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IMPROVING MARSH RESTORATION

Abstract:

Tidal wetlands are a prominent feature of New Jersey's coasts, providing many ecosystem services, including water filtration, habitat for commercially and recreationally important animals, and carbon sequestration. Increasing rates of sea-level rise threaten the existence of tidal wetlands in New Jersey, and land managers are actively developing techniques to enhance resilience. This study aimed to address two emerging needs to support marsh resilience: 1) an evaluation of the effects of the beneficial use of dredged material to increase marsh elevation and 2) the development of a systematic approach to evaluating marsh condition.

1. This project extended the monitoring of three pilot marsh enhancement projects where dredged material was beneficially used to increase salt marsh elevation. These three projects were implemented on State-owned public lands in coastal areas of southern New Jersey from 2014 to 2016, with funding from the National Fish and Wildlife Foundation through the Hurricane Sandy Coastal Resiliency Competitive Grant Program (Grant #43095). To-date, several publications and reports have been produced, and this report presents findings and lessons learned from implementation and monitoring from 2014 to 2021.

2. The *Site-Specific Salt Marsh Decision Support Tool* (now called WATCH – Wetlands Assessment Tool for Condition & Health) was developed by the Partnership for the Delaware Estuary as an evidence-based method to evaluate the condition and trajectory of a tidal wetland site and gain a holistic understanding of site-specific salt marsh condition to inform decision-making. WATCH was developed with two objectives: 1) to create a systematic approach to evaluate functional attributes against user-provided criteria (e.g., excessive erosion, elevation deficits, hydrological impairment) for the identification of site-specific deficiencies and 2) to align the WATCH with common regulatory concerns to assist practitioners in providing a thorough and contextualized explanation of the current and projected conditions to a variety of resource agencies (e.g., Army Corps of Engineers, National Marine Fisheries Service, U. S. Fish and Wildlife Service, and the State of New Jersey). WATCH is now available for use and several trainings have been held. PDE WATCH Tool (rutgers.edu)

Report Organization:

This report is divided into two major sections. The first section includes the reports produced on the salt marsh enhancement projects, and the second is the final report on the Site-Specific Salt Marsh Decision Support Tool (WATCH) from the Partnership for The Delaware Estuary. Each section can be read independently, and a project-wide summary and conclusion is provided at the end of this report.

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Overview of Need

The three pilot marsh enhancement projects monitored during this effort were among the first of their kind in New Jersey. Dredged material placement methods, as well as the types and thicknesses of the placed dredged material, varied among the three projects. At the commencement of this award, the enhanced marsh sites had been monitored for two to three years as part of a National Fish and Wildlife Foundation Grant[1]. Each project had documented increases in elevation but were in varying states of plant and animal community recovery. Continued monitoring was necessary to evaluate the effectiveness of the dredged material placement techniques and to track the post-placement marsh recovery and enhancement process. Monitoring was also continued at nearby control areas for comparison to the marsh enhancement areas and follows a Before-After-Control-Impact (BACI) approach. The metrics monitored include plant communities, benthic infauna, sediment characteristics, habitat changes, elevation, hydroperiod, water chemistry, and sediment accretion/subsidence. The monitoring goal was to assess the long-term benefits and effects of beneficially using dredged material for marsh enhancement purposes. This information is needed to inform future beneficial use of dredged material projects to enhance marsh habitats in the region.

Prior to this project, the tools and data products that existed to help restoration practitioners identify and prioritize potential sites typically relied on the use of a singular metric or the use of large, temporally- or spatially coarse data. Therefore, these tools and products were not designed for site diagnosis. The site-specific assessment methods, like Mid-TRAM, are multi-metric assessment methods, but were not designed for identifying restoration sites. Without a site-specific diagnostic tool that compiled multiple indicators of tidal wetland function and condition, there was often disagreement about marsh platform condition and, ultimately, evidence regarding intervention need.

Project Overview

Task A. Marsh Enhancment Project Evaluation

Objective: Continue monitoring (2018 - 2022) recently implemented marsh enhancement pilot projects at Ring Island (Middle Township), Avalon, and Fortescue in New Jersey.

Approach: Extended monitoring of key ecological metrics from the original NFWF/DOI grant. The data were collected using methods consistent with the monitoring protocols and Quality Assurance Project Plan used during implementation of the NFWF/DOI grant.

Monitoring occurred at all three marsh enhancement sites. Data were collected from both marsh enhancement and nearby control areas following the BACI approach so comparisons of ecological health could be made between the placement and control areas overtime. Not all metrics were monitored annually.

[1] #43095 DOI/NFWF - Reusing Dredge Material to Restore Salt Marshes and Protect Communities

Responsibilities and Deliverables: The New Jersey Division of Science and Research 1) oversaw monitoring and subcontractors, 2) conducted some of the research, and 3) developed a technical monitoring report and updated the NFWF/DOI “Lessons Learned” document (Section 1, Task 3).

Task B. Improving Decision-Making Processes For Wetland Restoration

Objective: To improve NJDEP wetland policies and regulations so that our coastal wetlands are healthy and resilient by increasing our understanding of beneficial marsh and shoreline restoration techniques.

Approach: A key aspect of identifying appropriate restoration techniques is a correct diagnosis of the underlying drivers of ecologic deficiency. This project developed a holistic salt marsh diagnosis framework that can be sued to evaluate the states and trajectories of salt marsh health before interventions. A report was generated by the subcontractor that identifies and evaluates previously developed independent and science-based assessment methods and efforts as well as gaps and needs and develops a novel site evaluation tool. Interviews and model evaluation were conducted to identify needs from other regions which can be used to derive policy recommendations. Additionally, an integrated cross-walk between decision tool metrics and regulatory implementation requirements a) allows regulatory agents to better understand the outcomes of site-evaluations, b) guides the user in site assessment in a manner appropriate under current regulations, and c) provides feedback on current regulations that may inhibit appropriate resilience efforts to NJDEP’s Land Use Management Program and the NJ Division of Fish and Wildlife

Responsibilities and Deliverables: The NJDEP Office of Coastal and Land Use Planning oversaw a subcontractor to complete the report and the framework for a draft decision tool.

Section 1: Marsh Enhancment Project Evaluation

Activity Overview

The following tasks reports were completed between 2018 and 2022.

Task 1. Monitoring

The table below provides an overview of the monitoring activities completed during the grant.

Table 1 Monitoring conducted on the marsh enhancement projects between 2014 and 2022.

	Initial NFWF Grant				Funded by WPDG		Conducted with funding from USFWS		Funded by WPDG		
	2014	2015	2016	2017	**2018**	**2019**	2018	2019	**2020**	**2021**	**2022**
Plant Community	x	x	x	x		x				x	
Benthic Invertebrate Species		x	x	x		x		x			
Avian Use	x	x	x				x	x			
Habitat Change Analyses											
Site Visits	x	x					x	x			
Surface Elevation Tables			x	x	x	x			x	x	x
Topographic Surveys	x	x	x	x		x					
Sediment Characteristics	x	x	x	x		x		x			
Hydrological and Topographic Evaluation		x	x	x		x					

Task 2. Monitoring Report

A monitoring report summarizing the key findings for each of the metrics in Table 1 was completed in 2022. Monitoring results have been presented at many local and national meetings during the grant. The report will be posted on the NJDEP DSR website after EPA approval and is included as Appendix A.

Task 3. Updated "Lessons Learned" Report

The report on early lessons learned from implementation of the marsh enhancement projects was updated, approved by partners, and widely distributed and presented. This is a link to the final report: Beneficial Use of Dredged Material to Enhance Salt Marsh Habitat in New Jersey : Project Summary and Lessons Learned (https://dspace.njstatelib.org/handle/10929/97940). It is also included as Appendix B.

Section 2: Improving Decision-Making Processes For Wetland Restoration

Activity Overview

The Site-Specific Salt Marsh Decision Support Tool version 1.0, now WATCH, was completed in March of 2020 by the Partnership for the Delaware Estuary (PDE). The following tasks were completed during the grant:

Task 1. Literature Review:

a. PDE conducted the following survey and interviews as well as a primary literature review to collect information regarding the current processes of data collection occurring locally and nationally by practitioners and regulatory agents:
    a. Local Practitioner Survey
    b. Regulatory Agent Interviews
    c. National Practitioner Interviews
    d. Primary Literature Review
b. Review of secondary literature

Task 2. Synthesis of Literature

a. Identified six major categories of metrics of known value in current local use that interactively influence salt marsh function.
b. Compiled commonly used methods
c. Conceptual model development
d. Tool development

Task 3. Workshops

a. Special session at the 2019 PDE Science and Environmental Summit
b. Tool presented to 31 practitioners spanning the public, private, and academic sectors On July 9, 2019, a workshop was held to introduce the decision tool and to solicit feedback
c. Tool was renamed WATCH and became publicly available: WATCH Tool

The final report on the tool can be found in Appendix C.

Project-Wide Summary and Conclusions

Tidal marshes are an integral part of New Jersey's estuaries. They form a charismatic green band that cleans water; sequesters carbon; provides critical habitat and food sources for fish, shellfish, and birds; and buffers coastal communities from storms, erosion, and flooding (Mitsch and Gosselink 2007, Narayan et al. 2017). However, the continued existence of many tidal wetlands is threatened by sea-level rise. To maintain healthy salt marsh vegetation, marshes must accrete sediment and plant matter to gain elevation at a rate that keeps pace with sea-level rise and subsidence (Nyman et al. 2006, Mitsch and Gosselink 2007, Cahoon et al. 2009, Kirwan and Megonigal 2013). Some salt marshes are stressed and literally "drowning" because they cannot gain surface elevation at a rate that keeps pace with accelerating sea-level rise (Hartig et al. 2002, Ganju et al. 2017, Watson et al. 2017).

Salt marsh restoration and resilience projects are being pursued to maintain salt marsh function in the face of stressors, but the complexities of identifying the correct tactics for each site can be daunting. This project compiled lessons learned and monitoring results from three pilot marsh enhacnemnte projects and developed a tool to standardize the way restoration practitioners assess functional deficiencies at the site scale.

The reports developed or refined through this grant highlight the need to use detailed field date in a science based framework for identifying restoration goals and designing projects. Projects need to be coordinated at multiple levels and throughout all phases of project development, implementation, and monitoring. An adaptive management approach is required throughout the lifecycle of the project to ensure goals can still be met when conditions change.

The monitoring completed at the pilot projects suggests a dredged sediment slurry can be pumped over large areas of salt marsh and generally reach target elevations, but a high level of variability in thickness and elevation is to be expected without the use of grading equipment or new technology. We found that when sediment of any thickness is placed on an existing vegetated marsh, plants and benthic infauna died. The thickness of the sediment was less important than the final elevation's effect on flooding in the rate of plant regrowth and there were tradeoffs between the rate of vegetation regrowth and elevation gain. It is hypothesized that changes in animal species are a result of changes in the habitat. Bare areas with little organic matter in the soil are not hospitable to typical marsh birds and benthic infauna. They instead drew fiddler crabs, shorebirds, and opportunistic benthic infauna that had a higher tolerance for disturbed sites.

There are inherent challenges in targeting high marsh elevations in beneficial use of dredged material projects. The range of elevations that fall into the high marsh tidal datums (approximately 0.5 feet) is much smaller than the range of elevations that fall into the low marsh tidal datums (generally 2-3 feet in marshes in SE New Jersey), creating some inherent challenges for using thin-layer placement techniques to reach high marsh elevations because the room for error is much smaller.

The Site-Based Salt Marsh Decision Tool (WATCH) filled a major gap for tidal wetland restoration practitioners. It standardizes the integration and interpretation of site-specific data, collected using scientifically defensible methods, via evidence-based evaluation of whether a variety of salt marsh attributes exhibit, or are forecasted to exhibit, signs of deficiency. There are two intended audiences: those planning restoration projects (e.g., restoration practitioners, municipalities) and those evaluating the merits of proposed projects (e.g., regulatory agents, funding agencies).

Restoration Project Planning: For those planning restoration projects, this tool will guide the user in considering the primary attributes influencing salt marsh function, and identifying qualities that are likely either currently deficient, on a negative trajectory, or both. The output of this tool will inform the user whether there is enough evidence to further consider an intervention project, and discuss this potential with landowners, funding agencies, and regulatory agents. Additionally, it will facilitate the gathering and documentation of pertinent regulatory information (e.g., endangered species, critical habitat) prior to regulatory conversations and/or application submission.

Proposed Project Evaluation: For those evaluating proposed projects, this tool will summarize the data-based findings of site evaluation and present them alongside justifications for all data selection/collection activities and decisions.

Future Work

The salt marsh enhancement projects are being incorporated into the Mid-Atlantic Coastal Wetland Assessment and the New Jersey Tidal Wetlands Monitoring Network. NJDEP and partners will continue to monitor both control and placement sites to see how they change overtime. There is a still a lot that can be learned from the sites. We plan to continue to collect drone imagery to track vegetation recovery and measure elevation change and accretion relative to sea-level rise.

The WATCH Tool 2.0 was recently completed in 2022. An interactive online version of the tool was developed that includes the addition of a sediment metric. Future plans for the Tool include housing it with other tidal wetland restoration tools on a Rutgers University website and adding an interactive map to help the user find appropriate reference data.

Acknowledgements

These reports are the result of many years' worth of research, writing, and editing. Thank you to researchers and practitioners from NJDEP, The Nature Conservancy, The Partnership for the Delaware Estuary, The Army Corps of Engineers, Rutgers University, The Wetlands Institute, Princeton Hydro, and GreenVest for their dedication and patience.

Special thanks to the US EPA Region 2 for funding this work and to Brittany Wilburn and Joel Pecchioli for their excellent writing and editing.

The monitoring and lessons learned compiltion completed under this grant on the three pilot salt marsh enhancement projects was a continuation of work started with National Fish and Wildlife Foundation funding (#43095 DOI/NFWF - Reusing Dredge Material to Restore Salt Marshes and Protect Communities).

Appendix

A. Monitoring Report

B. Lessons Learned from Implementation Report

C. Improving Decision-Making Processes For Wetland Restoration (WATCH) Report

Citations: from final report

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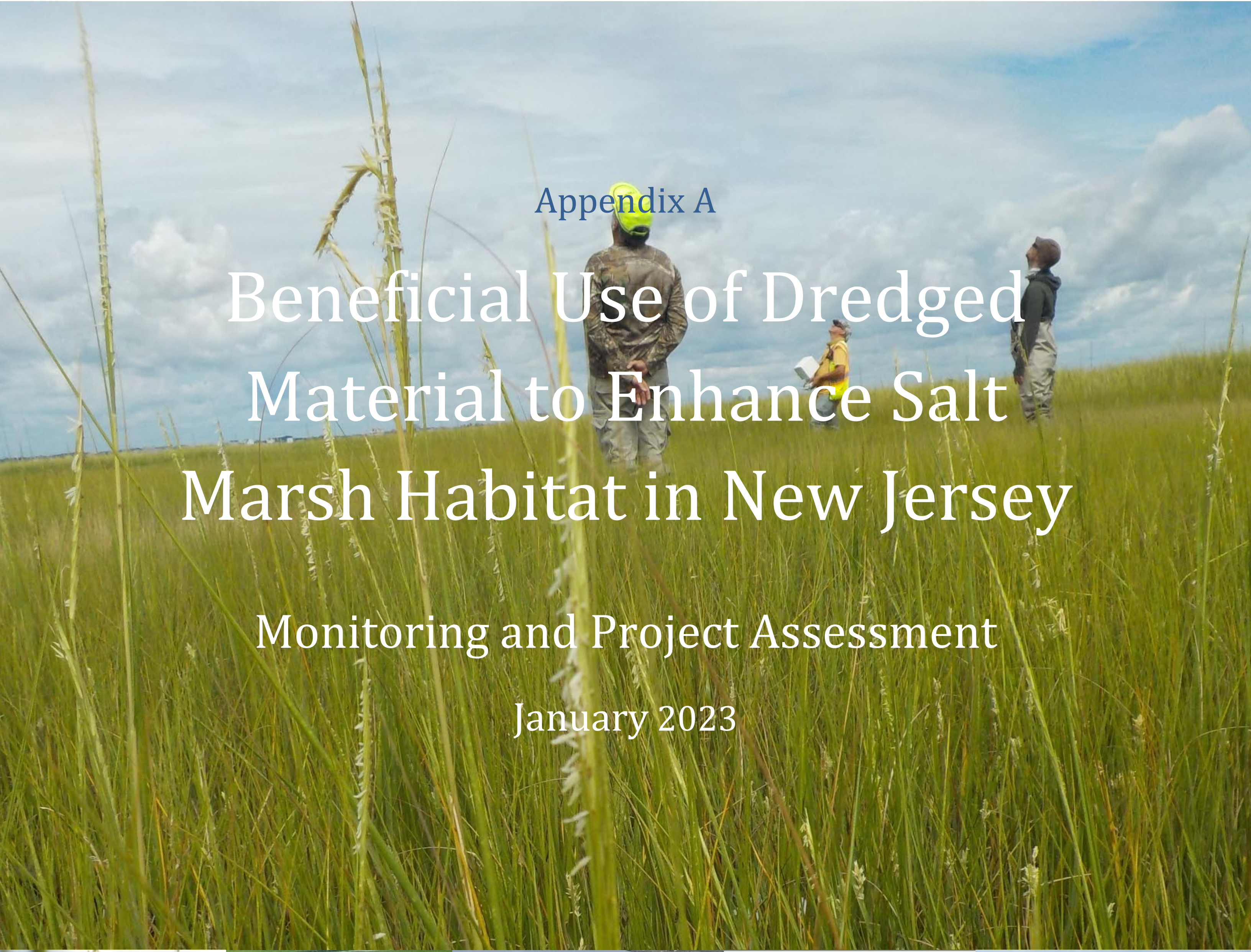

Appendix A

Beneficial Use of Dredged Material to Enhance Salt Marsh Habitat in New Jersey

Monitoring and Project Assessment

January 2023

Acknowledgments:
This project was supported and funded by the National Fish and Wildlife Foundation through the Hurricane Sandy Coastal Resiliency Competitive Grant Program (Grant #43095), The U.S. Environmental Protection Agency Wetland Program Development Grant (CD-96273100), and a U.S. Fish and Wildlife Wildlife Restoration Grant (Grant #F17AF00813). The project was sponsored by the New Jersey Department of Environmental Protection (NJDEP), with support from the Office of Dredging and Sediment Technology, the Division of Science, the Bureau of GIS, and the Division of Fish and Wildlife. Additional support was also provided by project managers, research scientists, and engineers from the NJDEP, the New Jersey Department of Transportation – Office of Maritime Resources, the U.S. Army Corps of Engineers (USACE) - Philadelphia District, the USACE Engineer Research and Development Center, GreenVest LLC, Princeton Hydro LLC, The Wetlands Institute, Rutgers University, Stockton University, and The Nature Conservancy in New Jersey.

Recommended citation*: New Jersey Department of Environmental Protection and The Nature Conservancy (2023). Beneficial use of dredged material to Enhance Salt Marsh Habitat in New Jersey: Monitoring and Project Assessment. (Eds. M. Yepsen, B. Wilburn, J. Woollard). Trenton, NJ. 122 pp.*

Title page photo credits: Metthea Yepsen (NJDEP Division of Science and Research), Steven Jacobus (NJDEP Bureau of GIS), and ACE Aerial Images and Video Production

Abstract:
This report summarizes monitoring conducted at three pilot beneficial use of dredged material to enhance salt marsh projects in New Jersey. Constructed between August 2014 and April 2017, these projects tested sediment addition techniques that included thin-layer placement (TLP) of dredged material on the platform of vegetated, stressed marshes (Ring Island, Avalon, and Fortescue) and the filling of degraded and expanding pool-panne complexes with dredged material on the surrounding stressed marsh platform (Avalon). The objectives for the three marsh pilot projects were (1) to increase and maintain the optimal tidal elevation (hydroperiod) for native salt marsh species, (2) to increase the cover and health of native salt marsh vegetation, and (3) to return all other metrics to baseline (*i.e.*, pre-implementation) conditions (unless they were expected to change due to habitat conversion). Topographic surveys indicated that 1) on average sites reached target elevations, but the placement was uneven, 2) all sites initially gained elevation, but it was challenging to measure small elevation changes, 3) the higher the final elevation, the slower vegetation grew back, and 4) sites gained resilience against 10- to 27-years' worth of sea-level rise. As of 2021, none of the salt marsh sites had increased plant cover from baseline conditions or established the targeted *Spartina patens* habitat. However, several sites matched control site conditions, and much was learned about how to increase the rate of plant recovery. Soil makeup, benthic infauna communities, and epifaunal macroinvertebrates did not return to baseline conditions by 2021, but water chemistry returned to control conditions. Nekton and avian use were variable and results were dependent on changes to vegetation and elevation. These findings suggest that both thin- and thick-layers of sediment addition to existing tidal marshes led to large initial changes in the habitat, from which the ecosystems rebounded/are rebounding at different rates.

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Executive Summary

Due to the growing evidence that tidal wetlands of the Northeast United States are not keeping pace with sea-level rise (Cahoon 2015, Haaf et al. 2022, Hartig et al. 2002, MERI 2015, US EPA 2019), there is an effort to find mechanisms to enhance their resilience and prolong their existence. This report summarizes the monitoring conducted at three pilot resilience projects in New Jersey where sediments taken from channel beds as part of navigational dredging projects were pumped onto the marsh to increase the salt marshes' elevations. The objectives for the three marsh pilot projects were (1) to increase and maintain the optimal tidal elevation (hydroperiod) for native salt marsh species, (2) to increase the cover and health of native salt marsh vegetation, and (3) to return all other metrics to baseline (*i.e.*, pre-implementation) conditions (unless they were expected to change due to habitat conversion).

Monitoring was conducted at the salt marsh enhancement projects between 2014 and 2020. Where possible, monitoring followed a Before-After-Control-Impact (BACI) design. Metrics were selected to see how closely the projects were built as designed to determine whether the project objectives listed above were met and to inform adaptive management. More than 50 metrics were collected by nine organizations over seven years in three sites and associated control sites. Using these data and associated reports, we can answer the following questions:

1. Were projects built as designed?

All marsh enhancement sites were smaller than planned, especially Fortescue. Ring Island was 0.89 acres of the targeted 1.0-1.4 acres. Avalon was 45 of the planned 51 acres, and Fortescue was 6.5 of the targeted 23 acres. The reasons for this are discussed in the 2021 Beneficial Use of Dredged Material to Enhance Salt Marsh Habitat in New Jersey: Project Summary and Lessons Learned report.[1]

The dredged material was generally placed at the Target Dredged Material Placement Elevations in around 50% of each marsh enhancement site. The remainder of the sites was generally higher than planned at Ring Island, lower than planned at Fortescue, and both above and below at Avalon. By 2019, Avalon had a fairly even mix of areas that were above, below, and within the site's Target Ecological Elevations. Elevation gains at Fortescue were no longer measurably different from baseline conditions by 2019 (both because the reported change was too small to be measured by a real-time kinematic global positioning system (RTK-GPS) and because of questionable gains and losses in areas of the site that did not receive sediment).

2. Did the projects gain elevation? If so, how much?

In 2019, Ring Island had maintained the initial elevation gain (a median increase of 0.55 feet), Avalon had maintained some of the initial elevation gain (a median increase of 0.34 feet), and an elevation

[1] https://hdl.handle.net/10929/97940

change could no longer be reliably measured at Fortescue (a median measured increase of 0.2 feet).

3. How many extra years of elevation capital did the sites gain relative to sea-level rise?

The current short-term rate of sea-level rise in New Jersey is 6 mm/year (Haaf et al. 2016), which is equivalent to 0.02 feet. Given the median elevation gains at the sites measured in 2019, Ring Island, Avalon, and Fortescue gained 27.5, 16.5, and 10 years, respectively.

4. Were the elevations at optimal tidal elevations (hydroperiod) for native salt marsh species?

All projects stated the desire to increase marsh elevation to high marsh, targeting primarily *Spartina patens*. Although Avalon and Fortescue had large areas in the target tidal elevation (between Mean High Water (MHW) and Mean Higher High Water (MHHW) levels) for *Spartina patens* and the species was planted at the sites, it did not become the dominant species.

At Ring Island, where elevation targets were not used, we saw that the addition of a median of 0.55 feet of elevation moved the site from low marsh to above high marsh, which was perhaps too high. Raising the elevation above MHHW may explain why the site has been slower than Fortescue and Avalon to revegetate. At Avalon, three out of the five placement areas had Target Ecological Elevations above MHHW, and anecdotal evidence from site visits has suggested that persistent bare areas tend to correlate with the lowest or highest elevations. Fortescue targets were consistent with the upper end of the high marsh range.

There are inherent challenges in targeting high marsh elevations. The range of elevations that fall into the high marsh tidal datums (approximately 0.5 feet) is much smaller than the range of elevations that fall into the low marsh tidal datums (generally 2-3 feet in marshes in SE New Jersey), creating some inherent challenges for using TLP techniques to reach high marsh elevations because the room for error is much smaller.

5. Was there an increase in the cover and health of native salt marsh vegetation?

The short answer is no, vegetation loss was widespread where sediment was placed at all three sites and the vegetation cover not only did not surpass baseline conditions, but also was still below the baseline six to seven years after construction. However, the sites quickly recovered native species richness and maintained native salt marsh plant communities. In addition, plant cover in most control sites dropped over time resulting in no significant difference in cover with placement sites.

6. Why did vegetation recover quickly in some areas and not in others?

The differences in recovery between the three sites can be attributed to a variety of potential factors, including differences in how the projects were constructed and the environmental characteristics of the sites. We found three main driving forces affecting revegetation rates: 1) for the first few years, vegetation recovery was higher in areas with thinner placement; 2) vegetation was denser in areas near existing vegetation, suggesting that higher edge-to-placement ratios may speed up the recovery rate;

and 3) while final elevation is important in long-term plant recovery (as evidenced at Ring Island), placement depth was not (as evidenced by vegetation growth in Avalon's pool plots).

7. Did all other metrics return to baseline conditions?

Soil makeup, benthic infauna communities, and epifaunal macroinvertebrates had not returned to baseline conditions.

- While control site soils were 90% silt and clay, placed sediments at Ring Island and Fortescue were predominately sand. Placed sediments had much lower concentrations of total phosphorus, total nitrogen, total sulfur, and organic matter than control sites.
- There was an immediate decline in the abundance of benthic infauna across all three sites. Ring Island showed minimal recovery of any taxa four years post-placement and the abundance was similar between placement and control sites at Avalon and Fortescue in 2019. The proportion of benthic infauna taxa in the samples remained different in placement sites through 2019.
- The density of *Melampus bidentatus* (salt marsh snails) remained lower in Avalon and Fortescue placement areas when compared with baseline and increased at Ring Island. There was no measured change in *Guekensia demissa* (ribbed mussels), likely because of the small number of plots where mussels were found. *Uca* sp. (fiddler crabs) burrows decreased at Fortescue and increased at Avalon placement areas when compared with the baseline.

Water chemistry was generally similar in placement and control areas; however, surface water chemistry monitoring documented periods of high pH and salinity in contained areas in the year following sediment placement at Avalon. Tidal flushing was and important moderator of more extreme surface water chemistry conditions. Ground water pH at Avalon slightly increased at placement sites from initial measurements in 2017 to 2019. There was a larger range in groundwater pH and surface water salinity measurements at Avalon placement sites than in control areas and water chemistry evolution was documented as the site aged.

The placement of dredged material on the marsh surface initially made acute changes to the habitat available to birds using each project site. Shorebirds increased with the creation of open, sparsely vegetated areas, and marsh-dependent species decreased. Marsh species began to rebound as vegetation recovered. Reproductive success at Ring Island was comparable to control areas in the marsh. The marsh enhancement areas of Ring Island supported fewer species and fewer nests compared to the Elevated Nesting Habitat and control areas, but the number of species nesting in these areas increased over the five-year monitoring period.

Nekton was variable based on changes to vegetation and elevation. Decreased fish, decapod, and total nekton density were observed in placement areas at Fortescue and Ring Island during the first and second post-restoration years. This was expected because increasing elevation and removing pools were expected to decrease nekton access and habitat.

Key takeaways:

1. A dredged sediment slurry can be pumped over large areas of salt marsh and generally reach target elevations, but a high level of variability in thickness and elevation is to be expected without the use of grading equipment or new technology.
2. Even a very thin layer of sediment can kill existing marsh vegetation.
3. The thickness of the sediment is less important than the final elevation's effect on flooding in the rate of plant regrowth.
4. There are tradeoffs between the rate of vegetation regrowth and elevation gain.
5. Plants tend to regrow from the edges of placement, suggesting that a higher edge to the interior area of placement ratio may increase the rate of revegetation.
6. *Salicornia* sp. (commonly called sea beans, glasswort, or pickleweed) were the first plants to recolonize the placement areas but were subsequently replaced by *Spartina alterniflora* (smooth cordgrass) and *Distichlis spicata* (saltgrass) as a result of planting and natural recruitment.
7. It is hypothesized that changes in animal species are a result of changes in the habitat. Bare areas with little organic matter in the soil are not hospitable to typical marsh birds and benthic infauna. They instead drew fiddler crabs, shorebirds, and opportunistic benthic infauna that had a higher tolerance for disturbed sites.

Next Steps: The sediment addition and control sites will continue to be monitored as part of the New Jersey Tidal Wetlands Monitoring Network and publications based on the monitoring are being prepared for peer-reviewed publications.

Table of Contents

Glossary

The following terms have been defined according to how they have been specifically used in this document and in the context of the marsh enhancement projects discussed herein. These definitions may differ from those used by others for the same/similar terms.

Adaptive management—The process of continually, iteratively reviewing data and information to develop, design, construct, monitor, and manage a project, in order to meet the project objectives.

Beneficial use of dredged material—The placement of dredged material to enhance, create, or restore a variety of habitats, as opposed to the usual practice of disposing of it in a confined disposal facility or other practices that remove sediment from the system.

Biological benchmarks—The optimum tidal elevation range of the plant species of interest. These benchmarks are used (at least, in part) to design a habitat (e.g., marsh) enhancement and to establish Target Ecological Elevations for enhancement projects.

Coastal resiliency—The ability of coastal communities and natural habitats to withstand and recover from the impacts of storms, flooding, accelerating sea-level rise, and other natural hazards.

Dredging team—Personnel whose primary responsibility is to ensure the dredging success of the projects.

Ecological resiliency—The ability of an ecosystem (e.g., a salt marsh) to resist, respond to, and recover from a disturbance (e.g., an increase in the rate of sea-level rise).

Elevated Nesting Habitat (ENH)—Colonial shorebird nesting habitat created by placing sandy dredged material in a mound on the marsh platform to increase the elevation of the land and create sparsely vegetated sandy habitat. The ENH is high enough to protect the nests from flooding during high tides and storms.

Enhancement—The improvement of a wetland's ability to support natural aquatic life, through substantial alterations to the soils, vegetation, and/or hydrology, as defined by New Jersey Regulations. Also called "restoration" in other parts of the country.

Marsh team—Personnel whose primary responsibility is to ensure the ecological success of the projects.

Mean High Water (MHW)—The average of all the daily tidal high water heights observed over a period of several years.

Mean Higher High Water (MHHW)—The average height of the highest tide recorded at a tide station each day during the recording period.

New Jersey Intracoastal Waterway (NJIWW)—A system of navigation channels maintained by the U.S. Army Corps of Engineers that extends along the New Jersey Coast from the Atlantic Ocean at Manasquan Inlet to Delaware Bay, about 3 miles north of Cape May Point.

Placement areas—Specific areas on the marsh selected for enhancement that received sediment dredged from a nearby navigation channel or marina. Also called "marsh enhancement areas" or "dredged material placement areas."

Stressed marsh—Marshes in need of enhancement (not a regulatory term). Characteristics of stressed marshes include eroded edges, expanded and degraded pools with undercut banks, sparse (low percent cover) and stunted vegetation, mosquito ditches, fragmented high marsh vegetation, elevation deficits, and minimal faunal usage of pools.

Target dredged material placement elevation—The initial elevation up to which dredged material is placed on the habitat enhancement site (e.g., marsh plain). After placement, the material undergoes predicted dewatering and consolidation of the dredged material, sinking from the target dredged material placement elevation to achieve the Target Ecological Elevation.

Target Ecological Elevation—The elevation necessary to meet the specific habitat (e.g., marsh) enhancement ecological objectives for a project. The Target Ecological Elevation is lower than the target dredged material placement elevation and is based on biological benchmarks, desired hydrology, and other conditions at the project site.

Thin-layer placement (TLP)—A wetland enhancement method in which dredged material (i.e., sediment) is intentionally placed on a wetland to increase its elevation, enhancing its resiliency while maintaining the hydroperiod necessary for native wetland vegetation. The thickness of the material is limited to enable the vegetation to grow back through the placed dredged material. Wetland ecosystems are expected to recover more quickly after TLP than after thicker applications of dredged material.[2]

[2] The U.S. Army Corps of Engineers defines TLP as "Purposeful placement of thin layers of sediment (e.g., dredged material) in an environmentally acceptable manner to achieve a target elevation of thickness. Thin layer placement projects may include efforts to support infrastructure and/or create, maintain, enhance, or restore ecological function." (Berkowitz et al., 2019)

The funding provided by the NFWF grant (Grant #43095) and the EPA grant (Grant #96273100) allowed the Project Team to develop a scope of work that incorporated a wide variety of monitoring and assessment activities. As such, project assessment included (1) the development of a monitoring plan that included flexibility for adaptive management monitoring, (2) data evaluation, (3) an analysis of key project costs, and (4) an analysis of the project's potential impact on community resilience. Most of the monitoring activities were focused on the marsh enhancement portions of the project, as well as avian responses to the creation of the elevated nesting habitat (ENH) on Ring Island. Protocols for these activities can be found on the New Jersey Department of Environmental Protection's Division of Science and Research website[3]. Contact Metthea Yepsen at Metthea.Yepsen@dep.nj.gov to request access to monitoring reports with detailed results and data.

The results presented in this report represent the responses of the marsh ecosystem between three to seven years after the placement of dredged material. The marsh enhancement activities were inherently disruptive and, thus, caused initial impacts on the ecosystem. This was expected, and continued monitoring is needed to track the ecosystem's trajectory and to determine if the success criteria of the projects have been achieved.

Detailed project summaries can be found in *The Nature Conservancy and New Jersey Department of Environmental Protection (2020). Beneficial use of dredged material to Enhance Salt Marsh Habitat in New Jersey: Project Summary and Lessons Learned on Project Development and Implementation.*[1]

[3] https://www.nj.gov/dep/dsr/wetlands/

Summary of Projects

Between August 2014 and April 2017, **enhancement** pilot projects were constructed at two locations – Ring Island and Avalon – in the Cape May Wetlands Wildlife Management Area and at a third location in the Fortescue Wildlife Management Area in Fortescue (Cumberland County; Figure 1). The marsh enhancement techniques included **thin-layer placement** (**TLP**) of dredged material on the platform of a vegetated, **stressed marsh** (Ring Island, Avalon, and Fortescue) and the filling of degraded and expanding pool-panne complexes with TLP on the surrounding stressed marsh platform (Avalon). Additional project components included the creation of **Elevated Nesting Habitat (ENH)** for birds at Ring Island and dune restoration and beach restoration projects at Fortescue. Table 1 shows a summary of the projects.

Figure 1. *Pilot beneficial use of dredged material projects were implemented at three locations in Cape May and Cumberland Counties, New Jersey.*

Table 1. *Summary of the pilot projects at Ring Island, Avalon, and Fortescue.*

Project	Ring Island		Avalon		Fortescue		
	Marsh	**ENH***	**Phase 1**	**Phase 2**	**Marsh**	**Beach**	**Dune**
Constructed	Aug 2014	Aug 2014	Dec 2014 to Jan 2015	Nov 2015 to Feb 2016	March 2016	Mar to Apr 2016	Feb to Apr 2017
Habitat Size (acres)	0.89	1	6.9	45	6.6	1.3	2.25
Sediment Volume (CY)**	1,000	6,000	~6,000	~49,300	6,490	7,245	18,335
Sediment Type	96% fine sand	96% fine sand	65% silt/clay	72% silt/clay	30% silt/clay	>80% Sand	>90% Sand
Placement Technique	Spray	Direct pumping	Spray	Spray & Direct pumping	Direct pumping	Direct pumping	Direct pumping
*ENH: Elevated Nesting Habitat **CY: Cubic Yards							

Ring Island

The dredged material for the Ring Island project was 96% fine sand, which came from a shoaled area in the New Jersey Intracoastal Waterway (NJIWW) located next to the island. The sand was used to construct two TLP areas (~0.5 acres each) and an ENH (~1 acre).

Elevated Nesting Habitat

The purpose of the ENH at Ring Island was to create suitable habitat for the State-endangered black skimmer (*Rynchops niger*) and other bird species of concern (Figure 2). It was designed to be a 1-acre mound with a platform elevation of 6 feet above Mean Higher High Water (MHHW) and 1:12 (vertical to horizontal) side slopes.

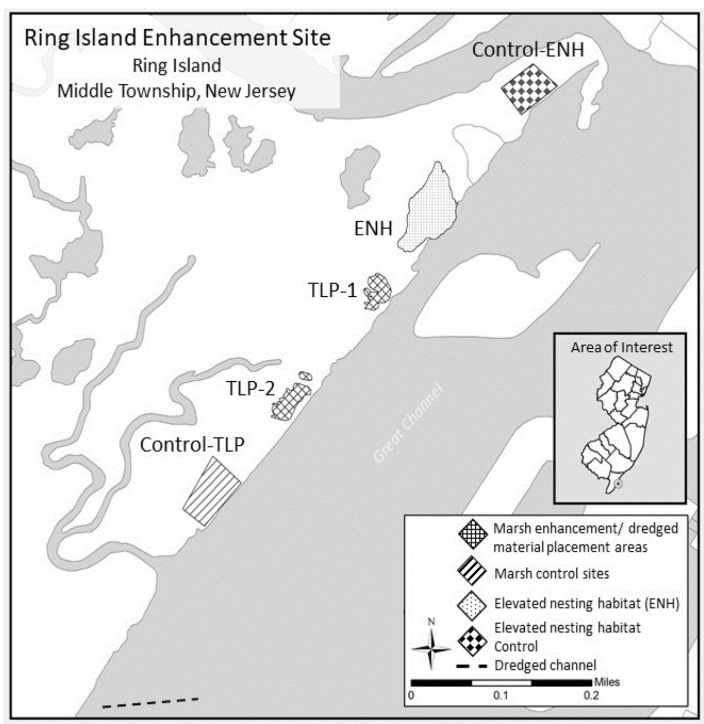

Figure 2. *Ring Island Project Site, showing the locations of the marsh enhancement/dredged material thin-layer placement areas (TLP-1 and -2), elevated nesting habitat and associated Control areas (Control-TLP and Control-ENH).*

In August 2014, the 1-acre ENH was created from approximately 6,000 cubic yards (CY) of the dredged sand. To keep the dredged material within the boundary of the ENH, the area was mostly enclosed during placement (except for a small outlet area for water to exit) using straw bales, a sand berm, and a silt fence. A skid loader was used to grade the placed dredged material and form the ENH mound. The top of the ENH was above the spring high tide line – an important nest survival threshold for coastal birds – but below the target elevation in the design and the permit. Post-construction adaptive management included planting vegetation on the slopes of the site, removing *Phragmites australis* from the site, removing plants from the top of the platform, and in early 2018, placing additional dredged material to restore elevations above the spring high tide.

Marsh Enhancement

The goal of this component was to increase the abundance and rigor of native marsh vegetation by increasing the elevation of "low-lying"[4] marsh by spraying thin (3- or 6-inch-thick) layers of sandy dredged material. These placement depths were expected to allow existing vegetation to survive and quickly recover, growing through the placed dredged material (Ray 2007). No perimeter containment was used because the surrounding areas of the marsh platform were at higher elevations than the placement areas and the sand did not disperse far during placement.

Over a period of two days in August 2014, approximately 1,000 CY of fine-grained sand were sprayed on two 0.5-acre sections of marsh platform using a hydraulic dredge and a spray nozzle system. The discharge end of the dredge pipe was placed on a pontoon at the edge of the marsh, with the spray landing approximately 150-200 feet from the pipe. Spraying the sand to achieve an even thickness of placement was difficult as it accumulated wherever it landed, with little natural spreading. Dredging was stopped intermittently, and water was sprayed through the nozzle system in an unsuccessful effort to disburse placed sand across the marsh platform.

Topographic surveys and depth measurements made in the weeks immediately after construction indicated that, although the average placement depth (6 inches) was within the 3- and 6-inch targets, placement was uneven, ranging between 0.5 to 9 inches. In March 2017, half of the bare areas within each of the TLP areas were experimentally planted with native salt marsh species.

Avalon

The Avalon Project site consisted of two phases of dredged material placement. The dredged material for these projects came from the NJIWW located near the project site; following Superstorm Sandy, this stretch of the NJIWW was one of the critical channel shoals that the USACE-OP needed to dredge. The sediment in the channel was predominantly silt and clay.

[4] The location of the possible TLP sites on Ring Island changed several times in the weeks preceding placement due to the presence of nesting birds and a change in the dredging schedule. As a result, the baseline topographic data could not be used to quantitatively assess the elevation of the selected TLP areas. However, based on observations during site visits, the selected TLP areas were lower than the surrounding and more densely and diversely vegetated, marsh. The Project Team decided it was worth moving forward with the project as an experiment and learning experience. Based on assessments conducted after construction, the baseline elevation of the TLP areas was closer to Mean High Water than Mean Higher High Water and 0.75 feet below the lower end of the range in elevation at which *Spartina patens* was found at the site.

Building upon the Ring Island project, the goal of the Avalon marsh enhancement project was to increase the area of vegetated marsh by filling expanding and degraded pools and pannes to the elevation of the surrounding marsh. The newly created topography was also expected to improve the drainage of the marsh, reducing excessive ponding of water, which is a primary stressor to plants. To accomplish this, the dredged material was either sprayed or directly pumped into the pools, with the overflow resulting in a thin layer of dredged material on the adjacent marsh platform. To keep the fine-grained dredged material within the placement area boundaries, perimeter containment (coconut-fiber logs) was installed before construction. Containment was added as needed during construction.

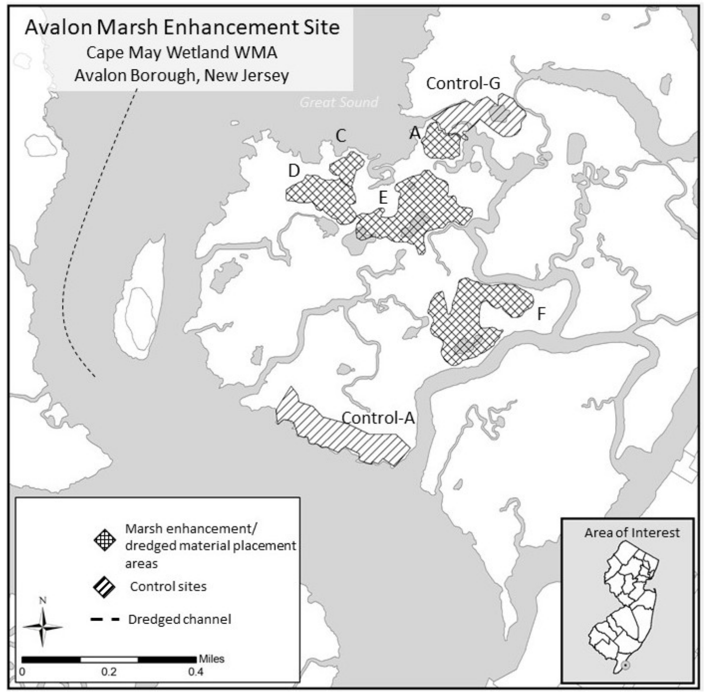

Figure 3. *Avalon Project Site, showing the locations of the marsh enhancement/Dredged Material Placement Areas (A through F) and marsh Control areas (Control-A and -G).*

Avalon Phase 1

In early January 2015, approximately 5,000 CY of predominantly fine-grained sediment were placed on 7 acres of the marsh (Areas A and C in Figure 3). The goal was to fill pools and add 3-6 inches of sediment to the surrounding marsh platform. In addition, sediment was sprayed directly on the marsh platform to learn how TLP with fine-grained material differed from sandy material.

Avalon Phase 2

Additional data collection and detailed engineering work were completed to design the Avalon Phase 2 project. Topographic surveys, high marsh **biological benchmarks,** and tidal data were used to establish **target dredged material placement elevations** and **Target Ecological Elevations**, rather than simply establishing target dredged material placement thicknesses. Between November 2015 and March 2016 about 50,000 CY of fine-grained dredged material from the nearby NJIWW navigation channel were placed on approximately 45 acres of the Avalon marsh (Areas A, C, D, E, and F in Figure 3).

Topographic surveys in the weeks following sediment placement showed the mean elevation of each placement area was within 4 inches of the target dredged material placement elevations. However, based on the range in these elevations, it is clear that sections of each placement area did not achieve the target dredged material placement elevations, while in other areas, the targets were exceeded by more than 1 foot. The depth of sediment placed on the marsh platform ranged from 1- 9 inches (placement was thicker in pools). Two years after placement, the areas lost some of their initial elevation and the mean elevation was within 1 inch of the Target Ecological Elevations at four of the five placement areas. However, some pools had reformed by 2017, indicating differential settling, consolidation, and compaction of the placed dredged material and underlying marsh.

After construction of the Avalon Phase 2 project, an adaptive management program was implemented. For example, based on observations that the dredged material was still dewatering and elevations were changing, combined with concerns regarding the potential to disrupt nesting birds, planting was delayed for a year. The original planting plan was also adaptively implemented in the field in response to the changed conditions. In addition, during the first summer after construction, vegetation die-off was observed in some areas outside and directly adjacent to the perimeter containment. Supplemental monitoring was conducted to investigate the cause(s) of the die-off and to suggest potential adaptive management actions to mitigate it. Initial results from this monitoring suggested that the containment was blocking tidal flow and preventing dewatering of the sediment. This, in combination with acid produced by the oxidation of the placed dredged material, may have created extreme water chemistry fluctuations (e.g., extremely high pH and salinity in surface waters) and less-than-optimal flooding patterns. This led to the removal of most of the containment at both Avalon and Fortescue rather than continuing with the original plan for it to biodegrade in-place.

Fortescue

The marsh enhancement component of the Fortescue pilot project was designed to improve growing conditions for native salt marsh plants and create positive drainage of the marsh platform by increasing the elevation of a low-lying ditched marsh. In addition, to protect the marsh and nearby marina from erosion, a dune restoration project was designed, and a nearby eroding beach was restored (Figure 4). To construct these projects, mostly sandy sediment from the nearby Fortescue Creek navigation channel was dredged.

Marsh Enhancement

The Fortescue project was designed to increase the elevation of the marsh by approximately 9 inches. The target dredged material placement elevation of 3.3 feet and the Target Ecological Elevation of 2.8-3.0 feet NAVD88 were based on biological benchmarks and local site hydrology with the objective to

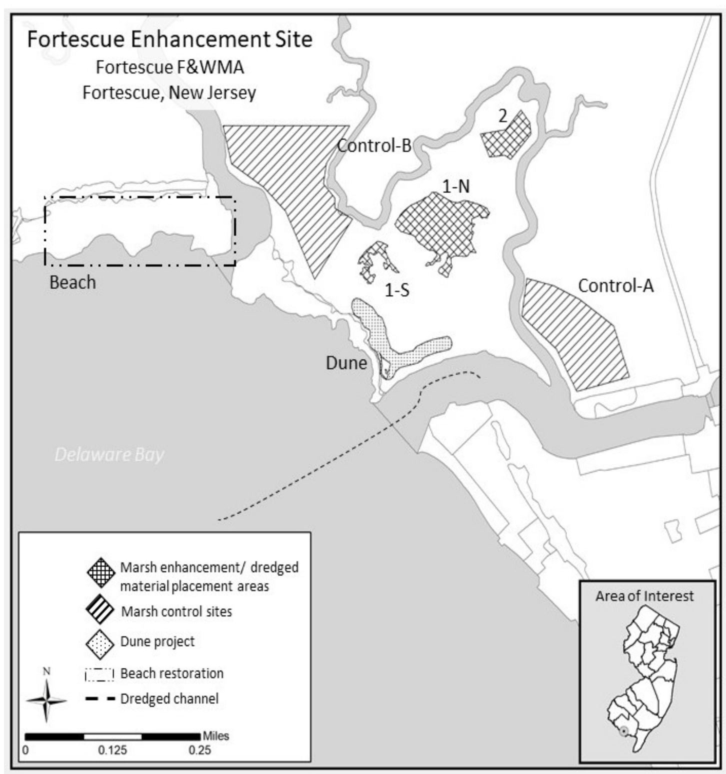

Figure 4. *Fortescue Project Site, showing the locations of the marsh enhancement (1-S, 1-N, 2), dune restoration (Dune) and beach nourishment (Beach) Dredged Material Placement Areas and the marsh Control sites (Control-A and Control-B).*

produce high marsh habitat. The Project Team applied the lessons learned from the construction of the Avalon Phase 2 project to the design and construction of the Fortescue project. The marsh enhancement design included a branching system of pipes with valves that could be opened and closed and included some flexible pipes that could be moved more easily by hand. This design would, in theory, avoid the costly downtime that was experienced during the Avalon Phase 2 project when the discharge of dredged material had to be stopped to prevent overflow of the containment and when the dredge pipe had to be repositioned. A double containment row of plastic mesh tubes filled with wood chips (Filtrexx SiltSoxx™) was installed around each Dredged Material Placement Area.

In March 2016, 6,490 CY of a heterogeneous mix of sandy and fine-grained dredged material from the Fortescue Creek navigation channel were placed on two areas, totaling 6.4 acres of the marsh, which was less than 30% of the originally planned marsh enhancement area. The efficacy of the highly engineered dredge pipe network could not be evaluated because it was not used to its full advantage, and large machinery was used to move the position of the pipe outlet rather than employing the smaller flexible pipes. Several challenges were encountered during the marsh enhancement. For example, the dredged material was sandier than expected, the winter weather was especially harsh and there were contracting issues. As a result, the Project Team was unable to complete construction in the first year and decided not to finish the project in the second year. A survey of dredged material depth in permanent monitoring plots found that the average depth of placement was 6 inches and ranged from minimal to 18 inches.[5]

After construction, portions of the bare sections of the marsh enhancement areas were planted with native salt marsh species. As part of the project adaptive management plan, the plastic netting around the Filtrexx SiltSoxx™ was removed and the woodchip filling was dispersed across the marsh.

Dune Restoration

The Fortescue dune restoration was designed to protect the adjacent marsh and the marinas on Fortescue Creek from erosion caused by tidal flow and storm waves. Originally, this project component was designed to be constructed mainly in the footprint of an existing dune adjacent to the marsh platform, but after a winter storm eroded portions of the shoreline the dune footprint was redesigned to be further in the marsh.

In early 2017, approximately 18,000 CY of sandy dredged material were used to construct the dune. Containment made from Filtrexx SiltSoxx™ and sand berms was used to retain the dredged sand. Outlets through the containment on the marsh side of the dune were constructed to allow fine-grained sediment to flow into the marsh creating an area of TLP.

[5] While RTK transect surveys of the elevation at Fortescue were conducted each year, the Control Areas showed improbable gains in elevation. For this reason, elevation data is not summarized here.

"As built" surveys show that the final constructed dune was 900 feet long, 40 feet wide at the top, and 80 feet wide at the bottom, with an elevation of 10.0 feet NAVD88 (5-6 feet above the marsh surface). After construction, the dune was planted with native shrubs and grasses.

Beach Nourishment

The Fortescue project's beach nourishment component was designed to restore a natural beach near Fortescue Creek. The beach was eroded by winds and waves. Approximately 7,000 CY of sediment (at least 80% sand) dredged from the Fortescue Creek navigation channel were spread over 1.3 acres (700 linear feet) of beach at a 15:1 (horizontal to vertical) slope. It was expected that a plateau would form naturally as the placed dredged material was "worked" by the tides and wind.

Monitoring Plan: Objectives

As the first of their kind in New Jersey, the salt marsh enhancement projects tested the idea that the application of dredged material (i.e., sediment) on existing, but stressed and vulnerable salt marshes can result in ecological enhancement and help them persist into the future in the face of sea-level rise, erosion, and subsidence. With three different project sites, the Project Team was able to test a variety of dredged sediment types, placement methods, and sediment depths on a range of baseline conditions. In the long run, the projects will be considered a success if there is (1) an increase in and maintenance of an optimal tidal elevation and hydroperiod for native salt marsh biota, (2) an increase in the abundance and vigor of native salt marsh plants, and (3) a return for all other parameters to pre-construction conditions unless they were expected to change from the conversation of habitat.

The Ring Island Elevated Nesting Habitat (ENH) was designed to create nesting habitat primarily for the black skimmer (*Rynchops niger*), a State-endangered species, and other colonial and marsh nesting species. The project would be considered a success if (1) the increased elevation kept the nests from being flooded, (2) the vegetation in the sandy ENH habitat remained at densities low enough to maintain suitable nesting habitat and was not colonized by invasive plants (for example, *Phragmites australis*), and (3) black skimmers and other colonial and marsh nesting species were successful in fledging chicks from the habitat. Due to the unexpected use of this habitat by other species of interest, the definition of success for the ENH project has expanded beyond its original avian targets to include other species of sandy habitat nesters including horseshoe crab (*Limulus polyphemus*) and the diamondback terrapin (*Malaclemys terrapin*).

The beach restoration and dune enhancement projects at Fortescue were primarily evaluated based on the consistency of their "as built" condition with their design. In addition, goals for the enhanced dune included (1) the successful survival and establishment of native plantings, (2) the removal and prevention of future establishment of *P. australis*, and (3) low rates of erosion.

Several different types of monitoring were conducted during the implementation of the projects. Baseline data collection before project construction (i.e., placement of dredged material) was used to characterize existing conditions and inform final site selection and project design; "as built" surveys were conducted to determine if the projects were built as designed. A formal Monitoring Plan was created in 2014 and implemented to track progress toward meeting the ecological goals of the projects. HAZUS modeling was used to estimate the potential socioeconomic benefits of the Avalon and Fortescue projects (Ferencz et al., 2017). Adaptive management monitoring addressed several issues identified during post-construction monthly site inspections.

Monitoring Plan: Data Evaluation

The Monitoring Plan was devised to track the initial responses (one to three years post-construction) of a variety of ecological salt marsh parameters to dredged material placement, as well as to track the progress/trajectory toward meeting the project goals; thus, it is purposefully comprehensive. The Monitoring Plan and subsequent modeling and adaptive monitoring were designed to answer research questions to help inform future projects of this kind and to help determine the feasibility of scaling up this work within the state. As such, all project work was carefully documented, and project sites continue to be monitored.

The questions that the team hoped to answer through monitoring included:

- Can dredged material be placed on a marsh consistent (vertically and horizontally) with the project’s design?
- Were Target Ecological Elevations appropriate for developing native high marsh plant communities?
- How much does the placed dredged material consolidate over time?
- Does the marsh ecosystem (i.e., structure and functions) recover or show uplift within two to three years of dredged material placement? (And the related “How long does it take for the marsh to recover and achieve uplift?”)
- Did differences in structural factors (e.g., grain size, elevation, placement thickness) correlate with recovery and uplift?
- Were there any unexpected outcomes of the placement of dredged material?
- What parameters should be included in a marsh enhancement monitoring program (before, during, and after placement)? And how long should the post-placement program be conducted?

The monitoring activities used widely accepted and scientifically defensible methods. Where possible, these methods were adapted from the Salt Marsh Integrity Index Protocols used by the U.S. Fish and Wildlife Service (USFWS) Region 5 (Neckles et al. 2013). The USFWS New Jersey National Wildlife Refuges planned to use these protocols for their beneficial use of dredged material projects, and the Project Team intended the data to be comparable. When possible, monitoring activities took place before and after placement of dredged material and in a control site, following a Before-After-Control-Impact (BACI) design. “Impact” portions of the project are typically referred to as dredged material “placement areas.” The elements of the Monitoring Plan are listed in Table 2. Additional research on sediment and water chemistry characteristics at Avalon and regular site inspections at project sites were added after the dredged material had been placed as part of an adaptive monitoring program; these activities proved to be very helpful in adaptively managing the projects.

***Table 2**. Gantt chart of monitoring categories. Red coloration signifies the year that dredged material was placement within the site. Green represents that monitoring of the specific metric occurred within the year. Monitoring was performed generally during peak biomass season (summer to fall).*

	Metric	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Ring Island	Placement										
	Plant Community										
	Benthic Invertebrate Species										
	Avian Use										
	Habitat Change Analyses										
	Site Visits										
	Surface Elevation Tables										
	Topographic Surveys										
	Sediment Characteristics										
	Water Level										
	Nekton										
	Water Chemistry										
Avalon	**Metric**	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	Placement										
	Plant Community										
	Benthic Invertebrate Species										
	Avian Use										
	Habitat Change Analyses										
	Site Visits										
	Surface Elevation Tables										
	Topographic Surveys										
	Sediment Characteristics										
	Water Level										
	Nekton										
	Water Chemistry										
Fortescue	**Metric**	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	Placement										
	Plant Community										
	Benthic Invertebrate Species										
	Avian Use										
	Habitat Change Analyses										
	Site Visits										
	Surface Elevation Tables										
	Topographic Surveys										
	Sediment Characteristics										
	Water Level										
	Nekton										
	Water Chemistry										

1. Horizontal Extent of Dredged Material Placement

Jackie Jahn[1,2], Lisa Ferguson[3], Metthea Yepsen[2,4]
[1]GreenVest, [2]The Nature Conservancy, [3]The Wetlands Institute, [4]New Jersey Department of Environmental Protection

At each site, areas were selected for placing sediment based on several criteria and a variety of mechanisms were used to attempt to get sediment spread into and across those areas. Details are discussed in the 2021 Beneficial Use of Dredged Material to Enhance Salt Marsh Habitat in New Jersey: Project Summary and Lessons Learned report.[6]

Monitoring Design

Extent of Placement

The extent of sediment placed in marsh enhancement areas was mapped by GreenVest. The perimeter of placed sediment areas was walked shortly after placement with a Global Positioning System (GPS) to create placement polygons. Polygons were imported into ArcGIS ArcMap (Version 10.4) and used to calculate acres of placement area.

Results

Ring Island TLP

It was difficult to spray dredged material into the "inland" corners of the rectangularly delineated placement areas, and spraying had to stop once the maximum elevations had been reached in some areas; as a result, dredged material was placed on 0.89 acres of the targeted 1- to 1.4-acre TLP area (Figure 5).

Ring Island ENH

The planned footprint of the ENH was 1.14 acres in size, and the footprint of the constructed projects was 1.49 acres one month after placement.

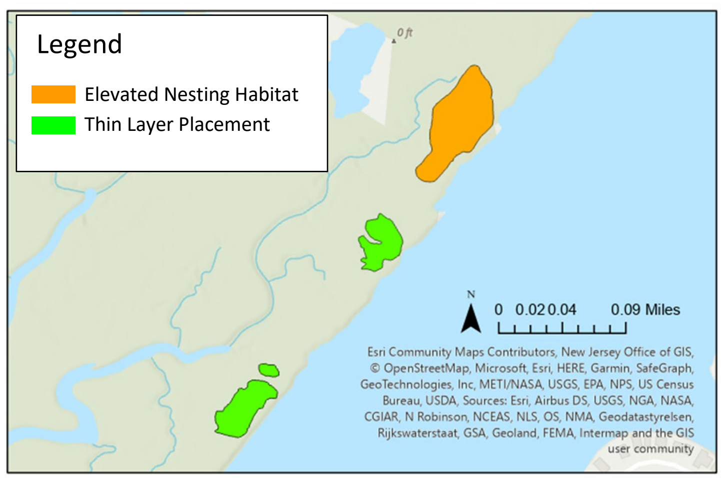

Figure 5. *Placement extent the month after construction at Ring Island.*

The extent of the ENH suitable for nesting by the target species changed over time (see Figure 6). This "nesting platform" was defined as the contiguous area above the Spring Tide level. At the time of placement (September 2014), the platform was 0.9 acres. As the platform was high with somewhat steep

[6] https://www.nj.gov/dep/dsr/wetlands/beneficial-use-dredged-material-project-summary-lessons-learned.pdf

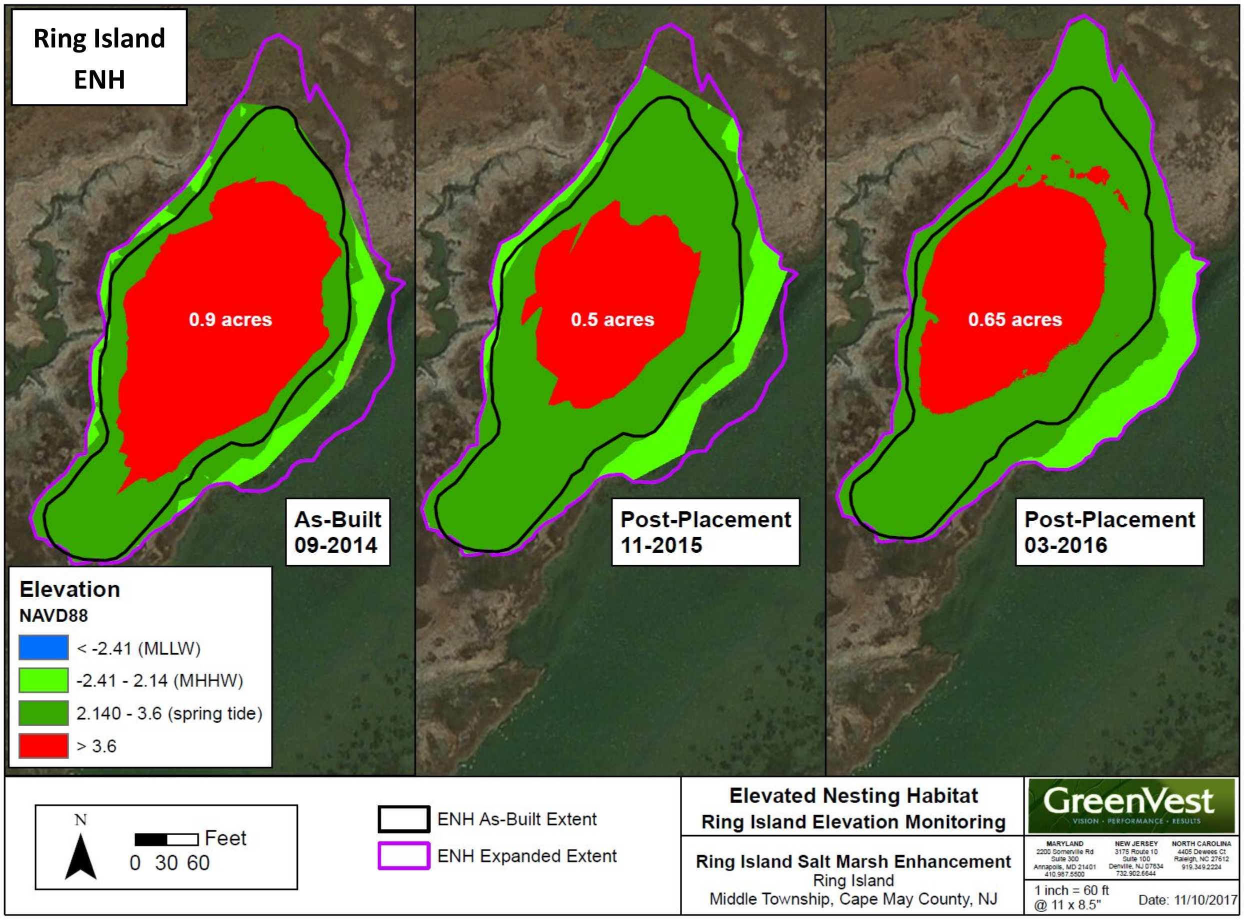

Figure 6. *Change in the shape and elevation of the Elevated Nesting Habitat at Ring Island from September 2014 to March 2016. Surveys from 2014 and 2015 were conducted using RTK-GPS and the survey from March 2016 was conducted using ground-based LiDAR. The acreage for the nesting platform was measured to be 0.9 acres in 2014, 0.5 acres in 2015, and 0.65 acres in 2016. The acreages correspond only to the nesting platforms and not the overall placement area.*

slopes, it was expected that wind and water forces would reduce platform elevation. By November 2015, the platform reduced to 0.5 acres and by March 2016, it expanded slightly to 0.65 acres. This increase may be due to the difference in survey methods between 2015 and 2016 and/or a result of sand moving from the platform onto surrounding areas.

Although the overall nesting platform reduced in size by 2016, the remaining platform was found to be heavily utilized by nesting birds and vegetation began to establish. However, the ENH had lost a significant amount of elevation (on average 0.36 ft NAVD 88; see Section 3: Elevation). Therefore, the project team decided to create a larger nesting platform through the addition of more dredged material in early 2018.

Avalon

43.9 acres of the planned 51 acres of marsh received dredged material (Figure 7). Placement areas that received sediment were larger than planned due to sediments overtopping containments. Additionally, sediment placement took longer than expected, and the project ran out of time before all placement areas received sediment.

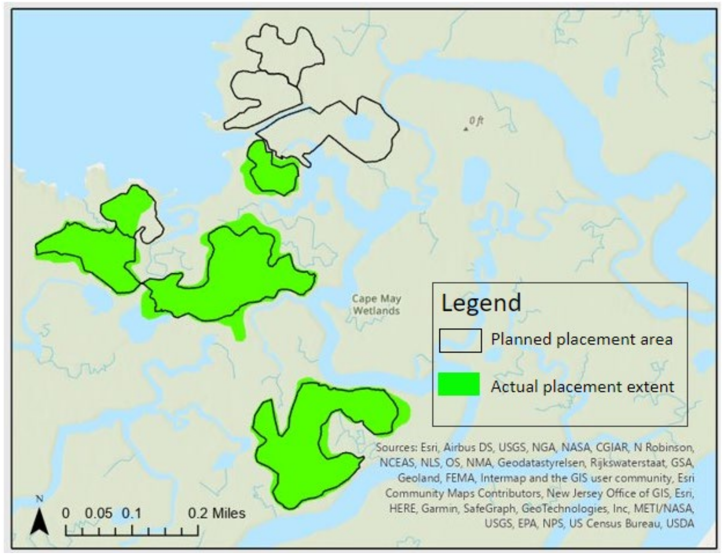

Figure 7. *Planned vs actual marsh project at Avalon.*

Fortescue

6.5 of the targeted 23 acres received sediment in late winter of 2016 (Figure 8). NJDOT intended to return and place more sediment at the site but was unable to do so due to bad weather in the spring of 2016 and courser than expected sediment. Figure 8 depicts areas planned for placement and areas that received dredged sediment.

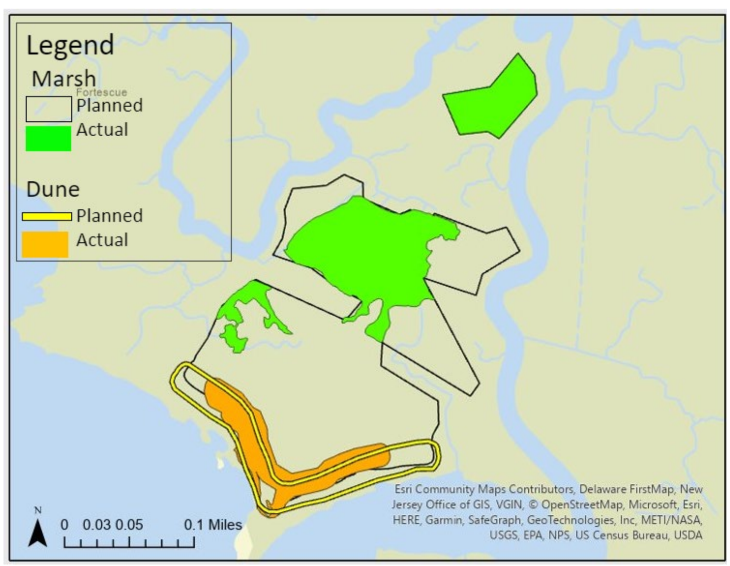

Figure 8. *Planned vs actual marsh and dune projects at Fortescue.*

Conclusions

- All projects ended up being smaller than planned due to time constraints and difficulty spreading the heavy sediments.
- At Ring Island, it proved too difficult to spray sand in an even layer or a rectangular shape. As a result, the team had to stop pumping before it could reach the corners and interior portions of the placement area, which were more difficult to reach.
- At Avalon, the individual placement areas were larger than planned because sediment overflowed the containments, and the team ran out of time to place sediment in all planned areas.
- At Fortescue, there were a variety of factors that led to a smaller project, including bad weather and difficulty spreading sandy dredged materials.
- Based on these analyses, we can answer the following monitoring question: Can dredged material be placed on a marsh consistent (horizontally) with the project's design?
    - We found the answer to be no, it is unlikely that the sediment can be placed on the marsh exactly according to design. Complications can arise during placement, such as difficultly moving the sediment and machinery needed, which can prevent complete coverage of a planned area.

2. Depth of Dredged Material Placement

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[1]The Nature Conservancy, [2]New Jersey Department of Environmental Protection

In addition to changing the elevation of the marsh, the depth of the dredged material placed on the marsh was expected to affect vegetation and animal species survival and the trajectory of post-placement recovery (see Vegetation Recovery Section). In cases where plants or animals were completely smothered, it was expected that recovery (and potentially ecological) uplift would take longer than areas of the marsh covered with a comparatively thin layer of dredged material. Previous research demonstrated that salt marsh plants can recover after the placement of sediment for elevation enhancement. For example, Ray (2007) found that plants recovered best after placement of 0.17-0.50 feet of material, and Reimold et al. (1978) found excellent vegetation recovery after placement of up to 0.75 feet of sandy material.

Monitoring Design

There are a number of different ways to measure the depth of dredged material placed on the marsh. The results reported here are based on two methods: 1) measurements taken by TNC in the permanent vegetation plots for two-years post-placement by piercing the dredged material with a ruler and measuring the depth down to the underlying original marsh surface/root mat (five measurements per plot; see Section 5: Vegetation from Plot Based Monitoring), and 2) digital elevation models (DEMs) based on topographic surveys (Table 3). Measurements of sediment depth in plots were likely more accurate than interpolated RTK-GPS points due to the error associated with RTKs as well as with interpolation of topographic data. However, the interpolation maps give a much better picture of the spatial variability of sediment depth and are thus still worth evaluating.

Table 3. *Design and metrics used for monitoring the depth of dredged material placement at Ring Island, Avalon, and Fortescue project sites.*

Metrics	Method	Design
Depth of dredged material placement (cm and ft)	Ruler measurements	Five measurements in each permanent vegetation plot during peak of growing season
Change in elevation (ft)	Digital Elevation Models (DEMs)	Interpolated RTK-GPS transect surveys or ground based LiDAR surveys.

Results

Ring Island TLP

The dredged material used at Ring Island was 96% sand and the average depth of placement across the site as of two-years post-placement was 15.0 cm (0.5 ft, SD = 5 cm or 0.2 ft). Although it was observed that individual plots experienced small increases or decreases in their average placement depths from two to three years post-placement, there was no significant net increase or decrease for the project (ANOVA, $p > 0.05$). Despite large ranges in elevation, a comparison of DEMs from the baseline and as-built surveys indicate that 64% of the site gained 7.62-15.34 cm (0.25-0.5 ft) of sediment, which matched the target depths set for the project. The spatial distribution of elevation changes between the baseline and the "as built" can be seen in Figure 9.

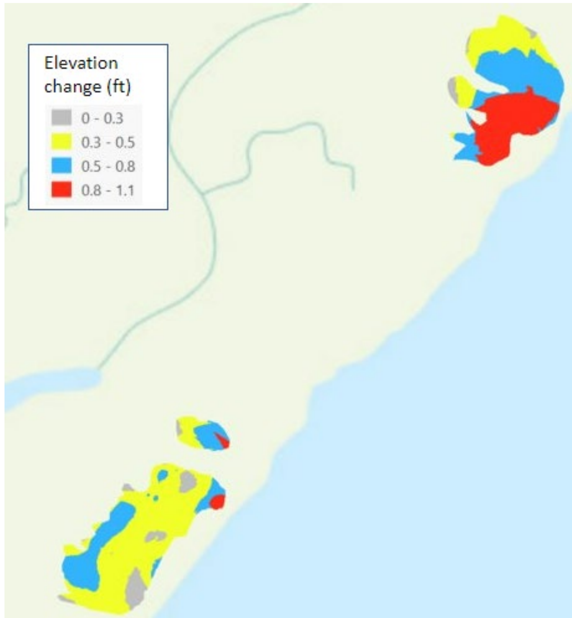

Figure 9. *Change in elevation (ft) between baseline and "as built" at Ring Island TLP areas.*

Avalon Phase 2

During the "as built" survey, the average depth of placement was 30.8 cm (1.0 ft, SD = 27.1 cm or 0.9 ft) for plots that started as marsh platform, and >62.6 cm (2.1 ft, SD = 37.3 cm or 1.2 ft) for plots that started as a pool (Figure 10). Sediment tended to stack up around pipe outlets and depth decreased moving away from pipe outlets. Two-years post-placement, these averages both decreased to 19.8 cm (0.7 ft, SD = 18.9 cm or 0.6 ft) and 42.9 cm (1.4 ft, SD = 37.4 cm or 1.2 ft), respectively. However, these decreases were not statistically significant (ANOVA, $p > 0.05$ platform; Kruskal-Wallis, $p > 0.05$ pool).

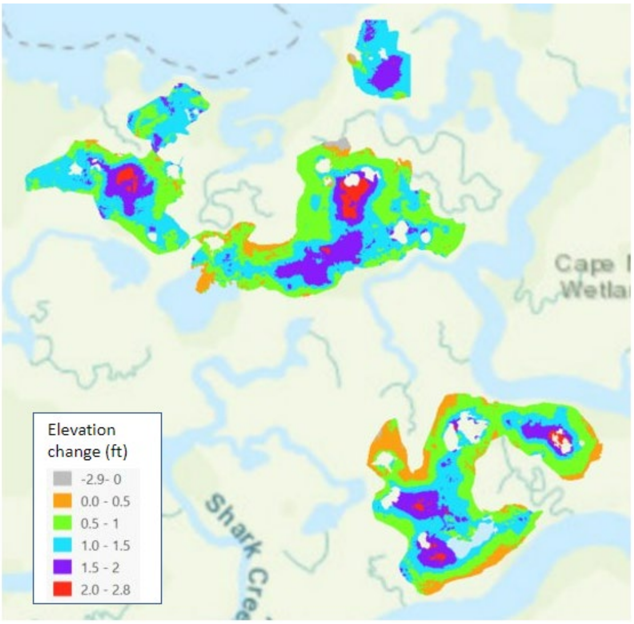

Figure 10. *Change in elevation (ft) between baseline and "as built" at Avalon in placement areas.*

Fortescue

The dredged material placed at Fortescue was a silt and sand mixture, and the average depth of placement measured in the vegetation plots one-year post-placement was 17.4 cm (0.6 ft, SD = 15.4 cm or 0.5 ft). This average decreased slightly, but not significantly, to 15.4 cm (0.5 ft, SD = 6.6 cm or 0.21 ft) two-years post-placement (ANOVA, $p > 0.05$; Figure 11).

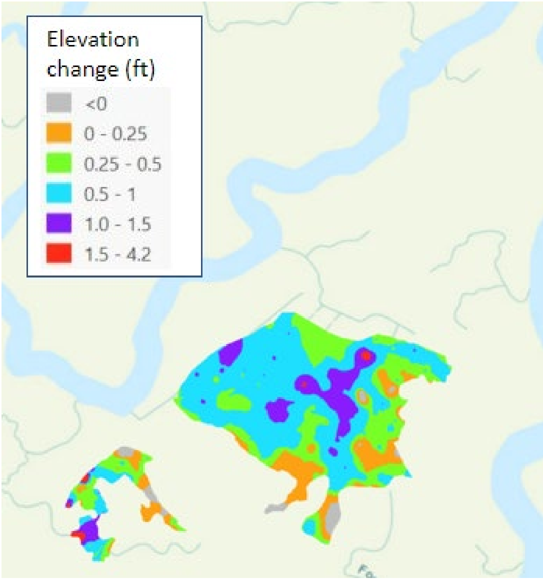

Figure 11. *Change in elevation (ft) in Fortescue TLP areas between baseline (2015) and "as built" (2016).*

Conclusions

- On average after two years post placement, dredged material depth at Ring Island and Fortescue was 0.5 ft, and at Avalon, it was 1 ft on the vegetated marsh platform and 2 ft deep in pools. However, there was a large range of placement depths at all sites.
- Sediment tended to stack up where it first made contact with the ground rather than spread into an even surface. This was even true at Avalon where the sediment was primarily fine-grained. The effect of dredge material depth is explored in Section 5: Vegetation from Plot Based Monitoring below. It is possible that this variability is not ecologically detrimental and instead may lead to a more diverse habitat with niches for a variety of native salt marsh species.
- Based on these analyses, we can answer the following monitoring question: Can dredged material be placed on a marsh to achieve a consistent elevation?
    - We found the answer to be likely no. Due to issues with equipment and sorting of the sediments during application, the sediment was not placed at an even depth across the marsh platform. Pools and ponds resulted in additional differences in depth due to the high rates of compaction and vast depths of the ponds themselves.
    - The dredged material was generally placed at the Target Dredged Material Placement Elevations in around 50% of each site. The remainder of the site was generally higher than planned at Ring Island, lower than planned at Fortescue, and both above and below at Avalon.

3. Elevation

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The primary objective of the placement of dredged material on the Ring Island, Avalon, and Fortescue salt marshes was to increase the elevation of the marsh surface to reduce flooding and change the marsh topography. Changes in the elevation and topography in a salt marsh influence hydrology, which, in part, determines the floral and faunal communities that are integral to the ecological structure and functions of the marsh. To attribute changes to the marsh ecosystem to the addition of dredged material, it is first imperative to accurately document elevation changes in project sites and control sites. In addition, as pilot projects, there was an interest in seeing how closely the projects were built to their design. Observed changes in elevation should be consistent with the depth of the placed dredge material under the assumptions that there is minimal subsidence of the marsh and that data collected using different methods are comparable.

Monitoring Design

Table 4. *Design and metrics used to monitor elevation, topography, and accretion at all three project sites.*

Metrics	Method	Design
Elevation (Ft NAVD88)	LiDAR or RTK-GPS	Minimum of baseline, "as built", and one-year post construction and 2019 in placement and control sites.
Elevation (mm)	Shallow and Deep Surface Elevation Table	Installed post-placement. 3 per control site and 3 per placement site. Read annually in late summer.
Net Accretion (mm)	Marker Horizon Plots – Feldspar Plots and Sediment Grids	Installed post-placement. 4 per SET. Read annually in late summer.
Shallow Subsidence (mm)	Surface Elevation Tables combined with Marker Horizon Plots	Calculated annually.

Elevation surveys were conducted using Real-Time Kinematic-Global Positioning Systems (RTK-GPS) and ground-based Light Detection and Ranging (LiDAR) over five to six years, depending on the placement site (Table 4). Surveys before placement documented baseline conditions and informed placement targets. Surveys immediately post-placement ("as built" survey) were used to determine the thickness (depth) of dredged material placement and how similar the new elevations were to those targeted by the restoration design. Surveys conducted after the "as built" documented how the elevations changed as sediments consolidated, shifted, and compressed the marsh below it. Measurements in Years 1 and 2 post-placement were used to develop planting plans. Measurements in control sites were used to document natural variation and the sampling method accuracy. Measurements of pre- and post-placement elevations were compared with tide range, tidal amplitude, hydroperiod, and key biotic parameters to evaluate the efficacy of using dredged material for salt marsh enhancement. Although not well documented throughout the project, the vertical accuracy of the RTK-GPS units was set at 0.16 feet. As such, changes in elevation under 0.16 feet were assumed to be too small to measure.

Shallow and deep surface elevation tables (SETs) with marker horizons were installed post-construction by The Nature Conservancy (TNC) in control and placement areas. SETs are fine-scale instruments designed to capture changes in elevation (at the scale of millimeters) over time and help to explain the processes responsible for observed elevation changes (https://www.pwrc.usgs.gov/set/), including the accretion of sediment. To account for a heterogeneous, dynamic marsh surface and the noise within the data, SET data must have a minimum of three to five years of data that need to be collected before elevation changes are analyzed. At the time this report is being written, each site has at least six years of data accumulated for the SETs and associate marker horizon plots. These data are currently being analyzed and will be posted in the NJ Tidal Wetland Monitoring Network (NJTWMN) database[7].

Topographic surveys, data interpolation, and data interpretation were worked on by many groups including USACE, NJDOT, GreenVest, Princeton Hydro, TNC, Delaware Valley Data Collection, GBA, and NJDEP.

Results

Ring Island TLP

Based on studies by Ray (2007) and Reimold et al. (1978) that demonstrated plants could survive sediment placement, TLP Area 1 and TLP Area 2 at Ring Island were designed to receive 0.25 feet and 0.5 feet of dredged material, respectively. No statistical difference was found in the depth of placement between the two areas (0.4 ± 0.1 ft and 0.5 ± 0.1 ft, respectively), so they are being analyzed together.

Ring Island Elevation

Surveys at Ring Island were conducted using RTK-GPS and ground-based LiDAR over six years. Low marsh at Ring Island was defined as -0.40 to 1.69 feet NAVD88, and high marsh between 1.69 to 2.08 feet NAVD88 (see Section 4: Water Level Monitoring). Based on the RTK-GPS surveys, the elevation in the TLP areas immediately after placement increased by an average of 0.55 feet (Figure 12). The general elevation gain was maintained over the next five years or, in some locations, showed a slight increase (Figure 13B, Table 5). The measured median elevation in Ring Island control sites increased by 0.13 feet from baseline conditions in 2014 to 2019, five years post-construction. The measured median elevation in placement sites increased by 0.55 feet during the same period. By 2019, the median elevation in the placement sites was 0.25 feet higher than the control site (Kruskal-Wallis chi-squared, $p < 0.001$). Elevation gain measured in the control site was not greater than the vertical accuracy of the survey equipment (0.16 feet) and the sample size increased greatly from 2014 to 2019, thus, it was not possible to conclude that the median elevation increased at the control site (Table 5).

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[7] The NJTWMN website and database are currently being finalized and have not been approved for public posting yet.

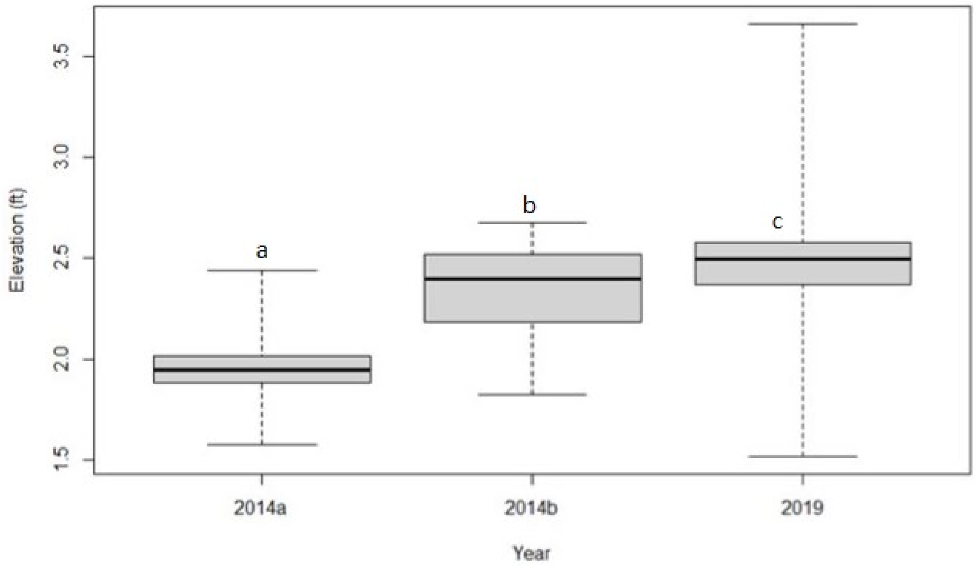

Figure 12. *Elevation (Ft NAVD88) quantiles at Ring Island placement areas based on RTK-GPS transect surveys at the site. Box and whisker plots include the minimum, quartiles, median, and maximum elevation. Elevations were statically different from year to year (Kruskal-Wallis chi-squared, p < 0.05). 2014a: n=46; 2014b: n=109; 2019: n=126).*

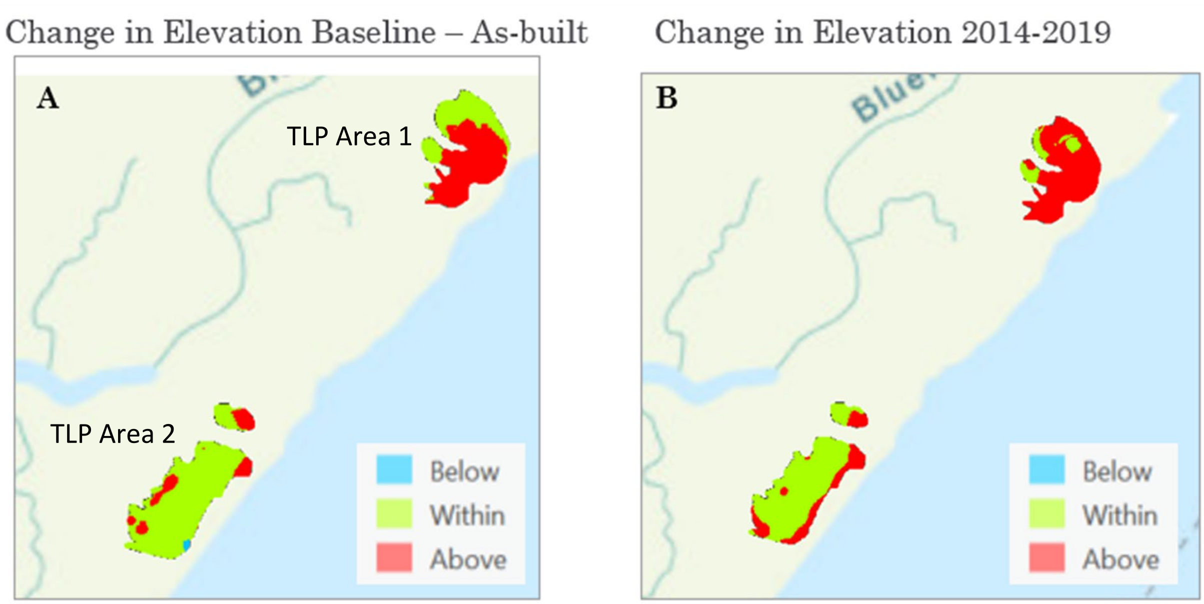

Figure 13. *Areas of Ring Island that were below, within, or above the 0.25-0.75 ft target elevation gains during the A) "as built" (2015) and B) five years post-placement surveys.*

Table 6. *Elevation (Feet, NAVD88) quartiles at Ring Island in Control and Placement sites during baseline (2014) and five years post-placement in 2019 based on RTK-GPS surveys.*

		Elevation Quartiles (Feet, NAVD88)				
	n	**0%**	**25%**	**50%**	**75%**	**100%**
Control Baseline	7	1.90	2.05	2.12	2.17	2.19
Control 2019	150	0.06	2.13	2.25	2.34	3.31
Placement Baseline	50	1.65	1.90	1.95	2.02	2.44
Placement 2019	119	1.52	2.38	2.50	2.58	3.66

Ring Island Target Ecological Elevations

64% of the TLP area gained elevation between 0.25 and 0.75[8] feet of sediment, which was considered "within" target elevations (Figure 13A). The median elevation of the placement areas post-placement in 2019 was 2.5 feet NAVD88 (Table 5), which is above Mean Higher High Water elevation and above the upper-end of the elevations suitable for high marsh (see Section 4: Water Level Monitoring).

Ring Island Elevated Nesting Habitat (ENH)

The ENH was designed to add 5 feet of elevation above the existing marsh. This would place the top of the ENH 6 feet above Mean Higher High Water at 2.14 feet NAVD88. The "as built" survey showed that a large portion of the interior of the ENH placement area was above the spring high tide level (3.6 feet NAVD88), which is an important nest survival threshold for coastal birds. The results in Table 6 indicate that the high interior ENH platform (represented by the maximum elevations) lost 1.8 feet in elevation from the "as built" survey in the Fall of 2014 to the second post-placement survey in March of 2016, while the surrounding areas (assumed to be represented by the minimum elevations) gained 0.5 feet in

Table 5. *Elevation of the Elevated Nesting Habitat (ENH) at the Ring Island project site based on RTK-GPS and LiDAR surveys. No pre-placement data were collected.*

Elevated Nesting Habitat Elevation (Feet, NAVD88)				
	"As built" RTK survey Sept 2014	**Post-Placement RTK Nov 2015**	**Post-Placement LiDAR March 2016**	**Post-Placement LiDAR June 2017**
Minimum	0.27	0.22	1.38	1.62
Maximum	7.61	5.84	5.83	5.96
Range	7.34	5.62	4.45	4.34
Mean	**3.88**	**3.00**	**3.52**	**3.17**
Standard Deviation	1.49	0.90	0.71	0.77
n	279	176	NA	NA
Change in maximum elevation per year		-1.77	-0.01	+0.13
Change in mean elevation per year		-0.88	+0.52	-0.35

[8] An elevation buffer was added to the 0.25 to 0.50-foot target range to account for survey and interpolation error.

elevation. The loss of elevation from the interior platform was balanced largely by an increase in elevation of the surrounding platform area. The loss between the November 2015 and March 2016 surveys is indicative of transport and deposition during winter storms. By 2017, the losses in elevation of the interior ENH platform continued. In response, additional dredged material was placed on the interior portion of the ENH in February 2018.

Avalon Phase 2

The dredged material placement goals of the Avalon Phase 2 marsh enhancement project were to fill expanding pools to an elevation slightly above the surrounding vegetated marsh plain, with the areas around the pools receiving a thin layer placement of dredged material. Target dredged material placement elevations were set for each placement area based on the existing topography of the area and expected dewatering and consolidation of the dredged material (Table 7; see Section 4: Water Level Monitoring for further details on high and low marsh range elevations). This is the elevation up to which dredged material was planned to be placed. After placement, the dredged material underwent predicted dewatering and consolidation, sinking from the target dredged material placement elevation to achieve the Target Ecological Elevation. While Target Ecological Elevations are the elevation necessary to meet the specific habitat enhancement ecological objectives for a project, Target Ecological Elevations are lower than the target dredged material placement elevation and are based on biological benchmarks, desired hydrology, and other conditions at the project site.

Table 7. *Target elevations for placement areas at Avalon Phase 2.*

	Placement Area Elevation Targets (Feet, NAVD88)				
High Marsh Range	2.03 to 2.39				
Low Marsh Range	-0.03 to 2.03				
Placement Areas	**A**	**C**	**D**	**E**	**F**
Placement Target	3.00	2.61	3.00	2.39	3.00
Ecological Target	2.50	2.11	2.50	1.89	2.50

Avalon Elevation

Surveys were conducted using RTK-GPS and ground-based LiDAR over six years[9]. Based on interpolated RTK-GPS surveys conducted during the baseline and interpolated ground-based LiDAR surveys conducted in 2016 after sediment was placed, the initial "as built" increase at Avalon in mean elevation was between 0.90-1.23 feet across all five placement areas. Minimum, maximum, and mean elevations were increased in all dredged material placement areas and the variability in elevation decreased in all placement areas when compared with the baseline.

Median elevations in control and placement sites were statistically different in the baseline (Kruskal-Wallis chi-squared = 2726.7, df = 143, $p < 0.001$), but at 0.17 feet difference, just above the error associated with the RTK-GPS measurements (0.16 ft; Figure 14A and Table 8). The elevation difference between placement areas and control sites significantly increased to 0.27 feet five years after placement

[9] An elevation buffer was added to the 0.25 to 0.50-foot target range to account for survey and interpolation error. dditionally, the LiDAR surveys were not corrected for vegetation and may over-estimate elevation as a result. Despite these two potential sources of error, a comparison of the RTK-GPS and LiDAR data collected during the same season produced similar enough results that we felt comfortable combining data sets for the analysis.

in 2019 (Kruskal-Wallis chi-squared = 1243.8, df = 269, $p < 0.001$; Figure 14B and Table 8). The difference in median elevations between placement sites in 2019 and 2015 was 0.33 feet by 2019 (Kruskal-Wallis chi-squared = 5084.1, df = 259, $p < 0.001$; Figure 14C and Table 8).

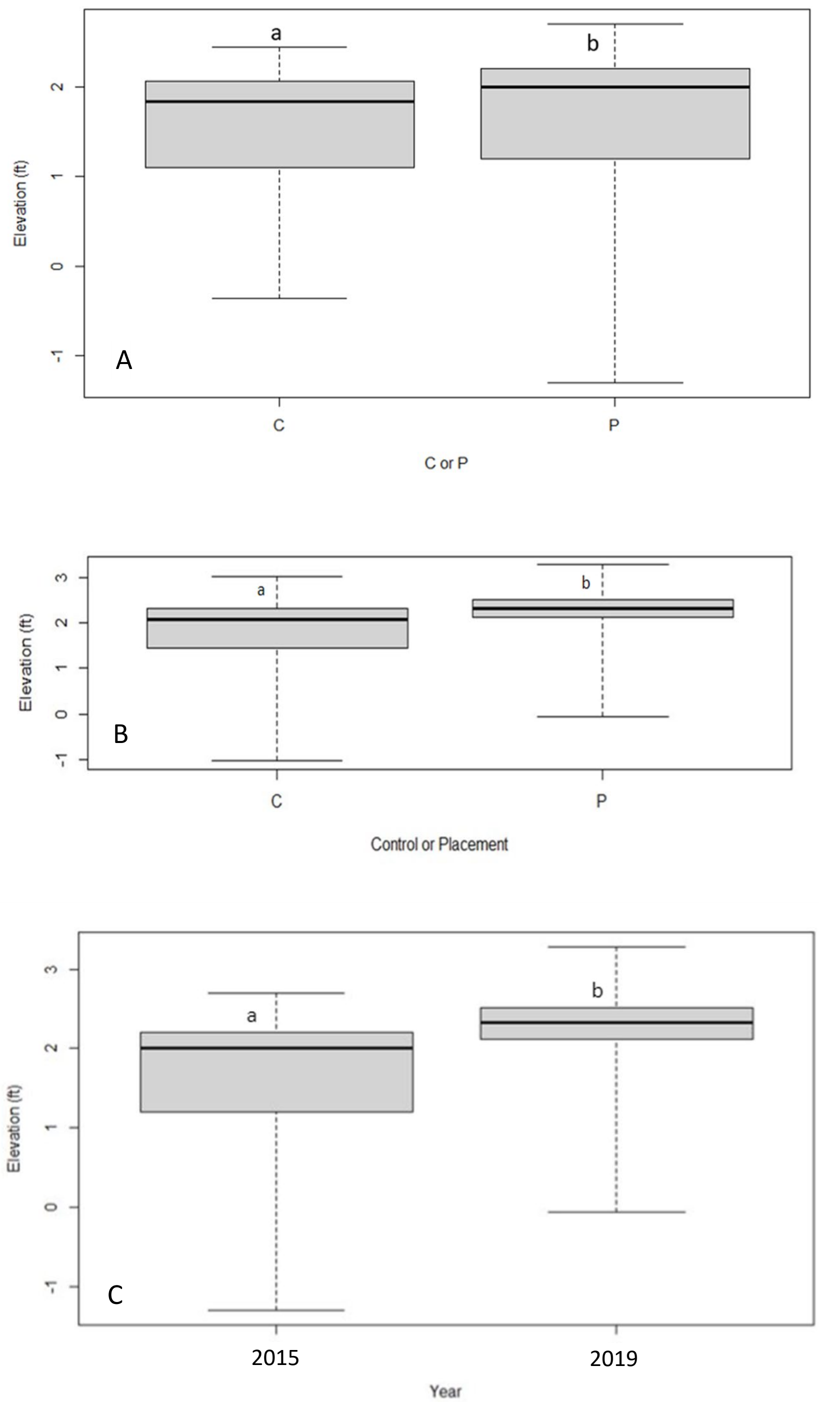

Figure 14. *Box and whisker plots include the minimum, quartiles, median, and maximum elevation of A) baseline conditions (2015) between Control (C) and Placement Areas (P), B) four years post-placement (2019) conditions between Control and Placement Areas, and C) change between baseline conditions (2015) and four years post-placement conditions (2019) in only Placement Areas in Avalon.*

Table 8. *Elevation (Feet, NAVD88) quartiles at Avalon in Control and Placement sites during baseline (2014/2015) and four years post sediment addition in 2019 based on RTK-GPS surveys.*

	Elevation Quartiles (Feet, NAVD88)					
	n	**0%**	**25%**	**50%**	**75%**	**100%**
Control Baseline	66	-0.36	1.12	1.83	2.06	2.44
Control 2019	1434	-1.04	1.44	2.06	2.31	2.61
Placement Baseline	2750	-1.3	1.2	2.0	2.2	2.7
Placement 2019	3162	-0.07	2.12	2.33	2.51	3.28

Avalon Elevation vs Target Elevations: Based on interpolated ground-based LiDAR points, measured mean "as built" elevations were 0.1-0.34 feet below the Target Dredged Material Placement Elevation for all areas except E, which was 0.17 feet above. Given the reported minimum and maximum "as built" elevations, it is clear that some portions of each placement area did not achieve the target placement elevation, while the target elevation was exceeded in other parts of each placement area (in some cases by more than a foot). The "as built" surveys demonstrated that 44% of the area that received sediment was within the target sediment placement elevation, 36% fell below, and 20% was above (Figure 15A). Most of the area above the target sediment placement elevation was in area E where the target elevations were lower than the other areas. By 2019, approximately 50% of the areas were within their Ecological Target Elevation ranges with 30% below and 20% above (Figure 15B).

