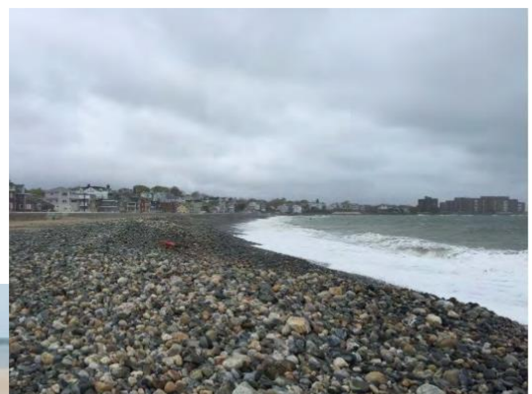
Living Shorelines in New England: State of the Practice



Prepared For:
The Nature Conservancy

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July 2017

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Project Funding:
NOAA Regional Resilience Grant Program
Federal Award ID: NA16NOS4730013
Administered by NERACOOS-NROC

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EXECUTIVE SUMMARY

Increasing erosion and inundation of coastal wetlands across New England due to sea-level rise and storms threatens property and valuable natural resources. Historic practices of hard revetments and seawalls have limited effectiveness and may exacerbate erosion, destroy intertidal habitat, and alter sediment transport patterns. For these reasons, hard structural solutions are not permitted in many environmentally-sensitive coastal areas.

In the Mid-Atlantic and Gulf of Mexico states, there have been a number of applications of nature-based restorative approaches that include some combination of biotic natural media like oyster shell, natural fiber, marsh and native vegetation plantings, and the use of large sand envelopes or stone, sometimes seeded with live shellfish. These installations are designed to protect property and prevent erosion while improving habitat, water quality, and ecological condition in a way that appears natural and is consistent with the character of coastal communities and uses of the shore.

While these "living shoreline" practices are relatively new to the northeast, and practitioners have had limited experience in New England, the Coastal Zone Management Agencies of the five New England coastal states and the Northeast Regional Ocean Council (NROC) partnered with The Nature Conservancy under a grant from the National Oceanic and Atmospheric Administration (NOAA) to conduct an assessment of the State of The Practice on Living Shorelines and provide considerations for their application along the coast of New England.

For purposes of this assessment, the term living shoreline, refers to a set of coastal erosion control practices, ranging from non-structural vegetated approaches to hybrid hard structural/restorative natural methods, that address erosion and inundation in a manner that improves or protects the ecological condition of the coastline[1]. Living shorelines are a coastal subset of a larger group of green infrastructure practices, which include a greater range of nature-based techniques for inland areas that address storm water control, nutrient retention, and habitat enhancement in place of hard infrastructure.

This report provides a range of practical considerations for property managers, regulators, coastal municipal leaders, scientists and practitioners, who are interested in advancing living shoreline policies and practices. The living shoreline profiles provide an overview of the techniques, conceptual designs, case studies, siting characteristics and design considerations and regulatory and review agencies that oversee the designs. Additionally, an applicability index has been developed for common living shoreline types in New England. It is intended to serve as a guide for the development of regulations and policies to explicitly incorporate these approaches into the coastal management programs of the respective states and New England's coastal communities.

[1] The NOAA definition: "A living shoreline is made up mostly of native material. It incorporates natural vegetation or other living, natural soft elements alone or in combination with some type of harder shoreline structure, like oyster reefs, rock sills, or anchored large wood for added stability. Living shorelines connect the land and water to stabilize the shoreline, reduce erosion, and provide ecosystem services, like valuable habitat, that enhances coastal resilience." [18]

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Acronyms

LS	Living Shorelines
MHW	Mean high water
MLW	Mean low water
NERACOOS	Northeastern Regional Association of Coastal and Ocean Observing Systems
NOAA	National Oceanic and Atmospheric Administration
NROC	Northeast Regional Ocean Council
TNC	The Nature Conservancy

