Changing with the Tides:
Addressing Salt Marsh Erosion on Nantucket

Prepared by:
Emily Anstett

Nantucket Conservation Foundation

UVA | FRANK BATTEN SCHOOL *of* LEADERSHIP *and* PUBLIC POLICY

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Disclaimer

The author conducted this study as part of the program of professional education at the Frank Batten School of Leadership and Public Policy, University of Virginia. This paper is submitted in partial fulfillment of the course requirements for the Master of Public Policy degree. The judgments and conclusions are solely those of the author, and are not necessarily endorsed by the Batten School, by the University of Virginia, or by any other agency.

Honor Pledge

On my honor, I have neither given nor received unauthorized aid on this assignment.

Emily Anztett

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Dedication

I dedicate this work to my grandfather "Grandy," Andy Zagayko, who passed away before I could share the final version of this project with but has always been one of my strongest supporters. I could not have gotten to this point without your unwavering support and encouragement.

Executive Summary

The erosion of salt marshes on Nantucket poses significant challenges to the resiliency of the island. Salt marshes provide critical ecological services including coastal protection against storm surge, habitats, and carbon sequestration (Adams, et al. 2021). The erosion of these marshes has the potential to cause approximately $3.4 billion in cumulative damages, to eliminate critical habitats, and to threaten the security of nearby properties by 2070 if no actions are taken (Town of Nantucket, n.d.; Thorne, et al. 2019). This policy analysis recommends installing oyster reefs in the waters surrounding salt marshes to mitigate the impacts of erosion.

Salt marsh erosion jeopardizes the longevity and viability of Nantucket Island in Massachusetts. These marshes provide critical ecosystem services including coastal protection from flooding. Nantucket is currently facing the impacts of sea level rise and deteriorating salt marshes, necessitating action to manage the Island's salt marshes to promote its resiliency. For example, in 2023, Easy Street in downtown Nantucket was flooded for 75 days at high tide (Town of Nantucket, n.d.a).

The Nantucket Conservation Foundation (NCF) owns 75% of the salt marshes on Nantucket and seeks to engage in land management and conservation efforts to promote the endurance of these marshes. If no actions are taken to help these deteriorating marshes, critical ecosystems, homes, historic buildings, and businesses are at risk of being lost to flooding.

This policy analysis examines the problem context of salt marsh erosion on Nantucket and the impacts. This analysis examines the available literature on potential interventions to restore deteriorating salt marshes. The "Resist-Accept-Direct" (RAD) Framework was used to frame the literature review which informed the selection of alternatives for improving salt marshes. Each of the alternatives were evaluated by five criteria including impact (in terms of projected change in marsh elevation), cost, cost-effectiveness, feasibility, and sustainability. The following alternatives were examined:

1. Sediment application to salt marshes
2. Installation of oyster reefs in waters surrounding salt marshes
3. Construction of living shoreline on the edge of the salt marsh

Based on the evaluation of the available alternatives, the oyster reef installation is recommended as the best alternative for mitigating salt marsh erosion on Nantucket. The oyster reef intervention was projected to outperform the other alternatives on all the criteria. Specifically, the oyster reef intervention is projected to have the biggest impact on marsh elevation, an estimated 17cm increase in elevation. The oyster reef was also the least costly, most cost effective, would likely have high feasibility and public support as well as require little intervention and maintenance. The oyster reef intervention is best suited to promote the resilience of Nantucket salt marshes in the face of sea level rise.

To install an oyster reef, NCF would need to acquire funding, likely from state or private grants, obtain the necessary permits, and partner with the Nantucket Shellfish Association to obtain the oyster spat and construct the reefs. Once the reefs are constructed and installed in the waters, NCF will monitor and evaluate changes in elevation, sediment supply, and oyster spat growth rates for the five years following initial construction.

Definitions

Salt Marsh: a coastal wetland located along coastlines and in inner protected harbor regions, which floods daily with salt water at high tide. Salt marshes are made up of water-logged organic material and marsh grasses that die, replenishing the peat as new grasses grow.

Sediment: rock particles that are broken down from weathering and erosion processes, often considered synonymous with soil particulate (Wu, 2024)

Sediment Transport: the process of erosion, transportation, and deposition of sediment throughout an ecosystem. Specifically, sediment is formed through erosion and then transported via waterways and deposited to different regions of a system. A salt marsh is one "stop" along the road of sediment transport wherein sediment is deposited on the marsh (Wu, 2024).

Sediment Accretion: the process by which sediment is deposited on the marsh bed leading to elevation gain, also called sediment accumulation.

Salt Marsh Erosion: in relation to sea level rise, the process wherein increased tidal inundation of sea water erodes away the sediment on the marsh bed, pushing salt marshes inland as water inundates marsh edges (Fagherazzi, et al., 2020).

Biodeposition: the process in which oysters filter sediment, removing nutrients and particulate matter that can harm ecosystem health and deposit "feces," which are sediment that are deposited on the seabed or marsh bed. Biodeposition can increase the available sediment supply in the water (Tenore and Dunstan, 1973).

Client Overview

The Nantucket Conservation Foundation (NCF) owns over 9,000 acres of land and shoreline on Nantucket Island (NCF, 2024a). NCF's mission is to conserve and manage the land for recreational use. Most of the land that NCF owns has been donated, but NCF also purchases plots of land that have "conservation value." These plots include land with endangered and rare species that require protection and monitoring. A key component of NCF's work is to conduct scientific research on the resources and species on their properties. This research serves two purposes. First, the results of research are used to increase education about the Island's natural resources. Second, the results of research are used to inform NCF's land management strategies. NCF's land management seeks to protect resources and ensure people's continued access to these natural spaces.

In 2010, NCF began recording salt marsh dieback on the island. Since 2010 dieback has become an increasing problem. There are approximately 1600 acres of salt marshes on Nantucket, 1200 of which are owned by NCF (Karberg, n.d.) NCF engages in several restoration projects across the island and is beginning to investigate ways to address the increasing erosion of salt marshes. NCF has engaged in several projects related to their salt marshes to better understand the state of salt marsh erosion on the island. Specifically, in 2020 NCF began conducting research on the potential success of placing an oyster reef in their salt marshes in Medouie Creek. NCF was able to place an oyster reef in the waters of Medouie Creek in 2021 (NCF, n.d.a). NCF will monitor the impacts of the oyster reef for five years to see long-term impacts on the salt marsh. NCF also conducted research examining the impact of the purple crab populations on salt marsh dieback. NCF found that marshes where there was an over-population of purple crabs (because of changing environmental conditions) had greater dieback as the crabs were eating marsh vegetation at a rate that could not be replenished by regrowth (NCF, n.d.b). This analysis seeks to aid NCF's work in restoring deteriorating salt marshes.

Nantucket Conservation Foundation

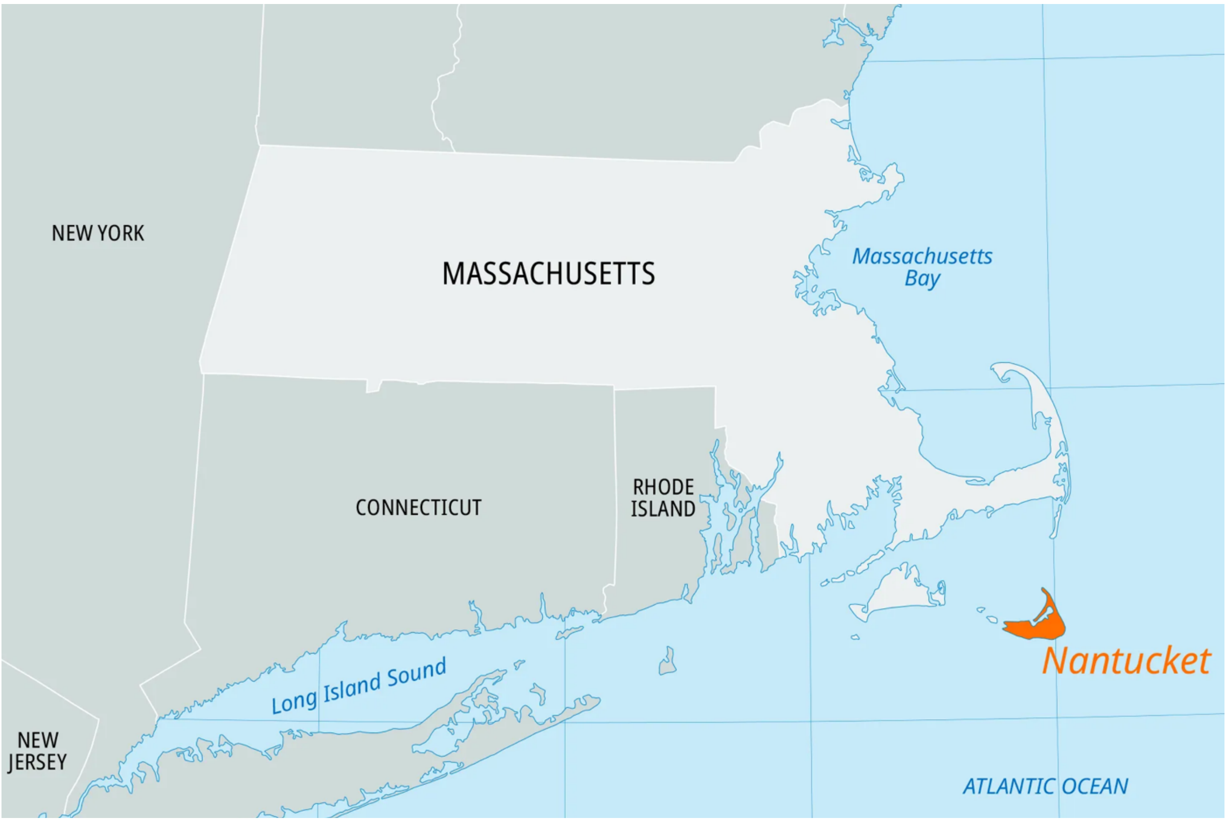
Problem Statement

The erosion of salt marshes on Nantucket poses significant challenges to the resiliency of the island. Salt marshes provide critical ecological services including coastal protection against storm surge, habitats, and carbon sequestration (Adams, et al. 2021). The erosion of these marshes has the potential to cause approximately $3.4 billion in cumulative damages, to eliminate critical habitats, and to threaten the security of nearby properties by 2070 if no actions are taken (Town of Nantucket, n.d.; Thorne, et al. 2019).