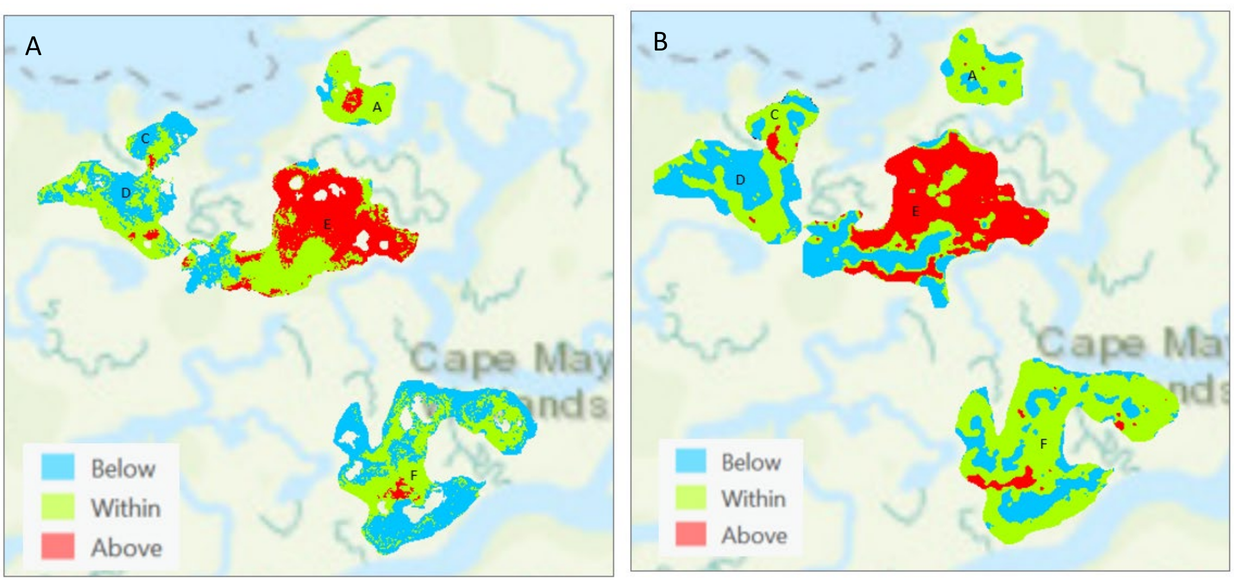

Figure 15. *A) 2016 ("as built") map of Avalon placement areas that were below, within, or above Target Placement Elevations. Transparent areas have no data because they were ponded. B) 2019 map of placement areas that were below, within, or above Target Ecological Elevations. Each Target Elevation was buffered by 0.25 ft above and below to create a range.*

Fortescue

In Fortescue, the range for low marsh was determined to be -0.39 to 2.66 feet NADV88, and high marsh to be 2.66 to 3.08 feet NAVD88 (see Section 4: Water Level Monitoring). The Fortescue marsh enhancement project was designed to increase the elevation of 23 acres of ditched and low-lying salt marsh to 2.80 to 3.00 feet NAVD88 (in addition to the enhancement of 1,350 linear feet of coastal dune, and the restoration of 3.90 acres of beach; not monitored). Topographic surveys were completed at Fortescue using RTK-GPS between 2015 and 2019.

Fortescue Elevation

Topographic surveys at Fortescue were difficult to draw conclusions from. Median elevations in the placement areas were higher than in the control site before sediment placement (Table 9). Elevation gains in the placement areas were observed after placement but were no longer measurably different from baseline conditions by 2019 (i.e., the difference in the median elevation was below the 0.16-foot accuracy of the RTK-GPS). Another complicating factor was that control sites gained improbable elevation during the 4-year time frame (0.36 feet).

Table 9. *Fortescue elevations over time (Feet NAVD88). Minimum, 25 percent, median, 75 percent, and maximum.*

	Elevation Quartiles (Feet, NAVD88)					
	n	**0%**	**25%**	**50%**	**75%**	**100%**
Control Baseline	1780	-0.90	2.10	2.40	2.70	3.60
Control 2019	1719	0.01	2.46	2.76	3.06	3.96
Placement Baseline	664	-0.08	2.25	2.60	2.79	3.60
Placement 2019	624	1.24	2.62	2.80	2.95	3.59

Fortescue Elevation vs Target Elevations

At Fortescue, the 2016 "as built" surveys demonstrated that 56% of the site was within target elevation ranges, with the majority of the rest of the area below targets (Figure 16A). By 2019, the median elevation in placement areas was on target at 2.80 feet NAVD88 but was uneven across the site (Figure 17). Median elevations were higher in placement areas than control areas in baseline conditions (2015, Kruskal-Wallis chi-squared = 2407.8, df = 745, $p < 0.001$) and in 2019 (Kruskal-Wallis chi-squared = 1253.8, df = 768, $p < 0.001$). Elevations were additionally higher in placement areas in 2019 than during baseline. (Kruskal-Wallis chi-squared = 1253.8, df = 768, $p < 0.001$). However, median elevations in control areas also increased by 0.36 feet between 2015 and 2019 (Kruskal-Wallis chi-squared = 2911.4, df = 325, $p < 0.001$). Despite these increases, the area within the target elevation ranges had reduced to 37%, and the area below the target elevation ranges increased to 53% (Figure 16B).

In addition, while surveys of placement areas and control sites showed gains in elevation from 2015 to 2017, the marsh surrounding sediment placement show a loss in elevation (Figure 18). It is unknown how much of these unexpected results can be attributed to a larger-than-expected error in the surveys and how much of the results are accurate. Elevation loss around placement areas could be the result of compaction during construction activities (like heavy equipment use) or the area being especially vulnerable to sea-level rise.

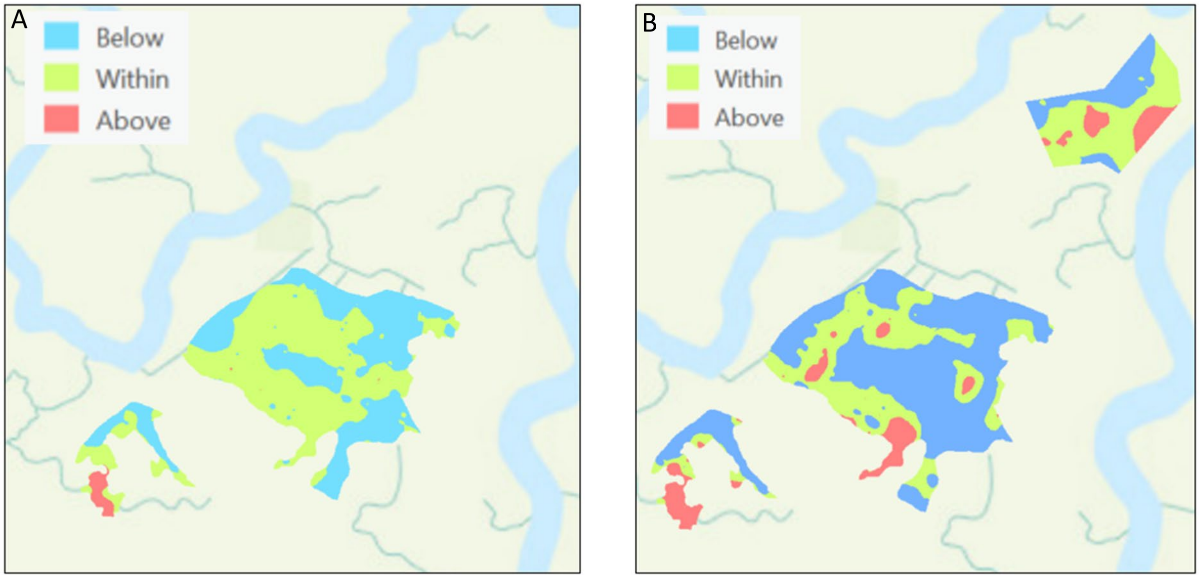

Figure 16. *Fortescue: A) 2016 ("as built") map of areas that were below, within, or above Target Placement Elevations, and B) 2019 map of areas that were below, within, or above Target Ecological Elevations. Each Target Elevation was buffered by 0.25 ft above and below to create a range.*

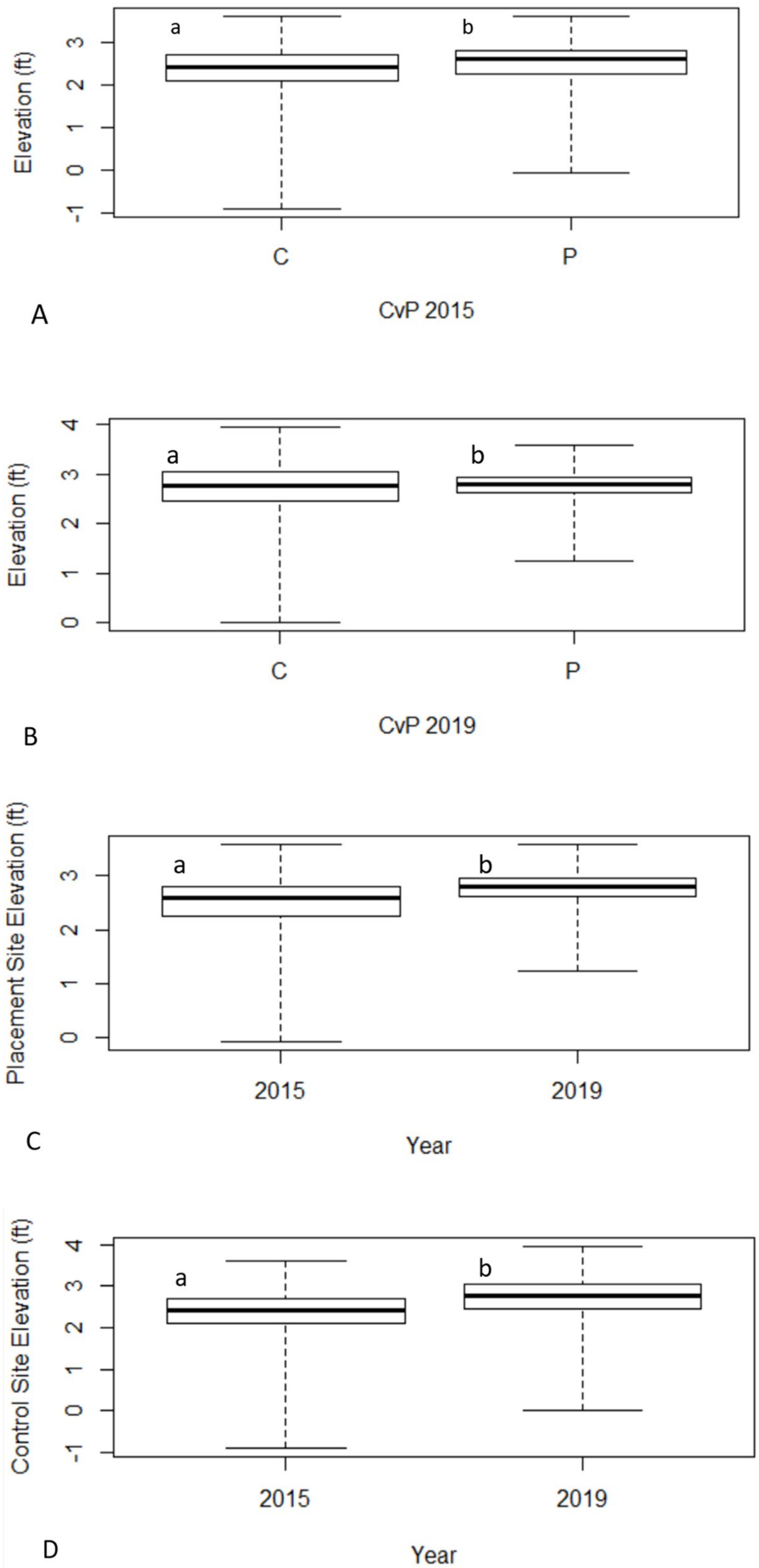

Figure 17. *Median, minimum, maximum and quartile elevations (ft, NAVD88) at Fortescue based on topographic surveys during A) 2015 and B) 2019, with additional comparisons of elevations of C) Placement Areas (P) and D) Control Areas (C) over time.*

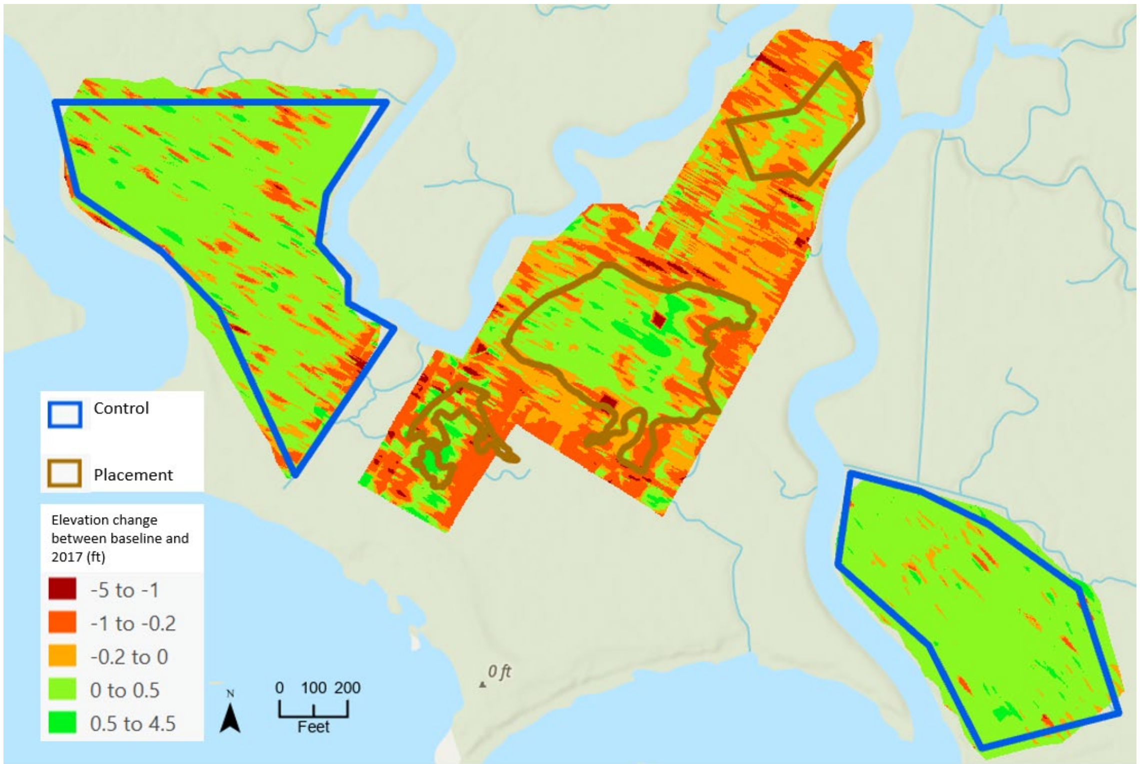

Figure 18. *Change in elevation between 2015 (baseline) and 2017 at Fortescue in Control and Placement areas.*

Conclusions

Elevation

- The relationship between elevation and vegetation is discussed in Section 5: Vegetation from Plot Based Monitoring.
- The dredged material was generally placed at the Target Dredged Material Placement Elevations in around 50% of each site. The remainder of the site was generally higher than planned at Ring Island, lower than planned at Fortescue, and both above and below at Avalon.
- In 2019, Ring Island had maintained the initial elevation gain (median increased by 0.55 feet), Avalon had maintained some of the initial elevation gains (median increased by 0.34 feet), and an elevation change could no longer be reliably measured at Fortescue (median increase around 0.2 feet).
- The current rate of sea level rise in New Jersey is 6 mm/year (Haaf et al. 2016), which is equivalent to 0.02 feet. Given the median elevation gains at the sites, this suggests that Ring Island, Avalon, and Fortescue gained 27.5, 16.5, and 10 years, respectively, before they are back to starting conditions relative to sea level (Table 10).

Table 10. *Elevation gains from placement of dredged material vs years of resilience against the current rate of relative sea-level rise in New Jersey.*

Site	Elevation gains as of 2019 (ft)	Equivalent number of years of SLR
Ring Island	0.55	27.5
Avalon	0.33	16.5
Fortescue	0.20	10

- The Project Team expected to see decreases in elevation over time as the dredged material dewatered, consolidated, and was redistributed within and outside the placement areas as a result of daily tides, storms, and wind. Subsidence of the marsh platform under the weight of the dredged material was also considered a possible contributor to elevation loss. This was especially likely at Avalon, where most of the site began as pools, many with unconsolidated bottoms. Loss of some initial elevation gains was observed at Avalon and Fortescue. Some redistribution of sandy sediments and/or compaction of the marsh in the thin layer placement areas of Ring Island were observed. The ENH at Ring Island also lost elevation as sand was redistributed or compacted the marsh surface. It is possible that because the sediment was coarse, it redistributed around the site rather than completely eroding (for example, a beach formed directly to the east of the original ENH footprint).
- The nesting platform experienced numerous high-water events but was not overtopped after construction. Elevations at constructed nesting habitats will need to be maintained over time to maintain suitable habitat for coastal nesting birds. Suitable nesting habitat is early successional habitat, so poorly vegetated, sandy habitats are ideal. Periodic elevation refurbishment would help maintain these conditions. Sediment redistribution elsewhere on the marsh platform may further enhance adjacent marsh areas by providing additional sediment influx and increasing marsh accretion.
- Despite most areas of Avalon being close to their Target Ecological Elevations, achieving the Target Ecological Elevations and even application of dredged material are likely to be major challenges for sediment addition projects that do not use machinery to contour the dredged material after it has been placed. This results from the difficulty in predicting consolidation of the sediment and subsidence of the underlying marsh platform to set Target Placement Elevations as well as difficulty directing and spreading sediment as it is being placed.
- Based on these results, we can answer the following monitoring questions: 1) Were Target Ecological Elevations appropriate for the creation of native high marsh plant communities, and 2) How much does the placed dredged material consolidate over time?
    - 1) All projects stated the desire to increase marsh elevation to high marsh, targeting primarily *Spartina patens*. Although Avalon and Fortescue had large areas in the target tidal elevation (between Mean High Water (MHW) and Mean Higher High Water (MHHW) levels) for *Spartina patens* and the species was planted at the sites, it did not become the dominant species. Ring Island did not have specific Target Ecological Elevations but instead target thicknesses as this was an initial attempt at placing dredged material and

determining the methodology. On average, we were able to achieve target thicknesses, although some areas exceeded the target range. This sediment placement resulted in elevations above the high marsh zone (MHW to MHHW). The Target Ecological Elevations for Avalon were mixed in terms of appropriate ranges. The Avalon platform was a mixture of low marsh, high marsh, and nearly upland elevations. This was largely due to the inconsistency of placement due to the difficulty of directing and spreading sediments. Fortescue was determined to be largely within high marsh elevations several years after placement, demonstrating that the Target Ecological Elevation was appropriate.

- 2) Ring Island maintained the initial elevation gain (median increased by 0.55 feet). While some areas of Avalon compacted, particularly around the ponded habitats, there was an overall elevation gain of 0.33 feet NAVD88, suggesting that sediments were subject to horizontal movement rather than vertical. Fortescue demonstrated similar findings, with an estimated elevation gain of 0.2 feet NAVD88 over time, despite some areas compacting.

Monitoring Methods

- Accurate and consistent topographic surveys were a major challenge for this project. RTK survey error was expected to be up to 0.16 feet and there was an additional interpolation error when ArcPro was used to make Digital Elevation Models of the sites. Thin-layer placement projects targeting under 0.5 feet of elevation gain are likely to have a difficult time documenting elevation change using current survey methods.
- There were differences in the topographic survey methods used at Ring Island and Avalon, making comparisons between years at the placement areas difficult, especially at Ring Island. When possible, it would be advisable to use the same survey methods over time. In addition, when using LiDAR data, it must be corrected for vegetation and standing water.
- SETs and marker horizons were installed after sediment was placed on the marsh primarily because of the uncertainty as to what areas would receive sediment, but also because of tight dredging timeframes and concerns about damaging the SETs during placement. This was less than ideal, as the SETs and marker horizons could have been used to look at dredged material consolidation and subsurface compaction of the marsh. In addition, the marker horizons eroded at some sites because they were placed on top of dredged sediments that hadn't stabilized. Plastic grids were installed with new feldspar marker horizons to allow comparison of the two methods.
- At Avalon, it would have been advisable to install permanent platforms to install and monitor the SETs because the unconsolidated, fine-grained sediments were easily disturbed.

4. Water Level Monitoring

Metthea Yepsen[1], GreenVest, Brittany Wilburn[1,2]
[1]The New Jersey Department of Environmental Protection, [2]Drexel University

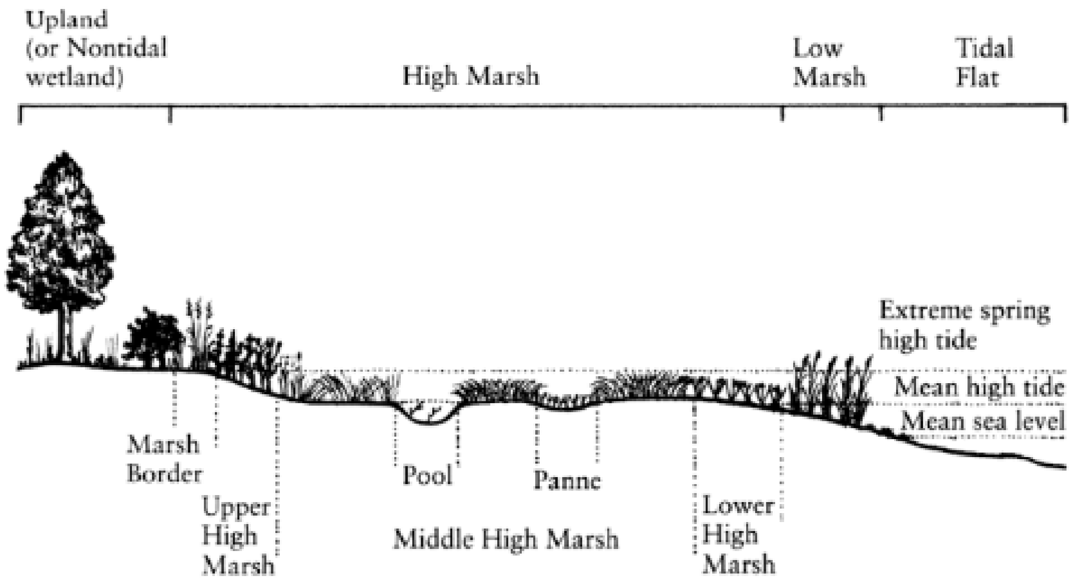

Figure 19. *"Generalized plant zonation in northeastern salt marshes: (1) low mash and (2) high marsh. The high mash can be farther subdivided into several subzones. Pools and depressions called "pannes" occur within the high mash." From Tiner 2009.*

Surface elevation and marsh topography determine the depth and duration of tidal flooding at a site. Tidal flooding and other factors determine what vegetation can grow (Figure 19). All three enhancement projects were targeting high marsh, which generally occurs between Mean High Water and Mean Higher High Water. Since the placement of dredged material changes the topography and elevation of a marsh, it is crucial to monitor changes to the tidal flooding regime (i.e., marsh hydrology). Water surface elevations were continuously measured at Avalon and Fortescue, converted into NAVD88 elevations, and correlated with the site topographic surveys (Table 11). Tidal datums (e.g., elevations of mean high tide, mean tide, etc.) and hydroperiod were also calculated using the water level monitoring data using the available National Tidal Datum Epoch (1983-2001). To account for sea-level rise, water surface elevations were monitored a second time in 2019 in Avalon, Fortescue, and Ring Island in Middle Township. 2019 data was then used to calculate a new tidal datum based on the 2002-2021 epoch following the NJ Tidal Wetlands Monitoring Network (NJTMWN) Tidal Datum Calculation SOP[10].

[10] A draft version can be requested from the NJ Tidal Wetland Monitoring Network by emailing DSR.wetlands@dep.nj.gov

Table 11. *Design and metrics used for surface water level monitoring at the Avalon and Fortescue project sites.*

Design	Hydrology
B-A-C-I	Hydroperiod
Continuous monitoring from February 2015 to December 2017	Mean Higher High Water (MHHW) Elevation
	Mean High Water (MHW) Elevation
	Mean Tide Level (MTL) Elevation
Additional continuous monitoring from June to October or November 2019	Mean Low Water (MLW) Elevation
	Mean Lower Low Water (MLLW) Elevation

Monitoring Design

Surface water elevations were continuously measured by GreenVest at Avalon and Fortescue from February 2015 through early-December 2017. Measurements include water elevations during baseline data collection before dredged material placement, during placement, and throughout the monitoring period after placement. Remote data logging equipment was installed at semi-permanent tide gauge stations at the Avalon and Fortescue project sites. This BACI design was intended to provide the data needed for important analyses of the relationships between changes to elevation and tidal flooding caused by dredged material placement and changes to other marsh features (e.g., plant community changes as a result of differential flooding regimes).

In situ Level Troll 500 water level loggers were installed in slotted PVC pipe in open water, in a creek, in a control site, and in two placement (impact) locations at both Avalon and Fortescue. Water level elevation was measured at 15-minute intervals. Periods of anomalies and logger malfunctions were removed from the dataset before analysis. Key tidal elevations (Table 11) were calculated, when possible, and validated by Princeton Hydro using long-term data from NOAA tide gauges.

In 2019 surface water elevations were continuously measured by NJDEP from June to October (Fortescue) or November (Ring Island and Avalon). Semi-permanent tide gauge stations were positioned near existing SETs in each site, with two stations in the marsh interior and one station in a creek bed. Tide gauge stations were formed using a slotted PVC pipe with a HOBO U20L-04 water level logger inserted and a second HOBO U20L-04 logger acting as a barometric logger placed nearby. Water elevation levels were collected at 6-minute intervals to coordinate with NOAA tide gauges and to make later calculations easier. Data were checked for errors and corrected or removed when needed. The same key tidal elevations as above were calculated and checked against NOAA tide gauges, using the methods found in the NJTWMN Tidal Datum Calculation SOP. In brief, high and low tides of the short-term monitored water level data were parsed out and used to determine key tidal datum elevations. These elevations were then corrected relative to long-term tidal datum elevations of permanent tidal gauges of NOAA or the USGS, depending on the site. The tidal datums calculated using 2019 data were found to be similar to the design tidal datums of Fortescue and Avalon and are reported here as a secondary confirmation of design calculations.

Results

Ring Island

For the Ring Island TLP areas, the design tidal datum was calculated to have a maximum tidal elevation of

2.14 ft (Table 12). Secondary 2019 calculations were shown to have a relative percent difference of only -1.14%, suggesting that the original tidal datum calculations are accurate. No other monitoring of the surface water elevations was performed at this site.

Table 12. *Tidal datum boundaries calculated for Ring Island. The 2019 datums are based on water level monitoring conducted in a tidal creek at the projects site using the 2002-2021 National Tidal Datum Epoch. Median placement area elevations based on RTK-GPS point surveys.*

(Feet NAVD88)	Tidal Datums Elevation			Median Placement Area Elevation	
	NOAA Stone Harbor Tidal Gauge 8535581	Design	2019	2014 Baseline	2019
Mean Higher High Water	2.08	2.14	2.11		2.50
Mean High Water	1.69	-	1.72	1.95	
Mean Sea Level	-0.32	0.23	-		
Mean Tide Level	-0.40	-	-0.35		
Mean Low Water	-2.50	-	-2.41		
Mean Lower Low Water	-2.66	-2.41	-2.55		

Before placement, half of Ring Island was between Mean Tide Level and Mean High Water and half was between Mean High Water and Mean Higher High Water (Figure 20). In both “as built” (not shown) and year 5 post-construction surveys, elevations at Ring Island had increased and surpassed the tidal datum elevations calculated for high marsh habitat and were mostly above Mean Higher High Water (Figure 20).

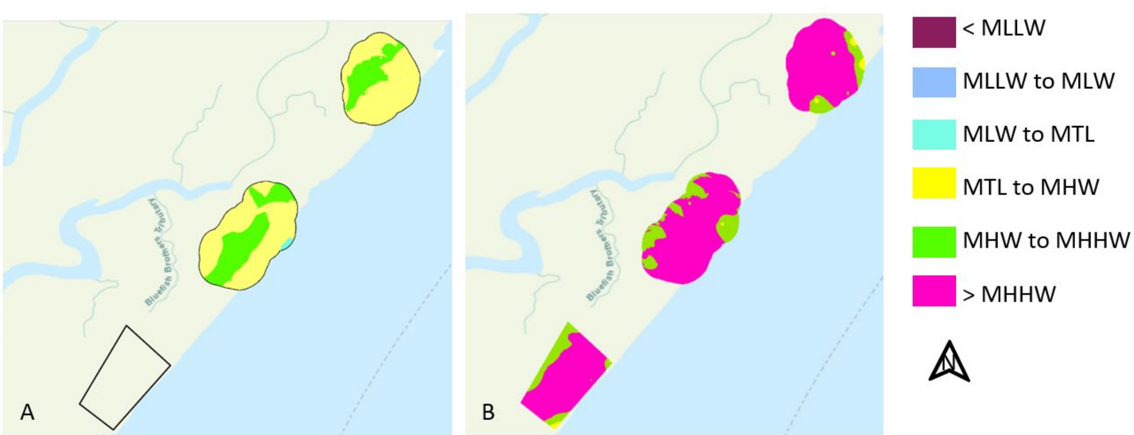

Figure 20*. Elevations relative to tidal datums at Ring Island A) Interpolated RTK-RPS survey from 2014, just before sediment placement. B) Interpolated RTK-GPS survey from 2019. Tidal datums were calculated using water level data collected in 2019.*

This is contrary to what was expected, as it was assumed that sediments would compact and reconsolidate after placement.

No target elevations were set for Ring Island. Thus, we cannot compare them to tidal datums.

Avalon Phase 2

GreenVest installed tide gauges on the site to observe tidal inputs and fluctuations and to monitor inundation, saturation, and drainage of the marsh plain. The tidal datums that were used for design were developed using two months of data compared to other gauging stations for reference. Tide elevations were obtained from National Oceanic & Atmospheric Administration (NOAA) VDatum program and tide gauges in Atlantic City (Station ID: 8534720; Table 13). However, subsequent monitoring showed a larger difference in surface water elevations for MHHW, with a relative percent difference of -8.73% in 2016. The secondary 2019 calculations were referenced to Stone Harbor NOAA tide gauges, and results were similar to 2016 monitoring levels and had a relative percent difference of -10.11% compared to the design MHHW levels.

Table 13 compares the tidal datums to the Target Ecological Elevations, the median baseline elevations, and the median elevations in 2019. The median placement elevation in Avalon placement areas started between Mean Tide Level and Mean High Water at the upper end of the low marsh range that was used for design. Target Ecological Elevations for Areas A, D, and F were all above the Mean Higher High Water elevations used during design. The Target Ecological Elevation for Area C was between Mean High Water

Table 13. *Tidal datums delineated from tide gauge MW-2 in 2015 and 2016 at Avalon and tide gauge located in a creek in 2019; compared with datums used for project design. 2017 data was not usable due to logger malfunctions. Mean Water level from 2015 was calculated using the 2015 Avalon data set at MW-2. Median placement area elevations based on RTK-GPS point surveys.*

Elevation (Feet NAVD88)	Tidal Datums						Target Ecological Elevations	Median Placement Area Elevation	
	NOAA Stone Harbor Tidal Gauge 8535581	NOAA Atlantic City Tidal Gauge 8534720	Design	2015	2016	2019		2014/15 Baseline	2019
Mean Higher High Water	2.08	2.39	2.39	2.35	2.19	2.16	2.5 (Areas A, D, F)		
Mean High Water	1.69	1.97	2.03	2.01	1.83	1.79	2.1 (Area C)		2.33
Mean Tide Level	-0.40	-0.03	-	-0.03	-	-0.34	1.9 (Area E)	2.0	
Mean Low Water	-2.50	-2.04	-2.00	-2.29	-2.49	-2.47			
Mean Lower Low Water	-2.66	-2.21	-2.61	-2.46	-2.79	-2.64			

and Mean Higher High Water, and the Target Ecological Elevation for Area E was between Mean Tide Level and Mean High Water. In 2019, four years after sediment was added, the median elevation of placement areas at Avalon was at the upper end of the Mean High Water to Mean Higher High Water range in the high marsh.

Figure 21 shows the spatial distribution of elevation ranges at Avalon parsed into tidal datums. During baseline conditions, the majority of both placement areas and controls were in the low marsh range between Mean Tide Level and Mean Higher High Water. After additions of sediment, followed by consolidation and subsidence, a wide elevational gradient from Mean Tide Level in yellow to above Mean Higher High Water in pink was observed. Interpretation of the water level data is complicated by the pools at Avalon that hold water as tides recede and do not receive tidal water until their bank elevations are

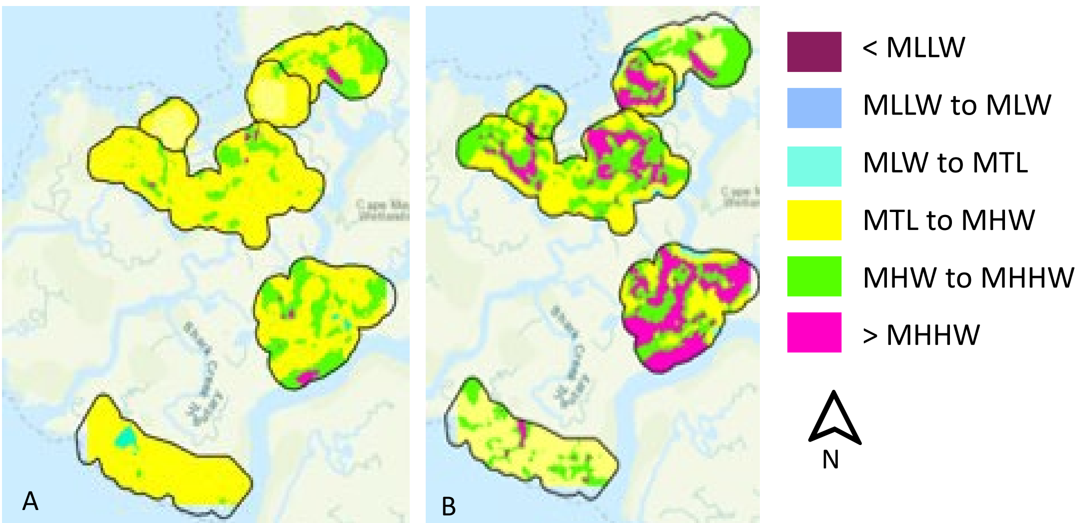

Figure 21. *Tidal datum elevations of Avalon in A) baseline (2014/15) and B) four years post-construction in 2019. Tidal datums are those used for project design and were based on water level data collected at the site in 2015 and are comparable to those used to set target elevations.*

exceeded. This made it difficult to determine the percentage of time an area of the Avalon marsh was flooded since it cannot be based on elevation alone.

Fortescue

Tidal datums used to set target elevations at Fortescue were based on three months of data collected at the site. Because the onsite data was from a relatively short period, tide range data was compared to other gauging stations for reference. Tide elevations were obtained from NJDEP Office of Engineering and Construction Bureau of Coastal Engineering Project 2155, page 2 of "Proposed Emergency Dredging Fortescue Creek, Township of Downe, County of Cumberland, dated June 12, 2013. These elevations were converted to NAVD88 using the NOAA Vdatum datum transformation program. Datums recorded from

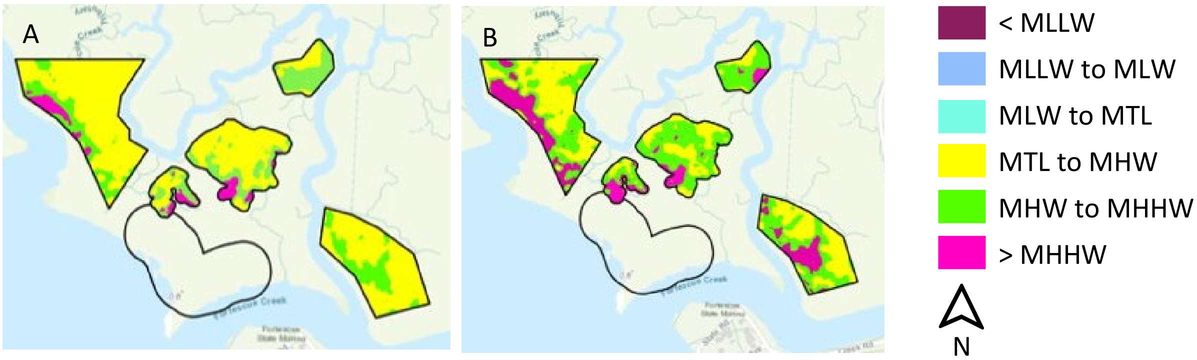

Figure 22. *Tidal datum elevations of Fortescue in A) baseline conditions in 2015 and B) four years post-construction in 2019. Tidal datums were those used in project design.*

2015 to 2019 in Fortescue Creek near the project site (Figure 22) were a few inches lower than those used to set the Target Ecological Elevations for the marsh enhancement project (Table 14).

Figure 22 compares the baseline hydrologic conditions at Fortescue in 2015 (A) to the conditions two years after dredged material placement (2019; B). For the analysis, tidal datums were calculated using the NOAA Vdatum transformation program on tide elevations from the NJDEP Office of Engineering and Construction Bureau of Coastal Engineering Project 2155. These tidal datums were used to design Fortescue placement depths. In the areas that received sediment, some locations (mostly in Area 2) have increased in elevation from between MTL and MHW to between MHW and MHHW.

Table 14. *Tidal datums calculated based on tide gauge TG-1 in 2015 and 2016 and on quality check tide gauges at Fortescue in 2019 compared to the tidal datums used for project design. Median elevations in placement areas calculated from RTK-GPS point survey.*

Elevation (Feet NAVD88)	Tidal Datums					Target Ecological Elevation	Median Elevations in Placement Areas	
	NOAA Bivalve Tidal Gauge 8535055	Design	2015	2016	2019		2015 Baseline	2019
Mean Higher High Water	2.86	3.08	2.81	2.82	2.85			
Mean High Water	2.43	2.66	2.47	2.43	2.45	2.8 to 3.0		2.8
Mean Tide Level	-0.39	-			-0.24		2.6	
Mean Low Water	-3.22	-3.29	NA	-2.37	-2.93			
Mean Lower Low Water	-3.41	-3.47	NA	-2.51	-3.10			

Conclusions

- Based on tidal datums, Ring Island started as an even mix of low marsh (MTL-MHW) elevations but tended toward already being in high marsh elevation (MHW-MHHW); Avalon and Fortescue started at the upper end of low marsh elevation ranges.
- In 2019, four to five years post sediment addition, Ring Island was predominantly above high marsh elevation (>MHHW); Avalon was fairly evenly split between low marsh, high marsh, and above high marsh elevations; and Fortescue was predominantly in the upper end of high marsh elevations.
- As previously noted, elevation data at Fortescue is complicated by the fact that larger-than-expected increases in elevation were measured in the control sites, suggesting that there may be errors in the data.
- One way to use the analysis of tidal datums is to consider whether or not the correct Target Ecological Elevations were used in the project design. For this project, we wanted to see if we could bring the elevation of the marsh to the upper end of the high marsh range. At Ring Island, where elevation targets were not used, we can see that the addition of a median of 0.55 feet of elevation moved the site from low marsh to above high marsh, which was perhaps too high. Raising the elevation above MHHW may explain why the site has been slower than Fortescue and Avalon to revegetate (see Section 5: Vegetation from Plot Based Monitoring). At Avalon, three out of the five placement areas had Target Ecological Elevations above MHHW and anecdotal evidence from site visits has suggested that persistent bare areas tend to correlate with the lowest or highest elevations. Fortescue targets were consistent with the upper end of the high marsh range.
- The range of elevations that fall into the high marsh tidal datums (approximately 0.5 feet) is much smaller than the range of elevations that fall into the low marsh tidal datums (generally 2-3 feet in marshes in SE New Jersey), creating some inherent challenges for using TLP techniques to reach high marsh elevations because the room for error is much smaller.

5. Vegetation from Plot Based Monitoring

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[1]The Nature Conservancy, [2]New Jersey Department of Environmental Protection

Salt marsh vegetation is the primary driver of the net increase in marsh elevation, through the trapping of sediment from the water column and the build-up of slowly decaying plant material. The re-establishment of vegetation after the placement of dredged material is necessary for project success and will also likely correspond with all other environmental monitoring metrics. Monitoring vegetation provides information about the effects of placing dredged material on a variety of stressed salt marsh vegetation communities. Elevation and tidal flooding are important determinants of vegetative community composition, and the placement of dredged material on the marsh plain will be accompanied by immediate changes in marsh elevation and the depth and duration of flooding. Dredged material composition and thickness may also affect the recovery of vegetation after placement. The goal for monitoring vegetation was to determine the response of vegetative communities to placement, identify trends in vegetative recovery and ecological uplift over time, and identify the factors influencing vegetative recovery.

Monitoring Design

Table 15. *Design and metrics used for TNC's vegetation monitoring at the Ring Island, Avalon, and Fortescue project sites. *Metrics were collected in a subset of plots only in certain years.*

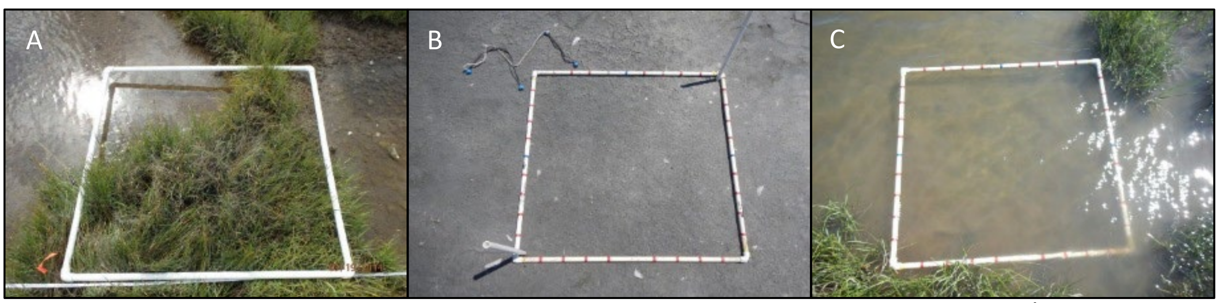
Design	Vegetation Monitoring Metrics
B-A-C-I	Species Richness and Composition
Once Annually During Peak Growing Season (July to September)	Average Stem Height of Dominant Species*
	Percent Cover by Species
	Above-Ground Biomass*
	Below-Ground Biomass*

Vegetation metrics were monitored in permanent 1m² plots annually, except during 2020 (Tables 15 and 16). Plant biomass was monitored in a 0.25m² plot adjacent to a subset of these permanent monitoring plots. Plants were identified to determine species richness, and dominant species were defined as species that covered more than 50% of the plot. Epifaunal macroinvertebrates (ribbed mussels, crabs, snails), sediment depth, and bearing capacity were also monitored within or next to these permanent vegetation plots. Spatial considerations for experimental design were site-specific and included variations in habitat types and elevation so that low marsh, high marsh, marsh plain, and pools were all represented in the data set.

Additionally, each plot was classified as one of three habitat types based on visual observation: if ≥ 50% of the plot was vegetated, it was classified as "vegetated"; if the plot was < 50% vegetated, it was classified as "bare"; if the plot was >50% standing water, it was classified as a "pool" (Figure 23A-C). During construction, some plots did not receive dredged material, and these plots were ultimately excluded from the analyses.

Table 16. *Labels used in this section and the corresponding years they signify relative to placement of dredged material.*

Label	Corresponding Year Referenced		
	Ring Island Placement	**Avalon Placement**	**Fortescue Placement**
PRE	2014	2014/15	2015
PP1	2015	2016	2016
PP2	2016	2017	2017
PP3	2017	2018	2018
PP4	2018	2019	2019
PP5	2019	NA	NA
PP6	NA	2021	2021
PP7	2021	NA	NA



Vegetated Bare Pool

Figure 23. *Photo examples of the classification of quadrats as vegetated, bare, or pool habitats.*

Results

Habitat Proportions

Ring Island

Before placement, the control and placement areas did not have a significantly different proportion of habitats (Figure 24; adjusted Fishers; $p > 0.5$). 75% of the plots in the treatment area converted from vegetated to bare in PP1. In PP7 treatment plots were beginning to show the same proportion of vegetation as control plots (Fishers; $p > 0.05$), with 75% of treatment plots vegetated in the final year. Control plots remained more highly vegetated compared to PP7 treatment plots (Fishers; $p < 0.05$).

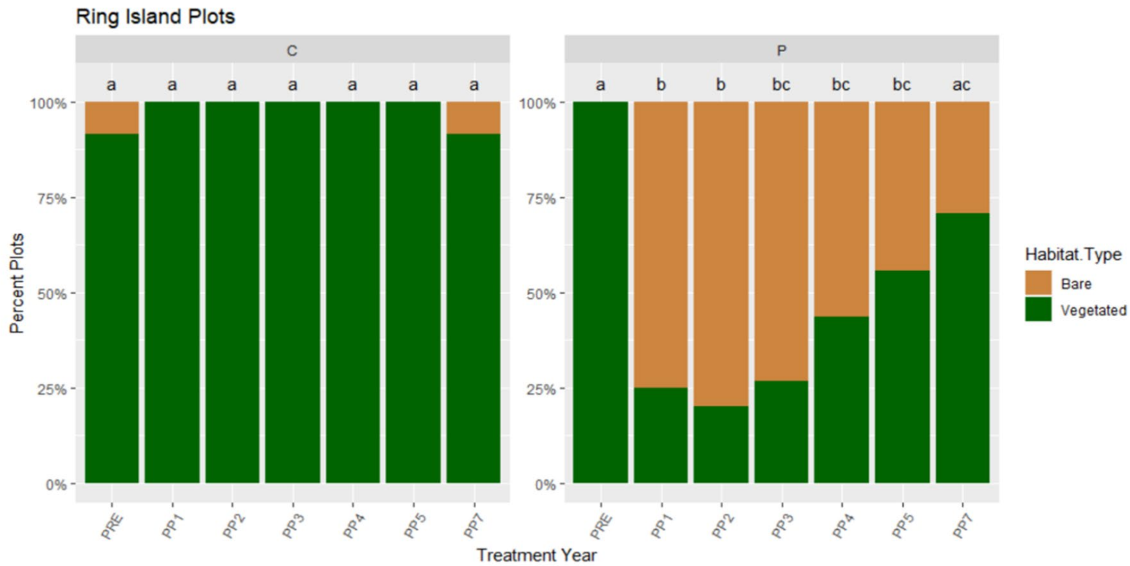


Figure 24. *Proportion of Ring Island monitoring plots categorized as bare or vegetated in control and placement areas pre- and post- placement (n = 12 for controls, n = 16 for placement, alpha = 0.05). Compact letter displays show which groups are not significantly different from one another by two-sample Wilcoxon tests.*

Avalon

Baseline conditions were different between control and treatment areas (Figure 25A; $p < 0.05$). 77% of control plots were vegetated with most of the remaining plots considered to be in pools, compared with 52% vegetated plots and 45% pool plots in the treatment area. The proportion of habitat types in the control plots did not change significantly over time (adjusted Fishers; $p > 0.05$) and changes noted between pool and bare plots have been due to the tidal stage during which the plots were sampled.

After sediment was placed on the marsh, the proportions of habitats changed significantly in treatment plots as both pool and vegetated plots converted to bare areas (Fishers; $p < 0.001$). The cover of this habitat type jumped from 2% to 80%. Over time and with re-vegetation, treatment plots are beginning to look more like control plots (Figure 25B). By PP6, treatment plots had decreased the proportion of pool plots (down to 15%) and increased the proportion of vegetated plots from baseline (up to 65%) but remained below control site proportions (Fishers; $p < 0.05$). Interestingly, the proportion of vegetated treatment plots that started as marsh platform (i.e., not a pool) increased more rapidly than in plots that started as pools (Figure 25C).

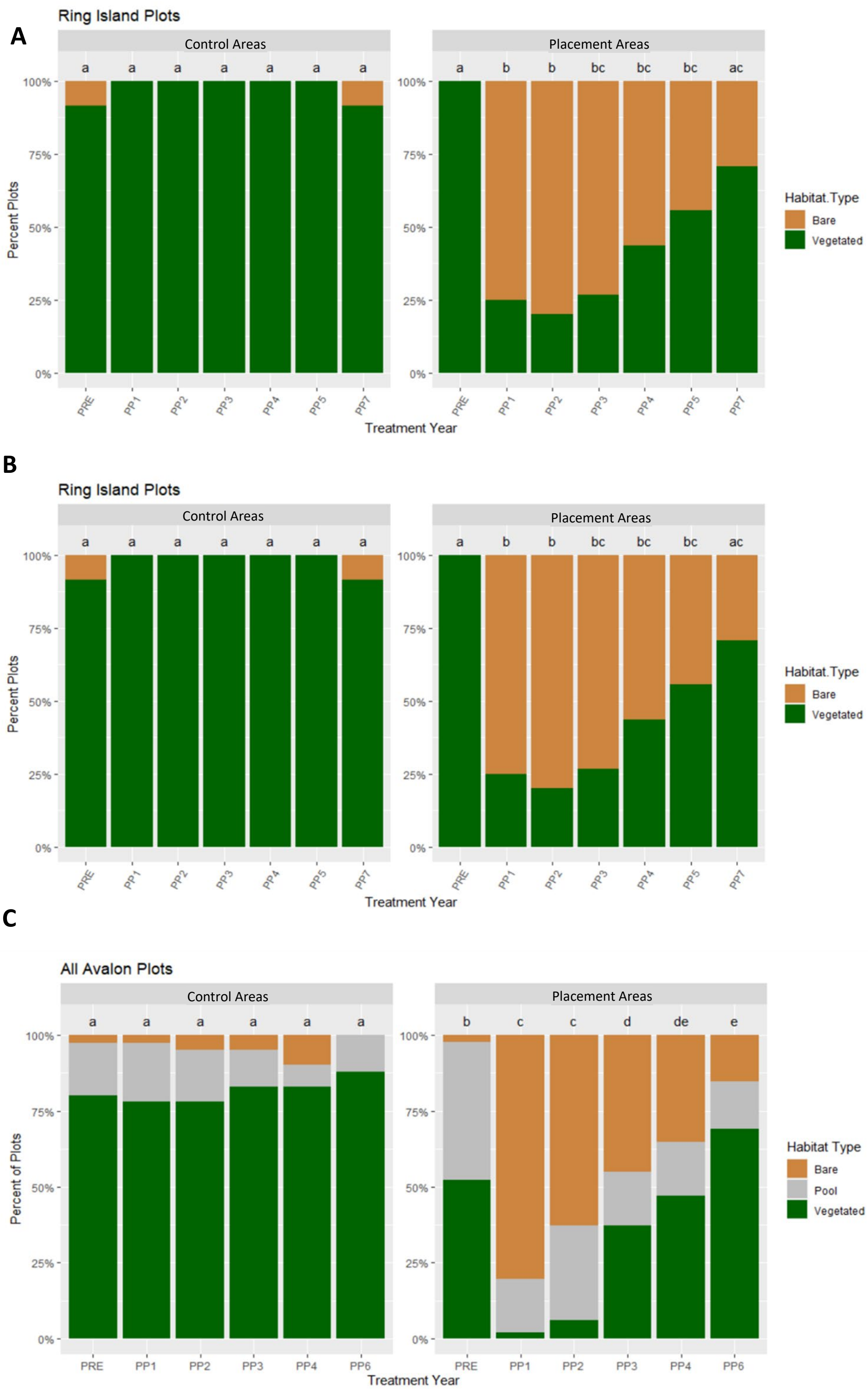


Figure 25. *Proportion of plots at Avalon that were bare, pool, or vegetated in control and placement plots. A) all plots combined, B) plots that started as marsh platform, C) plots that started at pools.*

Fortescue

Prior to placement, the control and placement areas did not have a significantly different proportion of habitats (Figure 26; Fishers; $p > 0.05$), and the proportion of habitat types in the control plots did not change significantly over time (adjusted Fishers; $p > 0.05$). After sediment was placed on the marsh, portions of habitats changed significantly in treatment plots by converting to bare areas or pools (Fishers; $p < 0.001$). Bare habitat type jumped to 84% after placement but then decreased to 0% by the final year. In PP6, 100% of the treatment plots were vegetated, as were 100% of the control plots.

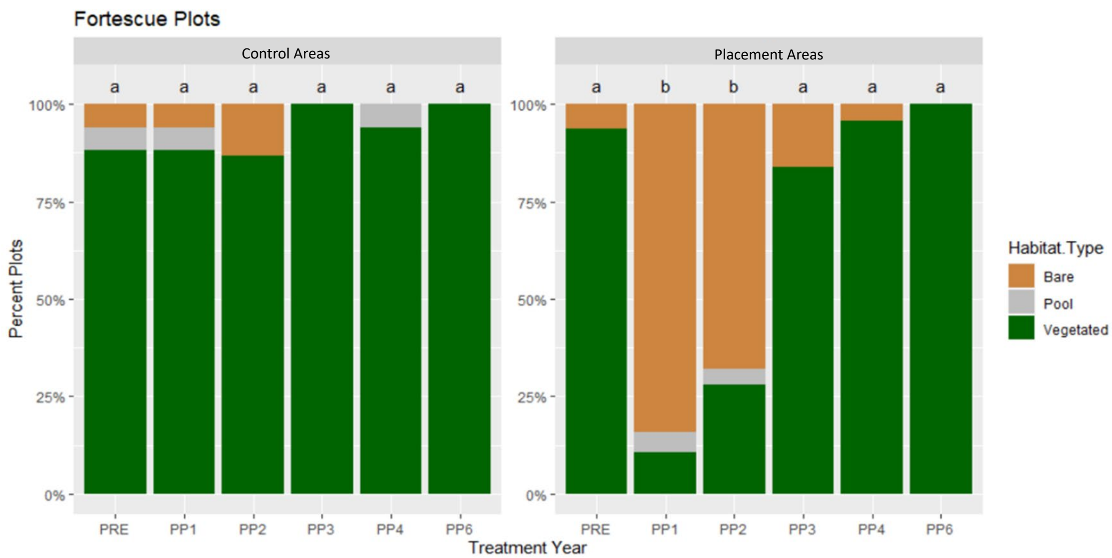


Figure 26. *Proportion of plots at Fortescue that were bare, pool, or vegetated overtime in Placement (P) and Control (C) areas.*

Vegetative Cover

Ring Island

Initial conditions between control and placement plots were not significantly different (Figure 27; Mann Whitney U; $W = 99.5$; $p > 0.05$). Control plots averaged 74% cover and treatment plots averaged 61% cover in the year before placement. Both control and treatment areas experienced a significant change in vegetation cover over time (Friedman $X^2(6) = 39.23$; $p < 0.01$ for controls, $X^2(6) = 17.16$; $p < 0.01$ for placement). In treatment areas, vegetation cover declined one-year post-placement to 20% cover and then showed some recovery in the interim. But, as of PP7, treatment plots average only 8% vegetative cover, significantly lower than baseline conditions (Wilcoxon $Z = -2.43$; adjusted $p < 0.05$). Vegetation cover in control plots significantly declined from initial conditions to an average of 30% cover in PP7 (Wilcoxon $Z = -2.81$, adjusted $p < 0.01$).

Vegetation cover at Ring Island declined immediately after placement. Since then, little vegetation has recovered in monitoring plots and levels remain lower than baseline and control conditions.

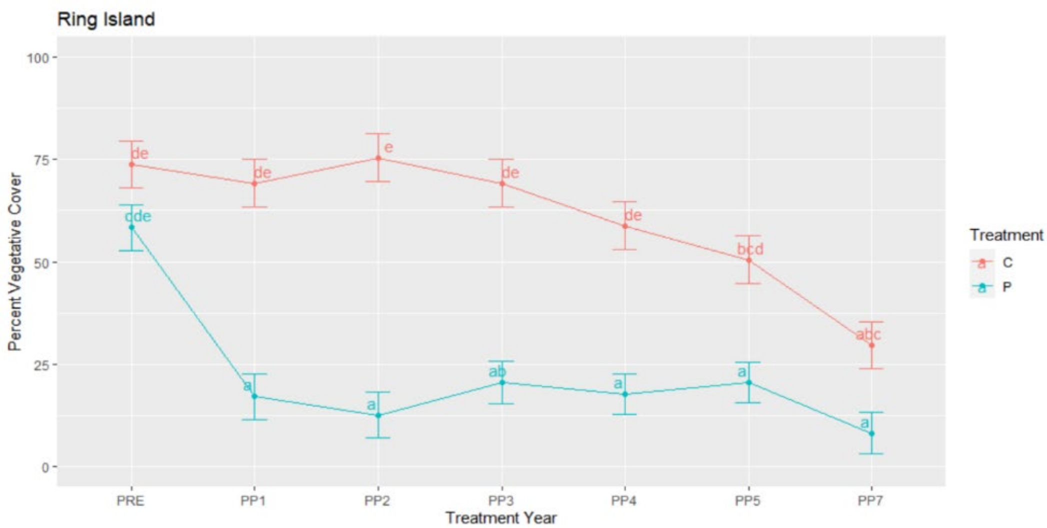


Figure 27. *Percent cover by plants at Ring Island in plots in both Control (C) and Placement Areas (P) overtime. Data presented are means ± one standard error.*

Despite the increasing trend in the proportion of plots that are vegetated, the trend in vegetation cover at Ring Island showed that the density of plants in placement areas stagnated in the seven years since placement Additionally, control site vegetation cover has deteriorated since PP2, and vegetation cover has deteriorated in the treatment plots since PP4.

Avalon

PRE placement and control sites had similar plant cover (Mann Whitney U; W = 1023.5, $p > 0.05$), and both areas experienced a significant change in vegetation cover over time (Friedman X 2(5)= 58.98; $p < 0.001$

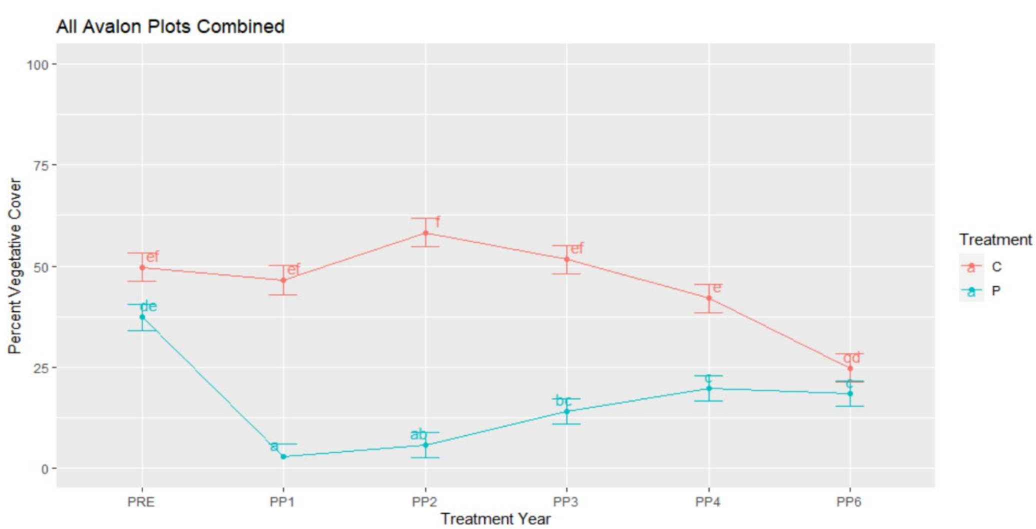


Figure 28. *Percent cover by plant at Avalon in plots in both Control (C) and Placement Areas (P) overtime. Data presented are means ± one standard error.*

for controls; $X^2(5)= 64.57$; $p < 0.001$ for placement). Large losses in vegetation cover were observed in placement PP1 plots (Wilcoxon Z = -3.9; $p < 0.001$), with vegetation cover dropping from 38% to 3.5% (Figure 28). Six years post-placement, the difference in vegetation cover was not significant between placement plots and control (Mann Whitney U W = 1269.5; $p > 0.05$), with average vegetation cover at 25% and 20%, respectively. Control plot averages, however, are significantly lower than baseline conditions in PP6, down from 50% cover in PRE conditions (Wilcoxon Z = -3.34; $p < 0.001$). Vegetation cover in the placement plots at Avalon declined immediately following sediment placement. After six years of recovery, vegetation cover in placement plots was not different from vegetation cover in control plots and baseline conditions. Overall, these results show large losses in vegetation cover at Avalon in placement areas one-year post-placement followed by recovery in the treatment areas to the same level of vegetation cover as the control areas, though not to baseline, and have not demonstrated uplift.

Fortescue

Placement and control plots did not initially differ in vegetation cover before dredged material was placed on the marsh (Figure 29; Mann Whitney U $W = 133$; $p > 0.05$), though vegetation cover was affected by time in both the placement and control areas (Friedman $X^2(5) = 17.5$; *$p < 0.01$ for controls,* $X^2(5) = 40.5$, *$p < 0.0001$ for treatment)*. Vegetation cover in PP1 plots was significantly reduced in placement areas from 51% to 11% (Wilcoxon $Z = -2.97$; $p < 0.01$).

By PP3, vegetation cover in placement plots was similar to cover in control plots (Mann Whitney U, $p > 0.05$) and was not statistically different from baseline conditions in placement plots (Wilcoxon $Z = -1.14$; $p > 0.05$). Average vegetation cover in both treatment and control plots declined from PP4 to PP6. In placement plots, vegetation cover became significantly lower in year 6 than in initial baseline conditions (Wilcoxon $Z = -2.35$; $p < 0.05$). Control plots declined from 61% to 30% average vegetation cover.

Vegetation cover at Fortescue declined immediately after placement. Three years after placement, vegetation cover was not different from baseline or control conditions. However, the sixth-year

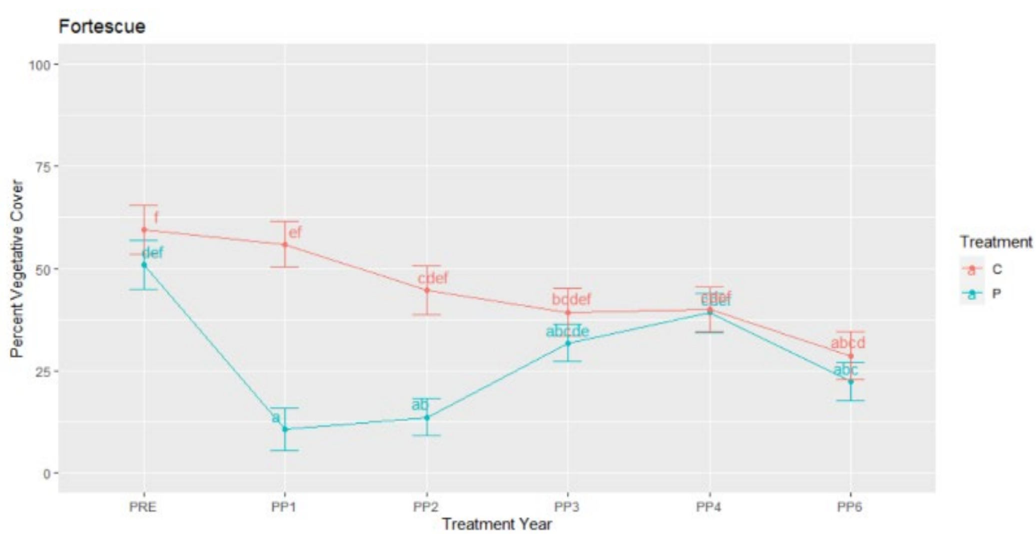


Figure 29. *Percent cover by plants at Fortescue in Control (C) and Placement Areas (P) overtime. Data presented are means ± one standard error.*

vegetation cover in both control and treatment areas had declined. While control and treatment percent cover levels are not significantly different from one another in year six (Mann Whitney U $W = 216$; $p > 0.05$), treatment plots display lower vegetation cover than their baseline conditions.

Overall, these results show that vegetation cover significantly decreased in placement areas one year after placement. Placement plot cover increased in the years after placement, but vegetation cover remains significantly lower than baseline conditions. While placement plot vegetation cover does not differ significantly from current control plot vegetation cover, control plot vegetation cover has slowly declined throughout the study.

Species Richness and Composition

Treatment plots primarily revegetated with *Spartina alterniflora*, a low marsh species, after sediment placement despite our initial goal of facilitating high marsh species habitat (characterized by *Spartina patens*). Richness remained low at all sites in both control and treatment plots in all years with individual plots generally containing one or two species and no more than four, as is typical of salt marsh islands (Niering and Warren 1980).

Despite low levels of native species richness initially, there was a significant decrease in species richness in treatment PP1 plots (Tukey; $p < 0.05$) at all three sites. Treatment plots at all sites regained pre-placement levels of native species richness within the timeframe of the study. Avalon platform and pool plots attained former species richness in PP3 (Tukey; platform $p > 0.05$, pool $p > 0.05$), Fortescue attained baseline species richness by PP2 (Tukey; $p > 0.05$), and Ring Island achieved it in PP3 (Tukey; $p > 0.05$).

Examination of vegetation species composition across all sites is another important measure of restoration success. Notable shifts were observed in native vegetation species at Avalon as plots re-established and became fully vegetated, as *Salicornia spp.* And *Distichlis spicata* briefly dominated some plots before *S. alterniflora* was established. *Phragmites australis* appeared in two study plots at Fortescue nearest to a sand dune restoration project where *P. australis* existed before restoration. The two plots that are dominated by *P. australis* are directly adjacent to the dunes, and there is no sign of *P. australis* spreading to the interior of the marsh as of PP6. Ring Island saw little vegetation recovery and, therefore, little change in species composition except for one *D. spicata*-dominated plot in the third year post-placement.

Ring Island

A mixed effects ANOVA showed that vegetative species richness was significantly affected by the interaction between treatment and time (Figure 30; $p < 0.001$), although changes were small. Before placement species, richness was not significantly different between control and placement areas (Tukey; $p > 0.05$). Within the placement area, species richness significantly declined post-placement (Tukey; $p < 0.01$) from an average of fewer than two species per plot to an average of less than one per plot. Since PP3, species richness has not been significantly different from baseline (PRE) condition, and since PP4 treatment plot richness has not varied significantly from control plot richness (Tukey; $p > 0.05$). Within the control area, there has been no significant change in richness over the seven years. Overall, these results show a significant decrease in Ring Island species richness in placement areas from PRE to PP1, with an increase each year since placement, however, richness remained low in both areas in all years, with individual plots containing no more than three species.

The composition of dominant species in Ring Island plots did not shift after placement in treatment plots. *Spartina alterniflora* was the only dominant vegetation in control plots and was the only dominant vegetation in treatment plots except for one plot in PP3 that was dominated by *Distichlis spicata* (Figure 31).

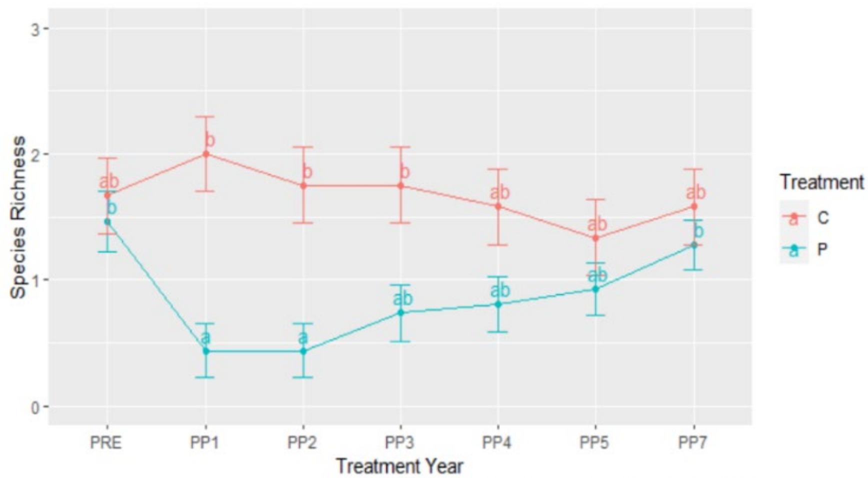


Figure 30. *Species richness in Ring Island plots over time in Control (C) and Placement Areas (P) overtime. Data presented are means ± one standard error.*

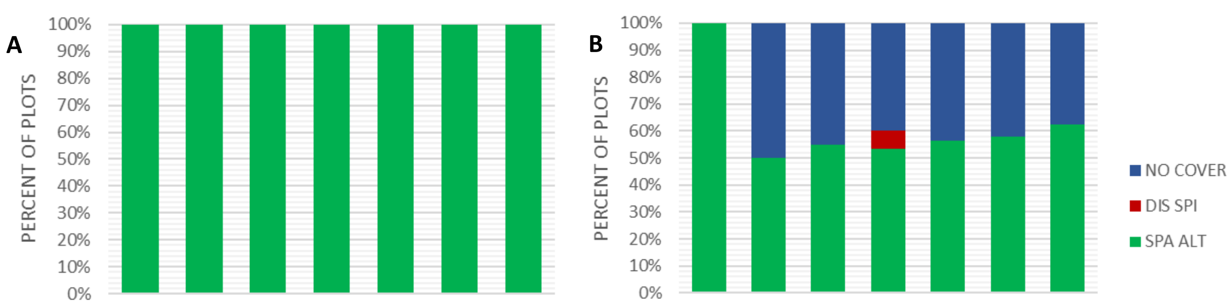


Figure 31*. Species dominance of Ring Island A) control and B) treatment plots by year. DIS SPI = Distichlis spicata; SPA ALT = Spartina alterniflora*

Avalon

There was a significant decrease in species richness at Avalon in treatment plots that started as marsh platform one-year post-placement (Figure 32; Tukey; $p < 0.001$). Both plots that started as marsh platform and plots that began as pools displayed significant recovery in species richness (Tukey; platform $p < 0.05$, pool $p < 0.001$), attaining the same level of richness as baseline conditions by PP6 (Tukey; platform $p > 0.05$, pool $p > 0.05$).

90% of control and treatment plots were dominated by short-form *Spartina alterniflora* during baseline sampling (Figure 33). This dominance remained in the control plots but changed over time in treatment plots. For treatment plots that started as marsh platform, *Salicornia* species became dominant in many plots in the first-year post-placement. In the second-year post-placement, *Distichlis spicata* became dominant in some treatment platform plots. There remained one *Distichlis spicata*- and one *Salicornia* species-dominated plot in the treatment area in PP6, with the rest of the plots containing vegetation dominated by *Spartina alterniflora*. In Avalon plots that started as pools, some *Salicornia sp.* Dominated plots appeared in PP1 and PP2, but otherwise, all plots with vegetation were dominated by *Spartina alterniflora* (Figure 33).

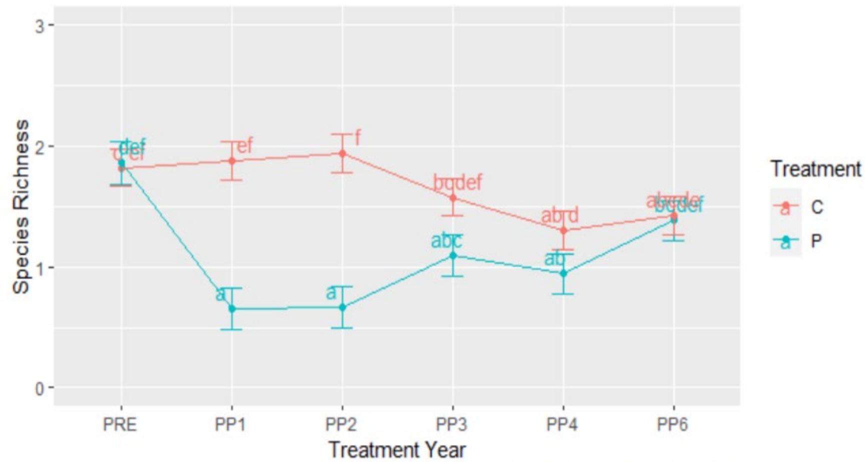


Figure 32. *Species richness in Avalon platform plots in Control (C) and Placement Areas (P) overtime. Data presented are means ± one standard error.*

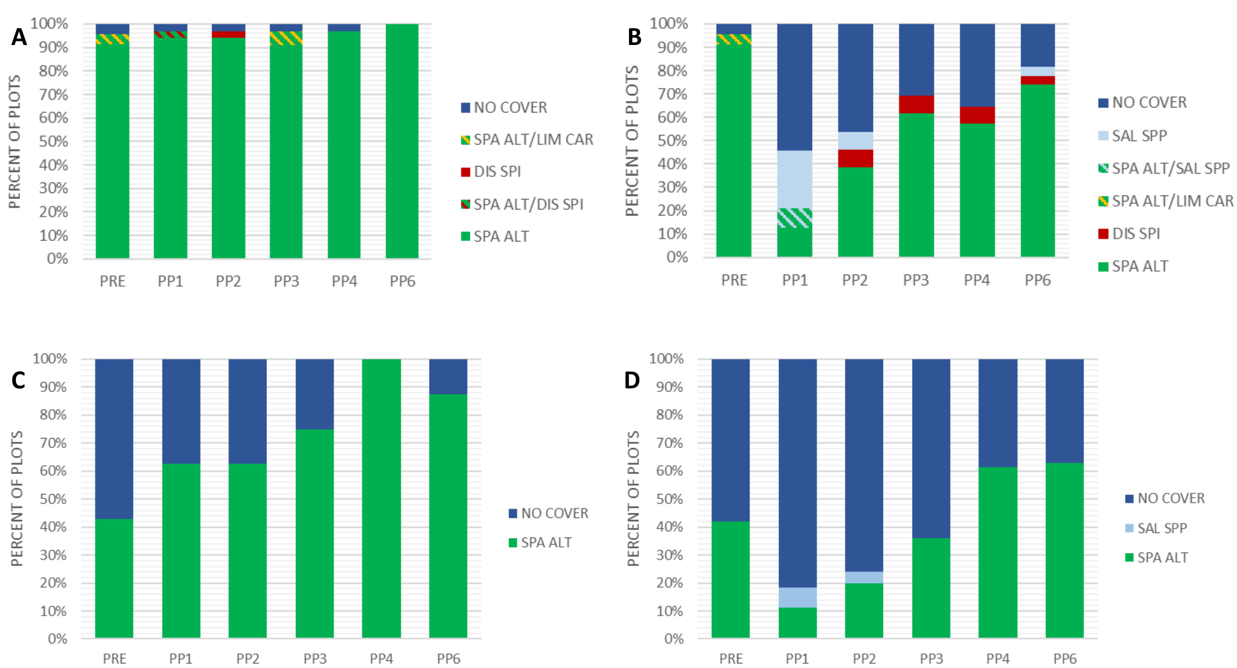


Figure 33. *Species dominance in Avalon A) platform control, B) platform treatment, C) pool control, and D) pool treatment plots by year. SPA ALT = Spartina alterniflora; LIM CAR = Limonium carolinianum; DIS SPI = Distichlis spicata; SAL SPP = Salicornia spp.*

Fortescue

A mixed effects ANOVA showed that vegetative species richness at Fortescue was significantly affected by the interaction between treatment and time ($p < 0.001$). Prior to placement, species richness was not significantly different between control and placement areas (Tukey; $p > 0.05$). Within the placement area, species richness significantly declined one-year post-placement (Figure 34; Tukey; p < 0.001) and then significantly increased from PP1 to PP2 (Tukey; $p < 0.05$), and from PP2 onwards species richness was no longer significantly different from baseline or control conditions. Within the control area, there has been no significant change in richness over time. Overall, these results show a significant decrease in species richness in placement areas from PRE to PP1, with recovery to baseline and control conditions by the second-year post-placement. Richness remained low in both areas with individual plots containing no more than five vegetative species.

The composition of dominant species in Fortescue plots shifted after placement in treatment plots (Figure 35). Most PRE plots were dominated by *Spartina alterniflora* with some *Spartina patens*. PP1 treatment plots were still largely dominated by *Spartina alterniflora* with one *Spartina patens*-dominated and one *Distichlis spicata*-dominated plot. In PP2, *Phragmites australis* appeared in two treatment plots. One *Salicornia* species and *Spartina alterniflora*-dominated plot appeared in the treatment area in PP4. The majority of the plots in PP6 were dominated by *Spartina alterniflora*, with *Phragmites australis, Spartina patens*, and *Distichlis spicata* plots present as well. In control plots at Fortescue, plots were roughly 60% dominated by *Spartina alterniflora* and 40% dominated by *Spartina patens*, with *Distichlis spicata* present in PRE, PP1, and PP4.

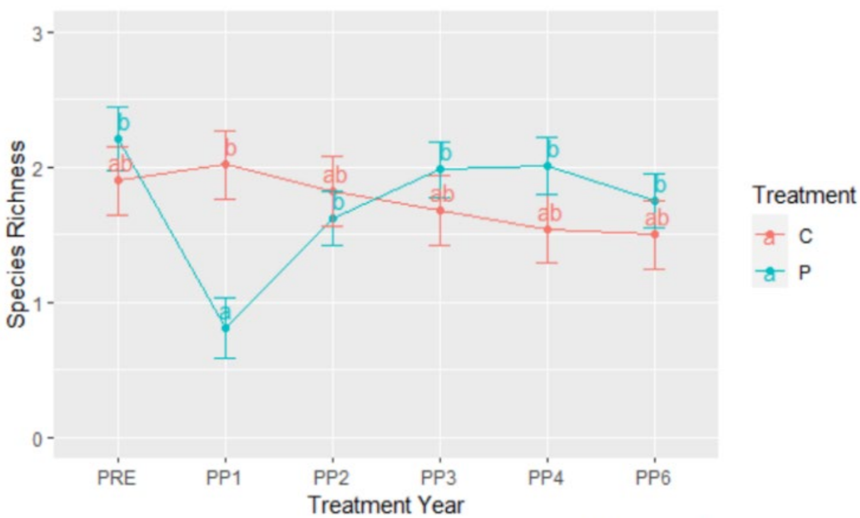


Figure 34. *Species richness in Fortescue plots in Control (C) and Placement Areas (P) overtime. Data presented are means ± one standard error.*

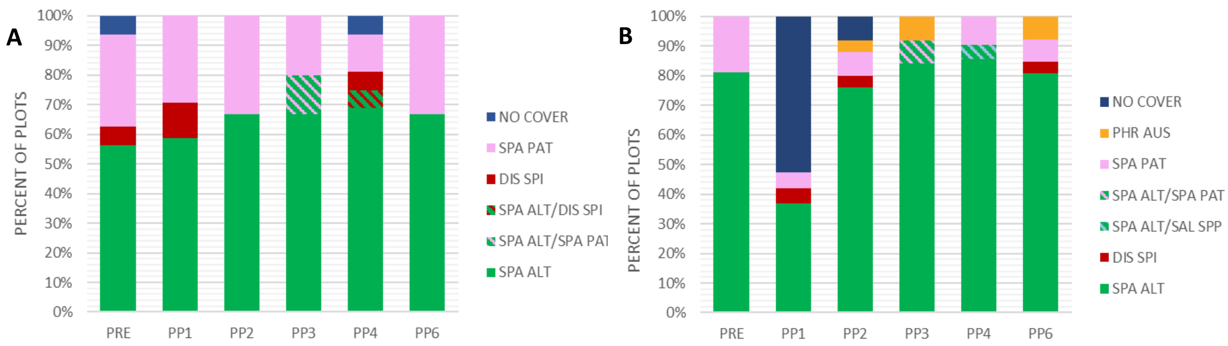


Figure 35. *Species dominance in Fortescue A) control and B) treatment plots by year. SPA ALT = Spartina alterniflora; LIM CAR = Limonium carolinianum; DIS SPI = Distichlis spicata; SAL SPP = Salicornia spp.; PHR AUS = Phragmites australis*

Multi-metric Analysis

Using program R (v. 4.2.2), robust linear regressions were performed for all possible nested models with predictor variables including placement depth (cm), elevation (ft. NAVD 88), distance to nearest tidal water body (water distance, m), distance to established vegetation (m), and penetration depth (cm). The response variables were vegetation cover (%) and stem height (cm) in permanent monitoring plots that had no vegetation after sediment placement. The sites studied were Ring Island, Avalon, and Fortescue. The Avalon dataset was separated into pool plot data and marsh platform plot data. Due to high correlation between vegetation cover and stem height, separate models were run for vegetation cover and stem height. Data was further divided by year, and models were created for PP3, PP5, and PP7 for Ring Island and PP2, PP4, and PP6 for Avalon and Fortescue (i.e., 2017, 2019, and 2021). Once the robust linear regressions were performed using the 'rlm()' function from the package 'MASS' (v. 7.3-58.1), Akaike's Information Criteria (AIC) values were calculated for each model using the 'stats' (v. 4.2.2) package to determine which model had the best fit (represented as a lower AIC value). For models that had the lowest AIC value and contained more than one variable, Variance Inflation Factors (VIFs) were calculated for each parameter to determine the extent of multicollinearity within the model using the package 'car' (v. 3.1-1). VIFs close to 1 were considered to represent non-collinearity, while values above 5 were considered to represent moderate to high collinearity. For all models with the lowest AIC value, *p*-values were determined using the package 'sfsmisc' (v. 1.1-14), and variable relationships were considered significant for value less than the alpha of 0.05.

Results

The VIFs of all linear regressions with multiple variables were found to be ≤ 3, suggesting minimal collinearity was found within selected models.

Ring Island

Vegetation Cover

In PP3, vegetation cover was not significantly related to any predictor variables measured (Table 17). However, in PP5, increased vegetation cover was significantly associated with thinner placement of sediment (slope estimate = -2.87, t = -3.04, $p < 0.05$). This relationship dissipated by PP7, as no predictor variables were found to be significantly associated with vegetation cover.

Table 17. *Robust linear regression results for Ring Island vegetation cover and stem heights in PP3 (2017), PP5 (2019), and PP7 (2021). Only significant parameters from best fit models are shown with arrows representing the direction of the regression slope estimates. Red downward arrows represent a significant negative correlation. Significance level is shown as inclusion of asterisks. Significance level: ' ' = no significance; *, p < 0.05; **, p < 0.01; ***, p < 0.001.*

Response Variable	Predictor Variable	PP3	PP5	PP7
Ring Island Vegetation Cover	*Placement Depth*		↓*	
	Elevation			
	Water Distance			
	Vegetation Distance			
	Penetration Depth			
Ring Island Stem Heights	*Placement Depth*			↓*
	Elevation	↓**	↓***	
	Water Distance	↓**	↓***	
	Vegetation Distance	↓**	↓***	
	Penetration Depth			

Stem Height

A significant increase in stem height was found in PP3 where elevation (slope estimate = -40.7, t = -7.67, $p < 0.01$), water distance (slope estimate = -0.85, t = -7.87, $p < 0.01$), and vegetation distance (slope estimate = -8.63, t = -7.22, $p < 0.01$) were smaller. Stem height remained significantly correlated with decreases in the same predictor variables in PP5 (elevation: slope estimate = -47.1, t = -7.44, $p < 0.001$; water distance: slope estimate = -0.71, t = -6.90, $p < 0.001$; vegetation distance: slope estimate = -3.93, t = -4.67, $p < 0.001$). However, only reduced placement depth was significantly correlated with stem height by PP7 (slope estimate = -0.86, t = -2.43, $p < 0.05$).

Overall Trends

Lack of correlation between vegetation cover and the predictor variables in PP2 could be due to the overall low percent cover of vegetation in the sampled plots during that time period (Figure 27). Vegetation cover at Ring Island could not be consistently predicted by any of the measured variables, suggesting that there are other unmeasured parameters that may be driving revegetation at this site. However, stem height was initially higher in areas of lower elevation and when closer to established vegetation and tidal water bodies. That difference was no longer observed in PP7, and thinner sediment placement was correlated with taller plants instead.

Avalon Pool Plots

Vegetation Cover

Within Avalon pool plots, changes in vegetation cover were not correlated with any of the measured predictor variables in PP2 (Table 18), similar to Ring Island (Table 17). Like Ring Island, lack of correlation between vegetation cover and the predictor variables in PP2 could be due to the overall low percent cover of vegetation in the sampled plots during that time period. However, by PP4, increased vegetation cover was found to be significantly correlated with decreased distance to other established vegetation (slope estimate = -2.67, t = -2.61, $p < 0.05$). By PP6, increased vegetation cover was significantly related to not only decreased vegetation distance (slope estimate = -3.52, t = -3.38, $p < 0.05$), but also decreased elevation (slope estimate = -29.5, t = -2.60, $p < 0.05$) and decreased penetration depth (slope estimate = -2.54, t = -2.78, $p < 0.01$).

Table 18. *Robust linear regression results for Avalon pool plot vegetation cover and stem heights in PP2 (2017), PP4 (2019), and PP6 (2021). Only significant parameters from best fit models are shown with arrows representing the direction of the regression slope estimates. Red downward arrows represent a significant negative correlation. Significance level is shown as inclusion of asterisks. Significance level: ' ' = no significance; *, p < 0.05; **, p < 0.01; ***, p < 0.001.*

Response Variable	Predictor Variable	PP2	PP4	PP6
Avalon Pool Plot Vegetation Cover	*Placement Depth*			
	Elevation			↓*
	Water Distance			
	Vegetation Distance		↓*	↓*
	Penetration Depth			↓**
Avalon Pool Plot Stem Heights	*Placement Depth*			
	Elevation			
	Water Distance			
	Vegetation Distance		↓*	↓***
	Penetration Depth			

Stem Heights

Similar to vegetation cover, PP2 stem heights were not associated with any predictor variables, but measurements from PP4 and PP6 demonstrate that plants were taller when in closer proximity to established vegetation communities (PP4: slope estimate = -2.66, t = -3.96, $p < 0.001$; PP6: slope estimate = -2.61, t = -4.22, $p < 0.001$).

Overall Trends

These results demonstrate that vegetation re-establishes and is taller in areas that are in closer proximity to existing vegetation in areas that started as unvegetated pools. Interestingly, reduced penetration depth was associated with an increase in vegetation cover in PP6, which suggests that firmer TLP sediments in former pool plots may have improved restoration results. (Figure 28C).

Avalon Platform Plots

Vegetation Cover

Increases in vegetation cover in PP2 were significantly associated with decreasing distance from nearby waterbodies (slope estimate = -0.28, t = -2.50, $p < 0.05$; Table 19). However, neither PP4 nor PP6 vegetation cover values were significantly related to any of the measured predictor variables.

Stem Heights

Similar to vegetation cover trends in PP2, stem heights of vegetation in platform plots increased with decreasing distance to the nearest waterbody (slope estimate = -0.36, t = -2.65, $p < 0.05$). However, stem heights were additionally found to increase with increased elevation (slope estimate = 21.3, t = 2.10, $p < 0.05$). In PP4, decreasing distance to the nearest established vegetation community was found to be the main predictor of stem height (slope estimate = -3.65, t = -2.61, $p < 0.05$). By PP6, both elevation (slope estimate = 33.3, t = 3.15, $p < 0.01$) and penetration depth (slope estimate = 8.77, t = 3.40, $p < 0.05$) were positively associated with stem height. Decreasing distance to the nearest established vegetation community was additionally found to be significantly correlated with increased stem height (slope estimate = -5.30, t = -2.69, $p < 0.05$).

Table 19. *Robust linear regression results for Avalon platform plot vegetation cover and stem heights in PP2 (2017), PP4 (2019), and PP6 (2021). Only significant parameters from best fit models are shown with arrows representing the direction of the regression slope estimates. Red downward arrows represent a significant negative correlation, while green upward arrows represent a significant positive correlation. Significance level is shown as inclusion of asterisks. Significance level: ' ' = no significance; *, p < 0.05; **, p < 0.01; ***, p < 0.001.*

Response Variable	Predictor Variable	PP2	PP4	PP6
Avalon Platform Plot Vegetation Cover	*Placement Depth*			
	Elevation			
	Water Distance	↓*		
	Vegetation Distance			
	Penetration Depth			
Avalon Platform Plot Stem Heights	*Placement Depth*			
	Elevation	↑*		↑**
	Water Distance	↓*		
	Vegetation Distance		↓*	↓*
	Penetration Depth			↑*

Overall Trends

Vegetation cover could not be consistently predicted by any measured variables, suggesting that different forces are acting on the marsh platform of Avalon compared to the pools. Stem heights were overall associated with a decrease in elevation and an increase proximity to established vegetation communities. in PP6, penetration depth was also associated with taller vegetation.

Fortescue

Vegetation Cover

In PP2, no predictor variables were found to be associated with vegetation cover changes (Table 20). In PP4, both water distance (slope estimate = 0.50, t = 4.41, $p < 0.001$) and vegetation distance (slope estimate = -50.1, t = -2.72, $p < 0.01$) were shown to be positively and negatively correlated with vegetation cover, respectively. These relationships were not found in PP6.

Stem Height

Stem height was found to be significantly higher with greater penetration depth in PP2. However, in both PP4 and PP6, only elevation was found to be negatively correlated with stem heights (PP4: slope estimate = -58.5, t = -3.73, $p < 0.01$; PP6: slope estimate = -29.0, t = -4.26, $p < 0.001$).

Overall Trends

Vegetation cover could not be consistently predicted by any measured variables, suggesting that different forces are acting on the marsh platform at Fortescue. Much of the revegetation occurred between PP2 and PP6, suggesting that the significant relationship between vegetation cover and proximity to water and existing vegetation was important at Fortescue. By PP6 all plots had at least some vegetation, making

*Table 20. Robust linear regression results for Fortescue vegetation cover and stem heights in PP2 (2017), PP4 (2019), and PP6 (2021). Only significant parameters from best fit models are shown with arrows representing the direction of the regression slope estimates. Red downward arrows represent a significant negative correlation, while green upward arrows represent a significant positive correlation. Significance level is shown as inclusion of asterisks. Significance level: ' ' = no significance; *, p < 0.05; **, p < 0.01; ***, p < 0.001.*

Response Variable	Predictor Variable	PP2	PP4	PP6
Fortescue Vegetation Cover	*Placement Depth*			
	Elevation			
	Water Distance		↑***	
	Vegetation Distance		↓**	
	Penetration Depth			
Fortescue Stem Heights	*Placement Depth*			
	Elevation		↓**	↓***
	Water Distance			
	Vegetation Distance			
	Penetration Depth	↑*		

proximity to existing vegetation 0 m for all plots. Only stem heights were found to be more consistently correlated with elevation in later years of monitoring. Similar to Ring Island (Table 17), but unlike Avalon (Table 18 & 19), lower elevation resulted in taller stems.

Trends of All Sites

Overall, higher vegetative cover was most often associated with closer proximity to existing vegetation. This tracks with the observation made at all three sites that vegetation spread from existing vegetation, either from the edges of placement or from the few clumps of plantings that thrived within the sites.

Stem heights were most closely associated with lower elevation and closer proximity to tidal water bodies and existing vegetation. Tall-form *Spartina alterniflora* plants is known to grow in lower elevations and closer proximity to creeks (Howes et al. 1986, Bertness and Ellison 1987; Tyler and Zieman 1999). It is less clear why there would be a strong relationship between plant height and proximity to other plants except that vegetation is likely to inhabit areas with fewer environmental stressors and those stressors can also stunt *S. alterniflora* plants.

These findings suggest that having smaller placement areas or placement areas with a higher edge to interior ratio may decrease vegetation recovery time.

Conclusions

- A look at habitat proportions (vegetated, pool, and bare) over time was useful for a general understanding of how the sites changed. All sites had a large initial conversion of vegetated plots to unvegetated plots and then saw a steady shift back to high proportions of vegetated plots. By 2021: 1) The proportion of vegetated plots at Ring Island was lower than in control sites and in baseline conditions, but there is an increasing trend over time. 2) At Avalon, there was an increase in vegetated plots from the baseline, in part because some pool plots became vegetated, but remained lower than in control sites, but there is an increasing trend over time. 3) Fortescue had an initial decrease of 80% of its vegetated plots but was back up to 100% by 2021.

- Percent cover is a density estimate that gives a closer look at how well plots are revegetating. All sites had very low percent cover in the first growing season post placement (3-11%). Since then, the sites have had highly variable recovery and none of the sites show an uplift from baseline conditions. There does not appear to be a set of environmental variables (at least among those evaluated) that consistently correlated with the percent vegetation cover recovery at all three sites. Therefore, site-specific factors appear to be more important than overall wetlands ecosystem factors.
- Despite the increasing trend in the proportion of plots that are vegetated at Ring Island, the trend in vegetation cover showed that the density of plants in placement areas stagnated in the seven years since placement and has not shown an uplift compared to baseline or control site conditions. At Avalon, after six years of recovery, vegetation cover in placement plots increased and was no longer different from vegetation cover in control plots or baseline conditions. At Fortescue, placement plot cover increased in the years after placement and is no longer different from control sites, but vegetation cover remained significantly lower than baseline conditions.
- Percent cover in control sites at all three projects declined over time.
- Correlations between percent cover and other environmental variables can help explain why the sites had different plant recovery rates and suggest improvements for planning future projects.
- The differences in recovery between the three sites can be attributed to a variety of potential factors including differences in how the projects were constructed and the environmental characteristics of the sites. We found three main driving forces affecting revegetation rates: 1) Short-term vegetation recovery was higher in sites that had less sediment placement and lower elevations; 2) vegetation was denser in areas near existing vegetation, suggesting that higher edge-to-placement ratios may speed up the recovery rate; and 3) while final elevation is important in long-term plant recovery (as evidenced at Ring Island), placement depth was not (as evidenced by vegetation growth in Avalon's pool plots).
- All three project sites experienced an initial decline in plant species richness. The decline was minimal due to the inherent low overall species richness (1-3 species) at the sites. It is encouraging that no native species were completely lost from the project sites, other than any subaquatic vegetation at Avalon due to the filling of pools.
- Treatment plots primarily revegetated with *Spartina alterniflora*, a low marsh species, after sediment placement despite our initial goal of facilitating high marsh species habitat (characterized by *Spartina patens*).
- This study documents a slight shift in species composition over time at the three sites after sediment addition, with placement plots being initially dominated by early colonizers like *Distichlis spicata* and *Salicornia* sp., and subsequently dominated by *Spartina alterniflora*.
- The invasive *Phragmites australis* was only found in plots located near the footprint of the constructed Fortescue dune where the elevation and hydrology are supportive of this species. *Phragmites australis* colonization of placement areas has been limited to only two treatment plots; however, as it is present within the Fortescue Dune and Ring Island ENH, it is being closely monitored. When *P. australis* is detected, it is treated with herbicide according to an adaptive management plan.
- These sites should continue to be monitored to determine the amount of time needed for all three sites to be enhanced beyond their baseline and control conditions and to further understand the

major factors influencing vegetation recovery.

- Based on these results, we can answer the following monitoring questions: 1) Does the marsh ecosystem recover or show uplift within two to three years of dredged material placement? (And the related, "How long does it take for the marsh to recover and achieve uplift?"); 2) Did differences in structural factors correlate with recovery and uplift?; and 3) What parameters should be included in a marsh enhancement monitoring program, and how long should the post-placement program be conducted?
    - 1) Significant uplift of the ecosystems was not shown within three years post placement at any of the sites. Ring Island vegetation cover was decreased significantly by dredged sediment placement. The percentage of cover did not significantly increase within two to three years of placement. Species richness was found to be insignificantly different from PRE conditions, although it remained low overall after three years. Avalon vegetation cover was found to be insignificantly different after three years compared to PRE conditions; however, platform plots were still much lower in coverage than PRE conditions. Pool plots were found to be similar, but no uplift was found after a few years post-placement. Species richness remained significantly lower than PRE conditions by PP3. Although the percent cover of vegetation did increase within three years after placement at Fortescue, the percent cover remained insignificantly different from PRE conditions. Species richness was found to be similar by the third year post-placement compared to PRE conditions, but it did not exceed previous conditions. Based on all years of vegetation monitoring, we can conclude that significant uplift has not occurred within six to seven years post placement; however, several parameters are on an upward trend. Significant uplift may take a decade or longer to be seen.
    - 2) At Ring Island, no variables were significantly correlated with vegetation cover due to a lack of vegetative recovery for the first few years. However, placement depths greater than 12 cm deep resulted in < 20% vegetation cover. In PP5, increased vegetation cover was associated with thinner placement, lower elevations, and closer proximity to existing vegetation. In PP7, increased cover remained associated with thinner placement and lower elevations. At Avalon, from 2016 through 2019, no variables were significantly correlated with vegetation cover in plots that started as marsh platform. By 2021 (PP6), plots that started as platforms compared to plots that started as pools had greater cover the closer they were to existing vegetation and tidal water bodies. Vegetation cover also increased with greater sediment placement depths and where the soil was firmer. At Fortescue, in PP2, thicker sediment was significantly correlated with lower vegetation cover. That trend disappeared in PP3, suggesting that vegetation can recover in areas of deeper sediment placement.
    - 3) Based on our findings, we suggest increasing the frequency of monitoring and expanding the monitoring area beyond the placement and control areas. We were able to determine valuable metrics as predictors of TLP success, with differences between vegetative cover and stem height response. Increase in vegetation cover was most closely associated with closer proximity to nearby established vegetation, while stem height increases were most closely related to lower elevation, closer proximity to tidal water

bodies, and reduced distance to nearby established vegetation. Other predictors, such as placement depth and penetration depth were not found to be consistently related to either vegetation cover or stem height. Although we were able to determine valuable metrics, we have found that there are further environmental effects that were not captured within our monitoring schema. Monitoring outside the typical study area may provide context for general environmental effects, such as water table elevation shifts, nutrient concentrations in runoff, and microbial community shifts. Additionally, post-placement monitoring timing should strive towards at least a decade due to the slow pace of recovery after sediment placement.

