quonochontaug salt marsh

As with the glacial moraine island in Ninigret Pond, the larger islands on Quonochontaug Pond support maritime woodland habitat including the Species of Concern, lance-leaved figwort *(Scrophularia lanceolata)* 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 *(Epipactus 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 sumac *(Rhus copallinum),* sassafrass *(Sassafras albidum),* and shad *(Amelanchier canadensis)*. Less frequently encountered species include swamp milkweed *(Asclepias incarnata),* sleepy catch-fly *(Silene antirhina),* 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 ST rose-gentian *(Sabatia stellaris)* and SC beaked spike sedge *(Eleocharis rostellata)*. 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. These included SE collared dodder *(Cuscuta indecora)*, SC fragrant flatsedge *(Cyperus odoratus)*, Wright's panicgrass *(Dicanthelium wrightianum),* and SC hairy stem gooseberry *(Ribes hirtellum).* 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 in the herbaceous understory, but the population is small and 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 (SC) Indian grass *(Sorghastrunm nutans)* 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

Two potential sites along the south shore of Winnapaug Pond have been identified as future Sediment Placement Impact Sites (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 the species in adjacent areas that could constitute sources for natural re-colonization following Sediment Placement. 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 five 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 old 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. The fourth species, annual rose-gentian *(Sabatia stellaris)*, currently listed as ST, existed as recently as 2002 as one population of approximately 300 plants on the Ray Preserve as well as another population, of 105 plants, growing along the southern edge of the marsh west of property owned by the Town of Westerly. No plants were found at either locale in 2018. Searches by others for recently monitored populations of *Sabatia stellaris* elsewhere in RI also failed to relocate populations and this species may have been extirpated from the state. A concerted effort should be undertaken to look for surviving populations (Enser*, personal communication*). A population of a few plants of *Atriplex glabriascula* (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. 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 glabriascula*, 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.

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

Table 6. Winnapaug Pond, Species of Interest

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).

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. It is these conditions that once supported the state listed rare species: annual rose-gentian and pine barren sand-plant. Unvegetated sandy soil within high marsh presently supports seaside plantain, both the perennial and dwarf glassworts, and saltmarsh gerardia.

Figure 30. Delicate soil lichens encrusted on sand surface, Ray Property, Winnapaug Pond

The maritime herbaceous dune habitat, located on the Ray property, immediately abutting Atlantic Avenue is unique along the south coast of Winnapaug Pond. Increasingly, fragile open areas, such as is this, have become rare and diminished 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 this site, has allowed for the proliferation of three species of soil lichen, *Cladodnia grayi* (Gray's cupped lichen) and *Cladonia subtenuis* (reindeer lichen), as well as *Placynthiella 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 within the surrounding area are damaged by storms, for example, 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.

Maritime woodland habitat located at the northern end of the Ray Property peninsula 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 corps 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 the site should be avoided if at all possible to minimize disturbance to the 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 on 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 the *Phragmites* to colonize a Sediment Placement site through vegetative expansion or seed germination. A second 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. *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. . In addition to surveys within salt marsh habitat, surveys were conducted on these upland lobes as well as an area of dredge spoil deposition 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 (Audubon) Lathrop Preserve 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* were in the past documented along the southern side of Winnepaug Pond. And a population for mock bishop's-weed *Ptillimnium capillaceum* was known from the north side of the pond. Locations for *Artemisia*, *Liatris*, and *Sabatia stellaris* were extant in 1978. By 2002, only one species, rose gentian *(Sabatia stellaris)*, was still extant, at two sites. Neither population of *Sabatia stellaris* was located during the 2018 survey. The survey also 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 (*Ptillimnium capillaceum*) (SC) was observed on the Lathrop Preserve. 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, the SC species Indian grass (*Sorghastrum nutans)* 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. 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.

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 *(Symphyotrichum tenuifolium)*, 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*.


Figure 31. Shad in bloom on a sandy upland knoll, Winnepaug Pond

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 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 Winnapaug Pond where the combination of canopy cover and hydrology provided suitable habitat. Among sand hummocks at the eastern end of the pond, the SE Nantucket shad *(Amelanchier nantucketensis)* was found, along with drought tolerant species that are more typical of inland sandy habitats:

wild indigo *(Baptisia tinctoria)*, Canada frostweed *(Crocanthemum canadensis)*, and grove sandwort *(Moehringia lateriflora)*.