Introduction

Nantucket Island is located 30 miles off the coast of Cape Cod, Massachusetts. Nantucket is 14 miles long and 3 ½ miles wide (Town of Nantucket, 2024a). Map 1 displays Nantucket in relation to the rest of Massachusetts. Over 50% of Nantucket's land is protected conservation land and protected from future land development (Town of Nantucket, 2024a). Nantucket's year-round population is approximately 14,000 people. However, Nantucket's primary industry is tourism where the population swells to 80,000 people in July and August (Town of Nantucket, 2024b). Tourism on Nantucket has risen significantly as the summer population increased 70% between 2014 and 2022 (Graziadei, 2022). The increasing summer population on Nantucket demonstrates the gravity of increasing threats to the ecological health of the Island, as they threaten the Island's main source of income.

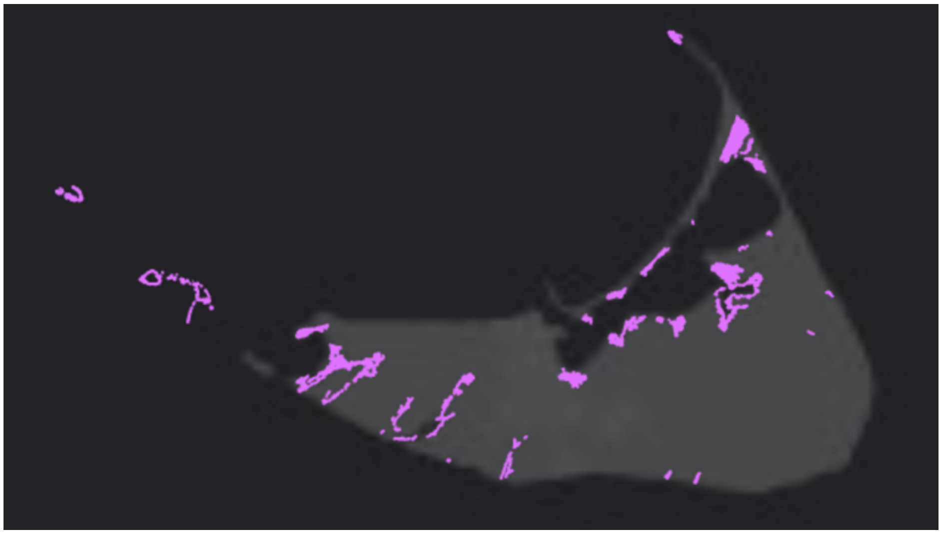
Salt marshes are a little-known ecosystem that serve a critical role in both global and local environments. The role salt marshes play in storing carbon, providing critical habitat to rare and endangered species, protecting coastal communities from flooding, as well as offering a natural recreational space is at risk of erosion. The erosion of salt marshes on Nantucket threatens the resiliency of Nantucket itself. These marshes provide protection from flooding and storm surge to the areas nearby. Since 1965, Nantucket has experienced an average of 8.7" of sea level rise, which increase flooding both during storms as well as daily during high tide (Town of Nantucket, n.d.). For instance, in 2023 Easy St. in downtown Nantucket was flooded 75 days during normal, non-storm high tides (Town of Nantucket, n.d.). This "sunny day" or "nuisance" flooding demonstrates the increasing threats to every-day life on Nantucket. The erosion of Nantucket's salt marshes increases the Island's susceptibility to sea level rise. The Nantucket Conservation Foundation (NCF) seeks to engage in land management strategies that mitigate the erosion of Nantucket salt marshes and improves marsh health.



Map 1: Nantucket in relation to the rest of Massachusetts (Britannica, 2025).

Background

Rising sea levels contribute to the erosion of salt marshes on Nantucket. Salt marshes are wetlands located along the coast. They are often located in more protected regions of coastline, such as inner harbor regions, and creeks. Nantucket has approximately 1600 acres of salt marshes. Map 2 below shows the location of salt marshes across Nantucket in pink. Marshes are made up of peat and vegetation including marsh grasses (NOAA, n.d.). These marshes flood daily with salt water during high tide. As such, marsh environments are maintained through a continuous process of decomposition of marsh vegetation and sediment deposition to the marsh bank to form the peat foundation that vegetation grows (NOAA, n.d.). A very important component of salt marsh ecosystems is the process of sediment transportation throughout an ecosystem. Specifically, salt marshes are maintained through sediment supply, which accumulates on the bed of a marsh (Mudd, 2011). Salt marshes are highly productive ecosystems that provide habitat for wildlife as well as critical ecosystem services such as carbon sequestration, coastal protection, filter out pollution, and erosion protection (NOAA, n.d.). Additionally, salt marshes serve as nurseries for approximately 75% of fish species, which has significant economic implications (NOAA, n.d.).



Map 2: Salt marshes on Nantucket, shown in pink (USGS, 2019).

The increased volumes of water and wave energy from sea level rise removes sediment from the marsh bank. The removal of the top layer of sediment is followed by the erosion of lower, underlying sediment that is less vegetated and therefore, less protected. This mechanism of erosion has been labelled as "terracing" as water erodes different layers of sediment over time (Mcloughlin, et al. 2010). Image 1 below illustrates salt marsh erosion in Medouie Creek on Nantucket. The diagram to the left depicts the process of salt marsh erosion as sediment is eroded from the creek bank, eventually revealing the mud flat. The erosion leads to "dieback," where vegetation retreats inland because of lost sediment on the marsh edge. Sea level rise can also lead to erosion through another mechanism. Specifically, increased water and wave energy can lead to cracks in a marsh bank. These cracks allow water to flow further back into a marsh in areas where vegetation and peat are not suited for significant water inundation. Erosion associated with the formation of cracks is called "block detachment" (Mcloughlin, et al. 2010).

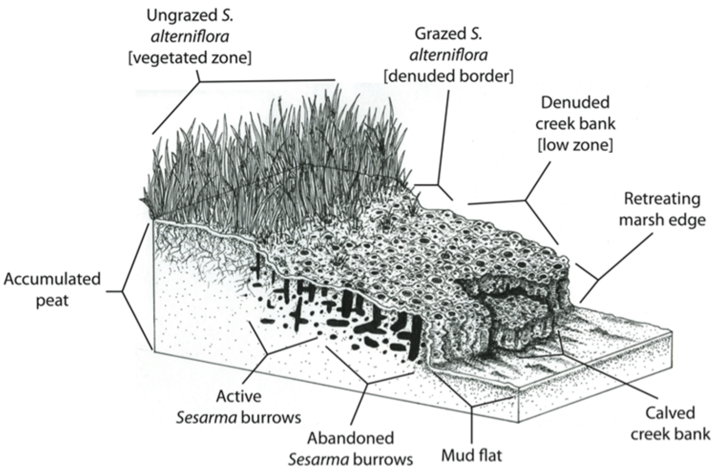


Image 1: Salt marsh erosion in Medouie Creek, Nantucket (NCF, n.d.c)

Sea level rise is the one of the primary root causes of salt marsh erosion. Other primary causes include increased frequency and intensity of storms and the relationship between sediment supply and peat formation. Increased wave energy (from storms) breaking on the edge of salt marshes both increases how much water is inundating a marsh as well as increases the energy that is breaking on the shore. Image 2 below shows the process by which sea level rise inundates low marshes with water. The marsh bank is eroded away as elevation is lost and marsh vegetation retreats inland. Marshes are resilient ecosystems that under normal, unaltered conditions can generally withstand storms. However, the increased frequency of these storms has produced long-term negative impacts on marshes that reduces marsh resiliency (Leonardi, et al. 2018). One measured long-term impact of increased storms includes the deepening of tidal flats. Deeper tidal flats are associated with increased wave energy, which over time greater wave energy breaking on a salt marsh can wear down and erode the marsh at a greater rate (Leonardi, et al. 2018). One potential caveat is that instances where storms increase the sediment supply in the water can increase sediment accumulation on a salt marsh and therefore mitigate erosion (Pannozzo, et al. 2021). However, the long-term consequences of increased storms may outweigh isolated instances of increased sediment supply (Leonardi, et al. 2018).