1.0 INTRODUCTION

As part of the National Oceanic and Atmospheric Administration (NOAA) Grant *High Resolution Coastal Inundation Modeling and Advancement of Green Infrastructure and Living Shoreline Approaches in the Northeast, Track 2: Advancing Green Infrastructure and Living Shoreline Approaches in the Northeast*, The Nature Conservancy (TNC) contracted Woods Hole Group to complete *Task 1 – Increase understanding of approaches in region by conducting a "state-of-the-science" analysis of living shoreline and coastal green infrastructure practice/project types, applicability, and performance.* The overall NOAA Grant is administered by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and Northeast Regional Ocean Council (NROC). Regulators, practitioners and non-profit experts in living shorelines (the 'Team') provided input during multiple workshops. Woods Hole Group and The Nature Conservancy facilitated the meetings and prepared this report using input from the Team and data and findings from numerous living shoreline (LS) compilations and publications. Members of the Team are acknowledged in Section 6.0.

1.1 PURPOSE OF STUDY

The goal of the Track 2 effort is *to develop tools, information and approaches to support sound decisions for the expanded implementation and innovation of green infrastructure/living shoreline approaches to increase coastal resilience to erosion, flooding, and storm impacts in the Northeast*. The purpose of this study is to increase the understanding of LS designs, site applicability and performance in the New England region through a "state-of-the-science" analysis. This report draws on information from existing literature, expert input and compilations of living shorelines practices across the United States, and provides a set of design profiles that compile photos, illustrations, design notes, maintenance considerations, site suitability factors and regulatory overviews for different LS designs. Compared to work in the mid-Atlantic region, New England is early in the process of LS application. This effort builds off of the work completed by many teams in New England such as the NROC Coastal Hazards Resilience Committee Living Shorelines Group, the Massachusetts Office of Coastal Zone Management Storm Smart Coasts program, and the Systems Approach to Geomorphic Engineering (SAGE), and provides an overview of LS designs accounting for unique regional site challenges, such as ice and cold temperatures, rocky coastal environments, large tidal ranges, and other unique conditions. The goal of this document is to inform practices and policies.

1.2 TARGET AUDIENCE

This report is developed for regulators, planners, practitioners, conservation leaders, academic researchers, coastal land owners and anyone seeking a summary of LS practices in New England. The report was developed to be accessible to a broad range of interested groups. The profile pages add value to site visits, and the applicability index tool can assist planners with the difficult task of matching designs with site characteristics (see Sections 3.0 and 4.0). Together, these tools have been designed to facilitate communication among the public, regulators, practitioners and researchers and to provide a common starting place for more detailed design discussions to follow.

1.3 LIVING SHORELINES DEFINITION

For purposes of this report, the term living shoreline refers to a set of coastal erosion control practices, ranging from non-structural vegetated approaches to hybrid hard structural/restorative natural methods, that address erosion and inundation in a manner that improves or protects the ecological condition of the coastline. LSs are a coastal subset of a larger group of green infrastructure practices, which include a greater range of nature-based techniques for inland areas that address storm water control, nutrient retention, and habitat enhancement in place of hard infrastructure.

The team understands that the preferred terms and definitions vary across agencies and practitioners and that these preferred terms can change over time. This definition is in line with the LS definition developed by NOAA:

> *A living shoreline has a footprint that is made up mostly of native material. It incorporates natural vegetation or other living, natural 'soft elements alone or in combination with some type of harder shoreline structure, like oyster reefs, rock sills, or anchored large wood for added stability. Living shorelines connect the land and water to stabilize the shoreline, reduce erosion, and provide ecosystem services, like valuable habitat, that enhances coastal resilience.*

The LS designs summarized in this report include:

1) Dune Restoration (Natural)
2) Dune Restoration (Engineered Core)
3) Beach Nourishment
4) Coastal Bank Protection (Natural)
5) Coastal Bank Protection (Engineered Core)
6) Natural Marsh Creation/Enhancement
7) Marsh Creation/Enhancement (w/Toe Protection)
8) Living Breakwaters

Dune Restoration (Engineered Core) in S. Kingston, RI
Photo courtesy of Janet Friedman (RI CRMC)

2.0 PERSPECTIVES ON NEW ENGLAND LIVING SHORELINES

The current analysis focused on compiling information from the many existing resources and current thinking from experts working on living shorelines in New England through the development of a state-of-the-science summary, centered on a set of LS design profile pages. Findings from existing resources and a series of interviews fueled the development of the profile pages, but also provide an opportunity to reflect on living shoreline applications in New England. Although this field of LSs is currently evolving, and an active discussion about implementation is still ongoing, this report provides a current (as of 2017) summary of the perspectives on design and implementation trends and the challenges and opportunities of LS development in New England today.