Along the south coast of Winnapaug 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 Preserve, 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 one of the historic population locations 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 a nesting site, the location corresponds with the area on Winnapaug Pond 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 III.

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, and other wetland 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 *(Ptillimnium 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. 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. The common freshwater wetland shrub *(Vaccinium corymbosum)* and upland tree *(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 32. 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 60cm 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 are commonly seen as colonizers among dead shrub species, including common reed *(Phragmites australis)*, 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 utilizing a method called the Floristic Quality Analysis (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 Wilhlm 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 11 and 12, Appendix II). Each is hydrologically connected to their 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.

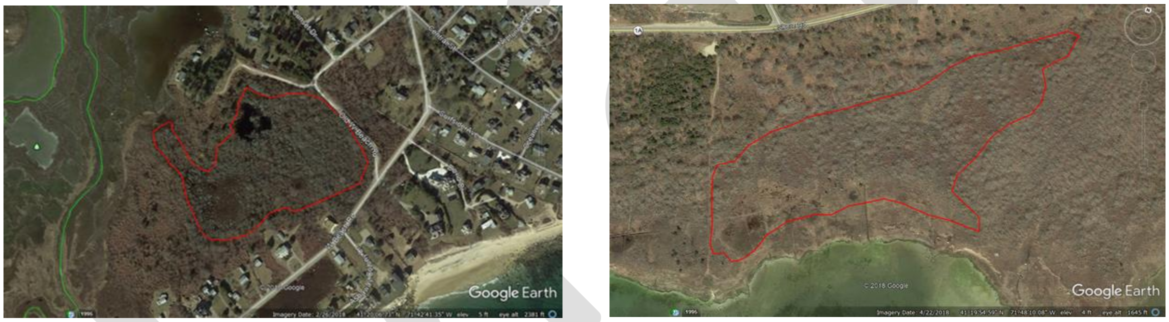

Figure 33. Outline of two FQA vulnerable coastal wetlands. Hathaway (left), and Lathrop (right) Preserves.

Methods

The FQA methodology followed for this report was based on the protocol utilized 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 a floristic survey which is then quantified through the assignment of a quality score, 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 conducted in the freshwater wetlands on Winnapaug and Quonochontaug Ponds deviated from Kutcher and Forester (2017), with concessions made as to transect location. Both wetlands contained extensive, 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 that described by Kutcher and Forrester (2017), to that utilized 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 being to create as complete a picture as possible of the wetland's flora, and to quantify 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, utilizing cover class ranges of either scarce (<10%), common (10-60%), or dominant (>60%). After all three transects were surveyed, an average cover class was assessed 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).

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

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, with 16 being 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 and glossy buckthorn *(Frangula alnus)*, which was found only on the Lathrop Preserve, were more widespread.

The median Coefficient of Conservatism assigned to the species present 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 wetlands, refer to Appendix I. State listed rare species are discussed above in the discussions of habitat on Quonochontaug and Winnapaug Ponds.

State Listed Rare Species	**Common Name**
Cuscuta indecora SE	collared dodder
Cyperus odorata SC	fragrant flatsedge
Dicanthelium writianum SC	Wright's panicgrass
Ligusticum scoticum SC	Scotch lovage
Ribes hirtellum SC	hairy-stem gooseberry
Infrequently Encountered Species	**Common Name**
Proserpinaca palustris	marsh mermaidweed
Lysimachia hybrida	yellow loosestrife

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

The 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. In Rhode Island the community type has been documented in less than six locations. All by definition 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 (NatureServe Explorer 2009). 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)*.