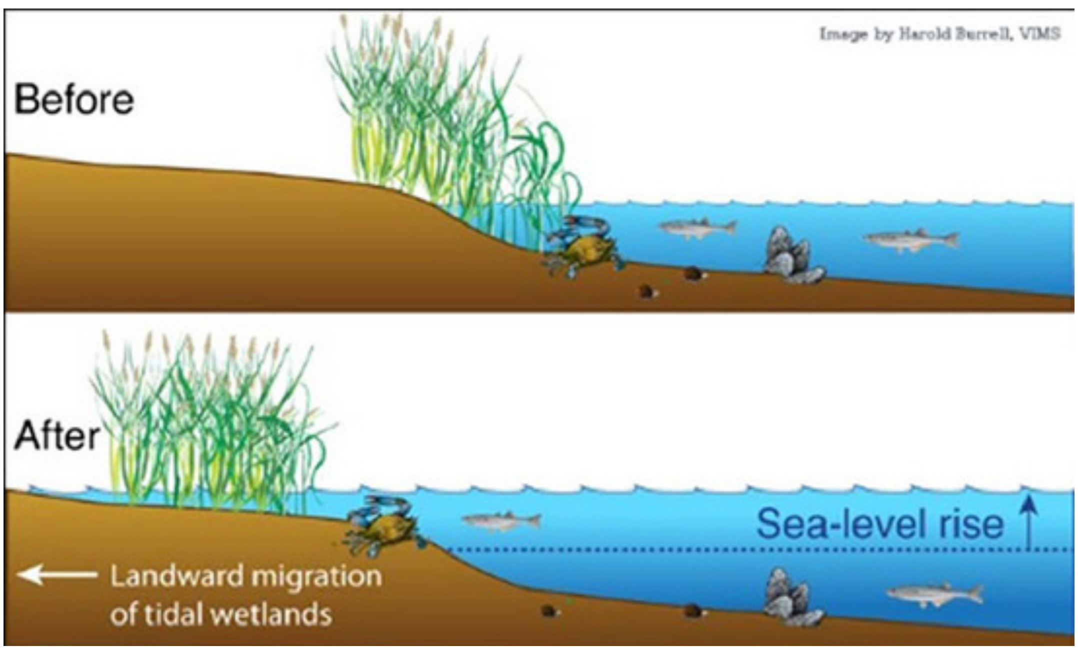


Image 2: Impact of Sea Level Rise on Salt Marshes (NOAA, 2019)

Available sediment supply has been posited as another cause of salt marsh erosion. Specifically, fluxes in the amount of sediment have been significantly associated with changes in salt marshes, namely erosion (Ladd, et al. 2019). Salt marshes exist within a broader ecosystem with interacting processes. Sediment transportation exists as a process that flows throughout an ecosystem delivering sediment to different areas including salt marshes, tidal basins, etc. Salt marshes have evolved to be dependent on certain amounts of sediment to maintain their elevation. Marshes where sediment levels remain relatively constant may be able to persist in an age of sea level rise if the accretion (accumulation) rates surpass sea level rise. This distinction highlights a key factor related to the extent of salt marsh erosion in a specific marsh. If sediment supply and accretion rates remain relatively steady, a marsh may be able to persist. Therefore, while sea level rise is a significant factor pushing erosion, a key mechanism that contributes to the magnitude of salt marsh erosion is changes in sediment supply. Reductions in sediment supply can have significant impacts on the resiliency of salt marshes (Ladd, et al. 2019).

Generally, sediment accretion rates and erosion rates are measured through elevation changes. Specifically, many studies measure changes in marsh elevation in either centimeters or millimeters. Elevation changes are usually discussed in terms of loss or gain on a yearly basis to measure average changes in a marsh over time (Davis, et al. 2022). There are various models for projecting the long-term impact of sea level rise on salt marsh erosion. If a marsh's accretion rate exceeds projected sea level rise, the marsh may sustain for the foreseeable future. One model incorporates changing storm patterns in conjunction with sea level rise projections to predict salt marsh survival in the face of sea level rise (Schuerch, et al. 2013). These models offer more hopeful outlooks where storms may supply sediment to a marsh which can help with accretion and maintenance in the face of sea level rise (Schuerch, et al. 2013). However, one limitation of these models is that storms may not always increase sediment accretion in the long term. Other models focus on comparing estimated rates of sea level rise to marsh accretion. These models predict salt marshes "drowning" from sea level rise within 120 years (Best, et al. 2018).

Erosion of salt marshes poses significant threats to the resiliency of coastal ecosystems as well as the global environment. Beginning to look broadly at the consequences of salt marsh erosion, lost habitat threatens biodiversity and the survival of rare and endangered species. Salt marshes provide a substantial amount of habitat to rare species, particularly birds. Current damages from salt marsh erosion have been associated with reduced habitats for species of sparrows as well as nursery habitats for approximately 75% of fishery species (Rosencranz, et al. 2018; Thorne, et al. 2019; NOAA, n.d.). One of the greatest ecosystem services that salt marshes provide is carbon sequestration. Specifically, wetlands such as salt marshes store four times the amount of carbon that terrestrial ecosystems provide (Byun, et al. 2019). Erosion of salt marshes releases carbon into the atmosphere exacerbating climate change and sea level rise, which in turn further erodes salt marshes, creating a positive feedback loop. One hectare of salt marsh is valued at approximately $6,600 for its carbon sequestration capacity (Byun, et al. 2019). Therefore, salt marsh loss not only poses environmental challenges but can lead to economic losses and costs associated with increased damages from climate change. One of the most localized impacts of salt marsh loss is the increased risk of flooding and the costs associated with flood damage. In a functioning system, salt marshes provide significant flood protection. One study found that healthy salt marshes were associated with an 18% reduction in wave height, which reduced flooding of nearby areas (Möller, 2014).

In addition to the global consequences of salt marsh loss, Nantucket faces localized impacts of salt marsh erosion. Specifically, erosion and loss of Nantucket marshes has led to changing environmental conditions. These new environments have led to the over-population of purple crabs in Nantucket salt marshes. The purple crabs over-eat marsh vegetation which leaves patches of exposed peat. These patches are more susceptible to erosion. The purple crabs create positive feedback loops as they create patches, which become larger and larger as the water erodes sediment (NCF, n.d.b). Salt marsh erosion threatens Nantucket's resiliency as it becomes more susceptible to flooding. Specifically, estimates project that by 2070, 2,300 buildings are likely to either flood or be at significant risk of erosion, 84% of these are residential homes and 50% are considered historic buildings (Town of Nantucket, n.d.). By 2070, 30 miles of roadway are projected to flood daily at high tide with approximately six inches of standing water if no actions are taken to address diminished flooding protection from salt marsh erosion (Town of Nantucket, n.d.). The consequences of salt marsh erosion on Nantucket are numerous and have both localized and global impacts. If no actions are taken to mitigate the erosion of these marshes not only is the longevity of Nantucket threatened but the loss of critical carbon sequestration and habitat pose global challenges.

Evidence Review: Addressing Salt Marsh Erosion through the RAD Framework

The literature outlines several options for mitigating salt marsh erosion. Many of the tested ways to reduce salt marsh erosion involve restoration projects aimed at rebuilding marshes. Traditional land management strategies emphasize a stationary perspective on restoration projects. Specifically, these projects may fail to adequately address the ever-changing nature of climate change (Thompson, et al. 2020; Schuurman, et al. 2022). A new ecological management framework incorporates the changing landscape of ecosystem management under climate change. Specifically, the “RAD” Framework expands land management practices to better address changing climates (Schuurman, et al. 2022). RAD stands for Resist, Accept, or Direct. Efforts falling under the resist category involve management practices aimed at resisting changes and restoring an area to previous, historical conditions. Efforts falling under the accept category involve management practices that leave ecosystems to change in response to new environmental conditions. Accept practices do not seek to alter the trajectory of an ecosystem. Efforts falling under the direct category involve management strategies that seek to shape ecosystems to account for changing environmental conditions. Direct management practices accept the changing nature of an environment and seek to instigate changes that increase the productivity of an ecosystem while considering changing environmental conditions (Schuurman, et al. 2022). The alternatives explored in this literature review will be divided into sections based on the type of land management practice: Resist, Accept, or Direct. The decision tree below highlights the key decisions involved when determining which type of land management practice to use for a certain project.