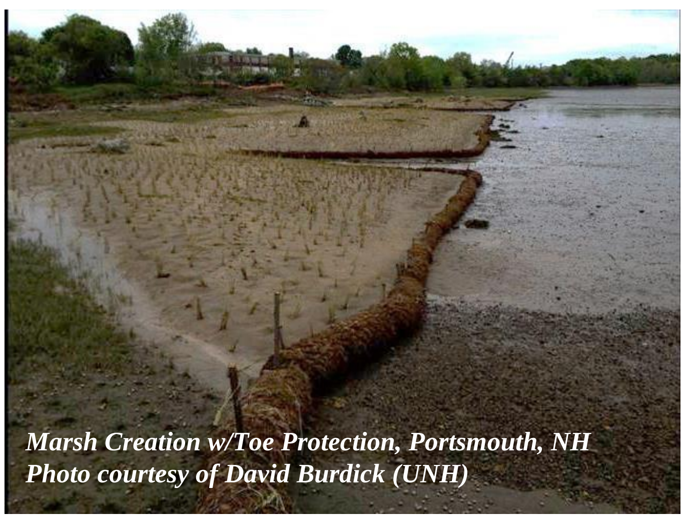
There is general agreement that LSs are an important tool for protecting sensitive coastal areas in New England, because in addition to providing erosion control they also provide a multitude of other ecosystem services, such as enhanced habitat, maintenance of natural sediment transport dynamics, and improved nutrient retention. Because of these beneficial services, LSs are a regular focus of coastal restoration and climate change adaptation discussions in the region. Increasingly, consideration of a LS alternative is required before a hardened design will be allowed by state regulators. While there is general agreement that LSs should be applied more frequently, homeowners and the public (and even some practitioners, engineers, and regulators) express hesitation. Misperceptions about the durability of the designs and lack of long-term studies of LS applications in New England underlie this hesitation. The supporting framework, already well-established in the mid-Atlantic for example, is continuing to be developed in New England. This includes standardized definitions, guidance developed based on long-term scientific studies, training on best practices, incentives for application, monitoring program requirements and public education. For example, disagreements about the terminology are common and important when the terminology is codified in permitting and regulatory requirements. As the framework is refined, consensus is reached on assessment metrics and monitoring approaches and case study results are communicated, these alternatives will likely gain wider acceptance. Of course, with increased visibility and popularity, the LS community will need to protect against those claiming to implement LSs, but proceeding without considering engineering principles and peer reviewed approaches.

With agreement that LSs can be an important and appropriate tool for coastal protection in New England and the increasing consideration and implementation of LS projects, the experts and sources consulted for this report emphasize the importance of matching the design with the characteristics of a given project site. If a LS design is not a good fit to the characteristics of the site, it will not succeed [4, 7, 10, 16]. A number of sources presented guidance for site selection, design selection, or both. The design guidance developed by the Stevens Institute emphasizes the importance of siting criteria and following a clear stepwise approach when selecting a site and design [7]. This approach includes system parameters (erosion, sea level rise and tidal range), ecological parameters (water quality, soil type, sunlight exposure), hydrodynamic parameters (wind waves, wakes, currents, ice, storm surge and terrestrial parameters (upland slope, shoreline slope, width, nearshore slope, offshore depth, soil bearing capacity) [7]. The authors also recommend considering the permitting process, the end effects of the project, construction feasibility, balance of native/invasive species, debris impacts and monitoring [7]. Similarly, Cunniff and Schwartz (2015) provide design-specific criteria such as the strengths and weaknesses of different designs, how a design reduces risk, uncertainties, siting considerations, performance factors, climate considerations, and research needs for a range of living shoreline types [10]. Maryland Department of Natural Resources with NOAA and the Natural Resources Conservation Service also provide a guide to siting LS [16]. To incorporate this important concept, the use of key siting criteria and applying those criteria to design selection are integrated into the profile pages and applicability index associated with this report, and capture the unique challenges facing LS implementation in New England.