6. GIS Habitat Characterization Analysis

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As noted in Section 5, vegetation is an important component in the maintenance of long-term salt marsh health. In addition to the permanent vegetation plots, aerial imagery was used to evaluate overall shifts in habitat cover to monitor the sites on a landscape level. Although vegetation plots offer a more detailed evaluation of plant species and vigor, they do not capture the large-scale changes resulting from TLP. Additionally, habitat cover allows for the evaluation of hydrologic and topographic effects on vegetation cover. Classification of aerial imagery of the projects can demonstrate the direct effects of landscape changes on the ground cover type. Object-based image analysis (OBIA) is a method of classification that uses machine learning to group similar pixels together and treat these groups as objects rather than evaluating the image on a pixel-by-pixel basis. Important metrics, such as the rate of vegetation recolonization and percent cover of vegetation, or other classification types can be evaluated using OBIA of aerial imagery collected at key time points during the project.

Monitoring Design

Object-Based Image Analysis

An object-based mapping workflow was utilized to generate the landscape data used in this project. Object-based mapping offers a powerful and efficient means of classifying imagery by grouping the pixels of imagery into objects rather than analyzing the image on a pixel-by-pixel basis (Addink and Coillie, 2010). Segmentation and training sample data are two key components of the workflow for this analysis. Segmentation groups the pixels into simplified objects based on spectral detail, shape, and size of the object neighborhood (Addink and Coillie, 2010). Alternatively, pixel-based classifiers classify pixels based on spectral detail and texture (Congalton et al., 2017). The object-based method was preferred over the pixel-based method because of the high-resolution imagery and general classes used to create the landscape datasets. The segmented image was used as the basis for training sample data to assign labels (or classes) to these objects. This served as a type of supervised classification scheme (Congalton et al., 2017). The labels used for the classification schema included “Non-Veg,” “Vegetation,” and “Water.” The resulting datasets were put through a machine learning algorithm in ESRI’s ArcGIS Pro v2.6 and 2.7.3 (ESRI, 2020 and 2021) to produce a classified image of the marsh.

For this analysis, nine different sets of imagery were processed and assessed. Aerial imagery was obtained for each control and impact site in Avalon, Ring Island, and Fortescue. NJDEP drone imagery (captured using a DJI Phantom 4 PRO quadcopter with a 1-inch 20-megapixel RGB camera) was used in combination with aerial imagery from NAIP and additional sUAS imagery from The Nature Conservancy (Table 21). A description of NAIP imagery collection methods can be found at USDA NAIP Imagery Program. Imagery collected in 2013, 2016, and 2020 represent the baseline, “as built”, and current conditions of each site, respectively. Imagery included only red-, green-, and blue-wavelengths (RGB), so analyses focused on detecting the presence and coverage of vegetation rather than health indices or other multispectral imagery. Additionally, the 2016 datasets do not include Control areas.

A segmented image and training sample data were derived for each of the 2013, 2016, and 2020 imagery datasets because of the differing resolution, spectral signatures, and collection conditions between the three datasets. The segmented image and training samples were then used with the Support Vector Machine (SVM) machine learning algorithm to classify the presence of each class on the marsh. Total acreage per testing site as well as percent coverage of each class were calculated based on the grouping of "Non-Veg" categories (consisting of "Water" & "Non-Veg" classes) and "Vegetation", respectively.

Table 21. *Summary of aerial imagery sources and parameters.*

Time Period	Year of Collection	Resolution	Source	Collection Method
Baseline	2013	39-inch	NAIP	Aerial Collection
"As Built"	2016	6-inch	The Nature Conservancy	sUAS*
Current	2020	3-inch	NJDEP	sUAS
*sUAS = Small Unmanned Aircraft System				

Segmentation and Training Datasets

The creation of the segmented image reduced the variability and spectral detail the original orthomosaic provided. This streamlined the classification of vegetation, soils, and water because the machine learning algorithm used training samples to predict the classification based on the similarity of spectral and spatial detail of adjacent object neighborhoods instead of using the complex spectral detail and texture of pixels (Congalton et al., 2017). The main goal of creating a segmented image is to create objects that are spectral and spatially distinct from other objects while preserving variability within each object (Congalton et al., 2017). Using ArcGIS Pro's "Segmentation" tool, a low spectral detail and a low spatial detail were favored so that the different species of vegetation were merged into similar object neighborhoods, but not so low that it merges with the features of the other classes (ESRI, "Segmentation"). The simplified spectral information reduced the complexity of the model and the number of training samples needed because of this similarity in object neighborhoods within each class. The training sample data were composed of polygons manually drawn on the map to represent each class of the marsh. The amount of each training class polygon depended upon the size of each testing site, the presence of each class on the map, spectral detail of the imagery, and conditions when each imagery dataset was collected. Because of this, the amount of training data for each class differs from year to year and from site to site. Each training sample must also represent each class consistently, exclusively, and completely to avoid adding confusion into the model (Congalton et al., 2017) Training the data to get a representative sample of the spectral variability in each class was preferred over taking equal samples to ensure the classes were correctly classified without overfitting the model.

Classification and Review

The segmented image and training samples then were used to classify the imagery using the Support Vector Machine (SVM) machine learning algorithm using ArcGIS Pro's "Classify" tool. Once the image was classified, a manual review of the data was done within each testing site boundary to ensure thematic accuracy. Areas outside of the site boundaries were clipped out and did not receive edits. Classification errors were corrected using the Pixel Editor tool in ArcGIS Pro. The minimum mapping unit used for each feature was approximately 1 sq. ft. Because of the differing resolutions of the imagery, the classified raster output was edited at different scales. Data derived from the 3-inch 2020 imagery datasets were edited between a 1:50 and 1:300 scale. Data derived from the 6-inch 2016 datasets were edited between 1:100 and 1:300. Data derived from the 1-meter 2013 imagery datasets were edited between 1:800 and 1:1,100. This was to ensure the accuracy of feature boundaries between classes as well as to correct errors within each feature boundary.

Other features not represented in the class labels were also present in the imagery. This included debris, wrack, field and flight crew members, field equipment, other ongoing projects present on the marsh, fencing, and a boat. These features were often initially classified as “Non-Veg,” but were reclassified as the class of the feature beneath it based on site knowledge. In areas of dense wrack, it was chosen to classify the area as “Non-Veg” due to a combination of unknown underlying cover and the possibility that the wrack could cause vegetation die-off underneath its dense layers (Bertness and Ellison, 1987). However, if the wrack wash was sparsely distributed across the marsh, it was reclassified as the underlying class. Once the datasets were corrected, they were converted from raster format to vector form, clipped to the testing site boundary, and enriched with the attributes of other project data. The analysis and display of the final classification, acreage of each class, and percent coverage were based on these added attributes.

Calculations

Based on the image classification, the acreage and percent coverage of each testing site were calculated using each testing site buffer and site type (control group or experimental group), respectively. One caveat is this image classification was based on the visual presence of each class and does not take recent tide and rain events into account when digitizing each class. Depending on when the imagery datasets were collected, different water levels may be present on the marsh. Therefore, although the water and bare soil features were classified as their respective classes, they were grouped using the “Non-Veg” subcategory in the final calculations because of these fluctuations in tidal and pooled water. The final comparison was between the “Non-Veg” class, which was composed of the “Water” and “Non-Veg” main classes, and the “Vegetation” class. These calculations will be integrated into the broader analysis of this project to assess the success of using dredge material as a means of helping salt marsh habitat.

Accuracy Assessment

The thematic accuracy assessment was conducted with suggestions outlined in *Assessing the Accuracy of Remotely Sensed Data* (Congalton and Green, 2019). Overall accuracy was the primary accuracy statistic used to gauge the thematic accuracy of each dataset. As a general accuracy standard, 90% accuracy was designated as the minimum allowable accuracy for each collection. Anything below this was considered unacceptable and further editing of the classified data was done. Several checkpoints were designated for each testing site due to the differing size of the three testing sites. Due to the disproportionate presence of each class on each of the three testing sites, the checkpoints were divided up proportionately based on the overall percentage of area each class possesses (Congalton and Green, 2019). For instance, if a class takes up 30% of the overall area of the testing site, 30% of the checkpoints used to test the thematic accuracy of that testing site will be used for that class.

Results

Ring Island

Classification of Ring Island in 2013 revealed baseline conditions of thorough vegetation, with a total percent cover of 87.5%, or 8.97 of the 10.25 acres (ac) (Figure 36A and 37). Within the control area, 99.1% was vegetated (1.47 ac), while pre-placement areas had 85.6% plant cover (7.52 ac) (Figure 38). Classification of 2016 imagery, collected two years post-placement, demonstrated significant decreases in vegetation cover, with patterns of centralized non-vegetation patches and rings of vegetation on the outer edges of the treatment areas (Figure 36B).

However, six years post-placement in 2020, there are clear signs of revegetation within both the TLP areas and the ENH area. Vegetation began to fill in the center of the ENH treatment area, and non-vegetated patches of the TLP areas were reduced (Figure 36C). 2020 levels of vegetation do not match baseline conditions, with only 69.1% total vegetation cover (7.12 ac, a loss of 3.13 ac; Figure 37). However, within the control area, there is also an increase in the non-veg cover, rising to 7.8% (or 0.12 ac) from its baseline condition of 0.9% (or 0.01 ac), resulting in a less contiguous and patchier habitat (Figure 38). This suggests

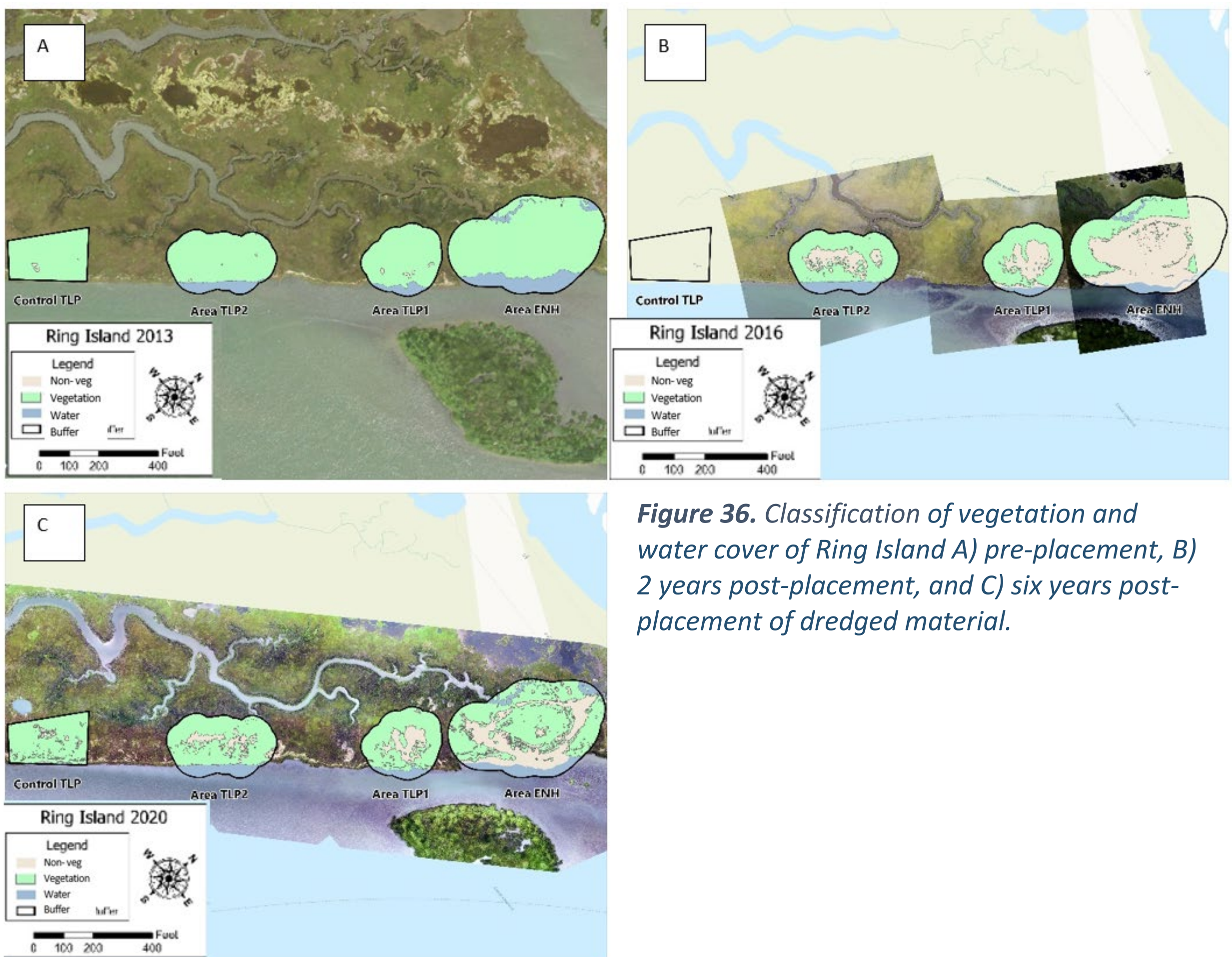


Figure 36. *Classification of vegetation and water cover of Ring Island A) pre-placement, B) 2 years post-placement, and C) six years post-placement of dredged material.*

that there are ongoing conditions causing vegetation die-off in the overall site. Broadly, Ring Island placement areas revegetated at a rate of 0.43 ac per year (3.7% of the site per year) based on vegetation change from 2016 to 2020. This slow rate of revegetation could be a result of higher elevations (see Section 4: Water Level Monitoring and Section 5: Vegetation from Plot Based Monitoring).

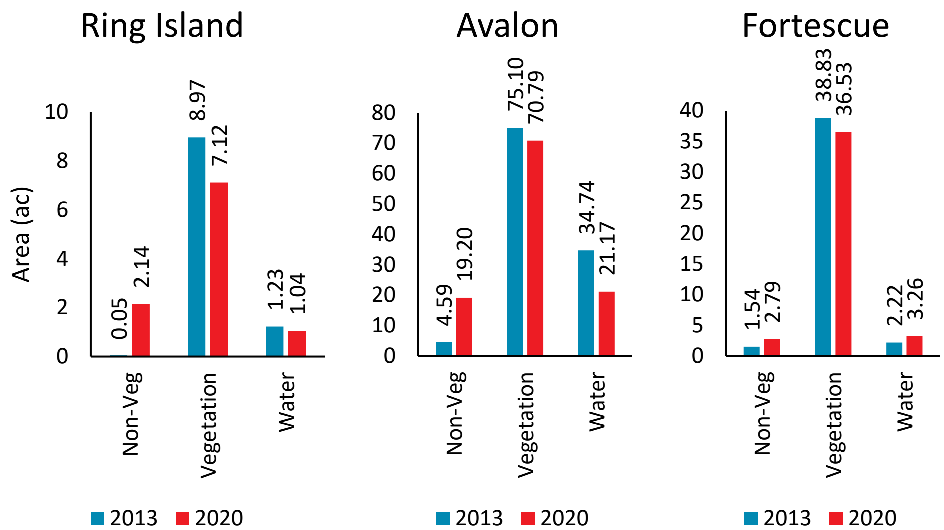


Figure 37. *Change in total (i.e., control and placement areas combined) non-vegetative, vegetative, and water cover square acreage in Ring Island, Avalon, and Fortescue from pre-placement to multiple years post-placement of dredged material.*

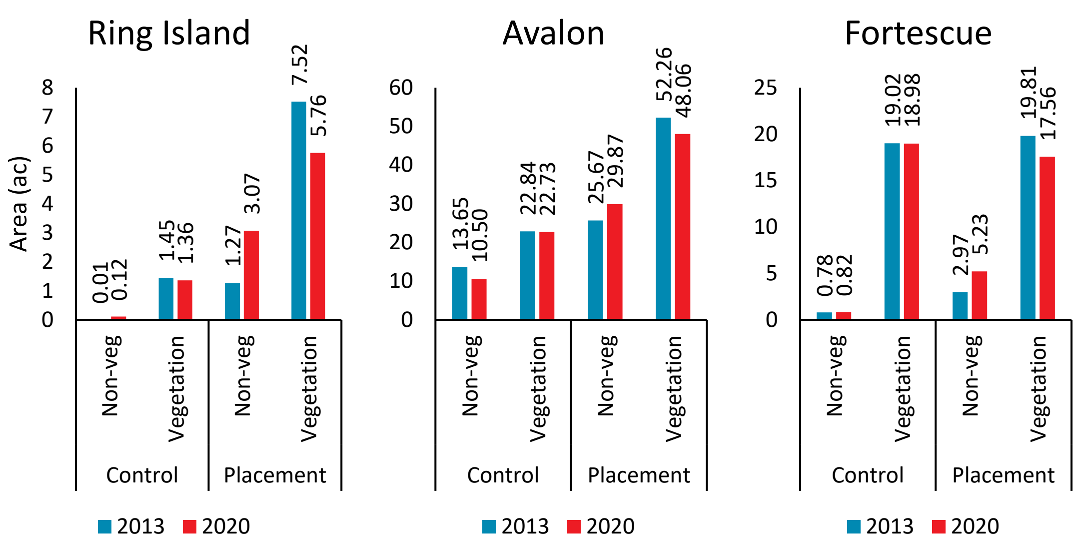


Figure 38. *Change in vegetative cover square acreage in Ring Island, Avalon, and Fortescue control and placement areas from pre-placement to multiple years post-placement of dredged material.*

Avalon

Baseline classification of Avalon control and pre-placement areas show that the marsh was heavily influenced by ponding, with open water habitat constituting 30.4% (or 34.74 ac) of the total area and vegetation covering 65.6% (75.1 ac; Figures 39A and 37). Control and pre-placement areas had similar ratios of vegetated to non-vegetated area, with 62.6% (22.84 ac) and 67.1% (52.26 ac) vegetation coverage, respectively (Figure 38).

Classification of the 2016 Avalon habitat (collected the summer after Phase 2 of placement) shows significant retention of ponds within the placement areas (Figure 39B). Similar to the Ring Island site, vegetation remained as a ring outside of the placement areas, with non-vegetated areas and ponding centered within the treatment areas.

Four years post-placement in 2020, classification shows substantial revegetation of the placement areas. The final percent cover of vegetation in placement areas reached 61.7% (48.06 ac), nearly reaching baseline conditions measured in the 2013 dataset (Figures 39C and 37). Ponding and non-vegetated areas were more mosaiced when compared to the larger contiguous ponds found in the 2013 classification. Control sites remain steady in terms of vegetation cover at 22.7 ac in 2020 compared to the 22.8 ac in

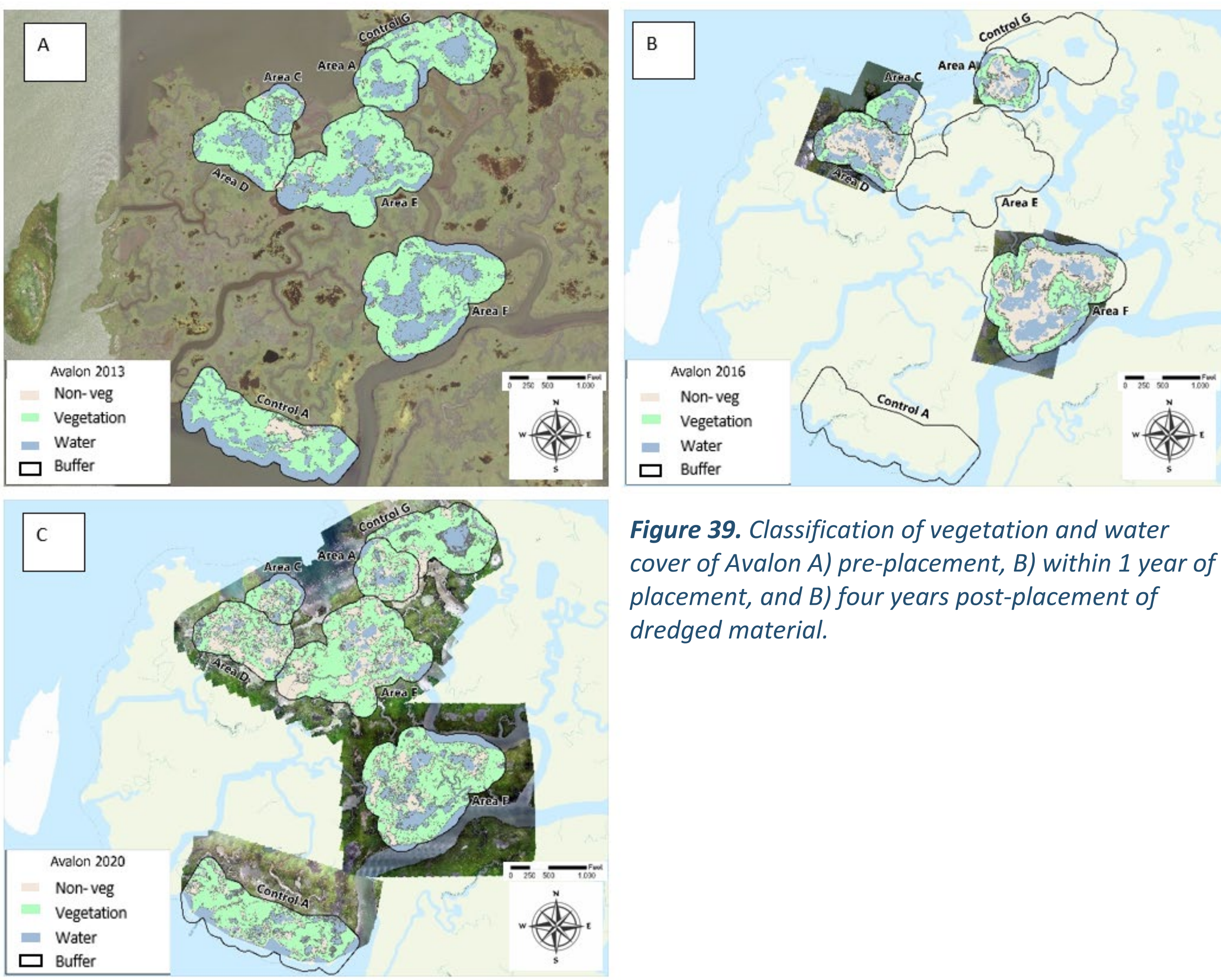


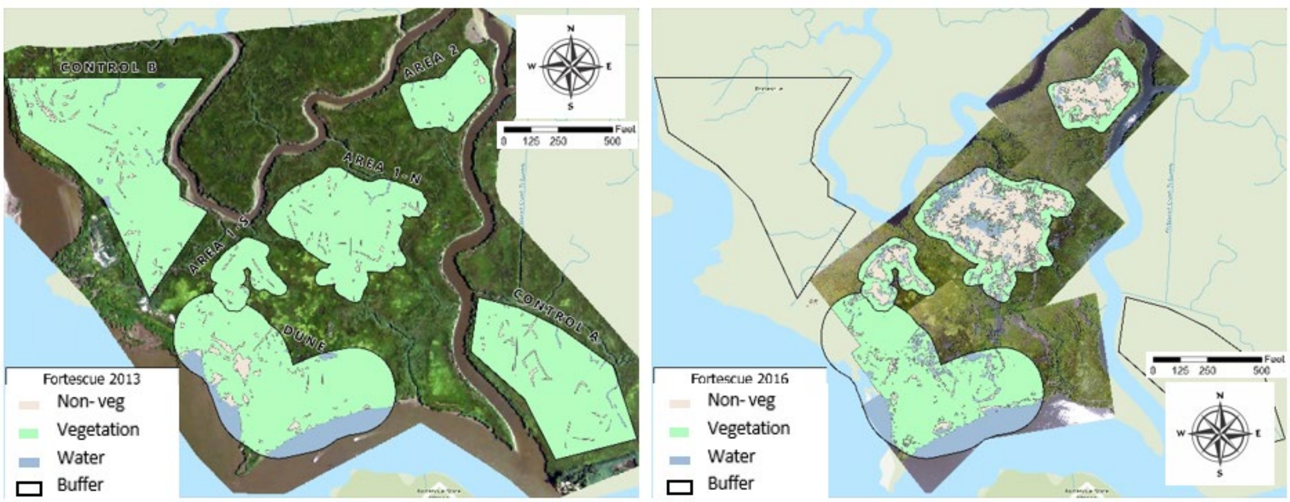
Figure 39. *Classification of vegetation and water cover of Avalon A) pre-placement, B) within 1 year of placement, and B) four years post-placement of dredged material.*

2013 (68.4% vs 62.6% cover respectively; note, that percentages are different due to clipping of the Control Area A by lack of full imagery coverage of 2020 imagery; Figure 38). Within Avalon placement areas, we found that the sites revegetated at a rate of 8.01 ac per year (7.0% of the site per year) from 2016 to 2020. This rate of revegetation was much faster than Ring Island and could be attributed to the overall lower final elevation (Tables 5 and 8 in Section 3: Elevation).

Fortescue

2013 classification of the habitat within the Fortescue site shows 91.2% (38.83 ac) of the total site was vegetated, with minimal ponding and other non-vegetated cover (water: 3.6%, 1.54 ac; non-veg: 5.2%, 2.22 ac; Figure 37 and 40A). Control areas had a slightly higher percent cover of vegetation of 96% (19.02 ac) compared to pre-placement areas with a percent cover of 87% (19.81 ac; Figure 38).

2016 classification of Fortescue included placement areas just after treatment with dredged material, but before the dune and beach restoration. Placement areas showed significantly higher proportions of non-vegetated areas as expected; however, there were additional developments of ponding within placement areas that were not present in the 2013 classification (Figure 40B).



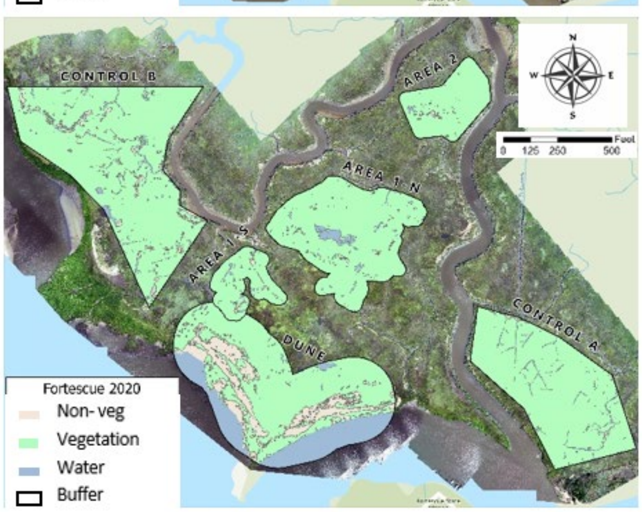


Figure 40. *Classification of vegetation and water cover of Ring Island A) pre-placement, B) within 1 year of placement, and C) four years post-placement of dredged material.*

By 2020 (four years post-placement and three-years post-restoration of the dune and beach areas), much of the area that was unvegetated in 2016 had grown in (Figure 40C). Much of the dune enhancement site was still unvegetated, but some of the plantings had begun to increase in cover. Overall, the final vegetation cover did not meet baseline conditions, reaching 85.8% (36.53 ac) compared to baseline levels of 91.2% (38.83 ac; Figure 37). Additionally, some of the newly developed ponding remained, reducing the vegetative cover slightly. This increase in ponding, in conjunction with higher elevations similar to Ring Island (Tables 5 and 9 in Section 3: Elevation), may have contributed to a reduced rate of revegetation (in comparison to Avalon) of 1.16 ac per year (4.3% of the site per year) from 2016 to 2020. Additionally, the analysis included the dune restoration, where much of the vegetated cover converted to unvegetated cover from 2016 to 2020, thus potentially skewing the vegetation rate lower. Plot-based monitoring (see Figures 27, 28, and 29 in Section 5: Vegetation from Plot Based Monitoring), however, found that Fortescue revegetated much faster within the placement areas than Avalon and Ring Island. These differences in revegetation rates between this classification and the findings of the plot-based monitoring could be largely attributed to the inclusion of the dune restoration, which was much slower to revegetate over time. Permanent plots were not placed in the dune, and vegetation was not examined in detail in this area.

Accuracy Assessment

Due to the varying sizes of each testing site, a different number of checkpoints were used to evaluate the accuracy of the classification but were consistent from year to year (Table 22). Across all sites, we were able to achieve >90% classification accuracy.

In addition to manually checking the classification, percent cover and habitat proportions defined by the classification workflow were compared to what was found in the permanent vegetation plots. Figure 41 reflects the percent cover vegetation, or vegetation density, as calculated by permanent vegetation plots and drone imagery (see Section 5: Vegetation from Plot Based Monitoring for more detailed results). Classification from drone imagery was found to have higher estimates of the percent cover of vegetation compared to the on-the-ground permanent plots. In part, this may be attributed to the different scales of analysis, as the drone imagery was evaluating land cover over multiple acres while the vegetation plots could be analyzed in detail by the field team. It is also likely that the plots-based cover estimates underestimate cover due to their locations away from the edge of placement areas where vegetation recovered first.

Habitat proportion was much more easily comparable between the vegetation plots and drone imagery (Figure 42). This landscape-scale metric was found to be very similar between the two methods, suggesting that drone imagery is a good proxy for measuring habitat cover (“Non-Veg,” “Vegetation,” and “Water”).

Table 22. *Thematic accuracy assessment of habitat classification at each site.*

Site Name	Year	Number of Checkpoints	Overall Accuracy
Ring Island	2013	125	95.5%
	2016	125	92%
	2020	125	98.5%
Avalon	2013	200	96%
	2016	200	96.5%
	2020	200	99%
Fortescue	2013	200	97.5%
	2016	200	96%
	2020	200	99.5%

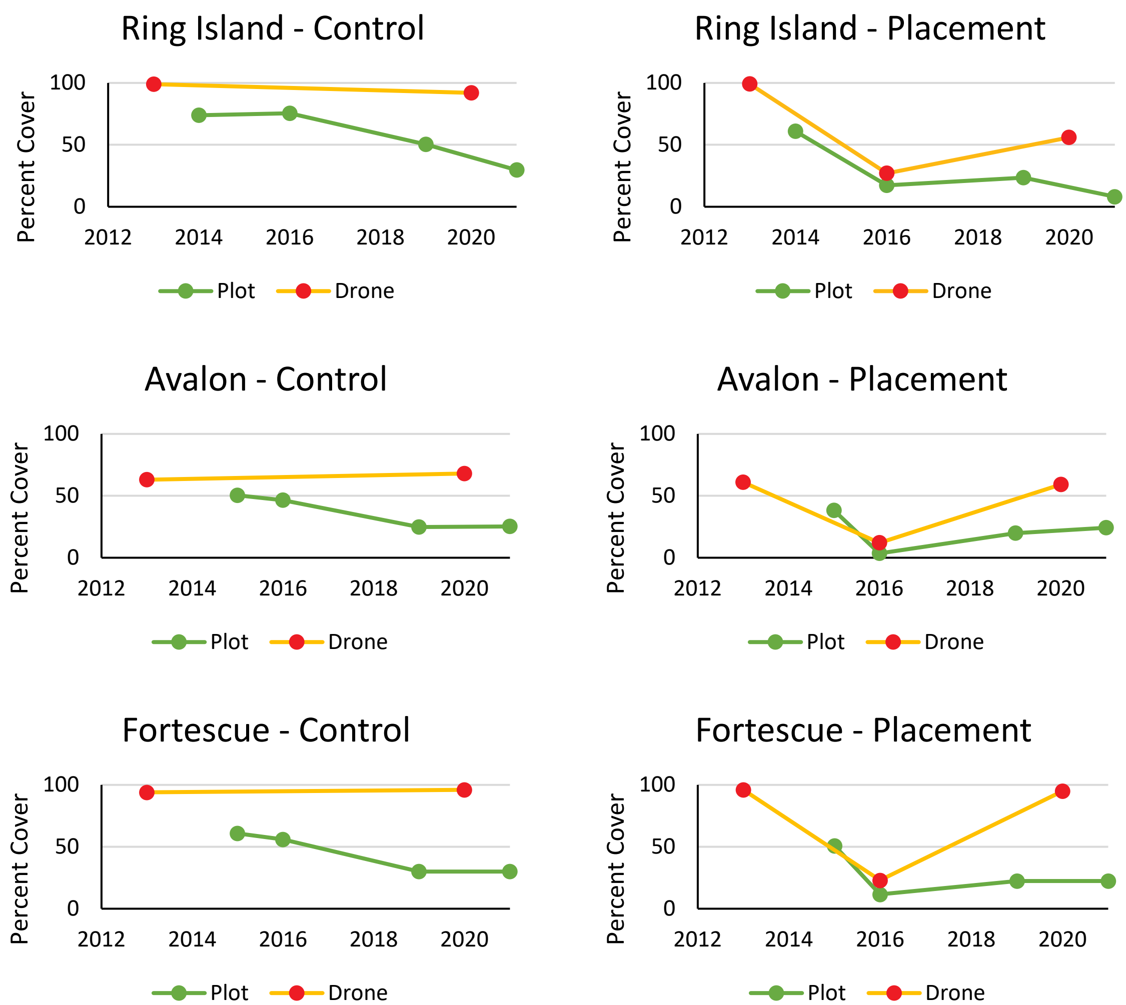


Figure 41. *Vegetation percent cover comparison between drone classification and on-the-ground permanent plot measurements. Drone imagery consistently was found to overestimate vegetation percent cover at a landscape level.*

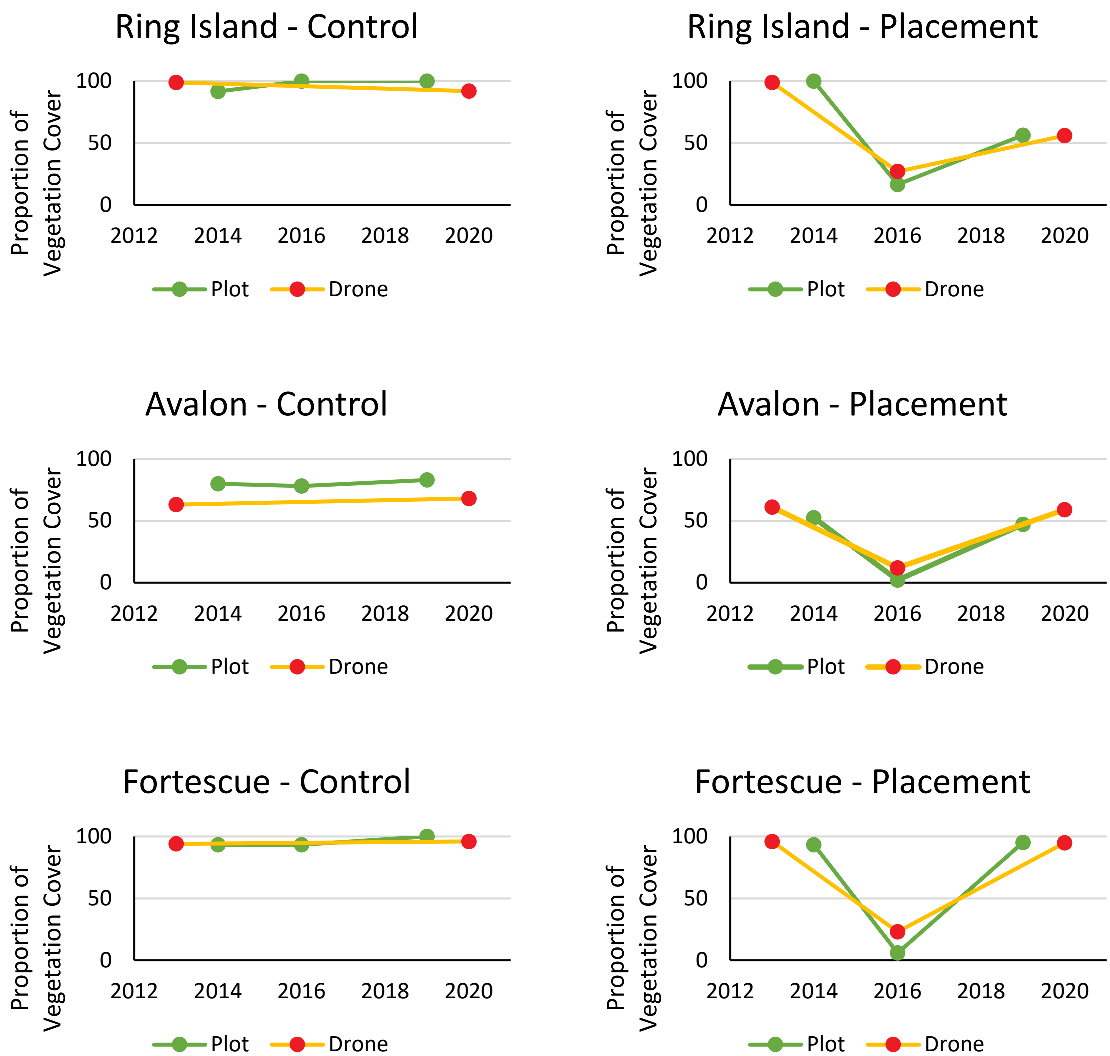


Figure 42. *Habitat proportion comparisons between drone classification and on-the-ground permanent plot measurements. Drone imagery and plot measurements were closely matched as the two measurement types can determine habitat ratios more easily across a landscape level.*

Conclusions

- Revegetation after placement of dredged material may take several years to reach baseline conditions. No sites reached baseline conditions by the time we collected the 2020 drone imagery five to six years post sediment addition. However, Avalon was the closest to reaching baseline vegetation conditions at 61.7% cover in 2020 compared to 67.1% cover in 2013. Ring Island revegetated up to 65.2% in 2020, with a baseline 2013 cover of 85.6%. Fortescue had the most vegetation cover by 2020 at 77.1%, with a baseline 2013 cover of 87.0%.

- Rates of revegetation are controlled by several factors, especially elevation of placed material, proximity to existing vegetation, thickness of material placed, erosion rates, and rates of ponding and subsidence. We found that vegetation tended to grow from outside of the placement area into the treated area, rather than from underlying surviving roots from previous vegetation.

- Drone imagery may overestimate vegetation cover due to the difficulty in analyzing density at a smaller scale compared to on-the-ground vegetation plots or it may provide a better estimate because plots were located away from the edge of where sediment was placed. Drone imagery was found to closely match the proportions of habitat cover, as this was a landscape-level metric.

- Areas of significant ponding may not be possible to fill in due to the weight of sediments and local subsidence rates. Although we filled in large ponds within Avalon, we quickly saw the ponds reemerge, although the area of the ponds was slightly decreased.

- Sediment addition can lend itself towards increasing subsidence, resulting in additional low-lying areas and ponding, as demonstrated by the Fortescue site. How sensitive a site is to subsidence and compaction relative to sea-level rise should be considered during design.

- Based on these results, we can address the following monitoring questions: 1) “Does the marsh ecosystem (i.e., structure and functions) recover or show uplift within two to three years of dredged material placement? (And the related “How long does it take for the marsh to recover and achieve uplift?”)” and 2) “Were there any unexpected outcomes of the placement of dredged material?”

    - 1) Revegetation after placement of dredged material may take more than six years to reach baseline conditions. No sites reached baseline conditions by the time we collected the 2020 drone imagery five to six years post sediment addition. However, Avalon was the closest to reaching baseline vegetation conditions at 61.7% cover in 2020 compared to 67.1% cover in 2013. Ring Island revegetated up to 65.2% in 2020, with a baseline 2013 cover of 85.6%. Fortescue had the most vegetation cover by 2020 at 77.1%, with a baseline 2013 cover of 87.0%. Post-placement monitoring timing should strive towards at least a decade due to the slow pace of recovery after sediment placement.

    - 2) Habitat classification revealed that sediment placement at the ENH resulted in a “bathtub” feature, where vegetation grew specifically at lower elevations and higher elevations, but not between. The exact cause of this ring of bare habitat is unknown, but it could be related to patterns of vegetation regrowth, where lower vegetation patches could be a result of higher seed counts from nearby vegetation patches and incoming flooding, and higher elevation vegetation patches could be a result of avian dispersal. Additionally, there could be underlying sediment changes that resulted in a gradient of prohibitive growing conditions.

7. Epifaunal Macroinvertebrates and Bioturbation

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[1]The Nature Conservancy

Epifaunal macroinvertebrates (EMI) (for example, mussels, snails, and crabs) provide important trophic linkages within salt marsh ecosystems. They are prey for a variety of avian and aquatic species, grazers of vegetation, and contribute to the structure of the marsh soil by digging burrows (*Uca* sp., fiddler crabs) or binding soils together, preventing erosion (*Geukensia demissa,* ribbed mussels; Bertness 1984). EMI are vulnerable to sudden changes in microhabitats within the marsh because of their relatively small size, and in some cases limited mobility. Monitoring EMI is important to document the effects of dredged sediment placement on faunal species diversity, especially in the case where a significant decline or an increase in species diversity or abundance could result in dramatic shifts in the ecological function of the marsh plain. the placement of dredged material.

Monitoring Design

Table 23. *Design and metrics used to monitor epifaunal macroinvertebrates at Ring Island, Avalon, and Fortescue project sites.*

Metrics	Method	Design
Species Richness	Presence or absence of species or crab boroughs	Surveys completed in ¼ m^2 section of permanent monitoring plots once during peak of growing season. BACI design.
Species Diversity		Surveys completed in ¼ m^2 section of permanent monitoring plots once during peak of growing season. BACI design.
Species Abundance		Surveys completed in in ¼ m^2 section of permanent monitoring plots once during peak of growing season. Post placement only.

EMI metrics (Table 23) were monitored by TNC in 0.25 m^2 subplots within the permanent 1 m^2 vegetation monitoring plots (see Section 5: Vegetation from Plot Based Monitoring) concurrent with annual vegetation sampling. Burrows were used as a proxy for crab abundance since crabs are highly mobile.

Paired Samples Wilcoxon tests were conducted on *Melampus bidentatus*, *Geukensia demissa*, and *Uca pugnax* burrow counts (Table 24) to compare abundances before placement (PRE) and the first year following placement (PP1) and to compare abundances before placement and in the final year post-placement (PP6/7). When the data were parametric, paired t-tests were used, as indicated.

Ring Island

At Ring Island, there were no *M. bidentatus* counted in plots before treatment (Table 24). The first year post-treatment averaged 1.6 *M. bidentatus* per plot (n = 9, Wilcox's $p > 0.05$, d = 0.33). By PP7 *M. bidentatus* averaged 9.1 per plot (n = 9, Wilcox's $p < 0.05$, d = 0.76), a significant increase from the mean of 0 in PRE. Due to missing data, we could not determine the averages of *G. demissa* and *Uca pugnax* in the pre-treatment year for Ring Island plots. However, the average number of *G. demissa* per plot in PP1 at Ring Island was 4.6 and 0.7 in PP7 (n = 12, Wilcox's $p > 0.05$, d = -0.36). *U. pugnax* burrows averaged 3.4 per plot in PP1 and 7.8 by PP7 (n = 12, Wilcox's $p > 0.05$, d = 0.41).

Table 24. *Average EMI counts per plot in the years PRE, PP1, and PP6 for Avalon and Fortescue and PP7 for Ring Island. Values highlighted in red and green had a difference in means compared to PRE averages that was significantly different than zero. Green indicates a difference in means significantly greater than zero (positive change in mean count) and red indicates a difference in means significantly less than zero (negative change in mean count).*

EMI Species	Year	Fortescue	Ring Island	Avalon
Melampus bidentatus	PRE	25.8	0	10.6
	PP1	0.7 ↓	1.6	0 ↓
	PP6/7	3.7 ↓	9.1 ↑	4.9 ↓
Geukensia demissa	PRE	2	-	-
	PP1	0	4.6	-
	PP6/7	0.4	0.7	-
***Uca pugnax* (burrows)**	PRE	10.3	-	2.3
	PP1	0.8 ↓	3.4	6.7 ↑
	PP6/7	2.7 ↓	7.8	10.0 ↑

Avalon

At Avalon, the mean number of *M. bidentatus* per plot was 10.6, and in PP1 the mean was 0 snails per plot. The average population of snails per plot in PP1 was significantly lower than in PRE (n = 18, Wilcox's $p < 0.05$, d = -0.44). The average number of *M. bidentatus* per plot in PP6 was 4.9, also a significantly lower average than in PRE (n = 17, Wilcox's $p < 0.05$, d = -0.289). Significance change in *G. demissa* was not detectable at Avalon due to only one out of 19 plots containing any mussels at either time point. The single plot that did contain mussels in PP1 increased from 2 individuals to 8 individuals in PP6. The mean number of burrows per plot increased significantly over time (Figure 43). Burrow count means increased from 2.3 in PRE to 6.7 in PP1 (n = 18, Wilcox's $p < 0.05$, d=0.58). The mean number of burrows per plot at Avalon in PP6 was 10.0, and the difference in mean to PRE counts was significantly greater than 0 (n = 14, paired t-test $p < 0.01$, d = 0.96).

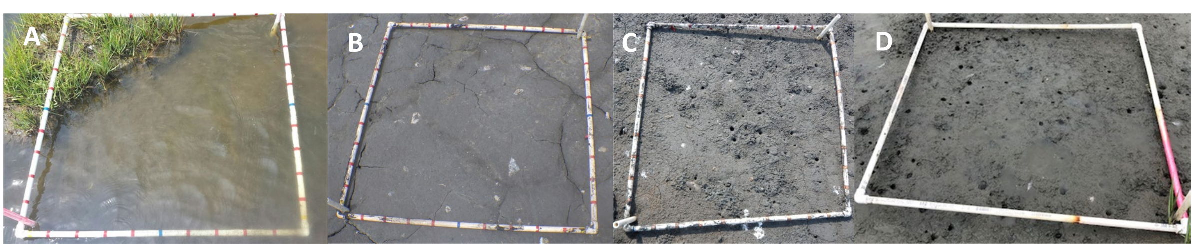

Figure 43. *Photo evidence of increase in burrow count during A) PRE, B) PP1, C) PP2, and D) PP3 in an Avalon Placement plot.*

Fortescue

At Fortescue, the mean number of *M. bidentatus* per plot in PRE was 25.8 and 0.7 in PP1, a significant decrease (n = 12, Wilcox's $p < 0.01$, d = -0.93) By PP6, the mean number of *M. bidentatus* per plot at

Fortescue was 3.7 (n = 12, Wilcox's $p < 0.05$, d = -0.78) the differences in means between PRE and PP6 still significantly greater than 0. The average number of *G. demissa* per plot was 2 in PRE and 0 in PP1, not a significant change in means (n = 12, Wilcox's $p > 0.05$, d = -0.49). By PP6 the mean per plot had increased to 0.4, not significantly different from PRE (n = 12, Wilcox's $p > 0.05$, d = -0.37). Crab burrows at Fortescue started with a mean of 10.3 burrows per plot in PRE and were reduced to 0.8 burrows per plot in PP1 (n = 12, Wilcox's $p < 0.05$, d = -1.23). By PP6 average burrow counts per plot had increased to 2.7, though still significantly different from PRE levels (n = 12, paired t-test $p < 0.05$, d = -0.92)

Conclusions

- The three most dominant EMI species found at all three project sites were salt marsh snails (*Melampus bidentatus*), ribbed mussels (*Geukensia demissa),* and burrowing crabs (fiddler crabs, *Uca* sp*).*

- The initial decline in *M. bidentatus* and *G. demissa* abundances may be attributed to direct burying by the placement of dredged material. *M. bidentatus* and *G. demissa* are also closely associated with vegetation, specifically *Spartina alterniflora,* so it is intuitive that as vegetation cover declined post-placement, so did the abundance of these species. On the contrary, crabs are highly mobile and were observed to burrow within the placed sediment. Ring Island and Avalon had higher abundances of crab burrows in the bare, non-vegetated placement areas than in the vegetated control areas post-placement. Burrows at each site were primarily made by *Uca sp*. (both *Uca pugnax* and *Uca minax were* observed) as opposed to *Sesarma reticulatum* (as indicated by their shape and size). Though mortality via burying is thought to have occurred initially within the footprint of the project, surviving *Uca sp.* from the surrounding marsh complex quickly recolonized the top layer of the dredged material at Avalon (but not at Fortescue). Although purple marsh crabs (*S. reticulatum*) were observed at all three sites, they were found in very low abundances, and a caging study was utilized to determine that herbivory by crabs was not a problem for recovering marsh vegetation in the study area.

- Based on these results, we can address the following monitoring question: "Does the marsh ecosystem (i.e., structure and functions) recover or show uplift within two to three years of dredged material placement? (And the related "How long does it take for the marsh to recover and achieve uplift?")"
    - Only *Uca pugnax* showed significant increases soon after placement and only within Avalon, and *Melampus bidentatus* took greater than six years to show significant recovery and only within Ring Island. Uplift of the epifaunal macroinvertebrates was not achieved soon after placement. While some species counts have recovered, it may be unlikely for all species to recover at all sites within a decade of the placement. Additional monitoring may be needed to fully determine the timescale in which these representative species will recover and exceed their previous population counts.

8. Penetration Resistance

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[1]The Nature Conservancy, [2]New Jersey Department of Environmental Protection

Bearing capacity measures the loading response or maximum force that the substrate can support and acts as an indicator of the firmness of the substrate. In traditional wetland monitoring, penetration resistance is used as a proxy for vegetative biomass belowground. The addition of dredged material changes the marsh substrate composition which influences penetration resistance and the ability of vegetation and EMI to colonize and grow. Harder substrates may be more difficult for roots and shoots to penetrate. Conversely, soft substrates may not be stable enough for root systems. By collecting penetration resistance data, vegetation success in relation to substrate hardness can be measured and optimal substrate hardness levels can be understood.

Monitoring Design

Table 25. *Design and metrics used by TNC for penetration resistance measurements at Ring Island, Avalon, and Fortescue projects.*

Design	Bearing Capacity & Sediment Characterization
Impact and Control Measured Once Annually During Peak Growing Season in 2016 and 2017 (July to September) next to permanent monitoring plots (see Section 5: Vegetation)	Penetration Depth Loading Response Depth of Standing Water

Penetration resistance metrics in Table 25 were measured by TNC directly outside a corner of the permanent vegetation plots (see Section 5: Vegetation from Plot Based Monitoring). A 2-inch diameter capped PVC tube was placed onto the wetland soil surface, and a standard force was applied with a slide hammer. The depth that that PVC tube sunk into the marsh after repeated drops of the slide hammer was used to calculate the penetration resistance. Soil color and texture were also documented.

Ring Island TLP

Because there was only one bare plot in the control area and no pool plots, we did not conduct a comparison of penetration resistance by habitat type at Ring Island (Figure 44). No significant differences were found comparing treatment and control plots (ANOVA: $p > 0.05$) or in treatment plots over time (Tukey; $p > 0.05$). However, there was an increase in penetration depths in the control plots from PP2 to PP7, although insignificant (Tukey; $p > 0.05$).

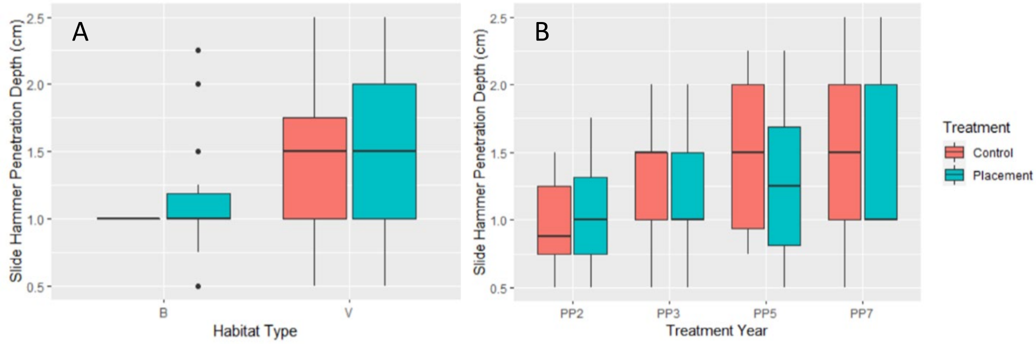

Figure 44. *Difference in penetration depth between Ring Island control and placement areas by A) habitat type, where B = bare and V = vegetated, and by B) years post-placement. Data shown includes median with interquartile ranges, minima, maxima, and outliers.*

Avalon

Soil penetration depth, which was only measured post-placement, was compared between control and treatment plots over time and between habitat types (Figures 45 and 46). Over the years, penetration depths have not significantly changed in control or treatment plots (Friedman; $p > 0.05$ and ANOVA; $p > 0.05$ respectively). Within control areas, soil penetration depth was significantly lower in vegetated plots compared to either bare ($p < 0.001$) or pool ($p < 0.01$) plots and was similar between bare and pool plots ($p > 0.05$). Penetration depths were lower in bare treatment plots than bare control plots (ANOVA; $p < 0.01$) most likely due to the compaction of dredge material during placement compared to the natural peat substrate of the controls.

For Avalon plots that started as pools, penetration depths were higher than in plots that started as platform (ANOVA; $p < 0.001$). Penetration depth was also significantly different between habitat types in these plots (ANOVA; $p < 0.01$) with penetration depths being lowest in bare plots and highest in pool plots.

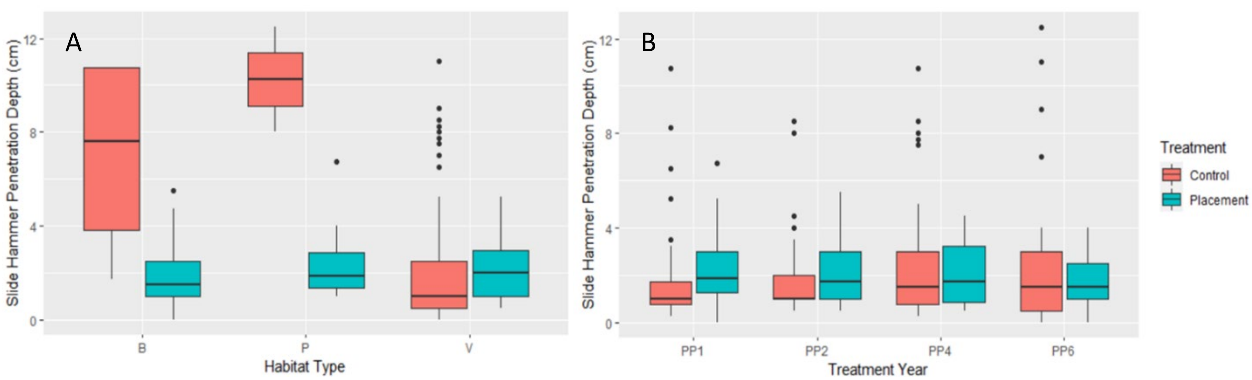

Figure 45. *Difference in penetration depth of Avalon control and placement platform plots by A) habitat type, where B = bare, P = pool, and V = vegetated, and by B) years post-placement. Data shown includes median with interquartile ranges, minima, maxima, and outliers.*

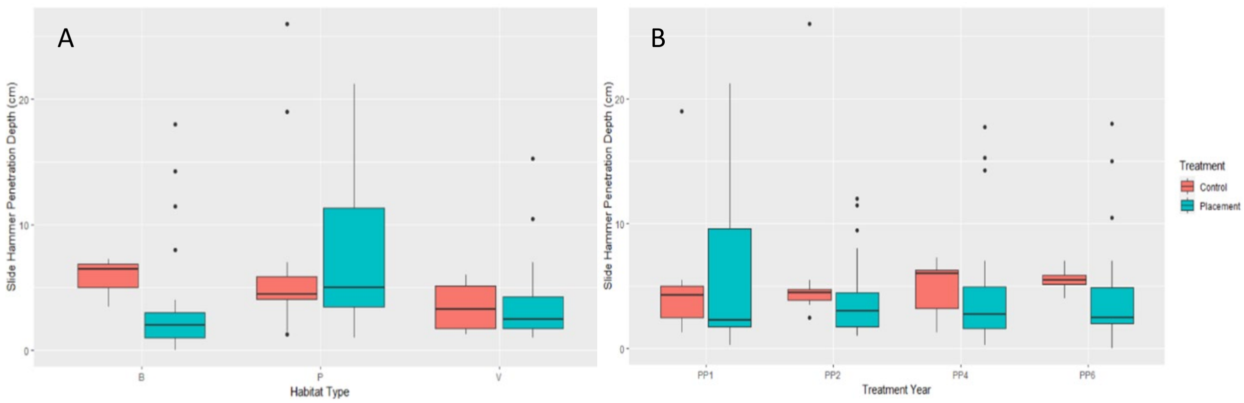

Figure 46. *Difference in penetration depth of control and placement pool plots by A) habitat type, where B = bare, P = pool, and V = vegetated, and by B) years post-placement. Data shown includes median with interquartile ranges, minima, maxima, and outliers.*

Fortescue

For Fortescue, soil penetration depths were log-transformed for normality. Penetration resistance was significantly affected by treatment (control vs. placement) (ANOVA, $p < 0.05$), but not by timeframe (ANOVA, $p > 0.05$). Placement plots had lower penetration depths than control plots every year that data was collected and for each habitat type (Figure 47). There were no pool plots in the control area, so pools are not part of the comparison by habitat type.

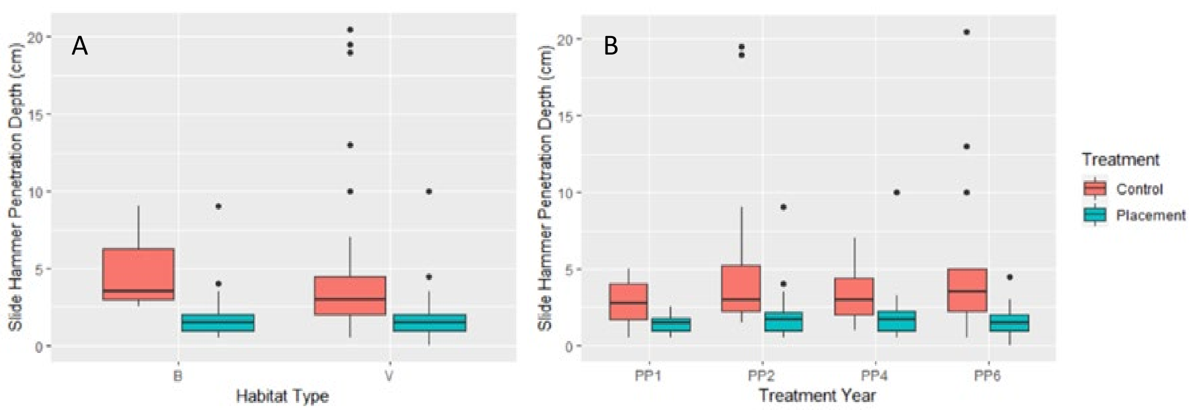

Figure 47. *Difference in penetration depth of control and placement plots by A) habitat type, where B = bare and V = vegetated, and by B) years post-placement. Data shown includes median with interquartile ranges, minima, maxima, and outliers.*

Conclusions

- Vegetated control plots at all sites had generally well-established root mats, resulting in relatively higher penetration depths than in bare control plots.
- At Avalon and Fortescue, it was observed that the surface sediments of bare placement plots were often dried and/or compacted, sometimes with a leathery algal mat on the surface that resisted penetration. It was hypothesized that compacted soils or thick algal mats might make it more difficult for plants to re-establish.

- In Avalon, penetration depths were lower in bare treatment plots than bare control plots, likely resulting from the compaction of dredge material during placement compared to the natural peat substrate of the controls.
- At Fortescue, placement areas had lower penetration depths than controls across time. Additionally, vegetated plots in placement and control areas had similar penetration depths. This could indicate that similar bearing capacity facilitated vegetation recovery within placement plots.

9. Benthic Infauna and Sediment Properties

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Benthic infauna live in the sediment and are prey items for juvenile fish and larger invertebrates that live in the marsh. Infauna play a role analogous to earthworms in keeping the sediment aerated, breaking down organic matter, and returning nutrients to the water column. Due to the intimate association of benthic infauna with the sediment in which they live, the placement of dredged material can have an immediate effect on the abundance and composition of the benthic community. Dredged material is likely to differ from natural marsh sediment in particle size, concentrations of key nutrients (carbon, nitrogen, sulfur, and phosphorus), and organic matter content – properties that fundamentally affect benthic infauna.

Table 26. *Design and metrics used for benthic infauna monitoring and sediment properties at all three project sites.*

Metrics	Method	Design
Benthic Infauna Species abundance Species diversity	3.8 cm diameter × 3 cm deep sediment cores sorted in lab	Ten samples collected at each marsh placement and control site during each sampling event. There were five sampling events in 2015 (Avalon and Ring Island only) and in 2016, two sampling events in 2017, and one in 2019. No baseline data were collected. Samples were collected in the same small area each time, except in 2019 when two separate placement sites were sampled. The placement site at Avalon received sediment in winter 2014–2015 and in winter 2015–2016.
Sediment Total organic matter Total C, N, S, P Grain size (phi)	7.6 cm diameter × 2 cm deep sediment cores processed in lab	Two samples collected at each marsh placement and control site during each sampling event. There were five sampling events in 2015 (Avalon and Ring Island only) and in 2016, two sampling events in 2017, and one in 2019. Samples from 2019 were not analyzed for P content due to Covid-19 restrictions. No baseline data were collected. Samples were collected in the same small area each time, except in 2019 when two separate placement sites were sampled. The placement site at Avalon received sediment in winter 2014–2015 and in winter 2015–2016.

Monitoring Design

The benthic infauna and associated sediment properties listed in Table 26 were monitored by Rutgers University. Ten benthic infauna samples and two soil samples were collected at each marsh placement and control site during each sampling event. There were five sample events in 2015 (Avalon and Ring

Island only) and 2016, two sample events in 2017, and one in 2019. Sample locations were in the same dredged material placement area at each project site, over time and were co-located with a vegetation plot. Given the heterogeneous nature of Avalon and Fortescue, the samples are not necessarily representative of the entire project site. This is especially true at Avalon, where conditions were the most heterogeneous. All of the samples were collected after the dredged material had been placed so only placement and control sites can be compared.

Results

Benthic Infauna

Ring Island

19 taxa were collected in the control area over all four years. Diversity was low; four taxa accounted for 97% of all individuals (Figure 48). There were little to no signs of recovery or recolonization of the placement area from 2015 through 2017. In 2019, the abundance of the opportunistic polychaete *Capitella* in one of the placement areas was similar to the control area.

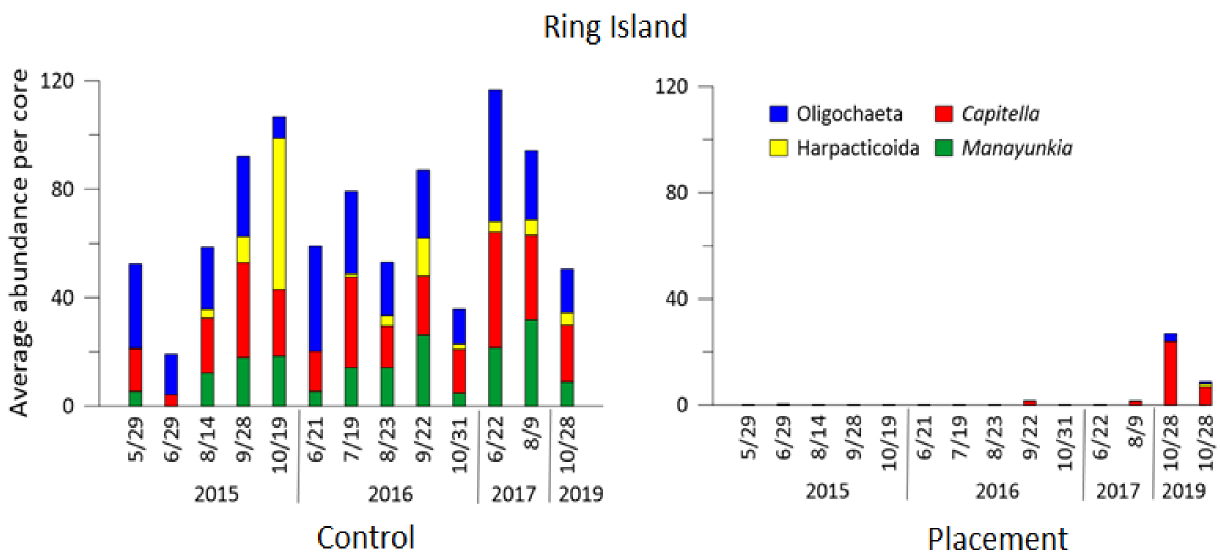

Figure 48. *Average abundance per core of the dominant benthic infauna taxa in control and placement areas at the Ring Island thin-layer project site. All samples were collected after placement occurred in 2014. The duplicate dates in the 2019 Placement bargraphs represent the two Placement areas that were sampled.*

Avalon Phase 2

21 taxa were collected in the control area over all four years. Diversity was low; five taxa accounted for 96% of all individuals (Figure 49). The Avalon "placement" samples were taken from Area C. This area had initially received dredged material in 2015 and again in 2016; therefore, the 2016 data is categorized as "one-year post-placement". The abundances of benthic infauna were minimal in 2015 and through September 2016. In October 2016, *Harpacticoida* began colonizing the area, with a mean abundance greater than those in the control area. The colonization by these small benthic copepods was coincident

with the appearance of *Capitella.* This may indicate facilitation of settlement by *Harpacticoida* by *Capitella*. These worms bind sediment particles with mucus to construct a 'tube' they reside within, and the copepods were found in large numbers within the mucus-sediment matrix.

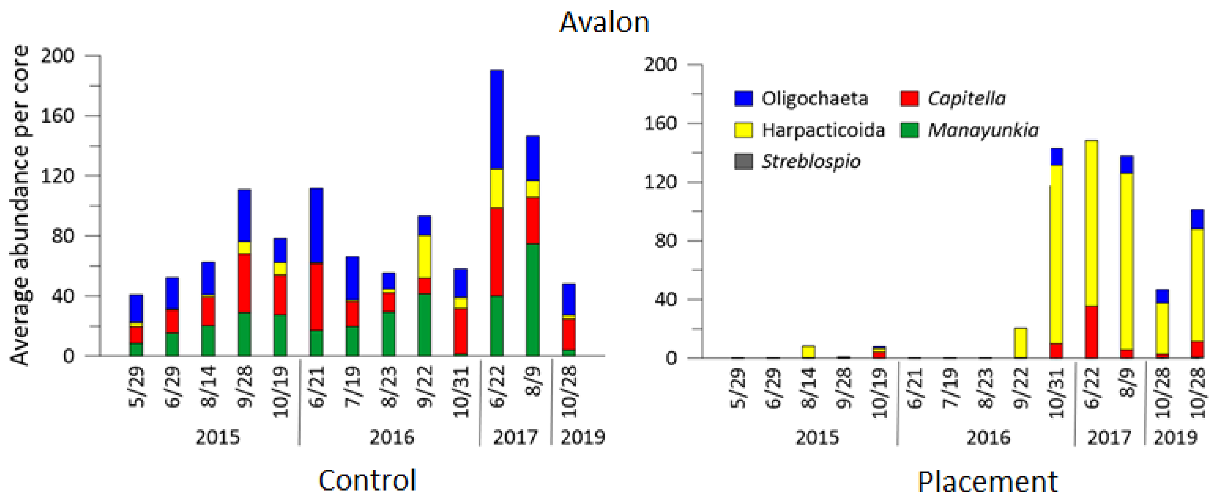

Figure 49. *Average abundance per core of dominant taxa in control and placement areas at the Avalon project site. The placement area sampled received sediment in the winter of 2014-2015 and winter 2015-2016. The duplicate dates in the 2019 Placement bargraphs represent the two Placement areas that were sampled.*

Fortescue

17 taxa were collected in the control area over all three years. Diversity was low; five taxa accounted for 96% of all individuals (Figure 50). There were no signs of recovery or recolonization in the placement area one-year post-placement (2016). Two years post-placement (2017) *Capitella* and *Harpacticoida* were found in the sampled placement area in numbers that were greater than those in the control area in the June sample. *Oliogochaeta* were also present but in lower abundance than in the control area. Numbers declined in the

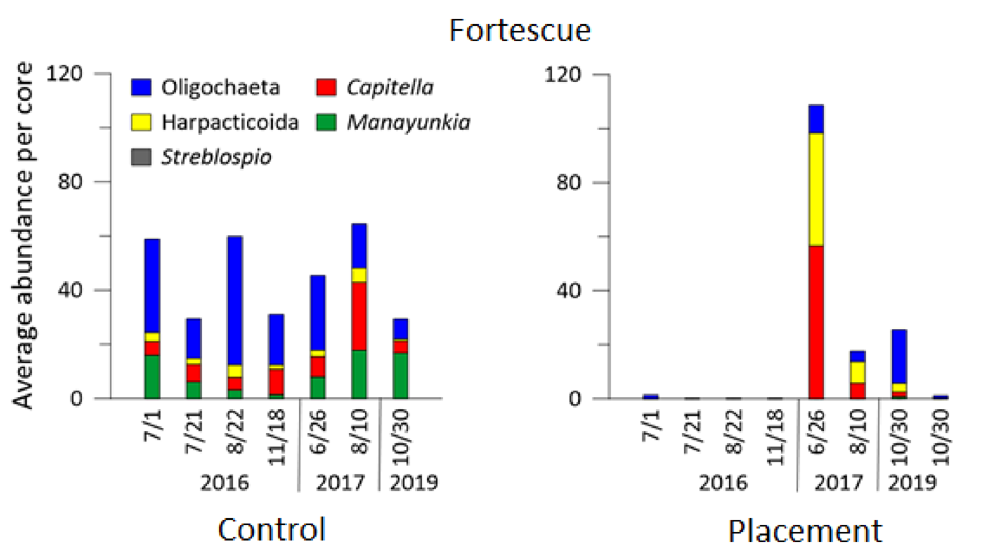

Figure 50. *Average abundance of benthic infauna per core of dominant taxa in control and placement areas at the Fortescue project site. All samples were collected after sediment was added in in the winter of 2015-2016. The duplicate dates in the 2019 Placement bargraphs represent the two Placement areas that were sampled.*

August samples, but all three taxa were present. In 2019 there were few infauna in one of the placement areas while the total abundance in the second placement area was similar to the control.

Sediment Properties

In the soils associated with the benthic infauna cores, soils in all marsh control areas were approximately 90% silt and clay (Figure 51). It was expected that placement areas had similar baseline conditions. In the soils associated with the benthic infauna cores, post-placement sediment had a much lower silt and clay content. Ring Island placement sediment was dominated by fine sand. Placement sediment at Avalon had 80% silt and clay when sampled in the summer and fall of 2015, but in 2016 and 2017 very fine sand and fine sand were the dominant size fractions. The area where samples were collected at Avalon received sediment additions in the winters of 2014 and 2015. Sediment was dredged from different parts of the navigation channel from one year to the next which is likely why the sand content of the sediment increased from 2015 to 2016. In 2019, Avalon placement sediment was again dominated by silt and clay. Fortescue placement area sediment had greater medium and coarse sand content than the other marsh locations.

Sediment sample sizes were low and the spatial distribution of the samples was limited to the same general location each time. This likely means that there was greater variability than is captured here. For

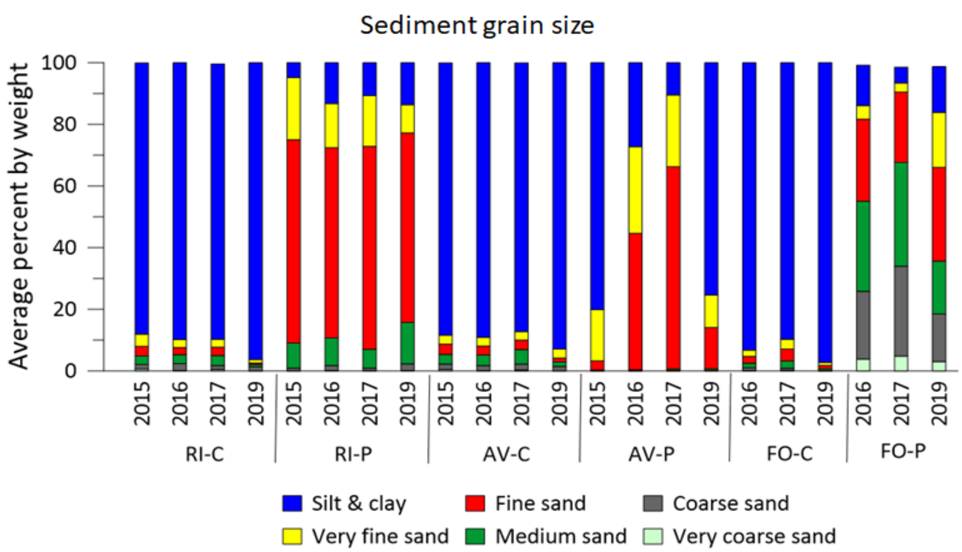

Figure 51. *Sediment size distributions at Ring Island (RI), Avalon (AV), and Fortescue (FO) post-placement in Control (C) and Placement (P) areas.*

example, based on navigation samples collected before dredging and a separate soils study conducted by Princeton Hydro at Avalon, there was a higher silt content in placed sediments than is reflected by the data. As a result, the sediment data collected at Avalon is not representative of the larger site and should only be used to interpret the associated benthic infauna data.

In sediment samples associated with benthic infauna cores collected post-placement, total organic matter, total carbon, total nitrogen, and total phosphorus concentrations were all much lower in placed sediments than in the controls (Figure 52). Sulfur concentration in the Avalon placement site sediment was similar to the control site. Ring Island placed sediment had lower sulfur concentration than the control

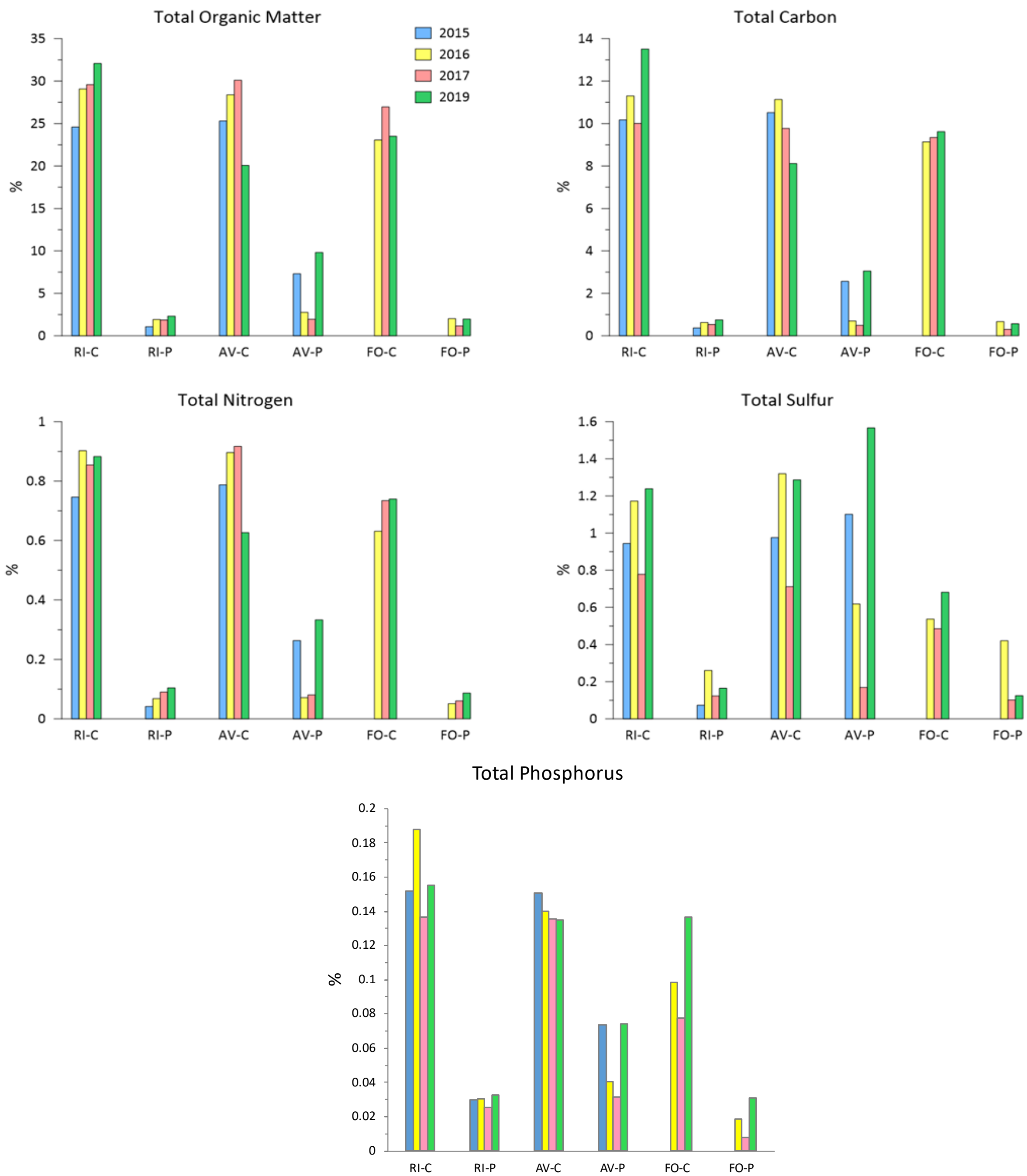

Figure 52. *Total Organic Matter, Carbon, Nitrogen, Sulfur, and Phosphorus concentrations of sediments at Ring Island (RI), Avalon (AV), and Fortescue (FO) post-placement in Control (C) and Placement (P) areas.*

in all years. The sulfur concentration of placed sediment at Fortescue was similar to control sediment in 2016, then decreased substantially in 2017 and 2019.

Conclusions

- There was an immediate decline in the abundance of all benthic infauna across all three sites, most likely attributed to mortality via direct burial. The Ring Island site showed minimal signs of recovery of any taxa four years post-placement. In 2019, the abundance of the opportunistic polychaete *Capitella* in one of the placement areas was similar to the control area. Taxa well suited to disturbed environments began to recolonize the sediment at the Avalon site in August one-year post-placement, and at the Fortescue site in June two-years post-placement. While abundance was similar between placement and control sites at Avalon and Fortescue in 2019, the proportion of taxa making up the cores remained different.
- Nutrient levels were generally lower in all placement sites compared to controls, except in Avalon, where sulfur concentrations tended to be higher in 2015 and 2019 samples from placement areas.
- Differences in the recovery response of the benthic infauna community may be attributed to differences among the placement sites (acreage of placement, time of construction, elevation, grain size, and composition of the material, etc.).
- It was expected that the placed sediments would bring nutrients into the marsh. However, based on a limited sample size from sandy sediments, this was not the case. One potential reason for this may be the coarse grain size of the sediment samples. Sands contain less nutrients and contaminants than silts as they consist of little to no organic matter.
- A larger sample size and broader spatial distribution of samples are recommended for future projects.
- Based on these results, we can address the following monitoring questions: 1) “Does the marsh ecosystem (i.e., structure and functions) recover or show uplift within two to three years of dredged material placement? (And the related “How long does it take for the marsh to recover and achieve uplift?”)” and 2) “Did differences in structural factors (e.g., grain size, elevation, placement thickness) correlate with recovery and uplift?”
    - 1) Ring Island surveys showed only minor recovery in population counts after five years post-placement. Avalon did have significant recovery in benthic infauna counts four years post-placement, nearly matching total counts in the control areas. However, there was a large shift in diversity, with fewer taxa represented post-placement. Fortescue had mixed results, with some surveys demonstrating high population counts and others with very low counts post-placement. There were additional diversity shifts in Fortescue populations post-placement, with fewer taxa represented in treated areas. For Ring Island and Fortescue, it may take several more years for populations to match and exceed previous conditions. Avalon, however, seems to have been successful in recovering its benthic infauna populations.
    - 2) All nutrient levels, except sulfur concentrations in Avalon, were decreased in placement

areas. This exception of sulfur in Avalon may be a potentially important parameter in benthic infauna recovery. This relates to the importance of sediment grain size and composition. Smaller grain-sized sediments are likely to impart more nutrients than sandier sediments, which may be a significant factor in the speed of marsh recovery after placement.

10. Avian Monitoring

Samantha Collins[1], Brittany Morey[1], Lisa Ferguson[1], Allison Anholt [1], and Princeton Hydro
[1]The Wetlands Institute

Coastal salt marshes provide habitat for many species of birds during nesting and migration with abundant food resources and low levels of human disturbance and mammalian predators. Avian species on the State and Federal Threatened and Endangered Species Lists use these areas for foraging, resting, and nesting. Some listed species documented in this project include black rails (*Laterallus jamaicensis*), black skimmers (*Rynchops niger*), red knots (*Calidris canutus*), and least terns (*Sternula antillarum*).

Monitoring Design

Avian surveys were performed seasonally at all three project sites in dredged material placement and control areas (Table 27) to assess the impacts of using dredged material for enhancement purposes on the avian community. Monitoring was conducted by The Wetlands Institute and Princeton Hydro. At Ring Island only, additional wildlife use surveys of the thin layer placement (TLP) areas and the elevated nesting habitat (ENH) were performed weekly from April through August. All final survey locations were chosen in the field based on accessibility and within major habitat types: low marsh, high marsh, pools, pannes, and control, and placement areas.

Table 27. *Metrics, method, and design for avian monitoring at all three project sites. The Before-After Control-Impact (BACI) design was utilized at Avalon (AV) and Fortescue (FT); 'Before' surveys were not performed at Ring Island (RI) due to timing restrictions.*

Metrics	Method	Design
Species Richness (SCj) Species Abundance Species Composition	Point Count and Playback-Response Surveys (Spring, Summer, Fall; AV, FT, RI)	B-A-C-I (AV & FT): Four placement and three control points were surveyed one time per season 2015-2017 Control-Impact (RI): Two placement and eight control points were surveyed two times per season 2015-2017; Four of these points (two placement and two control) were surveyed two times per season 2018-2019
Nest Status Predation Risk Number Location Behavior of Birds	Weekly surveys (April-August; RI)	Wildlife Use and Nesting Success Surveys (RI): Conducted at placement and control areas 2015-2019

The goals of the surveys were to (1) document which bird species use the dredged material placement areas during Spring, Summer, and Fall seasons in comparison to control areas and surrounding marsh, and (2) document how species of birds and other wildlife use the placement areas, and the marsh as a whole, during the breeding season.

Results

Ring Island

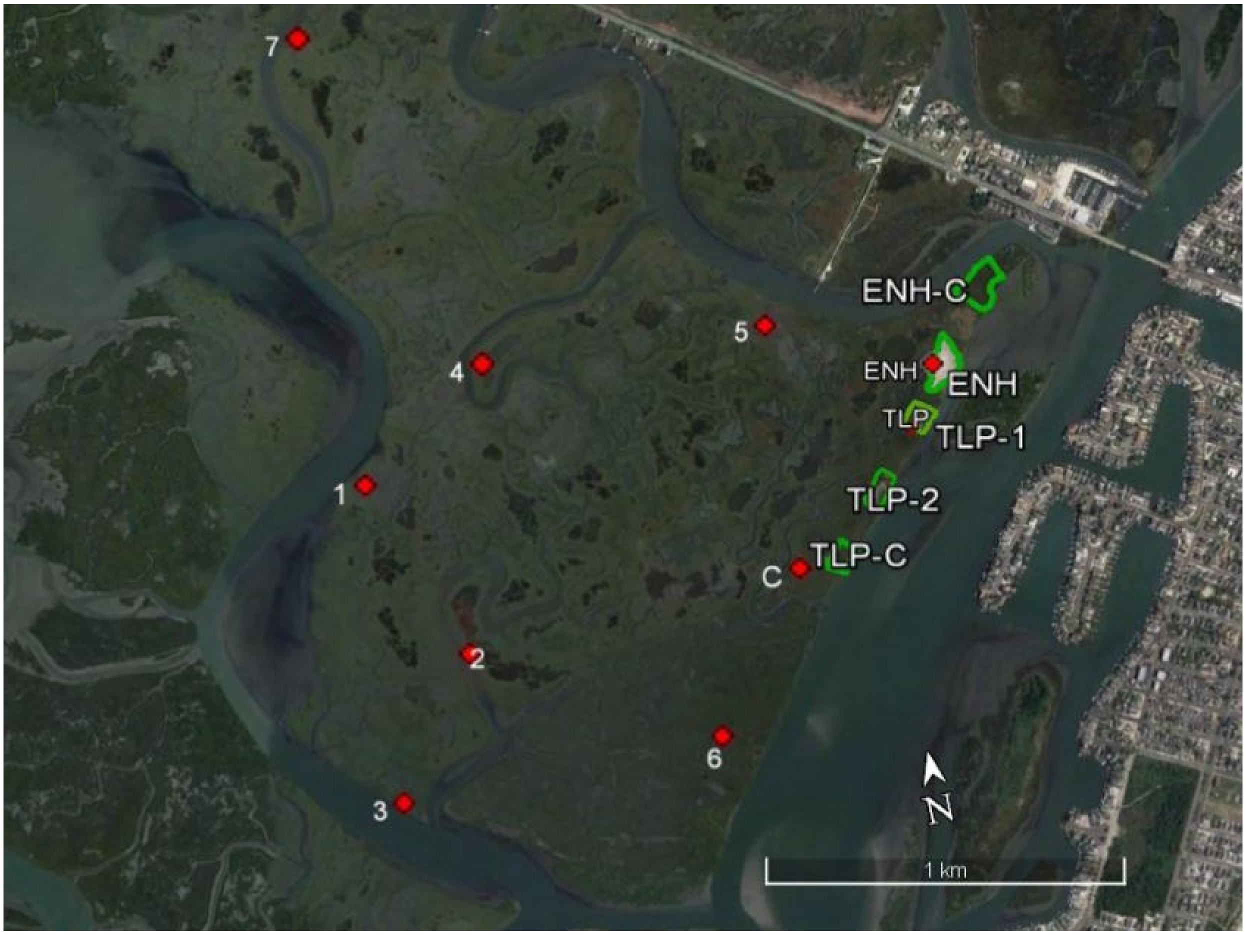

Figure 53. *Ring Island point-count locations for avian surveys indicated by red dots (N= 10; 2015-2017): Thin Layer Placement site (TLP), Elevated Nesting Habitat (ENH), and eight control points (C, 1-7). Four of these points (TLP, ENH, C, and 5) were surveyed in 2018-2019. Areas surveyed for wildlife use and nesting (2015-2019) indicated by green polygons: Thin Layer Placement areas (TLP 1 & 2), Elevated Nesting Habitat (ENH), and two Control sites (TLP-C and ENH-C). TLP point-count location is located within TLP-1.*

All surveys at Ring Island were conducted post-construction so placement areas (ENH and TLP areas) were compared to control areas, shown in Figure 53. A total of 72 species from 8 guilds were documented during point-count surveys (Guild and number of species: Gull: 4; Passerine: 23; Piscivore: 8; Rail: 1; Raptor: 5; Shorebird: 18; Wader: 8; Waterfowl: 5; Figure 54). The most abundant species was the Laughing Gull (*Leucophaeus atricilla*), which nests in large numbers on Ring Island and was documented at placement and control points. Clapper Rail (*Rallus crepitans*) was the only Rail species documented. Figure 55 shows the mean seasonal species richness at points surveyed in 2015-2019. A subset of the ten original points surveyed in 2015-2017 was included for continued monitoring (points TLP, ENH, C, 5; 2018-2019).

Species richness was affected by point, season, year, and their two-way interactions in a least squares means analysis of the 10 points surveyed 2015-2017 ($F = 10.9$, $df = 17,72$, $p < 0.01$; Figure 55). Species

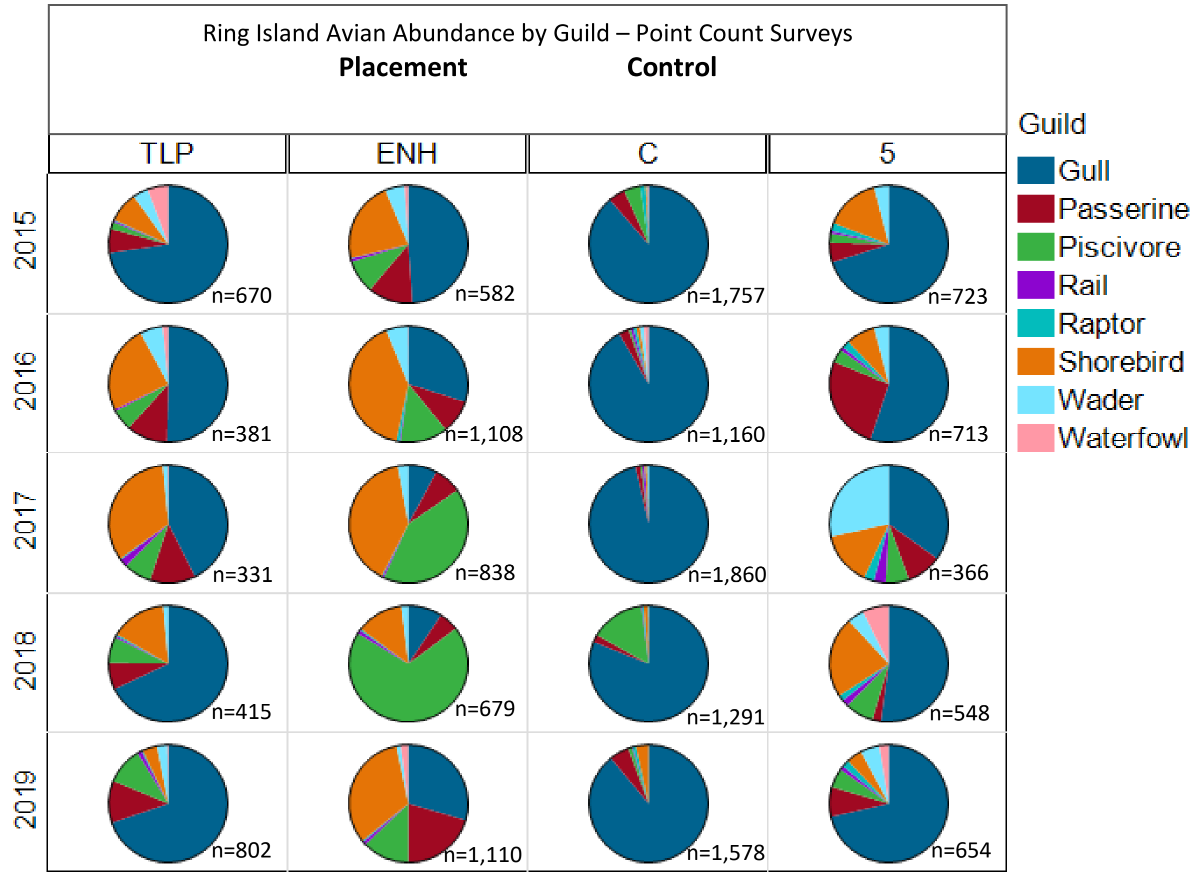

Figure 54. *Avian abundance by guild at Ring Island placement points (left) and control points (right) 2015-2019; n =total birds counted during surveys.*

richness varied by survey point (F = 18.8, df = 9, $p < 0.01$), with a greater number of species using the ENH area compared to other points. TLP fell in a mid-range of species richness with five control points. Seasonal and annual effects interacted (F = 3.4, df = 4, $p < 0.05$), which was due in part to high annual variability during fall surveys. No other effects were significant (all $p > 0.05$). These relationships were examined in a separate least squares means analysis of the four points surveyed over five years and similar results emerged (F = 8.5, df = 17,42, $p < 0.01$). Species richness varied by point (F = 35.1, df = 3, $p < 0.01$), and was highest at ENH, fell in the mid-tier at TLP and control point 5, and was lowest at control point C. Year and season had a significant interactive effect (F = 2.8, df = 8, $p < 0.05$). The proportion of birds belonging to each guild varied among the four points, shown in Figure 54. The high abundance and low species richness of point C are due to its proximity to high-density nesting area for Laughing Gull. The TLP point also had a large proportion of gulls but was used by a greater proportion of species belonging to other guilds, including 13 species of shorebirds. Species richness and the guild composition of species using the TLP was most similar to point 5, which is located near a panne that attracted a variety of species including 13 shorebird species. The guild composition of the ENH point is reflective of high species richness at the point, and a large proportion of piscivores (Black Skimmers and terns species) nest on the site in most years following construction. The ENH point was also used by a diversity of species during spring and fall migration and had the greatest diversity of shorebirds, at 16 species.

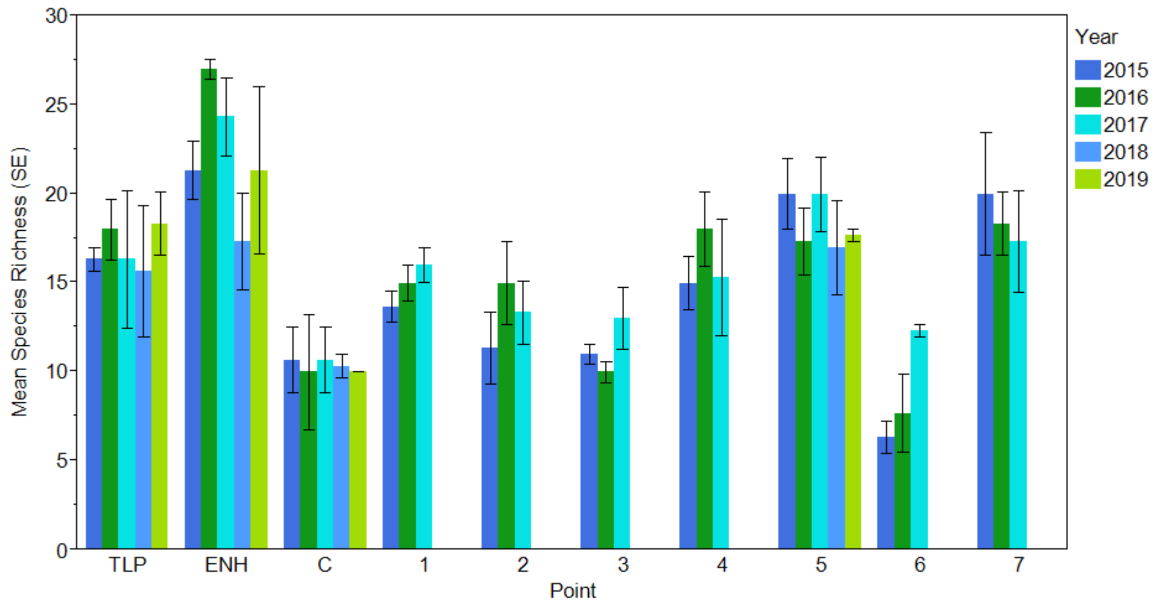

Figure 55. *Mean species richness counted within 100m at 10 observation points during point-count avian surveys at Ring Island, 2015-2019. Two surveys were conducted per season (Spring, Summer, Fall). Only four points were surveyed in all years. Error bars represent one standard error.*

Table 28 shows the number of breeding pairs, nests, and reproductive metrics documented during weekly surveys from April - August 2015-2019. Nests of nine species were documented in the study areas and a portion was monitored weekly. Black Skimmers nested on the ENH site beginning the third year following construction, and tern species nested on the site in all years of the study. Only two species were confirmed nesting on the ENH in 2019, the fewest since construction, while the number of species nesting in the TLP areas was the highest over five years. Predation of nests by Eastern Red Fox (*Vulpes vulpes*; 2017 and 2019) and Fish Crows (*Corvus ossifragus*; 2016-2019) reduced reproductive outcomes at placement and control sites. Several monitored nests were lost to flooding over the monitoring period. These nests were located in control and TLP areas or in areas of low elevation on the ENH (*i.e.*, not the nesting platform). The establishment of mixed species of vegetation on the ENH nesting platform reduced habitat quality beginning in 2018 and was adaptively managed with fire, sediment placement, mechanical and hand removal, and saltwater solution. The ENH provided nesting habitat for diamondback terrapins *Malaclemys terrapin*) and spawning horseshoe crabs *(Limulus polyphemus*).