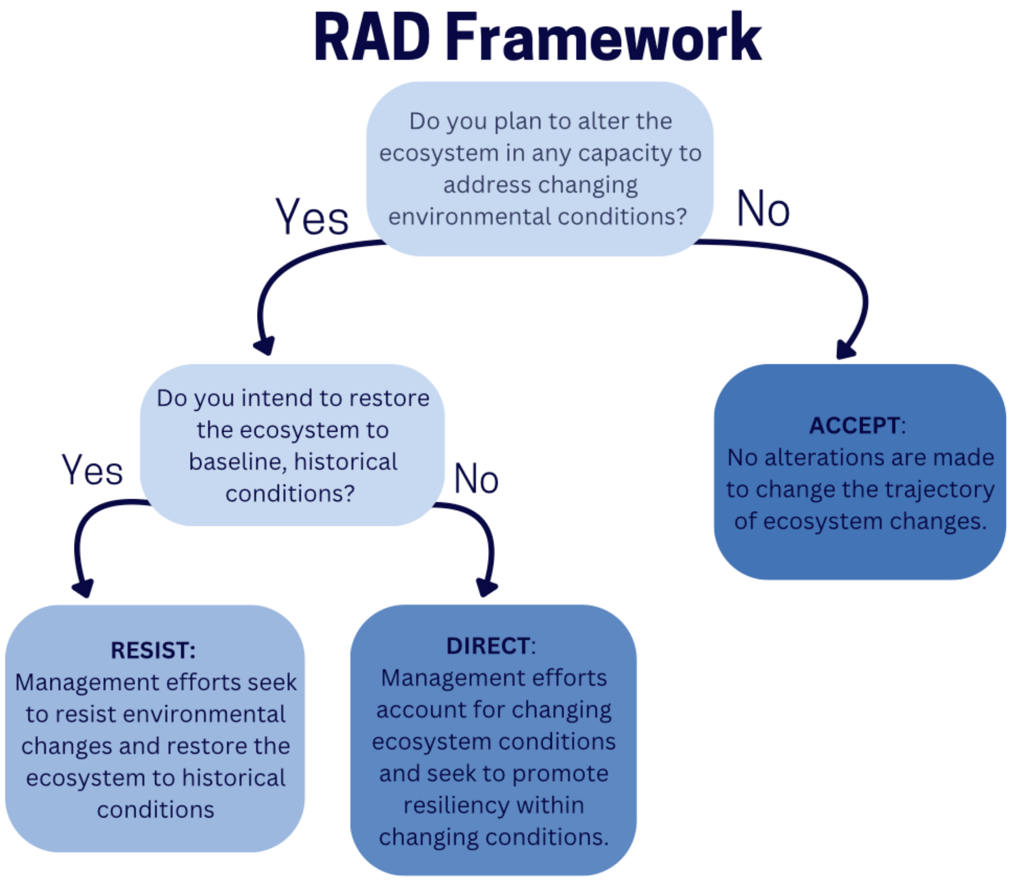


Figure 1: Decision tree for the "RAD" framework.

Resist:

One approach to managing salt marsh erosion is through sediment augmentation to increase a salt marsh's elevation (Fard, et al. 2023). The process of sediment augmentation involves collecting sediment from another area in an ecosystem (e.g., tidal channel) to place on a marsh (Kamal, 2019). Sediment augmentation has been found to increase marsh elevation and improve resilience in some cases (Slocum, et al. 2005; Stagg and Mendelssohn, 2010; Raposa, et al. 2022). However, it is important to note that the success of sediment augmentation on a marsh is highly dependent on the characteristics of a marsh (e.g., species composition, structural diversity, physical conditions such as sediment size, and ecosystem functions) (Billah, et al. 2022). The addition of sediment to a salt marsh in Louisiana was found to increase marsh elevation and reduce erosion by introducing sediment back into the system. Within two years of the sediment addition relative elevation across the marsh had been maximized at 10-22cm increased elevation and stabilized to around 5-12 cm increased elevation within seven years of sediment application; demonstrating prolonged benefits of the sediment application on marsh health (Slocum, et al. 2005). Furthermore, sediment augmentation kept pace with land subsidence and sea level rise (Slocum, et al. 2005). Average sediment accretion rates have been estimated to be 4.5mm/yr with high variability across marshes (Masselink & Jones, 2024). The average sea level rise is approximately 3.05mm/yr (Environmental Protection Agency, 2024). Marshes where accretion rates exceed sea level rise could survive. Studies in Louisiana and Rhode Island found similar impacts on marsh elevation (Stagg and Mendelssohn, 2010; Raposa, et al. 2022). One restoration project from southern California found that thick layer sediment augmentation had negative impacts on marsh vegetation and resilience, in contrast to other studies (McAtee, et al. 2020). Differing results demonstrates that ecosystems respond differently to restoration attempts. Specifically, variables such as sediment thickness, plant species, salinity, sediment coarseness, and sediment density have important implications for the success of a project (McAtee, et al. 2020). This is furthered by the findings of a study examining four marshes in Canada. The effects of sedimentation across the four marshes were non-linear and variable, indicating that the impacts of a sediment project are dependent on several factors (Cayer and Hatvany, 2023).

The characteristics of sediment used in augmentation also have important impacts on the success of a restoration project. Specifically, a project applying sediment to a marsh in California found that vegetation growth was diminished when the sediment applied was dissimilar to native sediment (Fard, et al. 2023). For instance, a site where non-native sediment was introduced to the system led to an accumulation of 1.2mm per year compared to the control site (where no sediment was applied) where sediment accumulated at a rate of 3.9mm per year (Fard, et al. 2023). The poor accumulation of the sediment was associated with sediment that did not resemble native sediment (e.g., coarser grain size) (Fard, et al. 2023).

A specific method of sediment augmentation, known as "thin-layer sediment placement," was found to revegetate marshes relatively quickly (Raposa, et al., 2023). Specifically, adding 7cm of sediment to a marsh led to an increase in low marsh elevation of 8.2cm and adding 14 cm of sediment to a marsh led to an increase in low marsh elevation of 14.6 cm (Raposa, et al., 2023). The success of thin layer sediment application was found in other studies where thin layer application was found to double vegetative mass and increase marsh elevation by 6 cm following applying 6 cm of sediment (a total elevation gain of 12 cm) (Davis, et al. 2022). Thin layer application was found to be more successful and beneficial to marshes than projects that applied thicker layers of sediment (McAtee, et al. 2020; Raposa, et al., 2023; Davis, et al. 2022).

Sediment augmentation is a prominent approach to salt marsh restoration. However, there are several cited concerns regarding the potential negative impacts of altering sediment dynamics in an ecosystem. Sediment transportation is the process by which sediment is carried downstream by a water current and deposited at various points in a wetland (e.g., deltas, mudflats, etc.) (USGS, n.d.). The process of sediment transport is critical for maintaining wetlands, like salt marshes. Therefore, removing sediment from one area, a tidal channel for instance, in an ecosystem to place on a salt marsh could potentially "starve" the area where the sediment in the tidal channel was intended to go (Kamal, 2019). This has the potential to disrupt sediment dynamics in other components of a system, causing negative, compounding impacts. Therefore, it is important to consider the impacts of removing sediment to place on a marsh.

Accept:

Land management practices under the accept approach are best suited in situations where the ecosystem is likely to resist restoration or intervention (Thompson, et al. 2020). Furthermore, high costs may prohibit taking actions that could either restore or redirect an ecosystem effectively. In these cases, acceptance of changes may be the best option (Thompson, et al. 2020). Acceptance of changing environmental systems have been used in ecosystems where a system continues to evolve into a relatively “new” system. Furthermore, a changing system may not respond well to restoration attempts because of the extent of change. For example, a study of the Kenai National Wildlife Refuge in Alaska used the accept framework for vegetation change when it became apparent that replanting native vegetation would not likely survive in the changed environment (Magness, et al. 2022). Acceptance may be the most cost-effective option when an ecosystem has evolved into a new system that cannot be restored to a historical baseline. A key indicator that a site has surpassed an ecological threshold is abiotic change (e.g., significant changes in a wetland’s salinity) (Hobbs, et al. 2014).

Direct:

Under the direct land management approach there are several methods to incorporate changing environmental conditions into land management. “Climate Change Adaptation Strategies” involves identifying vulnerabilities stemming from climate change when approaching management. Climate Change Adaptation Strategies include stabilizing shorelines to adjust for increased wave energy and sea level and enabling marsh migration upland (Wigand, et al. 2015). For instance, the construction and placement of oyster reefs in salt marshes have been used to adjust to the changing landscape. Oyster reefs can facilitate sedimentation in salt marsh ecosystems. One study found that marsh edges where oyster reefs were present were less eroded than marshes without and that constructed oyster reefs performed as well if not better than natural reefs (Stricklin, et al. 2010). Other studies found similar results. Specifically, oyster reefs helped slow down erosion and under the right elevations could facilitate sedimentation to restore some of the marsh (Ridge, et al. 2017; Chowdbury, et al. 2019; Chowdbury, et al. 2021). A study examining the impact of oyster reefs placed in 12 Louisiana salt marshes found that the marshes with oyster reefs had slower erosion rates (Piazza, et al. 2005). The success of an oyster reef’s impact on salt marsh erosion is contingent on whether the growth rate of an oyster reef’s oyster spat (infant oysters) is high enough to sustain prolonged reef growth (Piazza, et al. 2005).

Living shorelines are a nature-based solution that have been used to promote the resilience of salt marshes and protect against erosion (Smith, et al, 2018; Bilkovic, et al, 2016). Living shorelines include anchoring oyster reefs along the shoreline, placing rock on the shoreline, or planting additional vegetation (Ganju, 2019). A natural experiment comparing a living shoreline to a nearby marsh before and after Hurricane Matthew in North Carolina found that the living shorelines significantly maintained elevation compared to natural marsh (Smith, et al. 2018). Furthermore, the use of living shorelines is generally most beneficial to fringe marshes (e.g., more narrow marshes located on the shoreline as opposed to protected inland marshes) (Currin, et al. 2007). A restoration project in North Carolina found that fringe salt marshes where living shorelines were added had sediment accretion rates 1.5 to 2 times greater than reference marshes where no changes were made (Currin, et al. 2007). Living shorelines were found to improve ecosystem services and general health in addition to protecting from erosion (Gittman, et al. 2016). However, a study of living shorelines made completely of organic material (no rock or hard substrate) in Martha's Vineyard found no significant change in sedimentation or elevation on salt marshes where living shorelines were present (Schoell, et al. 2023). These results indicate the potential need for a combination of organic and inorganic materials in living shorelines for effective erosion mitigation.