Another key theme that resonated throughout the existing literature, as with the expert interviews, was the added benefits that LSs could provide. The benefits of LS use in New England are the same as those in other regions and include shoreline protection and stabilization, habitat improvement, provision of expanded ecological services, such as essential fish habitat and carbon sequestration, maintenance of natural coastal processes, enhanced aesthetic and property values, educational opportunities, and improved sediment transport, water quality and resilience [2, 11, 12, 16]. LSs allow ecological processes to continue building resilience as the components of the design mature, essentially creating a self-sustaining design. Because they are designed around the ecological processes found in an area, LS designs have less impact on neighboring properties than hard infrastructure, such as stone revetments, which can dramatically alter sediment transport processes and increase erosion on neighboring sites. Ecological services include improved habitat for wildlife such as nursery and foraging areas, carbon sequestration and natural buffering of runoff and the nutrients, chemicals, and suspended sediments that are transported in the runoff. Many consider the aesthetic value of LSs as better than that of gray designs. In terms of adaptation to the impacts of climate change, if sited well, LSs can migrate and naturally adapt to changing water regimes. Initial construction costs of LSs are less costly than hardened solutions [3], but total costs (including long-term maintenance) should be fully considered before implementing any shoreline project.

Coastal Bank Protection (Natural) in Orleans, MA - Photo courtesy of Wilkinson Ecological Design

Although with the myriad of benefits provided by LSs, there are also a number of implementation challenges cited repeatedly in the existing literature. Some of the challenges of implementing LS are consistent across regions such as lack of funding (particularly for long term monitoring and maintenance) limitations on available coastal areas suitable for LS, lack of public awareness and distrust about the benefits of LSs [2, 3]. Other implementation challenges are unique to New England. Because LSs are a more recent technique considered for shoreline protection in New England, the permitting process can be more challenging and uncertain. Regulations may be new, undergoing revision, or non-existent, in addition to the fact that they may vary from state to state, and the review process can be time-consuming. In addition, LSs in New England do not have a long history of implementation and monitoring from which to learn and adapt. LS designs have been used in other regions for many years, but the performance data for those designs may not inform how well a design will do in New England. Field analyses for extended periods are necessary to understand how well a design performs [11]. The lack of data on the performance of different designs and applications limits the opportunity to modify design [5]. Depending on the type of LS and the site, harsh weather conditions (e.g. ice), shorter growing seasons and large tidal ranges can also impact the viability and resilience of the LS designs [4, 5]. Ice and the shorter growing season (longer winter) can have noticeable impacts on a LS design, including ice damage to plants, ice damage to oysters in reef designs, increased plant loss during the winter from bird herbivory, increased winter storm impacts, and a shortened growing season [13]. In addition, climate change impacts, such as sea-level rise, increased storm intensity and increased temperature variability, will also affect the success of LS designs. These threats are not only to the long-term viability of the design, but also pose a unique challenge during the construction and implementation stages [14]. If design components that require multiple seasons to establish are not protected by other design elements during development, the overall project may fail [14]. Although specific actions to minimize these potential impacts are not required in current regulations, grant solicitations for LSs and standard practices include careful consideration of the threats presented by a changing climate to a site and the LS design. For instance, consideration of whether a LS can migrate as sea levels change or the resilience of plants to more frequent salt water inundation are a few current climate change-related considerations in project development and site selection. Also, in the case of a frontal dune restoration, the project location should consider the storm tide elevation [9]. The public perception that LS designs are less resilient than gray designs and not a 'tried and true' approach not only reinforces the need for more communication and monitoring, but may also impact opportunities to implement LS projects in the future. It is, therefore, crucial to carefully consider and address these challenges prior to constructing a LS project.