Table 28. *Number of breeding pairs, nests, apparent hatch success (% nests that hatched ≥1 egg), and productivity (number of chicks fledged/pair) from Elevated Nesting Habitat (ENH), Thin Layer Placement (TLP-1 and TLP-2), and control areas (TLP-C and ENH-C) study areas on Ring Island, 2015-2019. Metrics for colonial nesting species (Black Skimmer, Laughing Gull, Common Tern (Sterna hirundo), and Least Tern (Sternula antillarum)) represent minimum estimates. Unk=Unknown; NE=Not Evaluated.*

Metric	**Breeding Pairs**					**Nests**					**Hatch Success (%)**					**Productivity**				
Year	2015	2016	2017	2018	2019	2015	2016	2017	2018	2019	2015	2016	2017	2018	2019	2015	2016	2017	2018	2019
ELEVATED NESTING HABITAT																				
Black Skimmer	0	0	37	12	10	-	-	51	13	0	-	-	25.5	23.0	-	-	-	0.1	0	-
Common Tern	0	0	85	200	110	-	-	100	200	132	-	-	32.0	42.5	0	-	-	0.6	0.2	0
Least Tern	2	16	24	4	0	2	16	33	6	-	100	56.3	57.6	0	-	1.5	0.3	1.3	0	-
Great Black-backed Gull	1	1	1	0	0	1	1	2	-	-	100	100	0	-	-	2.0	1.0	0	-	-
American Oystercatcher	2	1	4	3	2	3	2	6	3	0	67	50	50	100	-	2.5	2.0	1.5	0.7	-
Willet	0	1	2	1	3	-	1	2	1	3	-	100	0	100	0	-	NE	0	NE	0
Clapper Rail	0	1	0	0	0	-	1	-	-	-	-	100	-	-	-	-	NE	-	-	-
Seaside Sparrow	0	0	1	0	0	-	-	1	-	-	-	-	0	-	-	-	-	0	-	-
THIN LAYER PLACEMENT																				
Laughing Gull	5	9	0	0	10	5	9	-	-	9	NE	100	-	-	22.0	NE	NE	-	-	0
American Oystercatcher	0	0	1	0	1	-	-	1	-	2	-	-	0	-	0	-	-	0	-	0
Clapper Rail	2	5	0	0	5	2	5	-	-	5	50.0	80.0	-	-	60.0	NE	NE	-	-	NE
Seaside Sparrow	0	0	0	0	2	-	-	-	-	2	-	-	-	-	0	-	-	-	-	0
CONTROL AREAS																				
Great Black-backed Gull	0	0	0	1	0	-	-	-	1	-	-	-	-	Unk	-	-	-	-	NE	-
Laughing Gull	0	20*	175	37*	125	-	20*	175	37*	150	-	85.0	85.7	54.0	27	-	NE	1.8	NE	0.2
American Oystercatcher	1	0	0	1	0	1	-	-	1	-	0	-	-	0	-	0	-	-	0	-
Clapper Rail	2	1	2	4	4	2	1	2	4	4	50.0	Unk	Unk	Unk	Unk	NE	NE	NE	NE	NE

*Only includes nests monitored, not total number of nests and breeding pairs in area

Avalon

In 2015, before the placement of dredged material, species richness varied by survey point, with placement areas exhibiting similar to or greater richness than the control areas (Figure 56). In 2016, 1-year post-placement, richness declined at all control survey points and generally increased at all placement survey points. Richness increased within the control areas in 2017, two-years post-placement, whereas richness generally decreased within the placement areas.

In the control areas, species richness increased significantly between 2016 and 2017 ($p < 0.05$); however, no significant change in species richness was detected in the placement areas between 2015, 2016, and 2017. When comparing control areas to placement areas, species richness was significantly higher ($p <$

0.05) in the placement areas in 2016 (one-year post-placement).

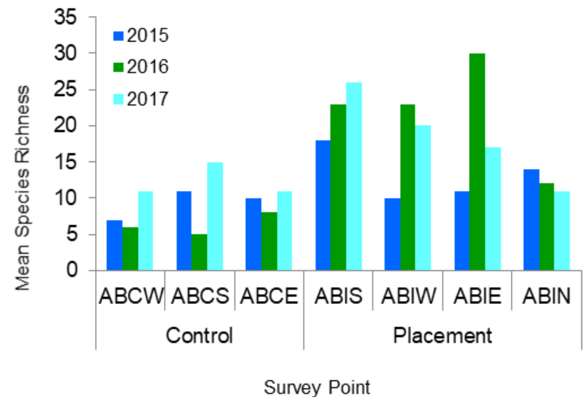

Figure 56. Avian species richness at Avalon by survey point pre-placement (2015) and post-placement (2016 and 2017) during point-count avian surveys.

Fortescue

Figure 57 presents avian species richness at Fortescue in placement and control areas pre-placement (2015) and post-placement (2016 and 2017). No statistically significant change in avian species richness was detected within control or placement areas throughout all three years, or between control and placement areas throughout all three years.

At Fortescue, the proportion of individuals belonging to each guild shifted between years in both the control and placement areas. When interpreting the following percentages, it is important to note the total birds counted during the survey efforts, as these vary widely.

Within the control areas, between 2015, 2016, and 2017, there was a shift in the gull community (3, 32, and 10% respectively), and a sharp decline in the rail community (31, 2, and 2% respectively). Passerines declined from 2015 to 2016, then nearly doubled in 2017 (38, 22, and 53% respectively), while wading birds increased from 2015 to 2016, then decreased in 2017 (9, 21, and 4% respectively). Shorebirds increased within the control area from 2015 to 2017 (4, 13, and 16% respectively).

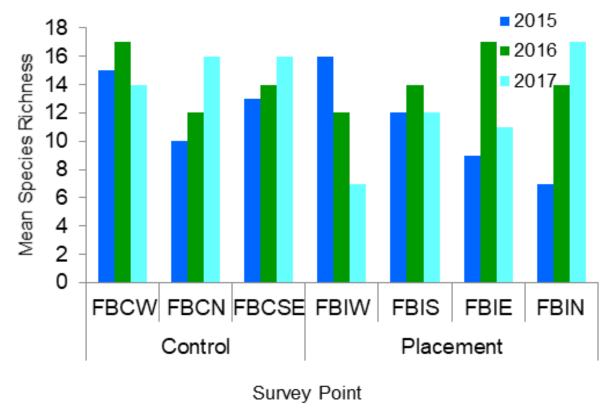

Figure 57. Avian species richness at Fortescue by survey point pre-placement (2015) and post-placement (2016 and 2017) during point-count avian surveys.

Within the placement areas, there were shifts in the rail, gull, and passerine guilds (2015 is baseline data, PRE placement of dredged material). Rails declined from 2015 to 2017 (25, 2, and 1%) at placement and control sites, while the proportion of gulls increased dramatically from 2015 to 2016 (5 to 55%), then decreased dramatically from 2016 to 2017 (55 to 7%). Passerines (sparrows, swallows, blackbirds, starlings, crows, wrens, grackles) declined dramatically from 2015 to 2016 from 60 to 21% then increased dramatically from 2016 to 2017 from 21 to 55%. All other guild proportions remained similar between years, though a small increase in shorebirds is noted within placement areas from 2015 to 2017 (2, 13, and 14% respectively).

Conclusions

- The placement of dredged material on the marsh surface initially made acute changes to the habitat available to birds using each project site.

- Shorebirds increased in abundance post-placement, most likely due to the creation of open, sparsely vegetated areas, which they prefer for foraging and resting.
- Marsh-dependent species, such as clapper rail (*Rallus crepitans*), willet (*Tringa semipalmata*), and seaside sparrow (*Ammodramus maritimus*), which require dense vegetation for nesting, were not recorded in large numbers in the placement areas at any of the sites post-placement, though a few pairs remained. These numbers started to rebound after two years post-placement. This could indicate that the species displaced by the placement of dredged material may return to the enhanced areas over time, as vegetation and other habitat components recover.
- Marsh-dependent species, including willet and seaside sparrows, nested in marsh vegetation at the Ring Island ENH that established on the site.
- The ENH site required vegetation management after three years from initial placement to maintain habitat for species initially targeted by the design.
- The TLP areas supported fewer species and fewer nests compared to the ENH, but the number of species nesting in these areas increased over the five-year monitoring period. Reproductive success was also lower, but the reproductive outcomes were comparable to control areas in the marsh.
- Based on these results, we can address the following monitoring questions: 1) "Does the marsh ecosystem (i.e., structure and functions) recover or show uplift within two to three years of dredged material placement? (And the related "How long does it take for the marsh to recover and achieve uplift?")" and 2) "Did differences in structural factors correlate with recover and uplift?"
    - 1) Avian populations overall demonstrated a quick response to placement treatments, with counts increasing at both Ring Island and Avalon within a short timeframe. At Ring Island, multiple species nested on the elevated nesting habitat in all years and within the thin-layer placement areas in four of the five years monitored. Reproductive success at ENH was high in all years except 2019 when predation was high, and the nesting platform became densely vegetated. Black skimmers and least terns, both endangered species in New Jersey, and a large colony of common terns nested successfully in two to three years. Avalon demonstrated significant increases in avian populations within one-year post-placement, and Fortescue populations were insignificantly different between control and placement areas in all years of monitoring.
    - 2) The habitat shifts caused by placement resulted in changes in species presence, resulting in increases in species that preferred open, bare habitat for foraging. More secretive species that prefer dense vegetation were negatively impacted at first. Elevation and corresponding vegetation cover were found to be important factors in avian population recovery and uplift.

11. Nekton Monitoring

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Salt marsh nekton communities encompass an array of species that aid and contribute to the local estuary ecosystem. Nekton are defined as organisms that are free-swimming fish, shrimp, and crabs (Raposa & Talley, 2012). Nekton take advantage of particular habitats at different life-history stages in salt marshes for foraging, reproduction, refuge from predation, and overwintering (Litvin and Weinstein, 2003). Utilizing ubiquitous quantities of habitats within a salt marsh, nekton communities are able to allocate the transition of energy to other regions of an estuary. Nekton species are ubiquitous, diversified, and abundant within salt marshes and provide essential food resources for opportunistic avian fauna and economically important fishery species (Barbier et al., 2011). Natural salt marsh degradation and human influences have impacted the life history of nekton. Upon successful tidal salt marsh restoration practices, marshes should experience improved hydrologic and biogeochemical components that would promote nekton habitat functions and aggregations associated with high species diversification found in natural salt marsh ecosystems (Raposa & Talley, 2012).

Monitoring Design

Nekton surveys were conducted during the growing seasons in 2015 (preplacement), 2016, and 2017 (both post-treatment) at Avalon and Fortescue. Sampling occurred during the annual vegetative growing season in September 2015, from August-November in 2016, and July-August 2017. These sampling events were correlated with spring tide events to ensure periods of active site use rather than diapause or reduced tidal inundation. Replicated sampling around the middle to late vegetative growing season also allowed time for the restored placement habitats to stabilize and partially revegetate after the short-term impacts of sediment placement. Each sampling event consisted of 40 or more sampling locations and took roughly five days to complete. A sampling day varied substantially given the number of sampling locations, the extent of processing, as well as the logistics (e.g., sampling at proper water depths for ebbing and flooding) of accessing and moving about the project sites. The metrics collected during sampling events are listed in Table 29.

Table 29. *Design and Metrics used for Nekton Monitoring at Avalon and Fortescue, NJ.*

Design	Metrics
B-A-C-I and Site-Specific Habitat (Pools, Marsh Shoreline, Subtidal Creek, Tidal Creek)	Species Abundance Species Density Species Richness Length
Water Quality	Temperature Salinity Dissolved Oxygen

Nekton monitoring followed a stratified random sampling design. Sampling was divided into two categories, control (i.e., controls) and enhanced (i.e., experimental) treatment sites at four habitats on a coastal salt marsh. Control locations are identified as locations unaffected by salt marsh enhancement, while enhanced sites included the beneficial placement of thin-layer dredged material to combat salt marsh subsidence and increase elevation. The site-specific habitats included: 1) marsh pools, 2) subtidal creeks and/or marsh ditches, 3) tidal creeks, and 4) the marsh shoreline edge. Five sample points in both control and enhanced categories were selected at random within each habitat. A total of 40 or more sampling locations were investigated per sampling event depending upon the location of dredged material during salt marsh enhancement. Candidate sample locations were determined before fieldwork but assessed and selected in the field. Sampling was repeated at the same location during post-placement sampling events where dredged material has not altered features that resulted in areas without surficial hydrologic activity. If a control sampling location became influenced by dredged material during restoration, it was changed and categorized as an enhanced sampling location. If restoration altered extant habitats, new sample locations were selected at random in the field within the affected habitat strata for post-placement sampling events.

Nekton were sampled using a standard 1.0 m x 1.0 m x 0.5 m throw trap with a 1.0 m x 0.5 m dip net for sampling large open bodies of water such as salt marsh pools, tidal creeks, and the marsh shoreline edge. Standardized ditch nets were also constructed and used for sampling narrow tidal channels and mosquito ditches up to 1.0 m wide with a depth of 1.0 m (Neckles et al., 2013; James-Pirri et al., 2012). Temperature, salinity, and dissolved oxygen were taken with a Hydrolab Quanta Multi-Probe Meter in concurrence with nekton sampling. It is important to indicate that water quality was only taken in marsh pools prior to the deployment of the throw trap. Water quality taken before sampling in marsh pools was done to minimize disturbance of sediment resuspension. All other water quality measurements for each habitat (i.e., tidal creeks, subtidal creeks, ditches, and the shoreline edge) were taken after deployment of the throw trap or ditch net. Before processing a throw trap, an estimation of vegetative percent cover and a direct measurement of water depth were evaluated for potential nekton habitat. Processing of throw traps consisted of sweeping a dip net through the throw trap until three consecutive dip net sweeps yielded a catch of zero nekton. Ditch traps were deployed for at least 30 minutes before retrieval and processing. Ditch nets were also measured for the dimensions of the trap to standardize nekton density calculations with throw traps.

Results

Results of these nekton surveys were published as part of a Master of Science thesis by Evan T. Kwityn,[11] and only the main results are discussed here.

In 2015, before salt marsh restoration, there were no significant differences between restored and unrestored treatment, or habitat locations for Avalon, New Jersey. Daggerblade grass shrimp (35%) were the dominant species, but other principal fish species, such as Atlantic silversides (23%), mummichogs (16%), and sheepshead minnows (16%) also demonstrated relatively high densities and abundance (Table 30).

At Fortescue, there were no significant differences between restored and unrestored treatment locations or habitats within the 2015 dataset (Table 31). Unlike Avalon, the nekton community at Fortescue was dominated by mummichogs (70%). The nekton community at Fortescue was also comprised of

[11] Assessing the Influence of Salt Marsh Enhancement on Nekton Communities (montclair.edu)

daggerblade grass shrimp (22%), Atlantic silversides (10%), and sheepshead minnows (8%). It is important to note that only one sampling event was conducted at each site (i.e., Avalon and Fortescue, NJ) and is likely not an accurate representation of the annual nekton assemblage for 2015.

Table 30. *Average nekton density (number of individuals per m² ± standard error) in control and placement areas at Avalon, NJ for 2015-2016.*

Species (Common Name)	*Site Avalon 2015 Unrestored n=20*	*Site Avalon 2015 Restored n=20*	*Site Avalon 2016 Unrestored n=36*	*Site Avalon 2016 Restored n=54*
Fundulus heteroclitus (mummichog)	9.50 ± 5.34	9.00 ± 4.59	13.61 ± 7.11	7.29 ± 3.63
Fundulus majalis (striped killifish)	5.10 ± 2.07	4.95 ± 2.3	3.71 ± 1.12	10.48 ± 6.55
Lucania prava (rainwater killifish)	0	0	5.24 ± 2.41	0.40 ± 0.21
Menidia menidia (Atlantic silverside)	16.05 ± 9.73	16.75 ± 6.99	1.78 ± 0.91	1.81 ± 0.96
Palaemonetes pugio (daggerblade grass shrimp)	6.50 ± 2.99	26.20 ± 10.88	29.00 ± 7.03	19.31 ± 6.87
Carcinus maenas (green crab)	0	0.05 ± 0.05	0	0
Crangon septemspinosa (sevenspine bay shrimp)	0	0	0.07 ± 0.05	0.08 ± 0.08
Callinectes sapidus (blue crab)	0.75 ± 0.40	0.70 ± 0.51	0.73 ± 0.18	0.44 ± 0.17
Panopeus herbstii (Atlantic mud crab)	0.30 ± 0.25	0.05 ± 0.05	0.31 ± 0.11	0.1 ± 0.05
Cyprinodon variegatus (sheepshead minnow)	12.70 ± 6.33	1.95 ± 1.33	4.61 ± 1.42	1.85 ± 1.22
Gobiosoma bosc (naked goby)	0.05 ± 0.05	0	0.27 ± 0.16	0.1 ± 0.1
Mugil cephalus (striped mullet)	0.05 ± 0.05	0	0	0.02 ± 0.02
Uca pugnax (Atlantic marsh fiddler crab)	0	0.09 ± 0.08	0	0.06 ± 0.06
Micropogonias undulatus (Atlantic croaker)	0	0	0.02 ± 0.02	0
Pogonias cromis (black drum)	0	0.08 ± 0.08	0	0
Brevootia tyrannus (Atlantic menhaden)	0	0	0.10 ± 0.10	0
Syngnathus fuscus (northern pipefish)	0	0	0.05 ± 0.05	0
Total fishes	43.50 ± 15.35	33.33 ± 9.04	29.39 ± 7.84	21.96 ± 10.45
Total decapods	7.55 ± 2.95	27.91 ± 10.85	30.12 ± 7.07	19.98 ± 6.92
Total nekton	37.85 ± 15.28	54.50 ± 14.09	59.05 ± 10.04	41.44 ± 14.07

Nekton were collected throughout using a throw trap and ditch nets
Densities are not log transformed
n= Total number of sampling locations

Table 31. *Average nekton density (number of individuals per m² ± standard error) in control and placement areas at Fortescue, NJ for 2016.*

Species (Common Name)	*Site Fortescue 2015 Unrestored n=20*	*Site Fortescue 2015 Restored n=19*	*Site Fortescue 2016 Unrestored n=34*	*Site Fortescue 2016 Restored n=35*
Fundulus heteroclitus (mummichog)	25.68 ± 9.96	33.90 ± 12.86	3.59 ± 0.90	7.21 ± 3.67
Fundulus majalis (striped killifish)	0	0	6.71 ± 2.15	14.24 ± 7.78
Lucania prava (rainwater killifish)	0	0	2.18 ± 1.00	0.94 ± 0.54
Menidia menidia (Atlantic silverside)	3.05 ± 1.96	2.15 ± 2.05	1.03 ± 0.58	0.30 ± 0.20
Palaemonetes pugio (daggerblade grass shrimp)	6.86 ± 3.68	4.55 ± 2.33	34.50 ± 12.87	19.30 ± 9.86
Crangon septemspinosa (sevenspine bay shrimp)	0.77 ± 0.68	0	0.12 ± 0.12	0.67 ± 0.41
Callinectes sapidus (blue crab)	0.05 ± 0.05	0	0.94 ± 0.29	0.58 ± 0.19
Panopeus herbstii (Atlantic mud crab)	0.11 ± 0.08	0	0.09 ± 0.07	0.03 ± 0.03
Cyprinodon variegatus (sheepshead minnow)	3.32 ± 3.09	0.78 ± 0.59	2.62 ± 1.15	1.30 ± 0.88
Gobiosoma bosc (naked goby)	0	0	0.09 ± 0.07	0
Uca pugnax (Atlantic marsh fiddler crab)	0	0	0.09 ± 0.05	0
Micropogonias undulatus (Atlantic croaker)	0.14 ± 0.1	0.05 ± 0.05	0	0
Trinectes maculatus (hogchoker)	0	0	0.09 ± 0.07	0
Total fishes	32.18 ± 10.97	39.90 ± 13.39	16.29 ± 3.63	24.00 ± 11.61
Total decapods	7.77 ± 3.71	4.55 ± 2.33	35.74 ± 12.9	20.58 ± 9.93
Total nekton	34.09 ± 11.36	40.15 ± 14.09	52.03 ± 14.55	44.58 ± 14.84

Nekton were collected throughout using a throw trap and ditch nets
Densities are not log transformed
n= Total number of sampling locations

Table 32. *Total nekton abundance in tidal creeks, pools, subtidal creeks, and the shoreline edge at Avalon, NJ 2016.*

Species (Common Name)	2016 Avalon							
	Unrestored				Restored			
	Tidal Creek n=6	Pools n=12	Shoreline Edge n=10	Subtidal Creek n=8	Tidal Creek n=14	Pools n=18	Shoreline Edge n=10	Subtidal Creek n=12
Fundulus heteroclitus (mummichog)	22	21	499	8	122	6	4	210
Fundulus majalis (striped killifish)	32	68	32	12	135	22	2	343
Lucania parva (rainwater killifish)		214	1			14		3
Menidia menidia (Atlantic silverside)	6	66	1		57		26	5
Palaemonetes pugio (daggerblade grass shrimp)	300	179	657	52	394	5	403	112
Carcinus maenas (green crab)								
Crangon septemspinosa (sevenspine bay shrimp)	3				4			
Callinectes sapidus (blue crab)	13	10	5	2	9	8	4	
Panopeus herbstii (Atlantic mud crab)		2	7	2	1			3
Cyprinodon variegatus (sheepshead minnow)	6	179	4		21	60		8
Gobiosoma bosc (naked goby)	1		10		2		1	1
Mugil cephalus (striped mullet)	1				1			
Uca pugnax (Atlantic marsh fiddler crab)								3
Micropogonias undulatus (Atlantic Croaker)	1							
Brevootia tyrannus (Atlantic menhaden)	4							
Syngnathus fuscus (northern pipefish)			2					
Pogonias cromis (black drum)								

n= number of sampling sites within each habitat

In 2016 following the application of thin-layer dredged material, an additional sampling event was conducted at both Avalon and Fortescue, NJ. This additional sampling event made a total of two sampling events per site per year. Sampling at Avalon, NJ was held during the middle and end of the annual growing season, during August and October of 2016.

At Avalon, there were significant differences between datasets (e.g., restored vs. unrestored) for percent cover for nekton density (Table 32). The most significant habitat among restored and unrestored treatments observed at Avalon was found between marsh pools. Unrestored salt marsh pools contained 739 nekton individuals and restored salt marsh pools contained 115 nekton individuals. Among restored marsh pools sheepshead minnows occupied the highest total abundance of 60 individuals. Daggerblade grass shrimp (47%) were observed to be the most dominant nekton and decapod species. Mummichogs (20%), striped killifish (15%), and sheepshead minnows (6%) encompassed the majority of the nekton community at Avalon.

In 2016, Fortescue displayed significant nekton density among all habitats (e.g., marsh pools, ditches, tidal creeks, and the marsh shoreline) (Table 33). However, no significant trends in nekton density were observed between restored and unrestored salt marsh restoration treatments. The most dominant nekton species at Fortescue was daggerblade grass shrimp (56%). Other common nekton species observed at Fortescue included striped killifish (22%), and mummichogs (11%).

In 2017 at Avalon there was a total of 12 (i.e., 8 fish and 5 decapod species) nekton species observed (Table 34). Fish species consisted of 63% and decapods consisted of 37% of the nekton community. The most dominant species was the daggerblade grass shrimp (34%). Other common nekton species observed at Avalon included striped killifish (28%), sheepshead minnow (13%), and mummichogs (10%).

At Fortescue in 2017, there was a total of 10 (i.e., 6 fish and 4 decapod species) nekton species observed (Table 35). Fish species consisted of 41% and decapods consisted of 59% of the nekton community. The most dominant species was the daggerblade grass shrimp (58%). Other common nekton species observed at Fortescue included striped killifish (19%), mummichogs (9%), Atlantic silverside (6%), and sheepshead minnow (5%).

Additional data and figures can be found in Appendix B.

Table 33. *Total nekton abundance in tidal creeks, pools, subtidal creeks, and the shoreline edge at Fortescue, NJ 2016.*

Species (Common Name)	2016 Fortescue							
	Control				Treatment			
	Tidal Creek n=5	Pools n=10	Shoreline Edge n=9	Ditch n=10	Tidal Creek n=5	Pools n=10	Shoreline Edge n=10	Ditch n=8
Fundulus heteroclitus (mummichog)	41	39		42	168	36	1	33
Fundulus majalis (striped killifish)	51	108	2	67	283	88	4	95
Lucania prava (rainwater killifish)		73		1		18		13
Menidia menidia (Atlantic silverside)	2	13	20		9		1	
Palaemonetes pugio (daggerblade grass shrimp)	384	671	63	55	221	102	310	4
Carcinus maenas (green crab)								
Crangon septemspinosa (sevenspine bay shrimp)			4			10	12	
Callinectes sapidus (blue crab)	2	11	15	4	5	4	10	
Panopeus herbstii (Atlantic mud crab)	1			2				1
Cyprinodon variegatus (sheepshead minnow)		80		9		31		12
Gobiosoma bosc (naked goby)			3					
Mugil curema (white mullet) or striped								
Uca pugnax (Atlantic marsh fiddler crab)	1			2				
Micropogonias undulatus (Atlantic Croaker)								
Brevootia tyrannus (Atlantic menhaden)								
Syngnathus fuscus (northern pipefish)								
Trinectes maculatus (hogchoker)			3					
Pogonias cromis (black drum)								

n= number of sampling sites within each habitat

Table 34. *Average nekton density (number of individuals per m² ± standard error) in tidal creeks, pools, and the marsh shoreline edge at Avalon, NJ for 2017.*

Species (Common Name)	Site Avalon 2017	
	Control n=41	Enhanced n=54
Fundulus heteroclitus (mummichog)	15.74 ± 10.37	2.26 ± 0.86
Fundulus majalis (striped killifish)	22.82 ± 14.80	14.56 ± 10.91
Lucania prava (rainwater killifish)	4.82 ± 2.13	0.20 ± 0.13
Menidia menidia (Atlantic silverside)	7.44 ± 2.47	1.31 ± 0.58
Palaemonetes pugio (daggerblade grass shrimp)	30.10 ± 12.10	9.44 ± 5.84
Carcinus maenas (green crab)	0	0
Crangon septemspinosa (sevenspine bay shrimp)	0	0.09 ± 0.06
Callinectes sapidus (blue crab)	2.95 ± 0.81	1.01 ± 0.30
Panopeus herbstii (Atlantic mud crab)	0	0
Cyprinodon variegatus (sheepshead minnow)	18.32 ± 8.78	1.20 ± 0.53
Gobiosoma bosc (naked goby)	0.41 ± 0.19	0.13 ± 0.08
Mugil cephalus (striped mullet)	0	0
Uca pugnax (Atlantic marsh fiddler crab)	0.16 ± 0.08	0.09 ± 0.05
Micropogonias undulatus (Atlantic croaker)	0	0
Pogonias cromis (black drum)	0	0
Brevootia tyrannus (Atlantic menhaden)	0.15 ± 0.09	0
Syngnathus fuscus (northern pipefish)	0.05 ± 0.05	0
Eurypanopeus depressus (flatback mud crab)	0.08 ± 0.08	0
Total fishes	32.69 ± 8.80	23.72 ± 11.86
Total decapods	30.47 ± 7.61	20.94 ± 6.46
Total nekton	62.31 ± 11.00	40.59 ± 14.93

Nekton were collected throughout using a throw trap and ditch nets
Densities are not log transformed
n= Total number of sampling locations

Table 35. *Average nekton density (number of individuals per m^2 ± standard error) in tidal creeks, pools, ditches, and the marsh shoreline edge at Fortescue, NJ for 2017.*

Species (Common Name)	Site Fortescue 2017 Control n=41	Site Fortescue 2017 Enhanced n=47
Fundulus heteroclitus (mummichog)	5.46 ± 2.90	2.41 ± 0.76
Fundulus majalis (striped killifish)	9.18 ± 4.08	6.99 ± 2.69
Lucania prava (rainwater killifish)	0.61 ± 0.21	0.46 ± 0.21
Menidia menidia (Atlantic silverside)	1.39 ± 0.50	2.67 ± 1.92
Palaemonetes pugio (daggerblade grass shrimp)	25.44 ± 9.89	18.43 ± 9.05
Crangon septemspinosa (sevenspine bay shrimp)	0	0
Callinectes sapidus (blue crab)	0.59 ± 0.18	0.12 ± 0.10
Panopeus herbstii (Atlantic mud crab)	0	0.02 ± 0.02
Cyprinodon variegatus (sheepshead minnow)	3.29 ± 1.54	0.88 ± 0.68
Gobiosoma bosc (naked goby)	0.03 ± 0.03	0
Uca pugnax (Atlantic marsh fiddler crab)	0.18 ± 0.09	0
Micropogonias undulatus (Atlantic croaker)	0	0
Trinectes maculatus (hogchoker)	0	0
Total fishes	19.95 ± 7.12	13.43 ± 4.07
Total decapods	26.21 ± 9.90	18.57 ± 9.14
Total nekton	44.18 ± 12.13	30.84 ± 9.81

Nekton were collected throughout using a throw trap and ditch nets
Densities are not log transformed
n= Total number of sampling locations

Conclusions

- In 2016, total fish, total decapods, and total nekton populations demonstrated a significant downturn in densities following placement of dredged material in both Avalon and Fortescue. Average fish density remained higher in control areas than in placement areas in 2017. This was true for all fish species, except Atlantic silversides. However, the density of total fish, decapods, and nekton was not significantly different in Fortescue across control and placement areas in 2017. We found the populations of total fish and total decapods to be proportionate across the control and placement areas. Success of these populations could be due to frequent tidal inundation at high tide, increasing the mobility of fish.
- Striped killifish and mummichogs were the most dominant fish species in 2016 and 2017 at both Avalon and Fortescue. In Avalon, although striped killifish were most dense within placement habitats in 2016, both striped killifish and mummichog populations had greater densities in control areas over placement areas, especially within tidal creeks, subtidal creeks, and the shoreline edge by 2017. However, both fundulid species had the greatest density within placement areas tidal creeks, while other habitat types within the placement areas had almost no individuals in 2017. We determined that these population preferences are likely due to differences in vegetative cover. Mummichog density was significantly correlated with a higher cover of *Spartina alterniflora*, *Ulva lactuca*, *Gracilaria* spp., and *Ruppia maritima*. Striped killifish were found to have a preference for sandier substrates with less vegetation, likely as a result of their reproductive requirements to lay eggs within sandy substrates within intertidal pools.
- At Fortescue, species richness of the whole nekton community in 2016 and 2017 did not significantly change. However, overall, there was a greater number of nekton species found in control areas than in placement areas. Some species were only found in control areas.

- At Avalon in 2017, nekton density was variable among the pools, possibly due to differences in sediment substrate, depth, tidal restrictions, or seasonal behavior of the fish.
- Daggerblade grass shrimp had a high abundance in placement tidal creeks compared to control tidal creeks in 2016. This is possibly due to the higher nutrient levels found within placement area tidal creeks. Sediments with elevated nutrient levels could result in higher abundances of macroinvertebrates, allowing fish predation to also increase. This would allow for higher trophic-level fish species to be successful within these habitats.
- Based on these results, we can address the following monitoring question: "Does the marsh ecosystem (i.e., structure and functions) recover or show uplift within two to three years of dredged material placement? (And the related "How long does it take for the marsh to recover and achieve uplift?")"
    - There was a shift in nekton species after the placement of sediment. Some species were lost from placement areas and are currently only found in control areas. Habitat type and corresponding sediment and nutrient conditions seemed to be significant drivers of species presence and population counts.

Additional Monitoring

Soil Sampling and Well Installation

Authors: U.S. Army Engineer Research and Development Center

Additional monitoring that was not part of the Monitoring Plan was conducted by the U.S. Army Engineer Research and Development Center (ERDC). This monitoring focused on the physical, nutrient, and biogeochemical processes of the soil. Prior to dredged material placement, core samples were collected in vegetated and open water areas within the dredged material placement areas and adjacent control regions of the marsh. The monitoring design provides the data needed to investigate baseline sediment property differences between vegetated and open water features in the marsh, as well as detect changes within control and dredged material placement areas.

Monitoring Design

Five locations were sampled by ERDC for the metrics in Table 36 across the marsh at the Avalon site only. Two locations were in areas that received dredged material (i.e., placement), and three were in areas that did not receive dredged material (*i.e.*, control). Within each sampling location, three vegetated and three pool locations were identified using a random sampling design in ArcGIS before the first field sampling. The same locations were monitored in subsequent years.

Water level data loggers were installed in conjunction with the three vegetated and three pool soil sampling locations in one placement area and one control area for a total of 12 water level data loggers. Two atmospheric loggers were also installed. Water level data is recorded every 15 minutes for approximately one month.

Table 36. *Design and metrics used by ERDC for soil and well monitoring at the Avalon project site.*

Design	Sediment Metrics	Nutrient Metrics	Microbial Metrics
Post-Construction	Depth of Dredged Material	Organic Matter	Biomass Carbon
Control-Impact	Bulk Density Root Distribution	Total Phosphorous Extractable Nitrogen	Biomass Nitrogen Potentially Mineralizable Nitrogen
Once Annually During Peak Growing Season (June to September)	Grain Size Moisture Content	Total Dissolved Nitrogen Dissolved Organic Carbon Total Nitrogen and Carbon Extractable Ammonium Soluble Reactive Phosphorus	

The results from this monitoring were published by ERDC and are not discussed here.[12]

[12] https://doi.org/10.1016/j.ecoleng.2018.05.012

Data Evaluation - Adaptive Management Monitoring

During the monthly site inspection in July 2016, several new areas of vegetation die-off were observed at the Avalon project site. The vegetation in the die-off areas had survived the initial placement of sediment. Most of these areas were along the outside edge of the perimeter containment, covered with a thin layer of dredged material that had passed through the containment, and surrounded by healthy marsh vegetation. The immediate cause of the vegetation die-off was not apparent, though it was suspected that the dredged material or containment had altered the hydrology and/or the chemistry of the marsh soil, surface water, and/or groundwater to the degree that vegetation could not survive. Two adaptive management monitoring plans were developed to further investigate the die-off areas:

1) The *Sediment Characterization and Analytical Testing* plan was developed to generally characterize the placed dredged material and help determine which factors might contribute to vegetation success and die-off.
2) The *Surface and Groundwater Chemistry* plan was developed to determine if the dewatering and subsequent consolidation of dredged material had created ponded water and areas of altered water chemistry that may be stressful for vegetation.

Prior to initiating these monitoring plans, a soil scientist with the Natural Resources Conservation Service (NRCS) joined the Project Team on-site and conducted a field study to observe and examine the placed dredged material. This NRCS study looked at soil horizon depths, horizonation and horizon boundaries, soil texture, fluidity, Munsell Soil color, hydrogen sulfide odor, pH, rock and shell fragment percentages, peroxide color change, and organic matter content.

This adaptive management monitoring at the Avalon project site was conducted to further identify any major variances in soil physical and chemical properties between sampling points at different stages of vegetation recovery and during periods of wet and dry weather. It was believed by the Project Team that this information was important to more accurately assess the potential causes of vegetation die-off and to better understand why some areas revegetated more quickly than others.

12.1 Sediment Characterization and Analytical Testing

Author: Princeton Hydro

Methods

Sediment (*i.e.*, placed dredged material) at Avalon was studied by Princeton Hydro using the metrics in Table 37 Samples of dredged material (surface top 6 inches) were collected to evaluate the potential importance of the following parameters on vegetation survival and growth: (1) placement elevations, (2) dredged material physical characteristics, and (3) dredged material chemical characteristics (metals, nutrients). 31 samples were collected within containment in dredged material placement areas, six in vegetation die-off areas, and three VEG samples in placement areas with 100% vegetative cover. The sample data were also compared to the 2015 pre-placement marsh surface soil sample data, though the number of samples collected (n), the collection method, and the locations of the samples differed.

Table 37. *Design and metrics used for sediment characterization and analytical testing at the Avalon project site.*

Design	Metrics
Post-Construction Adaptive Management Monitoring	Sulfates Nitrate Total Phosphorus Target Analyte List (TAL) of 23 Metals Particle Size Organic Content pH Unit Weight Porosity

Results

The only consistent difference in the post-construction (2017) marsh surface sediment physical parameters at Dredged Material Placement Areas A and D within containment and in the vegetation die-off areas (outside containment) was the significantly greater mean % sand composition within containment (51.4% and 44.1%) compared to that in the die-off areas (7.3% and 17.4%).

In general, the mean concentrations of metals were similar in the 2015 marsh, 2017 marsh within containment, and 2017 vegetation die-off area (outside containment) surface sediment samples.

However, the mean concentrations of arsenic ($p < 0.05$), chromium ($p < 0.01$), silver ($p < 0.01$), and zinc ($p < 0.01$) in the 2017 vegetation die-off marsh surface sediment samples were significantly greater (t-tests) than the mean concentrations of the marsh 2015 surface sediment samples. In addition, the mean % sand composition of the surface sediment from the vegetation die-off areas (14.0%) was significantly less (t-test; $p < 0.0001$) than that of the 2015 marsh surface sediment samples (45.2%). The mean % sand composition of the sediment from the vegetation die-off areas was less than that of the 2017 within containment sediment samples (35.3%), but not significantly different (t-test; $p > 0.05$).

Each of the three VEG samples was paired with a nearby sample within containment in which vegetation had not recovered. The values of the sediment physical parameters (% sand, % moisture, bulk density, porosity, and elevation), TAL metals, and nutrients (total phosphorus, nitrate, and sulfates) were not significantly different between the pairs of samples. Similarly, the concentrations of total phosphorus, nitrate, and sulfate did not statistically differ between the VEG samples and the die-off samples.

In general, the mean concentrations of the TAL metals, nutrients, and sediment physical parameters in the VEG surface sediment samples were similar to those in the sediment samples from the vegetation die-off areas at Area A and Area D. However, beryllium ($p < 0.05$) and zinc ($p < 0.05$) were significantly higher, and vanadium lower ($p < 0.05$; t-tests) in the vegetation die-off samples.

While a correlation between metal or nutrient concentration and vegetative cover was not established by this study, elevation exhibited the strongest correlation with plant cover (percent) within the containment area. Specifically, vegetation recruitment and cover at sample locations collected between elevations of 2.47 feet to 2.60 feet (NAVD88) were encouraging (Figure 58).

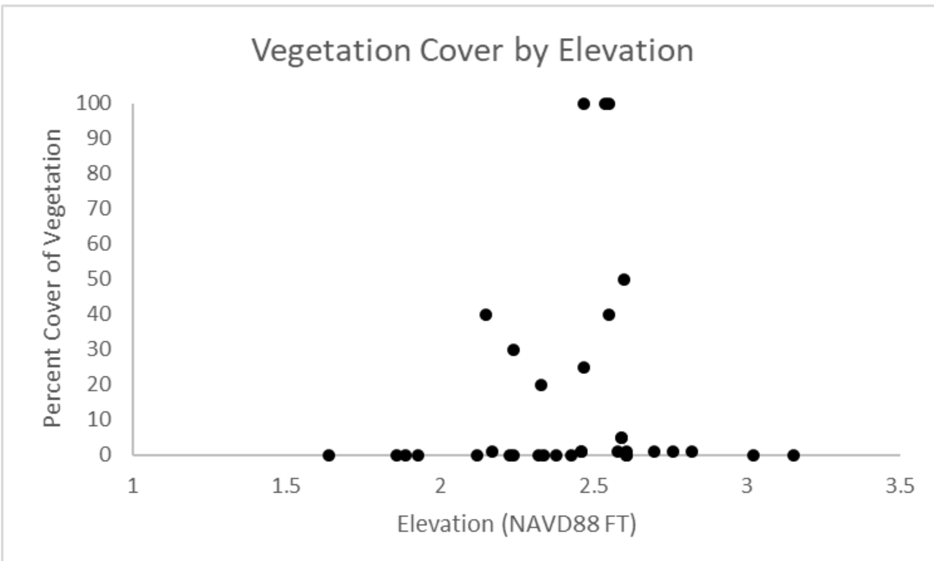


Figure 58*. Elevation and Vegetation Cover at Avalon based on Princeton Hydro's characterization during the 2017 soil monitoring.*

Conclusions

- Neither elevated metal, nutrient concentrations, nor the measured sediment physical parameters were found to be correlated with vegetative cover within containment. However, the number of “vegetated” samples was limited (n = 3).
- Likewise, neither elevated metal nor nutrient concentrations were found to be correlated with the incidence of vegetation die-off areas outside containment. However, the % sand composition within containment was significantly greater than that in the vegetation die-off areas.
- Vegetative recovery appears to be clustered in a specific elevation range. The effect of hydrology on vegetative regrowth at the site was not an initial study objective. However, based on this study and other site observations, it is the Team’s hypothesis that vegetative regrowth is not a function of soil characteristics, but rather site drainage/hydrology.

12.2 Surface and Ground Water Chemistry

Author: Lenore Tedesco[1]
[1]The Wetlands Institute

Methods

Table 38. *Design and metrics used for surface and groundwater chemistry monitoring at the Avalon project site in 2017.*

Design	Metrics	
Control	Temperature (°C)	Dissolved Oxygen (% saturation and mg/L)
Reference	Conductivity (µs/cm)	pH
Placement	Specific Conductivity (µs/cm)	Oxidation Reduction Potential (mV)
	Total Dissolved Solids (mg/L)	Sampling Depth (m)
	Salinity (ppt)	

Water chemistry was studied in the groundwater and surface water pannes and pools at Avalon by The Wetlands Institute from 2017-2020 with metrics outlined in Table 38. Surface water and groundwater chemistry in salt marsh pannes and pools and shallow groundwater wells and piezometers were measured following the placement of dredged material at the Avalon, NJ project site every quarter to document site conditions. This monitoring program was initiated in 2017 in response to observations of vegetation die-off and surface water chemical conditions that were stressful to vegetation. There was a pause in monitoring from Fall 2017 until late Spring 2018. The longer-term monitoring then utilized a sampling strategy focused on documenting the range of water chemistry that occurs seasonally to understand if the water chemistry is controlling vegetation recovery and/or survival of vegetation plantings at the Avalon site. The water chemistry of groundwater, accessed through USACE piezometers and groundwater wells, was included in the monitoring program following initial surface water

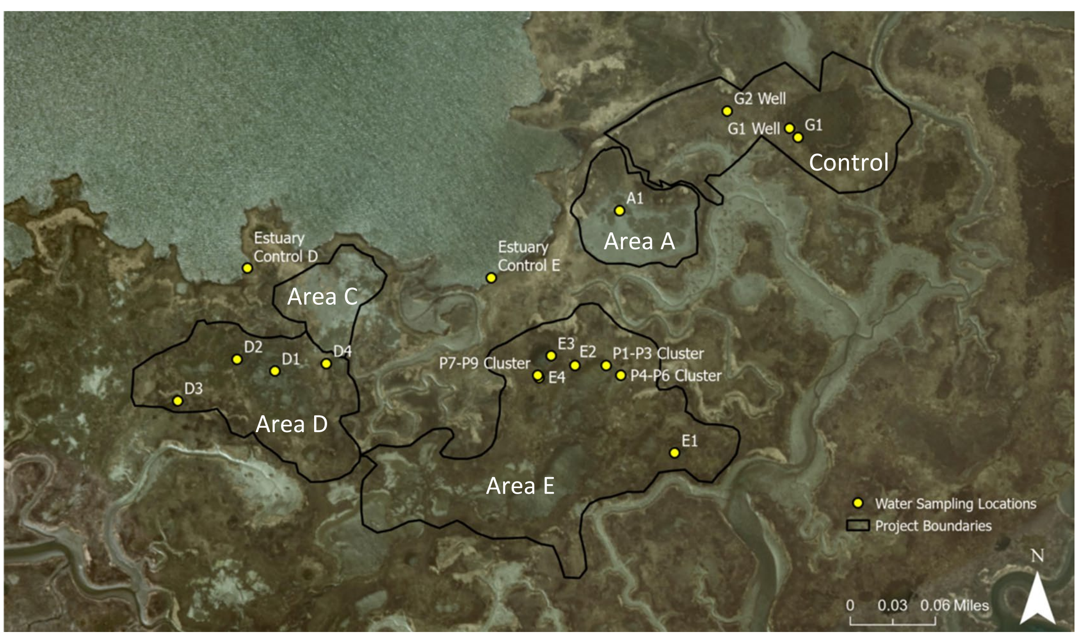


Figure 59. *Map of sampling locations for groundwater and surface water.*

monitoring. The groundwater monitoring effort was implemented in response to very high salinities measured on-site in the early spring of 2017, as well as the observation of new vegetation die-off areas. For comparative purposes, this monitoring program utilized groundwater wells and long-term monitoring data from pools and marsh depressions at a nearby site, control areas at Avalon, as well as two nearby estuary control sites (Figure 59).

Results

Surface Water Control and Reference Stations

One estuary control site was monitored at the Avalon site and one estuary control site was monitored at The Wetlands Institute (TWI). Salinity ranged from 16.8 to 41.6 parts per thousand (ppt) at the Avalon site and 19.3 to 32.6 ppt at TWI (Table 39). The lowest salinity measured at both sites followed 5-day prior rainfall events of 1.96" and 1.85". The higher salinity in the estuary at Avalon is interesting as it is higher than salinities measured in control and reference pannes, but similar to the reference depression at TWI. The control panne at Avalon (G1) ranged from 15.6 to 37.2 ppt. The reference panne at TWI (D) ranged from 16.8 to 39.1 ppt. The reference depression at TWI (E) displayed a similarly wide range of salinities as the Avalon estuary control site (16.1 to 41.3 ppt). The mean pH for the two estuary control sites was slightly lower than the Avalon control panne (mean 7.96; 7.91; 8.14, respectively), while the reference panne and reference depression had higher mean pH (8.33; 8.35, respectively; Table 39).

Table 39. *Average, Minimum, and Maximum values for select water chemistry sampling at Avalon and The Wetlands Institute in 2017. Ground water was sampled in wells and piezometers. Surface water was measured in pools, pannes, and other depressions that apply.*

		Temperature (^{o}C)			Salinity (ppt)			Dissolved Oxygen (percent Sat)			pH		
		Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
Ground Water	Placement Areas	24.5	21.7	28.0	38.2	31.8	48.5	9.4	3.1	39.5	7.0	6.3	8.1
	Control or Reference	22.9	18.1	27.3	36.5	31.7	44.3	10.6	4.1	28.1	6.8	6.5	7.0
Surface Water	Placement Areas	25.6	10.1	34.9	37.1	30.5	58.5	164.5	79.4	248.0	8.8	8.2	9.6
	Control or Reference	28.7	19.4	36.9	33.6	30.1	43.6	162.9	54.1	300.1	8.3	7.6	8.9
	Estuary Control	22.3	9.6	28.4	30.8	27.0	32.8	100.7	76.2	118.7	7.9	7.6	8.2

Dissolved oxygen saturation was highly variable among the control and reference sites (Figure 60). DO for the estuary sites were very similar, however, the control panne at Avalon (G1) had the lowest DO measurements (range 46-181%) and the reference panne and reference depressions at TWI had the highest DO measurements (295% and 369%, respectively). The reference depression at TWI was created by compaction of the marsh surface during construction and has restricted tidal flushing. The control panne at Avalon is well connected to tidal flushing and this may be moderating measured values overall. All surface control and reference sites had times of filamentous green algae to varying degrees and these occurrences affect DO and pH values in addition to the sampling timing relative to flushing conditions.

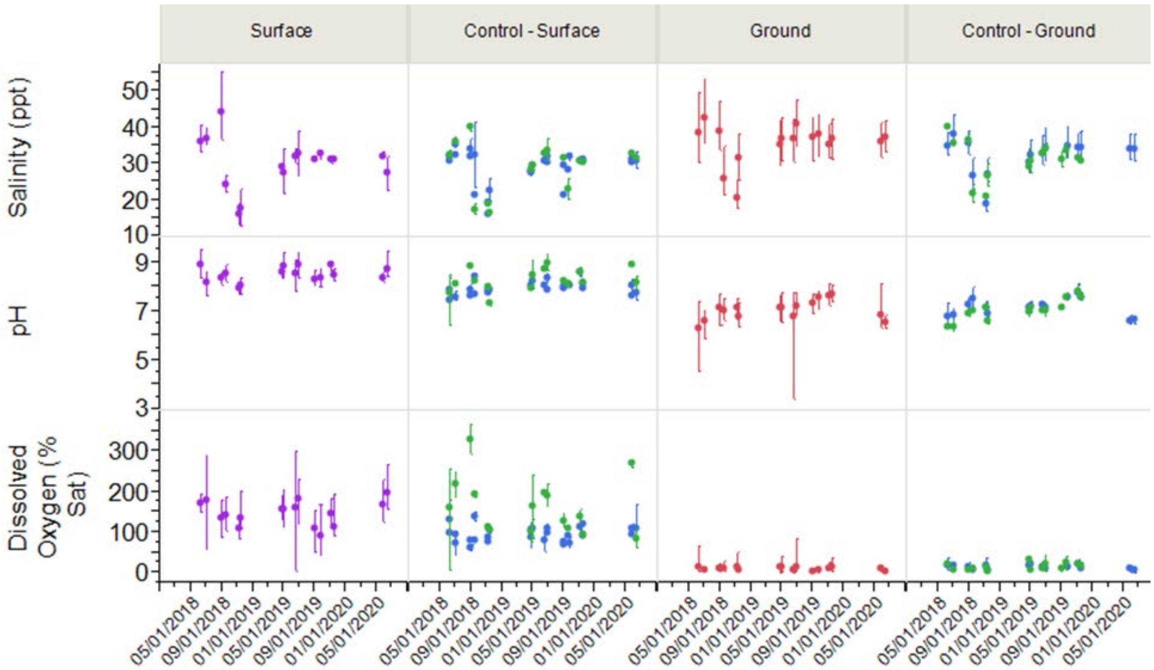


Figure 60. *Graphs of mean and range of measurements for Salinity (ppt), pH, and Dissolved Oxygen (%) of Surface Water Sites, Surface Control (Blue) and Reference (Green) Sites, Groundwater Sites and Groundwater Control (Blue) and Reference (Green) Sites, 2018-2020.*

Groundwater from Control and Reference Wells

One of the control wells (G2) located on the marsh platform at Avalon had higher maximum salinity (43.6 ppt) than all other control or reference wells (40.2 ppt TWI), the estuary control sites, and the control panne (41.6, 32.6, and 37.3 ppt, respectively; Table 34). This was measured in June of 2018 which corresponds to a time of low 5-day prior precipitation and also the time of the highest overall salinities measured during the monitoring period. The wells and control panne had the same minimum salinity (16.8 ppt). The reference wells in the marsh plain at TWI (Wells 1 and 2) showed similar salinity as the Avalon control wells (mean 31.0 vs 32.3 ppt, respectively). TWI reference wells and Avalon control wells had similar mean pH (7.1 and 7.2, respectively) and only slightly different max and min pH (Table 40).

Table 40. *Temperature (T°C), pH, Salinity (ppt) and Dissolved Oxygen (%) of Surface Water Sites, Surface Control and Reference Sites, Groundwater Sites and Groundwater Control and Reference Sites (2018-*

Site		N	Mean T (°C)	Max T (°C)	Min T (°C)	Mean pH	Max pH	Min pH	Mean Salinity (ppt)	Max Salinity (ppt)	Min Salinity (ppt)	Mean DO (% Sat)	Max DO (% Sat)	Min DO (% Sat)
Control Sites														
Avalon	Estuary Control	16	19.06	28.09	5.55	7.96	8.42	7.48	29.91	41.62	16.84	95.53	127.19	70.27
TWI	Estuary Control	16	19.85	29.66	9.18	7.91	8.65	7.44	28.48	32.60	19.34	97.13	132.63	62.57
Avalon	Control Panne	15	19.07	27.50	1.12	8.14	8.70	7.53	29.66	37.29	15.56	101.50	181.17	46.37
Avalon	Control Wells	45	17.82	25.74	8.55	7.17	8.15	6.48	32.25	43.61	16.94	14.94	38.10	0.10
Reference Sites														
TWI	Reference Panne	16	21.65	34.24	6.41	8.33	9.32	7.24	29.07	39.07	16.75	158.17	294.90	77.90
TWI	Reference Depression	16	23.66	36.68	6.89	8.35	9.07	7.41	29.29	41.31	16.06	178.67	368.80	62.97
TWI	Reference Wells	28	19.14	25.65	12.53	7.08	8.06	6.21	30.99	40.16	19.28	15.49	43.20	3.10
Beneficial Use Sites														
Avalon	Surface Water	126	21.52	37.22	3.09	8.49	9.53	7.64	29.78	55.62	12.82	147.13	300.93	5.53
Avalon	Groundwater	136	18.91	27.05	6.44	7.10	8.14	3.44	35.64	53.29	17.61	11.31	85.00	0.25

Surface Sampling Stations within Placement Areas

Salinity, pH, Temperature, and Dissolved Oxygen

Surface water site conditions varied widely at the Avalon dredge material placement site. A comparison of surface water salinity for site samples as compared with controls (excluding estuary controls) indicates that samples from sites within the dredge material emplacement areas have higher salinity and higher pH than the control and reference sites, especially early in the monitoring period. Salinity ranged from a minimum of 12.8 to a high of 58.5. The range of surface water salinity showed higher variability than the control and reference stations (Figure 60) and is especially pronounced in 2017 and 2018 and corresponded with times of stagnation both before and following containment removal. Salinity minima were associated with rainfall events and are more pronounced during neap tide conditions and are likely indicative of isolation. Salinity minima occurred at all surface water sites during the November 2018 sampling during both spring and neap monitoring visits (spaced one week apart) and were associated with 5-day prior rainfall of 1.88” during the neap monitoring and 1.96” during the spring conditions monitoring. There were no other times during the monitoring period with such persistent high rainfall amounts and salinity in 2018 was significantly lower than in all other years of the study ($p < 0.0001$ 2018, 2019; 0.033 in 2020). These results indicate that isolated surface water on the site is susceptible to rainfall events that can drive salinity variations. These rainfall events are responsible for salinity minima across the range of sample locations including the control and reference sites, but effects are most extreme at the surface sites within the placement areas. The salinity maximum was recorded at site D1 (58.5) in March 2017 and site A1 (55.6) in August 2018 with other surface sites recording their highest salinities in this timeframe, but not as extreme as these two sites. Both of these sites are isolated shallow pools with limited tidal flushing that were sampled when containment was still on sites or shortly after removal. Monitoring later during the study appears to indicate a reduction in extreme water chemistry documented as the site matures. The cause of this may be related to increased connectivity of sites with tidal channels, and/or overall maturation of the dredged material with dewatering and tidal flushing or both.

An annual effect was detected in separate tests of surface waters for pH ($F_{3,248}$ = 7.6, $p < 0.001$), salinity ($F_{3,259}$ = 13.8, $p < 0.001$), DO ($F_{3,259}$ = 3.9, $p < 0.05$), and temperature ($F_{3,259}$=11.1, $p < 0.05$). Salinity in 2017 (35.23 ± 0.86 ppt) was significantly higher than in other years (2018: 28.09 ± 0.70 ppt, $p < 0.0001$; 2019: 30.61 ± 0.0.63 ppt; 2020: 30.61 ± 1.30 ppt, $p < 0.05$), and salinity in 2019 was higher than 2018 ($p <$ 0.05).

pH ranged from a high of 9.6 (D2) with several measured pH values over 9 (at sites D1, D2, and A1) to a low of 7.6 (A1). All of these sites have demonstrated the most isolation, especially in 2017 and 2018. Overall pH values varied over slightly higher ranges than the surface control and reference sites (Figure 60). pH in surface water was significantly higher at placement sites (8.56 ± 0.04) than at control sites (8.30 ± 0.06; $p < 0.01$). Significantly lower pH was detected in 2018 (8.19 ± 0.05) compared to 2017 (8.49 ± 0.07, $p < 0.01$) and 2019 (8.47 ± 0.04, $p < 0.0001$).

The highest temperatures recorded occurred at sites D2 and D3 (37.2°C). Differences in temperature between years were significantly influenced by site type (control vs placement {F_3 = 4.39, $p < 0.01$}). Surface water temperatures in 2018 (22.59 ± 0.83 °C) were significantly lower than in 2017 (26.46 ± 1.01 °C, $p < 0.05$) and 2020 (27.85 ± 1.48 °C, $p < 0.05$); similarly, surface water temperatures in 2019 (19.41 ± 0.75 °C) were also significantly lower than in 2017 ($p < 0.0001$) and 2020 ($p < 0.0001$).

Dissolved oxygen values were widely variable over the sampling period (5.5 to 300.9%) with the maximum saturation reported at E4 (300.9% saturation). These findings of more extreme conditions in the surface pools are consistent throughout the study. Dissolved oxygen (% sat) was significantly affected by the interaction of water type (surface vs. groundwater) and site type (control vs placement {F_1 = 13.64, $p < 0.001$}). Dissolved oxygen in surface water at placement sites (150.8 ± 3.1 %) was significantly higher than at control sites (127.2 ± 3.9 %, $p < 0.001$). Where variables are moderated by flushing, variability decreased over time. For those variables that may be locally driven by biological factors (pH, DO) there does not appear to be any moderation.

When salinities were relatively low (<35 ppt), there does not appear to be a relationship between pH and salinity, and reference and control site values overlap with dredge material sites (Figure 61A). The lowest site salinities occur in 2018 along with the highest site salinities. Site salinities above 35 ppt are limited to 2017 and 2018, while site salinities are below 35 ppt throughout 2019 and 2020. High site salinities in 2017 and 2018 are also associated with pH values above 8.5. These observations support a relationship to isolation. During the monitoring period, pH in surface waters was always alkaline. No instances of acidic surface waters were documented during the study period.

The relationship between temperature and salinity of surface sites was investigated (Figure 61B) and indicates that temperature is not necessarily a driver of salinity. The fact that there is not a clear relationship between temperature and salinity also indicates that factors other than evaporation are in play and may include dredge material dewatering especially earlier in the study when dredge materials were newly emplaced. The highest salinities occur in 2017 (Figure 61B).

An evaluation of temperature and pH shows that high pH occurred more frequently in site surface water samples while lower pH (<7.75) was largely confined to reference and control stations. There are instances

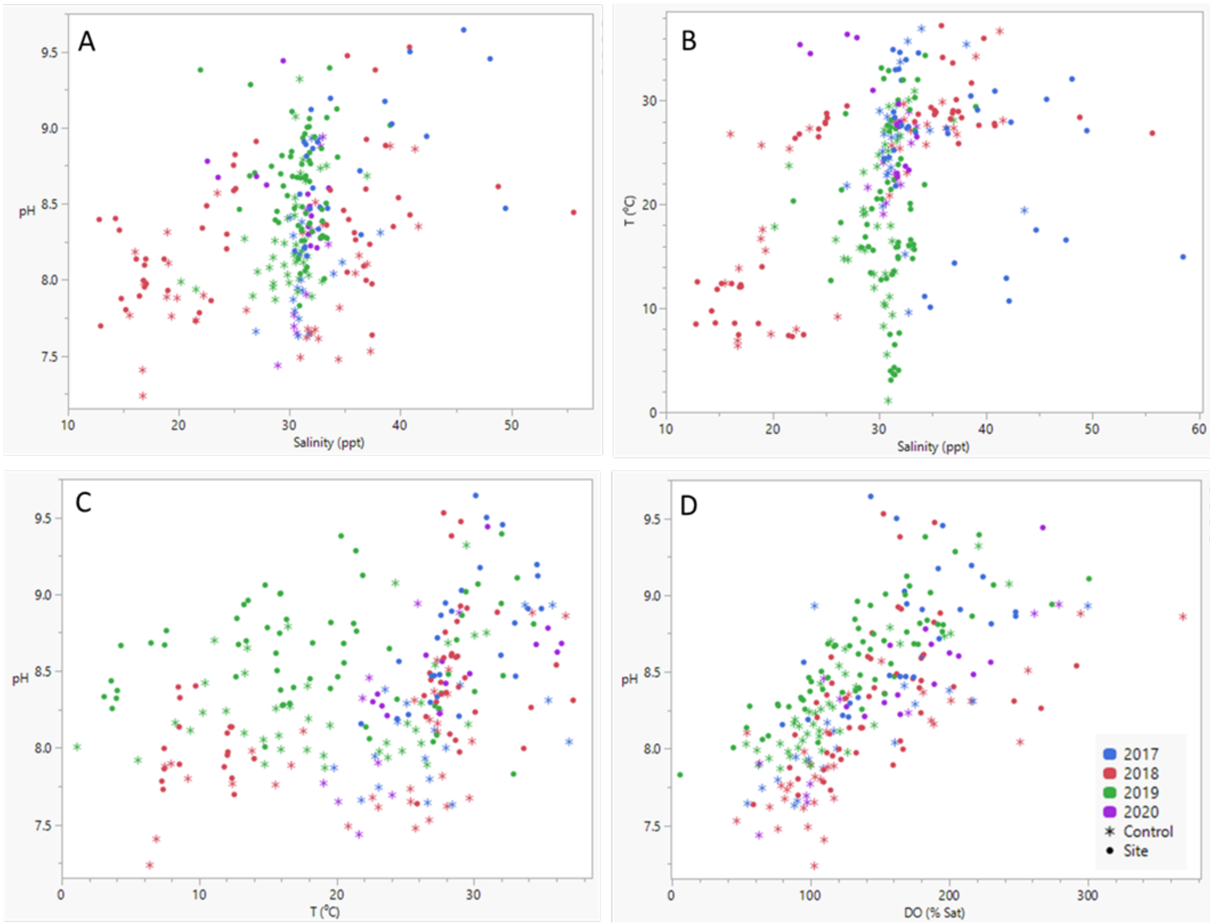


Figure 61. *Relationship of Site and Control Stations by Year comparing A) relative pH vs Salinity; B) Temperature vs Salinity; C) pH vs Temperature; and D) pH vs Dissolved Oxygen (%).*

of high pH occurring in control and reference sites, suggesting that, at times, this is a natural phenomenon. High pH (>8.5) occurs over a wide range of temperatures (Figure 61C) and temperatures exceeded 30^{o}C in some pools at both the site and in controls during the summer attesting to the extreme conditions that occur in shallow, isolated pools regardless of their origin. These observations, along with those of the salinity relationships, indicate other factors are at work and high pH and salinity are not solely driven by temperature or evaporation.

Dissolved oxygen was commonly supersaturated and, at times, was measured as high as 300% saturation. Analysis of pH and dissolved oxygen trends show that pH increased with increasing dissolved oxygen at both the control and reference sites and the dredge material sites. Dissolved oxygen can diffuse into the water from the atmosphere and can be produced *in situ* as a chemical byproduct of photosynthesis. As photosynthesis releases oxygen, it also draws down CO_2. Carbonic acid is removed from waters and pH increases. Biologically produced alkaline pH was occurring in the isolated pools at the dredge site and in the reference depression based on direct observation of cyanobacterial mats and bubbles (Figure 62), especially during the spring, summer, and fall seasons. The distribution and extent of cyanobacterial mats varied from site to site and throughout the year. They appeared to only be limited where there was

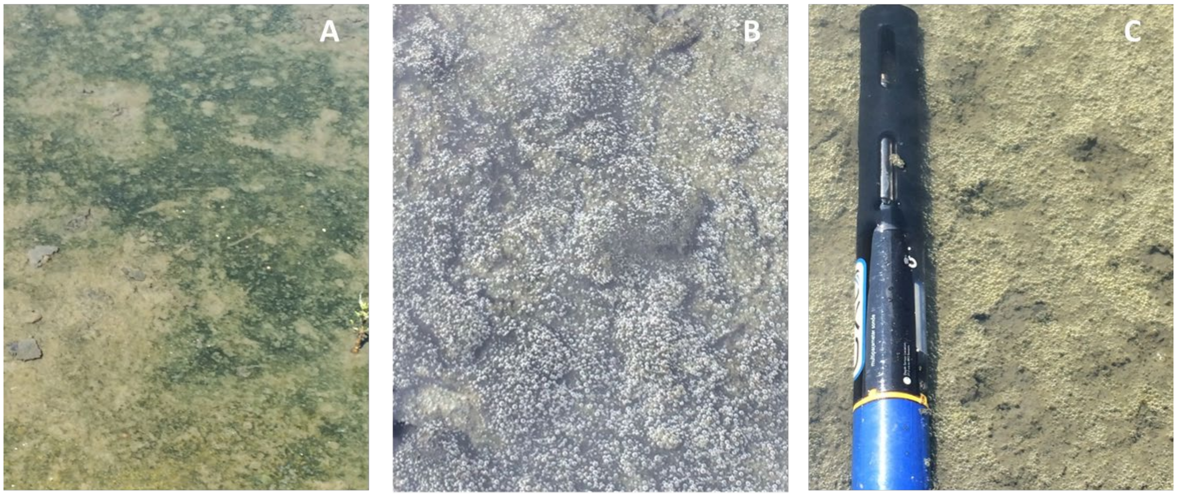


Figure 62. *Photographs of Cyanobacterial Mats and Oxygen Production. A) Cyanobacterial mat, site D1; 8/22/2017; B) Oxygen bubbles in cyanobacterial mat, well cluster P1-P3; 8/22/2017; C) Oxygen bubbles in cyanobacterial mat, site D3; 8/31/2017.*

prolonged drying or where waters were flushed enough to support grazing infauna. Cyanobacterial mats occurred naturally in pools and pannes in wetland settings and were not necessarily related to dredge material placement. While they were naturally occurring, the high pH and supersaturated oxygen conditions cyanobacterial mats caused extreme environments in isolated, shallow pools that formed in depressions in the dredge material surface. When combined with very warm water conditions (>35°C) and very high salinities (45 ppt and higher), isolated pools can be very inhospitable environments for plants and infauna. These conditions appeared to be largely driven by biological activity distinct from the presence of dredge material. Isolation is an important driver in the degree to which extreme conditions can be generated so that a goal of beneficial use projects should be to minimize the degree of isolation that results from ponded water formed in dredge material placement areas.

The role of flushing was evaluated by considering measured variables during spring vs neap tidal conditions over the study period. Both pH and salinity values are higher and more variable at sample sites relative to control and reference sites in 2017 and 2018 compared to later in the study (Figure 63). This did not hold true for dissolved oxygen saturation, which remained variable throughout the study period, and for sites within the dredge material placement area as well as reference and control sites.

pH was significantly affected by flushing condition ($F_1 = 4.24$, $p < 0.05$); higher pH was detected in neap tide conditions (7.76 ± 0.03) than in spring tide conditions (7.66 ± 0.03). The interaction between water type (surface water vs. groundwater) and site type (control vs placement) also affected pH ($F_1 = 22.11$, $p < 0.001$); surface water pH was significantly higher at placement sites (8.54 ± 0.04) than at control sites (8.12 ± 0.05, $p < 0.0001$), while there was no significant difference in groundwater pH between site types.

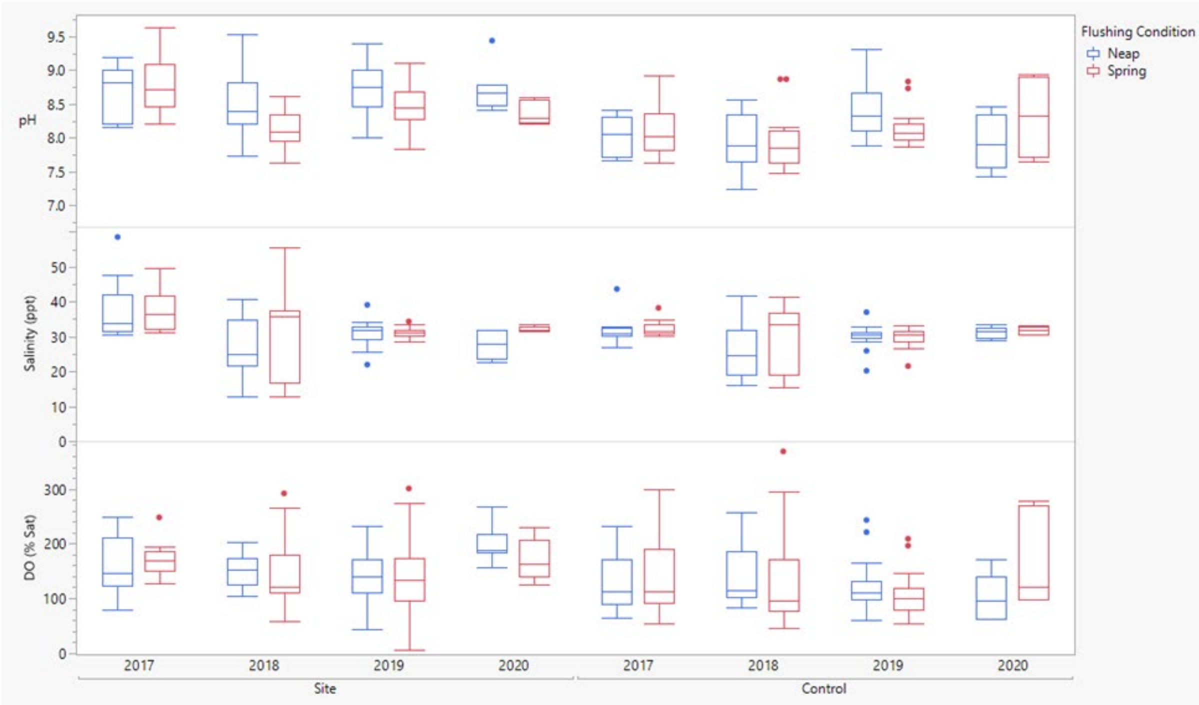


Figure 63. *Surface water pH, salinity and dissolved oxygen saturation (%) for reference/control and dredge material placement sites by year and flushing condition (spring vs neap) sampling periods.*

Groundwater Sampling Stations

Salinity and pH

The salinity of groundwater sampled from wells within the dredged material had higher overall salinities and wider ranges of salinity than groundwater sampled from control and reference wells (Figure 60). Wells and piezometers with the highest salinity (51.5 to 53.3, 46.3 to 45.1 ppt, respectively) were recorded from the P4-P6 cluster, which is located on the marsh plain above MHHW and differs from other well clusters in that it is not situated within the standing waters of a pool or panne. The lowest salinities were recorded in control and site wells and are especially concentrated around the 11/2018 sampling period with salinities as low as 17 ppt recorded at several stations. This was a spring tide sampling event associated with 5-day prior rainfall of nearly 2”. The estuary control site also showed very low salinity (16.8 ppt) at this time as did several surface water sites.

Salinity in groundwater (34.22 ± 0.45 ppt) was significantly higher than in surface water (30.63 ± 0.42 ppt, $F_1 = 34.25$, $p < 0.001$), and salinity at placement sites (33.72 ± 0.37 ppt) was significantly higher than at control sites (31.13 ± 0.49 ppt, $F_1 = 17.8$, $p < 0.001$). No significant impacts of flushing condition were detected for groundwater.

pH from groundwater sampled from wells located in the dredged material placement areas had similar mean pH to the control and reference wells (7.1, 7.1, and 7.0, respectively) but the range of pH for the groundwater sampling stations was more variable than the control and reference wells (Figure 60). Groundwater well P1-P3 Well 1 had a measured pH of 3.44 in June 2019 and 4.54 in June 2018 and well

P4-P6 Well 2 had measured pH of 5.71 and 5.91 both in June 2018. These are the lowest pH conditions recorded during the monitoring period and are lower than groundwater measurements in control and reference wells. The dissolved oxygen of all groundwater is low as expected (Figure 60).

The relationship between salinity and pH of groundwater sampled from wells within the dredge material was evaluated (Figure 64). For each piezometer and well, the depth below the surface of the screened interval was compared to the measured dredge material thickness at the sites. Sites were then categorized as to whether the screened interval was within the dredge material or below the dredge material in the underlying initial marsh, pool, or panne. The highest salinity and lowest pH (<6.5) occurred in the wells and piezometers that were within the dredge material (P1-P3 well 1, P3, P4-P6 Well 1, P4-P6 Well 2, P7-P9 Well 1, P9). This includes two instances of pH below 5. Sites with salinities >45 ppt are all from stations where the waters were drawn from wells/piezometers within the dredged material. The highest salinity measurements are concentrated in 2017 and 2018 samples and notably fewer in the 2019 and 2020 monitoring periods suggesting site evolution over time.

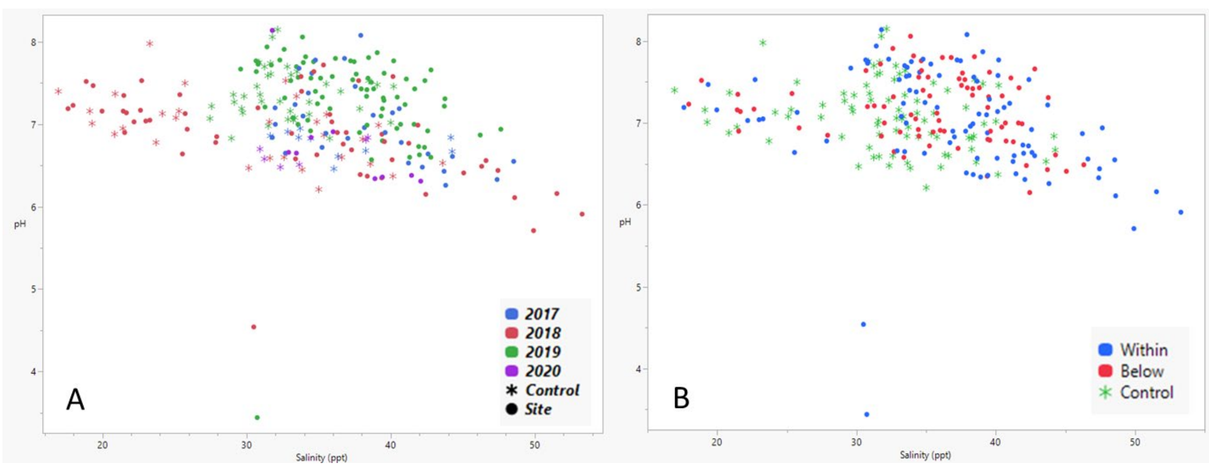


Figure 64. *A. pH and Salinity at Groundwater Control and Sampling Sites by Year, and B. pH and Salinity at Groundwater Control and Sampling Sites Identified by Location of Source Waters Relative to Dredged Materials.*

Samples that were drawn from below the dredge material (P1, P1-P3 well 2, P4, P6, P7) largely had higher pH (near 7 and above) and lower salinities (41 ppt and below). Surface sites adjacent to pools containing the wells and piezometer clusters (E2 and E4) displayed relatively high pH, further suggesting that the source of the lower pH in piezometers and wells with waters within the dredged materials was locally generated. Control and reference wells were predominantly comprised of waters with moderate pH and salinities relative to sites located in the placement areas (Figure 64). The control well and reference wells had mean pH of 7.1 and 7.0 and mean salinities of 32.8 and 31.7, respectively. Control well G2A on the marsh plain had relatively high salinities (44 ppt) and behaved as an outlier periodically.

These findings indicate that the dredge materials had relatively high salinities and were also likely generating acidic conditions. The very high surface water salinities recorded in isolated pools (e.g., D1) especially in 2017 when containment was still in place supports this interpretation.

Discussion

- Marsh pannes and pools display a wide range of surface water conditions that deviate from estuary controls and include wide ranges in pH, dissolved oxygen, and salinity into ranges that can be considered extreme. The degree of isolation and stagnation is an important driver of these conditions. Interior drainage of high salinity water generated by the dewatering of dredge materials is a likely cause of very high salinity surface waters especially since they were recorded early in the monitoring program. These highly variable conditions occurred in reference depressions as well as isolated ponded areas within the dredged material placement areas at Avalon indicating that the contribution to surface water chemistry from the dredged materials alone may be limited.
- The frequency of flushing is an important driver of surface water chemistry at dredge material placement sites. When sites were actively tidally flushed, surface water chemistry was more moderate. An initial goal of this monitoring program was to evaluate the effects of containment. However, only one monitoring event occurred prior to containment removal (March 2017). This monitoring event recorded the most extreme salinity conditions at the Avalon site (58.5 ppt). Overall, the most extreme surface water chemical conditions occurred in 2017 and 2018, with water chemistry parameters becoming more moderated over time. The limited data related to containment and the overall trend in more moderated water chemistry parameters makes it impossible to determine the effects of containment from this study.
- The presence of cyanobacterial mats within pools is an important driver of surface water chemistry and is likely responsible for elevated pH and oxygen supersaturation. Cyanobacterial mats occurred in abundance in the very shallow pools and depressions at the site, especially in the spring, summer, and fall. They did not occur in deeper natural pannes or where grazing epifauna were noted.
- Analysis of groundwater from dredge material sites revealed periods of high salinities and acidic conditions, especially among site wells and piezometers with water sourced from within dredged sediment. The range of pH measured in the groundwater wells was more variable than in the control and reference wells. Two groundwater wells within placement areas had measured pH values as low as 3.44 in June 2019 and 4.54 in June 2018 while a nearby well had measured pH of 5.72 and 5.91, both in June 2018. These are the lowest pH conditions recorded during the monitoring period. These conditions are lower than measured pH in control or reference wells and indicate that acidic conditions were being locally generated in the dredged sediments at least for a portion of the study period.
- This monitoring program did not document acidic surface water however, biologically produced alkaline pH may have masked those signals. The extremely reducing monosulfidic soils present in the dredge material are an important driver of soil chemistry. The effects of these reducing conditions were not apparent in surface waters. It is likely that cyanobacterial mats effectively sealed reducing conditions beneath the mats and also produced oxygen. In effect, the

biologically driven oxygenation of surface waters far exceeded any effects from reduced sediments, if any.

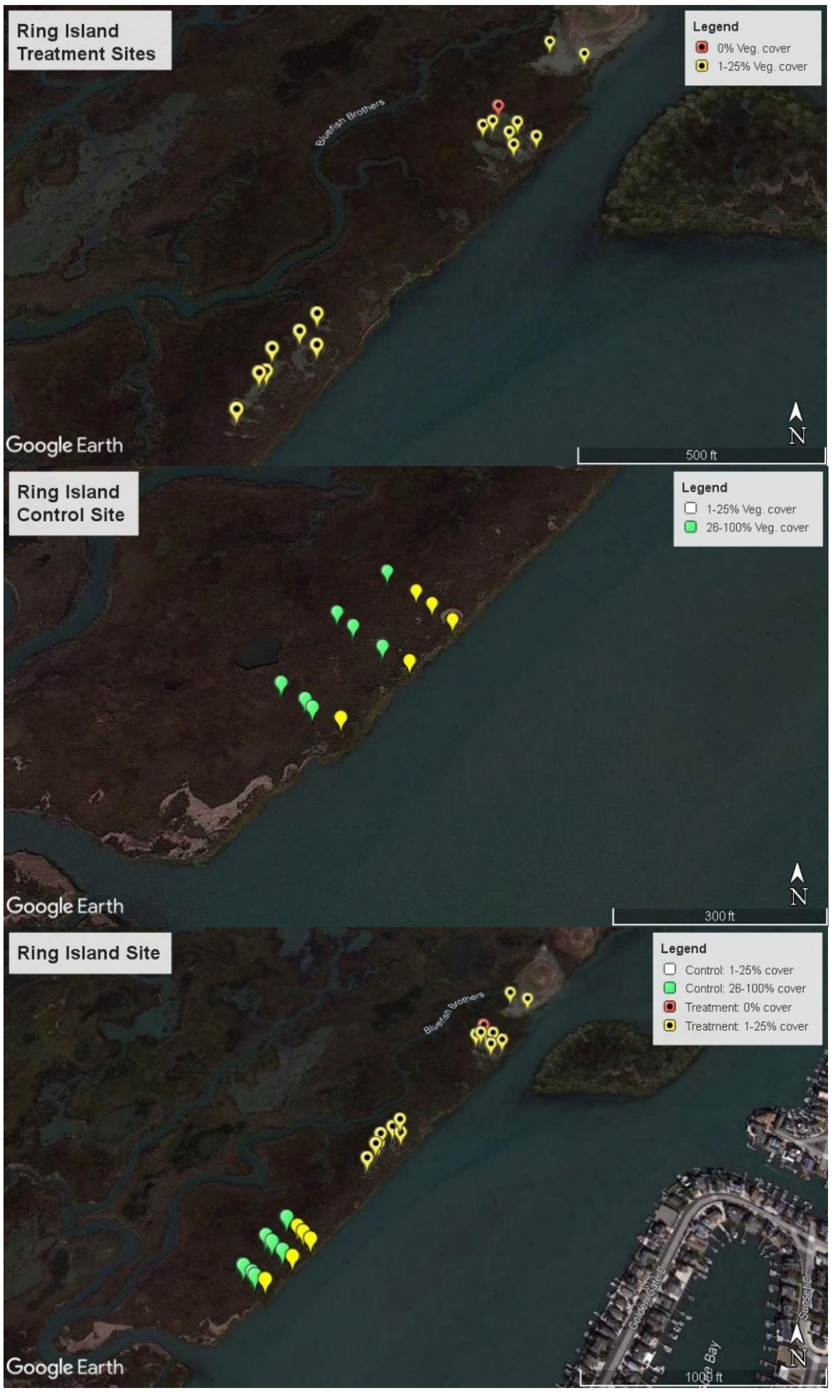
- Results of this study suggest that site water chemistry evolved over the study period and will continue to do so. This study documented that shallow, isolated pools have extreme water chemistry. These conditions can be naturally occurring; however, they occurred most frequently in the monitoring timeframe early in the study.

Appendices

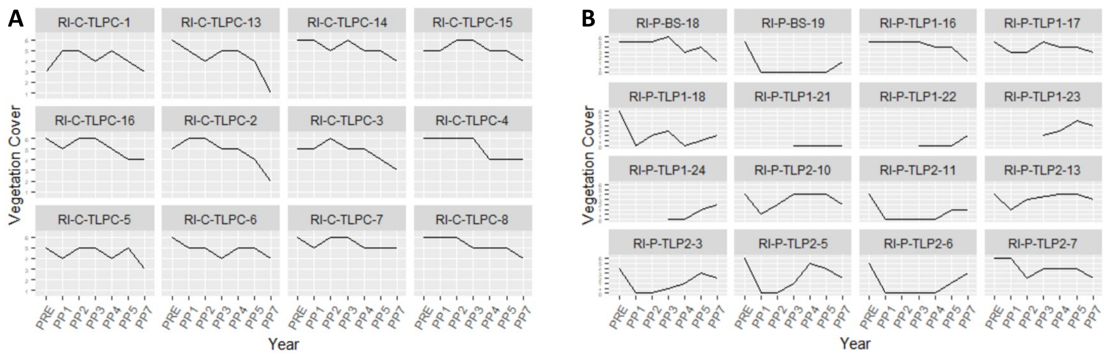
Appendix A

Additional Vegetation Recovery Figures

Ring Island



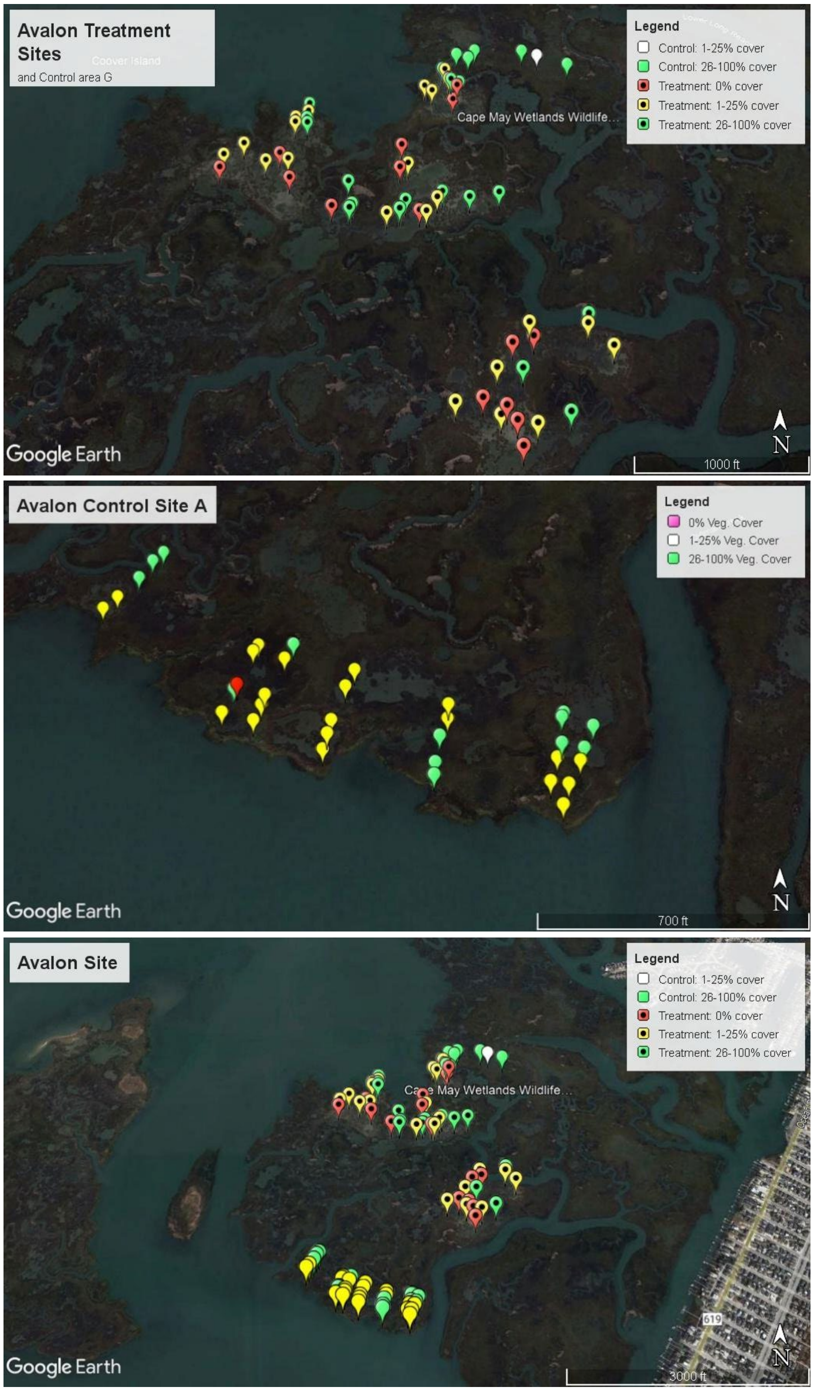
Map of plot recovery levels at Ring Island. Top map is a close-up of all Ring Island treatment sites. The center map is a close-up of the Ring Island control site, and the bottom map is the entirety of the Ring Island site in relation to the town of Stone Harbor and the back bay geography. Plots with black dots in the center of the icon are treatment plots, those without dots are control plots. Level of recovery is indicated by color, with 0% vegetation cover represented by red icons, 1-25% vegetation cover represented by yellow icons, and 26-100% vegetation cover represented by green icons.



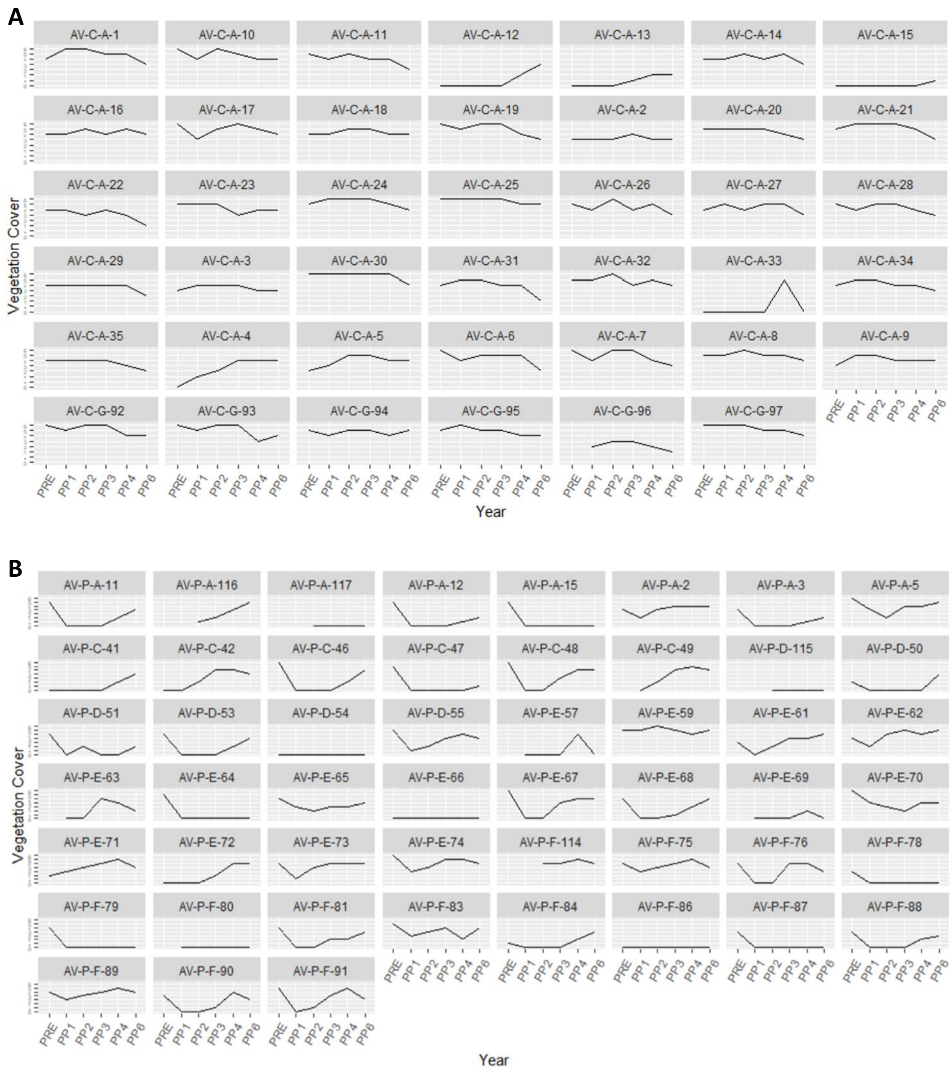
Vegetation percent cover change in individual A) control and B) placement plots at Ring Island over time.

Timeseries of plot 23 placement area 1 at Ring Island From left to right This was still predominantly bare inPP3 (left), the plot was initially colonized by Spartina alterniflora which gradually expanded into the plot from the edges in PP4 (middle) and PP5 (right).

Avalon

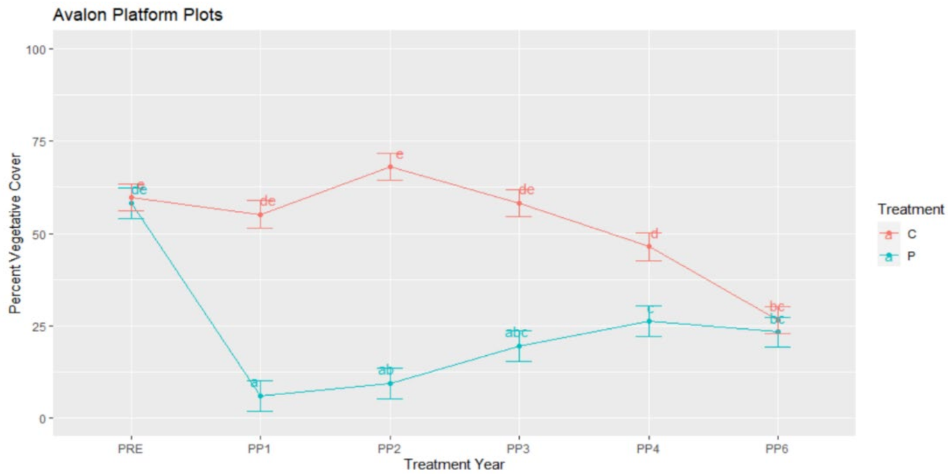


Map of plot recovery levels at Avalon. Top map is a close-up of all Avalon treatment sites, plus the control area G. The center map is a close-up of Avalon control site A, and the bottom map is the entirety of the Avalon site in relation to the town of Avalon and the back bay geography. Plots with black dots in the center of the icon are treatment plots, and those without dots are control plots. The level of recovery is indicated by color, with 0% vegetation cover represented by red icons, 1-25% vegetation cover represented by yellow icons, and 26-100% vegetation cover represented by green icons.

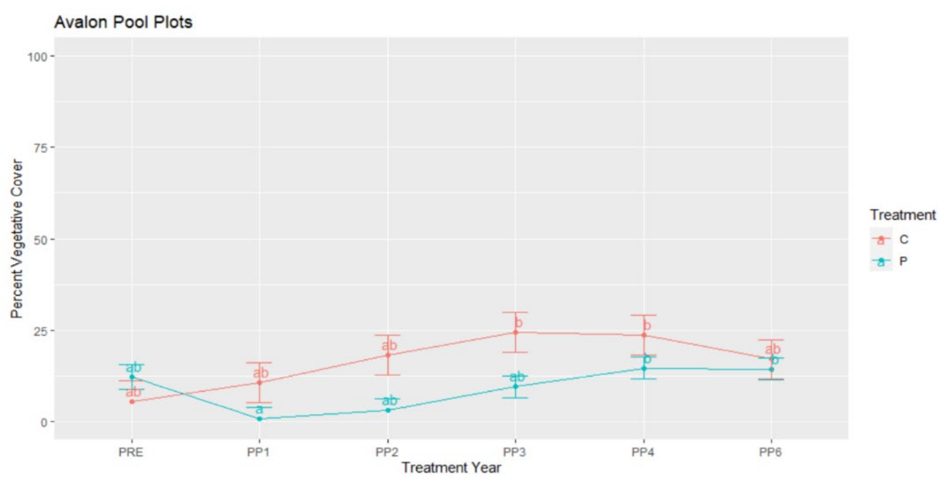


Vegetation percent cover change in individual A) control and B) treatment plots at Avalon over time.

Timeseries of plot #71 in Avalon placement area E. This plot started as a pool prior to placement PRE (left). The plot was considered bare the first 2 years post placement. In PP2 (middle left) the plot was colonized by Salicornia sp. In PP3(middle right) Spartina alterniflora began to establish and by PP4 (far right), the plot is fully vegetated by Spartina alterniflora.

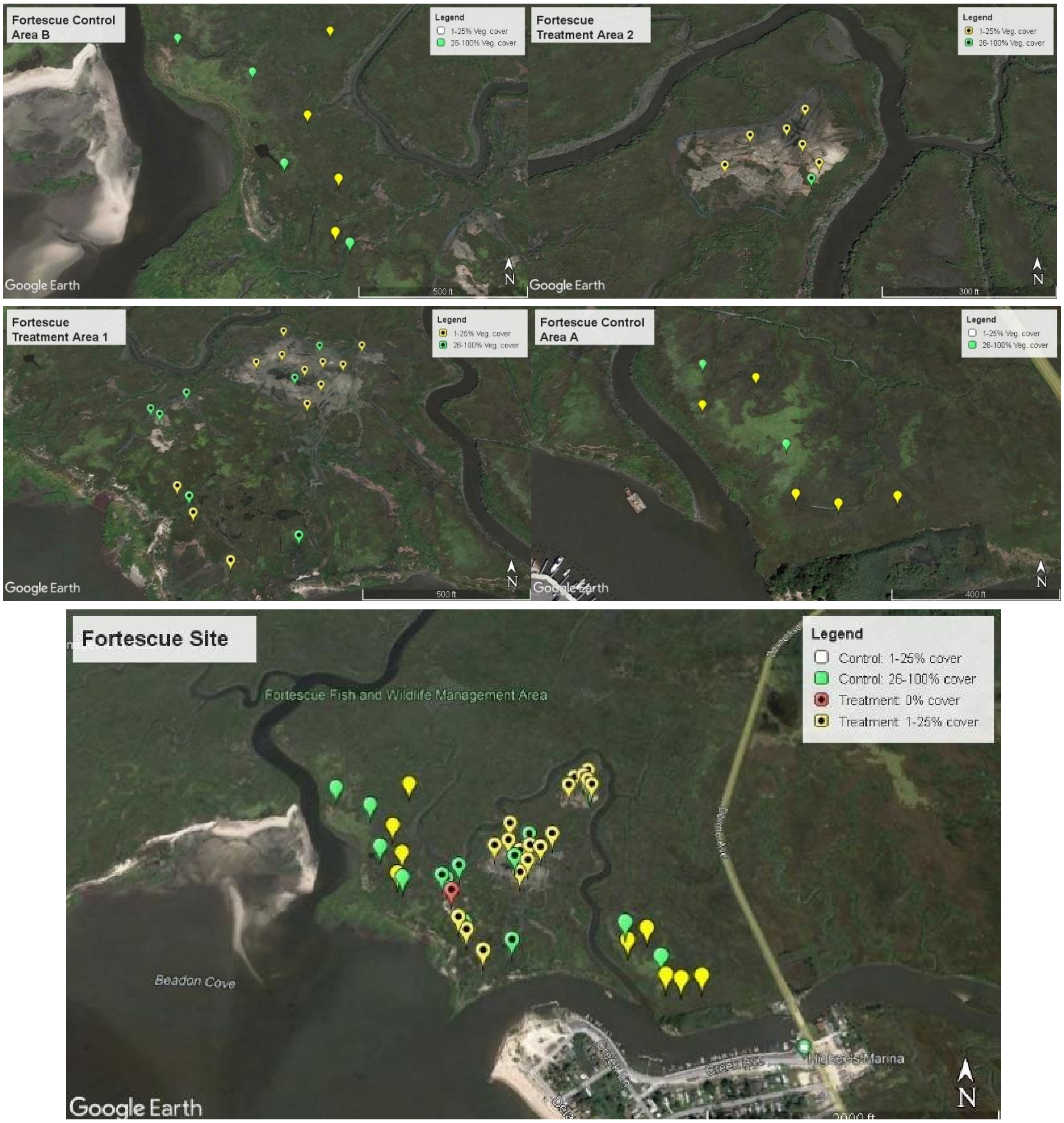


Percent cover by plant at Avalon in platform plots in both Control (C) and Placement Areas (P) overtime. Data presented are means ± one standard error.