Conclusion:

Much of the research on alternatives to address salt marsh erosion falls into the restoration or "resist" category of the RAD Framework. This is consistent with historical land management practices that focused on restoring land back to its baseline, historical conditions. Many of these projects were successful but there are other options for management. The direct option offers ways to manage salt marshes through mechanisms beyond simply attempting to restore a marsh to its baseline, especially when this may not be feasible. For instance, living shorelines and adding oyster reefs have been productive. Accept strategies offer a status quo approach when costs may be too high, or management may not be successful. Applying the findings from the literature to the salt marshes of Nantucket was helpful for considering the potential ways to mitigate salt marsh erosion.

Alternatives

This section describes the three alternatives that were evaluated for their potential impacts on salt marsh erosion on Nantucket. The analysis of the problem and literature has revealed the importance of analyzing interventions that increase the available sediment supply in the marsh ecosystem to facilitate sediment deposition on to the marsh bed. Sediment accumulation rates are critical to managing salt marshes to persist in the face of sea level rise. Therefore, all the evaluated alternatives were included in the analysis for their potential ability to increase the sediment supply in the marsh ecosystem, which is associated with increased marsh elevation. The alternatives examined include direct sediment application to the marsh bed, installation of oyster reefs in waters nearby salt marshes, and the construction of a living shoreline. In terms of the RAD framework none of the alternatives included fall into the accept framework due to the need to address changing conditions quickly to prevent continued damages. The graphic below highlights the three alternatives and where they fall in the RAD framework.

Figure 2: The type of land management strategy of each of the alternatives in relation to the RAD framework.

Alternative 1: Sediment Application to Marsh Bed

Sediment application is the process wherein sediment is applied directly to the surface of a marsh bed to increase marsh elevation. The sediment used is either dredged from another area in the ecosystem (e.g., a tidal channel) or brought in from a different ecosystem altogether and sprayed on the marsh bank. Thin layer sediment application has been used in several instances to mitigate salt marsh erosion and is characterized by applying sediment in a way that mimics natural sediment deposition (NCCOS, 2022). Depending on the location, thin layer application ranges from a couple centimeters up to a meter (Myszewski & Alber, 2017). Sediment application directly introduces sediment into the ecosystem thereby increasing the available sediment supply. In terms of the RAD framework, sediment application falls under the "resist" category because it seeks to restore marsh ecosystems to their baseline, historical conditions. The image below demonstrates the process by which sediment application mitigates erosion.

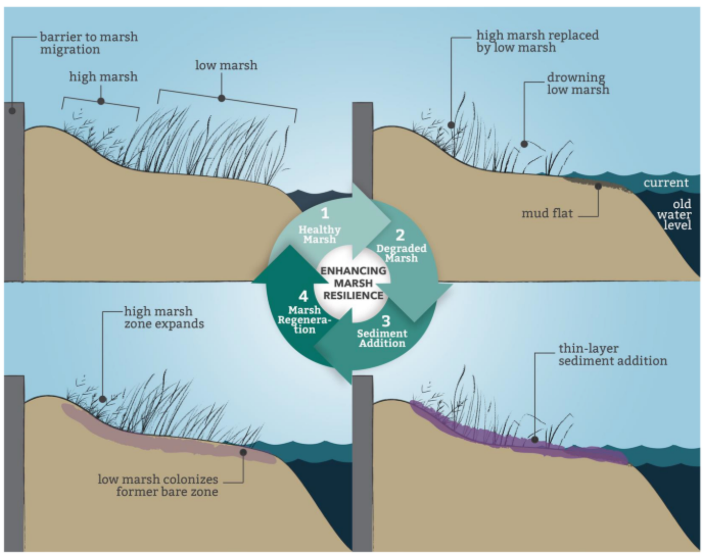


Image 3: Thin layer sediment application to marsh bed (Raposa, et al. 2023).

Alternative 2: Oyster Reef Installation in Marsh Waters

The installation of oyster reefs in the water surrounding salt marshes improves marsh resiliency through two key mechanisms. First, oyster reefs increase the sediment available through filtration and biodeposition (Hoellein, et al. 2014). Biodeposition is the process wherein oysters filter in sediment and nutrients and then deposit the filtered material back into the water supply. This filtered sediment that is introduced into the water then deposits on to the marsh bed (Locher, et al. 2021). Secondly, oyster reefs absorb wave energy, which dissipates the amount of energy breaking on marsh edges leading to physical erosion (Hong, et al, 2023). In terms of the RAD framework the installation of oyster reefs is considered a "direct" intervention where it seeks to alter the ecosystem given changing environmental conditions to promote resiliency. The image below illustrates where in the ecosystem the oyster reefs would be placed and the impact they have on absorbing wave energy.

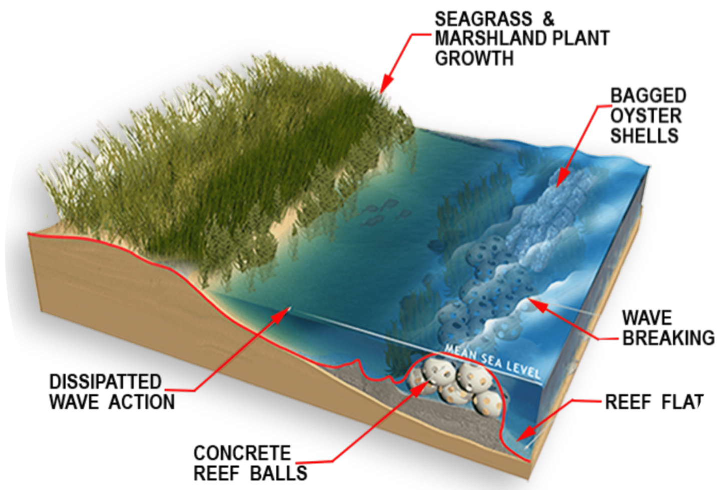


Image 4: Oyster reef installation in the waters of salt marshes (NCF, n.d.a).

Alternative 3: Living Shoreline

The construction of living shorelines on the edges of marshes has the potential to mitigate salt marsh erosion and improve sediment accumulation on the salt marsh. Living shorelines include a combination of vegetation, plants, sand, rock, and oyster reefs anchored to the shoreline to stabilize the marsh edge (NOAA Fisheries, n.d.). The vegetation present in living shoreline serves as the mechanism by which sediment supply is increased and then deposited on the marsh bed. In terms of the RAD framework the construction of a living shoreline is considered a "direct" intervention. Specifically, the living shoreline alters the ecosystem to improve its resiliency in the face of changing environmental conditions, not to restore the system to historical or baseline conditions. The image below demonstrates the components of a living shoreline and how the system changes with a living shoreline.

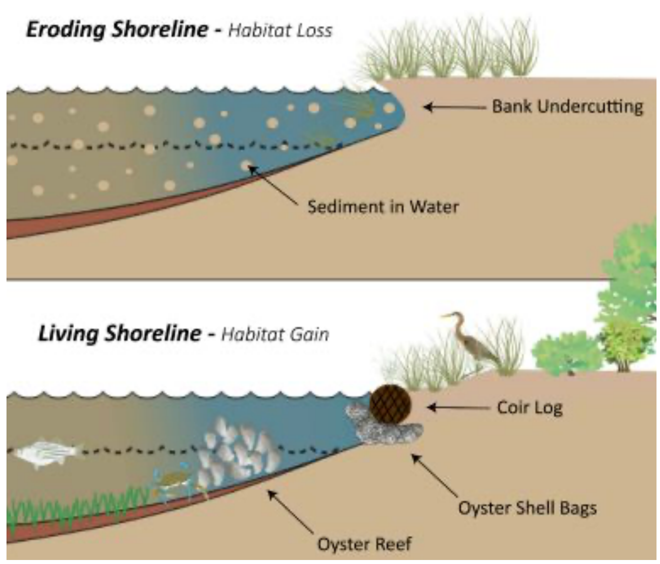


Image 5: Changes to shoreline from the installation of a living shoreline (Delaware Department of Natural Resources and Environmental Control, 2025).

Criteria

This section describes the criteria used to evaluate the different alternatives for their ability to mitigate salt marsh erosion on Nantucket.

Impact: The impact criterion measures the estimated impact of each alternative on salt marsh erosion. Specifically, the increase in marsh elevation following the project was estimated based on the results of prior cases where the intervention has been conducted and evaluated. Impact estimates include the range of impacts found in the literature on studies of the intervention. Furthermore, the projected impact was calculated by taking the average of impacts on salt marsh erosion found in comparable studies that are applicable to a similar intervention on Nantucket.

Cost: The cost criterion measures the material, labor, planning, and implementation costs associated with each proposed alternative. The projected costs of each alternative were based on cost estimates that have previously been calculated for similar projects. All the cost estimates were calculated in terms of 2025 real dollars to adjust the estimates for inflation. To make the costs comparable for each alternative, the costs were calculated for the 34.14-acre Eel Creek salt marsh on Nantucket. This provides commensurable cost estimates to compare each alternative.

Cost Effectiveness: The cost effectiveness criterion measures which alternative achieves the desired outcome of increased marsh elevation for the lowest cost. Specifically, the projected increased marsh elevation measured in centimeters will be used as projected outcome for each alternative. The cost effectiveness criterion measure will be in terms of how much is spent to achieve a one-centimeter increase in marsh elevation.