Marsh Creation w/Toe Protection, Portsmouth, NH
Photo courtesy of David Burdick (UNH)

Responses from those interviewed, as well as other available resources, provide numerous recommendations to ensure that living shorelines succeed in New England. For instance, since vegetation is a central component of a LS design, plant selection, preparation and maintenance will all determine whether a design succeeds or fails [16]. Selection of robust native vegetation (e.g. salt tolerant, extensive root mat, survive dry – wet periods, etc.)

including shrubs (*Iva frutescens* and *Baccharis halimifolia)* ensures that the plants will survive and meet the habitat improvement and stabilization expectations [5, 9]. 'Cape' American beach grass (*Ammophila breviligulata*) is most commonly used to build dunes, and fencing is also used in conjunction with the vegetation to trap sand while the newly planted beach grass establishes [9]. Also, initial site preparation work can provide the foundation for successful plant growth and might include using natural fiber blankets to stabilize an eroded area and allow plants to establish [5]. Upland areas adjacent to the LS also benefit from planting of native vegetation, e.g. shading out invasive species [14]. For project locations at or below mean high water (MHW), siting a LS in an area with gentle slopes, the use of more resilient vegetation (i.e. shrubs), and including physical protection (e.g. logs, roughened surfaces) to encourage establishment can limit the impact of ice [4, 8]. Those interviewed recommended that project plants be grown offsite (pre-started) and that planting should occur in the early spring to allow more time for the plants to mature and establish prior to the first winter. Irrigation may also be required [5]. Finally, monitoring and maintenance, such as replacing plants that do not establish, will ensure that the system continues to function effectively even if there are some initial losses. Because of the unique challenges in New England, these monitoring and maintenance practices are particularly important [5].

Dune Restoration (Natural), Saco, ME
Photo courtesy of Pete Slovinsky (ME Geological Survey)

Experts also provided a series of other recommendations to ensure the success of a LS project. For instance, in areas of high wave energy, reef balls have been successfully used in LS designs. They provide habitat, can serve as a break on wave energy and can withstand some moderate icing. Sills can also increase the resiliency of LS. Additionally, using a heterogeneous grain size in beach nourishment projects is recommended. Like wave action, up-gradient stress can also imperil a LS project. For example, runoff can destabilize a LS project and should be managed to prevent erosion. Finally, although definitions and opinions vary regarding whether hybrid designs still classify as living shorelines, they can be used to increase resilience in LS design. Most importantly, a design well-matched to the site characteristics will have the best chance of overcoming the unique challenges presented in New England.

All of those interviewed, as well as the background literature reviewed, emphasized the challenge presented by the unpredictable and time-consuming permitting process. The regulating entities vary by state, and often include multiple agencies within a single state, with varying requirements. It is therefore unsurprising that collaboration and cross-agency and -state communications were raised as important components of successful LS implementation [5]. Uncertainties in permitting a LS design can extend permitting timelines, resulting in the misleading conclusion that gray infrastructure is cheaper, because the permitting process is more predictable and streamlined for gray designs. However, there is currently a regulatory shift underway in favor of LS designs. A permitting process that is transparent and predictable will be necessary to encourage greater investment in LS projects.

With this shift, it is likely that public misperceptions can be countered with emphasis on success stories, longer term monitoring results, more accurate accounting of costs and benefits and an increasingly predictable permitting process. Although LS designs are aesthetically more pleasing to many, there is a predisposition to view natural designs as less effective than a cement wall. The challenge in shifting these perceptions is to properly account for all the ecosystem services provided by LSs, as well as all the costs and potential adverse impacts of the alternative gray infrastructure designs. The key is to objectively and fully account for all the costs and benefits of LSs, gray designs and a no action alternative. Establishing broadly accepted assessment metrics is necessary to evaluate success over time.