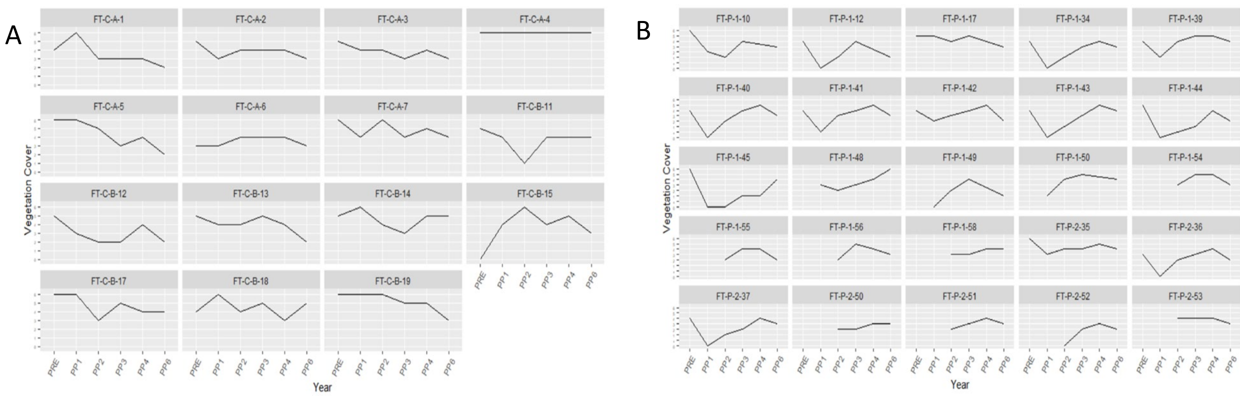


Percent cover by plant at Avalon in pool plots in both Control (C) and Placement Areas (P) overtime. Data presented are means ± one standard error.

Fortescue



Map of plot recovery levels at Fortescue. The top four maps are close-ups of treatment and control sites at Fortescue. The bottom map is the entirety of the Fortescue site in relation to the marina, local development, and the nearby bay geography. Plots with black dots in the center of the icon are treatment plots, those without dots are control plots. The level of recovery is indicated by color, with 0% vegetation cover represented by red icons, 1-25% vegetation cover represented by yellow icons, and 26-100% vegetation cover represented by green icons.



Vegetation percent cover change in individual A) control and B) treatment plots at Fortescue over time.

Successional photos taken from a permanently established photo point at the Fortescue project site in 2016 and 2017 (PP1 and PP2, respectively).

Timeseries of plot #37 in Fortescue placement area 2. From left to right as described: the plot was completely bare following placement In PP1. Some vegetation began expanding into one corner from nearby existing vegetation in PP2., In PP3 the plot was sparsely vegetated throughout most of the area with PP4 showing much denser vegetation at 38% cover.

Appendix B

Additional Avian Monitoring Figures

Avalon

Map of monitoring locations for avian counts in Avalon. All birds within the red circles were considered part of the analysis. Site names are coded for location (e.g., A = Avalon), the timing of placement (i.e., before or after; B or A, respectively), site descriptor (i.e., control, impact, or demo; C, I, or D, respectively), and cardinal direction (e.g., N = north).

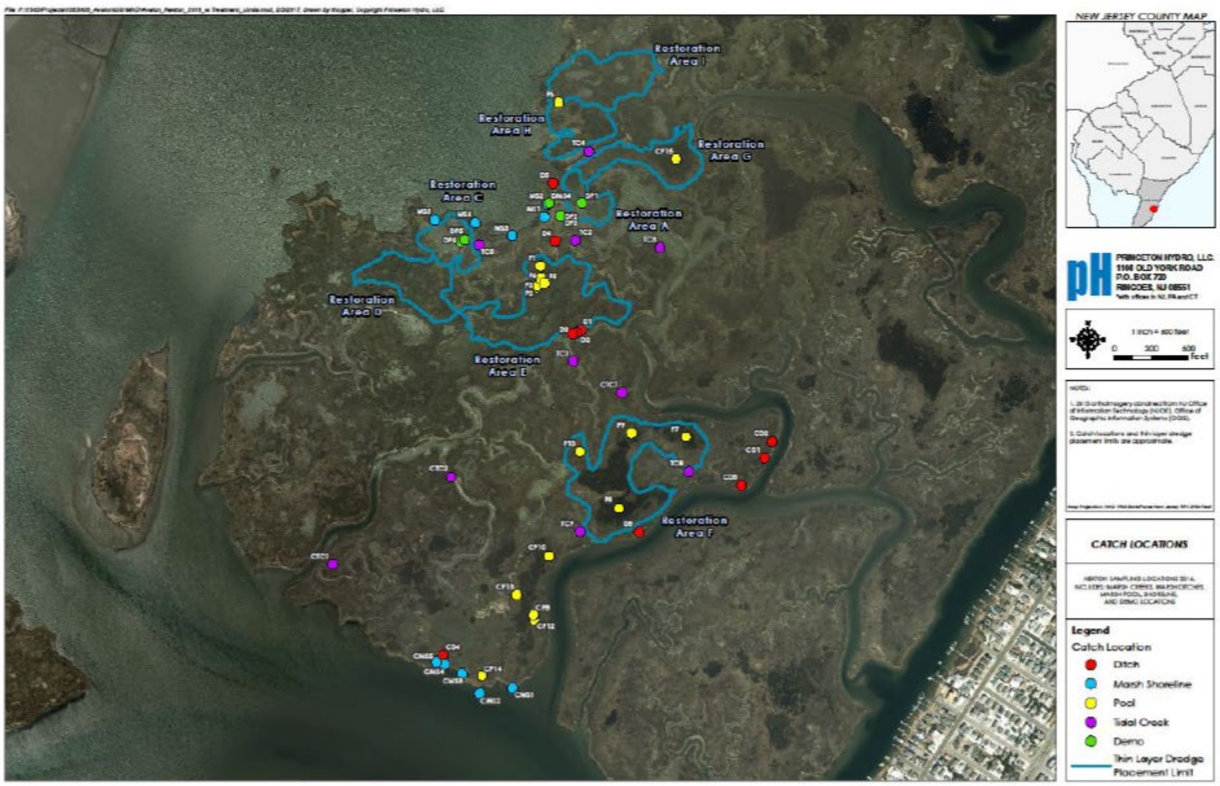
Fortescue

Map of monitoring locations for avian counts in Fortescue. All birds within the red circles were considered part of the analysis. Site names are coded for location (e.g., F = Fortescue), the timing of placement (i.e., before or after; B or A, respectively), site descriptor (i.e., control or impact; C or I, respectively), and cardinal direction (e.g., N = north).

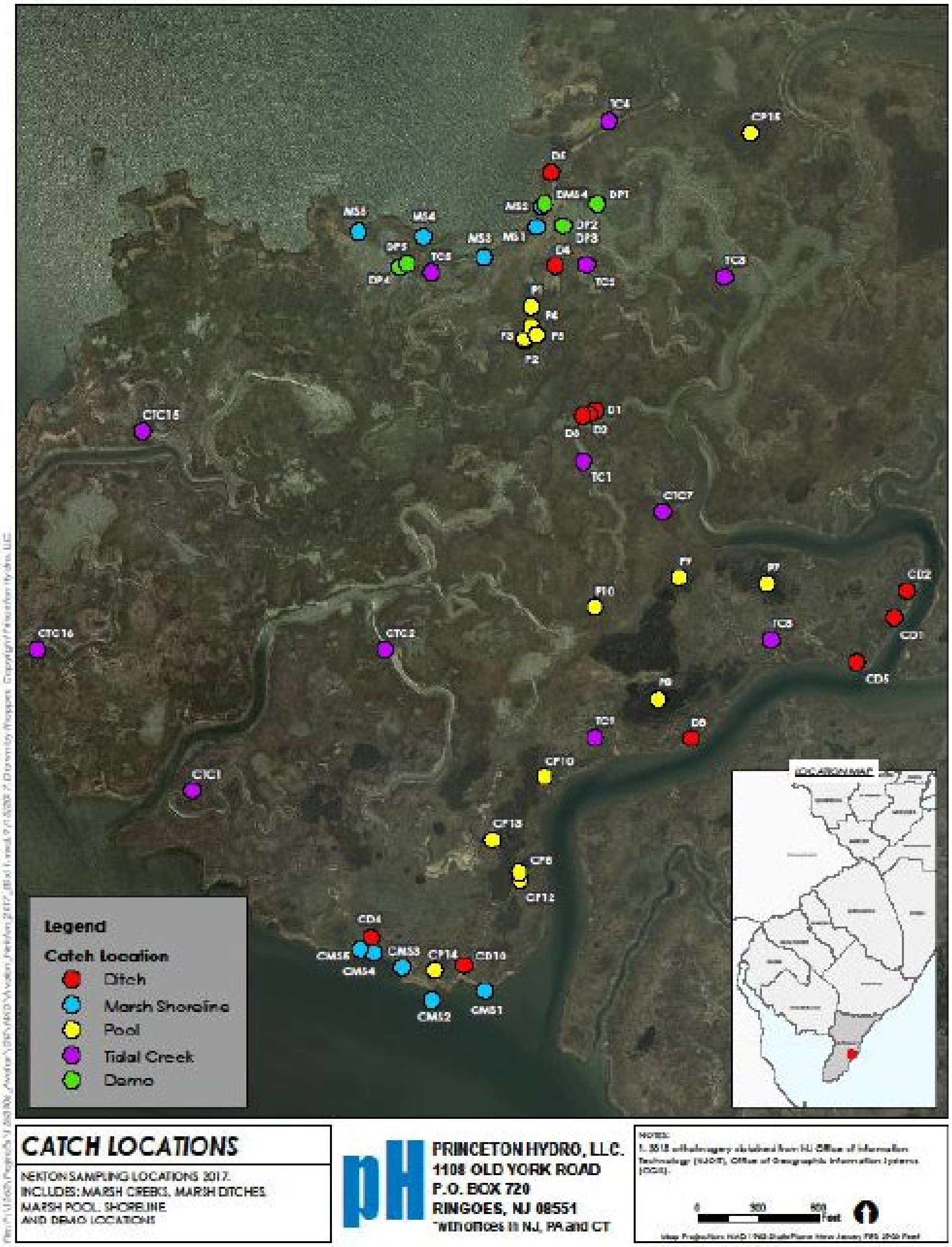
Appendix C

Additional Nekton Data and Figures

Avalon



Nekton by treatment and habitat sampling locations at Avalon, New Jersey 2016. Maps created by Thomas Hopper of Princeton Hydro, LLC.

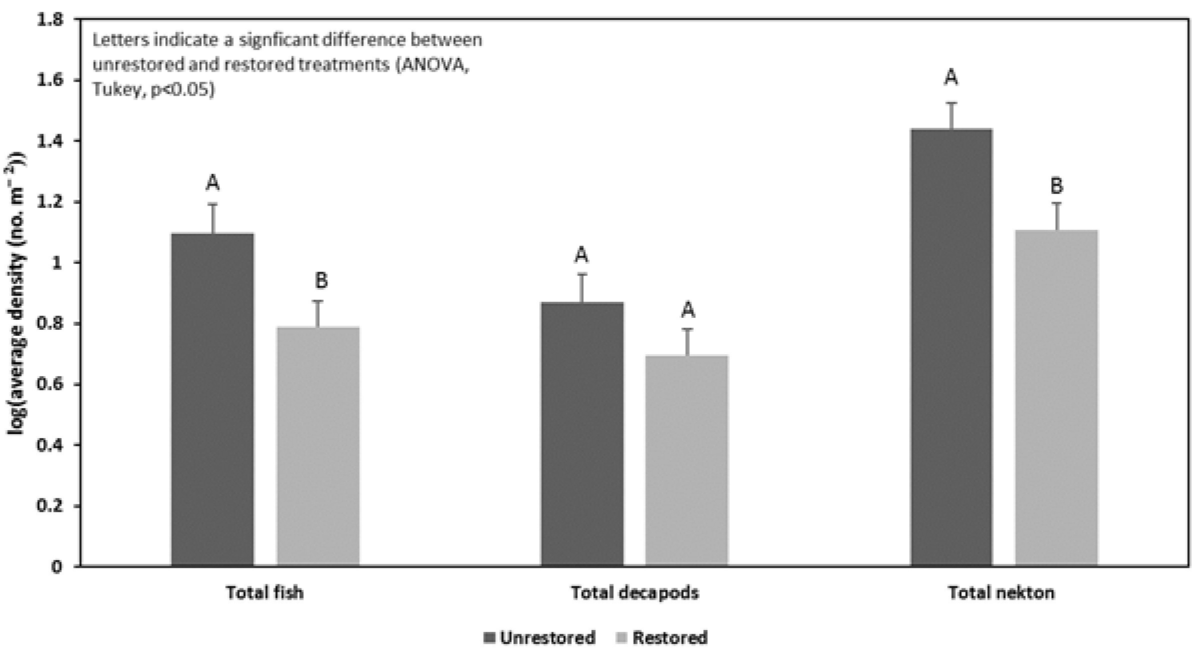


Nekton by treatment and habitat sampling locations at Avalon, New Jersey 2017.

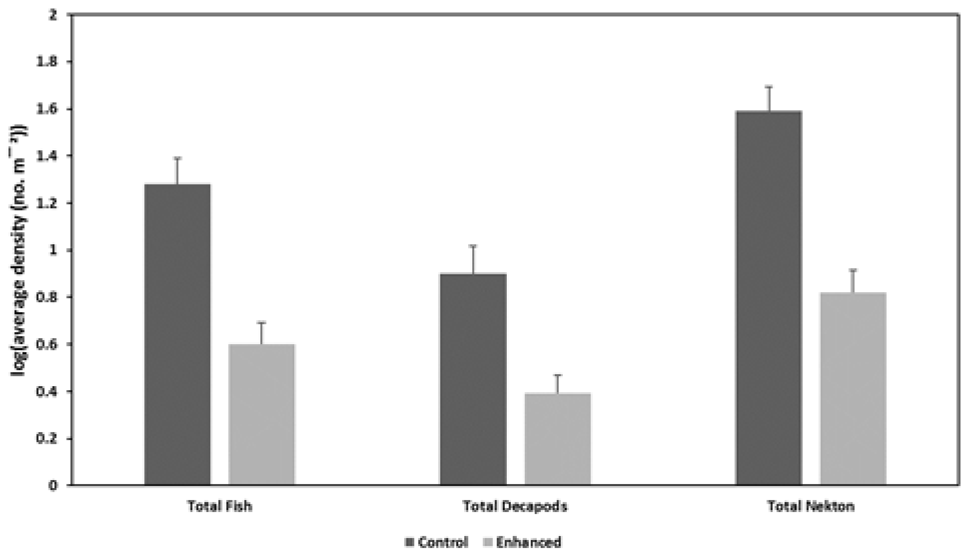
Total nekton abundance in tidal creeks, pools, subtidal creeks, and the shoreline edge at Avalon, NJ 2017

Species (Common Name)	2017 Avalon							
	Control				Enhanced			
	Tidal Creek n=5/5	Pools n=6/6	Shoreline Edge n=5/5	Subtidal Creek n=5/4	Tidal Creek n=7/7	Pools n=9/9	Shoreline Edge n=5/5	Subtidal Creek n=6/6
Fundulus heteroclitus (mummichog)	98	16	85	203	99	2		13
Fundulus majalis (striped killifish)	189	51	66	284	711	40	2	23
Luconia parva (rainwater killifish)		186	2			5		6
Menidia menidia (Atlantic silverside)	139	44	27	66	47	3	16	5
Palaemonetes pugio (daggerblade grass shrimp)	482	65	600	21	443		34	28
Carcinus maenas (green crab)								
Crangon septemspinosa (sevenspine bay shrimp)							5	
Callinectes sapidus (blue crab)	37	5	61	7	17	2	25	
Panopeus herbstii (Atlantic mud crab)								
Cyprinodon variegatus (sheepshead minnow)	3	400		150	6	59		
Gobiosoma bosc (naked goby)	2		14		1		6	
Mugil cephalus (striped mullet)								
Uca pugnax (Atlantic marsh fiddler crab)	1			3				4
Micropogonias undulatus (Atlantic Croaker)								
Brevootia tyrannus (Atlantic menhaden)	1		5					
Syngnathus fuscus (northern pipefish)			1					
Pogonias cromis (black drum)								
Eurypanopeus depressus (flatback mud crab)	3							

n= number of sampling sites within each habitat during Event 1/Event 2



2015-2016 average nekton density for fishes, decapods, and nekton at Avalon



2017 average nekton density for fishes, decapods, and nekton at Avalon

Average nekton length (length mm ± standard error) in tidal creeks, pools, subtidal creeks, and the shoreline edge at Avalon, NJ 2016.

Species (Common Name)	2016 Avalon Unrestored Tidal Creek n=6	Unrestored Pools n=12	Unrestored Shoreline Edge n=10	Unrestored Subtidal Creek n=8	Restored Tidal Creek n=14	Restored Pools n=18	Restored Shoreline Edge n=10	Restored Subtidal Creek n=12
Fundulus heteroclitus (mummichog)	37.80 ±5.96	26.36± 1.66	35.93± 3.31	37.43± 2.79	43.61 ±4.96	43.00 ±0	27.80± 0	42.16± 2.89
Fundulus majalis (striped killifish)	43.28 ±6.75	26.96± 1.98	46.70± 4.26	47.18± 9.97	47.37 ±6.45	28.35 ±3.95	34.50± 0	39.86± 3.59
Lucania parva (rainwater killifish)		20.39± 1.11	22.00± 0			16.47 ±4.62		21.00± 0
Menidia menidia (Atlantic silverside)	25.33 ±2.67	31.68± 3.38	31.00± 0		32.45 ±3.04		35.75± 1.75	32.00± 0
Palaemonetes pugio (daggerblade grass shrimp)	26.88 ±1.51	22.9± 2.39	28.67± 1.94	35.00± 4.51	24.57 ±1.63	14.00 ±0	25.17± 1.60	28.4 ±1.72
Carcinus maenas (green crab)								
Crangon septemspinosa (sevenspine bay shrimp)	25.50 ±0.5				27.00± 0			
Callinectes sapidus (blue crab)	22.60 ±6.59	63.5± 9.33	12.50± 0.50	14.00 ±0	24.67 ±10.65	10.33 ±1.67	35.67± 20.80	
Panopeus herbstii (Atlantic mud crab)		12.00± 0	14.80 ±1.88	23.50± 6.50	8.00 ±0			18.33± 0.33
Cyprinodon variegatus (sheepshead minnow)	36.50± 0	25.22± 1.65	32.00± 0		37.13 ±2.07	32.47 ±1.60		40.30± 0
Gobiosoma bosc (naked goby)	41.00± 0		33.00± 4.16		29.50± 0		36.00 ±0	29.00± 0
Mugil cephalus (striped mullet)					40.00± 0			
Uca pugnax (Atlantic marsh fiddler crab)								14.00± 0
Brevootia tyrannus (Atlantic menhaden)	88.80 ±0							
Micropogonias undulatus (Atlantic Croaker)	62.00± 0							
Syngnathus fuscus (northern pipefish)			76.5± 0					
Pogonias cromis (black drum)								

n= number of sampling sites within each habitat

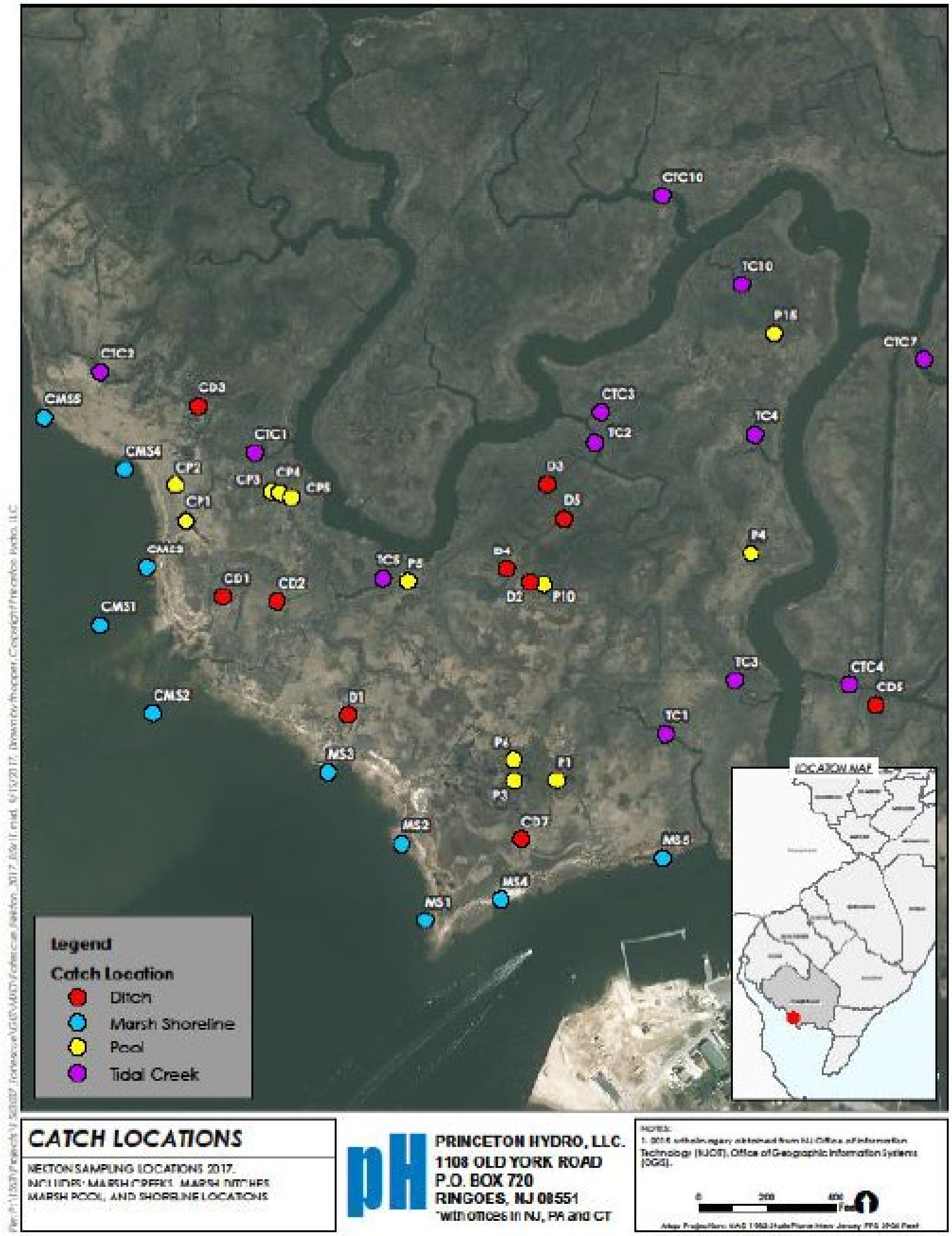
Average nekton length (length mm ± standard error) in tidal creeks, pools, subtidal creeks, and the shoreline edge at Avalon, NJ 2017.

Species (Common Name)	2017 Avalon							
	Control				Enhanced			
	Tidal Creek n=5/5	Pools n=6/6	Shoreline Edge n=5/5	Ditch n=5/4	Tidal Creek n=7/7	Pools n=9/9	Shoreline Edge n=5/5	Ditch n=6/6
Fundulus heteroclitus (mummichog)	38.34 ± 1.01	35.46 ± 1.62	26.41 ± 2.21	44.78 ± 1.14	38.41 ± 2.13	10.50 ± 0		33.44 ± 4.12
Fundulus majalis (striped killifish)	41.48 ± 3.65	28.93 ± 1.36	27.00 ± 3.32	34.82 ± 2.79	33.26 ± 2.07	34.40 ± 5.89	27.00 ± 5.00	33.54 ± 2.70
Lucania prava (rainwater killifish)		19.38 ± 1.09	17.00 ± 0			19.40 ± 6.40		22.70 ± 0
Menidia menidia (Atlantic silverside)	34.85 ± 3.10	28.10 ± 2.93	31.39 ± 4.53	33.98 ± 2.55	32.54 ± 3.71	33.50 ± 4.50	32.38 ± 7.95	33.33 ± 3.33
Palaemonetes pugio (daggerblade grass shrimp)	25.67 ± 1.38	22.60 ± 1.21	27.78 ± 1.14	27.60 ± 1.75	27.25 ± 1.11		25.33 ± 4.60	26.20 ± 0.80
Carcinus maenas (green crab)								
Crangon septemspinosa (sevenspine bay shrimp)							20.67 ± 2.73	
Callinectes sapidus (blue crab)	13.00 ± 2.08	56.00 ± 18.27	13.25 ± 0.88	13.00 ± 4.00	21.60 ± 7.28	8.50 ± 0.50	32.43 ± 18.22	
Panopeus herbstii (Atlantic mud crab)								
Cyprinodon variegatus (sheepshead minnow)	31.25 ± 2.75	23.27 ± 1.05		33.50 ± 0	29.63 ± 1.28	19.75 ± 3.08		
Gobiosoma bosc (naked goby)	38.00 ± 0		29.64 ± 1.42		28.00 ± 0		28.75 ± 10.25	
Mugil cephalus (striped mullet)								
Uca pugnax (Atlantic marsh fiddler crab)	19.00 ± 0			16.00 ± 4.04				18.33 ± 2.03
Brevoortia tyrannus (Atlantic menhaden)	27.00 ± 0		14.77 ± 2.43					
Micropogonias undulatus (Atlantic Croaker)								
Syngnathus fuscus (northern pipefish)	128.00 ± 0							
Pogonias cromis (black drum)								
Eurypanopeus depressus (flatback mud crab)	17.30 ± 0							

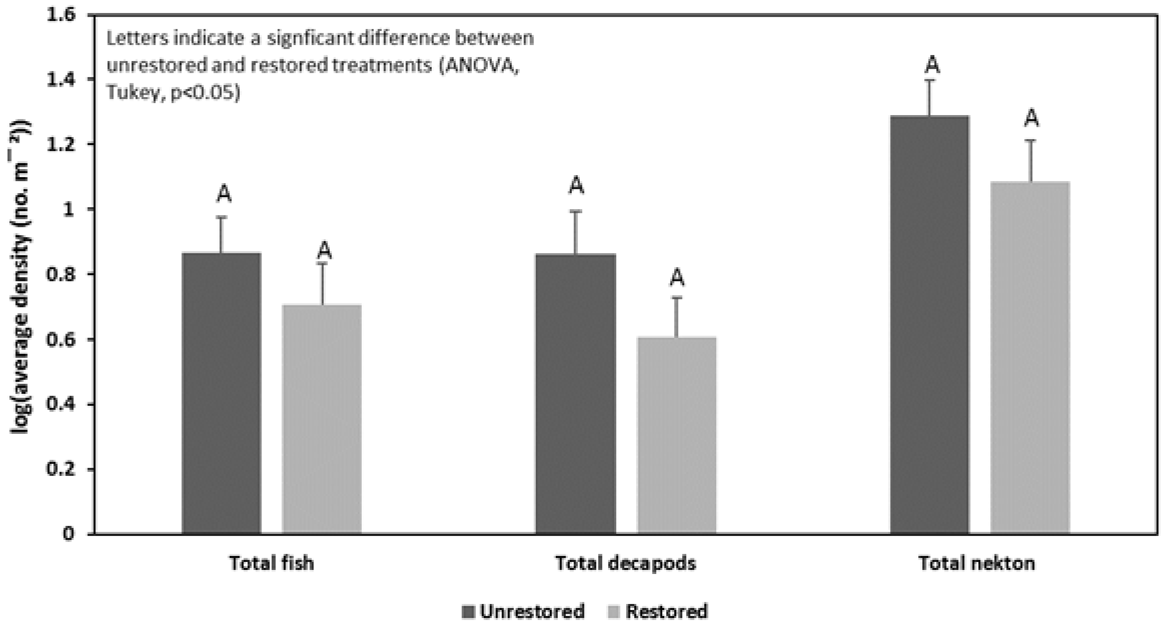
n= number of sampling sites within each habitat

Fortescue

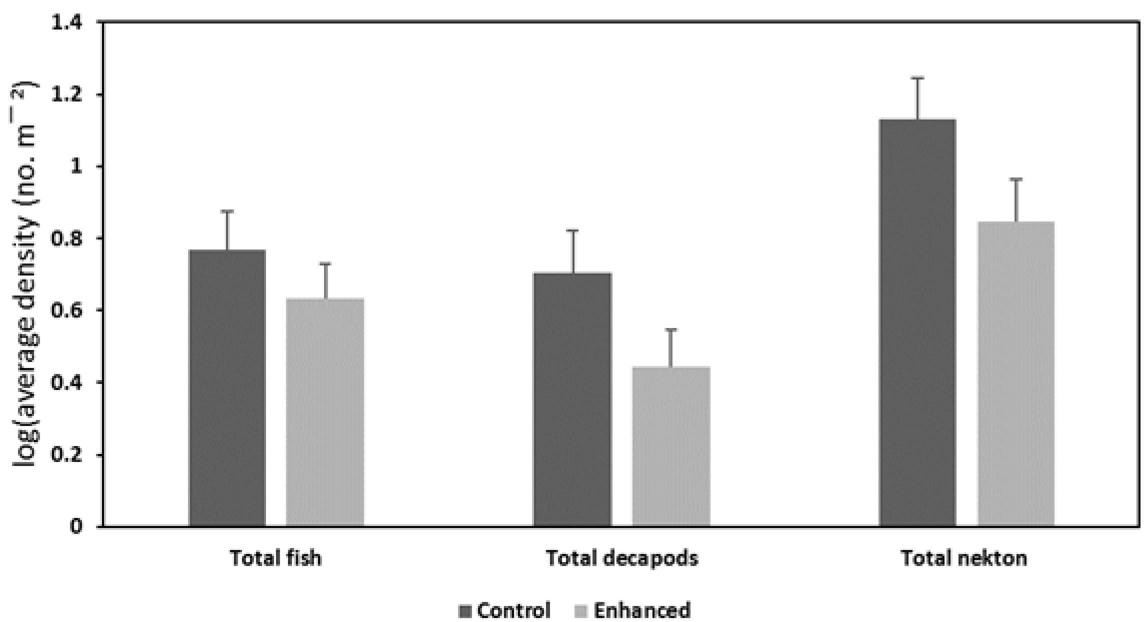
Nekton by treatment and habitat sampling locations at Fortescue, New Jersey 2016. Maps created by Thomas Hopper of Princeton Hydro, LLC.



Nekton by treatment and habitat sampling locations at Avalon, New Jersey 2017.



2016 average nekton density for fishes, decapods, and nekton at Fortescue



2017 average nekton density for fishes, decapods, and nekton at Fortescue

Average nekton length (length mm ± standard error) in tidal creeks, pools, subtidal creeks, and the shoreline edge at Fortescue, NJ 2016.

Species (Common Name)	2016 Fortescue							
	Unrestored				Restored			
	Tidal Creek	Pools	Shoreline Edge	Ditch	Tidal Creek	Pools	Shoreline Edge	Ditch
	n=5	n=10	n=9	n=10	n=5	n=10	n=10	n=8
Fundulus heteroclitus (mummichog)	39.03 ± 2.43	35.16 ± 3.43		38.22 ± 3.36	49.74 ± 5.80	36.58 ± 3.01	89.00 ± 0	37.93 ± 0.52
Fundulus majalis (striped killifish)	39.47 ± 2.76	31.90 ± 2.90	52.00 ± 0	35.52 ± 2.74	45.85 ± 7.95	33.73 ± 2.28	74.30 ± 0	31.80 ± 2.52
Lucania prava (rainwater killifish)		24.21 ± 1.45		25 ± 0		28.87 ± 1.85		29.75 ± 1.55
Menidia menidia (Atlantic silverside)	40.00 ± 0	38.04 ± 2.84	61.53 ± 6.14		37.75 ± 3.08		28.00 ± 0	
Palaemonetes pugio (daggerblade grass shrimp)	21.75 ± 1.49	19.71 ± 3.44	24.40 ± 2.38	20.00 ± 1.92	29.67 ± 2.67	16.33 ± 1.58	26.17 ± 1.08	19.00 ± 0
Crangon septemspinosa (sevenspine bay shrimp)			29.00 ± 0			12.50 ± 0.50	36.00 ± 1.00	
Callinectes sapidus (blue crab)	11.50 ± 0.50	29.80 ± 4.53	14.00 ± 4.92	33.00 ± 0	17.00 ± 1.00	38.5 ± 15.37	24.80 ± 9.02	
Panopeus herbstii (Atlantic mud crab)	5.00 ± 0			8.00 ± 0				8.00 ± 0
Cyprinodon variegatus (sheepshead minnow)		31.80 ± 1.67		29.83 ± 5.63		32.13 ± 0.30		35.10 ± 0
Gobiosoma bosc (naked goby)			19.00 ± 8.00					
Uca pugnax (Atlantic marsh fiddler crab)	22.00 ± 0			39.00 ± 6.00				
Micropogonias undulatus (Atlantic croaker)								
Trinectes maculatus (hogchoker)			25.50 ± 2.50					

n= number of sampling sites within each habitat

Average nekton length (length mm ± standard error) in tidal creeks, pools, subtidal creeks, and the shoreline edge at Fortescue, NJ 2017.

Species (Common Name)	2017 Fortescue							
	Control				Enhanced			
	Tidal Creek	Pools	Shoreline Edge	Ditch	Tidal Creek	Pools	Shoreline Edge	Ditch
	n=5/6	n=5/5	n=5/5	n=5/5	n=7/6	n=7/7	n=5/5	n=5/5
Fundulus heteroclitus (mummichog)	39.34 ± 2.08	31.05 ± 2.22		41.18 ± 5.00	46.88 ± 2.47	37.29 ± 1.80		31.15 ± 1.85
Fundulus majalis (striped killifish)	38.37 ± 1.37	29.11 ± 1.73		33.18 ± 1.42	38.58 ± 4.70	29.59 ± 2.18		28.98 ± 2.15
Lucania prava (rainwater killifish)		26.42 ± 1.42		23.75 ± 1.75	23.37 ± 2.30			21.50 ± 0.50
Menidia menidia (Atlantic silverside)	49.18 ± 6.00	36.45 ± 5.67	41.67 ± 9.39		36.79 ± 1.55		24.71 ± 0	
Palaemonetes pugio (daggerblade grass shrimp)	25.25 ± 0.86	21.67 ± 1.75	30.83 ± 1.62		28.00 ± 1.40	20.80 ± 2.40	28.50 ± 0.50	25.00 ± 0
Crangon septemspinosa (sevenspine bay shrimp)								
Callinectes sapidus (blue crab)	45.75 ± 17.82	39.33 ± 15.96	31.40 ± 15.92		32.00 ± 20.00			
Panopeus herbstii (Atlantic mud crab)					4.00 ± 0			
Cyprinodon variegatus (sheepshead minnow)		35.08 ± 2.72		29.00 ± 0	34.00 ± 3.00	33.08 ± 0.66		22.00 ± 0
Gobiosoma bosc (naked goby)		22.00 ± 0						
Uca pugnax (Atlantic marsh fiddler crab)	13.00 ± 0	32.50 ± 0		15.00 ± 1.00				
Micropogonias undulatus (Atlantic Croaker)								
Brevoortia tyrannus (Atlantic menhaden)								
Syngnathus fuscus (northern pipefish)								
Trinectes maculatus (hogchoker)								
Pogonias cromis (black drum)								

n= number of sampling sites within each habitat during Event 1/Event 2

Appendix D

Monitoring Metrics, Sub-metrics, and Corresponding Units

Metric	Sub-metrics	Units
Vegetation in permanent plots	Average stem height of dominant plant species	cm
Vegetation in permanent plots	Percent cover of vegetation (total and by cover types)	%
Vegetation in permanent plots	Species richness	Names and count
Vegetation	Above and below ground biomass	g (wet weight)/m^2; g (dry weight)/m^2
Salinity in permanent plots		ppt
Epifaunal macroinvertebrates in permanent plots	Species richness; abundance; density	NA; NA; classes
Bearing capacity in permanent plots	Depth of penetration	cm
Depth of placement in permanent plots		cm
Habitat changes over time (drone photos and orthophotos from GTA elevation surveys)		Acres or %
SETs and marker horizons	Elevation	NAVD 88
SETs and marker horizons	Elevation	mm
SETs and marker horizons	Shallow subsidence	mm
SETs and marker horizons	Net accretion	mm
Benthic infauna	Species diversity	Polychaetes to species level, crustaceans and mollusks to order level, count all nematodes, count all oligochaetes
Benthic infauna	Species density	Average abundance per core (3.8 cm diameter cores, top 3 cm)
Soil properties	Sediment grain size	% sand, silt, and clay
Soil properties	Organic matter	%
Soil properties	Soil moisture	mL H_20 per g_{soil}
Soil properties	Bulk density (without roots)	g/cm^3
Soil properties	Total volatile solids	%
Soil properties	Carbon	%
Soil properties	Nitrogen	%
Soil properties	Phosphorus	%
Soil properties	Sulfur	%

Soil properties	Microbial biomass carbon/nitrogen; potentially mineralizable nitrogen; extractable nitrate, ammonium, and phosphorus analysis	
Topography & Elevation		NAVD 88
Horizontal extent of placement		NAD 83
Surface Water Elevation & Tide Range Monitoring	Mean Higher High Water (MHHW) Elevation	NAVD 88
Surface Water Elevation & Tide Range Monitoring	Mean High Water (MHW) Elevation	NAVD 88
Surface Water Elevation & Tide Range Monitoring	Mid Tide Line (MTL) Elevation	NAVD 88
Surface Water Elevation & Tide Range Monitoring	Mean Low Water (MLW) Elevation	NAVD 88
Surface Water Elevation & Tide Range Monitoring	Mean Lower Low Water (MLLW) Elevation	NAVD 88
Surface Water Elevation & Tide Range Monitoring	Hydroperiod or tidal inundation depth/duration	
Nekton	Taxa richness	
Nekton	Composition	
Nekton	Species density	Number of individuals/m^2
Nekton	*Fundulus spp*. length	mm
In situ water quality	Temperature	°C
In situ water quality	Salinity/conductance	ppt
In situ water quality	Dissolved oxygen (concentration and percent saturation)	mg/L; %
In situ water quality	pH	
In situ water quality	Clarity/turbidity	
In situ water quality	Water depth	cm
Avian	Species richness	Number of species
Avian	Species abundance	Number of individuals per species
Avian	Species age	Classes
Avian	Species behavior	*e.g.,* nesting, loafing, foraging
Avian	Productivity	Number of fledglings per nesting pair
Avian	Number of nests	
Avian	Hatch success	Proportion of nests that hatch at least one egg
Avian	Fledging success	Proportion of nests that fledge at least one chick
Monthly observations	Fixed photo points	
Monthly observations	Depth of dredged material at the permanent depth stakes	cm

Monthly observations	Vegetation recovery/recruitment, vegetation die-off/notable absence, containment problems, sediment observations, instances of pooling, wildlife observations, planting success, planting failure, other	
Hydrology	Tidal datum	NAVD 88

Appendix E

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Beneficial Use of Dredged Material to Enhance Salt Marsh Habitat in New Jersey

Project Summary and Lessons Learned

August 2021

NEW JERSEY DIVISION OF Fish and Wildlife

The Nature Conservancy New Jersey

GreenVest One Step Ahead.

PRINCETON HYDRO

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Table of Contents

Glossary

The following terms have been defined according to how they have been specifically used in this document and in the context of the marsh enhancement projects discussed herein. These definitions may differ from those used by others for the same/similar terms.

Adaptive management—The process of continually, iteratively reviewing data and information to develop, design, construct, monitor, and manage a project, in order to meet the project objectives.

Beneficial use of dredged material—The placement of dredged material to enhance, create, or restore a variety of habitats, as opposed to the usual practice of disposing of it in a confined disposal facility.

Biological benchmarks—The optimum tidal elevation range of the plant species of interest. These benchmarks are used (at least, in part) to design a habitat (e.g., marsh) enhancement and to establish target ecological elevations for enhancement projects.

Coastal resiliency—The ability of coastal communities and natural habitats to withstand and recover from the impacts of storms, flooding, accelerating sea-level rise, and other natural hazards.

Dredging team—Personnel whose primary responsibility is to ensure the dredging success of the projects.

Ecological resiliency—The ability of an ecosystem (e.g., a salt marsh) to resist, respond to, and recover from a disturbance (e.g., an increase in the rate of sea-level rise).

Elevated Nesting Habitat (ENH)—Colonial shorebird nesting habitat created by placing sandy dredged material in a mound on the marsh platform to increase the elevation of the land and create sparsely vegetated sandy habitat. The ENH is high enough to protect the nests from flooding during high tides and storms.

Enhancement—The improvement of a wetland's ability to support natural aquatic life, through substantial alterations to the soils, vegetation, and/or hydrology, as defined by New Jersey Regulations. Also called "restoration" in other parts of the country.

Marsh team—Personnel whose primary responsibility is to ensure the ecological success of the projects.

Mean High Water (MHW)—The average of all the daily tidal high water heights observed over a period of several years.

Mean Higher High Water (MHHW)—The average height of the highest tide recorded at a tide station each day during the recording period.

New Jersey Intracoastal Waterway (NJIWW)—A system of navigation channels maintained by the U.S. Army Corps of Engineers that extends along the New Jersey Coast from the Atlantic Ocean at Manasquan Inlet to Delaware Bay, about 3 miles north of Cape May Point.

Placement areas—Specific areas on the marsh selected for enhancement that received sediment dredged from a nearby navigation channel or marina. Also called "marsh enhancement areas" or "dredged material placement areas."

Stressed marsh—Marshes in need of enhancement (not a regulatory term). Characteristics of stressed marshes include eroded edges, expanded and degraded pools with undercut banks, sparse (low percent cover) and stunted vegetation, mosquito ditches, fragmented high marsh vegetation, elevation deficits, and minimal faunal usage of pools.

Target dredged material placement elevation—The initial elevation up to which dredged material is placed on the habitat enhancement site (e.g., marsh plain). After placement, the material undergoes predicted dewatering and consolidation of the dredged material, sinking from the target dredged material placement elevation to achieve the target ecological elevation.

Target ecological elevation—The elevation necessary to meet the specific habitat (e.g., marsh) enhancement ecological objectives for a project. The target ecological elevation is lower than the target dredged material placement elevation and is based on biological benchmarks**,** desired hydrology, and other conditions at the project site.

Thin-layer placement (TLP)—A wetland enhancement method in which dredged material (i.e., sediment) is intentionally placed on a wetland to increase its elevation, enhancing its resiliency while maintaining the hydroperiod necessary for native wetland vegetation. The thickness of the material is limited to enable the vegetation to grow back through the placed dredged material. Wetland ecosystems are expected to recover more quickly after TLP than after thicker applications of dredged material.[1]

[1] The U.S. Army Corps of Engineers defines TLP as "Purposeful placement of thin layers of sediment (e.g., dredged material) in an environmentally acceptable manner to achieve a target elevation or thickness. Thin layer placement projects may include efforts to support infrastructure and/or create maintain, enhance, or restore ecological function." (Berkowitz et al. 2019)

This drone photo shows the salt marsh enhancement project in Fortescue, NJ, after sediment was added (outlined in black). Photo credit: TNC 2016

Summary

Tidal marshes are an integral part of New Jersey’s estuaries. They form a charismatic green band that cleans water; provides critical habitat and food sources for fish, shellfish, and birds; and buffers coastal communities from storms, erosion, and flooding (Mitsch and Gosselink 2007, NJDEP 2007, Narayan et al. 2017). However, the continued existence of many tidal wetlands is threatened by sea-level rise. To maintain healthy salt marsh vegetation, marshes must accrete sediment and plant matter to gain elevation at a rate that keeps pace with sea-level rise and subsidence (Nyman et al. 2006, Mitsch and Gosselink 2007, Cahoon et al. 2009, Kirwan and Megonigal 2013). Some salt marshes are stressed and literally “drowning” because they cannot gain surface elevation at a rate that keeps pace with accelerating sea-level rise (Hartig et al. 2002, Ganju et al. 2017, Watson et al. 2017a).

A variety of factors decrease tidal wetland resilience to sea-level rise, including historic alterations, like ditching and diking, and ongoing stressors, such as severe storms, dredging, decreased sediment content of tidal waters, and edge erosion (Bertness et al. 2002, Hartig et al. 2002, Church and White 2011, Partnership for the Delaware Estuary 2012, Weston 2014, Watson et al. 2017b).

One possible solution to the problem is increasing the elevation of a salt marsh by placing sediment on it (e.g., dredged material; Daiber 1986, Ray 2007). An increase in marsh elevation reduces inundation by the tides, promoting the growth of vegetation. The vegetation in turn stabilizes the marsh soil and promotes further accretion and increased elevation via sediment trapping and root production. It forms a positive feedback loop that increases marsh resiliency (Wolanski et al. 2009).

New Jersey’s navigation channels and marinas must be dredged regularly to maintain safe passage for recreational and commercial vessels, which creates a ready supply of dredged material. There is great interest in leveraging existing dredging projects to restore and enhance salt marshes. This practice, the **beneficial use of dredged material**, combines the routine maintenance and post-storm dredging required to keep waterways navigable with projects to enhance, restore, and create salt marshes and other estuarine habitats.

One of the many impacts of Superstorm Sandy in 2012 was major shoal creation in the navigation channels along New Jersey’s coast. Traditionally, in coastal areas of the state, dredged material was placed in confined disposal facilities, effectively removing it from the coastal system. New Jersey lacks confined disposal facilities with the capacity to accept additional dredged material, and this has become a major problem for coastal communities, as well as for state and federal agencies that need to maintain navigable waterways. Following Hurricane Irene (2011) and Superstorm Sandy, the U.S. Army Corps of Engineers, Philadelphia District (USACE-OP), obtained emergency supplemental funding to clear critical shoals from the **New Jersey Intracoastal Waterway (NJIWW)**, and the New Jersey Department of Transportation’s Office of Maritime Resources (NJDOT-OMR) planned to restore navigability by removing sediment from channels in Cumberland County.

In 2013, the New Jersey Department of Environmental Protection, Division of Fish and Wildlife (NJDEP-DFW), partnered with the USACE-OP, the USACE Engineer Research and Development Center (USACE-ERDC), NJDOT-OMR, The Nature Conservancy (TNC), and the Green Trust Alliance (GTA) to initiate three pilot projects. These projects intended to advance the concept that beneficial use of dredged material on stressed salt marshes to increase their elevation would increase the abundance of native salt marsh vegetation and would result in ecological uplift over their baseline condition, ultimately increasing their resiliency to sea-level rise. All parties acknowledged that this was an opportunity to explore a paradigm shift from thinking of dredged material as waste to thinking of it as a resource. The total cost of the pilot projects was $8 million. Approximately half of the funds were provided to NJDEP-DFW from the Hurricane Sandy Coastal Resiliency Competitive Grant Program (Grant #43095, administered by the National Fish and Wildlife Foundation; NFWF). The grant period was August 2014 through October 2017. The other half of the funds were provided by the USACE-OP and NJDOT-OMR.

Project Goals and Objectives

One of the main components of the project was the development, implementation, and monitoring of the three pilot projects to enhance approximately 90 acres of salt marsh, with associated restoration of beach and dune and creation of avian nesting habitat. The goals of these pilot projects were to (1) improve existing management of dredged material, (2) increase the technical and practical knowledge and science behind these innovative beneficial use projects, (3) change standard dredged material management practices in the state of New Jersey, and (4) in the aftermath of Superstorm Sandy, advance these practices to enhance **coastal resiliency**.

Project locations were selected on the basis of three factors: (1) USACE-OP and NJDOT-OMR needs for dredging and management of the dredged material, (2) the needs of state-owned salt marshes for **enhancement**, and (3) the potential for the marsh to provide wave attenuation and storm surge buffering services for a coastal community. The three pilot projects differed in the composition of dredged material used (sand, silt, or clay), the dredged material placement methods (spraying or direct pumping), the depth of placed dredged material, and the existing condition of the marshes. The pilot projects were monitored comprehensively for three primary purposes: (1) to evaluate how the salt marsh ecosystem responded to dredged material placement in the short term, (2) to identify factors that negatively impact marsh recovery, and (3) to determine whether the condition of the marsh was improved (i.e., whether it experienced ecological uplift).

The objectives for the three marsh pilot projects were (1) to increase and maintain the optimal tidal elevation (hydroperiod) for native salt marsh species, (2) to increase the cover and health of native salt marsh vegetation, and (3) to return all other metrics to baseline (i.e., pre-implementation) conditions (unless they were expected to change due to habitat conversion).

Purpose of This Document

This document (*Project Summary and Lessons Learned*) discusses the planning and implementation of the three pilot projects. This report is being released before the project objectives have been fully achieved. This is because many similar potential projects in New Jersey need information about how these pilot projects were implemented. It can take considerable time to recover the biogeochemical functions and structure of a natural marsh after restoration (Zedler 2000; Moreno-Mateos et al. 2012). We will continue monitoring the projects to learn how they change over time. We are also preparing another report, the *Monitoring and Data Evaluation Report*, that will present, analyze, and evaluate the project monitoring data through 2019.

Project Development

The project team[2] consisted of USACE-OP and NJDOT-OMR navigation managers, the landowner (NJDEP-DFW), conservation practitioners, scientists, state regulators, and engineers. Beginning in 2014, this team identified salt marsh sites that were within hydraulic pumping distance of planned dredging projects and that could benefit from the placement of dredged material. All state-owned marshes within one mile of the planned dredging projects were preliminarily assessed via desktop analyses using a combination of LiDAR mapping, current and historic aerial photos, and TNC's NJ Living Shoreline and Marsh Explorer Apps[3] (internet-based decision support tools).

The project team visited the sites several times to select specific areas for additional evaluation and to discuss potential techniques to enhance the marsh and other habitats. The marshes selected for enhancement were dominated by short form, stunted *Spartina alterniflora*. During the selection of preliminary **placement areas**, the team documented qualitative observations of vegetative health, pool and panne conditions, platform stability, edge erosion, flooding, and faunal use. Sites adjacent to coastal towns and infrastructure were prioritized for their potential storm buffering capacity. Project feasibility analyses and quantitative data further refined the selection of placement areas and the appropriate enhancement technique(s) for each area, considering the grain size and chemistry of the source sediment, schedule of the dredging projects, and elevation of the site.

Monitoring

To track progress toward achieving project objectives and to better understand the effects of placing dredged material on the marshes, the team developed a comprehensive monitoring program that included multiple ecological parameters and generally followed a Before-After-Control-Impact (BACI)

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[2] See page 2 for full list of project team members.

[3] The Nature Conservancy's Marsh Explorer App on its Coastal Resilience decision support tool. The Marsh Explorer App is focused on salt marshes along New Jersey's Atlantic coast and identifies the need for tidal marsh restoration based on the amount and size of linear ditches, marsh edge erosion, unvegetated marsh, and unused dredge lagoons. https://maps.coastalresilience.org/newjersey/

design. The parameters that were monitored included elevation, depth and extent of the placed dredged material, sediment characteristics, surface water elevation, vegetation, invertebrates, fish, birds, and habitat changes. In addition, the team made qualitative observations during monthly site visits that informed post-construction **adaptive management** of the projects.

Summary of Projects

Between August 2014 and April 2017, pilot projects were constructed at three locations: Ring Island and Avalon in the Cape May Wetlands Wildlife Management Area, and the Fortescue Wildlife Management Area in Fortescue, Cumberland County (Fig. 1). The marsh enhancement techniques included **thin-layer placement** (**TLP**) of dredged material on the platform of a vegetated, **stressed marsh** (all three sites) and the filling of degraded and expanding pool–panne complexes with TLP on the surrounding stressed marsh platform (Avalon). In addition, **Elevated Nesting Habitat (ENH)** for birds was added at Ring Island, and

Figure 1. *Pilot projects for the beneficial use of dredged material were implemented at three locations in New Jersey.*

dune restoration and beach restoration projects were conducted at Fortescue. Table 1 shows a summary of the projects.

Table 1. Summary of the pilot projects at Ring Island, Avalon, and Fortescue

Project	**Ring Island**		**Avalon**		**Fortescue**		
	Marsh	**ENH***	**Phase 1**	**Phase 2**	**Marsh**	**Beach**	**Dune**
Constructed	Aug 2014	Aug 2014	Dec 2014 to Jan 2015	Nov 2015 to Feb 2016	Mar 2016	Mar to Apr 2016	Feb to Apr 2017
Habitat Size (Acres)	0.89	1	6.9	45	6.6	1.3	2.25
Sediment Volume (CY)**	1,000	6,000	~6,000	~49,300	6,490	7,245	18,335
Sediment Type	96% fine sand	96% fine sand	65% silt/clay	72% silt/clay	30% silt/clay	>75% sand	>90% sand
Placement Technique	Spray	Direct pumping	Spray	Spray, direct pumping	Direct pumping	Direct pumping	Direct pumping

* ENH = Elevated Nesting Habitat
** CY = cubic yards

Ring Island

The dredged material for the Ring Island project was 96% fine sand and came from a shoaled area in the NJIWW located next to the island. The sand was used to construct two TLP areas (~0.5 acres each) and an ENH (~1 acre).

Elevated Nesting Habitat

The purpose of the ENH at Ring Island was to create suitable habitat for the black skimmer (*Rynchops niger*), which is endangered in New Jersey, and other bird species of concern (Fig. 2). It was designed as a 1-acre mound with a platform elevation of six feet above the **Mean Higher High Water (MHHW)** and 1:12 (vertical to horizontal) side slopes.

In August 2014, the 1-acre ENH was created from approximately 6,000 cubic yards (CY) of the dredged sand. To keep the dredged material within the boundary of the ENH, the area was mostly enclosed during placement (except for a small outlet area for water to exit) using straw bales, a sand berm, and a silt fence. A skid loader was used to grade the placed dredged material and form the ENH mound. The top of the ENH was above the spring high-tide line—an important nest survival threshold for coastal birds—but below the target elevation in the design and the permit. Post-construction adaptive management included planting vegetation on the slopes of the site, removing invasive *Phragmites australis*, removing plants from the top of the platform, and, in early 2018, placing additional dredged material to restore elevation above the spring high tide.

Marsh Enhancement

The goal of marsh enhancement at this site was to increase the abundance and rigor of native marsh vegetation by increasing the elevation of "low-lying"[4] marsh. We accomplished this by spraying thin (three- or six-inch thick) layers of sandy dredged material. These placement depths were chosen to allow existing vegetation to survive and quickly recover, growing through the placed dredged material (Ray 2007). No perimeter containment was used because the surrounding areas of the marsh platform were at higher elevations than the placement areas and the sand did not disperse far during placement.

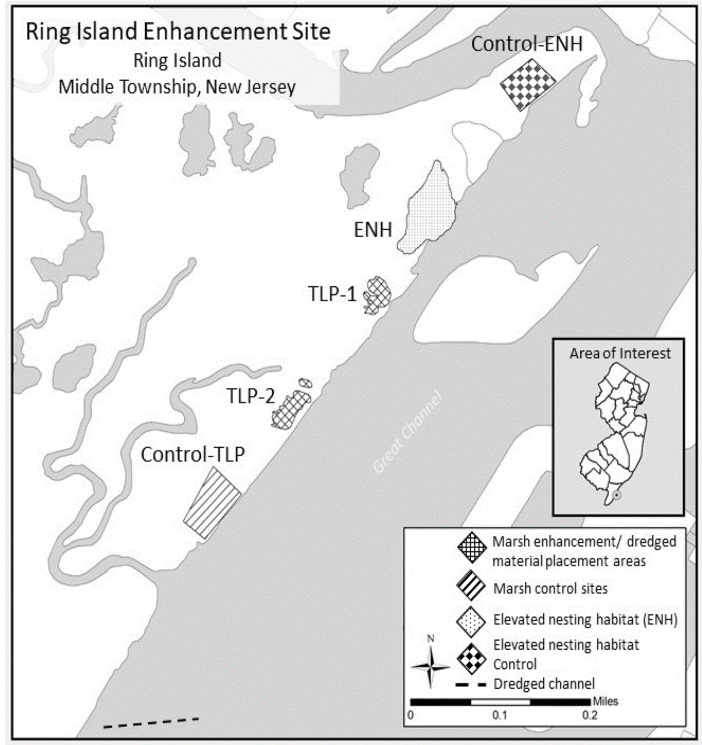


Figure 2. *This map of the Ring Island site shows the elevated nesting habitat (ENH), the marsh enhancement thin-layer placement areas (TLP-1 and TLP-2), and the control areas (Control-ENH and Control-TLP).*

During two days in August 2014, approximately 1,000 CY of fine-grained sand was sprayed on two 0.5-acre sections of marsh platform using a hydraulic dredge and a spray nozzle system. The discharge end of the dredge pipe was placed on a pontoon at the edge of the marsh, with the spray landing approximately 150–200 feet from the pipe. Spraying the sand to achieve an even thickness of placement was difficult, as it accumulated wherever it landed, with little natural spreading. Dredging was stopped intermittently and water was sprayed through the nozzle system in an unsuccessful effort to disperse the placed sand across the marsh platform.

Topographic surveys and depth measurements in the weeks immediately after construction indicated that, although the average placement depth (6 inches) was within the 3- and 6-inch targets, placement was uneven, ranging from 0.5 to 9 inches. In March 2017, native salt marsh species were planted on half of the bare areas within each of the TLP areas.

[4] The location of the possible TLP sites on Ring Island changed several times in the weeks preceding placement, due to the presence of nesting birds and a change in the dredging schedule. As a result, the baseline topographic data could not be used to quantitatively assess the elevation of the selected TLP areas. However, observations during site visits suggested that the selected TLP areas were lower than the surrounding, more densely and diversely vegetated marsh. The project team decided it was worth moving forward with the project as an experiment and learning experience. Assessments after construction showed that the baseline elevation of the TLP areas was closer to the Mean High Water level than the Mean Higher High Water level and was 0.75 feet below the lower end of the range in elevation at which *Spartina patens* was found at the site.

Avalon

At the Avalon site, there were two phases of dredged material placement. The dredged material for these projects came from the NJIWW near the project site; following Superstorm Sandy, this stretch of the NJIWW was one of the critical channel shoals that the USACE-OP needed to dredge. The sediment in the channel was predominantly silt and clay.

Building on the Ring Island project, the goal of the Avalon marsh enhancement project was to increase the area of vegetated marsh by filling expanding and degraded pools and pannes to the elevation of the surrounding marsh. The newly created topography was expected to improve drainage off the marsh and reduce excessive ponding of water, which is a primary stressor to plants. To accomplish this, the dredged material was either sprayed or directly pumped into the pools, with the overflow resulting in a thin layer of dredged material on the adjacent marsh platform. To keep the fine-grained dredged material within the placement area boundaries, perimeter containment (coconut-fiber logs) was installed prior to construction. Containment was added as needed during construction.

Avalon Phase 1

In early January 2015, approximately 5,000 CY of predominantly fine-grained sediment was placed on 7 acres of marsh (Fig. 3, Areas A and C). The goal was to fill pools and add 3 to 6-inches of sediment to the surrounding marsh platform. In addition, sediment was sprayed directly onto the marsh platform to learn how TLP of fine-grained material differed from that of sandy material.

Avalon Phase 2

Additional data collection and detailed engineering work were completed to design the Avalon Phase 2 project. Topographic surveys, high marsh **biological benchmarks**, and tidal data were used to establish **target dredged material placement elevations** and **target ecological elevations**, rather than simply establishing target dredged material placement thicknesses. Between November 2015 and March 2016, about 50,000 CY of fine-grained dredged material from the nearby NJIWW navigation channel were placed on approximately 45 acres of the Avalon marsh (Fig. 3, Areas A, C, D, E, and F).

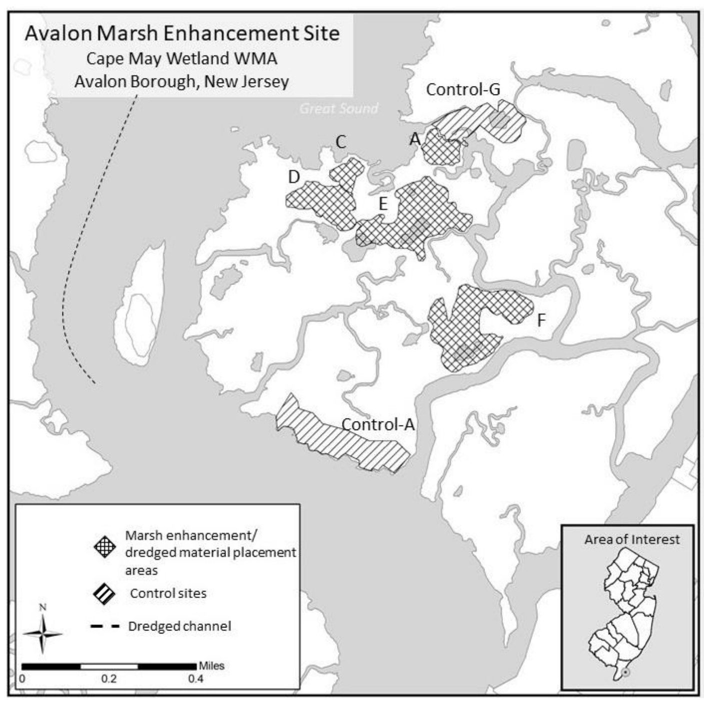


Figure 3. *This map of the Avalon site shows the locations of the marsh enhancement areas (A through F) and marsh control areas (Control-A and Control-G).*

Topographic surveys in the weeks following sediment placement showed the mean elevation of each placement area was within 4 inches of the target dredged material placement elevations. However, it is clear that some sections of each placement area did not achieve the target dredged material placement elevations, while in other areas, the targets were exceeded by more than 1 foot. The depth of sediment placed on the marsh platform ranged from 1 to 9 inches, while the depth in some pools was even greater. Two years after placement, the areas had lost some of their initial elevation and the mean elevation was within 1 inch of the target ecological elevations at four of the five placement areas. However, some pools had re-formed by 2017, indicating differential settling, consolidation, and compaction of the placed dredged material and underlying marsh.

After construction of the Avalon Phase 2 project, an adaptive management program was implemented. For example, based on observations that the dredged material was still dewatering and elevations were changing, combined with concerns regarding the potential to disrupt nesting birds, planting was delayed for a year. The original planting plan was also adaptively implemented in the field in response to the changed conditions. In addition, during the first summer after construction, vegetation die-off was observed in some areas outside and directly adjacent to the perimeter containment. Supplemental monitoring was conducted to investigate the cause(s) of the die-off and to suggest potential adaptive management actions to mitigate it. Initial results from this monitoring suggested that the containment was blocking tidal flow and that this, in combination with acid produced by the oxidation of the placed dredged material, may have created extreme water chemistry fluctuations and less than optimal flooding patterns. In response, we removed most of the containment at both Avalon and Fortescue rather than continuing with the original plan for it to biodegrade in place.

Fortescue

The marsh enhancement component of the Fortescue pilot project was designed to improve growing conditions for native salt marsh plants and create positive drainage off the marsh platform by increasing the elevation of a low-lying ditched marsh. In addition, to protect the marsh and nearby marina from erosion, a dune restoration project was designed and a nearby eroding beach was restored (Fig. 4). These projects used mostly sandy sediment that was dredged from the nearby Fortescue Creek navigation channel.

Marsh Enhancement

The Fortescue project was designed to increase the elevation of the marsh by approximately 9 inches. The target dredged material placement elevation of 3.3 feet and the target ecological elevation of 2.8 to 3.0 feet NAVD88 were based on biological benchmarks and local site hydrology, with the objective of producing high marsh habitat. The project team applied the lessons learned from the construction of the Avalon Phase 2 project to the design and construction of the Fortescue project. The marsh enhancement design included a branching system of pipes with valves that could be opened and closed and included some flexible pipes that could be moved more easily by hand. This design would, in theory, avoid the costly downtime that was experienced during the Avalon Phase 2 project when the team had to stop the discharge of dredged material to prevent overflow of the containment and had to reposition the dredge pipe. A double containment row of plastic mesh tubes filled with wood chips (Filtrexx SiltSoxx™) was installed around each dredged material placement area.

In March 2016, 6,490 CY of a heterogeneous mix of sandy and fine-grained dredged material from the Fortescue Creek navigation channel was placed on two areas, totaling 6.4 acres of the marsh, which was less than 30% of the originally planned marsh enhancement area. The efficacy of the highly engineered dredge pipe network could not be evaluated because it was not used to its full advantage, and the team used large machinery to reposition the pipe outlet rather than employing the smaller flexible pipes. Several challenges were encountered during the marsh enhancement. For example, the dredged material was sandier than expected, the winter weather was especially harsh, and there were contracting issues. As a result, the team was unable to complete construction the first year and decided not to finish the project in the second year.

In permanent monitoring plots, the average depth of placement was 6 inches and the material depth ranged from minimal to 18 inches.[5]

After construction, portions of the bare sections of the marsh enhancement areas were planted with native salt marsh species. As part of the project adaptive management plan, the plastic netting around the Filtrexx SiltSoxx™ was removed and the wood chip filling was dispersed across the marsh.

Dune Restoration

The Fortescue dune restoration was designed to protect the adjacent marsh and the marinas on Fortescue Creek from erosion caused by tidal flow and storm waves. Originally, this project component was designed to be constructed mainly in the footprint of an existing dune adjacent to the marsh platform, but after a winter storm eroded portions of the shoreline, the dune footprint was redesigned to be farther inside the marsh.

In early 2017, approximately 18,000 CY of sandy dredged material was used to construct the dune. Filtrexx SiltSoxx™ and sand berms were used to retain the dredged sand. Outlets through the containment on the marsh side of the dune were constructed to allow fine-grained sediment to flow into the marsh, creating an area of TLP.

As-built surveys showed that the final constructed dune was 900 feet long, 40 feet wide at the top, and 80 feet wide at the bottom, with an elevation of 10.0 feet NAVD88 (5 to 6 feet above the marsh surface). After construction, the dune was planted with native shrubs and grasses.

[5] Results from annual real-time kinematics (RTK) transect surveys of the elevation at Fortescue showed improbable gains in elevation for the control areas. Therefore, elevation data are not summarized here.

Beach Nourishment

The Fortescue beach was eroded by winds and waves. The project's beach nourishment component was designed to restore a natural beach near Fortescue Creek. Approximately 7,000 CY of sediment (at least 80% sand) dredged from the Fortescue Creek navigation channel was spread over 1.3 acres (700 linear feet) of beach at a 15:1 (horizontal to vertical) slope. The team expected that a plateau would form naturally as the placed dredged material was "worked" by the tides and wind.

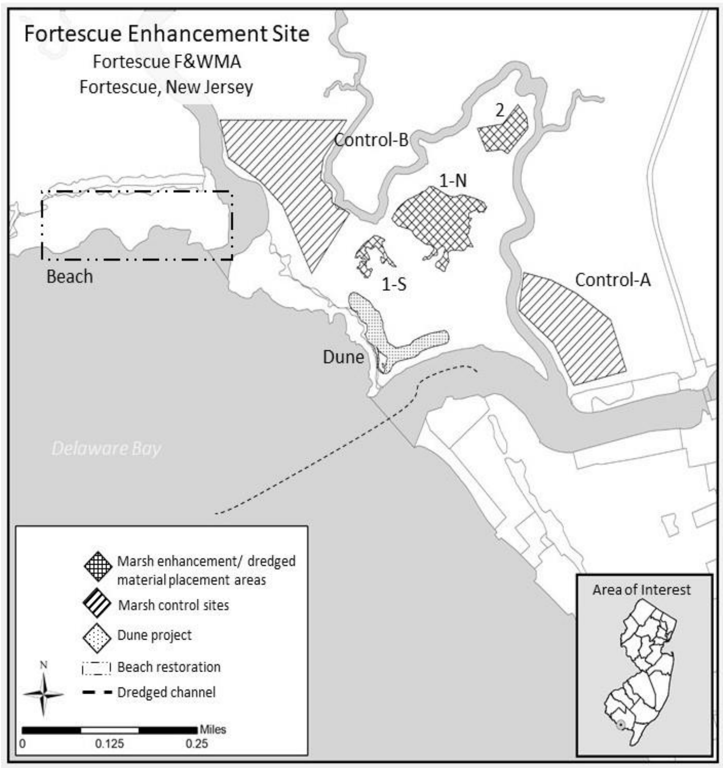


Figure 4. *This map of the Fortescue site shows the locations of the marsh enhancement (1-S, 1-N, and 2), dune restoration (Dune) and beach nourishment (Beach) dredged material placement areas and the marsh control sites (Control-A and Control-B).*

Cost Analysis

After construction of all three pilot projects, the project team estimated the total cost of each project and the costs of selected project components. While these estimates do not represent the full life-cycle costs of the projects, and while the Fortescue project was led by the NJDOT-OMR and not USACE-OP (leading to different contracting processes and associated costs), the cost per CY of placed dredged material and acre of enhanced habitat were highest at Fortescue ($150 per CY and $470,000 per acre) and lowest at Avalon ($45 per CY and $55,000 per acre). The per-acre costs are comparable to the reported median and average costs of salt marsh restoration in developed countries, which are $61,160 per acre and $421,730 per acre, respectively (in 2010 U.S. dollars; Bayraktarov et al. 2016), as well as other similar projects that used dredged material in Rhode Island. The pilot project costs can also be compared with the cost of placing dredged material in confined disposal facilities (CDFs), which has historically been the "business as usual" method of managing dredged material in New Jersey's estuaries. The expense of placing sediment in a CDF is highly variable but is typically $15 to $75 per CY.

The dredging and the placement of the dredged material on the marshes were the most expensive components of each marsh enhancement project, ranging between 50% and 60% of the total project budget. The second largest expense for the pilot projects was monitoring, ranging from 10% of the budget at Fortescue to 31% at Ring Island.

Chapter 1: Lessons Learned

The three pilot projects evaluated the potential of using dredged material for marsh enhancement and tested potential placement methods for dredged material. From the outset, the project team was focused on implementing these projects to inform the development of best management practices for similar marsh enhancement projects across New Jersey. The team developed a series of lessons learned and associated recommendations and applied them from earlier projects to the design and construction of the subsequent projects.

As any marsh enhancement project is unique in its design and objectives, the lessons learned presented in this report should be used as general guidance and not as firm standards to inform future projects. Future experiences will vary as these techniques become more commonplace in New Jersey and as new lessons are learned. However, we recommend that practitioners focus on the following key lessons learned as they investigate and develop similar marsh enhancement projects:

Key Lesson 1. Coordinate at multiple levels and throughout all phases of project development, implementation, and monitoring. This includes coordination within an interdisciplinary team of ecologists, engineers, and dredge contractors, as well as coordination between the team and federal and state regulatory agencies, resource managers, landowners, and other stakeholders. Such coordination helps to ensure smoother project implementation and more timely and effective adaptive management.

Key Lesson 2. Use an adaptive management approach throughout the lifecycle of the project. Adaptive management will likely start in the site selection phase of the project, when the needs of the marsh enhancement project, including sediment volume and characteristics, must be matched to those of a nearby dredging project. Adaptive management is critical during construction of the project and throughout the post-construction monitoring and maintenance period if the trajectory of marsh response differs from what was anticipated. Adaptive management impacts both the project timeline and the budget, so plan accordingly and set aside funds.

Key Lesson 3. Use data from initial assessment and from ongoing monitoring as the foundation for the design and implementation of marsh enhancement projects. Projects that beneficially use dredged material are not typical dredging projects. Their primary goal is the ecological uplift of natural habitats, not simply the disposal of dredged material. Substantial data are needed to identify a potential marsh enhancement site and pair it with a suitable dredging project. Additional data are needed to design the marsh enhancement project, and multiple years of post-construction monitoring are needed to assess the trajectory of marsh response and determine the need for adaptive management and maintenance (especially now, as these types of projects are relatively new in New Jersey). The data needed will vary with the scope of the project and may decrease over time as more experience is gained with these projects.

While the beneficial use of dredged material to restore and enhance salt marshes has great potential to support the resilience of both coastal habitats and coastal communities in New Jersey, these projects must be planned and implemented in a technologically and ecologically sound manner. The project team hopes this report and the lessons learned can guide similar projects as they are proposed, discussed, planned, and implemented throughout New Jersey.

The project team gained considerable insights into the technical and ecological aspects of these types of projects over the first four years. These lessons learned and the team's recommendations for similar projects are presented in this chapter. However, due to the unique nature of individual marsh enhancement projects, these lessons learned and recommendations should be considered guidelines, not hard and fast prescriptions.

The lessons learned are grouped into the project phase with which they are most closely associated:

- Phase 1: Marsh Assessment and Placement Area Selection
- Phase 2: Project Design
- Phase 3: Permitting
- Phase 4: Bidding and Contracting
- Phase 5: Construction
- Phase 6: Post-Construction Adaptive Management
- Phase 7: Project Assessment

The phases are discussed in greater detail in Chapter 2 of this document. In addition, many of the most important lessons learned were derived from the iterative nature of project development and the adaptive management approach used throughout the projects. These cross-phase lessons learned are presented here.

Cross-Phase Lessons Learned

Cross-Phase Lesson 1. Tailor development and assessment plans to specific projects. Each project is unique and should be developed accordingly. Existing marsh conditions were very different at each of our pilot sites, as were the characteristics of the dredged material. As a result, the objectives and strategies of the marsh enhancement projects at each of these sites differed. We also expect that the trajectory of marsh response—and the habitat or habitats that ultimately develop—will differ among sites.

Cross-Phase Lesson 2. Establish SMART objectives and results chains at the beginning of the project to ensure that all members of the team understand and address these same objectives. SMART objectives are Specific, Measurable, Achievable, Relevant, and Time-bound. Marsh enhancement projects are complex, and combining them with dredging projects makes them more complex. Having a working results chain can help the various team members understand the objectives for each step in the project, how they relate to one another, and how they build toward the SMART objectives. The combination of the SMART objectives and results chains that clearly explain assumptions can help the team make decisions as they adaptively manage the project. When issues arise, the team will have a better idea of how management options will affect the overall project objectives. See Figure 5 for an example of a results chain and its assumptions.

Cross-Phase Lesson 3. Use an iterative project development process. The development of a marsh enhancement/dredged material beneficial use project is inherently an iterative process, from its conceptualization through site identification, placement area selection, design, and permitting and contracting (i.e., Phases 1–4). These projects include many components that must be developed in a coordinated manner by all the project partners to help ensure project success. Project development and design should also be coordinated with the dredging project manager, landowner, dredging contractor, and the state (NJDEP) and federal (USACE) regulatory agencies. Recommendations and issues raised by any of these parties could result in the need to acquire and evaluate additional data and require revisions to the scope of the project (including design/engineering, dredging, and monitoring plans).

Development of the marsh enhancement/dredged material placement component of the project must be closely coordinated with the design of the associated dredging component. As data are collected for both components, revisions to the scope of one may require revisions to the other. In particular, the characteristics of the sediment to be dredged must be determined to evaluate its suitability for marsh enhancement. Not all the available dredged material may be suitable for use on a marsh, which can limit the volume that can be dredged if there is no suitable option to dispose of the excess dredged material. This was the situation at Fortescue, and it required us to develop multiple projects (marsh enhancement, beach nourishment, and dune restoration) to make the dredging project economically viable. The multiple projects allowed us to test the enhancement of multiple habitats using dredged material.

Cross-Phase Lesson 4. Be aware when scheduling a project that the process, from site selection through post-construction monitoring and evaluation, may require a minimum of eight years. The objectives of both construction and marsh enhancement must be realistically achievable and measurable within the project timeframe. Table 2 presents the minimum estimated timeline to complete a marsh enhancement/dredged material beneficial use project, including post-construction monitoring.

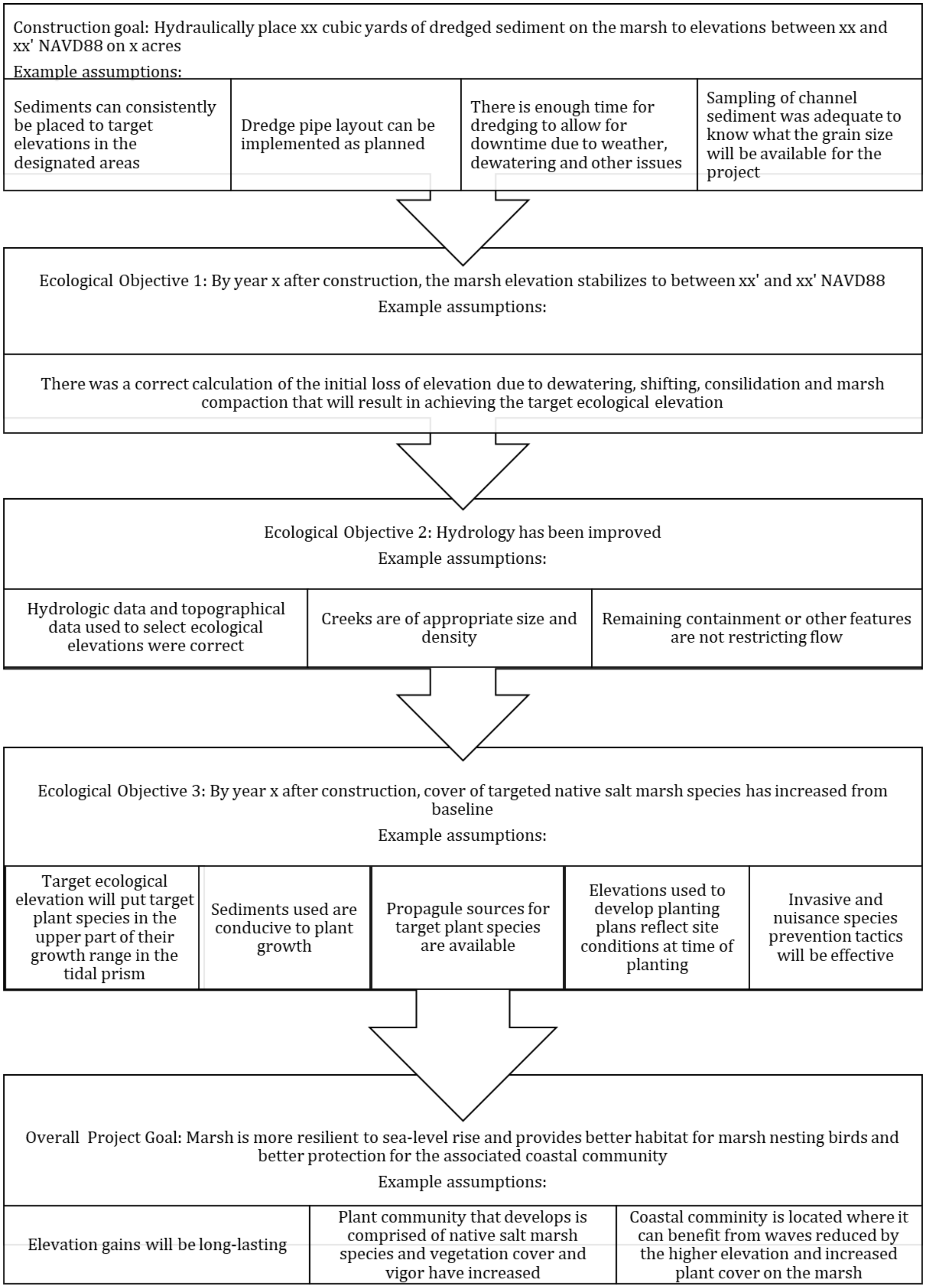


Figure 5. *This figure shows a results chain, including the assumptions associated with various ecological objectives, for a hypothetical marsh restoration project.*

The marsh enhancement objectives should include not only achieving the **target ecological elevations**, but also recovering marsh structure (e.g., achieving ecological uplift of vegetation) and function (e.g., providing wave attenuation) to approach the conditions of a reference marsh. In general, the scientific literature recommends that marsh enhancement projects be monitored either until their objectives have been met or for at least five years after construction. A minimum monitoring period of ten years is frequently recommended (Neckles and Dionne 1999, Niedowski 2000, Zedler 2001).

It is apparent that the initial two-year timeframe of the National Fish and Wildlife Federation grant to design, construct, and monitor these projects was unrealistic. This timeframe, which was later extended, limited pre-construction site assessment at each site. Although a one-year grant extension allowed time for construction, the post-construction monitoring was limited to only two years at Avalon and Fortescue, and three years at Ring Island. At the end of the grant period, the sites were still changing, and vegetation, soils, and faunal use did not yet match baseline conditions. This is a common issue for grant-funded voluntary restoration projects.

As shown in Table 2, it takes a minimum of three years to complete Phases 1–5 (i.e., site assessment through construction) of a marsh enhancement project. This assumes that marsh assessment is completed in one year (Phase 1) and that dredging and dredged material placement are also completed in a single year, immediately followed by planting. Larger and more complex marsh sites (particularly those with limited available data) may require more than one year to properly evaluate marsh enhancement areas and design and permit projects. In addition, the construction phase of larger dredging and marsh enhancement projects may take longer, and the placed dredged material may need to settle, consolidate, and stabilize chemically for a year or more before it is suitable for planting. See Phase 6: Post-Construction Adaptive Management, Phase-Specific Lesson 10, and Phase-Specific Lesson 12.

Cross-Phase Lesson 5. Be aware that the costs of a marsh enhancement project can vary widely, as can the cost of individual project components. The largest component cost for the pilot projects was for dredging and dredged material placement (50–60% of total project costs). The total cost of each project ranged from $45 per CY dredged and $55,000 per acre enhanced at Avalon to $140 per CY and $405,000 per acre at Fortescue. A driving factor in this difference was the marsh enhancement components (for example, containment and planting) rather than the volume of dredged material that was placed. This may be different for projects that use larger volumes of dredged material. Monitoring can also be a significant portion (10–30%) of total project costs, while sediment sampling (1–3%) and planting (3–11%) can be a much smaller portion. See the Cost Analysis section.

Cross-Phase Lesson 6. Use adaptive management throughout the course of project development, construction, and post-construction monitoring. This approach is critical to ensure compliance with all regulatory requirements and to achieve the project objectives. No matter how well a project is planned, questions and issues are likely to arise during implementation, and they will need to be addressed and evaluated to ensure the success of the project. Therefore, project managers should set aside time and money for adaptive management.

An adaptive management plan outlines potential issues that could arise during and after construction. The plan should be closely coordinated with the monitoring program. It should include a list of "if-then" statements that can be revised as the project is implemented and the marsh responds to the enhancement, such as "if X is observed, then Y monitoring will be implemented" and "if A results are observed during monitoring, B actions will be implemented." In addition, the project budget should include contingency funds to address issues as they arise. See Cross-Phase Lesson 2, Phase-Specific Lesson 2, and Phase 6.

Cross-Phase Lesson 7. Determine the scope of containment required to control the placement of dredged material. This is a critical design decision that can affect the success of the project and minimize adverse impacts to the surrounding marsh. Containment is difficult and expensive to install, and if equipment is used to install and remove material, it can damage the marsh. To minimize potential impacts to the marsh, the amount of containment should be the minimum required to meet the objectives of the project. For example, containment could be limited to the amount needed to (a) minimize the dispersal of the placed dredged material out of the designated placement area, (b) protect waters, and (c) consistently achieve the target dredged material placement elevations. In addition, it is important to consider whether to remove containment during or after construction if it is blocking tidal flow or otherwise impeding the potential for marsh recovery.

Dispersal of the placed dredged material across the marsh will vary with the grain size composition and the marsh topography, which will change during construction as the dredged material is placed, settles, and dewaters. Because silt and clay remain in suspension longer, containment may be needed to efficiently achieve the target dredged material placement elevation and to keep it within the placement area. This is less of a concern when placing sandy dredged material, and containment may not be needed in that case.[6]

Here are some other considerations when planning containment:

- During construction of the Avalon Phase 2 project, dredging was stopped for significant periods of time to allow dredged material that had reached the top of containment to undergo dewatering.
- Containment may block tidal flow to and within the marsh, leading to ponding adjacent to the containment. As pooled water on the marsh evaporates and the pool is not regularly flushed by the tides, the soil and water can develop unusual and challenging chemical conditions (e.g., hypersalinity, sulfide concentration, production of acid sulfate soils). Such conditions can impede marsh recovery and adversely impact the marsh directly outside the material placement areas.
- The various containment options have advantages and disadvantages. For example, Filtrexx SiltSoxx™ and coconut-fiber logs retained sediment equally well, but Filtrexx SiltSoxx™ were more difficult to install, and the coconut-fiber logs were more difficult to remove.

[6] This lesson learned reflects the project team's experience with hydraulically placed dredged material and may not be applicable to mechanically placed dredged material.

Table 2. Estimated Timeline to Implement a Marsh Enhancement/Dredged Material Beneficial Use Project

Project Phase and Step	Time to Complete*	Notes
Phase 1. Marsh Assessment and Placement Area Selection	**1.5+ years**	
Step 1. Project Conception	3 months to several years	Varies with available site information at project initiation.
Step 2. Dredging Project Data Collection	6 months	Includes sediment sampling.
Step 3. Marsh Enhancement/ Placement Area Selection	1+ years	Requires assessment during the growing season. May take more than one year. May be combined with baseline monitoring (Phase 7).
Phase 2. Project Design	**6+ months**	
Step 1. Placement Area Design	6 months	
Step 2. Dredging Design	6 months	
Phase 3. Permitting	**6 months**	
Phase 4. Bidding and Contracting	**3–6 months**	
Phase 5. Construction	**3+ months**	Consider environmental timing restrictions for dredging and work on marsh.
Step 1. Pre-placement	1 month	Varies with project size; includes site preparation.
Step 2. Placement	1 week to several months	Varies with project size.
Step 3. Post-placement	1–2 months	Includes site inspection, clean-up and as-built topographic survey.
Phase 6. Post-Construction Adaptive Management	5–10 years**	Includes planting and containment management.
Phase 7. Project Assessment	**6 years**	Minimum
Monitoring/Data Evaluation	**1+ to 5–10 years**	Baseline monitoring (1+ years) and post-construction (5-10 years).
Total Estimated Time to Phase 5	**3+ years**	Larger projects could take longer.
Total Estimated Time to Phase 7	**5+ years**	Post-construction.
Total Estimated Time to Complete	**8+ years**	Larger projects could take longer.

* This table assumes that each step within a phase may be implemented concurrently and in coordination with the other steps to varying degrees and in an iterative manner. The time to complete each phase will be longer if the steps are implemented sequentially.

** Contemporaneous with placement and post-placement (phase 5 steps 2 and 3) and post-construction monitoring/data evaluation (phase 7). Planting the marsh enhancement site may be delayed up to one year until the dredged material consolidates and chemically stabilizes after construction.

Cross-Phase Lesson 8. Coordinate the design and construction of the marsh enhancement closely with the dredging. This is critical to the success of the project. The objectives of the dredging project will probably differ from the ecological objectives for a marsh enhancement project, and the project team and the state and federal regulatory agencies must agree to both sets of objectives. Establishing the project team at the conceptual stage of project development helps to ensure that enhancing the marsh is a primary objective, while meeting the needs of the dredging community and remaining feasible from a technical and budgetary perspective. Ideally, all members of the project team have experience with marsh enhancement projects. The project team should include state (NJDEP) and federal (USACE) dredging project and wetland regulators, the landowner, dredging project managers (USACE-Operations, NJDOT-OMR, municipal and private contractors), the dredging contractor (if known), a wetland ecologist, a restoration ecologist, an environmental engineer, a wetland hydrologist, and a soil scientist.

The managers of the dredging project and marsh enhancement project should communicate early and often during the development of both projects. In addition, the dredging project manager and its construction contractor must be fully aware of the marsh enhancement objectives of the project: it is not just another dredging and dredged material disposal project. Coordination is important during the design phase to ensure that the project is feasible, including identifying the available dredging equipment and its capabilities. (This was a problem during construction at both the Avalon Phase 2 and Fortescue projects.) Adaptive management and shared decision-making between the **marsh team** and the **dredging team** during project construction are also crucial to the success of the marsh enhancement project. See Cross-Phase Lesson 2.

The ability to construct a successful marsh enhancement project using dredged material depends on the volume and characteristics of the sediment to be dredged. The project needs to be large enough to accommodate the volume of dredged material generated by the dredging project, or else alternatives to handle the dredged material need to be identified. The selection and design of marsh enhancement areas can vary with the ability to route the dredge pipeline onto the marsh and move it, as needed, to achieve the target dredged material placement elevations. Dredged material placement must also be adaptively managed to achieve both the target placement elevation and marsh enhancement target ecological elevation. Coordination is needed to ensure that adaptive management actions implemented by one set of project partners do not prevent other partners from reaching their goals.

Cross-Phase Lesson 9. Take the characteristics of the dredged material to be used for the marsh enhancement project into consideration when planning. The dredged material must be physically and chemically suitable for the specific use, and its characteristics (grain size distribution and chemical composition) significantly affect the design, construction, and adaptive management of the project. The volume of dredged material needed to achieve target elevations depends, in part, on the grain size composition of the sediment, which affects the sediment bulking factor, the extent of dredged material dispersal across the marsh (see Cross-Phase Lesson 7), the rates of dewatering, and the degree of short- and long-term consolidation of the placed dredged material. At best, the dredging project manager can only develop an estimate of the volume and types (coarse/fine-grained) of sediment to be dredged. The ability to meet the project objectives will depend, in part, on the accuracy of this estimate.

For marsh enhancement purposes, very fine dredged material (i.e., predominantly silt and clay), which remains in suspension longer, requires less frequent repositioning of the dredge pipe outlet than does sand. This results in greater dispersal of dredged material and more even coverage of the enhancement site, which makes it easier to reach the target dredged material placement elevations. However, sorting by grain size will naturally occur during placement of any hydraulically dredged material that is a mixture of sand, silt, and clay. Because sand falls out of suspension first, it tends to build up within a short distance of the dredge pipe outlet. The pipe must be moved more often to consistently place hydraulically dredged material that has a high sand content across a large area without grading; this increases the time to complete the project and its cost.

Hydraulically spreading sand for TLP across a marsh plain is challenging. At Ring Island, Avalon, and Fortescue, sand content above 30–35% resulted in dispersal problems. If dredged material exceeds that threshold, stationary hydraulic placement (i.e., cribbing the pipe and pumping from a set location for a long period) may be unacceptable, as the dredged material likely will not disperse throughout the placement area. Future projects should further explore and evaluate this issue. Better equipment and placement methodology are needed, in order to (1) reduce the amount of downtime to move the dredge pipe or reposition the spray direction and (2) improve the accuracy and precision in attaining the target elevations.

With a good estimate of the initial, short-term rate of dewatering for dredged material, it may be possible to use adaptive management to improve placement during construction, thereby more efficiently and accurately achieving the target dredged material placement elevations. Dewatering rates depend on a variety of factors, including grain size, type and permeability of containment, containment configuration (e.g., a small gap every 10 feet vs. every 100 feet) and amount of water incorporated during hydraulic dredging.

Cross-Phase Lesson 10. Be aware that it is challenging to estimate the volume of dredged material needed to meet the target ecological elevations. The volume of material needed depends, in part, on the grain size composition of the sediment, the potential compaction of the marsh, and the sediment dispersal (see Cross-Phase Lesson 7 and Cross-Phase Lesson 9). More accurate estimates of the bulking factor for the dredged material would make it possible to more accurately determine the target dredged material placement elevations and estimate the volume of dredged material that could be placed into each enhancement area. In addition, better estimates of post-placement dewatering and consolidation factors and the amount (if any) that the marsh surface subsides due to the weight of sediment and water placement would also improve the ability to achieve the target ecological elevations.

Cross-Phase Lesson 11. Choose an accessible project site if possible. It is difficult to execute a project at a site that can only be accessed by boat, as was the case for all three of our pilot project sites. Our access was further limited each day by four-hour periods during low tide when boats could neither reach nor leave the sites. In addition, containment could only be transported to and from the sites via barges during high tide. Safely traversing the Avalon and Fortescue sites was also a problem, as creeks and ponds could not be crossed or accurately surveyed on foot. After placement, large areas of the Avalon site were hazardous to traverse because people could quickly sink up to the waist when they stepped on areas that were formerly pools.

Phase-Specific Lessons Learned

Phase 1: Marsh Assessment and Placement Area Selection

Phase-Specific Lesson 1. Allow sufficient time (at least 12 months, including one full growing season) to collect data that identify and characterize marsh sites, determine the cause(s) of stress, and determine whether the beneficial use of dredged material can address those causes. The identification of marsh enhancement sites should be conducted in an iterative manner as data are collected, decisions are made, the project scope is refined, and additional data needs are identified. In some cases, the need to complete a dredging project may be the primary driving force for a proposed project, but the primary consideration must be the identification of a marsh that could benefit from dredged material placement.

Biological benchmarks and hydrology and topography data are useful in determining whether a marsh might benefit from sediment addition. Such data are also needed for monitoring, using a Before-After-Control-Impact (BACI) design.

Phase-Specific Lesson 2. Identify more and larger potential enhancement areas at each marsh site than are needed for the volume of dredged material. The marsh enhancement areas initially selected by the project team may ultimately be reduced in number and size, so it is helpful to have enough sites as options. Site assessments may conclude that some of the initially identified marsh enhancement areas would not benefit from dredged material placement (which occurred at both the Avalon Phase 2 and Fortescue projects). Also, the volume of dredged material that has suitable physical and chemical characteristics may be limited (which was an issue for the Fortescue project). Other limiting factors, such as site accessibility and timing restrictions based on the presence of endangered or threatened species, can also affect the final areas selected for the placement of dredged material.

Phase-Specific Lesson 3. Multiple beneficial uses for the sediment may be required to meet the minimum needs of the dredging project. Since a minimum volume of sediment must be dredged to meet the navigational needs of a dredging project and make it cost-effective, this situation may arise frequently. For example, the initial scope of the marsh enhancement project at Fortescue was reduced to account for a smaller volume of fine-grained dredged material available than was originally estimated, and beneficial uses had to be found for the sandy sediment. This resulted in the creation of multiple projects at Fortescue: marsh enhancement, dune restoration, and beach nourishment. At Ring Island, the TLP project was purposely kept small (1 acre total) to test the spraying of sand. In order to make the dredging project viable and to create desired habitat for threatened and endangered species, the shorebird ENH project was created and implemented there.

Phase-Specific Lesson 4. Keep local stakeholders informed about the proposed marsh enhancement project, beginning in the initial phases of the site identification process. The objectives of such communication are to obtain local input, resolve potential issues, and garner local support for the project prior to submitting permit applications. Stakeholders might include local officials, environmental groups, fishers and birdwatchers, and residents who can see the project from their properties. Ideally, this stakeholder engagement would continue throughout the life of the project. In the course of adaptive management, stakeholders could participate in monitoring as citizen scientists, which would encourage them to feel ownership of the project and increase the chances of success as the project evolves.

Phase 2: Project Design

Phase-Specific Lesson 5. When designing the marsh enhancement project, address factors that could potentially constrain the constructability of the project. These factors include the abilities and limitations of the available technology for transporting and placing dredged material and the abilities and limitations of the dredging contractor. For examples, see the Phase 5 Lessons Learned. The project's design should consider the numerous factors that could affect the contractor's ability to dredge and construct the project. To ensure that the project can be constructed as designed, ideally involve the dredging contractor in the project before finalizing the design.

Phase-Specific Lesson 6. In addition to basic elevation data, understand the topography and integrity of the marsh, including locations of pools and tidal creeks. In each dredged material placement area, assess the stability of the existing marsh surface and whether the weight of placed dredged material would compact the existing marsh surface. Compaction could affect whether the target ecological elevations can be achieved and whether the marsh can recover from the placement. For example, at Avalon, former pools in placement areas lost more elevation over time than did the marsh plain. In some places, this resulted in shallow pools re-forming in pre-existing pool areas. These factors should also be considered when estimating the volume of dredged material needed to achieve the target ecological elevations. Understanding the marsh topography can result in better dredge pipeline routes, staging, and outlet and discharge locations, resulting in more efficient and accurate dredged material placement.

Phase-Specific Lesson 7. Be flexible about the design of marsh enhancement projects. While careful planning of these projects is key, so is adaptive management. This requires flexibility to be built into the design, with continual oversight from a team of technical experts. Flexibility and the ability to adaptively modify the design during and after dredged material placement improve the chance of implementing both the dredging and marsh enhancement projects in a cost-effective manner.

Phase 3: Permitting

Phase-Specific Lesson 8. Coordinate between the project team and the regulatory agencies to ensure that permits are issued in a timely manner. These coordination activities should be initiated early in project development (Phase 1) so that all issues can be addressed before the permit applications are submitted to the regulatory agencies. This coordination should include at least one Joint Permit Processing meeting, if possible, with the NJDEP, USACE, and other federal regulatory and resources agencies.

Phase-Specific Lesson 9. Allow adequate time for permitting and contractor mobilization. Permit application packages should be submitted to the regulatory agencies (NJDEP, USACE, and any others) a minimum of six months prior to the intended start of project construction. Both the NJDEP and USACE regulatory reviews can take this long to resolve outstanding issues and issue the required permits, assuming no major concerns are raised and significant project revisions are not needed to minimize potential adverse environmental impacts. In addition, requirements for public notice and, potentially, a public hearing may increase the time to review permit applications. Close coordination between the permit applicants and the regulatory agencies could reduce this timeframe (see Phase-Specific Lesson 8). Once the permits are issued, the contractor also needs time to mobilize and begin construction.

Phase 4: Bidding and Contracting

Phase-Specific Lesson 10. Be aware that the type of dredging contract may impact the ability to innovate and adaptively manage the construction phase of the project. The marsh team had very different experiences working with two dredging contractors due to the type of contract. One contractor had a lease-of-plant maintenance contract with USACE-OP, and the other contractor had a pay-per-cubic-yard dredging contract (which is more typical of the industry) with NJDOT-OMR. In the lease-of-plant contract, the dredge contractor was paid for each day that the dredge was available for work, regardless of whether it was actively dredging, which increased the options for adaptive management and added flexibility during project construction (for example, dredging could be ceased temporarily to allow for dewatering of the dredged material).