Sustainability: The sustainability criterion measures the longevity of each alternative. Specifically, sustainability refers to how long an alternative will last before requiring additional intervention or maintenance. This criterion will be projected based on the results of previous studies where the intervention was studied. This criterion will be ranked on a low, medium, and high scale. A rating of “low” sustainability refers to an intervention that requires substantial intervention and maintenance in the years following the initial construction of the project to maintain initial elevation gains. A rating of “moderate” sustainability refers to an intervention that requires some maintenance and a little intervention in the years following initial construction to maintain initial elevation gains. Finally, a rating of “high” sustainability refers to an intervention that requires little if any maintenance or intervention in the years following initial construction to maintain initial elevation gains.

Feasibility: The feasibility criterion encompasses both political and permitting feasibility, weighted equally. Political feasibility is based on the likelihood that community members and Select Board members for the Town of Nantucket will push back against a proposed intervention to prevent the project from going forward. Permitting feasibility is based on the likelihood that permitting agencies and Town officials will reject a project. A rating of "low" overall feasibility refers to an intervention that is projected to receive significant backlash from both community members, members of the Select Board, as well as likely be rejected by permitting agencies and officials. A rating of "moderate" overall feasibility refers to an intervention that is projected to receive substantial backlash from community members however may receive permitting feasibility. A rating of "high" overall feasibility refers to an intervention that is projected to receive little if any political and permitting backlash, indicating a high likelihood of the project being approved.

Evaluation

This section includes the results of evaluating each alternative by five criteria including impact, cost, cost effectiveness, feasibility, which included both political and permitting feasibility, and sustainability. The evaluation of these alternatives informs the recommended intervention that is best positioned to mitigate salt marsh erosion on Nantucket.

Alternative 1: Sediment Application to Marsh Bed Applying sediment to salt marshes is a prominent restoration approach for deteriorating salt marshes. This alternative involves dredging sediment material from another region in the ecosystem (e.g., a tidal channel) and then spraying sediment onto the marsh from a boat to increase elevation and increase the sediment supply in the ecosystem, which further leads to sediment accretion on the marsh bank.

> *Impact*: The relevant literature on sediment application to salt marshes has found an overall range of 0-22 cm of increased elevation following sediment application. The average increase in marsh elevation taken by averaging the results of studies in the literature for sediment application to salt marshes was 8 cm. This process was used to calculate impact estimates for each alternative. The studies that were examined have comparable ecosystem conditions to Nantucket. Two studies found an average elevation increase following sediment application to salt marshes equal to 6 cm (Davis, et al. 2022; Ford, et al., 1999). A study in California found that sediment application to marsh beds resulted in an average elevation increase of 22 cm, which was the largest increase in elevation observed (Thorne, 2019). A study of sediment application in North Carolina found that average increased elevation for the treated marshes ranged from 2 cm to 12 cm increased elevation, producing a range of 2-12 cm (Croft, et al. 2006). One study found that sediment did not result in any difference in marsh elevation (Rosencranz, et al. 2016). The projected change in elevation derived from taking the average impact found in the literature is an increase in elevation of 8 cm. Sediment application is tied for the lowest projected impact of the alternatives with an estimated average increase of 8 cm in marsh elevation.
>
> *Cost*: Costs for the sediment application intervention were estimated using cost per cubic yard ratios from a previous study of thin layer sediment application on the Ninigret Pond Salt Marsh in Rhode Island, which has similar conditions to Nantucket marshes. Adjusting the estimate for 2025 dollars estimated a $25.23 per cubic yard cost. Costs were estimated for Eel Creek salt marsh on Nantucket, which is 34.14 acres. The cost for sediment application to Eel Creek were estimated to be $1,390,934.97, giving this intervention **moderate** costs. Costs may vary from their estimated value. *See Appendix A for cost calculations.*
>
> *Cost Effectiveness*: The cost effectiveness measure was estimated by calculating a ratio based on the cost per 1 centimeter increase in elevation projected for the sediment

application intervention. The sediment application alternative's cost effectiveness measure was equal to $173,866.87 per 1 centimeter increase in salt marsh elevation, making this intervention the **moderate** cost-effective intervention. *See Appendix A for cost calculations.*

Feasibility (Political and Permitting): This criterion encompasses both political feasibility and permitting feasibility and is based on evaluating public, governmental, and agency support for similar projects. Political feasibility is projected to be low for this project due to significant community and governmental backlash to previous proposed erosion projects on Nantucket that involve significant temporary intervention in the project area (Green, 2022; Bushard, 2019; Bushard, 2021). Additionally, given the potential viewshed impacts during the implementation of sediment application there will likely be pushback due to negative visual impacts as there have in the past, even if impacts are temporary (Bushard, 2024). Permitting feasibility appears slightly higher as community members voted in support of permitting the dredging of Miacomet Pond in 2022, in addition to the Natural Resource Department and Land Bank receiving a one-million-dollar state grant for the project (Graziadei, 2022; Nantucket Current 2024). Therefore, this intervention has **moderate** feasibility when considering both political and permitting feasibility.

Sustainability: The evaluation of sediment application in relation to sustainability is based on how long the sediment application is likely to last before needing additional intervention and whether the sediment application would disrupt other ecosystem services. Studies have found that sediment application interventions may require additional application within three to five years following application to maintain elevation gains (Rosencranz, et al. 2015). Furthermore, sediment application has been found to negatively impact other ecosystem services by depriving other systems of sediment through the dredging processes (Ganju, 2019). In one case, sediment application was found to diminish sediment accumulation rates below marshes where there was no intervention (Fard, et al. 2023). The potential need for additional intervention in the years following the initial application of sediment and the potential negative impacts gives sediment application a **low** sustainability evaluation.

Alternative 2: Oyster Reef Installation in Marsh Waters The installation of artificial oyster reefs in waters nearby salt marshes is aimed at increasing the available sediment supply in the water that can accumulate on the marsh bed as well as reduce wave energy breaking on marsh edges. The oyster reefs would mitigate salt marsh erosion through two key mechanisms. The oyster reefs would absorb some of the wave energy breaking on the marsh which reduces the amount of water breaking off sediment. The oyster reefs would also increase the available sediment supply, which increases the sediment that can be deposited on the marsh bed.

Impact: Impacts from studies with similar environmental conditions to Nantucket were used to estimate the potential impact of the intervention on Nantucket. In North Carolina, oyster reefs placed near salt marshes increased marsh elevation between 14 cm and 20 cm across the treated marshes (Ridge, et al. 2016). Another study with similar wave height and energy to Nantucket marshes found that oyster reefs placed near salt marshes had an average increase in sediment accumulation of 29 cm (Chowdbury, et al. 2019). The smallest result associated with placing oyster reefs near salt marshes found that treated marshes increased elevation by 6.3 cm while non-treated marshes lost 3.2 cm in elevation (Meyer, et al. 2008). Therefore, estimates of the impact of oyster reefs of salt marshes range from 6.3 cm to 29 cm of increased elevation. The projected change in elevation derived from taking the average impact found in the literature is an increase in elevation of 17 cm when accounting for the range of potential outcomes, estimating this alternative to be the **most** impactful.

Cost: The estimated costs are based on the National Oceanic and Atmospheric Administration's Oyster Economics Projections (Petrolia, et al. 2022). The estimate is in 2019 dollars and projects the cost of bottom constructed oyster reefs per acre. Bottom constructed oyster reefs are anchored to the ocean floor. The Eel Creek Salt marsh on Nantucket is 34.14 acres. In a previous case for a 16.8 acre salt marsh, oyster reefs were placed in 0.17 acres of water (Department of Fish and Game, 2023). This creates a ratio of .0101 acres of oyster reefs per one acre of salt marsh. For Eel Creek Salt marshes there would be approximately .345 acres of oyster reefs for the 34.14 acres of marsh. Therefore, the cost estimate is based off .345 acres of oyster reefs. After adjusting for inflation and permitting costs, the estimated cost for .345 acres of oyster reef installation near salt marshes is equal to $12,514.58, making this alternative the **least** expensive option. Costs may vary from their estimated value.[*] *See Appendix A for cost calculations.*

Cost Effectiveness: The cost effectiveness measure was estimated by calculating a ratio based on the cost per 1 centimeter increase in elevation projected for the oyster reef installation intervention. The oyster reef installation's cost effectiveness measure is equal to $736.15 spent per 1 centimeter increase in marsh elevation. The oyster reef intervention is estimated to be the **most** cost-effective measure. *See Appendix A for cost calculations.*

Feasibility (Political and Permitting): The political feasibility for the oyster reef intervention is projected to be high. There has been support for an oyster shell recycling program between restaurants and the Nantucket Natural Resource Department to rebuild

[*] If this cost estimate was underestimated, it is still likely the lowest cost alternative. Specifically, a previous oyster reef installation project that included another intervention in addition to the oyster reef project received $84,270 in grants in 2023, indicating that even with an underestimation this alternative would still be the cheapest by far (Department of Fish and Game, 2023).

oyster reefs (Pykosz, 2014). Additionally, there has been support for new technologies aimed at reducing erosion by placing submerged barges in the water to keep sediment from eroding from certain areas (Balling, 2009). Nantucket Conservation Foundation received a grant and permit to construct oyster castles in Medouie Creek (Nantucket Conservation Foundation, n.d.). Additionally, the Nantucket Conservation Foundation has installed oyster reefs in the past and received support. Replicating the project has a greater feasibility than a novel approach. There is also high permitting feasibility. In 2018, the Nantucket Division of Shellfish and Aquatic Resources began the Shimmo Creek Oyster Restoration project to place free-floating oyster reefs in Shimmo Creek (Town of Nantucket, n.d.). In 2021, Madaket Marine began a project of placing oyster reefs in Hither Creek to minimize algal blooms (Bushard, 2021). The number of oyster projects that have been implemented in recent years indicate a high likelihood of support for the projects both politically and from a permitting likelihood. The oyster reef installation intervention receives a **high** feasibility likelihood.