State Listed Rare Species	**Common Name**
Ptillimnium capillaceum SC	Mock Bishop's weed
Infrequently Encountered Species	**Common Name**
Argentina egedii	Pacific silverweed
Eleocharis uniglumis	One-glumed spikesedge
Ilex glabra	inkberry
Lilium superbum	Turk's cap lily
Lyonia ligustrina	maleberry

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 2017 study (Kutcher 2018). 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 disturbance within habitat adjacent to the Lathrop Preserve has resulted in colonization of the area by the invasive species, glossy buckthorn and other species. For both sites, the presence of dense stands of *Phragmites* was a factor. 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 WMCC value for the all 2017 sites was 3.4. The

MCC values for Lathrop were 3.7, and for Hathaway 3.4, with a total mean of 3.5. The overall MCC value in 2017 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 (for details of RIRAM see Kutcher, 2012). Never the less, the WMCC and percentage of native species data can be overlain onto graphs taken from the 2017 report (Figures 34 and 35), which compare FQA values of coastal freshwater wetlands with those of the RIRAM Reference Set (Kutcher and Forester 2017). 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 (Figure 34). This is the result of more than 50% of the plant species at both sites having CC's of 3, which indicates that more than half of the species present are tolerant of disturbance. Additionally the WMCC values for the two wetlands are in line with the linear regression models (Figure 35) comparing WMCC with surrounding land use. Although for this report, surrounding land use was not evaluated, the similarity of placement along the regression line, possibly indicates the prevalence of disturbance tolerant species within the surrounding landscapes, and their contribution, as seed sources, to the plant communities of the two wetland sites evaluated.

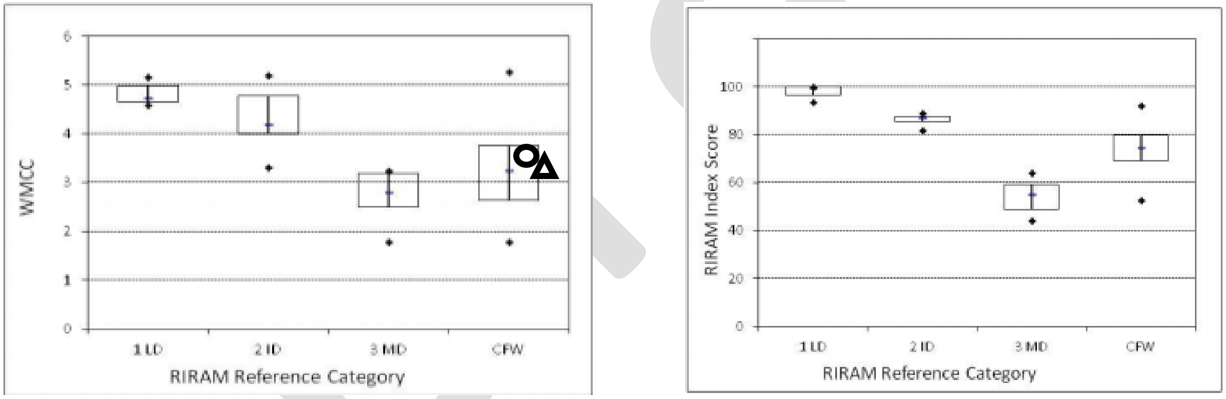

Figure 34. Box plots depicting the distributions of floristic index and RIRAM values among RIRAM-based reference designations of freshwater wetland conditions for 20 reference wetlands, compared with 16 vulnerable coastal freshwater wetlands; boxes represent interquartile ranges, crosses represent minimum 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.

The percentage of native species occurring on the Hathaway Preserve is in line with the linear regression created across the values for native species presence among Forrester and Kutcher's set of reference wetlands. The percentage for the Lathrop Preserve falls slightly above the regression line (Figure 35), although not significantly, the values place the two sites among the top tier of coastal freshwater wetlands evaluated by Kutcher in 2017. These values reflect the diversity of habitat types, and consequent niche opportunities for a diversity of species located within each of the wetlands 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.