Because the three projects were pilot projects, operational flexibility during construction was important. The lease-of-plant contract took the financial risk off the dredge contractor because costs were borne by the USACE-OP. In addition, the lease-of-plant contractor fully understood and supported the objectives of the marsh enhancement projects, and there was close coordination and a good working relationship between the marsh team and the dredging team. In contrast, at the Fortescue site, the dredging contractor was operating under the typical pay-per-cubic-yard dredging contract. The project lacked flexibility and ease of coordination. See Phase-Specific Lessons 4, 5, and 13.

Phase 5: Construction

Phase-Specific Lesson 11. Realize that the maximum pumping distance without using booster pumps will vary with the size of the dredge and the characteristics of the dredged material. In addition, marsh topography (e.g., tidal creeks, pools, unstable substrate) and the need to minimize equipment use on the marsh can limit pumping distance. In the three pilot projects, pumping distance was only a limitation at the Avalon Phase 2 project, where marsh topography dictated where the dredge discharge pipe could be located on the marsh. The location of the discharge pipe outlet, in combination with marsh topography, affected the ability to achieve target dredged material placement elevations in the areas that were farthest from the outlets. There were tradeoffs between construction efficiency and environmental impacts, that affected equipment selection and use, the volume of sediment that could be placed, and the amount of construction-related marsh damage. The use of machinery, such as a Marsh Master, increases the distance that a dredge pipe can be pushed and pulled into the marsh, but even low-pressure equipment like this can leave scars on the marsh.

Phase-Specific Lesson 12. The time available to dredge and place dredged material may limit how much marsh can be enhanced, which may limit the achievement of project objectives. To avoid additional costs associated with mobilization and demobilization, dredging and dredged material placement should be completed in a single, uninterrupted construction operation. This construction timeframe is typically limited by applicable “dredging windows,” or restrictions on the time(s) of year when dredging and dredged material placement can occur due to the presence of threatened and endangered species, anadromous fish, colonial nesting shorebirds, and other protected natural resources. Construction can also be interrupted by inclement weather and equipment breakdowns. For example, winter storms limited site preparation and construction at both Avalon and Fortescue. In addition, depending on the design of the project, it may not be possible to dredge 24 hours per day due to restrictions on when dredged material can be placed (e.g., avoiding high tide to minimize sediment loss out of the project site). These factors will increase the construction time and project costs.

The dredging contractor and design team must consider these factors when they schedule and plan dredging and placement of dredged material. In addition, it can require considerably more time to use dredged material for marsh enhancement than to dispose of it in a traditional way, such as at a CDF.

Phase-Specific Lesson 13. As these construction techniques are in an early stage of development, the success of marsh enhancement projects depends heavily on adaptive management. For all three pilot projects, tentative dredged material placement strategies were developed, but activities were adaptively managed in real time during placement. The key to successfully constructing the projects and achieving the target dredged material placement elevations was to have the marsh team constantly on site and observing the dredged material placement. Frequent communication between the marsh team and the dredging team ensured that any problems or modifications were promptly addressed during construction. In addition to this active communication during construction, weekly project status meetings were useful for construction planning and adaptive management.

Phase-Specific Lesson 14. The maximum distance that hydraulically dredged sediment can be sprayed onto a marsh will vary with the equipment used and is likely limited to 150–200 feet. At Ring Island, hydraulically dredged sand was sprayed a maximum distance of about 170 feet onto the marsh. The USACE-OP expects dredge contractors to be capable of spraying dredged material 100 feet using a 12- to 14-inch dredge and 75 feet using a smaller dredge. In contrast, high-pressure spray equipment has been reported to reach nearly 300 feet into the marsh (Ray 2007). These limitations should be considered when designing a project. Once the dredged material is placed on the marsh, the distance it spreads will vary with its grain size and marsh topography. Sandy dredged material falls out of suspension relatively quickly and is minimally dispersed when it is hydraulically sprayed on to a marsh plain; for example, at Ring Island, the dredged material was 96% fine sand and settled in areas that were approximately 50 feet from the pipe outlet. Dredged material that is predominantly silt or clay will disperse across a much larger area, but dispersal distance depends on marsh topography and the presence of containment or vegetation.

Phase-Specific Lesson 15. Both heavy equipment and extensive equipment use on the marsh can damage it and slow marsh recovery after dredged material is placed. Even low-ground-pressure equipment damaged the marshes at both Fortescue and Avalon. In 2019, tracks from the low-pressure machinery remained at both sites, two to three years after work had been completed. If straw bales and coconut-fiber logs are used to contain placed dredged material, the use of equipment on the marsh to install and remove these items should be minimized, and such equipment use should be clearly described in contracts for site work.

Phase 6: Post-Construction Adaptive Management

Phase-Specific Lesson 16. Monthly qualitative monitoring, through visual inspections and photographs, is very useful after construction to adaptively manage the marsh enhancement project. This type of monitoring can be very effective in identifying problems in the marsh that should be addressed immediately. While there is no substitute for comprehensive quantitative monitoring of marsh response, there is typically a time delay between collecting the quantitative data and reporting the monitoring results. In contrast, qualitative monitoring can be the basis for rapidly implementing additional monitoring and adaptive management. For example, observations of vegetation die-off at the Avalon Phase 2 project resulted in the implementation of both new types of monitoring and the experimental removal of some containment.

Phase-Specific Lesson 17. Adaptive management may be needed if unexpected wildlife use the site. The presence of such wildlife may be either desirable or undesirable. For example, at Ring Island, erosion of the sand placed for the ENH created a beach that was used by horseshoe crabs (*Limulus polyphemus*) and diamondback terrapins (*Malaclemys terrapin*), which was an unintended positive outcome. In contrast, portions of the ENH were colonized by common reed (*P. australis*; an invasive plant) and other plant species, to which the team responded with adaptive monitoring and control (i.e., vegetation removal). In addition, the marsh enhancement areas at Avalon, which were not designed as shorebird habitat, attracted American oystercatchers (*Haematopus palliates*) due to the creation of large elevated and unvegetated areas. Planting of the site had to be pushed back a year out of concern for this species.

Phase-Specific Lesson 18. For ecological, practical, and safety reasons, finalizing and implementing the planting plan cannot occur until the placed dredged material has dewatered, consolidated, and chemically stabilized. The time needed for the dredged material to stabilize enough for planting can be highly variable. A topographic survey must be conducted to verify that the dredged material elevations are consistent with those in the planting plan. The planting plan may also need to be revised based on vegetation recovery and soil composition in the marsh enhancement site. In addition, areas that do not drain during the tidal cycle (i.e., where pools form and re-form) may not be suitable for planting. Planting should occur in early spring, before birds nest and before summer’s higher temperatures and low rainfall could adversely impact the newly planted vegetation. Waiting to plant may be advisable if preliminary soil survey data indicate that the placed dredged material has extreme physical or chemical characteristics. These characteristics may normalize over time[7].

The following is a possible schedule for post-construction planting:

- Growing Season #1
  - No planting
  - Monitor natural recovery of the marsh enhancement/dredged material placement areas
  - Monitor topography and dredged material properties
  - Develop a pilot planting plan and order plants
- Growing Season #2
  - Implement and evaluate the pilot planting plan
  - Continue monitoring
  - Develop a final planting plan and order plants
- Growing Season #3
  - Implement the final planting plan and continue monitoring

Phase-Specific Lesson 19. Reserve contingency funds for adaptive management and monitoring. Adaptive management of a marsh enhancement project will be needed during construction and post-construction monitoring phases. Expect that unplanned situations will require additional monitoring or management, and set aside funds to address conditions that may develop on the marsh and hinder its recovery.

Phase 7: Project Assessment

Phase-Specific Lesson 20. The project team should be dedicated to consistently implementing a comprehensive monitoring program and should have the resources to do so from the start of project development. The monitoring goals, metrics, and methods should be developed early in the process. The monitoring program should be designed to provide the data needed to (1) determine whether the specific marsh enhancement project goals and objectives have been met, (2) evaluate whether the project was built as designed (as-built survey), (3) evaluate the effects of the project on populations of interest (*Spartina* spp., birds, crabs, etc.) and (4) inform potential adaptive management. In addition, all data should be collected from the same monitoring locations in a consistent manner, using standardized protocols and formats. If a database will be used to house the data, it is helpful to collect the data in a format that can be input easily. Both baseline (pre-construction) and post-construction data should be collected at the spatial and temporal scales needed to evaluate the project and the trajectory of marsh response.

The marsh team initially found that most ecological parameters responded negatively to the placement of dredged material and recommend not drawing conclusions about project success or failure too soon after placement. They recommend that the monitoring program include baseline monitoring for at least

[7] See USDA NRCS Soil Survey Technical Note 430-SS-11 Acid Sulfate Soils in the Coastal and Subaqueous Environment: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcseprd1461815

one year and post-construction monitoring for at least five, but preferably ten, years. The project team should secure funding for a long-term, comprehensive monitoring program. See Cross-Phase Lesson 2.

Phase-Specific Lesson 21. Map habitats at the project site (e.g., vegetated and unvegetated areas of the marsh plain and marsh pools) before and after construction. The post-construction monitoring program should take these different habitat types into consideration. The baseline marsh habitat can have a significant influence on how the placed dredged material dewaters and consolidates, ultimately determining whether the target ecological elevations are achieved. In addition, vegetation recovery and colonization can be impacted by the pre-existing habitats and their connectivity. Without this spatial information on pre-existing habitat types, which should also be used as covariates in many analyses, it will be difficult to interpret post-construction monitoring data.

Phase-Specific Lesson 22. Review the monitoring plan after construction to ensure that it adequately characterizes and represents post-construction conditions. The horizontal extent of dredged material placement and the elevations achieved after the dredged material has consolidated and stabilized may vary from those on which the sampling strategy was developed. This may require relocation of the sampling point (e.g., some planned locations may not have received dredged material) and parameters.

Chapter 2: Project Details

Tidal marshes are an integral part of New Jersey's Atlantic Ocean and Delaware Bay coasts. They form a charismatic green band that cleans water; provides critical habitat for fish, shellfish, and birds; and buffers coastal communities from storms, erosion, and flooding (Mitsch and Gosselink 2007; NJDEP 2007; Narayan et al. 2017). However, the long-term resiliency of New Jersey's coastal tidal wetlands is threatened by a variety of factors, including historic alterations, such as ditching and diking, and ongoing stressors, such as accelerating sea-level rise, severe storms, and subsidence (Bertness et al. 2002; Hartig et al. 2002; Church and White 2011; Partnership for the Delaware Estuary 2012).

To offset the effects of sea-level rise and subsidence, salt marshes must receive sufficient sediment and organic matter to gain elevation and maintain a hydroperiod (duration of tidal flooding) that is optimal for or at least tolerated by salt marsh plants (Nyman et al. 2006; Mitsch and Gosselink 2007; Kirwan and Megonigal 2013; Fig. 6). Sediment accretion on a marsh is a function of both sediment budget and plant root growth (Nyman et al. 2006; Linhoss et al. 2015). A marsh with a healthy sediment supply receives sediment not only at a rate that exceeds what it loses to erosion (i.e., net positive deposition rate), but at

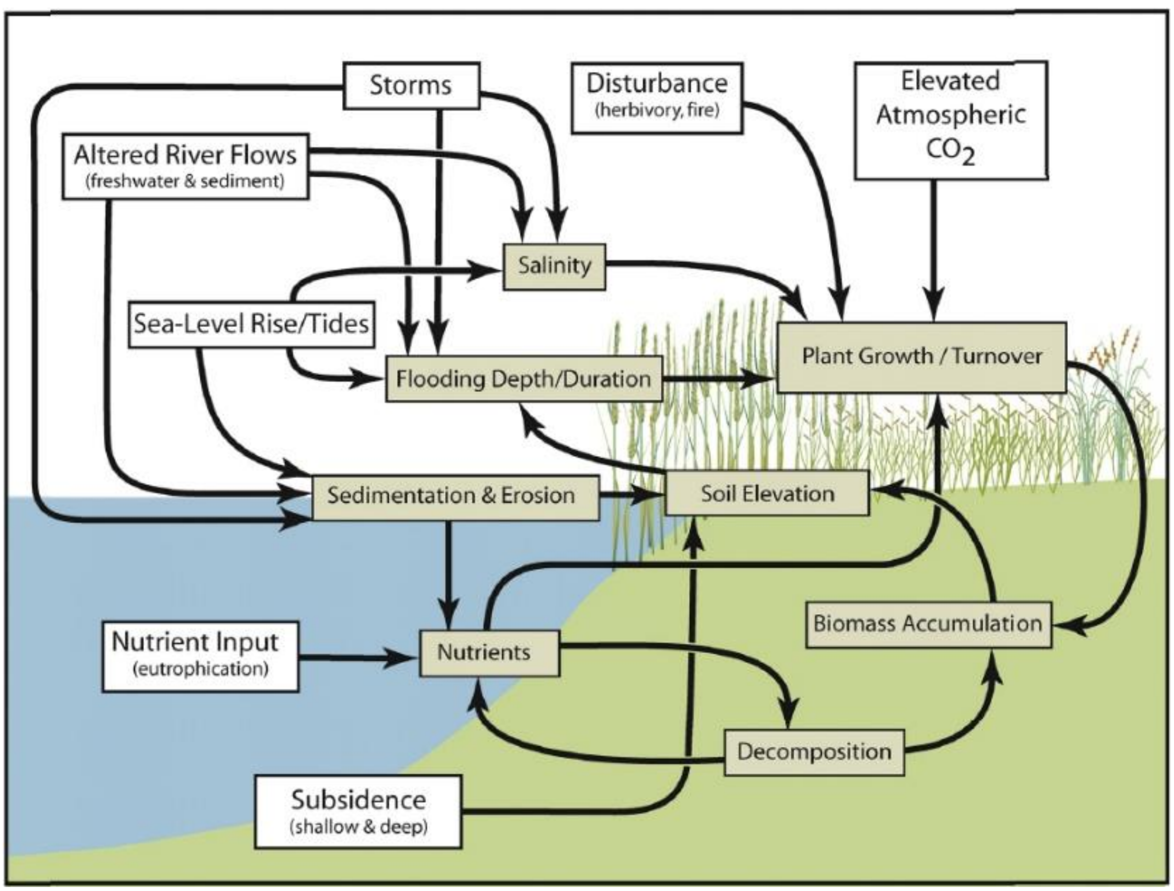


Figure 6. *This conceptual model of a tidal marsh shows how substantial tidal inputs of mineral sediment are influenced by environmental drivers and factors affecting accretion processes (Cahoon et al. 2009).*

a rate that allows a net increase in marsh elevation (Nyman et al. 2006; Mitsch and Gosselink 2007; Cahoon et al. 2009; Kirwan and Megonigal 2013).

Historically, the natural rate of accretion in marshes has usually been able to keep pace with sea-level rise (Cahoon and Gunterspergen 2010). However, sea level is rising at the fastest rate in at least 2,000 years (Horton 2017), averaging 4 mm/year in New Jersey between 1911 and 2018 (Fig. 7; NOAA 2019). As the rate of sea-level rise accelerates, some marshes have been unable to maintain the elevation they need to survive (Wamsley et al. 2010), and there is growing concern that marshes will be lost at increasing rates (Hartig et al. 2002; Kennish et al. 2012).

As we understand more about the important roles that marshes play in the biosphere, we are focusing more on enhancing their resiliency (Lotze et al. 2006). **Ecological resiliency** is the capacity of an ecosystem to maintain or recover its normal functions in response to disturbances (Cahoon and Gunterspergen 2010). It may be possible to increase the resiliency of a **stressed marsh** by placing sediment, such as dredged material, on it. This action may help additional sediment and organic matter accrete on the marsh at a rate that can maintain marsh elevation as sea level rises (Ray 2007).

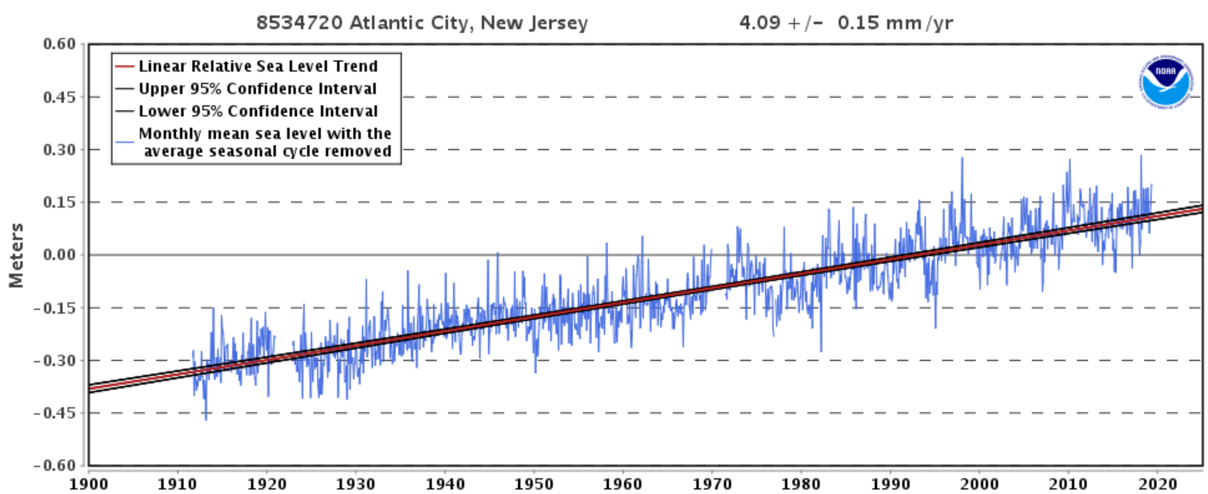


Figure 7. *The relative sea-level trend is an increase of 4.09 mm/year, with a 95% confidence interval of +/- 0.15 mm/year, based on monthly mean sea-level data from 1911 to 2018. This is equivalent to a change of 1.34 feet in 100 years (NOAA. https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8534720. July 1, 2019).*

New Jersey's navigation channels and marinas require regular dredging to maintain safe passage. However, the state has a dearth of CDFs with capacity to accept additional dredged material; this has become a major problem for coastal communities, as well as the agencies that need to maintain navigation channels. As a result, within the state and the larger Mid-Atlantic region, there is great interest in restoring and enhancing salt marshes using material dredged from channels. This activity combines routine maintenance and post-storm dredging with wetland enhancement. The combined cost of the two types of projects could potentially be less than if the dredging and salt marsh enhancement projects were implemented separately.

One of Superstorm Sandy's many impacts was major shoaling of navigation channels along New Jersey's Coast. Traditionally in New Jersey, dredged sediments have been placed in confined disposal facilities (CDFs), effectively removing from estuaries the sediment needed by tidal wetlands. However, New Jersey has a dearth of CDFs with capacity to accept additional dredged material; this has become a major problem for coastal communities, as well as State and federal agencies, that need to maintain navigation channels.

In addition, increasing the resiliency of a salt marsh may produce significant socioeconomic and ecological benefits for coastal communities (McDonough et al. 1999). Although this beneficial use of dredged material is considered a pilot method in New Jersey, it is being used in other areas of the country. Stakeholders, including the NJDEP and The Nature Conservancy (TNC), are further refining the development, permitting, and implementation of these types of projects.

Project Background

In 2013, the New Jersey Department of Environmental Protection-Division of Fish and Wildlife (NJDEP-DFW) partnered with the USACE-Philadelphia District Operations Division (USACE-OP), the USACE Engineer Research and Development Center (USACE-ERDC), NJDOT-OMR, The Nature Conservancy (TNC), and the Green Trust Alliance (GTA) to initiate three pilot projects to enhance salt marshes. The projects sought to determine whether beneficially using dredged material to increase the elevation on existing, but stressed, salt marshes could increase the abundance of native salt marsh vegetation and result in ecological uplift compared with their baseline condition. The ultimate goal was to increase their resiliency to accelerating sea-level rise. All parties acknowledged that this was an opportunity to explore a paradigm shift from treating dredged material as waste to treating it as a valuable environmental resource. The NJDEP, USACE-OP, and NJDOT-OMR agree that retaining sediment within estuaries provides more environmental benefits than disposing of it in CDFs. In addition, many CDFs are filled to capacity, and there are no CDFs within a reasonable pumping distance of many navigation channels and marinas. Thus, dredging sediment from these sites and disposing of it can be very costly. In addition to improving sediment management practices, the USACE-OP and NJDOT-OMR expected that beneficially using dredged material for marsh enhancement projects could decrease overall project costs.

To evaluate and further develop this method of marsh enhancement in New Jersey, it was important to carry out pilot projects. Pilot projects would demonstrate that the beneficial use of dredged material for salt marsh enhancement could provide the expected benefits, while not damaging coastal habitats, by providing local proof-of-concept examples.

The total cost of the pilot projects was $8 million, including $3.4 million from the Hurricane Sandy Coastal Resiliency Competitive Grant Program awarded to NJDEP-DFW and remaining funds provided by the USACE-OP and NJDOT-OMR. The grant period was August 2014 through October 2017 (Table 3). The pilot projects included three main components:

1. Demonstrate the use of dredged material to enhance approximately 90 acres of salt marsh (and associated restoration of dune, beach, and avian nesting habitats).
2. Analyze the effects of dredged material placement on the marsh ecosystem and the resiliency of nearby coastal communities.
3. Develop an interactive web-based mapping tool to provide data and information for developing future marsh enhancement projects in New Jersey.

The goals of these pilot projects were as follows:

1. Improve existing dredged material management practices.
2. Increase the technical and scientific knowledge behind these innovative beneficial use projects.
3. Change standard dredged material management practices in New Jersey.
4. In the aftermath of Superstorm Sandy, promote these practices to enhance coastal resiliency.

The overall goal for the marsh enhancement pilot projects was to advance the concept that placing dredged material on stressed salt marshes would provide ecological uplift and increased resiliency of the habitat, helping the marshes persist despite accelerating sea-level rise, increased storms, and subsidence. The projects would evaluate the use of a variety of different sediment types (predominantly sandy and fine-grained material), dredged material placement methods (spraying and direct pumping) and placement thickness on a range of salt marsh conditions. The pilot projects would be monitored comprehensively to evaluate how the ecosystem responded to dredged material placement in the near term, identify factors that negatively impacted recovery, and determine whether the structure and functions of the marsh were improved.

The long-term objectives for the marsh enhancement components of the pilot projects were the following:

1. Increase and maintain the optimal tidal elevation and hydroperiod for native salt marsh biota.
2. Increase the abundance and vigor of native salt marsh plants.
3. Return all other parameters to pre-construction conditions unless they were expected to change from the conversation of habitat.

In order to use enough dredged material to make the dredging projects economically viable, additional project components were added at Ring Island and Fortescue. At Ring Island, a sandy **Elevated Nesting Habitat (ENH)** was created for the state-endangered black skimmer (*Rynchops niger*) and other colonial nesting shorebird species of concern. At Fortescue, a nearby beach was restored and a constructed dune was enhanced to provide protection for the marsh and boat launch in Fortescue Creek.

Table 3. Pilot Project Timeline

2012	October	Superstorm Sandy
2013	March	USACE begins development of the Environmental Assessment and awards dredging contracts
	Summer to Fall	Project conceptual development (NJDEP, USACE, and TNC)
	October	NFWF grant announcement
Late 2013 to early 2014		USACE NJIWW channel sediment sampling and bathymetric surveys

2014	January	NJDEP NFWF grant application submission
	July	USACE NEPA EA/FONSI (Avalon, Ring Island)
	Summer	Ring Island and Avalon (site assessment and baseline monitoring for placement areas A, B, and C)
	August 7	NJDEP permits issued for Ring Island pilot projects
	September	Fortescue site assessment visits (marsh, beach, dune)
	September	Ring Island dredged material placement
	December 23	NJDEP permits issued for Avalon Phase 1 (placement areas A and C)
2014 to 2015	December to January	Avalon Phase 1 dredged material placement
2015	March to October	Ring Island post-construction monitoring
	May, June, & July	Avalon site assessment (placement areas D, E, F, G, H, and I)
	July	Fortescue site assessment visits (marsh, beach, dune)
	October	NJDEP and USACE permits issued for Fortescue pilot projects
	November	NJDEP permits issued for Avalon Phase 2
2015 to 2016	December to March	Avalon Phase 2 dredged material placement
2016	January to March	Fortescue dredged material placement (marsh, beach)
	March to October	Ring Island, Avalon, and Fortescue post-construction monitoring
	May & June	Fortescue site assessment visits (dune only)
	November 21	NJDEP and USACE permit modifications; Fortescue dune redesign
2017	January to March	Fortescue dredged material placement (dune)
	May & June	Vegetation planting (Avalon, Ring Island, Fortescue)
	March to September	Ring Island, Avalon, and Fortescue post-construction monitoring
2018 to 2022	March to September	Ring Island, Avalon, and Fortescue post-construction monitoring

Project Implementation

The pilot projects at each of the three locations followed seven phases:

- Phase 1: Site Identification and Placement Area Selection
- Phase 2: Project Design
- Phase 3: Permitting
- Phase 4: Bidding and Contracting
- Phase 5: Construction
- Phase 6: Post-Construction Adaptive Management
- Phase 7: Project Assessment

Here, we summarize the major steps undertaken by the project team during each phase.

Phase 1: Site Identification and Placement Area Selection

In Phase 1, the team identified salt marsh sites that were stressed due to an elevation deficit, identified an appropriate dredging project near the stressed marsh, selected the specific dredged material, or beneficial use, placement areas at those sites for habitat enhancement, and identified control areas. Control areas were sites that represented the baseline condition of the sites that received treatment. They represented what the placement areas would have looked like if sediment was not placed on them. They also helped to capture natural variation in the monitoring metrics.

All three of the marsh enhancement projects discussed in this report were developed using the same general four-step site identification and placement area selection process. The timeline specified by the NFWF grant and the USACE-OP dredging schedule limited both the time available for this phase and the collection of baseline monitoring data to characterize each site. However, with each successive project, more time was available to collect and analyze baseline data. In addition, the experience we gained developing the early projects was invaluable for selecting the placement areas for the subsequent projects. It is also important to note that we did not follow the four-step process sequentially in each project. In some projects, the steps were implemented concurrently, while in others they were implemented iteratively.

Four-Step Process for Site Identification and Placement Area Selection

- Step 1: Project Conception
- Step 2: Collection of Data for Dredging Project
- Step 3: Marsh Enhancement/Placement Area Selection
- Step 4: Project Design and Construction

Step 1: Project Conception. This first step in the site identification process included a series of meetings between NJDEP-DFW, USACE-OP, NJDOT-OMR, TNC, and GTA.

Early in the development of these pilot projects, a diverse project team was established, which was one of the keys to project success. The project team consisted of land managers, navigation managers, state regulators, engineers, dredge contractors, dredging experts, senior environmental scientists, biologists, bio-environmental engineers, and hydraulic engineers. These technical experts focused on implementing a systems approach to use sediment dredged from navigation channels to restore/enhance marshes.

The team included a dredging team (NJDOT-OMR or USACE-OP, USACE ERDC scientists and engineers, and dredging and engineering contractors) and a marsh team (NJDEP, TNC, GTA, Princeton Hydro [PH] and The Wetlands Institute [TWI]). The dredging team's primary responsibility was to ensure that the channels would be cleared for safe navigation and that the dredged material would be placed on the marsh following the marsh enhancement project design plans. The marsh team's primary responsibility was to ensure the ecological success of the projects. Regular communication and cooperation between the two teams was critical to initiating, planning, and constructing these projects.

The NJDEP and conservation organizations were interested in experimenting with new ways of enhancing stressed salt marshes. The USACE-OP and NJDOT-OMR were interested in developing these types of pilot projects because managing dredged material can be both difficult and costly. The USACE-OP is also committed to the efficient use of dredged material and to rebuilding and supplementing coastal marshes and beaches wherever possible. It has demonstrated this commitment by hosting USACE's Regional Sediment Management Program since 2002 and by being designated an Engineering with Nature Program Proving Ground in 2016.

Marsh enhancement beneficial use projects are an innovative and proactive regional sediment management approach that retains sediment in the estuarine system and potentially can have socioeconomic and ecological benefits. All parties recognized that combining dredging and marsh enhancement projects may decrease project costs compared with conducting these efforts independently. During the initial meetings in 2013 and 2014, the team identified potentially stressed or degraded marshes, potential funding sources for marsh enhancement, dredging projects that needed alternative ways to dispose of dredged material, and possible timelines for all phases of the projects.

At Ring Island and Avalon, conceptual plans were developed to use sediment dredged from the nearby NJIWW for marsh enhancement and habitat creation. These areas were selected for evaluation because NJDEP-DFW owns large tracts of potentially stressed salt marsh in proximity to critical channel shoals in the NJIWW that the USACE-OP would be dredging.

At Fortescue, three potential habitat projects near the Fortescue Creek navigation channel were identified: enhancement of a portion of a historically ditched marsh adjacent to the channel, restoration of the eroding dune fronting the marsh along Delaware Bay, and restoration of an eroding natural beach. These areas were selected for evaluation because New Jersey manages large areas of salt marsh near a navigation channel (Fortescue Creek) that NJDOT-OMR considers to be in critical need of dredging. Managing the associated dredged material from this channel has been a longtime problem for the state. The channel requires dredging every three to five years, and traditional management options for the dredged material are not available locally.

Next, implementation timelines were developed for each project. In spring and early summer 2014, the team developed contracts, collected baseline data and further evaluated the potential marsh enhancement sites, developed marsh enhancement designs, obtained permits, and developed monitoring plans. Construction was scheduled for the fall of 2014, with the possibility of completing construction in the fall of 2015. Post-construction monitoring was planned for the five years after construction. These timelines considered the USACE-OP's dredging schedule under an existing maintenance dredging contract, as well as environmental timing restrictions (i.e., "dredging windows") for winter flounder, marsh nesting birds, and other potential species of concern.

In January 2014, NJDEP-DFW applied to NFWF for a grant to pay for the design and monitoring of the projects, using the cost of the USACE-OP and NJDOT-OMR dredging projects to meet NFWF's matching fund requirement.

Step 2: Collection of Data for Dredging Project. The dredging project managers provided the project team with information about when and where they planned to dredge, the estimated volume of sediment to be dredged, the available sediment characterization data, and how far the dredged material could be pumped. The USACE-OP and NJDOT-OMR also worked with the NJDEP Office of Dredging and Sediment Technology (ODST) to develop Sediment Sampling and Analysis Plans to collect and analyze the channel sediment for physical characteristics, including grain size, total organic carbon, and potential contaminants. These data were needed to determine whether the dredged material was suitable for the proposed projects.

Ring Island: The USACE-OP studies of the nearby NJIWW channel confirmed that the sediment was 96% fine sand and the estimated volume of sediment to be dredged was 7,000 CY. Because of the high percentage of sand, NJDEP-ODST confirmed that additional testing for contaminants was not needed.

Avalon: The USACE-OP studies of the nearby NJIWW channel revealed that the sediment was primarily fine-grained silt and clay, the estimated volume of sediment to be dredged was 75,000 CY, and dioxins/furans were present at potential levels of concern in some sections of the channel. The USACE-OP also worked with their dredging contractor to better determine the maximum distance that the hydraulically dredged sediment could be pumped, given its physical characteristics, from each of the channels.

Fortescue: The analysis of sediment in Fortescue Creek channel indicated that it was a heterogenous mix of coarser-grained (sand) and fine-grained (silt and clay) material, the estimated volume of sediment to be dredged was 83,000 CY, and contaminants in the sediment to be dredged did not present an ecological concern and were generally present at lower levels than in the surface sediment of the Fortescue marsh.

Step 3: Marsh Enhancement/ Placement Area Selection. To preliminarily identify stressed marshes and delineate marsh enhancement and control areas, the project team evaluated all marshes within the pumping distances of the USACE-OP and NJDOT-OMR dredging projects. To determine which marshes within pumping range would benefit from sediment addition, the sites were assessed through desktop analyses, site visits, and marsh enhancement project feasibility evaluations.

Site assessment through desktop analysis consisted of reviewing readily available information about the condition of the marshes, evaluating maps of marsh elevation, and conducting various modeling analyses. Due to limitations in the distance that dredged material could be economically pumped, a first round of analysis evaluated marshes that were within approximately 1 mile of the planned dredging projects. LiDAR (Light Detection and Ranging) data were used to identify low-lying marsh platforms. Historic aerial photographs available through Google Earth and the NJDEP's GIS website were used to assess marsh stability, considering features such as expanding and contracting pools, shoreline erosion, tidal creeks, and mosquito control ditches. The project team also looked for marshes that might buffer communities from waves and storms, using TNC's Risk Explorer app for NJ (The Nature Conservancy n.d.). This information was used preliminarily to select portions of the marsh that might benefit from the addition of a thin layer of sediment. It was also used to help select control areas with similar conditions to the placement areas. Additional analysis and modeling were usually conducted after the initial site visits.

Ring Island: The marsh team and the USACE-ERDC conducted desktop studies to identify potential marsh sites that would benefit from the placement of the sandy sediment to be dredged from the Ring Island section of the NJIWW. Figure 8 shows a LiDAR map of the marsh areas within pumping distance of the channel. This map was used both to preliminarily identify low-elevation areas of the marsh and to guide initial site visits. In addition, potential areas of the marsh for ENH for colonial shorebirds were identified. Several locations for both types of habitat enhancement projects were initially identified for further study using current and historic aerial photos, maps of elevation, and erosion rates (Fig. 9). However, because birds were nesting on the preferred locations for marsh enhancement and ENH, new sites had to be selected.

Avalon: The marsh team and USACE-ERDC performed desktop analyses to identify sites that could benefit from the placement of sediment. Several locations were identified for further evaluation based on current and historic aerial photos, maps of elevation, erosion rates, and tidal connectivity. As at Ring Island, a LiDAR map (Fig. 10) was used to preliminarily identify low-elevation areas of the marsh and to guide initial site assessment visits. The project team considered a variety of options for beneficially using the dredged material, including TLP on low-lying marsh areas, filling expanding pools near the eroding marsh edge, recreating and stabilizing eroded marsh edge, and restoring part of an island that was lost to erosion. Once the project team decided to focus on filling expanding pools and enhancing the surrounding marsh platform at the Avalon site, USACE-ERDC performed a drainage analysis to identify pools that appeared to experience restricted tidal flow conditions.

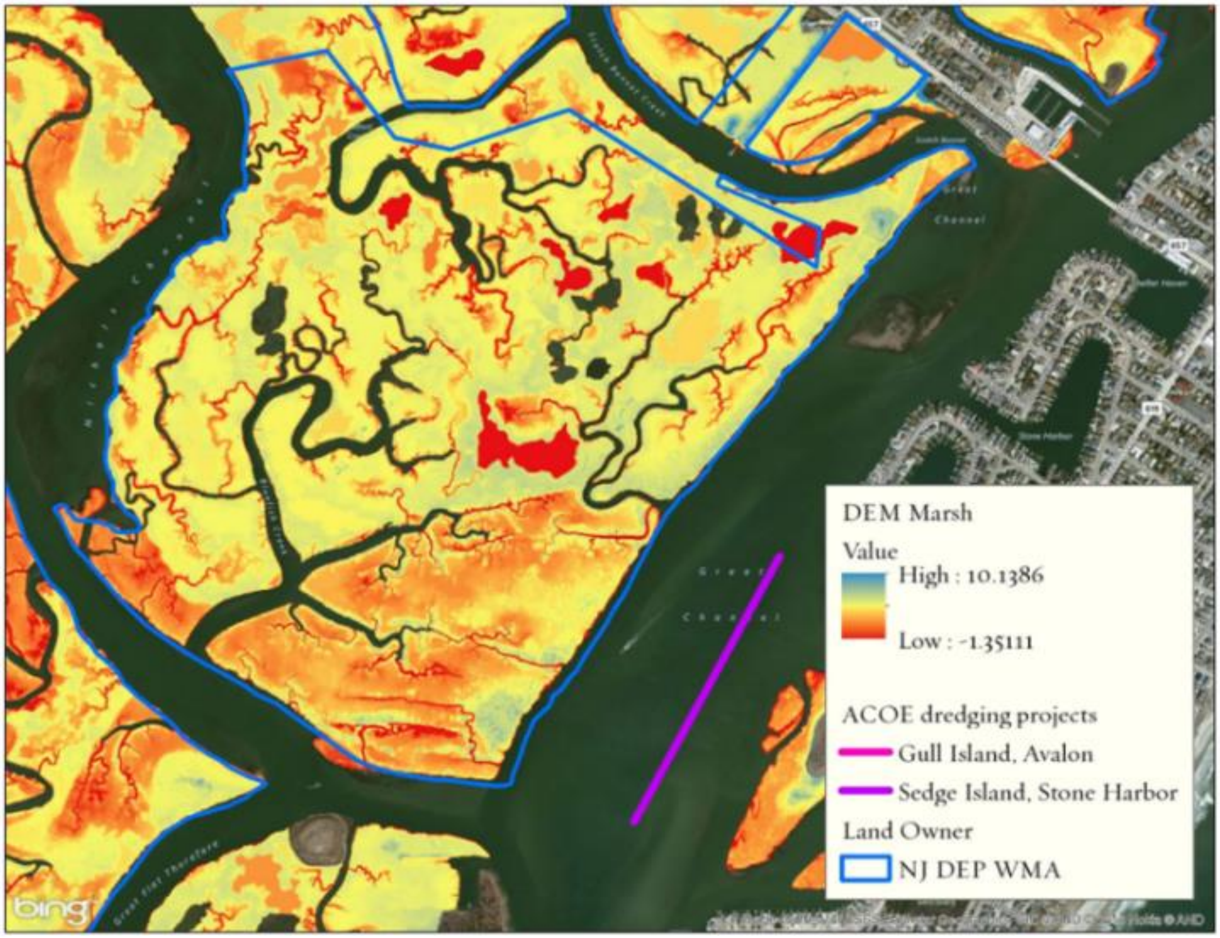


Figure 8. *This LiDAR map of Ring Island shows the relative elevation of salt marsh sites. Areas in red were especially low elevation and were selected for further evaluation.*

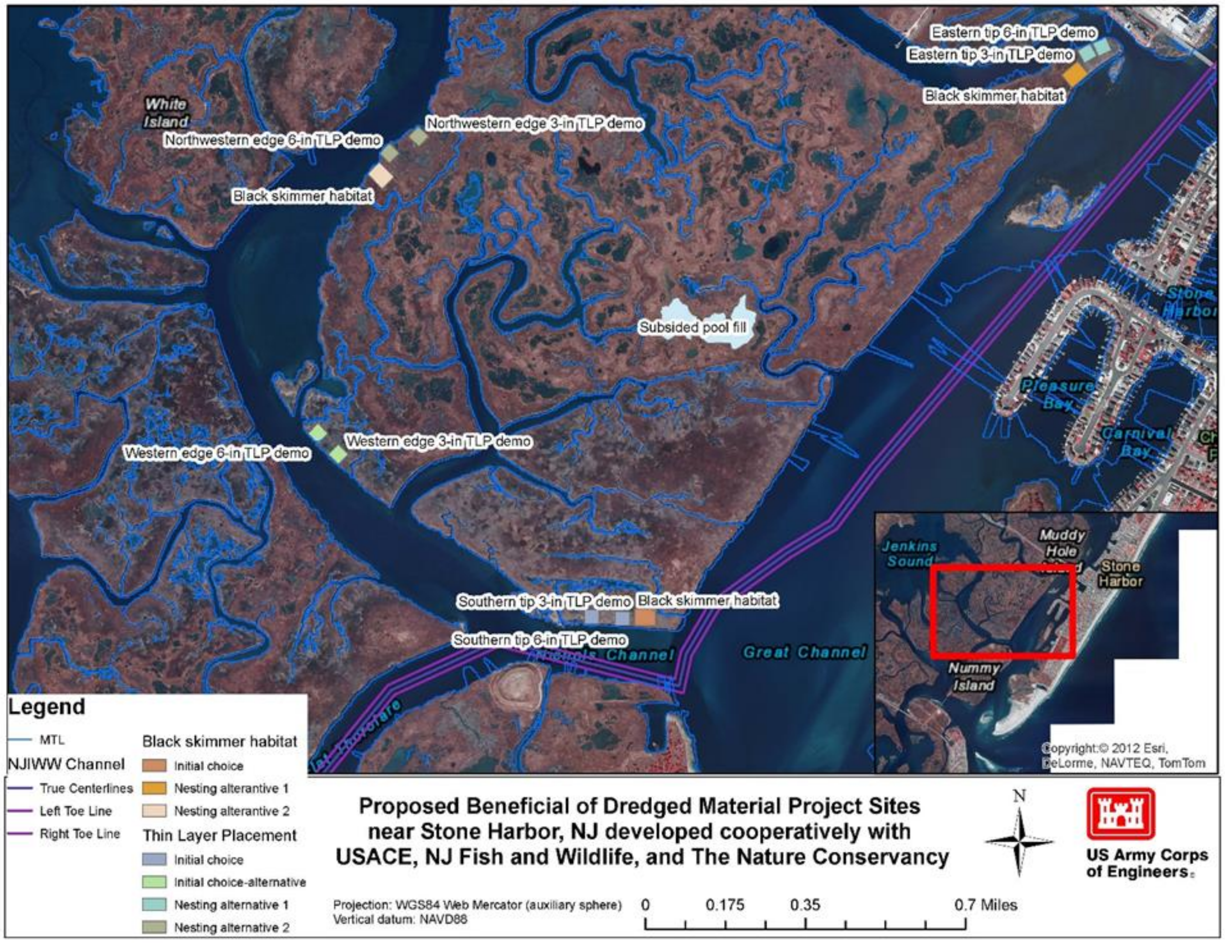


Figure 9. *This map shows the initial potential sites on Ring Island, with priority and secondary choices for the creation of black skimmer habitat and marsh enhancement. None of these areas were used because birds were nesting there during the scheduled construction time.*

Fortescue: The marsh team conducted desktop analyses to identify marsh sites that would potentially benefit from the placement of dredged material and that were within the estimated pumping distance from the Fortescue Creek channel. Using recent and historic aerial photos, maps of elevation, erosion rates, and tidal connectivity, several locations were identified for further evaluation. For example, a LiDAR map (Fig. 11) and topographic surveys were used to preliminarily identify low-elevation areas of the marsh and to guide site assessment visits. The marsh team also used a Marsh Futures report (Kreeger et al. 2015), which stated that the salt marshes next to Fortescue Creek were vulnerable to die-off due to their low elevation within the tidal spectrum. This report also recommended TLP of dredged material to raise the marsh platform to the proper tidal range for native salt marsh plants. During this phase of marsh assessment, the marsh team was primarily considering TLP on low-elevation areas of the marsh directly adjacent to Fortescue Creek, particularly a depression that contained abandoned

Figure 10. *This LiDAR map of the marsh at Avalon shows the relative elevations of state-owned marsh near planned dredging and was used in combination with other information to preliminarily select marsh enhancement areas.*

mosquito ditches. In addition, an eroding beach and a *P. australis*–dominated constructed dune were identified as potential recipients of the sandy sediment to be dredged from the channel.

Site visits were conducted to evaluate vegetation health, pool condition, platform stability, faunal (primarily bird and fish) use, and enhancement feasibility. The project team visited the potential marsh enhancement and control areas selected through the desktop analyses several times. These site visits allowed the marsh team to narrow down the potential marsh enhancement areas to those that were clearly stressed and likely to benefit from the placement of dredged material.

Ring Island: The areas that were initially identified (Fig. 11) were heavily used by nesting birds or were too far away from the dredging area in the NJIWW. The project team conducted several site visits before selecting the final marsh enhancement and ENH areas shortly before dredged material placement began (Fig. 12). The selected marsh enhancement area had stunted, sparse vegetation (Fig. 13) and higher elevations than the originally selected areas. The project team decided to move forward with a dredged material TLP trial in two 0.5-acre areas at Ring Island, even though these areas were not the team's original choice, because of what could be learned from this pilot project.

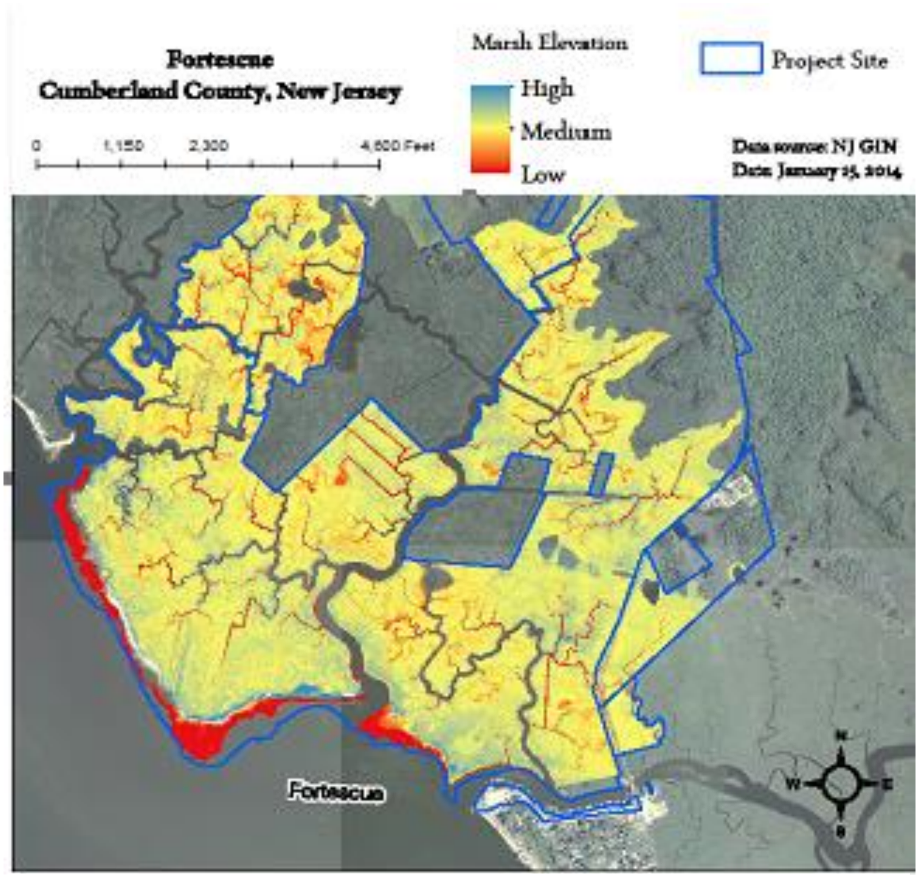


Figure 11. *This LiDAR map of the Fortescue site shows the relative elevations of state-owned marsh near the planned dredging area. This map was used in combination with other information to preliminarily select marsh enhancement areas.*

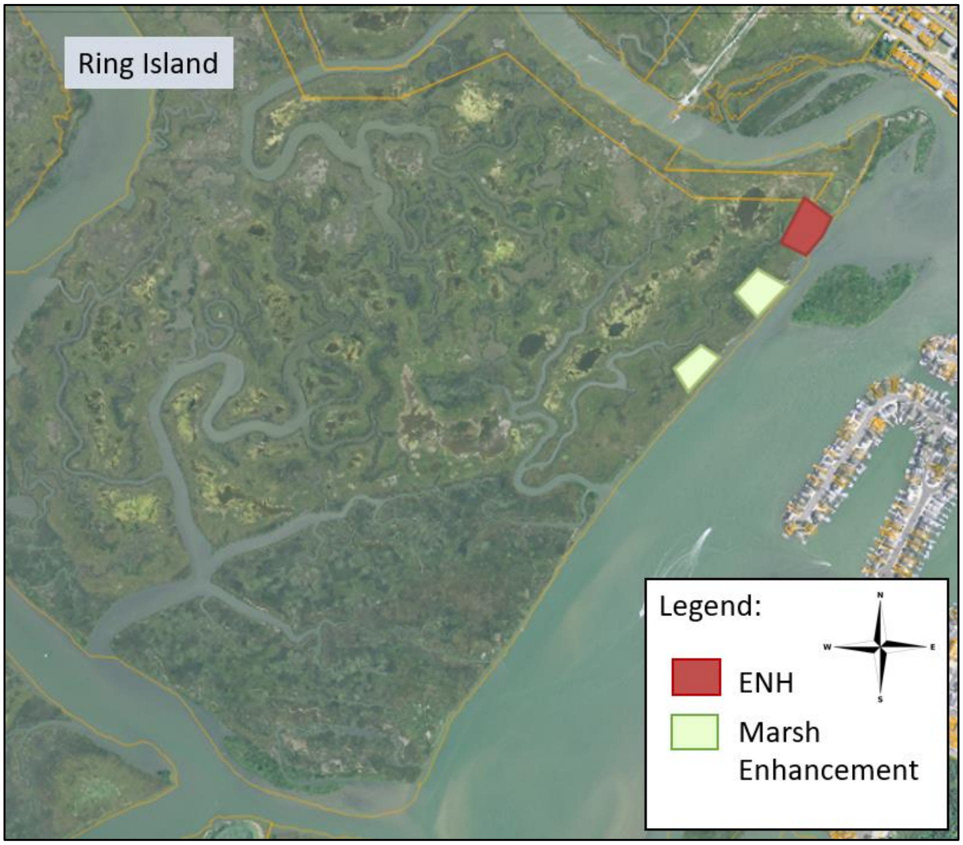


__Figure 12.__ This map shows the final placement sites at Ring Island. Elevated Nesting Habitat is marked in red and thin-layer placement areas are in green.

__Figure 13.__ Sparse and stunted vegetation was characteristic of the areas of the marsh at Ring Island selected for enhancement via thin-layer placement of dredged material.

Avalon: Site visits conducted by the marsh team considered marsh vegetation, hydrology, faunal use (particularly bird nesting), and marsh platform stability (particularly around the edges of pools). These observations helped the team identify stressed areas of the marsh for enhancement as well as areas of the marsh that were healthy and probably would not benefit from the addition of dredged material. Ultimately, the selected placement areas at Avalon had multiple characteristics typical of stressed marshes, including eroding edges, expanding and degrading pools with undercut banks (Fig. 14), sparse and stunted vegetation (Fig. 15), and minimal faunal usage.

For marsh enhancement at the Avalon site, the marsh team selected expanded and degraded pools that were surrounded by sparsely vegetated marsh platform. Most of these pools were also near an eroded marsh edge. The team predicted that as the marsh edge continued to erode and pools continued to expand, they would essentially coalesce, resulting in a "blowout," and a large area of the marsh would be lost and become open water. This prediction was supported by observations of remnant pools in open water adjacent to the marsh (Fig. 16). For the small Avalon Phase 1 project, three placement areas were chosen for construction in fall 2014 and winter 2015, and the edge of the marsh near those areas was evaluated for creation of a living shoreline. In 2015, a larger area of the marsh was evaluated, first by desktop analysis and then with site visits. Several additional placement areas were selected for the larger Avalon Phase 2 project.

Figure 14. *Expanded and degraded pools were present at the Avalon marsh. The white wrack in the picture is dried algae from the pond.*

Figure 15. *Vegetation at the Avalon marsh was sparse.*

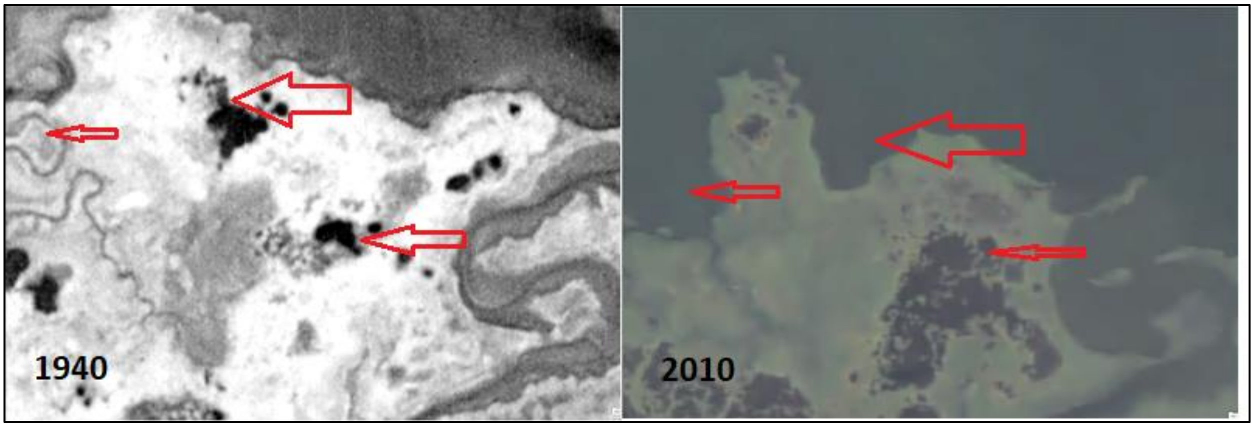


Figure 16. These aerial photos of Avalon Area C in 1940 and 2010 reveal conversion of the marsh platform to open water, which was caused by a combination of expanding pools that eroded the marsh edge.

Fortescue: As at Avalon, the marsh team performed site assessment visits to identify stressed areas of marsh that could benefit from the placement of dredged material and to narrow the list of potential dredged material placement areas. The team considered vegetation, hydrology, faunal use (particularly bird nesting), and marsh platform stability (particularly around the edges of pools). The selected enhancement areas exhibited multiple characteristics typical of stressed marshes, including undulating terrain, mosquito ditches, erosion, an unstable marsh platform (wobbly hummocks of *Spartina* spp. surrounded by unconsolidated mud), minimal faunal use, and sparse and stunted vegetation (Fig. 17).

***Figure 17.** At Fortescue, the team noted stunted vegetation on an unstable marsh platform (wobbly hummocks of* Spartina *spp. surrounded by unconsolidated mud).*

During site assessment visits to the proposed beach restoration area in Fortescue, the team confirmed that the area was eroding and was highly utilized by birds. As a result of the site visits, the size and configuration of the proposed dune restoration was changed in order to preserve a valuable patch of mature trees, which was used by many herons.

Many additional factors informed the final selection of enhancement areas at each site. These included the grain size distribution of channel sediment, the chemical composition of channel and marsh surface sediment, the distance from the marsh edge to the placement areas, the contours of dredged material placement areas (surface area and thickness required to achieve the target dredged material placement elevation and respective placement constraints), and timing restrictions for dredging and dredged material placement (“dredging windows”). Because these factors also affected the design of the projects, they are discussed in more detail in Phase 2: Project Design [Step 3].

At the Avalon site, the sediment to be dredged from the NJIWW was, on average, comprised of 27% fine sand, 53% silt, and 19% clay. The project team had originally planned to use some of the dredged material to restore part of the eroded marsh edge; however, it would have been very difficult and expensive to design, place, and stabilize the fine-grained sediment. Therefore, the team abandoned this plan. Based on the project team’s experience placing and spreading sandy material at Ring Island, the team decided that the sand–silt mix available at Avalon was ideal for filling marsh pools, with the overflow resulting in TLP of sediment on the existing marsh platform surrounding the pools. For additional information, see Phase 2: Project Design.

The Fortescue Creek navigation channel contained a heterogenous mix of fine-grained sediment, sand, and some gravel. After its experience at Ring Island, the project team knew that it would be difficult to place sandy dredged material evenly over large areas of marsh. Because the navigation channel needed to be dredged completely to make the dredging project economically viable, the team decided to use the coarser-grained dredged material to restore the adjacent dune and a natural beach. Dredging and placing the sandy dredged material for the dune and beach components could also be done faster than applying TLP on the marsh. These project components were added to help contain costs and increase the probability that the project could be completed before dredging was stopped by seasonal restrictions.

Step 4: Project Design and Construction. The team made final refinements to the selection and delineation of the marsh enhancement/dredged material placement areas during the design and construction phases (discussed in Phase 2: Project Design and Phase 5: Construction). This was an iterative process involving coordination and adaptive management of the project designs with the dredging and dredged material placement.

Phase 2: Project Design

After the dredged material placement areas had been selected at each site, the project design (Phase 2) was initiated. Project design included developing the target dredged material placement elevations and target ecological elevations (or thickness of placed dredged material), grading plan, planting plan, dredge pipe layout, and sediment erosion and control plans and specifications.

In salt marshes, the depth and duration of tidal inundation, which is controlled by elevation and topography, is one of the most important determinants of the habitat present at a site. The target ecological elevation is the elevation at which the depth and duration of flooding would be expected to create a specific type of salt marsh habitat, which is characterized by the predominant plant species. These elevations can be based on either biological benchmark data (the elevation at which a species is typically found) or on data from a reference site. These elevations, in combination with tidal datums, can be used to select target ecological elevations for a project. To accommodate future sea levels at the project sites, the team selected target ecological elevations at the higher end of the elevation range within which a target plant species occurred.

If the marshes are going to undergo manual revegetation, biological benchmarks and hydrology from a reference site can also be used to draft planting plans. To obtain the needed quantities of plants for large sites, specialty nurseries may require orders far in advance (likely at least 6 months), so creating a draft planting plan is helpful. However, to allow for elevation changes from dewatering and consolidation of the placed sediment, the planting plan cannot be finalized until the elevation stabilizes and the topographic survey has been completed.

The target dredged material placement elevation is the elevation to which dredged material should be placed on the enhancement project site. After dewatering and consolidation of the dredged material, the surface elevation should decrease to achieve the target ecological elevation. Hydraulically dredged sediment is mixed with water to form a slurry, which increases its volume. This increase in sediment water content and volume is called the sediment "bulking factor" and was estimated on the basis of USACE-ERDC research in the Gulf of Mexico. The bulking factor is then used in combination with the target dredged material placement and ecological elevations to estimate the volume of sediment needed for each enhancement area.

Another option for determining the volume of dredged material needed on the marsh is to select a target thickness of placed dredged material. This target could be based on what would be expected to accrete during a large storm, or on the thickness of placed dredged material that marsh vegetation would be expected to quickly grow through and recover (based on the scientific literature, expert interviews, or personal experience).

Sediment erosion and control plans for the pilot projects were based on the grain size of the sediment, the contours of the marsh, the elevation gain to achieve the target dredged material placement elevation, and the need to protect tidal creeks. Fine-grained sediment will disperse farther across the marsh and take longer to dewater than coarser-grained sediment, potentially requiring more containment.

At each project site, the project design was created through a collaboration of the dredging team and the marsh team, with each contributing extensive expertise and resources to the design process. The four general steps to design of the marsh enhancement components of the pilot projects were:

- **Design Step 1:** Complete assessment of biological benchmarks and tidal datums to establish target ecological elevations.
- **Design Step 2:** Conduct baseline topographic survey and map tidal creeks.
- **Design Step 3:** Review potential design constraints.

- **Design Step 4:** Develop the target dredged material placement elevations and enhancement design plan.

Design Step 1: Complete assessment of biological benchmarks and tidal data to establish target ecological elevations.

At **Ring Island, TLP:** The biological benchmark and tidal data (Table 4) were collected only a few days prior to construction and were not used to guide project design. Instead, design was based on the detailed literature review of Ray (2007), which indicated that plants recovered best after placement of 2–6 inches of material. In addition, Reimold et al. (1978) found excellent vegetation recovery after placement of up to 9 inches of sandy material. Based on these two studies, the team selected placement area depths of 3 and 6 inches. Because the dredged material was sprayed from the edge of the marsh, no pipe layout on the marsh was needed for this site.

Biological benchmark information was collected using real-time kinematics global positioning system (RTK-GPS), and tidal data for the sites were based on the nearest National Oceanic and Atmospheric Administration (NOAA) or U.S. Geological Survey (USGS) tide gauge. This information was also used after construction to develop the planting plan for the site and to identify a threshold elevation to be avoided, above which *P. australis* could potentially colonize. Biological benchmarks and tidal datums are presented in Table 4.

The Ring Island colonial shorebird ENH was designed so that the central area of the created mound would be above the spring high-tide line (the elevation that ensures nests will not be flooded during storms), with the majority of the surrounding area below the elevation at which *P. australis* can colonize. A detailed dredge pipe layout was not needed because the dredge pipe was cribbed into place on the marsh only a short distance from the marsh edge, and the dredged material was pumped directly onto the ENH site.

Table 4. Ring Island Marsh Enhancement Biological Benchmarks and Tidal Datums

Vegetation Zone/ Tidal Datum	Elevation (ft.; NAVD88)
Elevation above which *Phragmites australis* and *Iva frutescens* dominate	2.90+
Spring High Tide	**3.60**
Spartina patens* with lowest reaches of *Phragmites australis* and *Iva frutescens	2.76
Spartina patens	2.63
Short-form *Spartina alterniflora* with *Distichlis spicata, Limonium carolinianum*, and *Salicornia* spp.	2.52
Panne surrounded by stunted short-form *Spartina alterniflora*	2.16
Mean Higher High Water (MHHW)	**2.14**

Avalon Phase 1: As at Ring Island, the biological benchmark and tide data were collected only a few days prior to construction and were not used to guide the project design. In addition, because water-level loggers were not installed prior to construction, the design was based on filling targeted pools to the same elevation as the surrounding marsh plain and adding 3–6 inches of sediment onto the surrounding marsh plain.

Avalon Phase 2: For this phase, target elevations were based primarily on the need to restore high marsh habitat as well as on the surrounding topography of each placement area. Biological benchmark data were collected at 21 locations on the site prior to construction. A range of vegetation types (including *S. alterniflora* tall and short forms and *D. spicata)* were found. The benchmarks were synthesized into three habitat designations (Table 5).

Table 5. Vegetation Zones at Avalon

Vegetation Zone/ Tidal Datum	Elevation (ft.; NAVD88)
Mean Higher High Water (MHHW)	**2.39**
Lower limit of high marsh (*Distichlis spicata* dominated)	2.20
Mean High Water (MHW)	**2.03**
Upper limit of *Spartina alterniflora* tall form and lower limit of intermediate and short form *Spartina alterniflora*	1.90
Lower limit of low marsh (*Spartina alterniflora* tall form)	0.00
Mean Low Water (MLW)	**-2.00**
Mean Lower Low Water (MLLW)	**-2.61**

In each placement area, the mean elevation of the marsh platform surrounding the pools was determined based on the topographic survey. Then, based on the selected target ecological elevations (Table 6), an elevation of approximately 6 inches above that elevation was chosen for both the pools and marsh plain in each area. This increase in elevation would ensure that the enhanced marsh would be higher than the surrounding areas, facilitating drainage off the site to avoid waterlogging of the sediments and vegetation.

Table 6. Target Ecological Elevations (feet NAVD88) for Placement Areas at Avalon					
	Avalon Placement Areas				
	A	**C**	**D**	**E**	**F**
Target Ecological Elevations (ft.; NAVD88)	2.50	2.11	2.50	1.89	2.50

At Avalon, two months prior to design, water-level loggers were installed in wells on the marsh and in a tidal creek. NOAA VDatum[8] program was used on site-specific data combined with long-term data from tide gauges in Atlantic City (NOAA 2012; Table 6).

Fortescue: The project involved the enhancement of high and low marsh, a coastal dune, and a natural beach. Biological benchmarks were chosen to represent each type of marsh habitat and were evaluated to determine the upper and lower elevation tolerances for the target plant communities. The biological benchmarks were then used to select the target ecological elevations. In general, the upper elevation of the target plant community was used as the target ecological elevation. In addition, it was important to keep these elevations below those at which *P. australis* would colonize the site. To increase ecosystem resilience and habitat diversity, enhancement in some areas converted the existing habitat into another habitat, which was the case for creating high marsh and restoring the dune.

Biological benchmark data were collected at 33 locations on this site prior to the placement of dredged material. A range of plant species (*S. alterniflora*, *I. frutescens*, *D. spicata*, and *P. australis)* exhibited low, intermediate, and high vigor, and the benchmarks were summarized into vegetation zones (Table 7). In January 2015, a tide gauge was installed in Fortescue Creek to collect baseline data. Because the data of the tide range on-site were from a relatively short time span (five months), data from other tide gauges were also considered during the design process. However, just as in the Avalon Phase 2 project, the tide information used to set the target dredged material placement and ecological elevations was taken from the NOAA VDatum (Table 7).

For the Fortescue dune restoration, no biological benchmark data were used in the design. The restoration project was designed to create a more stable dune that would protect the marsh from the high wave energy in Delaware Bay. The original dune crest elevation was designed to be +6 feet NAVD88 with a 5:1 (horizontal to vertical) slope. This plan had to be modified because the shoreline eroded during the time between the initial design and construction. The modified design had a dune crest elevation of 10 feet NAVD88 with a 4:1 slope.

For the Fortescue beach restoration, no biological benchmark or water level data were used in the design. An 80-foot-wide, 5-foot-high (NAVD88) berm was designed for the marsh-beach interface (landward edge of the beach). From the berm waterward, sand was placed at an approximate slope of 15:1 (horizontal to vertical). The entire beach restoration area was in the intertidal zone.

[8] https://www.vdatum.noaa.gov/about.html

Table 7. Biological Benchmark Range Summaries, Tidal Datums, and Target Placement Elevations for the Fortescue Marsh Enhancement Project		
Vegetation/ Tidal Datum	Lower Limit (ft.; NAVD88)	Upper Limit (ft.; NAVD88)
High Tide Level (HTL)		**4.53**
Upper elevation of high marsh target placement elevation range		4.00
Phragmites australis	2.29	3.72
***Spartina alterniflora* tall form**	-0.75	3.69
***S. alterniflora* intermediate form**	2.18	3.69
Iva frutescens	3.18	3.65
High marsh	2.47	3.35
Lower elevation of high marsh and upper elevation of low marsh target placement elevation range		3.30
***S. alterniflora* short form**	2.47	3.08
Mean Higher High Water (MHHW)		**3.08**
Mean High Water (MHW)		**2.66**

Design Step 2: Topographic Survey

Baseline topographic surveys were collected at all sites except the ENH. These data were used in combination with biological benchmarks and tide range data to design the Avalon Phase 2 and Fortescue projects.

The topographic data were collected using permanent transects established at intervals of at least 50 feet, spanning the entire project area and the control areas. Within each project site, the limits of the areas to be surveyed were determined based on the results of Phase 1: Site Identification and Placement Area Selection, which established the potential treatment areas. The topographic surveys were conducted by NJ-licensed professional land surveyors using RTK-GPS survey equipment to capture point-by-point data with both horizontal (x, y) and vertical (z) information assigned to each point (horizontal and vertical accuracies were set at 0.1 feet). Qualitative descriptors for each point were also identified to generate topographic base maps that contained identifying information for the surface features, such as pools, platforms, channels, top of the bank, and bottom of the bank. The density of data points varied depending on the accessibility of the marsh. For example, because there was standing water in the pools and working conditions were unsafe, they were not surveyed in as much detail as the marsh platform, which was more accessible.

Ring Island: The topography of the existing marsh enhancement area and the control area were surveyed, but the data were not used to inform project design because they were not available before the project was constructed. Baseline topographic data were not obtained from in the area where the ENH was sited. Topographic information, including LiDAR information, from available online sources was also reviewed; however, it was not deemed accurate enough for design purposes.

Avalon Phase 1: The existing topography was surveyed in 2014 for marsh enhancement areas A, B, and C and at the control areas, but the data were not used for project design purposes because they were not available prior to construction. Topographic information from available online sources, including LiDAR information, was also reviewed; however, it was not deemed accurate enough for design purposes.

Avalon Phase 2: The existing topography was surveyed in July and August 2015. Some pools could not be surveyed because the conditions were too dangerous to traverse on foot. Because of this lack of data, some generalized assumptions were made about the depth of the pools. Project design was driven primarily by three factors related to site topography: (1) specific dredged material placement areas were selected in Phase 1, (2) a specified (and potentially limiting) volume of sediment was available to be dredged for this project and (3) the volume of dredged material was needed to achieve the target ecological elevation in each dredged material placement area. To aid in the design, estimates of the volume of dredged material needed in each placement area were made using the topographic data and observations of the marsh platform surrounding the placement areas.

Fortescue: Topographic surveys were performed in 2015 by the dredging team. To estimate the volume of dredged material needed for each of the three project components (marsh, beach, and dune restoration) the data from these surveys were used along with data for the distribution of grain size in the sediment to be dredged. Because a portion of the shoreline along the existing dune was eroded by a storm in January 2016, an additional topographic survey of the dune was completed prior to the dune restoration.

Design Step 3: Review Design Constraints

The designs of the Ring Island, Avalon, and Fortescue marsh enhancement projects were closely coordinated with the design and implementation of the associated dredging projects. A variety of potential site-specific constraints were considered regarding the design of each project, including:

- the distance between the dredging site and the dredged material placement areas,
- practical dredged material spraying and/or pumping distances,
- existing marsh elevations in relation to the location of tidal creeks, pools, pannes, and other potential obstacles to site access, as well as the need to place and move the dredge discharge pipe on the marsh,
- tidal creeks in the marsh,
- the need to minimize adverse impacts to the marsh from the use of heavy construction equipment,
- the volume of sediment to be dredged and its estimated bulking factor,
- the grain size distribution and chemical characteristics of the sediment to be dredged and the existing marsh surface sediment, and
- project-specific scheduling limitations.

To varying degrees, these factors interacted to affect how and where the sediment was used for habitat enhancement.

The goal of the design process was to develop feasible projects that focused on the delivery and placement of the dredged material to achieve the desired marsh enhancement objectives while minimizing both dredging costs and construction-related damage to the marsh. Potential obstacles to marsh access and positioning the dredge discharge pipe on the marsh were identified and addressed.

The distance between the dredging site and the dredged material placement areas was a design constraint that was addressed mostly during the Phase 1: Site Identification and Placement Area Selection and was a problem only for the Avalon Phase 2 project (discussed below). In general, the dredging projects were located within typical hydraulic dredging pumping distances of the marsh enhancement sites, and therefore booster pumps were not needed.

The grain size of the dredged material and obstacles such as tidal creeks and large pools can limit where the outlet pipe can be placed and moved on the marsh. The grain size of the dredged material affects how it will move and settle as it is placed. In general, the greater the proportion of silt and clay, the farther the dredged material will travel across the marsh; the longer it will take to settle, dewater, and consolidate; and the more even the application will be. The grain size of the dredged material will affect the number and locations of the dredge discharge pipe, which is further affected by the limited spraying and pumping distances.

One of the objectives of the projects was to maintain existing tidal creeks. To identify all the regulated channels and ditches on the marsh at each project site, the team reviewed the New Jersey Tidelands Claim Map. To avoid encroaching on Tidelands claim areas, general project limits-of-disturbance and limits-of-dredged-material-placement were established. The design and placement of perimeter containment was also based, in part, on the location of these creeks. To minimize the formation of new pools, target placement elevations should be high enough to ensure positive drainage off the marsh platform.

A dredged material slurry is the mixture of sediment and water transported in a pipeline by a hydraulic dredge. The sediment from a navigation channel increases in volume as it is dredged and mixed with water. This estimated bulking factor was used to determine the volume of dredged material needed to achieve the target ecological elevations. The typical percentage of solids (weight of dry solids divided by weight of wet slurry) varies in a hydraulic pipeline, but usually ranges from 10% to 20%; this variability causes errors in the estimates of the volume of dredged material needed.

Sediment composition, including grain size distribution and chemical characteristics, was a key factor in designing the Avalon and Fortescue projects; it was not a design consideration at Ring Island, where the dredged material was 96% fine sand. Hydraulically dredged sand (coarse-grained dredged material) will quickly settle and accumulate near the outlet of the dredge discharge pipe, leading to uneven placement depths and requiring the pipe to be frequently moved. In contrast, finer grained (predominantly silt and clay) dredged material will disperse farther from the pipe across the marsh. Thus, grain size of the dredged material is a prime consideration when selecting placement areas and enhancement activities.

One of the design objectives was to use dredged material that had physical and chemical characteristics similar to the existing marsh surface sediment. From a physical standpoint, the grain size distribution of the sediment to be dredged from the channel was integral to the overall designs of these three pilot projects. The site-specific importance of sediment composition to project design is discussed in more detail in Phase 3: Permitting.

The size and type of marshes selected for enhancement were influenced, in part, by two scheduling factors: (1) seasonal restrictions ("dredging windows") for dredging and material placement to minimize potential impacts to species of concern, and (2) availability of dredge contractors. At each site, project construction was planned to start soon after marsh nesting birds had fledged (typically, September) and needed to be completed by the following December to March to prevent potentially negative impacts to winter flounder, anadromous fish, and other species of concern. It was also highly desirable to complete construction in one continuous work period because it is expensive to re-mobilize dredging equipment. In addition, the TLP method is generally slower and pumps fewer cubic yards of sediment per day than other types of dredged material management operations, such as placement in a CDF. Combining marsh enhancement projects with other types of habitat projects with higher production rates, such as the beach nourishment and dune restoration at Fortescue and the ENH at Ring Island, allowed more sediment to be dredged from the navigation channels during the available "dredging windows."

The following examples show how these constraints impacted the pilot projects.

Ring Island, TLP: The two major design constraints for this project were the maximum distance (150–200 feet) that the dredged material could be sprayed from the marsh edge to the placement areas and the sandy texture (96% fine sand) of the dredged sediment. This sediment was deemed suitable for construction of the colonial shorebird ENH (discussed below). However, the project team was unsure how sand would spread when it was sprayed on the marsh or how the marsh sediment, which is composed of highly organic and silty soils, would respond to placed sand. So, the team conducted a test using a small volume of sandy dredged material to determine whether and how far it could be sprayed onto the marsh platform and whether its placement would enhance the marsh.

In addition, USACE-OP's dredging contractor built and modified the dredged material spray equipment during placement to improve its performance. Access to and across the marsh site was not a problem and no heavy equipment was used on the marsh. The dredged material was homogenous (96% fine sand), but only a limited volume was designated for TLP on the marsh.

The selection of the TLP site at Ring Island was also heavily influenced by environmental timing restrictions. The dredge contractor was on a fixed schedule, but birds were still nesting in the selected placement area during the planned construction time, so new sites had to be selected. This limited timeframe also influenced the decision to use most of the dredged material to create a sandy ENH.

Ring Island, ENH: The TLP and ENH sites had permit conditions to minimize dispersal of the dredged material from the placement area, particularly into creeks, and to otherwise minimize impacts to the surrounding marsh. To address these conditions, the TLP areas were set back from creeks and the heavy machinery used to grade the ENH site was kept within the footprint of the ENH.

Avalon Phase 1: Chemical analysis of the sediment to be dredged from the NJIWW and proposed for use in marsh enhancement showed the presence of contaminants in some samples, particularly dioxins and furans, at concentrations greater than the existing marsh surface sediment in dredged material placement areas A, B, and C. In addition, a limited time remained in the USACE-OP dredging contract to complete the work. These two factors reduced the scope of the Avalon Phase 1 project to dredging a limited section of the NJIWW that had physical and chemical sediment characteristics comparable with those in dredged material placement areas A and C (see Phase 3: Permitting).

Another consideration at Avalon was the limited distance (150–200 feet) that the dredged material could be sprayed from the marsh edge; however, the finer-grained material was expected to fill pools and pannes and to disperse throughout placement areas A and C. Site access was not a problem, and no heavy equipment was used on the marsh.

Avalon Phase 2: This marsh had many pannes and pools that affected access and placement of the dredge pipe. This project design constraint was integrated with the sediment composition design constraints discussed below. In addition, containment was needed to allow sediment to reach the target dredged material placement elevations and prevent sediment from running into creeks.

In the Avalon Phase 2 project, the grain size of the dredged material played a major role in the design. Given the grain size variability of both the marsh surface sediment and the sediment to be dredged from the NJIWW, one objective of the design was to place the dredged material on areas of the marsh with similar grain size.

The chemical characteristics of the dredged material also greatly influenced the design of the Avalon Phase 2 project. The USACE-OP's initial testing of the sediment to be dredged from the NJIWW near Avalon found dioxins and furans at potential levels of concern in some of the sediment. To further evaluate the potential to use the dredged material for marsh enhancement, the project team tested the marsh surface sediment in the placement areas and also tested samples of the sediment to be dredged from the NJIWW. The samples were analyzed for dioxins, furans, PCB congeners, pesticides, and metals.

The dredged material to be used in each placement area was required to have contaminant concentrations similar to or less than those of the existing marsh surface sediment. For this project, placing such dredged material on the Avalon marsh posed a minimal potential risk to human health and the ecosystem. The suitability of the dredged material for marsh enhancement was also evaluated considering the Effects Range-Low (ER-L) and Effects Range-Medium (ER-M) Sediment Quality Guideline values of Long et al. (1995). The testing results indicated that the range of contaminant concentrations in the sediment of the Avalon marsh and the NJIWW were similar and were usually less than their ER-L values. Further, it was decided that the more contaminated dredged material would be placed on areas of the marsh with existing sediment of similar concentration. See Phase 3: Permitting.

The placement of dredged material on placement areas A, C, D, E, and F was further limited by the volume of sediment, plus an estimated bulking factor of two in each reach of the NJIWW placement areas. The contract expired before the dredging team finished placing sediment in all placement areas, and the team was unable to complete the dredging.

Fortescue: The main factor affecting the design of the Fortescue marsh enhancement project was the heterogeneous composition of the sediment to be dredged from the channel. Although sediment contamination was not a problem, as the sediment to be dredged was overall less contaminated than the marsh surface sediment, its grain size limited the amount of predominantly fine-grained dredged material that was available for marsh enhancement. This reduced the area of marsh that could be enhanced and prompted the team to design the dune and beach restoration components that would accept the sandier portions of the channel sediment.

The NJ Tidelands Claim Map was used to set the limits for dredged material placement on the marsh and for the beach and dune project components. However, avoiding and protecting Tidelands-regulated channels and creeks posed a challenge for the containment design.

Fortescue Beach and Dune Restoration: Design of the beach restoration component followed typical beach nourishment guidelines. A major design constraint for the dune restoration component was to minimize encroaching upon and impacting the surrounding salt marsh during construction. This constraint became more significant when the team needed to redesign the dune after a January 2016 storm eroded part of its shoreline.

In addition to sediment grain size, the dune and beach restoration project components were influenced by biological timing restrictions and the need to dredge the entire reach of the Fortescue Creek channel to make the project cost-effective for NJDOT-OMR.

Design Step 4: Develop Target Elevations, Grading, and Planting

The target dredged material placement elevations were based on the estimated dredged material bulking factor and anticipated rates of consolidation of the dredged material after dewatering. The team assumed that the predominantly fine-grained dredged material to be placed on the marsh would likely have a bulking factor of two and would consolidate by approximately 50% after dewatering.

The project designs for the marsh enhancement projects did not include any provisions for post-construction grading of the placed dredged material. The Fortescue dune and beach restoration components and the Ring Island ENH project component were not expected to consolidate by 50% due to the sandy nature of the dredged material. To reach the specified target ecological elevations, the placed dredged material was graded during and after construction.

Perimeter containment was the primary sediment erosion and control technique evaluated and designed for all the projects, except the Ring Island marsh enhancement and Fortescue beach nourishment projects, where containment was not needed. To reduce sediment release into government-protected waters, some locations were identified where containment could be placed. These were typically low-lying areas where water concentrated for discharge off the marsh platform. During the design process, several containment products were evaluated. To avoid removing containment after the dredged material was placed, the marsh team preferred containment products that were composed of biodegradable materials. Containment products were available in a limited set of diameters and lengths, which were not necessarily consistent with the target dredged material placement elevations and the existing marsh elevations. As a result, in some locations, containment was considerably higher than the target dredged material placement elevation.

Containment design typically included a plan for securing the containment through staking and trenching and for stacking containment in areas where the channels, pannes, or pools were exceptionally deep. One problem was obtaining the quantity of containment needed for the Avalon Phase 2 and Fortescue projects. The team had to order it months in advance for the supplier to produce such large quantities. This was one reason why Filtrexx SiltSoxx™ was used instead of coconut-fiber logs at Fortescue.

Technical specifications associated with the site plan were prepared during Phase 4: Contract and Bidding and were included on the engineering drawings prepared for the projects.

Avalon Phase 1 Marsh Enhancement: The analysis of sediment for the Avalon Phase 1 project revealed that the portion of the NJIWW to be dredged near Shark Island had a much lower percentage of sand (34%) than that used at Ring Island (96%). This was expected to provide a more even and dispersed application of the dredged material. Given the high percentage of silt (49%) in the dredged material, some containment was installed to minimize the dispersal of this finer-grained sediment from the placement areas. The project team did expect, however, that the pools into which the dredged material would be sprayed would retain much of the material. The containment structures consisted of coconut-fiber logs, which are made of baled coconut fibers that slow and filter the water passing through them.

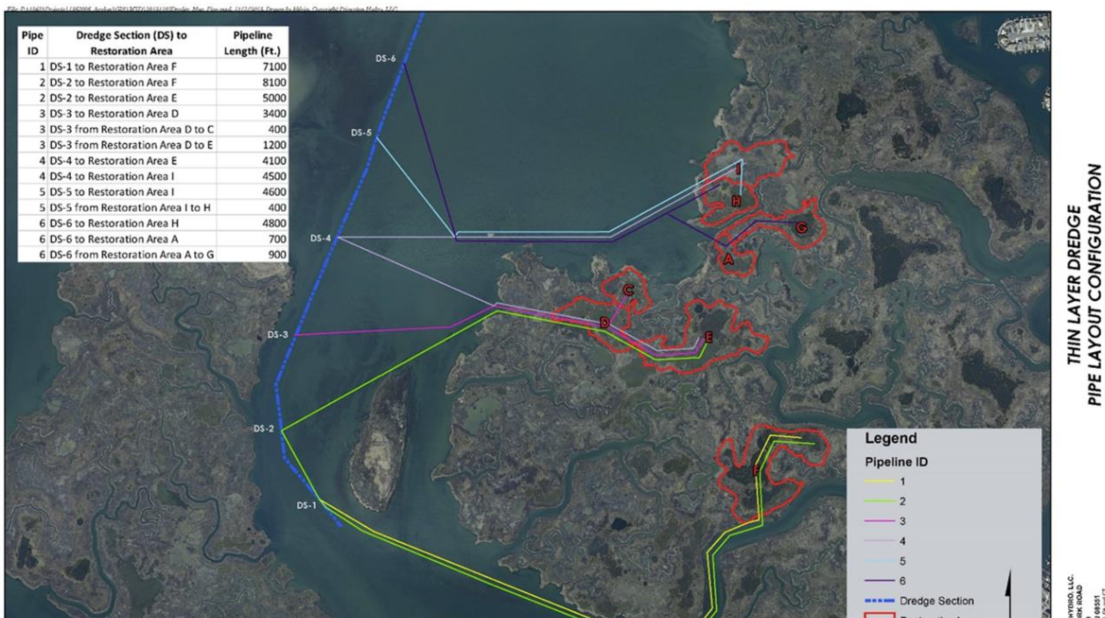
Avalon Phase 2 Marsh Enhancement: In general, target dredged material placement elevations were approximately 12 inches above the existing marsh elevation. The team expected the placed dredged material to settle and consolidate, resulting in an elevation of approximately 6 inches across most of the site, which would achieve the target ecological elevations. The selected target dredged material placement and ecological elevations for each placement area can be seen in Table 8.

Table 8. Target Dredged Material Placement Elevations and Ecological Elevations for Placement Areas

Placement Area	Placement Elevation (ft. NAVD88)	Ecological Elevation (ft. NAVD88)
A	3.00	2.50
C	2.61	2.11
D	3.00	2.50
E	2.39	1.89
F	3.00	2.50

After their experience with the Avalon Phase 1 project, the team decided that in order to keep the dredged material within its boundaries as much as possible, each dredged material placement area would be completely enclosed by containment. To achieve the target dredged material placement elevations, biodegradable coconut-fiber logs of various diameters were used for containment. At each placement area, the arrangement of containment was designed based on the local topography. Special emphasis was placed on identifying low points along the placement area perimeter toward which the slurry was predicted to flow. The containment slowed and filtered the slurry, allowing the sediment to fall out of suspension, and resulted in relatively clean water flowing through or over the containment.

A general layout of the dredge pipe from the NJIWW to each placement area is shown in Figure 18. The layout directed dredged material from each reach of the NJIWW to areas of the marsh with similar chemical characteristics to meet the "like-on-like" permit conditions. This approach minimized the distance the dredge pipe had to be pulled into the marsh and the number of times the pipe had to be moved during placement.



Pipe ID	Dredge Section (DS) to Restoration Area	Pipeline Length (Ft.)
1	DS-1 to Restoration Area F	7100
2	DS-2 to Restoration Area F	8100
2	DS-2 to Restoration Area E	5000
3	DS-3 to Restoration Area D	3400
3	DS-3 from Restoration Area D to C	400
3	DS-3 from Restoration Area D to E	1200
4	DS-4 to Restoration Area E	4100
4	DS-4 to Restoration Area I	4500
5	DS-5 to Restoration Area I	4600
5	DS-5 from Restoration Area I to H	400
6	DS-6 to Restoration Area H	4800
6	DS-6 to Restoration Area A	700
6	DS-6 from Restoration Area A to G	900

Figure 18. *This figure shows the planned dredge pipe layout for the Avalon Phase 2 marsh enhancement. Only one pipe was used, so each pipeline ID represents a repositioning of the pipe.*

Fortescue Marsh Enhancement: The selected target dredged material placement elevation was 3.3 feet (NAVD88), which was approximately 9 inches (on average) higher than the existing marsh platform. The team expected the dredged material to settle and consolidate, resulting in a final height of approximately 4–6 inches above most of the marsh. This placement depth was consistent with the target ecological elevation and would result in the desired low- and high-marsh plant communities based on biological benchmarks.

Each dredged material placement area was surrounded by a double row of non-biodegradable, but photodegradable, Filtrexx SiltSoxx™ that required removal once the dredged sediment stabilized. Primary (interior) containment consisted of 12-inch diameter Filtrexx SiltSoxx™. A secondary containment (6-inch diameter Filtrexx SiltSoxx™) was installed approximately 7 feet outside the primary containment. A minimum 50-foot buffer from the containment was established around larger creeks, and a 10-foot buffer was established around smaller internal creeks. Special emphasis was given to identifying low points along the placement area perimeters toward which the slurry was predicted to flow and where additional or stacked containment was needed. The containment was designed to slow and filter the slurry, allowing the sediment to fall out of suspension and resulting in relatively clean water flowing through or over the containment.

The dredge discharge pipe layout for placing dredged material on the marsh accounted for the grain size of the dredged material. In general, it was assumed that the coarser-grained sand would settle out more quickly than the silt and clay, which would disperse farther from the pipe outlet across the marsh. Therefore, the pipe layout was designed with a central “trunk line” with "branches" extending out from the trunk into the center of each dredged material placement area (Fig. 19). Multiple discharge points were positioned so that the sand fraction would accumulate to high marsh elevation and the finer-grained dredged material would disperse to the outer portions of the placement areas, where it would settle out of suspension. The size of the placement areas and the volume of material that could be placed in them were determined by the dredged material characteristics and existing site topography. In addition, at each discharge point, an on–off valve would allow continuous dredging and placement. In theory, this would more likely achieve the target dredged material placement elevations and allow the project to be completed within one season, eliminating the need to remobilize and finish the project the following year. However, in practice, the system did not operate as planned (see Phase 5: Construction).

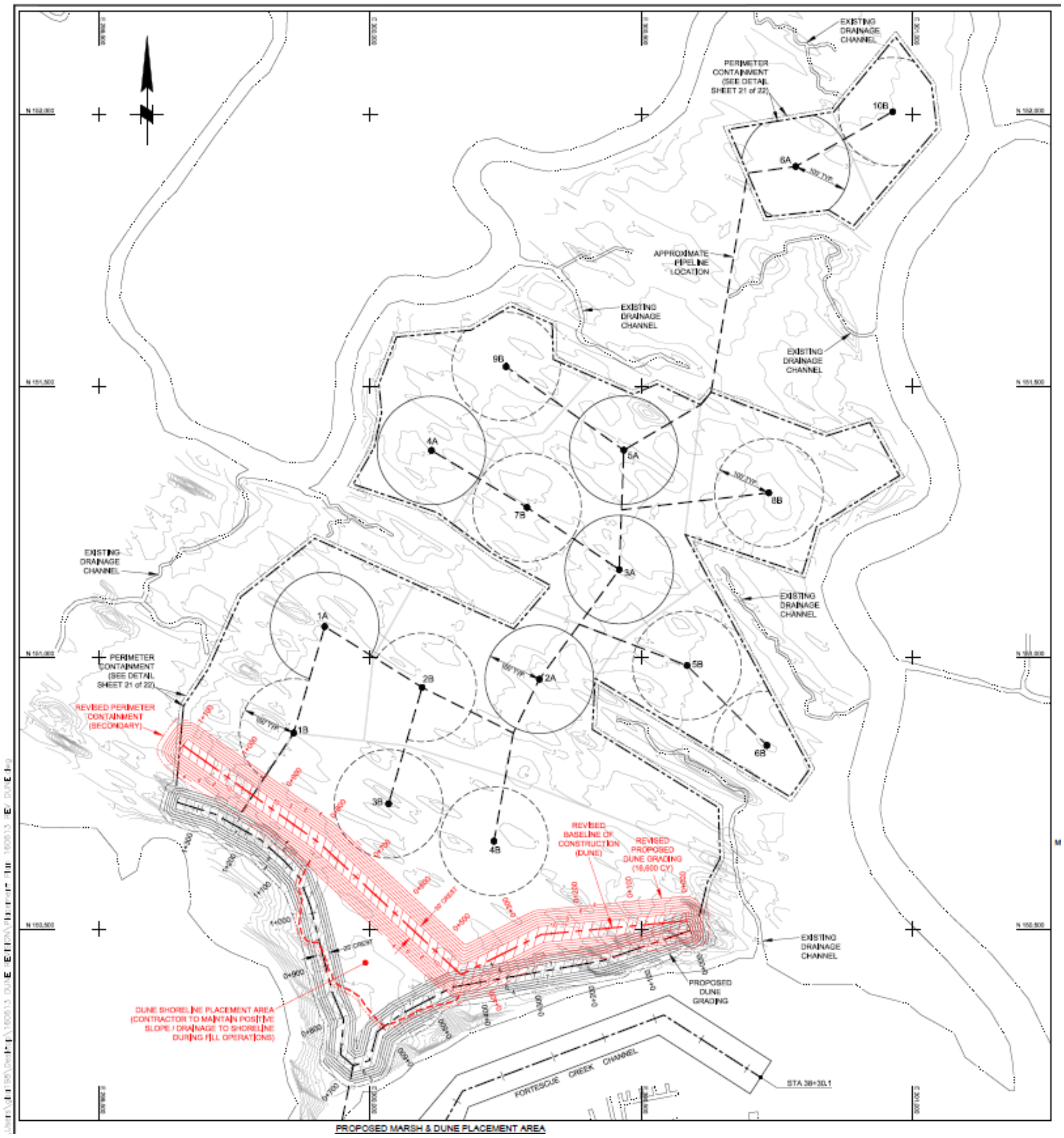


Figure 19. *This was the original design of the dredge discharge pipe system for the Fortescue marsh enhancement project component. The dune design is in red. The dashed lines represent the pipe layout across the marsh. Circles represent discharge areas where sand was expected to create high marsh. Black dash and dotted lines represent containment around placement areas.*

Fortescue Dune Restoration: The dune restoration component was designed to protect a municipal marina and the adjacent marsh from storms and waves. The height of the dune was established to minimize overtopping by waves. Target ecological elevations were not developed for the dune restoration project, although the constructed elevations were used to develop the planting plan for the dune. The dune was designed to allow the dredged sand to dewater and then graded to reach target elevations and desired slopes. A major design consideration was the need to minimize the impacts from dune construction to the adjacent marsh. To help stabilize the dune and minimize the dispersal and erosion of the placed dredged material, the dune footprint was enclosed by a single line of staked Filtrexx SiltSoxx™.

Phase 3: Permitting

This section summarizes the NJDEP and USACE regulatory processes as they were applied to the Ring Island, Avalon, and Fortescue projects. The Division of Land Use Regulation (NJDEP-DLUR) reviewed the state permit applications, and the USACE-Philadelphia District Regulatory Branch (USACE-RB) reviewed the federal permits applications. Pursuant to the New Jersey Coastal Zone Management (CZM) Rules (N.J.A.C. 7:7), the NJDEP regulates wetlands, dredging, and the management of dredged material. Specifically, Appendix G of the CZM Rules addresses *The Management and Regulation of Dredging Activities and Dredged Material in New Jersey's Tidal Waters*. Appendix G was developed to reflect the NJDEP policy that dredged material is a resource and that acceptable beneficial uses of dredged material should be encouraged and given priority over the disposal of dredged material.

Dredging projects not conducted by the USACE-OP (i.e., Fortescue) require permits from both the NJDEP-DLUR and the USACE-RB. A Waterfront Development Permit is required by the NJDEP, together with the associated Federal Consistency Determination and Clean Water Act Section 401 Water Quality Certificate (WQC). In areas where the dredged material is to be used beneficially, an Acceptable Use Determination (AUD) for the dredged material is also required from the NJDEP. The federal permits were issued pursuant to Section 404 of the Clean Water Act (33 U.S.C. 1344) and Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. 403).

CZM General Permit 24 (N.J.A.C. 7:7-6.24; formerly GP29) addresses habitat creation, restoration, enhancement, and living shoreline activities. This general permit applies to a habitat project, not to the associated dredging activities, and does not speak to the appropriateness of using dredged material to meet the habitat project objectives.

Dredging projects undertaken by the USACE-OP (i.e., Ring Island and Avalon) must receive a Federal Consistency Determination and a Section 401 WQC from the NJDEP; the USACE-OP applies to the NJDEP for these regulatory approvals. Because the USACE cannot issue permits to itself for its dredging projects, it undertakes a rigorous public Environmental Impact Assessment that evaluates projects for consistency with Section 404(b)1 of the Clean Water Act.

In order to address its National Environmental Policy Act (NEPA) requirements, in July 2014 the USACE issued an Environmental Assessment (EA) for "Channel Maintenance and Beneficial Use of Dredged Material Projects – New Jersey Intracoastal Waterway – Ocean and Cape May Counties, New Jersey." This NEPA EA evaluated the Ring Island and Avalon dredging and habitat enhancement projects. The USACE NEPA requirements for the Fortescue dredging and habitat enhancement projects were addressed as part of the Section 10 and Section 404 individual permit regulatory review of these projects.

For the three pilot projects (Ring Island, Avalon, and Fortescue), both the NJDEP and USACE regulatory review processes were coordinated and iterative. Prior to formally submitting permit applications to the NJDEP and USACE, the NJDEP-DFW worked with both agencies (as well as the U.S. Fish and Wildlife Service, NOAA, and the NJDOT-OMR) to develop the projects that met all the potential regulatory requirements. NJDEP-DFW started this coordinated process by requesting a Joint Permit Processing (i.e., pre-application) meeting with the USACE and NJDEP.

The proposed habitat enhancement projects had to meet two critical requirements:

- The regulatory agencies had to determine that the habitat was structurally or functionally in need of restoration or enhancement.
- The beneficial use of dredged material had to address the causes of stress to the habitat (i.e., provide ecological uplift).

If the regulatory agencies are satisfied that the permit applicant has demonstrated the habitat is stressed, then the beneficial use of dredged material can be evaluated and the habitat enhancement project can be designed to meet its objectives, consistent with all applicable regulations. The evaluation of dredged material acceptability includes consideration of both its physical and chemical characteristics (including contaminant concentrations), which requires a comprehensive sediment sampling and analysis plan (discussed below in Sediment Sampling and Testing).

The major components of the permit application submitted to NJDEP and USACE for the three pilot projects were:

- Analyses and evaluations, including a variety of qualitative and quantitative data, to support the conclusion that the proposed marsh enhancement/dredged material placement areas at each project site were stressed and needed enhancement or restoration
- A dredging plan identifying the source and volume of sediment to be dredged and how the sediment would be dredged and placed on the project sites, including the type and size of equipment to be used, dredge pipeline layout, etc.
- A habitat enhancement plan identifying the source and volume of dredged material to be placed, the target dredged material placement elevation, and the ecological elevation in the habitat enhancement areas. Habitat enhancement objectives and best management practices were developed to minimize potential adverse impacts of dredged material placement.
- A Coastal Zone Management Rules Compliance Statement
- Dredged material and marsh surface sediment data and evaluation (physical characteristics, bulk sediment chemistry, elutriate contaminant concentrations)
- A monitoring program for use during and after construction
- An adaptive management plan for use during and after construction, including provisions for planting and other methods to mitigate potential adverse impacts

NJDEP and USACE Permits

The dredging for the Ring Island and Avalon projects was conducted by the USACE-OP, which applied to NJDEP-DLUR for a Federal Consistency Determination and Section 401 Water Quality Certificate. The marsh enhancement and ENH creation components were managed by the NJDEP-DFW, which applied to NJDEP-ODST for the GP29 and Acceptable Use Determination for these projects (Table 9).

For the Fortescue project, the USACE-RB considered the dredging and the material placement to be one combined project requiring a single permit applicant. The dredging and dredged material placement were managed by NJDOT-OMR, and the marsh enhancement and dune and beach restoration components were managed by NJDEP-DFW. After much interagency discussion, NJDEP-DFW applied for and received the required permits – Coastal GP29 (currently redesignated as Coastal GP 24)/AUD – from the USACE-RB for both the dredging and dredged material placement (marsh, dune, and beach) components. NJDOT-OMR applied for and received a Waterfront Development Permit for the dredging projects (Table 9).

After the NJDEP and USACE permits were issued, storms in the winter of 2015–2016 eroded a section of the Fortescue Creek shoreline within the footprint of the dune restoration component. As a result, the dune restoration had to be redesigned and relocated, and the permits from both NJDEP-ODST and the USACE-RB had to be modified.