Sustainability: The oyster reef intervention was found to stabilize the edges of marshes which reduced erosion and marsh loss (Stricklin, et al. 2010). There is also a sustainability component wherein oyster reefs located adjacent to salt marshes were found to have increased oyster spat (larvae) growth rates which leads to sustained reef growth over time (Piazza, et al. 2005). Therefore, oyster reefs have a self-sustaining mechanism where they can continue to grow without requiring additional intervention. Oyster reefs were found to grow at a rate that exceeded models of accelerated sea level rise (Ridge, et al. 2015). The self-sustaining nature of oyster reefs in addition to the potential for oyster reefs to maintain in the face of sea level rise gives the oyster reef intervention a **high** sustainability estimate.

Alternative 3: Living Shoreline The construction of a living shoreline would include some combination of vegetation, rock, sand, and oysters to reinforce the marshes edge. In addition to offering structural reinforcement to marsh edges, living shorelines that include vegetation and oyster reefs have been associated with increased sediment supply and sediment deposition on the marsh bank. This increased sediment supply can promote marsh accretion rates, which is associated with elevation growth.

Impact: Impacts from studies with similar environmental conditions to Nantucket were used to estimate the potential impact of the intervention on Nantucket. One study found that living shorelines constructed on salt marshes in New England resulted in no significant change in marsh elevation compared to marshes where no living shoreline was constructed (Schoell, et al. 2023). This study examined the effect that living shorelines comprised solely of organic materials, no rock, sand, or hard substrate were used, which demonstrates the potential need for including hard substrates to reinforce living shorelines. Another study conducted in North Carolina found that living shorelines with oysters anchored to the marsh edge had an average 17 cm increase in marsh elevation (Polk & Eulie, 2018). The estimated impact of constructing a living shoreline on salt marshes ranges from no effect to 17 cm in gained elevation. The projected change is derived from taking the average elevation change found in the literature. The average elevation change based on the results from the literature, estimates an 8 cm increase in marsh elevation, which ties this intervention with the **lowest** impact.

Cost: Estimates of per foot costs for living shorelines were obtained from the U.S. Army Corps of Engineers estimates using their sill living shoreline estimate which includes rock and vegetation (U.S. Army Corps of Engineers, 2015). Costs were estimated for a 0.5 mile long living shoreline in Eel Creek based on the length of the most exposed regions of shoreline in Eel Creek being approximately a half mile long. After adjusting costs for inflation and permitting costs and assuming a .5 mile living shoreline the costs for a living shoreline were estimated to be $6,629,131.61, projecting this intervention with **high** costs compared with the other interventions. Costs may vary from their estimated value. *See Appendix A for cost calculations.*

Cost Effectiveness: The cost effectiveness measure was estimated by calculating a ratio based on the cost per 1 centimeter increase in elevation projected for the living shoreline intervention. The cost effectiveness measure for the living shoreline is equal to $828,641.45 per 1 centimeter increase in elevation. The living shoreline has **low** cost effectiveness in comparison with the other interventions. *See Appendix A for cost calculations.*

Feasibility (Political and Permitting): The political and permitting feasibility of a living shoreline is projected to be low. Nantucket town officials have publicly stated that living shorelines are considered intermediate, temporary projects that would not provide long-term protections (Bushard, 2022). There is increased focus on investing in long-term measures to promote coastal resiliency, indicating that perceptions of living shorelines being temporary may inhibit the likelihood of receiving both public and permitting support. Erosion and flooding interventions have received pushback from community members and permitting agencies (Graziadei, 2023; Town of Nantucket, 2023). One potential source of support that could increase the feasibility of a living shoreline is the Nantucket Coastal Resilience Plan's emphasis on "green" and "grey" infrastructure when mitigating erosion (Town of Nantucket, 2025b). Living shorelines are considered green infrastructure, which could be a source of support. The overall feasibility of living shorelines is considered **moderate**.

Sustainability: Living shorelines are found to minimize the impacts of storm events on marshes and can reduce erosion in these cases. (Polk, et al. 2021; Smith, et al. 2018;). Additionally, salt marshes where living shorelines were present were found to maintain elevation levels amid hurricanes whereas marshes with no living shorelines lost elevation during hurricanes (Smith, et al. 2018). A potential limitation of living shorelines lies in the fact that they are engineered systems that may not mimic natural systems despite best efforts. Specifically, plants are distributed in grid like patterns for living shorelines, which does not replicate natural systems where tidal inundation dictates plant development (Mitchell and Bilkovic, 2019). Furthermore, living shorelines are designed to absorb wave energy along sloped substrate to mitigate wave energy on vegetation. This design can impede sedimentation processes because natural marshes have varying topography that traps sediment, which designed shorelines do not replicate effectively (Mitchell and Bilkovic, 2019). Living shorelines provide benefits in terms of protection from storms and increased stabilization. However, there are concerns associated with longevity because living shorelines are unable to mimic certain features of natural marshes that contribute to long-term marsh maintenance. Thus, living shorelines require maintenance every couple of years, including replanting vegetation, replenishing sand fill, and removing debris (NOAA, 2015). While living shorelines can withstand storm events, they do require maintenance and upkeep because they cannot perfectly mimic natural systems. Therefore, living shorelines demonstrate a **moderate** degree of sustainability.

Outcome Matrix

Cost estimates based on Eel Point Salt Marsh (34.14 acres).

See Appendix A for cost calculations.

	Impact (increased elevation)	*Cost*	*Cost Effectiveness*	*Feasibility*	*Sustainability*
Alternative 1: *Sediment Application*	8 cm	$1,390,934	$173,866 per 1 cm increase in elevation	Political: Low Permitting: Moderate *Overall*: Moderate	Low
Alternative 2: *Oyster Reef Installation*	17 cm	$12,514†	$736 per 1 cm increase in elevation	Political: High Permitting: High *Overall*: High	High
Alternative 3: *Living Shoreline (0.5 miles long)*	8 cm	$6,629,131	$828,641 per 1 cm increase in elevation	Political: Low Permitting: Moderate *Overall*: Moderate	Moderate

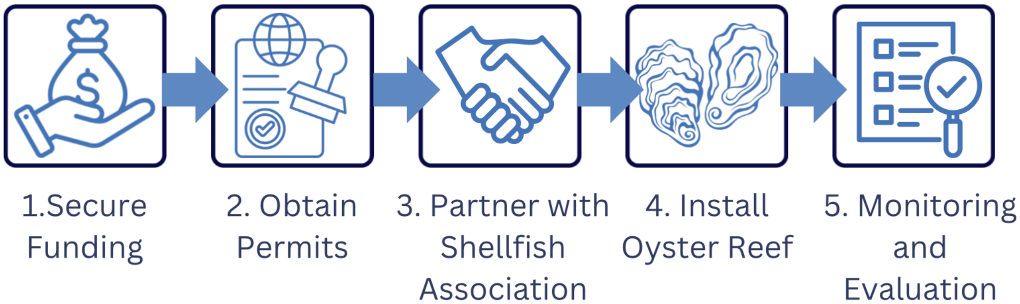
† If this cost estimate was underestimated, it is still likely the lowest cost alternative. Specifically, a previous oyster reef installation project on Nantucket that included another intervention in addition to the oyster reef project received $84,270 in grants in 2023, indicating that even with an underestimation this alternative would likely still be the cheapest by far (Department of Fish and Game, 2023).

Recommendation

Alternative 2: Oyster Reef Installation

Based on the foregoing analysis of the available alternatives, I recommend installing oyster reefs to mitigate salt marsh erosion on Nantucket. The oyster reef intervention is projected to have the highest impact with an estimated increase in elevation of 17 cm. This is substantially larger than both the sediment application and the living shoreline intervention, which both estimated an 8 cm increase in elevation. The oyster reef project has the lowest cost estimate and the highest cost-effectiveness measure when compared to the other alternatives. The oyster reef intervention has also been conducted on Nantucket and there has been high permitting and public support for oyster projects in the past. The high support and previous success with obtaining permits for similar projects gives the oyster reef intervention a high level of feasibility, particularly when compared with the other interventions which were projected to face greater challenges and backlash from both a permitting stance and in terms of public support. Finally, the self-sustaining and self-replenishing nature of oyster reefs gives this option a high sustainability rating. Based on the evaluation of the criteria, the oyster reef installation alternative is best posited to achieve the Nantucket Conservation Foundation's goals of mitigating salt marsh erosion, promoting ecologically conscious land management practices, and fostering sustainable land stewardship.