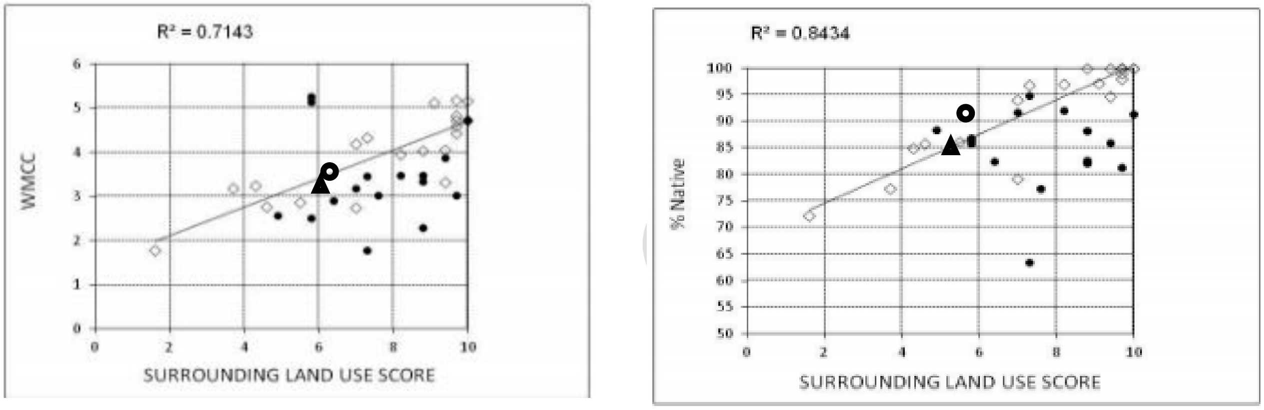

Figure 35. Scatterplots depicting the relationships between surrounding landscape integrity and floristic indicators of freshwater wetland condition among freshwater reference wetlands (white diamond symbols) and vulnerable freshwater coastal wetlands (black round symbols); trend lines and R^2 values represent linear regression models for reference wetland floristic values versus RIRAM Surrounding Land Use metric scores (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 Floristic Quality Assessment of sixteen vulnerable coastal wetlands in 2017 (Kutcher 2018). As was demonstrated for the 2017 coastal wetlands, the presence, on the Hathaway and Lathrop Preserves, 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. Aside from being preserved, and allowing 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 stonewalls, ditches, and berms. Stonewalls at both sites delineate boundaries between mesic or upland soils and those areas with 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.

Figure 36. Red maple and cinnamon fern in forested wetland; both common wetland species with CC's of 3. Lathrop Preserve, Winnapaug Pond.

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 were favored for woodlots (Foster 1992). The prevalence of species like *Ilex verticillata*, *Vaccinium corymbosum, Rosa palustris*, *Smilax rotundifolia*, and *Acer rubrum* indicate 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 low canopy cover, and access to sunlight. 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 seedlings and populations with fewer that ten stems.

Environmental stresses, stemming from salinity influx are reflected in the transitional nature of the vegetation long 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).

Figure 37. Highbush blueberry with Juncus gerardii understory, Hathaway Preserve, Quonochontaug Pond.

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 disturbance factors, these species will occupy a greater percentage of the brackish and freshwater plant communities, and that wetland species diversity and richness may trend towards greater simplification.

Propagation and Production Techniques for *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 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, required 35,000 plugs of *Distichlis spicata* and *Spartina alterniflora*, as well as 20,000 plugs of *Spartina patens,* 5,000 of each, *Juncus gerardii* and *Ammophila breviligulata,* 100 *Panicum virgatum,* 200 *Solidago sempervirens,* and 200 plants of *Baccharis halimifolia* and *Iva frutescens*. Of these, Rhody Native propagated 114 *Baccharis.* All other plants were propagated by Pinelands Nursery, from seed collected in Rhode Island. Seed collection for these projects was made possible as a result of federal funds allocated to states for salt marsh and dune restoration following the impact of Hurricane Sandy in 2011. Large scale, multi-year, seed collection has conducted by the New England Wildflower Society in partnership with the Mid-Atlantic Regional Seed Bank.

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, and have the expertise and ability to produce genetically diverse plant material, they lack production facilities needed for large scale restoration projects. However, the need for quantities of salt marsh species for habitat restoration, represents an opportunity for industry growth in New England.

Development of a local capacity to produce salt marsh restoration species, could facilitate communication abilities between resource managers and growers, which could lead to plants being better suited to particular site conditions. It is also possible that plants propagated locally, could experience less stress due to shorter transportation distances, and have greater rates of survivability. 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 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 is 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 38. (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 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 late October, and in Middletown in mid-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.

Figure 39. Shattered seed of Spartina alterniflora at Maidford Marsh (October 30, 2013).

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 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 for collection 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 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 100m^2. 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 dormany. 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.


Figure 40. Ergot fungus (Claviceps purpurea), with characteristic sticky exudate, in spikelet of Spartina alterniflora.

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 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.