Ring Island: Although NJDEP-DLUR issued the GP29 for this project within two days after the initial application was submitted, the project development and regulatory review timeframes for the marsh enhancement and shorebird ENH projects is better represented by the USACE-OP application process (to NJDEP-ODST) for the CZM Consistency Determination and Section 401 WQC for the dredging (Table 9). Throughout the summer of 2014, multiple draft plans for dredging, dredged material placement, marsh enhancement, and ENH creation were developed by NJDEP-DFW and the USACE-OP, reviewed by NJDEP, and revised by NJDEP-DFW and the USACE-OP. Ultimately, NJDEP-DFW and the USACE-OP formally submitted the final permit applications to NJDEP-ODST, which approved them on August 7, 2014.

The dredged material to be placed on Ring Island was 96% fine sand, which NJDEP considers unlikely to be contaminated at levels of concern, so it was excluded from additional testing for contaminants (see Appendix G-Chapter III-C of the New Jersey Coastal Zone Management Rules, N.J.A.C. 7:7).

Table 9. State and Federal Permits Issued for the Ring Island, Avalon, and Fortescue Projects

Project	NJDEP*	USACE**	Notes
Ring Island Marsh and Elevated Nesting Habitat	• GP29 and AUD (combined); CZM Consistency and Section 401 WQC	Not required	• Dredging and dredged material placement conducted by USACE • NJDEP GP29 and 24 permits issued to NJDEP-DFW • NJDEP CZM and Section 401 WQC issued to USACE
Avalon Marsh	• 2014 Phase 1 Project – GP29 and AUD; CZM Consistency and Section 401 WQC • 2015 Phase 2 Project – GP24 and AUD; CZM Consistency and Section 401 WQC	Not required	

Fortescue Marsh Fortescue Beach Fortescue Dune	● Combined GP29 and AUD, CZM Consistency and Section 401 WQC issued to NJDEP-DFW for habitat enhancement ● Combined Waterfront Development Permit, AUD, CZM Consistency and Section 401 WQC issued to NJDOT-OMR for the dredging and material placement	Combined Individual Section 404 permit for dredging and habitat enhancement issued to NJDEP-DFW	● Dredging and dredged material placement conducted by NJDOT-OMR ● Dune restoration redesign and permit modification required due to shoreline erosion after permit issued ● Adaptive management plan required as a condition of the USACE permit

* NJDEP: New Jersey Department of Environmental Protection (state permit)
** USACE: U.S. Army Corps of Engineers (federal permit)
Note: During the project, the NJ CZM regulations were revised and NJ GP29 was renumbered to be GP24.

Avalon Phase 1: The time available to implement this project, from fall 2014 to winter 2015, was limited by the USACE-OP dredging schedule, because a number of dredging projects needed to be completed that winter. In addition, the results of testing the sediment in the channel to be dredged and the sediment of the marsh surface in placement areas A, B, and C raised concerns (see Phase 2: Project Design [Step 3: Review Design Constraints] and Sediment Sampling and Testing below). It took several weeks to design the Avalon Phase 1 project, develop the required documentation, and submit the final permit applications to NJDEP-ODST. The NJDEP-ODST review of the permit application package for this project, which included coordination with other NJDEP programs to ensure consistency with the CZM Rules, took approximately seven weeks.

Avalon Phase 2: It took approximately four months to design the Avalon Phase 2 project, develop the required documentation, and submit the final permit applications to NJDEP-ODST. To ensure consistency with the CZM Rules, the NJDEP-ODST review of the application included coordination with other NJDEP programs and was completed in approximately seven weeks.

Fortescue: As previously discussed, it took time to develop the interagency agreement that allowed NJDEP-DFW to apply for the required permits from the USACE-RB for both the dredging and habitat enhancement. Designing the three components of the Fortescue project and the associated dredging project, developing the required documentation, and submitting the final permit applications to NJDEP-ODST and the USACE-RB took about three months. The NJDEP-ODST review of the Waterfront Development Permit application for the Fortescue dredging project was completed in approximately two months, while review of the GP29 application for the three associated dredged material beneficial use projects (which included more extensive coordination with other NJDEP programs to ensure consistency with the CZM Rules) was completed in approximately three months. The USACE-RB review of the application for a combined dredging–habitat enhancement Section 404 individual permit was completed in about three and a half months. To evaluate the potential impacts of these alternatives to the adjacent marsh, the redesign of the dune restoration component considered a variety of alternatives and an additional topographical survey. This work and the development of the documentation to apply for a permit modification was completed in approximately six weeks. Since the dune redesign was closely coordinated with NJDEP-ODST and the USACE-RB, these agencies completed their review of the request to modify the permits relatively quickly, in approximately one month.

Sediment Sampling and Testing

To evaluate the suitability of the sediment for the various habitat enhancement and restoration projects, the team tested the sediment to be dredged. Both physical and chemical (including contaminant concentrations) characteristics were tested, which required the implementation of a comprehensive Sediment Sampling and Analysis Plan approved by NJDEP-ODST. Likewise, to ensure that the placed dredged material would have similar physical and chemical characteristics, samples of the marsh surface sediment were tested at each project site, except Ring Island.

Ring Island: The test of the sediment to be dredged from the NJIWW revealed that it was comprised of 96% fine sand; thus, testing for contaminants was not required. In addition, because the marsh enhancement project was a pilot to evaluate whether such coarse-grained sandy dredged material could be sprayed onto the marsh, the Ring Island marsh surface sediment was not sampled and tested.

Avalon Phase 1: Both the sediment to be dredged from the NJIWW and the marsh surface sediment in placement areas A, B, and C were predominantly fine-grained silt–clay. In addition, both contained several contaminants at different levels of concern. After extensive analyses, NJDEP-ODST determined that the sediment from one section of the NJIWW had contaminants, including dioxins and furans, at similar concentrations to those in the surface sediment of dredged material placement areas A, B, and C. Thus, the project team decided to limit dredging for the Avalon Phase 1 project to that one section of the channel and to limit marsh enhancement/dredged material placement to placement areas A and C.

Avalon Phase 2: Both the sediment to be dredged from the NJIWW and the marsh surface sediment in placement areas A, C, D, E, and F were predominantly fine-grained silt–clay. In addition, both contained several contaminants at different levels of potential concern. The main factor affecting the Avalon Phase 2 project was the presence of this suite of contaminants, particularly dioxins and furans, in both the sediment to be dredged from the NJIWW and the marsh surface sediment. After extensive analyses, NJDEP-ODST determined that the sediment from multiple sections of the NJIWW contained contaminants (including dioxins and furans) at similar concentrations to those in the surface sediment of placement areas A, C, D, E, and F. The sediment from each section of the channel was directed to that placement area (A, C, D, E, or F) with similar contaminant concentrations.

Fortescue: The sediment from both Fortescue Creek channel and the marsh surface were analyzed for physical and chemical characteristics. The dredged material was found to be heterogenous in grain size with distinct areas of predominantly coarser-grained sandy and finer-grained silt–clay material. Overall, contaminant concentrations in the sediment to be dredged were lower than those in the Fortescue marsh surface sediment, so contaminants were not a problem. The dredging and habitat enhancement projects were designed to use the finer-grained dredged material on the marsh and the coarser-grained dredged material on the dune and beach restoration components.

Permit Conditions

A significant factor impacting the dredging and dredged material placement projects was timing restrictions due to ecological factors. To minimize the adverse impacts to fish, shellfish, and birds, these "dredging windows" were included as permit conditions.

Ring Island: Dredged material placement was limited to time periods when colonial shorebirds were not actively nesting at the proposed placement areas and was subject to consultation with the NJDEP Endangered and Nongame Species Program. Nesting birds were present into August 2014 at the southern and western preferred placement locations (Fig. 9). So rather than not implementing the Ring Island projects in 2014, NJDEP-DFW decided to use the selected sites on the northern end of Ring Island for the dredged material marsh enhancement and ENH projects. Additional practical limitations to implementing the projects included the original two-year project implementation timeframe of the NFWF grant and the dredging schedule and availability of the USACE-OP's dredge contractor.

Avalon Phase 1: No ecological timing restrictions were placed on the Avalon Phase 1 project. However, the project had to be completed in fall 2014/winter 2015 due to USACE-OP scheduling and contractual limitations with the dredge contractor (see Phase 2: Project Design [Step 3: Review Design Constraints]).

Avalon Phase 2: To minimize impacts to nesting ospreys (*Pandion haliaetus*), gull-billed terns (*Gelochelidon nilotica*), and common terns (*Sterna hirundo*), dredging and dredging material placement for the larger Avalon Phase 2 project were prohibited from April 1 through August 31. USACE-OP dredged during the winter of 2015–2016.

Fortescue: To protect several marine species, including winter flounder (*Pseudopleuronectes americanus*) and Atlantic sturgeon (*Acipenser oxyrhynchus oxyrhynchus*), dredging and dredged material placement were originally prohibited from January 1 through September 30. This limited dredging to October 1 through December 31 each year. As a result of ongoing review by the NOAA Fisheries, in 2016 the dredging and material placement prohibition for winter flounder was rescinded, reducing the restriction for dredging to April 15 through September 15.

Although the Avalon Phase 2 and Fortescue projects were designed to be completed within the allowable time periods specified in the permits, inclement weather and equipment problems affected the construction of these projects (see Phase 5: Project Construction).

Additional permit conditions included best management practices designed to limit the dispersal of the dredged material from the placement areas to (1) increase the probability of placing dredged material to the established target elevations and (2) protect the marsh, particularly creeks, outside the placement areas. In addition, a permit condition restricted dredged material placement when the placement areas were not covered by surface water (i.e., at lower tides). This could have had a significant impact on the dredging and dredged material placement, but in actual practice it did not.

As a condition of the permit for the Fortescue dredging/habitat enhancement project, the USACE-RB required an adaptive management plan and associated monitoring program. While NJDEP did not require a monitoring program for the Ring Island and Avalon Phase 1 projects, it did require monitoring of the Avalon Phase 2 and Fortescue projects. A comprehensive monitoring program was a major requirement of the NFWF grant and was implemented for all the projects (Phase 7: Project Assessment - Monitoring and Data Evaluation). Finally, an adaptive management approach was used throughout the projects.

Phase 4: Bidding and Contracting

The Ring Island and Avalon projects were completed as part of a contract that the USACE-OP awarded for maintenance dredging to remove critical shoals from the NJIWW following Hurricane Irene and Superstorm Sandy. A lease-of-plant contract was utilized whereby the dredge contractor bids required line items and then conducts work by priority assignment along the channel, paid by the day and not according to the specific quantity of sediment dredged. This type of contract allowed greater flexibility for the USACE-OP and the project team to adaptively manage dredged material placement on the marshes, with USACE-OP absorbing the costs of downtime.

The Fortescue beneficial use projects were managed by NJDOT-OMR. Its engineering contractors created the engineering and dredging design plans, while the construction specifications were prepared by the NJDOT-OMR design team. The NJDOT-OMR solicited bids for construction and the contract was awarded to a NJ-based dredging company. Under the NJDOT-OMR contract, the contractor was paid by the volume (cubic yard) dredged and placed and had very specific requirements for the dredging and material placement, which made adaptive management of the construction difficult.

Phase 5: Construction

After the marsh enhancement design was finalized and the permits for the dredging and marsh enhancement were obtained from the regulatory agencies, construction began. This phase varied somewhat among the sites, but for documentation purposes, it involves three stages: (1) pre-placement, (2) dredging and dredged material placement, and (3) post-placement.

The pre-placement stage included several phone calls and in-person meetings of the marsh team to discuss construction before the official pre-construction meetings. Discussions focused on pre-construction activities and site preparation. The subsequent pre-construction meetings included both the marsh team and the dredging team and covered the placement of dredged material on the marsh. Given that the marsh enhancement technique was new to the marsh team and that the dredged material placement technique was new to the dredging team, these meetings were a critical first step in the construction process. The other major component of the pre-placement stage was site preparation, which was site specific but generally involved installing containment, setting grade stakes, and staging the pipes for dredged material placement.

For all the projects, the dredging and dredged material placement stage (i.e., actual construction) consisted of the simultaneous hydraulic dredging of sediment from the channel, pumping the dredged material to the project site, and placing the dredged material onto the marsh. Tentative dredging and dredged material placement strategies were determined beforehand, but placement was predominantly performed using hands-on, real-time adaptive management. The keys to successfully implementing this stage of construction were (1) the marsh team's ability to constantly observe dredged material placement as it was happening, (2) clear communication between the marsh team and the dredging team, and (3) the ability to adjust the dredging and material placement during construction to achieve the target elevations. During dredged material placement, the marsh team had an inspector on the marsh and the dredging team had an inspector on the dredge. Communication between the teams occurred daily, and project status meetings occurred weekly.

The post-placement stage of construction was the short period immediately after cessation of dredging and placement. It involved a final inspection by representatives of both the marsh and dredging teams, clean-up of the project site, and as-built elevation surveys of the dredged material placement areas.

Ring Island Marsh Enhancement Project

This was the first marsh enhancement project implemented under the NFWF grant. The goal of the project was to test a method for placing a thin layer of sandy dredged material on to the marsh. The dredging team sprayed the material on the marsh surface in two areas, attempting to place homogeneous 3- or 6-inch thick layers. In addition, on a 1-acre section of marsh, an ENH was constructed for colonial shorebirds (Fig. 2). The dredged material came from a small stretch of the NJIWW maintained by the USACE-OP. The dredging and dredged material placement were implemented by a NJ-based dredging company overseen by the USACE-OP. The placement of dredged material on the marsh was overseen by the marsh team.

Ring Island Marsh Enhancement Project Construction Summary

Placement area: 0.89 acres (two areas)
Placement volume: 1,000 cubic yards
Placement depth: Average 6 inches
Sediment composition: 96% fine sand
Containment type: None
Distance from NJIWW to marsh edge: 2,000–3,000 feet
Dredge type: 14-inch (inside diameter of discharge pipeline) cutterhead dredge
Placement technique: Spray from discharge pipe mounted on a pontoon at the marsh edge
Shore construction machinery: None
Timing of placement: August 2014

Pre-placement: To communicate the project objectives and to refine the plans for dredged material placement, the marsh team and dredging team held a pre-construction meeting. Given the composition (96% fine sand) of the dredged material and topography of the marsh, the teams determined that containment was not needed.

Construction was originally scheduled for September 2014; however, dredging was moved to August to fit the USACE-OP dredging schedule for the NJIWW. This was a problem because, in August, laughing gulls (*Leucophaeus atricilla*) were still nesting on parts of the Ring Island marsh, and their chicks had not yet fledged. In response to this schedule change, the marsh team assessed the three areas for nesting chicks (Fig. 9) and selected the one area without chicks for marsh enhancement.

To prepare the site, the team marked the outer limits of the dredged material placement areas and installed grade stakes. Each grade stake was marked with a line to indicate the target elevations of 3 or 6 inches above the marsh surface.

Dredging and dredged material placement: During a few days in August 2014, the dredging and dredged material placement was completed. Sediment was hydraulically dredged from the NJIWW, transported as a slurry (a mix of sediment and bay water) and sprayed on the marsh (Fig. 20). The discharge end of the dredge pipe was mounted on a pontoon that was stationed at the edge of the marsh. The pipe was mounted at approximately a 45-degree angle to spray the dredged material in a high arc above and onto the marsh. The discharge pipe was also outfitted with a reducer, which narrowed the outlet diameter and increased the velocity of the slurry, allowing it to reach farther into the marsh.

Figure 19. *This photo shows the dredged material spray operation at the Ring Island marsh enhancement project.*

Almost immediately after placement of the dredged material began, the project team realized that simply spraying the slurry did not effectively spread the sand over the marsh. Initially, the dredge contractor tried to spread the material evenly by alternating between spraying the material and spraying water onto the same spot, but this did not accomplish the desired effect. Next, the dredge contractor tried increasing the velocity at the pipe outlet by compressing the reducer's diameter. This increased the spray distance to a maximum of about 150 feet from the marsh edge, allowing the slurry to cover more of the marsh platform, but it did not result in more even dispersal of the sand across the marsh platform.

Because of the way the dredge pipe reducer was compressed and due to the weight of the sand in the slurry, the spray separated into two streams and the dredged material was placed unevenly. Sand accumulated on the marsh directly under the two streams, leaving an area between them in which no material was placed. In an attempt to correct this, the dredge contractor tried moving and rotating the pontoon on which the dredge pipe was mounted, but movement of the pontoon was limited, especially during lower tide.

As a result of these difficulties and the high sand content (96% fine sand) of the dredged material, placement was patchy and the depth, or thickness, of placed sediment was not uniform as originally planned. The sand fell out of suspension rapidly and did not disperse across the marsh platform. The only way to achieve an even application of dredged material was to (1) continually move the dredging discharge pipe, which was not possible due to the limited mobility of the pontoon, or (2) grade the sand after it was placed. Grading would have required using heavy machinery on the marsh, which could have negatively impacted it.

In total, on the Ring Island marsh, about 1,000 cubic yards of sand was placed at an uneven depth in two small, irregularly shaped areas (0.40 and 0.49 acres) (Fig. 21).

Shortly after construction was completed, the USACE-OP performed an as-built survey of the site and removed the grade stakes. The marsh team measured and recorded the depth of the placed sand across the placement areas. The data showed that although the average placement depths were within the 3- and 6-inch targets, placement was uneven, ranging from 0 to 9 inches.

Figure 21. *Dredged material was placed on the Ring Island Marsh Enhancement site (left). An aerial view shows the placement area TLP-1 after placement (right).*

Ring Island Elevated Nesting Habitat Project Construction Summary

Placement area: 1 acre
Placement volume: 6,000 cubic yards
Placement depth: Up to 6 feet after grading (variable)
Sediment composition: 96% fine sand
Containment type: Straw bales, silt fence, and sand berm
Distance from NJIWW to marsh: Approximately 3,500 feet
Dredge type: 14-inch cutterhead dredge
Placement technique: Direct pumping
Shore construction machinery: CAT 459 tracked front-end loader
Timing of placement: August 2014

Figure 22. *Dredged material was placed on the Ring Island Enhanced Nesting Habitat site.*

Pre-placement: Prior to construction, the marsh team and dredging team met to review project objectives and to refine the plans for building the ENH. Given the composition of the dredged material (96% fine sand) and topography of the project site, they determined that containment measures were not needed. Site preparation consisted of marking the outer limits of the ENH dredged material placement area.

Dredging and Dredged Material Placement: Construction of the Ring Island ENH was completed during two weeks in August 2014. This project was built by cribbing the dredge discharge pipe in the approximate center of the site and directly pumping the hydraulically dredged sand onto the site (Fig. 22). As the sand slurry dewatered and accumulated, the cribbing was moved to direct the slurry to different sections of the placement area (Fig. 23). In addition, a baffle plate was attached to the end of the dredge discharge pipe to help spread the sand slurry more evenly. A small-tracked front-end loader moved the sand both during pumping and after dewatering to grade the sand into the final mound with the desired shape, height, and contours (Fig. 24).

The team expected that the dredged sand would rapidly fall out of suspension and containment measures would not be needed. However, this was not the case. Within hours after placement started and established a small mound of sand on the site, the slope of the mound was steep enough to cause some of the sand slurry to erode into adjacent tidal creeks. The team responded by enclosing the perimeter of the ENH with a silt fence and straw bales. As the sand mound grew and the slope became steeper, they also needed to construct a sand berm around the project area to adequately contain the dredged material. However, the team had to maintain an opening in the perimeter containment to allow dewatering, so dredged material flowed out of this opening and deposited onto a small area of the marsh south of the site.

Figure 23. *Containment measures were placed around the Ring Island Enhanced Nesting Habitat site.*

Figure 24. *A front-end loader was used to move the sand during pumping and after dewatering.*

Post-placement: Shortly after construction, the USACE-OP performed an as-built survey of the site and the dredging contractor removed the silt fence and sand berm. The team expected that the straw bales would decompose, but because mats could smother marsh vegetation and attract predators, NJDEP-DFW later removed the bales.

Avalon Phase 1 Marsh Enhancement Project

In late 2013, the Avalon project site was identified as a candidate for marsh enhancement via beneficial use of dredged material. The goal of this project was to enhance the marsh by filling large, expanding pools and providing a thin layer of dredged material over the surrounding marsh platform. The material to be dredged from the NJIWW contained a much lower percentage of sand than the sediment used at

Ring Island, so Avalon was a very different project in nature. The dredging and dredged material placement of both projects was conducted by the same dredging contractor, with oversight by the USACE-OP. The marsh team collaborated with USACE-OP to oversee the placement of dredged material on the marsh.

Avalon Phase 1 Marsh Enhancement Project Construction Summary

Placement area: 6.9 acres
Placement volume: ~6,000 cubic yards
Placement depth: Average 6 inches (excluding pools)
Sediment composition: 49% silt, 34% fine sand, 16% clay
Containment type: Partial containment with 6” diameter coconut-fiber logs
Distance from NJIWW to marsh edge: 3,500 feet
Distance from marsh edge to placement area: 100–150 feet
Dredge type: 10-inch cutterhead dredge
Placement technique: Spray from discharge pipe
Shore construction machinery: None
Timing of placement: December 29, 2014 to January 7, 2015

Pre-placement: During the pre-placement stage of construction of the Avalon Phase 1 project, the marsh and dredging teams had many conference calls and meetings to discuss how dredged material placement would be implemented. Dredged material placement areas A, B, and C had already been identified and staked out during the site selection process (Fig. 3), and area B was ultimately eliminated as a placement option during the project design phase (Phase 2: Project Design).

To minimize the potential for dredged material to run off placement area C and into the adjacent bay, 6-inch diameter coconut-fiber logs were installed in a few low-lying areas of the marsh and creeks (Fig. 25). To minimize the dispersal of dredged material beyond specified boundaries, additional logs were brought on-site for use as needed (i.e., adaptive management) during dredged material placement at both placement areas. To indicate elevations of 3 and 6 inches above the marsh surface, the marsh team installed grade stakes in the placement areas (Fig. 26).

At placement area C, the dredge discharge pipe was staged at the edge of the marsh, propped on a large float in the water with about 50 feet of pipe extending into the marsh. The pipe was laid directly on the marsh surface and a spray nozzle was attached to the pipe with an elbow (Fig. 26). At placement area A, the dredge pipe was extended farther into the marsh and cribbed into place.

Dredging and Dredged Material Placement: Avalon Phase 1 dredging and dredged material placement began on December 29, 2014, and these activities were completed on January 7, 2015. Representatives from the marsh team were stationed on the marsh, and the dredging team was stationed on the dredge. As soon as placement began at placement area C, the marsh team realized that the dredge pipe outlet was located much too close to the edge of the marsh. Because the dredged material was predominantly fine-grained, the slurry quickly ran off the marsh edge into nearby creeks and the bay, so dredging was stopped. To ensure that the slurry spray would land in the large pool, the dredge discharge pipe was moved farther into the marsh and the pipe outlet was elevated on a wooden crib. To prevent the slurry from running back toward the water, coconut-fiber logs were installed in a line behind the dredge pipe outlet. After spraying resumed, the marsh team noticed that any slurry that landed outside the pool overflowed from the pool, followed marsh drainage paths into creeks. To protect the creeks and to keep the dredged material within the placement area, they added containment to block these drainage paths. To help direct the slurry toward the pool, they added coconut-fiber logs and adjusted the angle of the dredge pipe outlet.

Figure 25. *At Avalon, a coconut-fiber log containment was installed to minimize the dispersal of the dredged material.*

Figure 26. *At Avalon, grade stakes helped indicate elevations about the marsh surface during dredged material spraying.*

The placement of dredged material in placement area A was implemented using the lessons learned from work at placement area C. Thanks to those lessons, the dredge pipe outlet was cribbed in place farther into the marsh and angled so that the spray landed in the large pool (Fig. 27). To minimize the dispersal of the slurry into nearby creeks, coconut-fiber logs were placed behind the dredge pipe outlet and in low-lying areas. To determine whether the placement in area A was increasing turbidity in the creeks, the team sampled the discharge water around the placement area and in creeks to which it was draining. By the time the discharge water passed through the containment and the narrow strips of tall-form *S. alterniflora* that lined the creek banks (Fig. 28), its turbidity was similar to that of the bay and neighboring creeks. The containment and the creek-bank vegetation, combined, effectively trapped suspended sediment before the discharge water reached the creeks.

Post-placement: In March 2015, the USACE-OP attempted an as-built survey of the Avalon Phase 1 project site. However, large portions of both placement areas were still dewatering and unconsolidated, making it very difficult (and dangerous) to walk there. Therefore, the surveyors could not completely survey either placement area. To document the application depth (thickness) and to verify the prior observation that the dredged material sorted (by grain size) during the placement process, the marsh team measured the placed material. Their measurements showed that in both areas, the marsh plain received an average of 6 inches of material. Placement depth in the pool areas ranged from 6 inches to more than 36 inches. In addition, the sediment analysis confirmed that the sand component of the material was deposited nearer to the place where the spray contacted the marsh (largely in the pools) and the finer-gained material (silt and clay), which stayed in suspension longer, was transported farther across the marsh plain.

Figure 27. *At Avalon, dredged material spraying in placement area A used the lessons learned from work at placement area C.*

Figure 28. *At Avalon, coconut-fiber log containment was installed to minimize the dispersal of the dredged material.*

Avalon Phase 2 Marsh Enhancement Project

After the Avalon Phase 1 project was completed in early 2015, it was clear that a larger marsh enhancement project could be implemented at the site using different construction methods. In addition, after observing how much the dredged material consolidated in Avalon Phase 1, the team decided to add more dredged material to areas A and C, as well as to several additional sites.

The Avalon Phase 2 placement areas selected (Areas A, C, D, E, and F) were large, expanding pool–panne complexes typical of the marsh on Shark Island. There was insufficient time to place dredged materials in Areas G, H, and I.

The design of Avalon Phase 2 focused on target dredged material placement and ecological elevations. This was a different focus from the Ring Island and Avalon Phase 1 projects, which attempted to place material to specific depths. The dredged material available for use in the Avalon Phase 2 project had slightly higher percentages of silt (53%) and clay (19%) than the Avalon Phase 1 material (49% silt, 16%

clay). Therefore, a condition of the permit for the Avalon Phase 2 project was the extensive use of containment. With oversight from the USACE-OP, the dredging contractor dredged the NJIWW. The marsh team oversaw the placement of dredged material on the marsh by the contractor.

Avalon Phase 2 Marsh Enhancement Project Construction Summary

Placement area: 45 acres
Placement volume: ~49,300 cubic yards
Placement depth: Average 9 inches (on marsh areas but not pools)
Sediment composition: 27% sand, 53% silt, 19% clay
Containment type: Full containment with (6- to 20-inch diameter) coconut-fiber logs
Distance from NJIWW to marsh edge: 3,500 to 5,000 feet
Distance from marsh edge to placement site: 150 to 875 feet
Dredge type: 14-inch cutterhead dredge
Placement technique: Spray and direct pumping
Shore construction machinery: Marsh Master and trailer
Timing of placement: November 23, 2015 to February 20, 2016

Pre-placement: During the pre-placement stage of the Avalon Phase 2 project, the marsh team and dredging team discussed how dredged material placement would be conducted, using both the lessons learned from the Ring Island and Avalon Phase 1 projects and the new permit conditions for the Avalon Phase 2 project. In the discussions, the teams determined exactly where on the marsh the dredged material would be placed, agreed on the order of operations for the dredging and placement, and finalized the target placement elevations for the dredged material. These meetings ensured that the dredge contractor fully understood the objectives and critical design elements of the project.

Site preparation was much more extensive for the Avalon Phase 2 project than for Ring Island or Avalon Phase 1. At four of the five dredged material placement areas, containment was installed around the full perimeter. Placement area E was only partially contained because some of the surrounding marsh was at an elevation equal to or greater than the target dredged material placement elevation, forming natural containment. Containment was critical to ensuring that the target dredged material placement elevations were effectively and efficiently achieved (by providing adequate time for the dredged material to settle within the placement areas) and to ensure that the dredged material did not disperse into creeks.

To guide containment installation, a surveyor staked out the perimeter of each area. For containment, the team used coconut-fiber logs ranging from 6 to 20 inches in diameter, depending on the thickness of the planned fill in a given location (the difference between the elevation of the marsh and the target dredged material placement elevation; Fig. 29). For the Avalon Phase 2 project, a crew of 8–10 people spent five weeks installing 15,300 linear feet of containment. The coconut-fiber logs were transported across the marsh and around the staked-out perimeter of each placement area using a low-pressure Marsh Master with a trailer (Fig. 30), the tracks of which inadvertently created unvegetated paths around the placement areas (Fig. 31).

Figure 29. *This photo of Avalon Phase 2 shows the containment area immediately after installation.*

Figure 30. *A Marsh Master and trailer were used to transport the coconut-fiber logs for containment.*

Figure 31. *At Avalon Phase 2, the Marsh Master used to transport the coconut-fiber logs inadvertently created tracks in the marsh.*

To guide dredged material placement in the Avalon Phase 2 project, grade stakes were installed at the site, marking the target dredged material placement elevation. The main purpose of the grade stakes was to avoid placing dredged material to an elevation greater than the target elevation. When dredged material reached the specified elevation, operations ceased, and the dredge pipe outlet was moved to a new location within the placement area. As this was a pilot project, the NJDEP-ODST did not set any regulatory thresholds for the target elevation, and there was no regulatory requirement to meet the target elevations.

Dredging and Dredged Material Placement: The Avalon Phase 2 dredging and dredged material placement began on November 23, 2015 and continued until February 20, 2016. During this time, dredging and placement was conducted 24 hours per day and six days per week. During daylight hours, a representative of the marsh team inspected placement on the marsh, and a USACE-OP inspector oversaw the dredge plant; the two teams communicated by radio and cell phone. At the beginning of each day of placement, the marsh team member on duty contacted the dredge operator or the USACE-OP project inspector to review the operations plan for the day, which had been developed the previous night, and to discuss any potential issues with wind and tide conditions and the condition of the placement area. For example, if a high tide was expected to overtop containment, placement would be prohibited for some time before and after high tide, as any dredged material placed during high tide would not be adequately contained.

During placement, the marsh team member walked around the placement area and communicated issues to the USACE-OP inspector. The most frequent reason for communication was that the dredged material was overtopping placement area containment. When this happened, the marsh team member would ask the USACE-OP to stop dredging in order to adjust the containment, dredge pipe outlet position, or dredged material placement operation. If overtopping was limited to a small stretch of containment and material still needed to be placed near the pipe outlet, dredging would be paused until additional containment was added and, if needed, the pipe outlet was adjusted to change the direction of flow, which would reduce pressure on the affected section of containment. If containment overtopping was extensive and the target dredged material placement elevation was nearly achieved near the pipe outlet, placement would cease to allow the material to dewater and consolidate, after which more material would be added (“interval pumping”).

At the end of each day, the on-site marsh team member would assess the condition of the placement area and, with the dredging team, develop a schedule for dredging and placement for the next 12–15 hours (i.e., overnight and into the next morning). Depending on conditions in the placement area, one of three options would be implemented: (1) dredging would continue through the night (provided there was no threat of overnight high tides over-topping or breaching the containment), (2) dredging would not be conducted through the night (usually because of the high potential to overtop or breach containment), or (3) "interval pumping” would be used.

Each week, the marsh team and dredging team met to review recently completed work, assess current work needs, and formulate the next steps considering the site constraints and field conditions. These meetings helped the dredging contractor understand how the marsh team used observations of the marsh to make decisions. These meetings also allowed the two teams to reach consensus and jointly develop solutions and plans so they could achieve their main objectives of careful placement of dredged material on the marsh (marsh team) and efficient dredging and placement (dredging team).

The dredge pipe outlet was fitted with either a spreader plate or a spray nozzle (Fig. 32). By reducing the energy of the sediment slurry as it was discharged, the spreader plate dispersed the slurry in multiple directions. Meanwhile, the spray nozzle increased the velocity of the slurry from the outlet so that it could be sprayed farther. In both cases, the pipe outlet was cribbed about 3–4 feet above the marsh surface.

Within each dredged material placement area, the dredge pipe outlet was positioned near the edge of a large pool (Fig. 33). If the dredged material was overtopping its containment and overtopping could not be stopped, the dredge pipe was moved within the placement area. In each placement area, the outlet usually needed to be moved two or three times to achieve the target elevation across the full extent of the area.

Figure 32. *The dredge pipe outlet at Avalon, Phase 2, was fitted with either a spreader plate (left) or a spray nozzle (right).*

In most cases, placed material reached the target dredged material placement elevations near the dredge pipe outlet before it reached that target in areas farther from the outlet. This outcome was not expected when the Avalon Phase 2 project was designed. Given the large proportion of silt and clay in the dredged material, the team expected that the dredged material would disperse evenly within the placement areas. However, the pools contained “bathtubs” (especially deep areas) that tended to hold the slurry and prevent it from dispersing. Once a "bathtub" was full, the dredged material spilled out though its lowest point, which was either predictable (e.g., an existing marsh drainage path) or unpredictable (with the slurry flowing along the path of least resistance created around mounds of dredged material). Frequently, the drainage path led directly to the containment, causing it to be overtopped. Although moving the pipe outlet more frequently could have resolved this problem, frequent moves were not possible for the reasons discussed below.

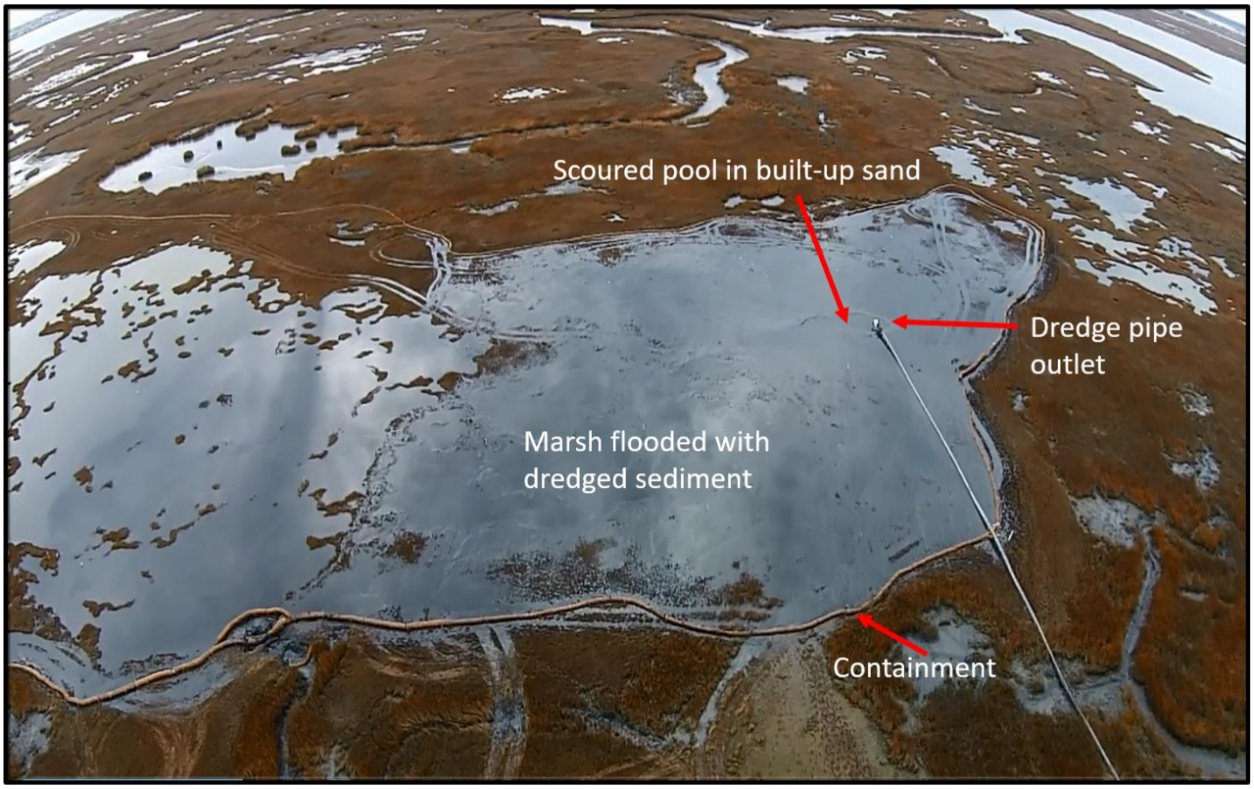


Figure 33. *This aerial view shows the dredged material being placed in the Avalon Phase 2 project. Source: TNC*

The accumulation of sand around the dredge pipe outlet often limited the dispersal of dredged material in placement areas. The sand fraction of the dredged material rapidly segregated and fell out of suspension, creating a mound near the dredge pipe outlet. Then, the dredged material carved into this sand mound, creating a pool with a berm edge (Fig. 33). Eventually the slurry in the pool broke through the berm and was funneled in one direction, which usually limiting its dispersal. Again, moving the dredge pipe outlet more frequently could have resolved this problem.

However, moving the dredge pipe was difficult, which limited the number of pipe outlet locations within each dredged material placement area. The location of the pipe and the ability to move it frequently were restricted by a number of factors:

- the amount (length) of available pipe
- the rigidity of the pipe, which was made of high-density polyethylene that could not be bent at sharp angles
- the marsh landscape (the pipe was moved by a Marsh Master, which could not traverse all areas, especially large deep pools)
- the short window of time for moving the pipe (a boat supported and moved the pipe at the marsh edge, which was only accessible at high tide)
- the difficulty of moving the pipe within unconsolidated dredged material, and
- the high cost of pausing the dredge (i.e., “downtime”) as the pipe was moved.

The limited mobility of the pipe greatly affected day-to-day operations and the outcome of the dredged material placement. Ultimately, the placement areas contained sandy humps near the dredge pipe outlets and predominantly silt–clay at lower elevations that were farther from the outlets. Thus, the placement areas varied in elevation, grain-size composition, dewatering rates, and placed volumes.

Construction at the Avalon Phase 2 project during the winter was also problematic. For example, at placement area C, only one pipe outlet location was used because Winter Storm Jonas hit during placement. The storm-driven waters removed half the perimeter containment. Because it was not possible to re-install containment, work in this placement area ceased. In addition, the storm waters sank one of the dredge contractor's boats and damaged the dredge plant's engine, halting work for about two weeks while repairs were made.

During the project, team members generated daily field reports and took photographs of the work in progress. GreenVest, a marsh team member, periodically provided updates to the team regarding the overall construction process, methods, and progress to date.

Post-placement: With the USACE-OP and its dredge contractor, the marsh team inspected the site immediately after placement was completed. Next, the dredge contractor removed as much of the wood cribbing used for the dredge pipe as possible. However, unconsolidated dredged material made access difficult and dangerous, so some pieces could not be removed from the placement area and had to be removed by the marsh team at a later date.

Sediment placement resulted in an average increase of 9.4 inches in marsh elevation across the entire area, excluding areas that started as pools. The placement depth on the marsh platform ranged from 0.9 to 19 inches and exceeded 36 inches in former pools.

Another important component of the post-placement period in the Avalon Phase 2 project was the completion of as-built topographic surveys of each dredged material placement area. Ideally, surveys are completed almost immediately after placement to determine the bulking factor and the extent of consolidation. Originally the project team planned to complete these surveys on foot, using RTK-GPS survey equipment. However, because the material was still unconsolidated, the placement areas were difficult and dangerous to traverse, and the team quickly realized that surveying was not a viable option in placement areas. Fortunately, in March 2015, the USACE-Engineer Research and Development Center (ERDC) was able to survey the site using ground-based LiDAR survey equipment (a RIEGL VZ-400 V-Line 3D Terrestrial Laser Scanner). This equipment produces a high density of highly accurate elevation measurements. However, a major limitation of this survey technique is the inability to measure through water to ascertain the elevation of the land below, which resulted in data gaps. In addition, using different survey equipment (RTK-GPS before construction and LiDAR after construction) added variability to the data, making it difficult to perform between-year comparisons.

Fortescue Project Marsh Enhancement Component

The pre-placement stage of the construction phase of this project began on January 29, 2016 (Table 3). Both the design and construction of the Fortescue marsh enhancement were based on the lessons learned from construction of the Avalon Phase 2 project, particularly those lessons associated with the placement of fine-grained dredged material and the limited mobility of the dredge pipe. Originally, the design of the Fortescue marsh enhancement involved a complex, branching system of pipes and valves (Fig. 19). This would have enabled the dredging team to place material in different parts of the marsh, without moving and repositioning the dredge pipe (see Phase 2: Project Design). In theory, this design would avoid the costly downtime that was experienced during the Avalon Phase 2 project when discharge was stopped to prevent containment overflow and reposition the dredge pipe. However, at Fortescue, the dredge discharge pipe was not installed as designed (see below).

For the Fortescue marsh enhancement, the dredging and dredged material placement was performed by a New Jersey-based contractor with oversight by NJDOT-OMR. The oversight of the dredged material placement on the marsh was performed by Princeton Hydro, a member of the marsh team.

Fortescue Marsh Enhancement Component Construction Summary

Placement area: 6.6 acres
Placement volume: 6,490 cubic yards
Placement depth: Average 6 inches
Sediment composition: 70% sand, 15% silt, 15% clay
Containment type: Full containment with Filtrexx SiltSoxx™
Distance from channel to marsh: 1,000 to 1,280 feet
Distance from marsh edge to placement site: 400 to 3,050 feet
Dredge type: 12-inch hydraulic cutterhead dredge (12-inch diameter intake pipe and 12-inch diameter discharge pipe)
Placement technique: Direct pumping
Shore construction machinery: Marsh Master, skid steer, excavator
Timing of placement: March 5 to March 20, 2016

Pre-placement: During the pre-placement stage, as NJDOT-OMR prepared the bid package for dredging and dredged material placement, the marsh team provided input. Specific areas of concern were limiting heavy equipment on the marsh, installing adequate containment, not exceeding target dredged material placement elevations, marsh team oversight of dredged material placement, and adding elevation while avoiding the creation of upland. After the dredger was under contract, the marsh team reiterated the goals of the project and the sensitive nature of the marsh to the dredging team.

In January 2016, the site was prepared by the dredge contractor or another NJDOT-OMR subcontractor overseen by a member of the marsh team. The site was prepared by installing containment, laying the dredge pipe, and installing grade stakes. The project design called for complete containment around the perimeter of each placement area. The team installed an inner perimeter and a second, outer perimeter, both consisting of Filtrexx SiltSoxx™ fabric tubes filled with hardwood chips (Fig. 34). Like the coconut-fiber logs used at Avalon, the Filtrexx SiltSoxx™ contained the dredged material as the suspended sediment settled out and allowed water to drain through, filtered by the fabric and woodchips. Although the marsh team had requested fully biodegradable Filtrexx SiltSoxx™ (cotton tubes), the manufacturer could not provide the required quantity prior to construction, so photodegradable polypropylene geotextile tubes were used instead. The inner perimeter consisted of 12-inch diameter tubes, most of which were stacked in a pyramid to the appropriate target elevation. The outer perimeter consisted of a single layer of 6-inch diameter tubes. Due to their buoyancy, the stacked tubes slipped out of alignment at channel crossings during high tide.

Because each Filtrexx SiltSoxx™ tube was so long (100 feet) and heavy (1500 pounds), they could not be moved by hand. Therefore, a Marsh Master fitted with a trailer was used to transport the tubes and aid in their installation. During installation, the Marsh Master used the same route across the marsh repeatedly, causing unanticipated damage (Figs. 35 and 36).

Figure 34. *At Fortescue, the team installed Filtrexx SiltSoxx™ containment in two concentric rows along the perimeter of the dredged material placement areas.*

Figure 35. *At Fortescue, damage to the marsh is evident in the right foreground area (darker ground) of this picture. This was caused by repeated travel and other activity over the same area.*

Grade stakes were installed in a 100 x 100-foot grid across the dredged material placement areas. Each grade stake was marked at the target dredged material placement elevation and at 6 inches above and below this elevation. Due to their experience with the Avalon Phase 2 project, the marsh and dredging teams concluded that it would be difficult to consistently place dredged material at more than one elevation (i.e., the high- and low-marsh target elevations specified in the design plans). Therefore, they

Figure 36. *This long pool was created accidentally by driving an excavator on the marsh at Fortescue.*

decided to use a single target dredged material placement elevation for the entire marsh: 3.3 feet NAVD88, which was the elevation at the upper end of the range of high marsh bio-benchmarks.

Dredging and Dredged Material Placement: From March 5 to March 20, 2016, the dredging and dredged material placement at the Fortescue marsh continued for 12 hours per day and 6 days per week. During this project component, material was placed in three general areas. A marsh team inspector from Princeton Hydro was always present on the marsh and the NJDOT-OMR resident engineer was stationed at an office in a nearby marina during the operation. The marsh team's inspector communicated to the dredge contractor through the NJDOT-OMR engineer. In general, the NJDOT-OMR resident engineer and inspectors were focused on maintaining the dredging schedule and maximizing the volume of dredged material placed, while the marsh team inspectors were focused on the marsh enhancement objectives of the project. To document work progress, the dredging team created daily field reports with photographs, and Princeton Hydro periodically updated to the marsh team about the overall construction process, methods, and progress.

The design plans, as permitted by the NJDEP-ODST and USACE-RB, consisted of a branched system of dredge pipes, valves, and sections made of more flexible pipe to allow easy movement (see Phase 2: Project Design). Instead of using this design, six branches were installed utilizing y-valves (Fig. 37) and the flexible pipe was never installed. The average length of pipeline across the marsh was 3,050 feet.

Figure 37. *This y-valve allowed the team to change the location of sediment placement without moving the pipe. Photo from Dewberry Engineers Inc., courtesy of NJDOT.*

Placement started in dredged material placement area 2 (Fig. 4). Immediately, the project team realized that the higher-than-expected amount of sand in the dredged material was a problem (Fig. 38). The sand mounded and blocked the dredge pipe outlet, which was lying directly on the marsh surface (in contrast with Avalon, where it was raised off the surface with cribbing). To resolve this problem, the dredge contractor used an excavator on the marsh to raise and move the pipe as material was being pumped (Fig. 39) and to knock down high mounded areas.

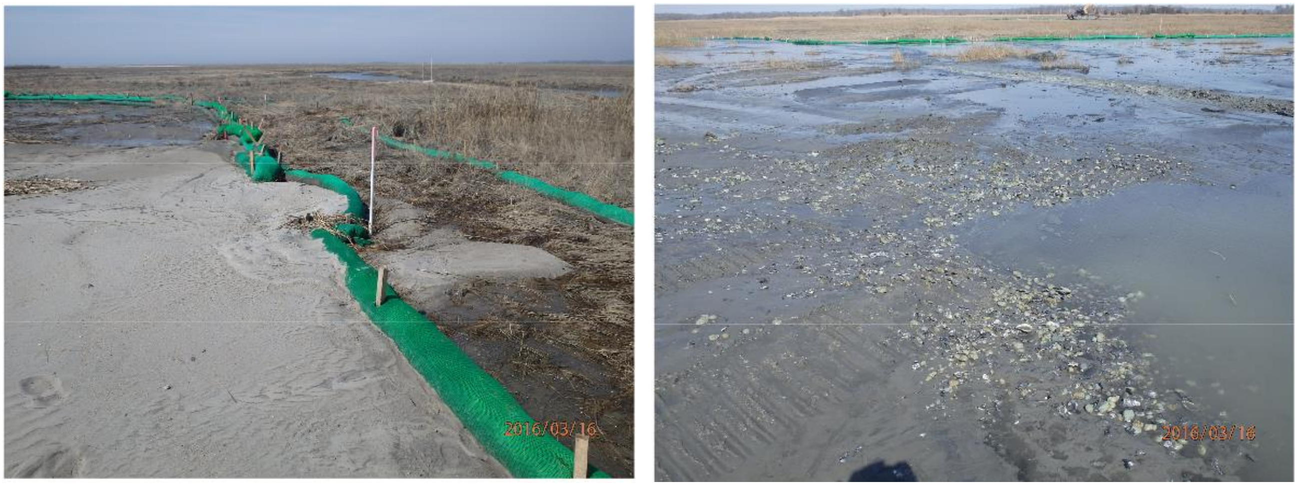


Figure 38. *The dredged material was sandier than expected at Fortescue.*

Figure 39. *At Fortescue, an excavator held and repositioned the dredge discharge pipe outlet.*

As at Avalon, the finer-grained dredged material flowed to the edge of dredged material placement area 2 and began to overtop the containment. To resolve this issue, the dredge contractor did not use the system of pipes and valves as originally intended. Instead, dredging was paused while the Filtrexx SiltSoxx™ containment was reinforced, sediment dewatered, and the dredge pipe outlet was moved.

After the work in placement area 2 was complete, placement began in placement area 1 (Figs. 4 and 40). Again, the pipe-and-valve system was not fully utilized, and sand mounding and limited pipe mobility were problematic. Because progress on the marsh was too slow, NJDOT-OMR redirected dredging and dredged material placement to the beach restoration project component. As a result, only two small sections of placement area 1 received material.

To allow the dredge contractor to complete placement in placement area 1, the permit was modified to extend the work on the marsh to April 15. However, weather prevented this work from continuing. Ultimately, 6,490 CY of dredged material were placed on 6.6 acres, compared with 11,350 CY on 22.4 acres specified in the design.

Post-placement: After the dredged material placement was completed on March 20, 2016, NJDOT-OMR performed an as-built survey of the placement areas in the marsh. A post-construction survey in permanent monitoring plots found that the average placement depth was 6 inches with a range of 0–18 inches. All the containment and grade stakes were left on the marsh because the project team intended to place more dredged material in fall 2016. However, this second placement of dredged material never occurred because the remaining material to be dredged from the channel was mostly sand, and the team wanted to prevent additional impacts of equipment use on the marsh. Containment and grade stakes were later removed from the site by NJDEP-DFW and GreenVest.

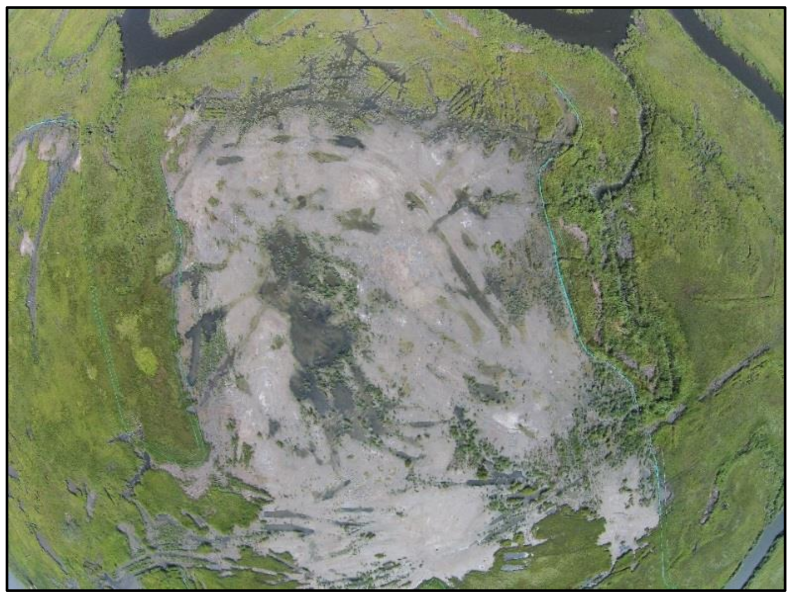


Figure 40. *This aerial view shows Fortescue placement area 1 immediately after placement was completed. Note the Filtrexx Siltsoxx™ containment (bright green lines) near the perimeter.*

Fortescue Dune Restoration Component

The Fortescue dune restoration component was designed and permitted together with the marsh and beach projects (note that all three components were needed so that the associated NJDOT-OMR dredging project could be completed). Unlike the pilot marsh enhancement projects, dune restoration and creation projects were well understood. The sand used for the dune restoration project was dredged from the Fortescue Creek channel.

Pre-placement: The marsh team stressed to the dredge contractor that protecting the marsh habitat was important. Site preparation started on January 18, 2017, and consisted of staking out the dune boundary, installing containment, laying out the dredge pipe, and excavating the dewatering pits where sand (dredged material) would be stockpiled. Prior to construction, to prevent the placed dredged material from migrating outside the dune footprint and into the adjacent marsh, containment (8-inch-diameter Filtrexx SiltSoxx™) was installed along the north and east perimeter of the proposed dune. Likewise, to provide some protection from onshore waves, containment was installed along the west and south perimeter of the placement area. All site preparation was performed by the dredge contractor or another NJDOT-OMR subcontractor, with input from the marsh team.

Fortescue Dune Restoration Component Construction Summary

Placement area: 2.25 acres
Placement volume: Approximately 18,355 cubic yards
Sediment composition: Primarily sand
Containment type: Partial perimeter, with Filtrexx SiltSoxx™
Distance from channel to dune: 2,000 feet
Dredge type: 12-inch hydraulic cutterhead dredge
Placement technique: Direct pumping into excavated dewatering pits, grading with bulldozer
Shore construction machinery: Marsh Master, skid steer, excavator, bulldozer
Timing of construction: February 15 to April 12, 2017

Dredging and Dredged Material Placement: Channel dredging and dune construction began on February 15 and continued until April 12, 2017. The sandy dredged material was pumped into dewatering pits within the dune. To contain the dredged material and to divert the dewatering discharge to the center of the placement area, the dredge contractor constructed sand berms around the dewatering pits (Fig. 41). To prevent the flow of water and dredged material from the placement area to the marsh, additional sand berms were built and Filtrexx SiltSoxx™ were used as needed during the construction.

Once it dewatered, the dredged material was moved into the dune footprint and then graded into a dune by a bulldozer. The marsh team and NJDOT-OMR resident engineer monitored the placement of the dredged material into the dune footprint. High winds frequently created unsafe working conditions, which temporarily halted dredging and placement.

Work progress was documented by the dredging team in daily field reports. Princeton Hydro (the marsh team member that was onsite during construction) provided periodic updates to the project team, discussing the overall construction process, methods, and progress.

Figure 41. *At the Fortescue dune restoration, berms were constructed from the first dredged sediment to create dewatering pits to retain the dredged material and to direct the dewatering discharge to the center of the placement area. Photo from NJDOT.*

Post-placement: After placement, NJDOT-OMR performed an as-built survey of the restored dune (Fig. 42). The final dune measured 900 feet long (~200 feet shorter than designed), 40 feet wide at the top and 80 feet wide at the base, with a dune crest elevation of 10 feet NAVD88 (5–6 feet above the marsh surface). The side of the dune graded to a slope of 4:1 (horizontal to vertical). Immediately after placement, the dredge contractor removed the dredge pipe and other construction equipment from the site. The placement area boundary stakes were removed, but the Filtrexx SiltSoxx™ containment was left in place to support the restored dune and minimize erosion into the marsh.

Figure 41. *This photo of the Fortescue dune restoration shows the bay side of the dune immediately after placement.*

Fortescue Beach Restoration Component Construction Summary

Placement area: 1.3 acres
Placement volume: 7,245 cubic yards
Sediment type: Sand
Containment type: None
Distance from channel to dune: 1,800 feet
Dredge type: 12-inch hydraulic cutterhead dredge
Placement technique: Direct pumping, grading with bulldozer
Shore construction machinery: Marsh Master, skid steer, excavator, bulldozer
Timing of construction: March 26 to April 14, 2016

The Fortescue beach restoration component was designed and permitted together with the marsh enhancement and dune restoration components. Unlike the pilot marsh enhancement/dredged material placement projects, beach restoration was well understood, and the dredging team had experience with such projects. The sand used for the Fortescue beach restoration component was dredged from the Fortescue Creek channel.

The dredging team provided daily field reports of work progress, including photographs. Princeton Hydro (the marsh team member onsite during construction) periodically provided the project team with updates of the overall construction process, methods, and progress.

Pre-placement: Prior to pumping material into this area, the topography of the existing beach was surveyed, and the limits of the placement area ("beach fill") were delineated with 1-inch PVC pipes marked with the target elevation. Additional stakes were added around a 25-foot offset from the beach fill area.

Dredging and Dredged Material Placement: The beach restoration followed standard methodologies. The dredged material was hydraulically pumped to the placement area and the slurry was directed into a created trench, which allowed the sand to settle out while the finer material and water flowed back to the bay (Fig. 43). The approximate dimensions of the trench were 100 feet long by 30 feet wide and 4 feet deep. The trench was surrounded by approximately 200-foot long "training" dikes, which prevented dredged material from flowing directly into the bay or across the beach into the adjoining marsh. As dredged material exited the pipe, it flowed through the trench, giving sand the opportunity to settle out. The trench was regularly cleared by an excavator and the accumulating sand was used to maintain the training dikes and restore the beach. Then, the sand on the beach was distributed and graded to design specifications using a small bulldozer.

Figure 43. *During the beach restoration component at Fortescue, dredged material flowed in a created trench surrounded by training dikes. Photo from NJ DOT.*

Post-placement: After placement, the grade stakes were removed and an as-built survey was completed.

Phase 6: Post-Construction Adaptive Management

This project phase addresses post-construction monitoring, adaptive management, and associated lessons learned at the three project sites. It is important to note that adaptive management was employed throughout the project implementation process, particularly in response to lessons learned as implementation proceeded from one project to the next.

It is well known that many years (possibly decades) are required for enhanced marshes to develop the structural and functional characteristics typical of “reference” (i.e., “healthy,” natural) marshes (Mitsch and Wilson 1996; Zedler and Callaway 1999; Williams and Faber 2001; Moreno-Mateos et al. 2012). In addition, the three pilot marsh enhancement projects—Ring Island, Avalon, and Fortescue—employed techniques that were new to New Jersey. Therefore, the trajectory of the marsh response was not predictable.

In the first few weeks after construction, the marsh team realized that the comprehensive monitoring plan was not tracking some elements of these projects. For example, the monitoring plan did not include the effects of containment on marsh recovery. Therefore, to better understand conditions in the dredged material placement areas, the marsh team developed and implemented a number of additional monitoring parameters, using an adaptive management approach. They also tested a variety of management techniques (e.g., planting test plots and removing some containment) intended to improve marsh recovery.

In April 2016, at the beginning of the first growing season post-construction, the marsh team performed the first formal post-construction inspections of the Avalon and Fortescue projects. These inspections raised many questions about how the sites were recovering. The comprehensive monitoring plan focused on quantitatively measuring single parameters, collected over the length of the growing season (April to October); thus, the data were not often analyzed and interpreted in “real time,” but long after they were collected. The main purpose of the additional inspections was to make qualitative real-time observations, including interactions between parameters, to guide adaptive management decisions and identify significant issues that the marsh team needed to address.

The marsh team’s monthly inspections, which occurred only during the growing season, observed changes in the marsh, the placed dredged material, and biological activity. Marsh team members walked the perimeter and interior (to the extent possible) of each placement area and made a variety of qualitative observations. In 2016, these observations focused on documenting the vegetation response, vegetation die-off areas, containment integrity, and containment impacts on marsh response and dynamics of the placed dredged material (e.g., dewatering, consolidation, erosion). In 2017, the team also began recording planting success and failure. The full list of parameters monitored are listed in Table 10. (For a detailed description of the monthly monitoring methods, see the Project Monitoring Protocols located at XX-LINK.)

Table 10. Site Features Monitored During Monthly Post-construction Site Inspections			
Vegetation Recovery/ Die Off	**Planting**	**Containment**	**Dredged Material**
Species present	Species present	Issue (e.g., blocking tidal flow, wildlife hazard, wrack collection)	Cracking or drying
Sediment characteristics (texture, colors, etc.)	Sediment characteristics (texture, colors, etc.)	Difference in sediment elevation inside and outside containment	Sediment characteristics (texture, colors, etc.)
Method of growth (recovery or recruitment)		Biodegradation	Consolidation

Ring Island Marsh Enhancement Adaptive Management

In September 2014, dredged material placement for the Ring Island marsh enhancement project was completed.

Initial Observations: Although the monthly site inspection program was not formally in place until July 2016, during the intervening months the site was qualitatively inspected by marsh team members who were conducting vegetation and avian surveys and during visits by marsh team members. Although there were almost no gains in vegetation cover during the 2015 growing season (Fig. 44), no adaptive management actions were considered until spring 2016. Because the dredged material placement areas were small (less than 0.5 acres), there was little risk associated with leaving the areas unvegetated, and leaving them alone offered an opportunity to learn about natural re-vegetation and colonization. During early post-construction visits, the marsh team noticed several things:

- The placed dredged material was heterogenous and its thickness varied across the placement areas.
- Plants that survived the initial placement senesced and died early.
- As birds began to use the placement areas for feeding, shell piles formed.

__Figure 44.__ At the Ring Island marsh enhancement site in October 2015, there was minimal vegetation recovery and colonization.

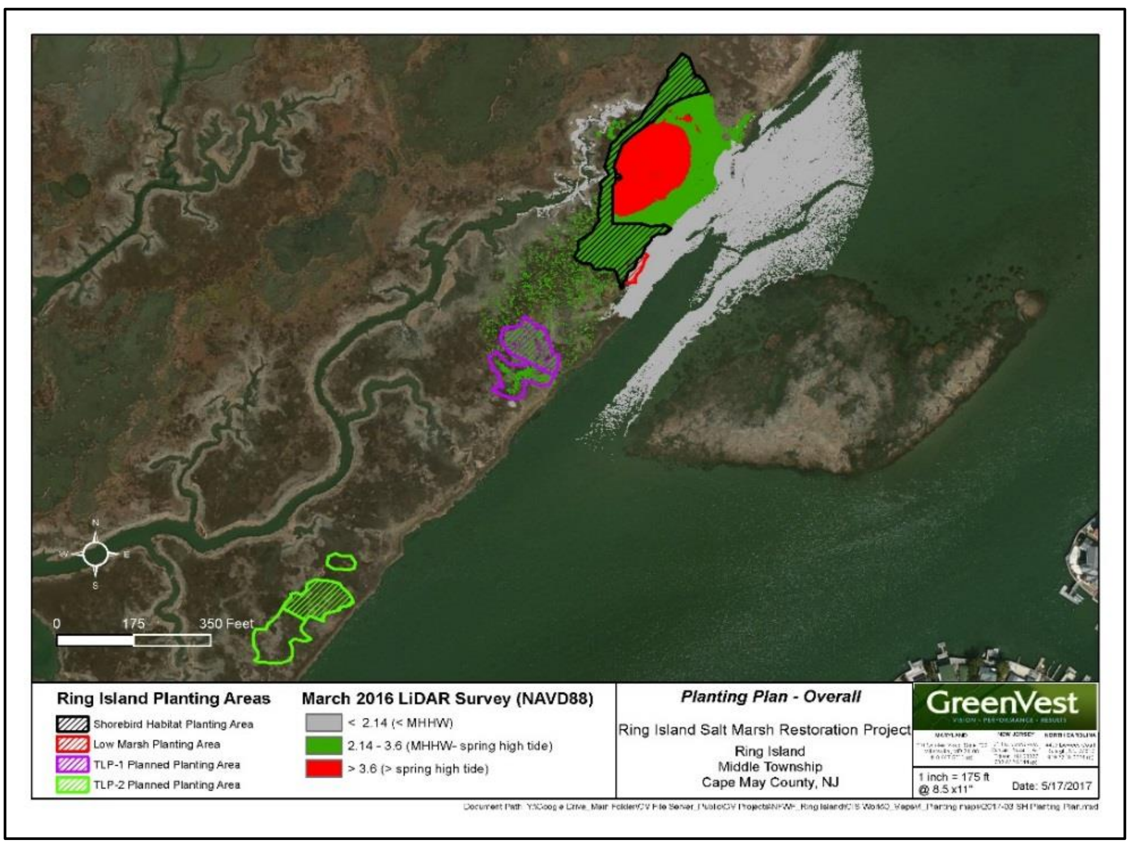


__Figure 45.__ This image shows the planting plan for the Ring Island marsh enhancement project.

Using biological benchmarks (Table 4), tidal range, and topography, the team developed plans to plant half of each of the two dredged material placement areas (Fig. 45) at Ring Island. The elevations of the two placement areas differed, so different plant communities were chosen in the plan, as follows:

- **TLP-1 Planting Area**: 25% *S. alterniflora*, 50% *S. patens*, and 25% *D. spicata*, all spaced at 3-foot centers
- **TLP-2 Planting Area**: 50% *S. alterniflora*, 25% *S. patens*, and 25% *D. spicata*, all spaced at 3-foot centers

On March 30, 2017, a crew of 10 people planted approximately 2,200 plugs on half of each placement area (0.46 acres in total). At the Ring island marsh enhancement project site, no other post-construction adaptive management actions were implemented.

Avalon Phase 1 Adaptive Management

Dredged material placement for the Avalon Phase 1 project was completed in January 2015.

Initial Observations: Although the formal monthly site inspection program did not begin until July 2016 (after construction of the Phase 2 project), the project team visited the site in April, June, September, and October 2015. The 2015 visits revealed that the placed dredged material had dewatered and consolidated to varying degrees, with significant consolidation and potential subsidence occurring in areas that were previously pools. The lesson learned from these observations was that placed dredged material may consolidate more than anticipated, particularly in former pools, and the final elevation may be lower than the target ecological elevation.

To achieve the desired marsh enhancement project objectives—the conversion of degraded pools to stable marsh plain—the marsh team decided to place additional dredged material in Avalon Phase 1 placement areas A and C.

Planting: Based on their observations from site visits, the marsh team implemented a small-scale test planting in placement area A. The purpose of this planting was to help inform future planting in the larger Avalon Phase 2 project.

According to the as-built survey, the elevation range for placement area A was approximately 2.0 to 2.4 feet NAVD88 and the Avalon biological benchmarks suggested that this was the elevation range of *S. alterniflora* and *D. spicata* (Table 5). However, *D. spicata* was not available from the local nursery at the time of planting, so *S. patens* was used in its place. The planting plan was implemented on July 21, 2015, and consisted of 12 plots with the following treatments: planting vs. no planting (i.e., natural recovery and recolonization), planting at 2-foot centers vs. planting at 3-foot centers, planting *S. alterniflora* vs. *S. patens*, and planting with goose netting versus no netting. By September 2015, only a few *S. alterniflora* plants survived (Fig. 46).

Figure 46. By October 2015, few plants survived at Avalon in dredged material placement area A.

The marsh team presumed that plant survival was poor because conditions in the middle of the growing season (late July) are not conducive to plant establishment. Other possible contributing factors include the chemical composition of the dredged material and lack of adequate pore space in the tightly consolidated fine-grained sediment.

Despite the failure of the experimental planting, by September 2015, *S. alterniflora* grew vigorously through the placed dredged material at some locations in placement area A (Fig. 47). However, recovery was patchy, and in some areas, vegetation died. Overall, vegetation recovery during the 2015 growing season was too variable to draw any firm conclusions about the marsh response.

Containment: During construction of the Avalon Phase 1 project, little containment was used, and what was used (coconut-fiber logs) was biodegradable. The marsh team left these logs in place to observe how long it would take for them to break down.

Figure 47. *At Avalon, existing marsh plants grew through placed dredged material in April (left) and June 2015 (right).*

Avalon Phase 2 Adaptive Management

On February 19, 2016, dredged material placement for the Avalon Phase 2 project was completed.

Initial Observations: During the first site visit on April 25, 2016, the project team observed the following:

- During the two months since construction had been completed, the extent of consolidation for the dredged material was highly variable.
- Due to dewatering and drying, the dredged material had formed thick plates in a number of areas (Fig. 48).
- At some locations, *S. alterniflora* was growing through the cracks in the dredged material (Fig. 49).
- Vegetation did not recover in the tracks left by the Marsh Master (Fig. 31).
- Water created drainage paths through some of the placement areas.
- It was difficult or impossible to walk across both former pools and sediment dominated by fine-grained material.

After this first site visit, the marsh team began formal monthly site inspections (described in the Phase 6 introduction) and decided not to attempt a large-scale planting in 2016 due to the difficulty of walking across the placement areas. There were additional reasons to delay a large-scale planting until 2017:

- There was not enough lead time for a nursery to grow the amount and species of plants needed (at least six months' notice would be required).
- There was not enough information on how much, if any, natural plant colonization would occur during the first growing season (e.g., if by the end of 2016, the site was significantly covered by plants, then planting in spring 2017 would be unnecessary).

- There was uncertainty about the consolidation and elevation loss of the placed dredged material (which would impact plant selection) and the re-formation of pools (in which plants would not survive).

Figure 48. *At Avalon, Phase 2, thick plates of drying and cracking dredged material were present in April 2016 (two months after construction was completed).*

Planting: The team planned to conduct a small-scale test planting in late spring/early summer 2016 at Avalon to examine the recovery of planted and unplanted areas and to plan for the 2017 planting. However, as happened at Ring Island, American oystercatcher and other birds used the new patches of bare sediment for nesting, so this planting could not be implemented.

In summer 2016, the team developed the draft planting plan that would be implemented in 2017. To delineate elevation zones and the corresponding plant communities, the team conducted a thorough review of the Avalon biological benchmarks (Table 5) and tidal datums. The plan involved the following elevation zones and plant community compositions:

- **<2.03 NAVD88 (MHW)**: 100% *S. alterniflora*
- **2.03–2.39 NAVD88 (MHHW)**: 50% *S. alterniflora*, 25% *S. patens* and 25% *D. spicata*
- **2.39–2.85 NAVD88**: 50% *S. patens* and 50% *D. spicata*
- **2.85–3.03 NAVD88**: 50% *S. patens* and 50% *D. spicata*; a 50:50 ratio of *I. frutescens* and *Baccharis halimifolia* covering only 50% of the area
- **>3.03 NAVD88**: 50% *I. frutescens* and 50% *B. halimifolia*
- **Pooling areas**: 100% *S. alterniflora*

Figure 49. *At Avalon, Phase 2,* S. alterniflora *grew through some of the cracks in the dredged material.*

Based on the scientific literature, the marsh team hypothesized that the original marsh vegetation covered with less than 6 inches of dredged material would recover naturally during the first few growing seasons, growing through the dredged material. Therefore, only areas covered with 6 or more inches of dredged material were planted. Because the island had no natural seed source for the selected species and because the team wanted to prevent colonization by *P. australis*, they decided to plant 100% of the two highest elevation zones and lower three elevation zones (with one-third left unplanted as a control), and 50% of the re-formed pools (Fig. 50). The as-built elevation survey from March 2016 was used to map and quantify areas that had received less than 6 inches of dredged material, identify areas of pooling water, and delineate the different plant communities.

The monthly inspection prior to the May 2017 planting revealed that the dredged material had consolidated, which would impact the original planting plan. Therefore, the plant community boundaries (based on elevation) were re-delineated. The team decided to plant two-thirds of the placement areas and leave the rest unplanted to compare the effects of planting with natural recruitment. A NJ-licensed surveyor staked out the planting areas based on horizontal data, not elevation data. To test the concept that clumped plantings would reduce environmental stresses and improve plant survival and growth (Silliman et al. 2015), the lowest two elevation zones were planted in clumps while the higher zones were planted in a grid pattern. Pools were not planted.

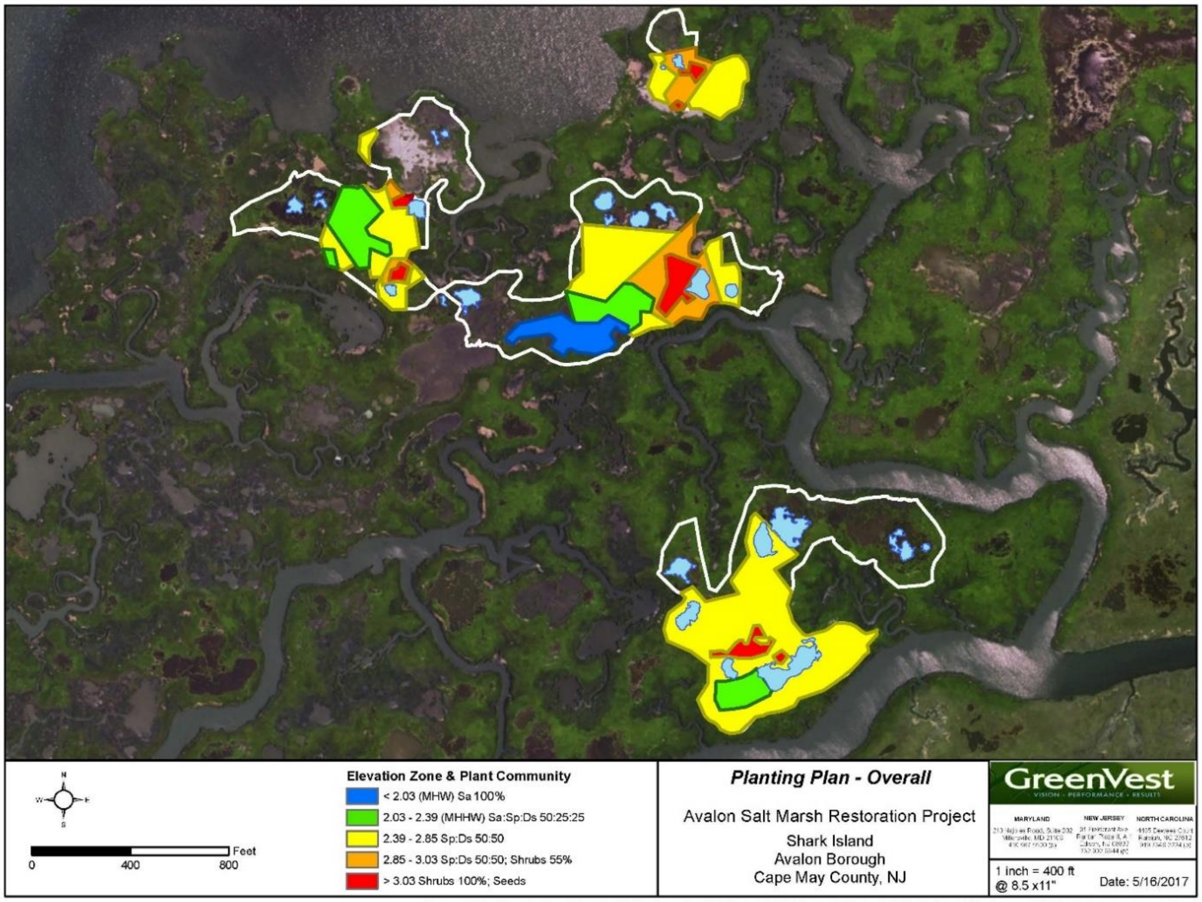


Figure 50. *Species selected in the Avalon Phase 2 planting plan were* Spartina alterniflora *(Sa),* S. patens *(Sp),* Distichlis spicata *(Ds),* Iva frutescens *(If), and* Baccharis halimifolia *(Bh).*

Over the course of nine days in early May 2017, eight people planted 106,708 plugs in 18.57 acres of the marsh; however, the actual planting deviated from the approved plan. In the field, it was apparent that the dredged material had consolidated even farther, as large areas of the marsh—mostly former pools—were at much lower elevations than recorded in the topographic survey from 10 months prior. In addition, healthy patches of *S. alterniflora* had colonized some areas. Using adaptive management in the field, the marsh team amended the planting plan to accommodate the elevation changes, gauging by eye, and to avoid existing vegetation.

Vegetation Die-Off Areas: Through spring and early summer 2016, the placement area seemed to be responding as expected, showing continued dewatering and plant growth. However, during the monthly inspection in July 2016 (five months after construction), the marsh team observed several patches of dead plants outside some of the placement areas that were directly adjacent to the containment (Fig. 51).

Figure 51. *At Avalon Phase 2, vegetation die-off (brown areas outside containment) occurred (top). The containment restricted tidal flow, keeping water higher outside the placement area than inside it. Photos from NJDEP.*

To understand why this vegetation die-off occurred and to evaluate its potential implications for plant growth throughout the site, the marsh team immediately delineated the affected areas and characterized them. It was important to understand whether the observed vegetation die-off areas indicated poor conditions in those areas only or throughout the site.

The bulk of the subsequent adaptive management at the Avalon project site was spurred by observations that the marsh team made during the July 2016 monthly site inspection:

- Areas where vegetation had died received only a very thin layer of dredged material and were 4–6 inches lower and, therefore, wetter than the adjacent placement area.
- Die-off occurred only adjacent to intact containment, and live plants occurred where containment was missing or severed.
- Patches of vegetation die-off seemed to occur at creek heads and along drainage pathways, but not elsewhere.
- Within the placement area, vegetation die-off occurred in areas of pooled water.
- There were also areas of vigorous plant growth both inside and outside the placement areas.

In light of these observations, the marsh team created several (not mutually exclusive) hypotheses to explain the cause of vegetation die-off and developed adaptive management actions to address the problem:

- **The containment acts as a physical barrier to surface water flow.** Water is retained outside or inside the placement area because it is either not flowing through the containment or flows through it very slowly, resulting in prolonged inundation.
    - **Adaptive management:** Remove the containment.
- **The placed dredged material acts as a physical barrier to surface and subsurface water flow.** The hydraulic spreading of dredged material from a stationary pipe likely caused sediments to sort by grain size, such that some areas of the placement area received material of homogenous composition. Areas dominated by silt or clay, which was observed adjacent to containment outside the placement area, could contain tightly packed material that either impeded the flow of subsurface water or impaired the function of plant roots. It is also possible that water was retained outside the placement area because the dredged material was blocking water flow.
    - **Adaptive management:** Dig runnels to improve drainage.
- **Altered sediment and water chemistry is inhibiting plant growth.** The chemical composition of the placed dredged material may be adversely affecting vegetation. The dredged material that was placed in the areas now experiencing vegetation die-off was predominantly composed of silt and clay, which may contain elevated concentrations of contaminants. Chemical factors of potential concern include metal toxicity, salt concentration, and highly acidic conditions that are created when mono-sulfidic sediment is exposed to oxygen (which were documented in the Avalon placement areas after construction). Alternatively, water flowing over and through the dredged material within the adjacent placement area carried solutes (e.g., salts, metals, acidic water) that concentrated in some areas, causing plant mortality.
    - **Adaptive management:** Investigate potential solutions or develop and implement a monitoring plan to answer questions about the problem (e.g., Why is it happening? Will it resolve without intervention? If so, within what timeframe? What does this mean for future projects?).
- **The weight of the placed dredged material is impacting plant survivorship.** The placed dredged material may have compacted the marsh substrate, including both the sediment and peat layer, impacting subsurface water flow or plant root function.
- **Site hydrology was altered by the elevation of the placed dredged material**. Site hydrology was altered simply as a function of the elevation of the placed dredged material.
- **Meteorological conditions killed plants.** Extreme short-term weather, such as drought and high temperatures during summer 2016, may have caused the plants to die around the marsh.

Before any adaptive management actions were implemented at Avalon, the marsh team conducted a variety of studies to investigate the potential cause(s) of the problem:

- **Die-off area characterization and mapping.** To evaluate the problem, the team first documented observations of the vegetation die-off areas during monthly site visits throughout 2016 and the following 2017 growing season. For each die-off area, they noted depth (thickness) of dredged material, presence of pooled water, presence (alive and dead) of plants and species, containment condition, presence of a drainage path, and color of the placed dredged material or sediment. Each die-off area was photographed and its limits were mapped using a Trimble GPS unit. To determine below-ground vegetation biomass, core samples were collected and permanent vegetation monitoring plots were established in the die-off areas. To observe water flow throughout the tidal cycle, trail cameras were set up to take photos of the die-off area and containment every 30 minutes.

- **Groundwater and surface water monitoring.** After the team observed unusual salinity and pH of ponded water and acidic soils, they began to monitor water chemistry in 2017. Their approach was to characterize surface water chemistry in salt marsh pannes and pools following placement of dredged material. Monitoring sites were chosen to test the effect of containment on vegetation, so sites were located both inside and outside containment and in die-off areas. The sampling frequency and timing were designed to capture the range of conditions post-placement, to understand the role of surface water chemistry in vegetation recovery, survival of plantings, and/or die-off. To determine the potential cause for surface water chemistry, the monitoring program also documented the water chemistry in groundwater within the emplaced dredged material. Surface and ground water in placement areas were compared with control sites and the reference site located at The Wetlands Institute.
- **Experimental removal of containment.** During the monthly site inspections, the marsh team often observed that water was retained directly outside or inside the containment surrounding the placement areas. They suspected that containment could be restricting the flow of surface water. However, immediate removal of all containment was not possible because of its high cost, the equipment needed (which could damage the marsh), and concerns that removing containment could jeopardize the integrity of the placed dredged material. Therefore, in November 2016, the team removed approximately 214 linear feet of containment from two die-off areas in order to answer key questions, such as: Is the die-off mitigated by containment removal? Is water still retained? Does the placed dredged material erode? What is the effort and cost to remove containment?

Based on initial results of the experimental removal of containment as well as observations of additional vegetation die-off areas, the marsh team determined that containment was inhibiting tidal flow and was a potential risk to new plantings. Therefore, prior to the 2017 planting, the team removed as much containment as the project maintenance budget would allow. They started removing it from the priority sections: those that bordered vegetation die-off areas and that crossed drainage paths. After they removed the priority sections, they created small openings in long continuous sections of containment in the non-priority areas to encourage drainage (Fig. 52). In March 2017, a crew of eight people, using no machinery, completed this work over three days. They removed or dismantled approximately 1,849 linear feet of containment. Segments of containment were either hauled off the marsh intact or cut open in place, allowing the coconut-fiber stuffing to loosen and spread over the marsh, while the netting was removed from the marsh. In September 2017, the team removed an additional several hundred linear feet of containment. Many of the wooden stakes that held containment down could not be efficiently removed from the marsh and were left in place. In later years, the stakes have been observed as places where wrack builds up.

Figure 52. Avalon Phase 2: Containment was removed from this section (dark line curving from bottom center to upper left) and the biodegradable coconut fibers (right of line) from the containment were spread over the marsh. The elevated placement area is to the right.

Figure 53. Acid sulfate soils with a pH below 3.8 appeared reddish and were found in the higher, drier, and sandier portions of the Avalon placement area. Photo from NRCS.

Acid sulfate soils: To further investigate soil chemistry at the Avalon site, soil scientists from the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) tested the placed dredged material in June 2017. They confirmed that the top layer of the higher, drier, and sandier sediments had acid sulfate conditions, with the pH in some areas falling below the detection limits (3.8) of their soil test. Sulfuric acid is produced when anoxic sulfidic sediments, like those found in the NJIWW channels, are exposed to oxygen (Natural Resources Conservation Service 2019). The areas of low pH were found within the rust-colored layer on top of some placement areas (Fig. 53). It was unknown how long these low pH conditions would last, but it was expected that the acids would be washed away by the tides over time. It was also unknown the degree to which low pH conditions might have prevented vegetation from establishing or led to the death of existing vegetation inside the placement areas or outside containment.

Fortescue Marsh Enhancement Project

For the Fortescue marsh enhancement component, dredged material placement was completed on March 20, 2016.

Initial Observations: During a site visit one month later (April 25, 2016), the marsh team observed vigorous patches of *S. alterniflora,* areas of pooled water inside and outside the placement area, and some areas of the marsh damaged by equipment.

Planting: As the project team planned to do a second round of dredged material placement in fall 2016, the marsh team decided not to plant the dredged placement areas in spring 2016. In the summer of that year, they created a draft planting plan to be implemented in 2017 (Fig. 54). To create the plan, the team thoroughly reviewed biological benchmarks (Table 6) and tidal datums to delineate elevation zones and the corresponding plant communities. The planting plan consisted of the following elevation zones and plant communities:

- **2.0–3.0 NAVD88**: 100% *S. alterniflora*
- **3.0–4.0 NAVD88**: 20% each *S. patens, D. spicata, Juncus gerardii, S. cynosuroides*, and *Solidago sempervirens*
- **3.5–4.0 NAVD88**: 33% *I. frutescens* and 67% *B. halimifolia*

The planting elevation zones were drawn using the as-built elevation survey from June 2016. Once they were drawn, the areas of each planting zone were calculated.

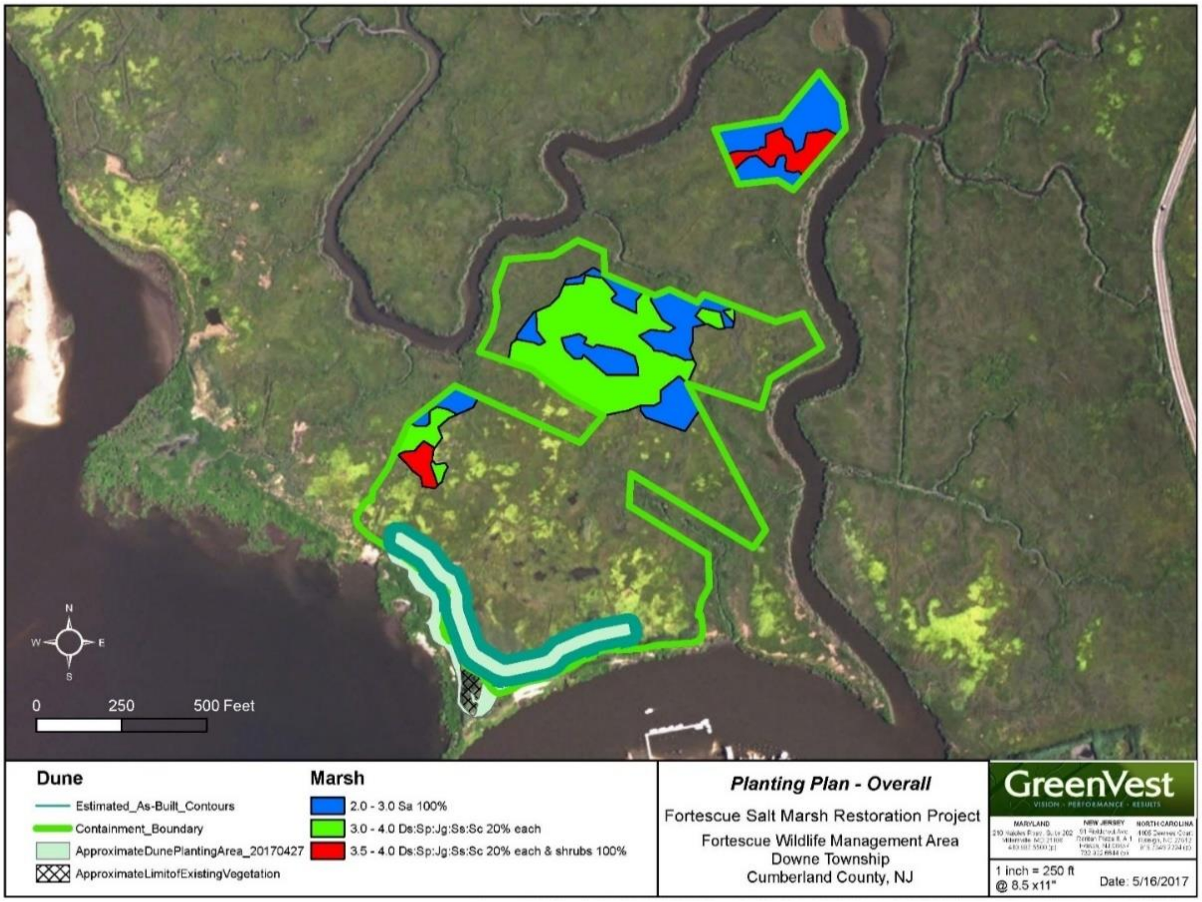


Figure 54. *Species selected for the Fortescue marsh enhancement component were* Spartina alterniflora *(Sa),* S. patens *(Sp),* Distichlis spicata *(Ds),* Juncus gerardii *(Jg),* S. cynosuroides *(Sc),* Solidago sempervirens *(Ss),* Iva frutescens *(If), and* Baccharis halimifolia *(Bh).*

In preparation for planting, the planting zones were staked out in April 2017. (Although a year had passed since the most recent elevation survey, the project team decided it was not necessary to conduct another one because, unlike at Avalon, the dredged material had a high sand content that would prevent it from consolidating very much.) In May 2017, the planting plan was implemented. However, because *S. alterniflora* colonized some of the planting areas and only unvegetated areas were planted, the plants were installed at a greater density than in the planting plan. Over the course of three days, eight people planted 27,765 plugs.

Containment: The Filtrexx SiltSoxx™ geotextile fabric would eventually break down into microplastics that are noxious in the aquatic environment; therefore, the team had decided at the outset to remove it entirely after placement. (The marsh team also wanted to remove it because they suspected that containment negatively affected hydrology at the site.) In May 2016, small sections of containment in placement area 2 were disassembled. The objectives of this management action were to: (1) determine whether removing some containment alleviated pooling inside the placement area, (2) evaluate the feasibility of removing containment on a larger scale, and (3) determine whether the placed dredged material would rapidly erode once it was no longer contained. The geotextile fabric was easy to cut and remove, and its woodchip mulch contents were dispersed across a small area of the marsh.

In early 2017, the marsh team weighed the potential outcomes of removing the rest of the containment versus leaving it in place. They determined that the potential risk of the containment to adversely impact site hydrology and the upcoming planting was greater than the risk of the dredged material eroding if the containment was removed. Therefore, over five days in March 2017, a crew of eight people disassembled approximately 14,816 linear feet of containment. In September 2017, the remaining containment on the site was broken down.

Fortescue Dune Restoration Component

On April 12, 2017, dredged material placement and grading for this project were completed.

Initial Observations: The ends of the dune were quickly eroded by storm-driven waves.

Planting: In early May 2017, immediately after construction, the dune was planted. Because the dune was constructed with dredged material that had a high sand content and was graded to design specifications, dewatering and consolidation were not expected to affect final elevations. Therefore, the planting plan could be implemented with much more certainty and without significant modifications. However, the final planting area was only 2.55 acres instead of the expected 2.90 acres, so the planting density was increased to accommodate this change. The dune was divided into four different areas for planting purposes:

- **Dune crest:** *Ammophila breviligulata* and *Panicum amarum* in a grid at 3-foot centers; *Myrica pensylvanica, Prunus maritima, Celtis occidentalis, Rhus copallinum*, and *Juniperus virginiana* at 8-foot centers.
- **Dune front face:** *A. breviligulata, P. amarum*, and *S. sempervirens* in a grid at 3-foot centers; *M. pensylvanica* and *B. halimifolia* at 8-foot centers.
- **Dune back face:** *P. amarum* in a grid at 3-foot centers; *P. maritima*, *C. occidentalis*, and *J. virginiana* at 8-foot centers
- **Phragmites treatment area:** *A. breviligulata* and *S. sempervirens* in a grid at 3-foot centers; *B. halimifolia* at 8-foot centers.

Aside from slightly modifying the dune planting plan, no other post-construction adaptive management was implemented for this project component.

Phase 7: Project Assessment

Monitoring and Data Evaluation

To document the initial response of salt marsh to dredged material placement, as well as to track and assess the trajectory of marsh response over the subsequent five years, a comprehensive monitoring plan was developed. The plan included collecting data on the placed dredged material, elevation, depth of placement, surface water elevation, vegetation, epifaunal macroinvertebrates, benthic infauna, fish, crabs, and birds. When possible, monitoring was initiated before the placement of dredged material at the marsh enhancement areas and control areas and utilized a BACI analysis design. The monitoring plan (and subsequent additional modeling and post-placement adaptive monitoring) was designed to answer specific research questions and to be useful to future similar projects in New Jersey. The complete monitoring plan is available as Appendix 1.

The monitoring used widely accepted, scientifically sound methods. Where possible, methods were adapted from the Salt Marsh Integrity Index Protocols used by U.S. Fish and Wildlife Service Region 5. The National Wildlife Refuges in New Jersey intended to use these protocols to monitor similar projects, and the project team intended the data from both the NJDEP and USFWS projects to be comparable.

Based on its experience and literature reviews, the project team knew that these types of projects generally do not show definitive trends until much longer than the two years of the NFWF grant period, which covered monitoring from 2015 to the summer of 2017. Therefore, they created the monitoring plan and secured the funds to extend beyond the end of the NFWF grant reporting period, through 2019, with some parameters monitored through 2021. To track the trajectory of marsh response, the project team prioritized the future monitoring of site elevation, vegetation, soil and water chemistry, benthic infauna, and avian surveys. A companion monitoring document (in preparation) will present the results of the monitoring of these projects through 2019.

Cost Analysis

This cost analysis is intended to provide those who are interested in developing similar projects with a general idea of the costs of the development, design, construction, and monitoring phases of the three pilot projects: Ring Island, Avalon (both Phase I and Phase 2) and Fortescue. Due to the complexity of these projects and the multiple partners involved, precise cost tracking was not possible, so the costs presented are approximate. They can be used to guide the development of future projects that use dredged material to enhance or restore salt marshes, as well as to inform the potential cost difference of traditional dredging projects that do not include marsh enhancement. The analysis does not include NJDEP staff time and other resources expended in project development, monitoring, data analysis, report preparation, and post-construction adaptive management.

It was not possible to separate the costs of the different project components at Ring Island (marsh enhancement and ENH creation), Avalon (Phase I and Phase 2 marsh enhancement), and Fortescue (marsh enhancement, dune restoration, and beach nourishment). In fact, the marsh enhancement projects could not have been implemented (nor could the channels have been dredged) without including these other project components. This may be characteristic of future projects that combine dredging and marsh projects: additional management alternatives for dredged material may be needed to make the projects viable.

Total Project Cost Comparisons

The total costs per CY of placed dredged material and per acre of habitat enhanced were the highest at Fortescue ($151 per CY and $467,000 per acre). Costs were lowest at Avalon ($45 per CY and $55,600 per acre; Table 11).

The largest portions (62.6% to 80.5%) of the costs were for construction, and the smallest portions (6.1% to 12.1%) were for development and design. Total costs varied among the projects by a factor of 3.4 per CY dredged ($151 vs. $45) and by a factor of 8.4 per acre of habitat enhanced ($467,000 vs. $55,600).

Table 11. Comparison of Total Project Costs ($)

	Ring Island	Avalon	Fortescue
Development and Design	42,000	302,000	479,000
Construction	428,000	1,762,000	3,913,000
Monitoring	214,000	439,000	469,000
Total Cost	**$684,000**	**$2,503,000**	**$4,861,000**
Total Volume Dredged	7,000 CY	55,300 CY	32,100 CY
Cost per CY	**$98**	**$45**	**$151**
Total Area Enhanced	2 acres	45 acres	10.4 acres
Cost per Acre Enhanced	**$342,200**	**$55,600**	**$467,000**

Project Development and Design Costs

For the purpose of this analysis, project development and design costs (Table 12) include costs associated with the initial ecological assessment of marsh condition, sediment sampling (navigation channel and marsh surface), engineering, and permitting. Within these categories, engineering costs were the highest percentage for the projects at Ring Island (59.5%; conducted by the USACE-OP) and Fortescue (49.2%; conducted by GreenVest). Sediment analysis costs were the highest portion (48.9%) for the Avalon project, where two rounds of sampling were conducted.

Table 12. Comparison of Project Development and Design Costs

	Ring Island	**Avalon**	**Fortescue**
Ecological Assessment (Initial Marsh Condition)	n/a	$31,000	$17,000
Sediment Sampling	$5,000	$147,000	$149,000
Engineering	$25,000	$93,000	$235,000
Permitting	$12,000	$31,000	$77,000
Total	**$42,000**	**$302,000**	**$478,000**
Total Volume Dredged	7,000 CY	55,300 CY	32,100 CY
Cost per CY	**$6.00**	**$5.50**	**$15.00**
Total Area Enhanced	2 acres	45 acres	10.4 acres
Cost per Acre Enhanced	**$21,000**	**$6,700**	**$46,000**

Costs of the Ecological Assessment of Initial Marsh Condition: As a percentage of the total project costs, these costs were negligible across the project sites, with a maximum of 1.2% at Avalon. However, these costs do not include the considerable time spent by the TNC-NJ staff to initially identify the three marsh enhancement sites *via* desktop analyses and site visits, NJDEP's costs to evaluate the project sites, and initial staff coordination of the marsh enhancement pilot projects with their associated dredging projects prior to the formal start of the grant period. For future similar projects, these costs will likely be higher both in absolute terms and as a percentage of total project costs.

The Ring Island placement areas were small test plots, so no formal ecological assessment of marsh condition was completed prior to construction. However, prior to final site selection, qualitative information was collected *via* desktop analysis and site visits to evaluate the condition of the marsh and document the location of nesting birds. More comprehensive ecological assessments were completed at Avalon and Fortescue, including multiple site visits to collect baseline information on several site characteristics. In addition, as required by the National Environmental Policy Act (NEPA), USACE completed an Environmental Assessment in July 2014 for the Ring Island and Avalon projects. The NEPA requirements for the Fortescue project were addressed as part of the USACE regulatory review of the project's permit application.

Costs of Sediment Sampling: At Avalon and Fortescue, sediment sampling costs were similar and accounted for 48.9% and 31.2%, respectively, of project development and design costs, and 5.9% and 3.1%, respectively, of total project costs. In order for dredged material to be used for marsh enhancement, both the sediment to be dredged from the channels and the existing marsh surface sediment had to be tested to determine their physical and chemical composition. The cost for this evaluation depended on the types of analyses conducted on the samples and the number of samples collected, which varied with the size of the placement areas and the volume of sediment to be dredged from the channels. Chemical analysis is not required when dredged material is greater than 90% sand, as at Ring Island.

Costs of Engineering: Engineering costs include any expenditure associated with creating the designs and specifications for each project. As a percentage of total project costs, engineering costs were similar for all three projects: 3.7% for Ring Island and Avalon, and 4.8% for Fortescue.

Costs of Permitting: As a percentage of total project costs, the permitting cost for all three projects was low (similar to ecological assessment costs), ranging between 1.2% and 1.8%.

Construction Costs

Construction costs for the three pilot projects included the oversight and implementation of the dredging and dredged material placement operations, and the installation and removal of containment (Table 13). Construction costs ranged from 62.6% to 80.5% of total project costs, with dredging (including dredged material placement onto the marsh) accounting for 52.7% to 60.2% of total project costs. Construction costs per CY dredged varied by a factor of 3.8 among the projects and by a factor of 9.6 per acre of habitat enhanced. Dredging costs (including dredged material placement) were the most expensive part of the construction costs for all three projects (92% at Ring Island, 75% at both Avalon and Fortescue). The cost of containment was negligible at Ring Island and accounted for 12.4% and 14.9%, respectively, of the construction costs at Avalon and Fortescue.