Steps for Implementation



This section outlines the steps for implementing the recommended oyster reef intervention on Nantucket. The first step requires securing funding. Historically, projects undertaken by NCF have been funded by a combination of federal, state, and private grants. NCF's previous oyster reef was funded by the In Lieu Fee Program through the state of Massachusetts (Department of Fish and Game, 2023). The In Lieu Fee Program is a partnership between the Massachusetts Department of Fish and Game and the Army Corps of Engineers, which aggregates paid in-lieu fees to fund projects seeking to mitigate damage to aquatic resources (Department of Fish and Game, n.d.). NCF would need to apply again for the In Lieu Fee Program or another grant to fund the project. Given the current political climate, it is uncertain that a federal grant would be granted and some state funding may be impacted. Funding challenges will be discussed later.

Once funding for the project has been secured, NCF would need to acquire the necessary permits to begin the project. Under the Massachusetts Environmental Protection Act, NCF would need an aquaculture permit because oysters are used (Division of Marine Fisheries, n.d.). Specifically, NCF would need a shellfish propagation permit.

NCF would need to partner with the Nantucket Shellfish Association, as they have done in the past, to obtain the oyster spat (oyster larvae) to begin constructing the oyster reefs. To construct artificial oyster reefs NCF would work with the Shellfish Association to apply oyster spat onto a hard substrate such as concrete or recycled oyster shells for the spat to attach to and grow. These reefs would then be placed into the water and anchored to the bottom. In previous restoration attempts NCF has constructed concrete "castles," wherein concrete blocks are layered in a lattice pattern that allows for the water to flow through the concrete blocks to enable growth and the free flow of sediment through the reef (NCF, n.d.c).

Following the installation of the oyster reefs, NCF could monitor and evaluate the restoration project. There are three key changes NCF would monitor for five years following the installation of oyster reefs including oyster spat growth rates, sediment supply, and elevation changes of surrounding salt marshes. Monitoring oyster spat growth is important to determine whether the reef is growing at a rate that will be able to exist independent of future intervention. Sediment supply can serve as both a proxy for oyster reef health as well as understand how the reef impacts sediment deposition on the salt marsh. Finally, measuring changes in salt marsh elevation serves as the indicator for the success of installing oyster reefs.

Stakeholders:

Key stakeholders involved in the implementation of an oyster reef project include NCF, the Nantucket Shellfish Association, conservationists, and government officials. The Nantucket Shellfish Association plays an important part in the construction stage by providing the oyster spat for the oyster reefs. Local conservationists are important for demonstrating support for the project in the planning and permitting stages of project implementation. Finally, governmental officials such as select board members and members of the Conservation Commission can approve or reject permit applications, which can significantly impact the success of implementation.

Challenges to Implementation:

Funding:

The change in Presidential Administrations and significant cutbacks in federal funding, especially environmental projects is a challenge to implementation. Specifically, NCF relies on a combination of federal, state, and private grants. The recent changes and freezes on funding will most certainty impact federal sources of funding and potentially impact state funding. Therefore, NCF likely cannot use federal funding and potentially state funding. If state funding is unavailable, NCF will need to look for private sources of funding, either through private grant applications or private donations to NCF explicitly. The Board of Directors could also engage in fundraising efforts for private donations.

Potential Community Backlash:

Although the oyster reef installation was projected to receive support from community members and permitting agencies, there is always the potential for a coalition to emerge in opposition to a proposed project. If community backlash arises, NCF would need to engage in education campaigns to demonstrate the importance and benefits associated with oyster reefs.

Conclusion

The erosion of Nantucket salt marshes jeopardizes the Island. The imminent and unfolding impacts require taking swift action to foster the resiliency of these marshes so they can continue providing the critical ecosystem services that Nantucket relies on. This policy analysis sought to evaluate the available interventions for mitigating erosion and promoting salt marsh resiliency. This evaluation found that installing an oyster reef in the waters surrounding salt marshes is the best option for mitigating erosion by increasing marsh elevation, enabling Nantucket salt marshes to persevere in the face of sea level rise. The installation of these oyster reefs both acknowledges the changing impacts of climate change on Nantucket ecosystems and seeks to improve the ecosystem’s ability to persist in rising sea levels. This intervention promotes ecologically conscious conservation to promote the longevity of Nantucket salt marshes and Nantucket itself.

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Appendix A: Cost Calculations

Alternative 1: Sediment Application

Cost:

Estimated cost per cubic yard for Ninigret Pond Salt Marsh in Rhode Island (2022 Dollars) (Raposa, et al. 2022): $22.35

Cubic Yards in 1 Acre: 1613.33

Eel Creek Acreage: 34.14

Total Cubic Yards for Eel Creek Restoration: 1613.13*34.14 = 55,079.08 cubic yards

2022 CPI: 281.148 (Bureau of Labor Statistics, 2022)

2025 CPI: 317.671 (Bureau of Labor Statistics, 2025)

$$Inflation\ Rate = \frac{2025\ CPI - 2022\ CPI}{2022\ CPI}$$

$$Inflation\ Rate = \frac{317.671 - 281.148}{281.148}$$

Inflation Rate = 0.129

$$2025\ Adjusted\ Cost\ Estimate\ per\ cubic\ yard = (1 + .129) * 22.35$$

$$2025\ Cost\ Estimate = \$25.25$$

$$Eel\ Creek\ Projected\ Cost = \$25.25 * 55{,}079.08$$

Total for Eel Creek (2025 $) = $1,390,934.97

Cost Effectiveness:

$$\frac{Cost}{Unit\ of\ Effectiveness}$$

Cost: $1,390,934.97

Unit of Effectiveness: 8 cm

$$\frac{\$\mathbf{1,390,934.97}}{\mathbf{8}} = \$\mathbf{173,866.87}\ \boldsymbol{per\ 1\ cm\ increase\ in\ marsh\ elevation}$$

Alternative 2: Oyster Reef Installation

Cost:

Projected 2019 average cost of bottom constructed oyster reefs: \$28,684 per acre (Petrolia, et al. 2022).

Inflation Calculation: 2019-2025

January 2019 CPI: 251.712 (Bureau of Labor Statistics, 2019)

January 2025 CPI: 317.671 (Bureau of Labor Statistics, 2025).

$$Inflation\ Rate\ (2019 - 2025) = \frac{2025\ CPI - 2019\ CPI}{2019\ CPI}$$

$$Inflation\ Rate = \frac{317.671 - 251.712}{251.712}$$

Inflation Rate =.26204

$$2025\ Adjusted\ Estimate = (1 + .26204) * 28{,}694$$

2025 Adjusted Estimate = \$36,200.40 per acre

Shellfish Aquaculture License: \$25 per acre (Town of Nantucket, 2025a).

Oyster Reef to Salt Marsh Acreage Ratio: Medouie Creek Oyster Project: .17 Acres of Reef per 16.8 Acres of salt marsh (Department of Fish and Game, 2023).

.17/16.8 = .01011908 acres of oyster reefs per 1 acre of salt marsh → Eel Creek has 34.14 acres of salt marshes

$$Oyster\ Reef\ Acreage = .0101 * 34.14$$

$$Oyster\ Reef\ Acreage\ for\ Eel\ Creek = .34546$$

$$Cost\ Estimate\ for\ Eel\ Creek = (.34546) * 36{,}200.40 + 25$$

Total for Eel Creek (2025 \$): \$12,514,58

Cost Effectiveness:

$$\frac{Cost}{Unit\ of\ Effectiveness}$$

Cost: \$12,514.58

Unit of Effectiveness: 17 cm

$$\frac{\$\mathbf{12,514.58}}{\mathbf{17}} = \$\mathbf{736.15}\ \boldsymbol{per\ 1\ cm\ increase\ in\ marsh\ elevation}$$

Alternative 3: Living Shoreline

Cost:

2015 Estimated cost for living shore, per foot: $1,500 (U.S. Army Corps of Engineers, 2015)
2015 Monitoring cost of living shoreline per foot: $100 (U.S. Army Corps of Engineers, 2015)

Inflation Calculation: 2015 – 2025
2015 CPI: 202.416 (Bureau of Labor Statistics, 2015)
2025 CPI: 317.671 (Bureau of Labor Statistics, 2025).

$$Inflation\ Rate\ (2015 - 2025) = \frac{2025\ CPI - 2015\ CPI}{2015\ CPI}$$

$$Inflation\ Rate = \frac{317.671 - 202.416}{202.416}$$

Inflation rate = .5693

$$2025\ Adjusted\ Estimate = (1 + .5693) * 1{,}500$$

2025 Adjusted Estimate = $2,354.10 per foot

$$2025\ Adjusted\ Monitoring\ Cost = (1 + .5693) * 100$$

2025 Adjusted Monitoring Cost: $156.94 per foot

Estimated Shoreline for Eel Creek: 0.5 Miles (2640 Feet)

2025 Adjusted Estimate	$2,354.10 * 2640 = $6,214,810.88
2025 Adjusted Monitoring Cost	$156.94 * 2640= $414,320.37
Total (2025 $):	$6,629,131.61

Cost Effectiveness

$$\frac{Cost}{Unit\ of\ Effectiveness}$$

Cost: $6,629,131.61

Unit of Effectiveness: 8 cm

$$\frac{\mathbf{\$6,629,131.61}}{\mathbf{8}} = \mathbf{\$828,641.45\ per\ 1\ cm\ increase\ in\ marsh\ elevation}$$