Although not unique to New England, experts agree that developing a standard monitoring approach for evaluating the effectiveness of a LS, as well as clear expectations for long-term maintenance are central components to the expansion of LS in this region. With the unique challenges facing LS in New England, it is important to identify and remedy issues early. Since loss of plants is one of the practitioners' primary concerns, periodic monitoring followed by targeted replanting until the plants fully establish, can increase project success. Some designs may require more maintenance than others. A dune restoration or beach nourishment may require periodic sand additions [9]. This does not mean that a design is failing, but only that living shorelines require maintenance to maximize resilience. Monitoring can also be valuable when quantifying benefits of ecological services provided by a LS. Observations through time can identify changes in species diversity, general habitat health and extent, visual/aesthetic changes and erosion control effectiveness. If a standard monitoring approach can be developed, then comparisons among LS projects can inform future design adaptations. Building from this background and overall perspective on LS in New England, the sections that follow present the living shoreline design profiles and applicability index follow.

3.0 PROFILE PAGES

A primary goal for this project was to develop profile pages for different living shoreline types that highlight site selection criteria, design criteria, case studies, and regulatory considerations. The profile pages are developed to improve understanding of different living shoreline designs. They are designed to facilitate communication among the public, regulators, practitioners and researchers and provide a common starting place for more detailed design discussions to follow. They are one of many resources available to those interested in coastal resilience. The layout provides a printable page that can be used in the field or office. The format captures the primary focus areas required to identify the designs that are a good fit for a specific site (there may be a number of options). The user is presented with specific site characteristics, conceptualization of the design, the challenges and benefits of different designs, identification of the regulators involved in approving a design and an illustration of how all of those components come together in a case study. These profile pages are expected to be updated periodically as more data are available. These profile pages should not take the place of a more comprehensive site evaluation and design process, but will help to further engage stakeholders and experts.

One of the initial challenges for this task was to develop the list of living shoreline types that would be used. A review of various studies and compilations revealed that a variety of different names and terms are often used to describe essentially the same LS design type. This required combining names of different living shoreline types into similar categories. A second, and ultimately more difficult challenge, was developing consensus on how many living shoreline design types should be highlighted. We collaborated with a large group of living shoreline experts including regulatory representatives from all coastal New England states (see Section 6.0). Multiple workshops and team calls provided valuable details that became part of the profiles. There was considerable discussion about whether particular living shoreline types should be treated separately or combined together as one and discussions regarding the details on each page. Ultimately, the LS design types that were evaluated are provided in Table 1 and profiles follow.

Table 1. Profile page living shoreline types.

Profile Page Living Shoreline Categories	Specific Terminology Used in Other Sources
1. Dune Restoration (Natural)	Dune nourishment
	Dune restoration
2. Dune Restoration (Engineered Core)	Artificial dunes
	Dune nourishment
	Cobble berm
3. Beach Nourishment	Beach nourishment
	Cobble berm
4. Coastal Bank Protection (Natural)	Coir rolls with vegetation
	Natural fiber blankets
	Regrading
	Natural fiber logs (or bio-logs)
5. Coastal Bank Protection (Engineered Core)	Regrading w/sand tubes
	Bank stabilization with coir envelopes
6. Natural Marsh Creation/Enhancement	Enhancement of marsh
	Creation of coastal wetlands
	Fringe marsh creation
7. Marsh Creation/Enhancement (w/Toe Protection)	Fringe marsh constructed with oyster or mussel shells
	Fringe marsh constructed with bio-logs
	Marsh sill or reef balls with planted marsh
8. Living Breakwaters	Oyster or mussel reef
	Reef balls

The interview results present diverse professional opinions concerning LSs, which have been incorporated into the profile pages. These materials are provided as informational resources and are not meant as final design guidance, for permitting, or as regulatory guidance. The profile pages for the eight (8) LS designs listed in Table 1 are presented below. An introduction sheet explains each component of the profile pages.