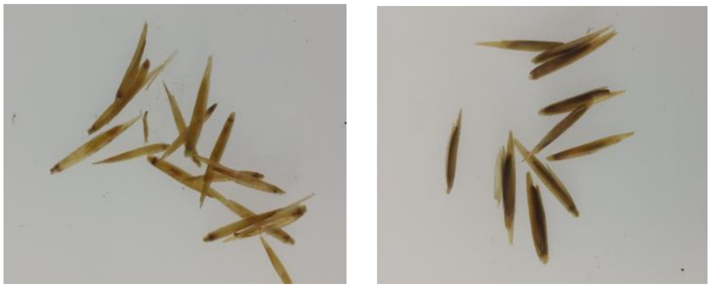

Figure 41. Spartina alterniflora caryopsis. Sterile seed (L), Fertile seed (R)

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 alteniflora* 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 the soil mixture. 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, and 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 flushing by spring rains which lower 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 100% sand with high drainage and medium-fine particle size, as well as 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™ *Spartina alterniflora* 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

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 was 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 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%.

Figure 42. Spartina alterniflora, germination in sand (L) and potting mix (R). Trays in front (R), sown with immature seed.

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.

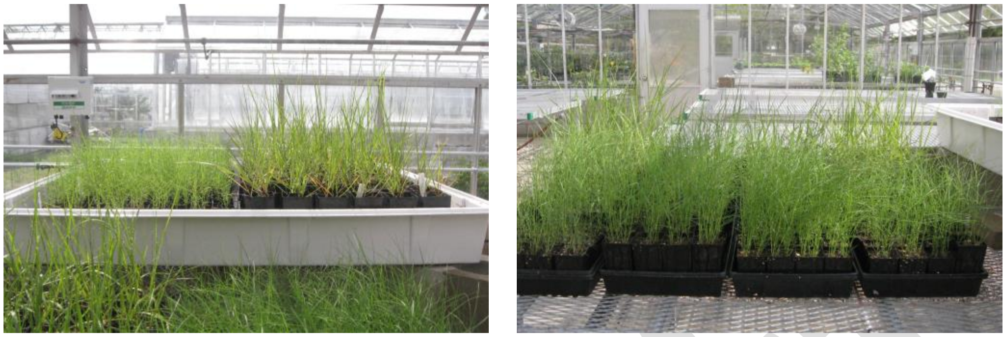

Figure 43. Spartina alterniflora and Distichlis spicata after 90 days of growth (2015); Ebb and Flow Table (L); Flooded flats (R).

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 a 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 myccorhizal additive, and delivered to USFWS for transport to the Maidford Marsh Sediment Placement Impact Site.

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 the single 4cm wide cells of the 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 the initial 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. Coincidently, we observed what we thought to be a similar phenomenon occurring at the Ninigret Sediment Placement Impact Site, where we observed *S. alterniflora* seedlings gradually become chlorotic over the course of a month, and eventually die (See Discussion, Section A).

Figure 44. 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 which had been planted at the Ninigret Impact Site, which were grown in the shorter plug sizes. The plug size, commonly used by Pinelands Nursery, measures 4.5cm x 4cm, which is the size of the smaller set of plug trays we used in 2018. 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 of the coir mat was to provide a surface for rhizomes to grow around, creating 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 45. 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.

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, with a medium fine texture 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 rate 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, but doesn’t specify when to begin the transition. 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*), necessitating weekly measurements of salinity levels.

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., *unpubished 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 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 was more time consuming, due to the horizontal nature of the plant material. Potential methods may include cutting *Spartina* mats in half, prior to transporting to the site. Volunteers would then dig a 30cm square area, measuring 5 to 7cm deep. *Spartina* mats would 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, or have high levels of environmental stress, where associated species can 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 facilitate the growth and survival of the 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, Saliconia depressa,* and *Symphyotrichum tenuifolium*. In 2019, we will seed 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 suggests the potential for a positive effect for *Spartina* 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. Flats of seedlings 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.

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, their understanding of site conditions and limitations, as well as plant responses, can be applied to plant production methods. Plants can be propagated in ways that better support stress responses, with growers producing plants with the highest potential for survival.

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Appendix I

Coastal Salt Pond Botanical Surveys

Appendix II

Coastal Salt Pond Maps

Appendix III

Studies of Additional Taxa