Costs of Oversight: Oversight costs included the staff time from the USACE-OP, NJDOT-OMR, and marsh team members who served as on-site inspectors during construction. This staff time accounted for 4.9% of total construction costs at Ring Island, 10.3% at Fortescue, and 12.8% at Avalon. Oversight costs were highest for the Fortescue project ($12.60 per CY dredged and $39,000 per acre of habitat enhanced). The oversight and management costs were similar per CY dredged and acre of habitat enhanced at Ring Island ($3.00 per CY and $10,500 per acre) and Avalon ($4.07 per CY and $5,000 per acre).

Table 13. Comparison of Construction Costs

	Ring Island	Avalon	Fortescue
Oversight/Management	$21,000	$225,000	$405,000
Dredging	$395,000	$1,319,000	$2,925,000
Containment	$13,000	$218,000	$583,000
Total	**$429,000**	**$1,762,000**	**$3,913,000**

Total CY Dredged	7,000 CY	55,300 CY	32,100 CY
Cost per CY	**$61.00**	**$32.00**	**$122.00**
Total Acres Enhanced	2 acres	45 acres	10.4 acres
Cost per Acre Enhanced	**$214,500**	**$39,000**	**$376,000**

Costs of Containment: At Ring Island, containment was limited to straw bales and silt fence (costing approximately $500) around the ENH component, including the use of a small compact track loader with operating personnel to construct a sand berm; the dredged material placement areas were not contained. Containment accounted for only 3% of the Ring Island construction costs. At Avalon, the marsh team installed, and eventually removed, coconut-fiber logs around most of the placement areas. At Fortescue, Filtrexx SiltSoxx™ were installed, and eventually removed, around most of the designed placement areas (but ultimately only 6.6 acres of the planned 22 acres received sediment, which increased the ultimate cost per acre enhanced).

Containment accounted for 12.4% of the construction costs at Avalon and 14.9% of the construction cost at Fortescue. At Fortescue, containment costs per CY dredged ($18.20) and per acre of habitat enhanced ($56,000) were substantially greater than at Ring Island and Avalon ($1.80 and $3.90 per CY; $4,800 and $6,500 per acre, respectively). This was at least partly because the placement areas in the design for Fortescue were almost four times greater in area than the placement areas that ultimately received dredged material. Had all of the designed placement areas at Fortescue received dredged material, the relative costs of containment would have been much lower.

Costs of Dredging. The cost of dredging for each project differed significantly. Dredging costs ranged from 52.7% to 60.2% as a percentage of total project costs, and 74.8% to 92.0% as a percentage of total construction costs. Also, while there were major differences in the cost of dredging per CY (which varied by a factor of 3.8 among the projects), the dredging cost per acre habitat enhanced varied among the projects by even more: a factor of 9.6. The dredging at Fortescue ($91.00 per CY) cost more per CY than at Ring Island ($56.40 per CY) and Avalon ($23.90 per CY), while the costs per acre habitat enhanced also varied considerably (at Fortescue, $281,000 per acre; at Ring Island, $197,500 per acre; and at Avalon, $29,300 per acre).

Monitoring Costs

As a percentage of total project costs, monitoring costs (Table 14) ranged from a low of 9.7% (Fortescue) to a high of 31.3% (Ring Island). While each of the three pilot projects were monitored for the three-year NFWF grant period, Ring Island and Avalon were also monitored for topography and some vegetation metrics in 2014, prior to the start of the grant. Per acre of enhanced habitat, monitoring costs were highest at Ring Island and lowest at Fortescue. Note that these costs do not include the additional monitoring conducted by USACE-ERDC to expand the understanding of projects that use dredged material to restore marshes.

Monitoring included topographic surveys that were conducted before construction, immediately after construction (as-built surveys), and after construction once the placed dredged material had time to settle and consolidate. Topographic survey costs per acre of habitat enhanced were much lower at Avalon ($2,360 per acre) and were higher at Fortescue ($14,970 per acre) and Ring Island ($17,200 per acre).

Some the reasons for the difference in the cost of monitoring per acre were that the time and expense of getting to the sites was the same regardless of whether a full day of sampling was needed. Another reason was that a minimum number of samples were required to capture variability at the smaller sites and to cover a control site. In addition, nesting success of birds was monitored at Ring Island, and not at the other sites.

Table 14. Comparison of Monitoring Costs

	Ring Island	Avalon	Fortescue
Topography	$34,000	$106,000	$156,000
Water Level	n/a	$55,000	$55,000
Plants	$31,000	$44,000	$33,000
Birds	$81,000	$54,000	$60,000
Benthic Infauna & Soil Properties	$67,000	$70,000	$67,000
Fish and Crabs	n/a	$101,000	$99,000
Total	**$213,000**	**$430,000**	**$479,000**
Total Acres Enhanced	2 acres	45 acres	10.4 acres
Cost per Acre Enhanced	**$107,000**	**$9,764**	**$45,135**

Post-construction Planting and Adaptive Management Costs

Planting costs consist of the costs of purchasing plant plugs from a nursery and hiring a crew to plant them (Table 15). These costs are not included in the total project costs (Table 11) because planting may not be necessary for other similar projects if plants naturally recolonize the placement areas. Per acre of enhanced habitat, the planting costs increased the total project costs by 4.6% at Ring Island, 3.4% at Fortescue, and 26.7% at Avalon.

Table 15. Comparison of Planting Costs

	Ring Island	Avalon	Fortescue
Planting	$19,000	$280,000	$142,000
Acres Planted	1.2 acres	18.86 acres	8.9 acres
$ per Acre	**$15,700**	**$14,850**	**$16,000**

Post-construction (non-monitoring) adaptive management activities were limited at the marsh enhancement sites and consisted of adjusting the planned planting design in the field in response to altered conditions on the marsh. Adaptive management/maintenance activities at the Ring Island ENH included vegetation removal and the placement of additional sandy dredged material; the costs of these activities are not available.

Discussion of Cost Analysis

The primary goal of this cost analysis was to help inform the development of similar future projects. While it would be useful to determine whether combining the two types of projects—dredging and habitat enhancement—would cost less than implementing them separately, this comparison is difficult because a wide range of site and project conditions affect project costs. In addition, total project costs are affected by project-specific objectives and, potentially, multiple project habitat components. These factors make it difficult to draw definitive conclusions about the costs of marsh enhancement/dredged material beneficial use projects. In addition, because pilot projects like these tend to be more expensive, future projects would cost less as they become more common and as dredged material placement volumes increase, due to factors such as less dredge downtime, more accurate placement procedures, and the ability to work safely at night.

However, the cost of these three pilot projects in New Jersey can be compared with the cost of other similar marsh enhancement projects elsewhere in the country. For all three pilot projects in New Jersey, the total project costs were $56,000 per acre at Ring Island, $342,200 per acre at Avalon, and $467,365 per acre at Fortescue (Table 11). In a recent paper, Bayraktarov et al. (2016) reported total restoration costs of salt marshes in developed countries in 2010 U.S. dollars (median: $61,160 per acre; average: $421,730 per acre), equivalent to 2017 U.S. dollars (median: $69,581 per acre; average: $479,800 per acre). However, it is unknown whether dredged material was used in the projects analyzed in that paper. The Nature Conservancy in Rhode Island (TNC-RI) recently completed a project along the Narrow River Inlet that used dredged material to increase the elevation of 30 acres of salt marsh. Unlike the New Jersey pilot projects, which were managed by multiple entities, TNC-RI was the sole project manager and contracting entity for the major project activities. To design, construct, and monitor that project, the estimated costs were $63.74 per CY dredged and $43,399 per acre restored (S. Cummings, personal communication). In another Rhode Island project at Ninigret Pond, about 20 acres of salt marsh were restored using dredged material at a cost approximately $24 per CY dredged and $80,978 per acre restored (C. Chaffee, RI Coastal Resources Management Council, personal communication).

Dredging in New Jersey, which is conducted by the state, USACE, municipalities, and private entities, also incurs a broad range of costs. Based on estimates from the NJDOT-OMR, traditional dredging projects, in which dredged material is pumped to a confined disposal facility (CDF), cost an average of $45 per CY (W. Douglas, personal communication). The costs of a recent dredging project conducted by the Borough of Avalon in New Jersey ranged between $33 per CY (excluding the cost to first empty the CDF) and $76 per CY (including the cost to empty a portion of the CDF). Dredging projects conducted by the USACE-OP typically cost $15 to $18 per CY dredged, not including any fees to empty an CDF, which can make a project prohibitively expensive (M. Chasten, personal communication). Although the per-CY total project costs of the Ring Island and Fortescue projects were significantly higher ($98 per CY and $152 per CY, respectively) they included all aspects of dredge material placement—design, construction, and monitoring—which are not part of a typical dredging-only project.

The question remains: Will combining dredging projects and marsh enhancement projects result in net cost savings, compared with separately implementing the projects? Also, would the marsh enhancement projects even be constructed if an associated dredging project did not need a non-traditional dredged material management option?

Since this is not an analysis comparing benefits and costs, the estimates of the benefits achieved (beyond acres of marsh enhanced) do not include the full economic value of the beneficial use of dredged material for salt marsh enhancement. Marshes provide many monetary benefits that are difficult to measure, including water filtration, nursery habitat for most commercially and recreationally harvested fish and shellfish, wave attenuation, and storm-surge reduction. These ecosystem services would be lost—and the coastal ecosystem would be less resilient—if stressed marshes were not restored and ultimately disappeared. Also, similar projects in the Gulf of Mexico show that as more coastal restoration projects are implemented, they have the potential to support businesses and could lead to the creation of new jobs, opportunities for workforce development, and innovation (Lowe et al. 2011; Stokes et al. 2012).

Factors Influencing New Jersey Pilot Project Costs. A variety of factors influenced the difference in cost among the three pilot projects, especially between Fortescue and Avalon. However, the project team cannot definitively state the extent to which each factor affected the total cost of the projects. Total project costs, development and design costs, and construction costs per CY dredged varied among the projects by a factor of 2.7 to 3.8, but varied by a factor of 6.9 to 9.6 per acre of habitat enhanced (Table 10). In addition, while the dredging cost per CY varied by a factor of 3.8, the dredging cost per acre of habitat enhanced varied among the projects by a much larger factor (9.6). This suggests that the major cost variables for these types of projects are not the volume of dredged material placed, but instead site- and design-specific characteristics, as well as the objectives, of the marsh enhancement projects. Several differences in scope, design, and contracting between Avalon and Fortescue may have contributed to the higher relative costs at Fortescue (Table 16). These differences include:

- *Number of Design Elements.* The Fortescue project consisted of three components: marsh enhancement, dune restoration, and beach restoration. This required additional costs in design and engineering, project oversight and management, and mobilization of the dredging equipment.
- *Sediment Analysis.* The sediment sampling costs were likely lower at Fortescue because (1) the volume of sediment to be dredged was smaller, (2) some of the sediment samples from the navigation channel were greater than 90% sand and thus needed no additional chemical testing, and (3) the placement areas were smaller so fewer samples were needed from the marsh. In addition, at Avalon there were two separate rounds of sampling and analysis of sediments from both the NJIWW and the marsh.

- *Engineering.* At Fortescue, more designs were needed, one for each of the three components: marsh, dune and beach. In addition, the marsh enhancement component had more design elements than the marsh enhancement designs for the Ring Island and Avalon projects. Also, Winter Storm Jonas eroded the existing shoreline, resulting in the need to update the dune restoration design.
- *Permitting.* The USACE does not issue permits to itself for dredging navigation channels, so the permitting costs were lower for the Ring Island and Avalon projects than for the Fortescue project. Note, however, that the permitting costs for these two sites did not include the cost to the USACE of preparing the NEPA Environmental Assessment for the projects. The Fortescue project required permits from both the NJDEP and USACE (which would be the case for most future similar projects). In addition, the re-design of the Fortescue dune restoration required permit modifications.
- *Designed vs. As-Built.* The Fortescue marsh enhancement project was expected to be approximately 22 acres in size and, therefore, the initial monitoring, design, and containment was for this area. However, weather and contracting delays reduced the final placement area to only 6.6 acres; thus, the final per-CY and per-acre costs were much higher.
- *Type of Dredging Contract.* The cost of projects can be greatly influenced by the type of contract used, the contracting process, the assumption of cost risks, and the design of the project. For the Avalon project, the dredge was leased on a per-day basis. Therefore, the USACE-OP absorbed the cost of dredge downtime (these costs are included in the cost analysis) when dredging was stopped (e.g., to let the dredged material settle, during inclement weather). For the Fortescue project, the dredging contractor was under NJDOT-OMR's performance-based contract, which paid by dredged material volume and some other line-item project expenses (e.g., containment). Therefore, to be paid the total contract amount, the dredge contractor needed to complete the entire job. Thus, while the USACE-OP assumed some of the "risk" and associated costs of the Avalon project (lowering the costs to an unknown degree), these "risks" were assumed by the dredge contractor at Fortescue (increasing the costs to an unknown degree). In the proof-of-concept stage of projects that use dredged material to enhance salt marshes, a per-day lease-of-plant dredging contract, rather than the typical performance-based contract, may be more economical. With the per-day contract at Avalon, the risk of unexpected costs was borne by USACE-OP; with the performance-based contract at Fortescue, the risk was borne by the dredge contractor. Many factors remain unknown for these types of projects, such as design costs, dredged material placement duration, and dredged material settlement time. At Avalon, because the dredge company was paid regardless of whether it was dredging, the company was willing to stop dredging when needed and let the project team experiment with a variety of placement methods at locations within the larger placement area. This also led to a more collaborative relationship between the dredge company and the project team, further fostering innovation.
- *Containment*. At Fortescue, containment costs per CY dredged ($18.16) and per acre of habitat enhanced ($56,060) were substantially greater than at Avalon ($3.90 per CY and $4,840 per acre). At Fortescue, containment consisted of a double row (with some stacking) that was installed around a 22-acre placement area, but only 6.6 acres received sediment. At Avalon, containment

consisted of only a single row, and it was not needed around the entire perimeter because the existing topography and vegetation in some areas of the Avalon site provided a natural barrier to slurry runoff.

Costs of Each Project Phase Compared with Total Project Costs (Table 17). Construction was the greatest cost (63%–80% of total project costs), with dredging and dredged material placement, combined, accounting for 52%–60% of total project costs. As a percentage of the total project costs, sediment sampling, containment, and planting varied with each project. However, at most, any one of these activities accounted for no more than 12% of the total project costs.

Table 16. Comparison of Design and Construction Costs for Avalon and Fortescue			
Factor	**Avalon**	**Fortescue**	**Notes**
Amount of dredged material	55,300 CY	32,100 CY	Larger projects potentially cost less per CY than smaller projects
Area of habitat enhanced	~45 acres	~10.4 acres	Fortescue: did not construct all that was designed and prepared
Project components	Marsh only	Marsh, dune, and beach	Fortescue: more designs and equipment mobilizations
Engineering	Marsh only	Marsh, dune, and beach	Fortescue: additional design components
Permitting	NJDEP only*	NJDEP and USACE permits	Fortescue: permit modification needed for dune
Type of dredging contract	Lease-of-plant (USACE-OP)	"Typical" (NJDOT-OMR)	USACE-OP: $/day NJDOT-OMR: $/CY dredged
Dredge mobilization	Coordinated with other projects	Multiple mobilizations	Avalon: dredge "shared" with 5 other USACE-OP projects
Containment	Single row Coconut-fiber logs	Double row Filtrexx SiltSoxx™	Fortescue: fewer acres contained. Avalon: more linear feet

*Environmental Assessment conducted by USACE pursuant to NEPA.

Table 17. Comparison of Total Project Costs for Marsh Enhancement/Dredged Material Beneficial Use Pilot Projects			
PROJECT PHASE			
	Ring Island	**Avalon**	**Fortescue**
Total Costs	$684,000	$2,503,000	$4,861,000
Phases 1, 2 & 3: Development, Design, and Permitting	6%	12%	10%
Phase 5: Construction	63%	70%	80%
Phase 7: Monitoring	31%	18%	10%
PHASE SUB-COMPONENTS			
Sediment Sampling	0.7%	6%	3%
Dredging	58%	52%	60%
Containment	2%	9%	12%
Planting	3%	11%	3%

Supplemental Cost Analysis: Mordecai Island

Another project conducted by the USACE-OP offers additional insights into the costs of using dredged material for marsh enhancement/restoration. Mordecai Island is a 45-acre uninhabited coastal salt marsh island located in Barnegat Bay (Ocean County, NJ). It supports a variety of breeding and migratory bird species, including American oystercatchers and black skimmers. The western shorelines of the island have eroded significantly, and a large cut has formed on the northwestern section, dividing the island into two segments. The island is adjacent to a section of the NJIWW that required dredging. Although this project differs from the three pilot projects in that dredged material was not placed on an existing marsh, it is nevertheless useful for comparing costs.

Led by the USACE-OP in 2015, the Mordecai Island project aimed to restore the island by connecting its two segments. Approximately 25,000 CY of sandy dredged material from the NJIWW channel was used to bring the gap between the two sections up to the elevation of the adjacent marsh. To hold the placed dredged material in place during construction, the dredging contractor used project-specific placement techniques, a small track loader, and a turbidity curtain along the along the eastern side of the placement area to protect submerged aquatic vegetation. (The curtain was jetted into the bay bottom and floated with the tides.) No containment was used on the western edge of the placement area, allowing water from the hydraulically placed dredged material to drain from the site. The placed dredged material raised the elevation approximately 3.5 ft (a range of -1 ft to +2.5 feet MLW) to better stabilize the placement area. The site was planted in May 2016.

Compared with the three pilot projects, the Mordecai Island project cost less ($33) per CY dredged, but the range of costs per acre of marsh enhanced were comparable ($277,800) (Table 18). The use of less containment at Mordecai Island contributed to this difference. Factoring in an additional $85,000 in planting costs on Mordecai Island, the cost of the project was approximately $37 per CY dredged and $305,200 per acre enhanced. As was the case for the three pilot projects, construction accounted for the highest percentage (82%) of total project costs, with the primary construction cost being dredging and dredged material placement. The cost per CY dredged and per acre restored for the Mordecai Island project are comparable with both routine dredging and marsh enhancement projects.

At Mordecai Island, many cost efficiencies were realized due to the design of the project, contracting strategies, and the dredging and dredged material placement techniques. Pre-construction data were collected (i.e., baseline monitoring), including marsh biological benchmarks (elevation of plant communities), physical and chemical characteristics of sediment, topography, and hydrography. Additional data from a separate USACE planning study of the island (USACE 1135 Ecosystem Restoration Investigation) also informed the design; this study provided most of the ecological assessment data that were used to support permitting for the project. Post-construction monitoring, which is ongoing, includes topography, hydrography, and bird nesting, as well as other data collected by other agencies and partners.

Table 18. Total Costs of the Mordecai Island Project	
Development and Design	
Ecological Assessment (Initial Marsh Condition)	$0
Sediment Sampling	$90,000
Engineering Design	$15,000
Permitting	$20,000

Total	***$125,000***
Construction	
Oversight/Management	$31,000
Dredging	$558,000
Containment	$91,000
Total	***$680,000***
Monitoring	
Topography, Avian, Vegetation	**$25,000**
Total	***$25,000***
Total Cost	**$830,000**
Total Volume Dredged	25,000 CY
Cost per CY	**$33**
Total Area Enhanced	3 ac.
Cost per Acre Enhanced	**$277,833**

Cost Analysis Summary

The project team conducted this high-level cost analysis to better understand the major costs of projects that use dredged material to enhance salt marshes and to inform discussions about the possible cost savings of combining dredging projects with marsh enhancement or restoration projects. Costs are unique to each individual project and are affected by many variables, some of which cannot be controlled (e.g., weather). As more projects like these are implemented in New Jersey and throughout the Northeast, more information-sharing may reduce the costs of design, permitting, construction, and monitoring. Additional research into the costs and benefits of these types of projects may inform decisions about the value of restoring and enhancing salt marshes, and reveal whether combining project types is a more cost-efficient way to accomplish multiple ecological, economic, and social goals.

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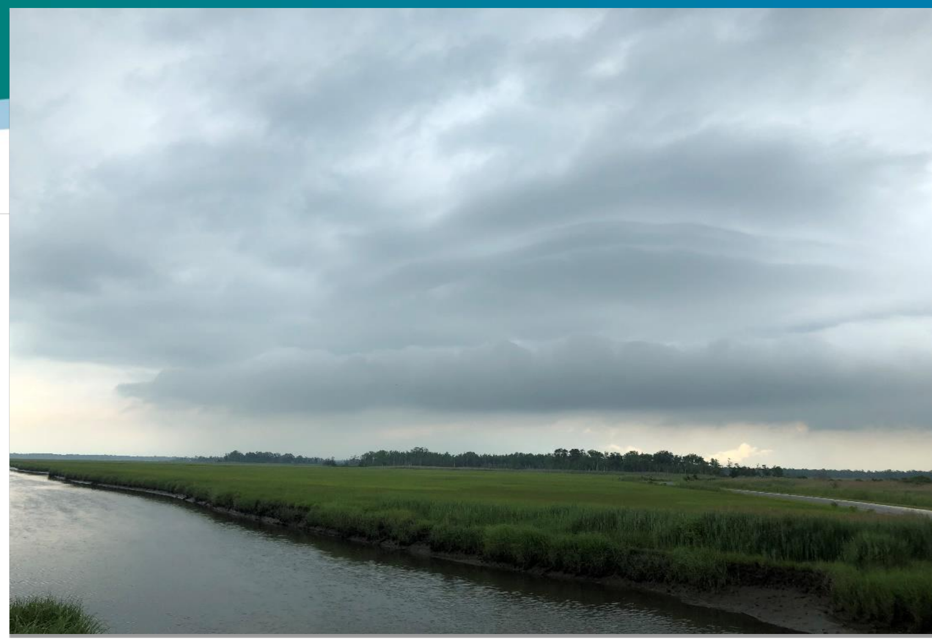
Appendix C



User Guide for the Site-Specific Salt Marsh Decision Support Tool

Prepared by the Partnership for the Delaware Estuary in Conjunction with New Jersey Department of Environmental Protection

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User Guide for the Site-Specific Salt Marsh Decision Support Tool

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Partnership for the DELAWARE ESTUARY

The Partnership for the Delaware Estuary brings together people, businesses, and governments to restore and protect the Delaware River and Bay. We are the only organization that focuses on the entire environment affecting the river and bay — beginning at Trenton, including the greater Philadelphia metropolitan area, and ending in Cape May, New Jersey and Lewes, Delaware. We focus on science, encourage collaboration, and implement programs that help restore the natural vitality of the river and bay, benefiting the plants, wildlife, people, and businesses that rely on a healthy estuary.

Version History

Site-Specific Salt Marsh Decision Support Tool version 1.0……………………………...March 2020

User Guide provides description and guidance on using version 1.0 of the Decision Tool. Version 1.0 incorporates feedback from one workshop (held in July 2019).

Acronyms and Abbreviations

Acronym/Abbreviation	Description
MACWA	Mid Atlantic Coastal Wetland Assessment
SSIM	Site Specific Intensive Monitoring
MidTRAM	Mid-Atlantic Tidal Rapid Assessment Method
USGS	United States Geological Survey
USDA NRCS	United States Department of Agriculture National Resource Conservation Service
DD	Deficiency Detected
NDD	No Deficiency Detected
FER	Further Evaluation Required
LiDAR	Light detecting and ranging (elevation survey method)
RTK-GPS	Real-time kinematic global positioning system
MHW	Mean high water
SLR	Sea level rise
VIMS-CCRM	Virginia Institute of Marine Science – Center for Coastal Resource Management
FEMA	Federal Emergency Management Agency
NOAA	National Ocean and Atmospheric Administration
ESA	Endangered Species Act
T&E	Threatened and/or endangered
EFH	Essential Fish Habitat
SMI	U.S. Fish and Wildlife Service Salt Marsh Integrity

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Introduction

Background

Salt marsh acreage decline, ushered by a legacy of human disturbance and climate change, is a principal concern to natural resource stakeholders in New Jersey. Salt marshes provide valuable ecosystem services, such as storm water attenuation, carbon sequestration and storage, and essential habitat to a myriad of endemic and transient species. As acreage is lost, these ecosystem services contemporaneously diminish, and therefore, intervening losses is a high priority. Some salt marshes, however, are more vulnerable to immediate loss. Identifying these priority locations is critical to successful statewide resiliency strategies given limited financial resources. It is difficult, however, to conceptualize and systematically assess the vulnerability of a salt marsh to the suite of stressors that it may experience, such as rapid shoreline erosion or sea level rise, which could climb to a rate of 10 $mm \cdot yr^{-1}$ by 2100 (Kopp et al. 2016; Callahan et al. 2017). A consistent means for the diverse group of stakeholders (ecologists, engineers, geologists, regulators, managers, *etc*...) to identify salt marsh vulnerability and prioritize intervention opportunities is therefore an important component of resiliency strategies across the salt marshes of New Jersey.

The Site-Specific Salt Marsh Decision Support Tool, hereafter the "Decision Tool," is a framework that integrates a variety of data regarding a suite of attributes shown to be fundamental to proper salt marsh function. It is able to accommodate data from a variety of sources, and provides an evidence-based determination of site-specific deficiencies. The Decision Tool was developed with two objectives. The first objective was to create a systematic approach to evaluate current and projected marsh conditions (*e.g.*, excessive erosion, elevation deficits, hydrological impairment) relative to a variety of salt marsh attributes. It was intended for the Decision Tool to be a platform for translating quantitative findings into easily communicated assessments of site-specific deficiencies and potential intervention needs. The second objective was to align the Decision Tool with common regulatory concerns to assist practitioners in providing a thorough, thoughtful explanation of the current and projected conditions that might relate to the missions of a variety of agencies (*e.g.*, Army Corps of Engineers, National Marine Fisheries Service, U. S. Fish and Wildlife Service, and the State of New Jersey). To facilitate this objective, the Decision Tool includes a checklist that includes a subset of data required for some common permit applications that synthesizes with requirements within the Decision Tool's framework. Although the Decision Tool does not fulfill all of the guidance needs associated with project implementation, it provides guidance to begin a dialogue about consistent data collection and interpretation related to resiliency intervention efforts that can evolve as new needs or interests arise.

Existing Resources, Tools, and Data Products

Many tools and data products currently exist to help restoration practitioners quantify site-specific metrics of interest, but they tend to focus on a singular metric or outcome (*e.g.*, habitat quality, inundation, erosion). As such, many of these existing tools or data products do not consider the variety of feedbacks that contribute to marsh function and therefore do not provide integrated diagnoses of current and future states. Although common multi-metric monitoring protocols, such as rapid assessments (*e.g.*, Mid-TRAM), integrate several metrics to score overall health, these relative, instantaneous measures were not intended to identify areas that may be suitable for restoration activities. Further, there is no framework integrating the abundance of available tools. Yet, an overall assessment of current and future site-specific salt marsh function is a necessary step to develop holistic coastal resiliency strategies and enhancement efforts with multiple working goals (*e.g.*, marsh drowning prevention *and* bird nesting habitat protection).

Existing tools and products to help restoration practitioners quantify metrics of interest include:

- Aerial imagery and LiDAR are available in many coastal states to quantify shoreline position and differences in land cover (https://coast.noaa.gov/dataviewer/#/)
- U.S. Fish and Wildlife Service Section 7 Information for Planning and Consultation tool streamlines the threatened and endangered environmental review process to identify site-specific concerns (https://ecos.fws.gov/ipac/)
- Coastal Resilience Mapping Portal provides information on variety of shoreline and near-shore metrics in combination with sea level rise projections, and then relates them to shoreline stabilization options (https://maps.coastalresilience.org/)
- New Jersey Flood Mapper is an interactive mapping portal that visualized flooding hazards over a variety of sea level rise scenarios (http://www.njfloodmapper.org/)
- NOAA Office of Coastal Management Digital Coast Sea Level Affecting Marshes Model provides predictions of long-term sea level rise on wetlands and shorelines (https://coast.noaa.gov/digitalcoast/tools/slamm.html)
- NOAA Office of Coastal Management Digital Coast Sea Level Rise Viewer provides information on the community-level impacts from coastal flooding and/or sea level rise (https://coast.noaa.gov/digitalcoast/tools/slr.html)
- Environmental Defense Fund Habitat Quantification Tool evaluates habitat quality and quantity for a species of interest (https://www.edf.org/ecosystems/habitat-quantification-tool)

Additionally, many available decision support tools utilize large, temporally coarse data that focus on edge stabilization needs and not overall marsh health (*e.g.*, Shoreline Management Tool and Undefended Shoreline Decision Tool). If lateral erosion is the primary deficiency of a salt marsh of interest, guidance is available regarding living shoreline design and implementation. Although shoreline stabilization supports salt marsh persistence, lateral erosion does not always drive changes in functionality, and therefore these tools and guidance documents do not capture various salt marsh platform dynamics. Available decision tools focused on edge stabilization include:

- VIMS-CCRM Undefended Shoreline Decision Tool (http://www.ccrm.vims.edu/decisiontree/undefended.html)
- VIMS-CCRM Shoreline Management Model (https://www.vims.edu/ccrm/ccrmp/bmp/smm/)
- NOAA Guidance for Considering the Use of Living Shorelines

(https://www.habitatblueprint.noaa.gov/wp-content/uploads/2018/01/NOAA-Guidance-for-Considering-the-Use-of-Living-Shorelines_2015.pdf)

- FEMA Bioengineered Shoreline Stabilization (https://www.fema.gov/media-library-data/1532021309766-274c41b3c5ed9c1e6e2150b16166e2c0/BioengineeredShorelineStabilizationJobAid.pdf)

- Steven's Institute of Technology Living Shorelines Engineering Guidelines (https://www.nj.gov/dep/cmp/docs/living-shorelines-engineering-guidelines-final.pdf)

Site-Based Salt Marsh Decision Tool Goals

The Site-Based Salt Marsh Decision Tool standardizes the integration and interpretation of site-specific data, collected using scientifically defensible methods, via evidence-based evaluation of whether a variety of salt marsh attributes exhibit, or are forecasted to exhibit, signs of deficiency. There are two intended audiences: those planning restoration projects (*e.g.*, restoration practitioners, municipalities) and those evaluating the merits of proposed projects (*e.g.*, regulatory agents, funding agencies).

- **Restoration Project Planning:** For those planning restoration projects, this tool will guide the user in considering the primary attributes influencing salt marsh function, and identifying qualities that are likely either currently deficient, on a negative trajectory, or both. The output of this tool will inform the user whether there is enough evidence to further consider an intervention project, and discuss this potential with landowners, funding agencies, and regulatory agents. Additionally, it will facilitate the gathering and documentation of pertinent regulatory information (*e.g.*, endangered species, critical habitat) prior to regulatory conversations and/or application submission.

- **Proposed Project Evaluation:** For those evaluating proposed projects, this tool will summarize the data-based findings of site evaluation and present them alongside justifications for all data selection/collection activities and decisions.

Decision Tool Approach

The Decision Tool integrates data produced from any source (personally collected or referenced) to gain a holistic understanding of site-specific salt marsh condition. The Decision Tool itself is an interactive spreadsheet into which the user enters data regarding the current state and rates of change of each described attribute (Fig. 1 Box 1; see following section for definitions).

For each attribute, the user chooses a single metric and enters quantitative data regarding its current state (Fig. 1 Box 2). The Tool automatically evaluates these data against criteria standards (Fig. 1 Box 3). Criteria standards are values that the user deems *a priori* to be appropriate or acceptable for the associated metric. If the metric does not meet the criteria, a violation for that attribute occurs (Fig. 1 Box 5, 7). The user can also provide trajectory information for selected metrics (Fig. 1 Box 4), which the Tool evaluates by calculating a projected value for the metric under a user-selected time frame (Fig 1. Box 6). If trajectory data surpass the defined criteria given a certain amount of time, declining function results in a trajectory violation for that attribute (Fig. 1 Box 8).

Finally, for each attribute, the Tool summarizes unique combinations of criteria and trajectory violations to discern whether each attribute is meeting functional requirements today, and is projected to do so within a future time frame (Fig. 1 Box 9).

Attribute violations are then integrated into a singular output (Fig. 1 Box 10) which classifies the weight of evidence at the site as: "Deficiency Detected"; "Further Evaluation Recommended", or "No Deficiency Detected" (Fig. 1 Box 11). The Tool then prompts the user to interpret violations, reflect on how the various conditions influenced the output, and how those results may support recommendations for intervention.

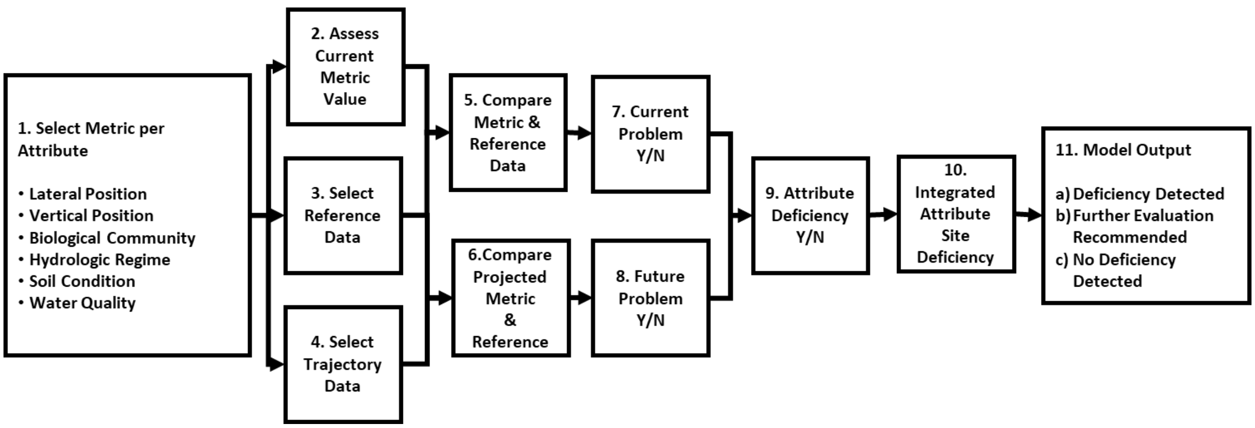

Figure 1**.** Workflow for the Site-Based Salt marsh Decision Tool.

Salt Marsh Attributes

Salt marshes develop as a result of several, interactive factors, like inundation, elevation, and plant production, which culminate to produce a platform with robust vegetation (Fig. 2). For the purposes of this Decision Tool, these dynamic factors, or attributes, represent measurable qualities of a marsh (Table 1) empirically shown to be fundamental for proper and resilient salt marsh function. Attributes represent different, yet equally important, aspects of salt marsh persistence. An important part of the Decision Tool is that it integrates information from multiple attributes to provide a holistic assessment of condition.

Attributes consists of a suite of metrics, each of which have defined methods for data collection. Each metric falls under a larger category related to the type of information it represents, but a method describes precisely how a user collects those data. For instance, elevation is a metric related to the overall category of vertical position, but users can obtain elevation data using a number of different methods such as on the ground surveys or LiDAR.

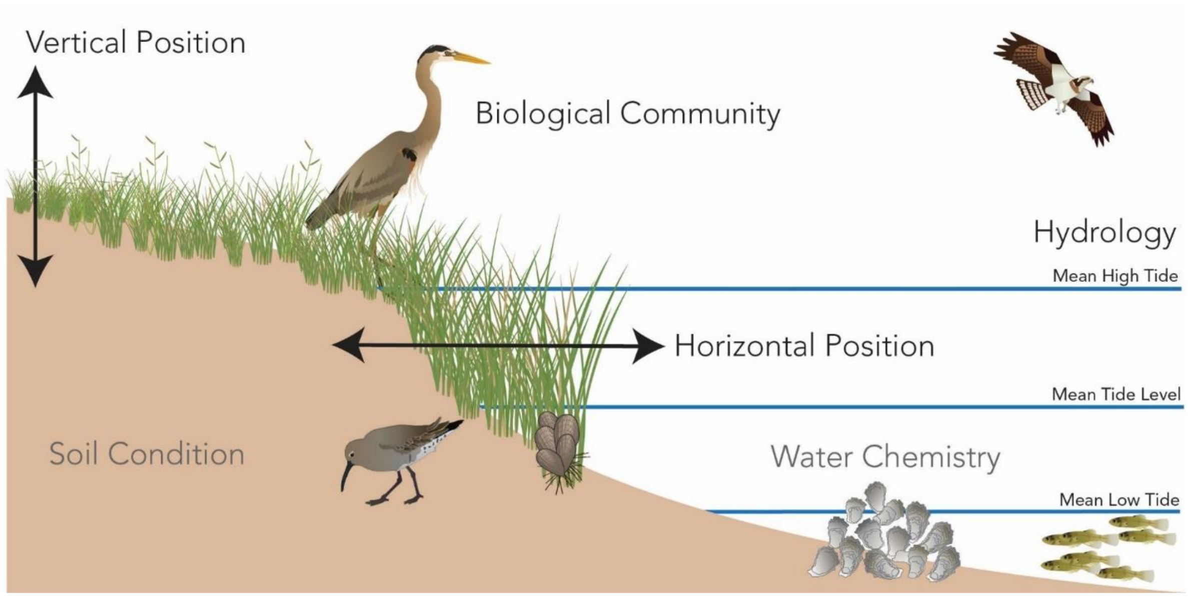

Figure 2. Attributes of the Decision Tool

Future salt marsh persistence, given a number of possible vulnerabilities, is dependent on adequate functioning, good condition, and resilience (Table 2). Interplay among physical, biological, and chemical factors results in changes to salt marsh function, vulnerability, and resilience over various temporal and spatial scales. For example, changes in platform inundation affects plant production and sedimentation. Alterations to certain functions might result in decreased condition, and affect the long-term ability of a marsh to sustain or regain performance and functionality over time.

To determine intervention suitability for a site, it is therefore critical to:

- **Evaluate** current conditions;
- **Isolate** underlying mechanisms of inhibited functioning;
- **Diagnose** current and future vulnerabilities; and,
- **Consider** the overall prognosis of the system through time.

Table 1. Attributes and associated metrics of the Decision Tool

Attributes and *metrics*	Description	Exemplifying Citations
Horizontal Position *Shoreline Position* *Reference Position*	Description of the lateral position of a feature of interest (*e.g.*, waterward edge, salt marsh scarp, contiguous vegetation line).	Haaf et al. 2017; Donnelly and Bertness 2001
Vertical Position *Elevation* *Foreshore Slope*	Features that describe, relate to, or influence elevation.	Cahoon and Guntenspergen 2010; Lynch et al. 2015
Biology *Vegetation Productivity* *Habitat* *Flora or Fauna* *Presence or Absence*	Description of the living community of interest at a site.	Cahoon et al. 2002; Morris et al. 2002; Ganju et al. 2017; Shriver et al. 2015
Hydrology *Tidal Restriction* *Drainage* *Groundwater*	Description of how water moves in relation to various features of a site.	Cahoon and Guntenspergen 2010; Cahoon 2015; Payne et al. 2019
Soil Condition *Accretion Rate* *Soil type*	Qualities of a site related to either sediment or *in situ* substrate characteristics.	Cahoon and Guntenspergen 2010; Lynch et al. 2015
Water Chemistry	Description of the water components of interest at a site.	Deegan et al. 2012

Table 2. Important Terminology Used in the Decision Tool Framework

Term	Definition	Examples
Function	Functions represent ways an ecosystem or habitat manages energy (*e.g.*, abiotic to biotic energy transfer) or resources (*e.g.*, sediments, light, nutrients). Functions, often communicated as rates, operate on specific time scales (*e.g.*, years, decades, centuries). A function also translates into a service if human communities directly benefit from its performance.	Keeping pace with SLR Trapping sediment Providing habitat for fauna Plant utilization of CO_2 or nutrients Attenuating waves Bacteria transforming nutrients
Condition	A practitioner assigns a condition value based on some belief of how the system is functioning with respect to a specific quality or an idealized service. For clarity, it is important to couple a condition with the quality it describes because a marsh may have multiple condition states, which depend on the perspective of the practitioner. For instance, a tract of *Phragmites australis* may be in good condition relative to carbon sequestration, but on the other hand, its condition may be poor relative to avian community diversity.	This salt marsh… "… has *dense vegetation*, and so, it is in *good condition*." "… traps a *substantial amount of sediment*, so it is in *good condition*." "… *does not support a robust bird community*, and so, it is in *poor condition*." "…has numerous, widening ditches, and so it is in *poor condition*."
Vulnerability	Vulnerability is the susceptibility of a function to changes brought by specific, often exogenous, impacts or stressors. Vulnerabilities are hypothetical, but educated, and include considerations for the future. When an impact occurs, or as it occurs through time, it is a disturbance. The change in marsh condition following a disturbance is a measure of the system's vulnerability to that type of impact.	*"This salt marsh is vulnerable to…":* Storm Erosion · Development Species Extinctions Drowning by SLR · Subsidence Non-native Invasions Nutrient Loading · Fill · Disease Diversity Loss · Contaminants
Stability	Salt marsh stability is its long-term persistence, often gauged by degrees of observed change.	"This salt marsh is *stable* because its areal extent *has not changed for 75 years*."
Resilience	Resilience is an estimate of how quickly a system recovers after a particular disturbance.	"This salt marsh is *resilient to storm surge* because it returned to its *previous condition within a year*."

Metrics and Methods

For each attribute, the Tool directs the user to provide site-specific data on a single metric, which may have multiple associated methods for data collection (see Appendix A for a brief inventory of methods). The Decision Tool's list of recommended metrics and methods are commonly used among both local and national restoration practitioners. All metrics and methods align with the Framework for Developing Monitoring Plans for Coastal Wetland Restoration and Living Shoreline Projects in New Jersey and the Developing Monitoring Plans for Living Shoreline Projects in Delaware: A Goal-Based Framework. Additionally if a project is implemented at the site of interest, data collected during this exploratory stage of site assessment can be used as a time series to evaluate results through project monitoring (Fig. 3).

Figure 3**.** Metrics and methods in the Decision Tool are the same as those described in project monitoring frameworks. Data collection efforts can transition smoothly from site assessment to project monitoring.

Criteria Standards, Trajectories, and Required Justifications

Criteria Standards

Criteria standards are conditional rules (*i.e.*, values) established by the user that the Tool evaluate site-specific data against to identify functional deficiencies. Users input what they consider to be acceptable criteria standard values into the spreadsheet for each metric per attribute. For example, when evaluating a site for the persistence of a specific vegetation that is required for a specific nesting bird, the desired vertical position may be between -0.25 m and 0.75 m relative to mean high water (MHW). These data represent the standard against which the Tool will compare the *in situ* data. If an RTK-GPS survey is used to evaluate the current elevation of the site shows the mean elevation is 0.5 m MHW, then it is within the bounds of the user-chosen criteria standard.

Allowing criteria standards to be user-defined provides flexibility for comparative analysis but also supports consistency in the analytical evaluation of current site-specific conditions. Since the user can define the criteria standard thresholds, there is opportunity to accommodate a variety of criteria standard values thus allowing the user to gauge the appropriate requisite reference data for their specific site. For example, for the lateral shoreline change metric (Horizontal Position attribute), a "local" average range of erosion rates may be between 0.5 m and 3.5 m per year as measured by an entity across a variety of local sites. If the goal is to maintain the shoreline at its current position, the criteria standard minimum and maximum thresholds can both be set to 0 m. If the user decides that further erosion is unacceptable but progradation is acceptable, users can set the thresholds to 0 m and 1,000 m. Setting thresholds in this fashion allows for positive position changes (*i.e.*, seaward) for this particular attribute, but also allows for bi-directional threshold setting for all attributes. Importantly, thresholds defined by the criteria standards are for evaluation only and are not enforceable through regulatory action. As users may derive reference data from different sources, the Decision Tool defines three types of criteria standards: quality, reference, and target criteria. Each standard represents a unique data type and reflects a specific intention of the user.

- **Quality Criteria Standard:** Quality criteria represent optimal values or levels of function that have been peer-reviewed or otherwise published in a high-standard format (*e.g.*, scientific publication, textbook, regulatory report). In the nesting bird habitat elevation example, if optimal elevations of -0.25 m and 0.5 m MHW were published in a peer-reviewed journal, these values would represent a quality criteria standard. Professionals including scientists and practitioners comprehensively assess these data, but they ultimately may lack site-specificity or broader replication.

- **Reference Criteria Standard:** Reference criteria are thresholds based on distributions of data from representative sites (*e.g.*, similar in salinity, tidal range, habitat type). Users can source these data from public or proprietary databases, or from studies conducted at other representative sites. Reference criteria standards typically represent an "average" function or range for a metric. Although site-specific and usually highly replicated, these data may lack formal review. The average erosion rate between 0.5 m – 3.5 m described in the example above, represents a reference criteria standard.

- **Target Criteria Standard:** Target criteria standards represent a specific metric value or range that the user requires at the site. The decision to set acceptable erosion rates at 0 m per year described in the erosion example above, represents a target criterion standard.

Trajectories

A trajectory represents the best scientific evidence of a rate of change for a given metric. For the appropriate application of restoration efforts, it is important to not only understand current site function, but also where that condition lies on a continuum over time. Disturbances can have large or small impacts on salt marshes, from which recovery time can be of a long or short duration (Fig. 4). Additionally, current site conditions may not be indicative of its long-term prognosis. Salt marshes that display reasonable function but are on a downward trajectory may be susceptible to future impairment without intervention. Conversely, salt marshes that exhibit a current deficiency but are on an upward trajectory may be recovering naturally, and an investment of limited resources at this location may be impractical.

Trajectory information may be difficult for a site evaluation team to collect *in situ* for a particular project, but locations monitored over time may greatly benefit from these data. Trajectory data, although helpful, is not required for the Decision Tool to operate. If no appropriate trajectory data are available, the model will evaluate the current data relative to the user-selected criteria standard. Although relatively coarse in terms of data resolution, several resources to help gauge broad changes over time through modeled outputs are currently available online through federal, state, or private databases (Appendix A).

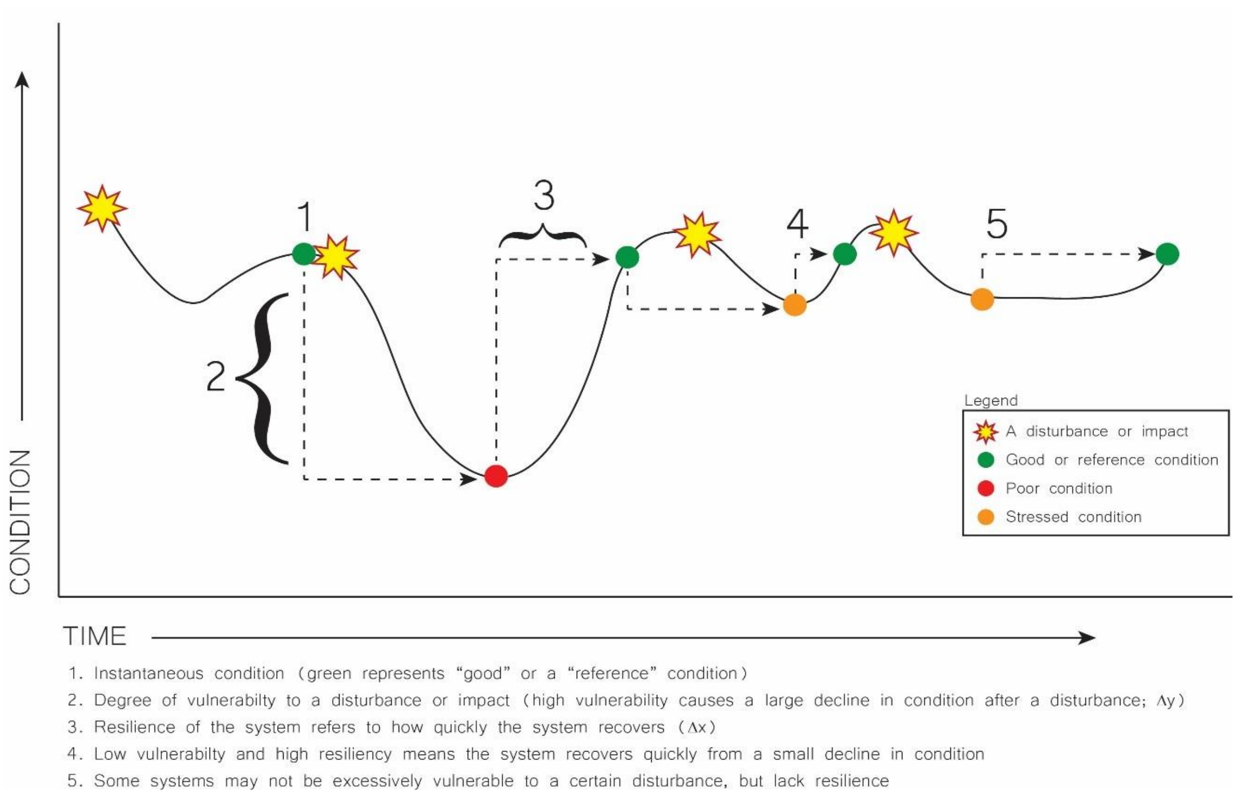

Figure 4. Schematic of salt marsh trajectory change as a result of disturbance over time.

Required Justifications

Justifications are required for each evaluated metric. These justifications should describe the spatial and temporal resolution of the data collected and/or the rationale regarding certain values/criteria. By filling out the justification portion of the attribute table, reviewers of the document can more easily determine if the data in the Tool is the best representation of current site-specific conditions (e.g. were most up-to-date values utilized). Tracking rationale and decision-making methods within the Tool helps clarify and organize the user's thought process. This facilitates communication between the user and other stakeholders (*e.g.*, regulatory and/or funding agents). The following justifications are required for all metrics in order for the Tool to evaluate each attribute:

- **Current Condition Measurement Justification:** A description as to why the user's selected method and its associated value represents the current conditions at the site.
    - Example: The values collected for the RTK-GPS survey of shoreline position were collected one month prior to evaluation at 0.25 m intervals along 1,000 m of shoreline with ±3 mm horizontal and ±7 mm vertical accuracy, and as such are representative of the current shoreline position.
- **Criteria Standard Justification:** A description as to why the user chose the type of criteria standard (*i.e.*, quality, reference, or target) as well as why the selected values are acceptable or reasonable.
    - Example: The range of elevation values acceptable for high marsh position were calculated as an average from three peer-reviewed studies conducted locally over the last five years.
- **Trajectory Justification:** A description of the source for the chosen trajectory data, and why it should be considered representative of the changing conditions at the site.
    - Example: The range of values used for elevation trajectory at the site, were averaged from changes documented at six local Sediment Elevation Tables over the past five years.
- **Forecasted or Projected Metric Justification:** A description of the user's reasoning to select the number of forecast years.
    - Example: Thirty years was selected as the forecast time frame as sea level rise projections past 2050 contain a larger margin of error than the evaluation team was comfortable using.

All justifications must be filled out for the Decision Tool to run calculations, including justification for absent data types. For instance, the justification of absent trajectory data should note that trajectory data was not included because there were no appropriate data for the site.

Violations

Violations indicate that either the current or projected state of an attribute lays outside the acceptable bounds of the user-defined conditional rule (*i.e.*, criteria), and therefore there is evidence of current or future diminished function. Three types of violations are evaluated by the Decision Tool: criteria standard, trajectory, and attribute.

Criteria Standard Violation

A criteria standard violation is indicates that the current functionality of an attribute is diminished. This type of violation occurs when the measured metric value for a particular attribute exceeds the user selected criteria range. For example, if the user measures an elevation metric value of -0.01 m MHW (vertical position attribute) and the quality criteria standard range is -0.5 m to 0.0 m MHW, then the measured (input) value did not violate the criteria standard. The measured metric value would only raise a violation if it was outside (above or below) the range of the criteria standard.

Trajectory Violation

A trajectory violation indicates that the projected functionality of an attribute will be diminished over the user-selected time frame. This type of violation occurs if the change in forecasted metric value (see Appendix B for this calculation) falls outside the criteria standard range. For example, if the proportional area of a particular habitat type (i.e. high marsh) at a site is currently measured to be 45%, and the trajectory was measured to be between -2% to -1% yr^{-1} (negative value indicates a decrease in habitat area), the expected range of proportional area after 10 years would be 25% and 35%, with a mean of 30%. Hypothetically, if this habitat needed to comprise 40% and 50% of the total area to be effective (quality criteria standard), the forecasted proportional area would be outside the bounds of the criteria standard and a trajectory violation would occur.

For the vertical position attribute, there is an additional step that incorporates sea level rise (SLR). To calculate the vertical position relative to a tidal datum under rising sea level, the SLR rate is multiplied by the number of forecast years. The Tool uses this value to adjust the predicted elevation relative to a tidal datum. If the elevation trajectory of the site was between -0.05 m to -0.01 m yr-1, the expected range of metric values after 10 years would be -0.5 m to -0.1 m MHW, with a mean change estimate of -0.3 m MHW. If a 4 mm SLR factor is also applied, the relative elevation range would be -0.9 m to -0.5 m MHW, with a mean estimate of -0.7 m MHW. Using the criteria standard range described above of -0.5 m to 0.0 m MHW, the predicted elevation based on the trajectory data would be outside the bounds of the criteria standard, and thus a trajectory violation would occur.

Attribute Violation

An attribute violation occurs when unique combinations of current criteria standard and trajectory violations occur. The violation combinations that trigger an attribute violation are not consistent across attributes (Table 3).

- **Horizontal Position:** A horizontal position violation occurs when there is either a current criteria standard or trajectory violation. Current horizontal position describes the distance of the marsh edge from a specified benchmark (*e.g.*, infrastructure) while the trajectory is the rate of change over time (typically in m yr^{-1}, *i.e.*, landward movement of the marsh edge). A current criteria standard violation occurs when there is evidence that the position of the marsh edge is undesirable relative to a specific feature of interest (*e.g.*, road, building), and as such may warrant intervention. A trajectory violation occurs when there is evidence that ongoing erosion is present, and therefore an intervention may be desirable. It would be uncommon for a user to not include horizontal position trajectory data, as they are widely available to multiple skill levels of potential tool users (*e.g.*, Google Earth, aerial photography).

- **Vertical Position, Biology, Hydrology, and Water Chemistry:** Violations to these attributes occur if there is a trajectory violation, with or without a criteria standard violation, or if there is criteria standard violation but no available trajectory data. The Decision Tool prioritizes trajectories over single, current data values for attribute violations regarding these metrics because long-term trends account for temporal variability. For example, a site may currently be in a deficient state, but changing in a positive direction (*e.g.,* current values for a particular metric are “moving” toward the criteria standard). Conversely, a site may currently be within an acceptable range for a specific metric with no evidence of deficiency, but long-term data shows that the site will continue on a negative functional trajectory. If trajectory data are not available, as noted in the trajectory justification, and the site displays a deficient current state for that metric, the Decision Tool errs on the side of caution and proposes an attribute violation based on current criteria standard violations. This assumption highlights the need for thorough review of attribute outputs when interpreting the final/holistic site-wide result. If the user becomes aware of trajectory information after the assessment is reviewed, we recommend the assessment be rerun with those data.

- **Soil Condition:** The soil condition metric has no associated criteria or trajectory violations, but an attribute violation can occur based on soil stability. Soil stability is calculated through the integration of organic thickness, parent material, and decomposition state characteristics (Table 4). These characteristics also help describe the soil type (Table 5; see USDA NRCS website for more about soil classifications). An attribute violation occurs if the soil condition is deficient; specifically the Tool assigns a deficiency if the organic thickness is less than 8” (~20 cm), the parent material is primarily silt-clay or clay, and the degree of humification is L3 level (levels H8-H10 in von Post classification classifies those organic horizons as sapric/muck/O_a). This translates as category C for all characteristics (Table 5). These qualities indicate that the soil has a shallow organic layer of highly decomposed peat with a clayey base. These qualities suggest that the soil drains poorly and may not support peat development (*i.e.*, decomposition outpaces peat formation). Thus, the soil—as it currently exists— is unlikely to provide suitable substrate for a robust biological community and is vulnerable to disturbance or drowning.

Table 3. Scheme for attribute violations (1 = violation, 0 = no violation) given criteria standard and trajectory violations. Y and N denote a violation or no violation, respectively, for criteria standards and trajectories. A hyphen indicates unavailable data that the Tool does not consider in the output recommendation. Note that Soil Condition attribute is not included here. Soil Condition attribute violations are discussed in Tables 4 and 5.

Attribute	Attribute Violation	Criteria Standard Violation	Trajectory Violation
Horizontal	1	Y	Y
	1	Y	N
	1	N	Y
	0	N	N
	1	-	Y
	0	-	N
Vertical	1	Y	Y
	0	Y	N
	1	N	Y
	0	N	N
	1	Y	-
	0	N	-
Biology	1	Y	Y
	0	Y	N
	1	N	Y
	0	N	N
	1	Y	-
	0	N	-
Hydrology	1	Y	Y
	0	Y	N
	1	N	Y
	0	N	N
	1	Y	-
	0	N	-
Water Chemistry	1	Y	Y
	0	Y	N
	1	N	Y
	0	N	N
	1	Y	-
	0	N	-

Table 4. Levels of soil characteristics and their associated categories. Combinations of categories that lead to an overall stability determination are reported in the last three rows.

Characteristic	Level	Category
Organic Thickness Horizon	<8"	C
	8"-16"	B
	16"-51"	A
	>51"	A
Parent Material	Sand, Loamy-sand	A
	Silty-loam, Loam	B
	Silt-clay, Clay	C
Degree of Humification	L1: H1-H4, Fibric, Peat Oi	A
	L2: H5-H7, Hemic, Mucky Peat, Oe	B
	L3: H8-H10, Sapric, Muck, Oa	C
Stability	**Levels**	
High	All Levels of each Characteristic are Category A	
Medium	All Mixed Combinations of A/B/C	
Low	All Levels of each Characteristic are Category C	

Table 5. General soil type based on organic thickness and parent material. Classifications based on USDA NRCS descriptions.

Soil Type	Organic Thickness Horizon	Parent Material
Broadkill / Appoquinimink	<8"	Silt-clay, Clay
Purnell	8"-16"	Sand, Loamy-sand
Boxiron	8"-16"	Silty-loam, Loam
Mispillion / Pawcatuck	16-51"	Sand, Loamy-sand
Honga	16-51"	Silty-loam, Loam
Bestpitch	16-51"	Silt-clay, Clay
Transquaking	>51"	Silt-clay, Clay

Decision Tool Output

Based on the unique combination of attribute violations, the Decision Tool will classify the site condition into one of three groups (Table 6): Deficiency Detected (DD); Further Evaluation Recommended (FER); or No Deficiency Detected (NDD).

Table 6. The Decision Tool evaluates deficiencies through unique combinations of attribute violations (violation =1; no violation = 0). Status denotes the classification of the Tool for the site: DD, FER, or NDD. An “X” regarding combo 1, denotes that a DD status can be achieve with a Horizontal Position violation in isolation. The column labeled “n Flagged” is a count of attribute violations.

		Attribute Status (Violated=1, Not Violated=0)						
Combo	Status	Horizontal Position	Vertical Position	Biology	Hydrology	Soil Condition	Water Chemistry	n Flagged
1	DD	1	X	X	X	X	X	1
2	DD	0	1	1	0	0	0	2
3	DD	0	1	0	1	0	0	2
4	DD	0	1	0	0	1	0	2
5	DD	0	0	0	1	1	0	2
6	DD	0	0	1	1	0	0	2
7	DD	0	1	1	1	0	0	3
8	FER	0	1	0	0	0	0	1
9	FER	0	0	1	0	0	0	1
10	FER	0	0	0	1	0	0	1
11	FER	0	1	0	0	1	0	2
12	FER	0	1	0	0	0	1	2
13	FER	0	1	0	0	1	1	3
14	FER	0	0	1	0	1	0	2
15	FER	0	0	1	0	0	1	2
16	FER	0	0	1	0	1	1	3
17	FER	0	0	0	1	1	0	2
18	FER	0	0	0	1	0	1	2
19	FER	0	0	0	1	1	1	3
20	NDD	0	0	0	0	0	0	0

Deficiency Detected

The Decision Tool assigns a status of “deficiency detected” to combinations of attribute violations that display evidence of an immediate or imminent deficiency. Due to the weight of the evidence, the Decision Tool recommends a discussion among all relevant stakeholders regarding the continued development of a project that addresses the identified deficiencies of the site. The violated attributes provide context to the nature of the site’s deficiencies and, therefore, discussion on which tactics can adequately address the issue(s).

Two combinations of attribute violations result in a site with this status:

- **A horizontal position violation**. This attribute violation indicates, independent of all other attributes, that there is an unacceptable rate of erosion at the site of interest. Any erosion can warrant a stabilization intervention depending on needs of the location and its associated stakeholders. The user can evaluate necessity given the weight of the evidence independently.

- **A combination violation for vertical position, biological community, hydrologic, and soil condition attributes.** As these attributes are highly interactive and violations of at least two indicate that the site is likely experiencing a reduction in function that is, or will ultimately, affect the persistence of the salt marsh at this site.

Further Evaluation Recommended

The Decision Tool assigns a status of "further evaluation recommended" when there is a violation for any single attribute, aside from a horizontal position violation (which itself receives a "deficiency detected" status), or a combination of attributes that do not merit a "deficiency detected" classification. Although there is not enough evidence to determine if the site is holistically deficient, these violations are important nonetheless. We recommend that the user continues to track these attribute-specific deficiencies as they could lead to more integrated deficiencies over time (*e.g.,* continuing hydrology issues may lead to emerging biological issues). These data can serve as baseline data for future monitoring efforts and to develop a trajectory dataset for the site.

No Deficiency Detected

The Decision Tool assigns a status of "no deficiency detected" when no attribute violations occur. This status indicates that all data fell within acceptable ranges as set by the user-defined criteria standards. Thus, there was insufficient evidence to conclude that the site is deficient either currently or will be within a specific time frame. These data also serve as baseline data for future monitoring efforts to develop a trajectory dataset.

The Decision Tool Output Summary

Results from the Decision Tool are provided in an *Output Summary* tab in three tables and one figure: the Site-wide Deficiency Detected Table; the Attributes of Concern Table; the Violation Summary Table and the Deficiency Summary Figure.

Site-wide Deficiency Detected Table

The Site-wide Deficiency Detected Table lists all combinations of attributes that had "Deficiency Detected" status (Table 7). As multiple combinations of violations can lead to this status, it is important for users to be able to identify all attribute deficiency combinations. All single (*i.e.,* horizontal position) or combinations (*e.g.,* vertical and biological) of attributes that trigger a "Deficiency Detected" classification are denoted by an "X" in the second column for the attribute(s) in column one.

Attributes of Concern Table

The Attributes of Concern Table shows all violated attributes (Table 8, column 2), including those that did not lead to a "Deficiency Detected" status. These attributes show some level of deficiency, and as such, should be included in any discussions regarding site-wide health and function. These metrics should be closely monitored in the future to better define their site-specific trajectory. This table also notes any associated attributes (column 3) that in combination with the violated attribute (column 2), lead to Deficiency Detected status (Table 8). This clarifies which associated attributes may be important to monitor in tandem with already deficient attributes. Importantly, these associated attributes may experience functional declines in concert with the deficient attribute. If the deficient attributes are included in a future assessment of the same site, the associated attributes would provide a more holistic evaluation of the site, while simultaneously increasing the Tool's capacity to detect a deficiency.

Table 7. Site-wide Deficiency Detected table provided on the *Output Summary* tab of the Decision Tool workbook. An "X" in the Violation column denotes evidence of diminished function for attributes listed in column 1 of the same row. In this table, the Horizontal Position attribute was identified as having site-wide deficiency, leading to a "Deficiency Detected" classification for the site. Note that multiple Site-wide Deficiency Detected Violations can occur and all will be noted in this table.

Table 1: Site-wide Deficiency Detected	
Attribute	Violation
Horizontal Position	X
Vertical+Biology	
Vertical+Hydrology	
Vertical+Soil Condition	
Hydrology+Soil Condition	
Biology+Hydrology	
Vertical+Biology+Hydrology	

Table 8. Attributes of Concern table provided on the *Output Summary* tab of the Decision Tool workbook. An "X" in the Violation column indicates that a there was evidence of diminished function for the associated attribute (column 1). If an attribute violation occurs, all attributes for which there is an association regarding functionality are listed in the Associated Attributes for Continued Monitoring column. In this table, the Horizontal and Vertical Position attributes were violated, and as such, associated metrics that could lead to a site-wide "Deficiency Detected" classification are noted in column 3.

Table 2: Attributes of Concern		
Attribute	Violation	Associated Attributes for Continued Monitoring
Horizontal Position	X	N/A
Vertical Position	X	Biology, Hydrology
Biology		
Hydrology		
Soil Condition		
Water Chemistry		

Violations Summary Table

The Violations Summary Table summarizes all violated criteria standards, trajectories, and attribute violations, as well as the output status of the site (DD, FER, or NDD).

- **Attribute Violations:** This row summarizes each site-wide attribute violation (a combination of current and trajectory comparisons). At the site of interest, was there evidence that this attribute was deficient, based on user selected criteria standards and/or trajectory information? Each violated attribute is noted in either the Site-wide Deficiency Detected and/or Attributes of Concern Table.

- **Criteria Violation:** This row summarizes metric criteria violations for each attribute. At the site of interest, what metrics within each attribute violated the user defined criteria standard? This indicates that, in their current state, there was evidence of a deficiency.

- **Trajectory Violation:** This row summarizes the trajectory violations for each attribute. At the site of interest, which attributes violated the adjusted user defined criteria standard for a time frame of interest? This indicates that, within that user-defined time frame, there was evidence that a deficiency may develop for that attribute.

For example, in Table 9, the Horizontal Position attribute was identified as having received criteria (reduced function currently) and trajectory (reduced function in the future) violations. As such, according to the rules outlined in Table 3, it received an attribute violation. The Vertical Position attribute had a trajectory violation but no criteria violation. This indicates no evidence of decreased function currently, but a deficiency may develop in the user-defined time frame. Thus, the Vertical Position attribute received an Attribute Violation as outlined by the rules in Table 3. The Biology attribute only received a criteria violation, indicating that it its current condition was deficient for this attribute, but as no trajectory violation occurred, there was no evidence that the site may not meet the criteria standards in the future. Because the Horizontal Position attribute was violated, a site-wide status of "Deficiency Detected (DD)" was awarded, but users should note that other issues may be present at the site as individual criteria and trajectory violations suggest.

Table 9. Violations summary table provided on the *Output Summary* tab of the Decision Tool workbook. This table shows criteria (today), trajectory (tomorrow), and attribute (site-wide) violations per attribute. This table allows users to view violations across all attributes. Violations are indicated by a "1", and "0" indicates no violation.

Table 3: Violations Summary

	Horizontal Position	Vertical Position	Biology	Hydrology	Soil Condition	Water Chemistry	Status
Attribute Violations	**1**	**1**	**0**	**0**	**0**	**0**	DD
Criteria Violation	*1*	*0*	*1*	*0*	*na*	*0*	
Trajectory Violations	*1*	*1*	*0*	*0*	*na*	*0*	

Deficiency Summary Figure

The Deficiency Summary Figure is a bar graph that summarizes which attributes fall into one of three categories (Fig. 5):

- **Current Deficiency:** This category counts the number of attributes with evidence of a current deficiency, without a negative trajectory. This category may suggest the site is currently deficient but recovering or that it is stable under a longer temporal scale. Further evaluation of the attribute's trajectory (*e.g.*, including or updating trajectory data) is recommended.

- **Trajectory Deficiency:** This category counts the number of trajectory deficient attributes where data do not suggest current deficiencies. This could indicate future deterioration of a currently functional site.

- **Current and Trajectory Deficiency**: This category counts the number of presently deficient attributes that also have a negative trajectory. This implies continued deterioration of an already compromised site.

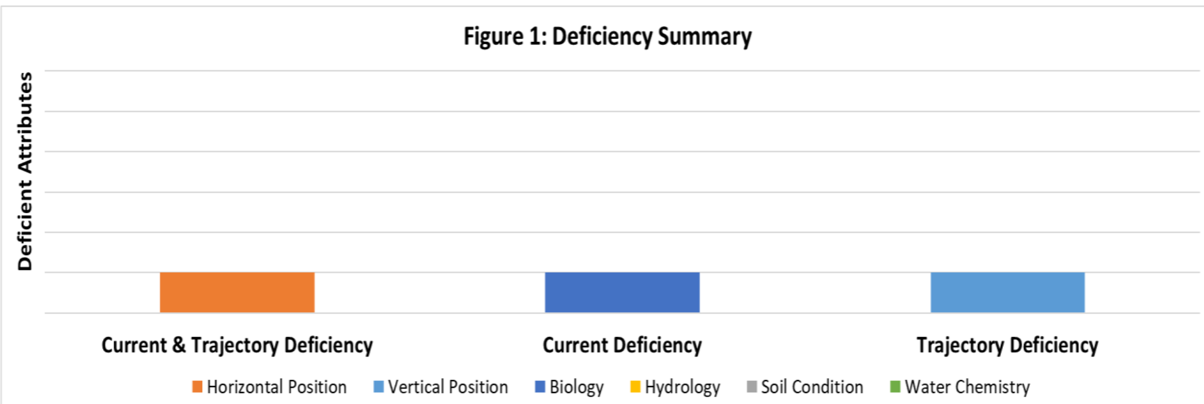

Figure 5. Deficiency Summary table provided on the *Output Summary* tab of the Decision Tool workbook. This table summarizes the evidence of attribute deficiencies as occurring either currently (Current Deficiency), projected to occur (Trajectory Deficiency), or both (Current & Trajectory Deficiency). In this figure, the Horizontal Position attribute received a criteria and trajectory violation, the Biology attribute a criteria violation, and the Vertical Position attribute a trajectory violation (see Table 9).

Decision Tool Output Reflection

The *Output Reflection* tab summarizes:

- The status of permit-specific requirements from the *Regulatory Checklist* tab selected by the user for concurrent preparation with the Decision Tool process, and;

- Additional regulatory considerations that the user should consider when interpreting the Decision Tool output.

Regulatory Checklist

The Decision Tool provides a checklist on the second tab of the spreadsheet to assist users in compiling information pertinent to regulatory applications. This checklist streamlines the data collecting process through the identification of attributes that meet assessment criteria as well regulatory inquiries. For example, a Tool user may analyze historical imagery to quantify change for the horizontal position attribute which, if desired, is also required to obtain an Army Corps of Engineers NWP27 permit for Bank Stabilization. Similarly, aquatic habitat distribution within a proposed project site that is covered with water for any portion of time will need to be considered by the NOAA Fisheries Office. A tool user can select aquatic habitat type distributions as the habitat metric (using the percent habitat composition method) for the biological community attribute. Thus, during the site investigation process, the Tool can support thorough permit applications by guiding the user to consider regulatory concerns and all appropriate federal and state mandatory reviews (ESA, EFH) before application review.

When a permit is activated on *Regulatory Checklist* tab (Tab 2, Column C), it is also activated on the *Output Reflection* tab. Initially, the activated permit row is "Incomplete" (permits not selected appear as "N/A"). When the user checks-off each permit requirement in the Evaluation column (Tab 2, Column I), indicating that the user considered each requirement, the associated permit in the *Output Reflection* tab is "Complete" (Fig. 6).

Regulatory Checklist	
COMPLETE	GP# 24: Habitat Creation, Restoration, Enhancement and Living Shoreline Activities
N/A	Creation, Restoration or Enhancement for a Coastal Wetland Mitigation Proposal
INCOMPLETE	NP #13: Bank Stabilization
N/A	NP # 27: Aquatic Habitat Restoration, Enhancement, and Establishment Activities
N/A	NP # 54: Living Shorelines
N/A	Subaqueous Lands Permit

Figure 6. Example of a "Complete" or "Incomplete" status in the Regulatory Checklist regarding two user-selected permits in the Output Reflection tab of the Decision Tool. In this example, the user selected GP# 24 and NP #13 on the *Regulatory Checklist* tab as permits of interest for a potential project, and as such compiled information concurrent with satisfying Decision Tool data requirements. Here, the user has indicated to the Decision Tool that all evaluations have been checked on the Regulatory Checklist tab of the Decision Tool for GP #24, but not for NP #13. The user can then revisit the incomplete items.

Regulatory Considerations

Regulatory considerations describe items that are not an explicit permit requirement, but are important details for regulatory, and some funding, agencies. Users may choose to consider these items in regards to any potential project proposed for the site. The following are regulatory consideration categories:

- **Characterization:** These considerations describe items that show due diligence regarding the identification of current deficiencies and how a proposed project intends to address those needs in an organized and efficient manner. As such, it is recommended that the user presents these considerations to stakeholders to provide context for a potential project and its expected outcome.

- **Habitat Trade-Offs:** Habitat trade-offs ask the user to consider how the conversion from a current landscape to a "restored" landscape will affect endemic and transitory species use. Trade-offs have implications regarding resource and migratory needs for individual species over various spatial and temporal scales which need to be considered regarding a potential project's impact.

- **Threatened and/or Endangered Species (T&E):** This category specifically asks the user to discuss any absolute or potential impacts to T&E species. These impacts can be positive or negative and users should discuss T&E impacts in a wide temporal context taking into account "natural" habitat change over time.

- **Fill Considerations:** Fill considerations ask the user to describe plans to meet vertical position targets and describe target maintenance over time. For any wetland restoration project, proper position within the tidal range is necessary. These considerations ask the user to discuss the ability of project to self-sustain and describe any plans for when and how to use outside fill materials. It should be noted that fill does not only relate to sediment, to any and all materials that would be placed to complete a project.

- **Adaptive Management Plans and Activities:** This category asks the user to discuss plans to attend to any ecological and/or physical deviations from projected trajectories described in a project implementation plan. The development of an adaptive management plan, and the associated monitoring plan that will inform the user of trajectory/developmental deficiencies, is key to maximizing the overall likelihood of the desired outcome under dynamic circumstances (*e.g.*, sea level rise, periodic storms).

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Appendices

Appendix A. Metrics and Methods per Attribute

Attribute	Metric	Methods	Trajectory Data Sources
Horizontal Position	Lateral Shoreline Change	1. Distance from marker or benchmark 2. Aerial imagery digitization 3. Surveying instrument (RTK-GPS, LiDAR, barcode leveling)	1.Aerial Imagery Databases (Landsat 8) 2.Google Earth 3. SLAMM 4.Coastal Resilience Mapper
Vertical Position	Elevation	1. Surveying instrument (RTK-GPS, LiDAR) 2. Laser level height relative to position on permanent post or structure (barcode leveling)	1. SSIM/MidTRAM/ MACWA 2. SLAMM
	Accretion Rate	1. Surveying instrument (RTK-GPS, LiDAR, barcode leveling) 2. Sedimentation Disk/Tile/Marker Horizon	
	Foreshore Slope	1. Surveying instrument (RTK-GPS, LiDAR, barcode leveling) 2. Acoustic imaging	1. Coastal Resilience Mapper
Biological Community	Vegetation Productivity	1. Above ground biomass 2. Below ground biomass 3. Percent cover 4. Stem density 5. C:N Ratio 6. Landsat / Infrared Imagery	1. SSIM/MidTRAM/ MACWA 2. SLAMM
	Habitat	1. Percent habitat composition 2. Percent Nuisance Species 3. Percent habitat of quality	1. SSIM/MidTRAM/ MACWA 2. SLAMM
	Fauna (Species of Interest)	1. Density 2. Presence / Absence 3. Biomass 4. Inhibition	1. SSIM/MidTRAM/ MACWA 2. SMI
Hydrology	Tidal Restrictions	1. Percent Area of Interest Restricted	1. Aerial imagery 2. Google Earth
	Drainage	1. Drainage density 2. Drainage capacity	1. Aerial imagery 2. Google Earth
	Groundwater	1. Depth to water table	1. Wells (USGS Groundwater Data)

Appendix B: Decision Tool Evaluation Code

Horizontal Position

Column	Type	Formula
A	Metric	Drop-down list
B	Method	Drop-down list
Current or Most Recent Metric		
C	Value	User-input Number
D	Units	User input Text (Metric)
E	Justification	User input Text Required
Criteria Standard Metric		
F	Low	User input Number
G	High	User input Number
H	Units	User input Text (Metric)
I	Type	Drop-down list
J	Justification	User input Text Required
Trajectory Metric		
K	Low	User input Number
L	High	User input Number
M	Units per Year	User input Text (Metric)
N	Justification	User input Text Required
Forecasted or Projected Metric		
O	Years in Future	User input Number
P	Justification	User input Text Required
Q	Low	(K3 x $O3) + $C3
R	High	(L3 x $O3) + $C3
S	Units	H3
Violations and Status		
T	Criteria Violation	IF(C<MIN(F3:G3),1,0))
U	Trajectory Violation	IF(OR(AVERAGE(Q3:R3)<MIN(F3:G3),AVERAGE(Q3:R3)>MAX(F3:G3)),1,0))
V	Attribute Status	IF(OR(AND(T3=1, U3="-"),U3=1),1,0)
W	Error notes	Model calculated

Vertical Position

Column	Type	Formula
A	Metric	Drop-down list
B	Method	Drop-down list
Current or Most Recent Metric		
C	Value	User-input Number
D	Units	User input Text (Metric)
E	Justification	User input Text Required
Criteria Standard Metric		
F	Low	User input Number
G	High	User input Number
H	Units	User input Text (Metric)
I	Type	Drop-down list
J	Justification	User input Text Required
Trajectory Metric		
K	Low	User input Number
L	High	User input Number
M	Units per Year	User input Text (Metric)
N	Justification	User input Text Required
Forecasted or Projected Metric		
O	Years in Future	User input Number
P	Justification	User input Text Required
Q	Low	(K3 x $O$3) + $C$3
R	High	(L3 x $O$3) + $C$3
S	Units	H3
Sea Level and Forescasted Elevation		
T	Current Mean Sea Level	User input Number
U	Sea-Level Rise Predicted Rate (per Year)	User input Number
V		User input Text (Metric)
W	Forecasted Elevation From	Q3-($T3+($U3*0.1*$O3))
X	Forecasted Elevation To	R3-($T3+($U3*0.1*$O3))
Violations and Status		
Y	Criteria Violation	IF(OR(C3<MIN(F3:G3), C3>MAX(F3:G3)),1,0)
Z	Trajectory Violation	IF(OR(MIN(W3:X3)<MIN(F3:G3), MAX(W3:X3)>MAX(F3:G3)),1,0)
AA	Attribute Status	IF(OR(Z3=1, AND(Z3="-",Y3=1)),1,0))
AB	Error notes	Model calculated

Biology

Column	Type	Formula
A	Metric	Drop-down list
B	Method	Drop-down list
Current or Most Recent Metric		
C	Value	User-input Number
D	Units	User input Text (Metric)
E	Justification	User input Text Required
Criteria Standard Metric		
F	Low	User input Number
G	High	User input Number
H	Units	User input Text (Metric)
I	Type	Drop-down list
J	Justification	User input Text Required
Trajectory Metric		
K	Low	User input Number
L	High	User input Number
M	Units per Year	User input Text (Metric)
N	Justification	User input Text Required
Forecasted or Projected Metric		
O	Years in Future	User input Number
P	Justification	User input Text Required
Q	Low	$C3+(K3*$O3))
R	High	$C3+(L3*$O3)
S	Units	H3
Violations and Status		
T	Criteria Violation	IF(C3<MIN(F3:G3),1,0)
U	Trajectory Violation	IF(OR(MIN(Q3:R3)<MIN(F3:G3),MAX(Q3:R3)>MAX(F3:G3)),1,0)
V	Attribute Status	IF(OR(U3=1, AND(U3="-",T3=1)),1,0)
W	Error Notes	Model calculated

Hydrology

Column	Type	Formula
A	Metric	Drop-down list
B	Method	Drop-down list
Current or Most Recent Metric		
C	Value	User-input Number
D	Units	User input Text (Metric)
E	Justification	User input Text Required
Criteria Standard Metric		
F	Low	User input Number
G	High	User input Number
H	Units	User input Text (Metric)
I	Type	Drop-down list
J	Justification	User input Text Required
Trajectory Metric		
K	Low	User input Number
L	High	User input Number
M	Units per Year	User input Text (Metric)
N	Justification	User input Text Required
Forecasted or Projected Metric		
O	Years in Future	User input Number
P	Justification	User input Text Required
Q	Low	(K3 x $O3) + $C3
R	High	(L3 x $O3) + $C3
S	Units	H3
Violations and Status		
Tidal Restriction		
T	Criteria Violation	IF(C3>MAX(F3:G3),1,0))
U	Trajectory Violation	IF(MAX(Q3:R3)>=MAX(F3:G3),1,0)
Drainage Capacity		
T	Criteria Violation	IF(D4<MIN(G4:H4),1,0)
U	Trajectory Violation	IF(MIN(R4:S4)<=MIN(G4:H4),1,0))
V	Attribute Status	IF(OR(U3=1, AND(U3="-",T3=1)),1,0)
W	Error Notes	Model calculated

Soil Condition

Column	Type	Formula
A	Metric	Drop-down list
B	Method	Drop-down list
Organic Thickness		
C	Depth (cm)	User-input Number
D	Depth (in)	Calculated conversion
E	Measure Method	User input Text Required
F	Grade	IF(AND(C3<=40.64,C3>=20.32),"B",IF(C3<20.32,"C"))
Parent Material		
G	Type	Drop-down list
H	Depth Collected	User input Number (Metric)
I	Measurement Method	User input Text Required
J	Grade	IF(G3='Metrics & Methods'!$B$51,"A",IF(G3='Metrics & Methods'!$B$52,"B",IF(G3='Metrics & Methods'!$B$53,"C")))
Decomposition State		
K	Level	Drop-down list
L	Depth Collected	User input Number (metric)
M	Measurement Method	User input Text Required
N	Grade	IF(K3='Metrics & Methods'!$B$56,"A",IF(K3='Metrics & Methods'!$B$57,"B",IF(K3='Metrics & Methods'!$B$58,"C")))
O	Suggested Soil Type	INDEX('Metrics & Methods'!$D$51:$G$53,MATCH('Soil Condition'!J3,'Metrics & Methods'!$A$51:$A$53,0),MATCH('Soil Condition'!D3,'Metrics & Methods'!$D$50:$G$50,0))
P	Attribute Status / Final Grade	=IF(A3="","-", IF(AND(F3="A",J3="A",N3="A"),"A", IF(AND(F3="C",J3="C",N3="C"), "C", "B")))
Q	Error Notes	Model calculated

Water Chemistry

Column	Type	Formula
A	Metric	Drop-down list
B	Method	Drop-down list
Current or Most Recent Metric		
C	Value	User-input Number
D	Units	User input Text (Metric)
E	Justification	User input Text Required
Criteria Standard Metric		
F	Low	User input Number
G	High	User input Number
H	Units	User input Text (Metric)
I	Type	Drop-down list
J	Justification	User input Text Required
Trajectory Metric		
K	Low	User input Number
L	High	User input Number
M	Units per Year	User input Text (Metric)
N	Justification	User input Text Required
Forecasted or Projected Metric		
O	Years in Future	User input Number
P	Justification	User input Text Required
Q	Low	(K3 x $O$3) + $C3
R	High	(L3 x $O$3) + $C3
S	Units	H3
Violations and Status		
T	Criteria Violation	F(OR(C3<MIN(F3:G3),C3>MAX(F3:G3)),1,0)
U	Trajectory Violation	IF(OR(MIN(Q3:R3)<MIN(F3:G3),MAX(Q3:R3)>MAX(F3:G3)),1,0)
V	Attribute Status	IF(OR(U3=1,AND(T3=1,U3="-")),1,0)
W	Error Notes	Model calculated

Output Summary

Row	Table 1: Site-wide Deficiency Detected	
4	Horizontal Position	IF($C$14=1, "X", "")
5	Vertical+Biology	IF(AND($D$14=1,$E$14=1, $F$14=0),"X", "")
6	Vertical+Hydrology	IF(AND($D$14=1,$F$14=1,$E$14=0),"X", "")
7	Vertical+Soil Condition	IF(AND(D14,G14)=1,"X","")
8	Hydrology+Soil Condition	IF(AND(F14,G14)=1,"X","")
9	Biology+Hydrology	IF(AND($E$14=1,$F$14=1,$D$14=0),"X", "")
10	Vertical+Biology+Hydrology	IF(AND($D$14=1,$E$14=1,$F$14=1),"X", "")
	Table 2: Attributes of Concern Monitoring	**Associated Attributes for Continued**
4	Horizontal Position	N/A
5	Vertical Position	IF($F$5="X",$E$6&", "&$E$7, "")
6	Biology	IF($F$6="X", $E$5&", "&$E$7,"")
7	Hydrology	IF($F$7="X", $E$5&", "&$E$6&", "&$H$13,"")
8	Soil Condition	F($F$8="X", $E$5&", "&$E$7,"")
9	Water Chemistry	IF($F$9="X", $E$6&", "& $E$7,"")
	Table 3: Violations Summary	
14	Attribute Violations	IFERROR(IF(COUNTIF('Horizontal Position'!$V$3:$V$4,1)>0,1,0), 0) IFERROR(IF(COUNTIF('Soil Condition'!$V$3:$V$6,"C")>0,1,0),0)
15	Criteria Violation	IFERROR(IF(COUNTIF('Horizontal Position'!$T$3:$T$4,1)>0,1,0), 0)
16	Trajectory Violations	
	Figure 1: Deficiency Summary	
21	Current & Trajectory Deficiency	IF(AND(C$14=1,C$15=1),1,0)
22	Current Deficiency	IF(AND(C15=1,C21=0),1,0)
23	Trajectory Deficiency	IF(AND(C16=1,C21=0),1,0)
Status		
IF(SUM($C$14:$H$14)=0,$L$15,IF(OR("X"=$C$4,"X"=$C$5,"X"=$C$6,"X"=$C$7,"X"=$C$8, "X"=$C$9,"X"=$C$10),$L$13,$L$14))		
L13	DD	Deficiency Detected
L14	FER	Further Evaluation Recommended
L15	NDD	No Deficiency Detected

Appendix C. Trajectory calculation formula

The forecasted metric value is calculated through the following mean change formula:

Mean change = 0.5*{[current value + (lower trajectory rate value* # of forecast years)] + [current value + (upper trajectory rate value* # of forecast years)]}

Appendix D. Scenario

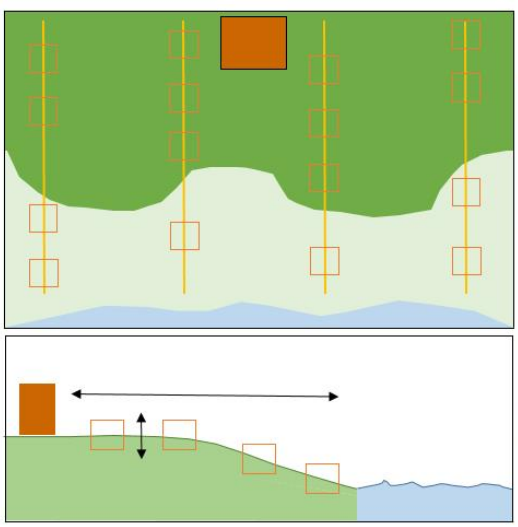
Should there be site intervention based on the evidence described below?

Horizontal Position: A permanent bird blind was 10 meters from the marsh's edge at the time of its installation. It cannot be less than 5 meters from the shoreline edge. Last year, it was 6 meters from the shoreline's edge after you conducted a marsh edge survey using an RTK-GPS. Your annual surveys have shown an erosion rate between 0.25m and 0.75m per year. In the next five years, will the bird blind need relocating?

Biological: There is currently 45% salt marsh hay coverage in the high marsh when you sampled square meter permanent plots, whereas five years ago there was 50% coverage. Healthy marshes in the region range in 45% to 55% plant species coverage. As salt marsh hay coverage decreases, the common reed coverage increases, which may lead to a monoculture in the future. Should you be worried about the current rate in species change in 5-years?

Vertical Position: This year, the average treatment plot elevation was +0.8 m NAVD88. The control plots ranged between +1.0 to +1.2 m NAVD88. Five years ago average treatment plot elevations were +1.0 m NAVD88 and eight years before that were +1.4 m NAVD88. Mean high water is +1.0 m NAVD88, mean sea level is +0.15 m NAVD88, and mean low water is -1m NAVD88. NOAA's sea-level rise rate is increasing by 0.05 centimeters per year. Is this location currently similar to the surrounding area? In five years, will its lowest predicted elevation be above or below future sea level?

Hydrological Regime: Results from a year-long water pressure sensor deployment showed water levels were above mean higher high water 100 days out of the year. Acceptable inundation, or what is preferred by the targeted bird species, is between 18% and 35%. Inundation rates are increasing 0.1% to 0.5% per year, according to recent studies in the area. In the next ten years, will the percentage of time the area is inundated above mean higher high water be at, above, or below target levels?



Appendix E. Scenario Key

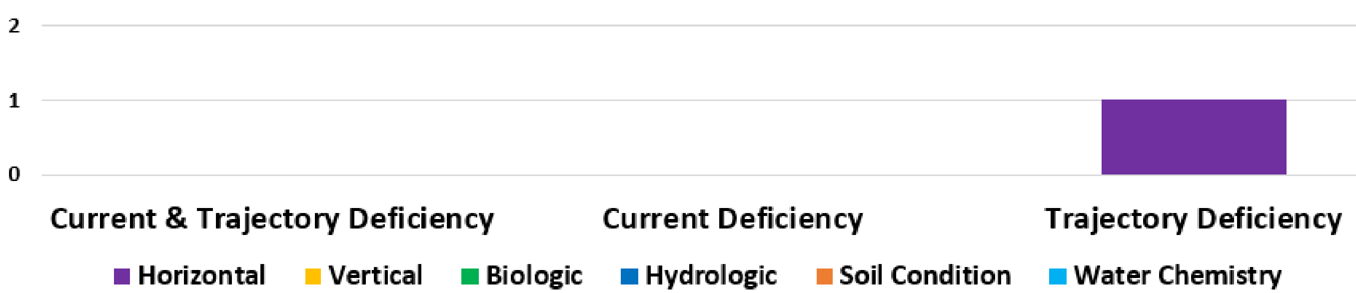
Horizontal Position

Metric	Method	Current or Most Recent Metric			Criteria Metric				
		Value	Units	Measurement Justification	Low	High	Criteria Standard Units	Criteria Type	Justification
Shoreline Position	Distance from Marker	6	m	from Bird Blind	5	10	m	Reference Criteria	3

Metric Trajectory Range		Units per Year	Metric Trajectory Source	Forecast Years	Forecast Justification	Forecasted Metric Values		Units	Criteria Violation	Trajectory Violation	Attribute Status
Low	High					Low	High				
-0.25	-0.75	m	3	5	3	4.75	2.25	m	0	1	1

Site-wide Deficiency Table	
Horizontal Position	X
Vertical+Biological	
Vertical+Hydrologic	
Vertical+Soil Condition	
Hydrologic+Soil Condition	
Biological+Hydrologic	
Vertical+Biologic+Hydrologic	

Attributes of Concern		Associated Attributes for Continued Monitoring
Horizontal Position	X	N/A
Vertical Position		
Biological		
Hydrological		
Sedimentation		
Soil Condition		
Water Chemistry		



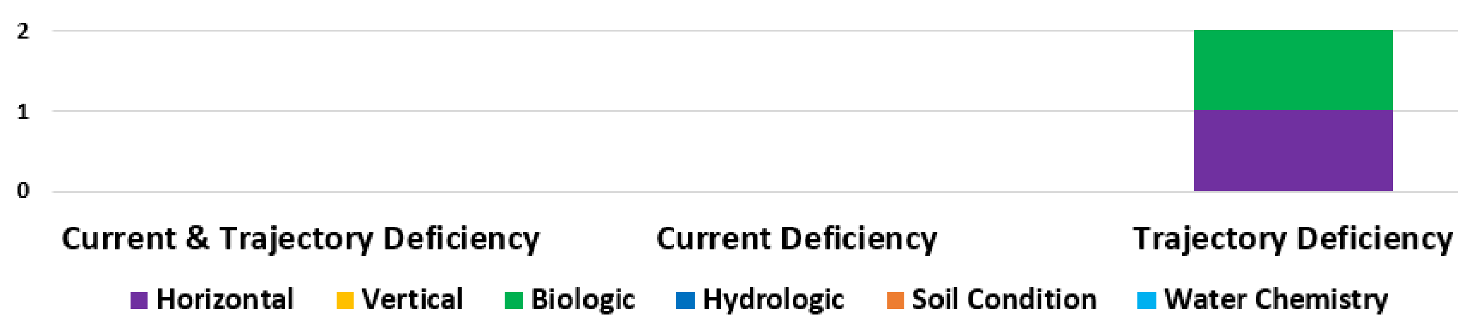
Biological

Metric	Method	Metric Value	Metric Units	Metric Measurement Justification and Species/Community of Interest	Criteria Range		Criteria Standard Units	Criteria	Criteria Standard Justification
					Low	High			
Vegetation Productivity	Percent Cover	45	%	Saltmeadow Cordgrass	45	55	%	Quality Criteria	Healthy surrounding marshes

Metric Trajectory Range		Units per Year	Metric Trajectory Source	Forecast Years	Forecast Justification	Forecasted Metric Values		Units	Criteria Violation	Trajectory Violation	Attribute Status
Low	High					Low	High				
-1	-1	%	Past surveys	5	Future	40	40	%	0	1	1

Site-wide Deficiency Table	
Horizontal Position	X
Vertical+Biological	
Vertical+Hydrologic	
Vertical+Soil Condition	
Hydrologic+Soil Condition	
Biological+Hydrologic	
Vertical+Biologic+Hydrologic	

Attributes of Concern		Associated Attributes for Continued Monitoring
Horizontal Position	X	N/A
Vertical Position		
Biological	X	Vertical Position, Hydrological
Hydrological		
Sedimentation		
Soil Condition		
Water Chemistry		



Vertical Position

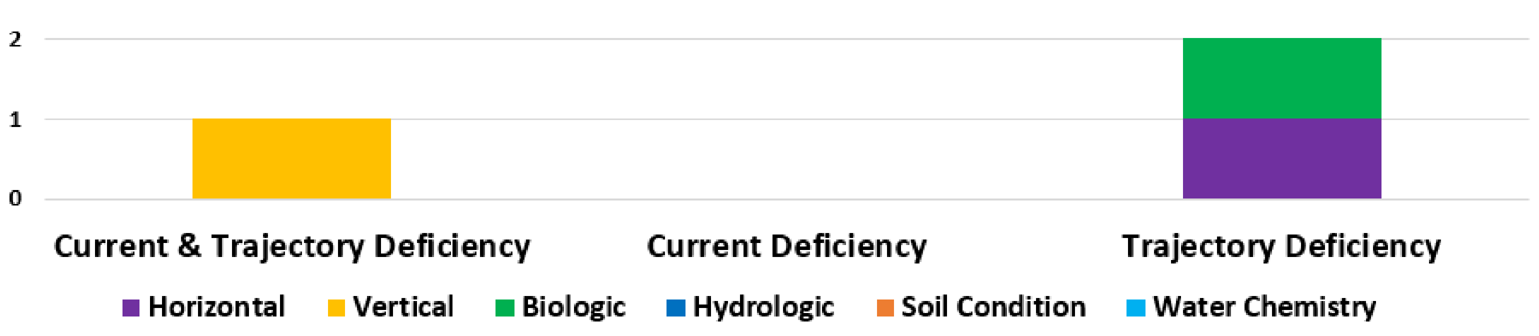
Metric	Method	Metric Value	Metric Units	Metric Measurement Justification	Criteria Range		Criteria Standard Units	Criteria	Criteria Standard Justification
					Low	High			
Marsh Platform Elevation	RTK-GPS Survey	0.8	meters	Average of Treatment Plots	1	1.2	meters	Reference Criteria	Control Plot Elevations

Metric Trajectory Range		Units per Year	Metric Trajectory Source	Forecast Years	Forecast Justification	Forecasted Metric Values		Units
Low	High					From	To	
-0.04	-0.05	meters	Range in elevation changes over four years	5	Given time frame	0.6	0.55	meters

Current Mean Sea Level (NAVD88)	Sea-Level Rise Predicted Rate		Forecasted Elevation (Relative to NAVD88)		Criteria Violation	Trajectory Violation	Attribute Status
			From	To			
0.15	0.05	centimeters per year	0.43	0.15	1	1	1

Site-wide Deficiency Table	
Horizontal Position	X
Vertical+Biological	X
Vertical+Hydrologic	

Attributes of Concern		Associated Attributes for Continued Monitoring
Horizontal Position	X	N/A
Vertical Position	X	Biological, Hydrological, Sedimentation
Biological	X	Vertical Position, Hydrological



Hydrological Regime

Metric	Method	Current or Most Recent Metric			Criteria Metric				
		Value	Units	Measurement Justification	Low	High	Criteria Standard Units	Criteria Type	Justification
Hydrological Manipulation	Percent Time Flooded	27.40	%	100 days out of the year when the water level is at or above mean higher high water	18	35	%	Target Criteria	Range for frequency of predicted water levels above MHHW

Trajectory Metric				Forecasted or Projected Metric				
Low	High	Units per Year	Justification	Years in Future	Justification	Low	High	Units
0.1	0.5	%	Potential increase in flooding days in the near future	10	Near Future	28.40	32.40	%

Criteria Violation	Trajectory Violation	Attribute Status
0	0	0