Living Shorelines Introduction

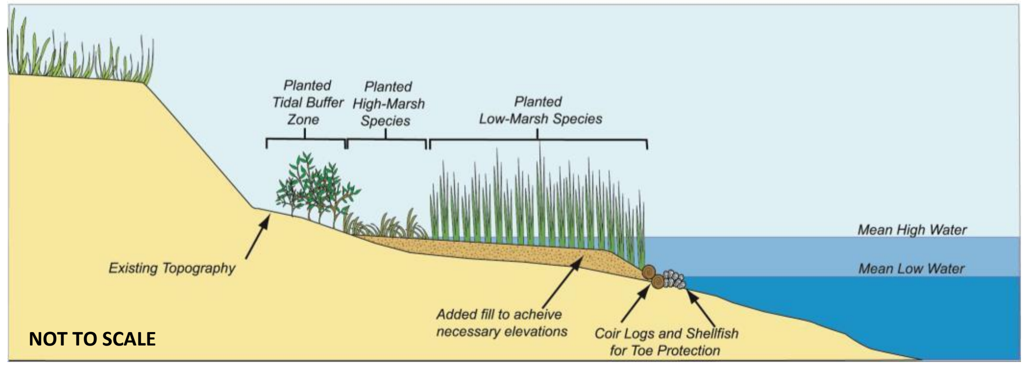
A detailed profile page was created for each of the eight (8) living shoreline types listed below. The purpose of these profile pages is to provide a comprehensive overview of the design recommendations, siting criteria and regulatory topics pertinent to a range of living shorelines designs that practitioners and regulators can use as a quick reference in the field or as an informational tool when educating home owners.

Living Shoreline Types

1. **Dune – Natural**
2. **Dune – Engineered Core**
3. **Beach Nourishment**
4. **Coastal Bank – Natural**
5. **Coastal Bank – Engineered Core**
6. **Natural Marsh Creation/Enhancement**
7. **Marsh Creation/Enhancement w/Toe Protection**
8. **Living Breakwater**

Design Schematics

The following living shoreline profile pages provide an example design schematic for each of the eight living shoreline types. Each schematic shows a generalized cross-section of the installed design. In addition, they illustrate each design's location relative to MHW and MLW, whether plantings are recommended, if fill is required, and any other major components of the design. It is important to note that these are not full engineering designs, and due to each sites unique conditions, a site specific plan, developed by an experienced practitioner is required for all living shoreline projects. Also note that these design schematics are meant to provide a general concept only, and are not drawn to scale.



Case Study

One example case study, with the following information, is provided for each living shoreline type.

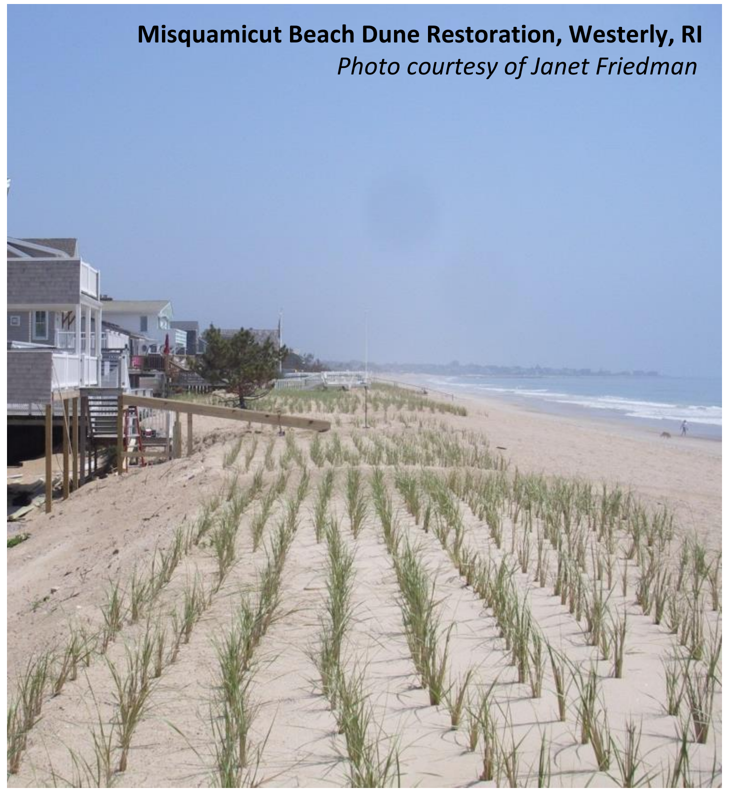
Project Proponent	The party responsible for the project.
Status	The status of the project (i.e. design stage, under construction, or completed) and completion date if appropriate.
Permitting Insights	This section notes any specific permitting hurdles that occurred, or any regulatory insights that might help facilitate similar projects in the future.
Construction Notes	This section identifies major construction methods or techniques, any unique materials that were used, or deviations from a traditional design to accommodate site specific conditions.
Maintenance Issues	If the project is complete and has entered the maintenance phase, this section will note whether the project has functioned correctly, if it is holding up, and/or if any specific maintenance needs have been required since construction.
Final Cost	This section provides costs for the project, broken down into permitting, construction, monitoring, etc. when possible.
Challenges	This sections highlights any unique challenges associated with a particular project and how they were handled.

Explanation of Design Overview Tables

Materials	A description of materials most commonly used to complete a living shoreline project of this type.
Habitat Components	A list of what types of coastal habitats are created or impacted by a living shoreline project of this type.
Durability and Maintenance	Although specific timelines are impossible to provide in this context, general guidelines and schedules for probable maintenance needs, and design durability are detailed here.
Design Life	Although specific design life timelines will vary by site for each living shoreline type, this section provides some insight into factors that could influence design life.
Ecological Services Provided	This section provides an overview of the ecological services that could be provided or improved through the installation of that particular type of living shoreline project.
Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)	This section provides any unique practices or design improvements that could be made to improve the performance of the design given New England climactic and tidal challenges.

Acronyms and Definitions

cy	Cubic yards; one cubic yard equal 27 cubic feet. Project materials are often measured in cubic yards.
MHW	Mean High Water: The average of all the high water (i.e. high tide) heights observed over a period of time.
MTL	Mean Tide Level: The average of mean high water and mean low water.
MLW	Mean Low Water: The average of all the low water (i.e. low tide) heights observed over a period of time.
SAV	Submerged aquatic vegetation, which includes seagrasses such as eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*).
Sediment	Naturally occurring materials that have been broken down by weathering and erosion. Finer, small-grained sediments are silts or clays. Slightly coarser sediments are sands. Even larger materials are gravels or cobbles.



Misquamicut Beach Dune Restoration, Westerly, RI
Photo courtesy of Janet Friedman

Living Shorelines Introduction

Overview of Regulatory and Review Agencies Table

This table is intended to provide a comprehensive list of all the regulatory and review agencies that would potentially need to be contacted for a particular type of living shoreline project. State agencies are listed separately for each of the five coastal northeast states (Maine, New Hampshire, Massachusetts, Rhode Island and Connecticut). Federal agencies that may need to be contacted for a project in any state are also listed. Note that these lists represent the full range of potential agencies. If projects do not exceed certain thresholds (e.g. extending below MHW, exceeding a certain footprint area) they may not be required to contact or receive a permit from all agencies listed.

City Beach Nourishment, Warwick, RI
Photo courtesy of Janet Freedman

Reef Ball Living Breakwater and Marsh Restoration
Stratford, CT
Photo courtesy of Jennifer Mattei

Use and Applicability of Profile Pages

The profile pages that follow have been developed to improve the understanding of eight (8) different living shoreline designs. They have been designed to facilitate communication among the public, regulators, practitioners and researchers and to provide a common starting place for more detailed design discussions to follow. They are one of many resources available to those interested in coastal resilience. The compact layout provides a printable 11” x 17” page that can be used in the field or office. The format captures the primary focus areas required to identify which living shoreline designs are a good fit for a specific site (note that there may be multiple living shoreline options for some sites). The reader is presented with specific site characteristics, a conceptualization of the overall design, the challenges and benefits associated with each living shoreline design type, identification of the regulatory agencies involved in approving a design, and an illustration of how all of those components come together in a case study for each living shoreline type. These profile pages are expected to be updated periodically as more data become available. These profile pages should not take the place of a more comprehensive site evaluation and design process, but are intended to help further engage stakeholders and experts in an informed discussion about various living shoreline types.

Explanation Key for Siting Characteristics and Design Considerations

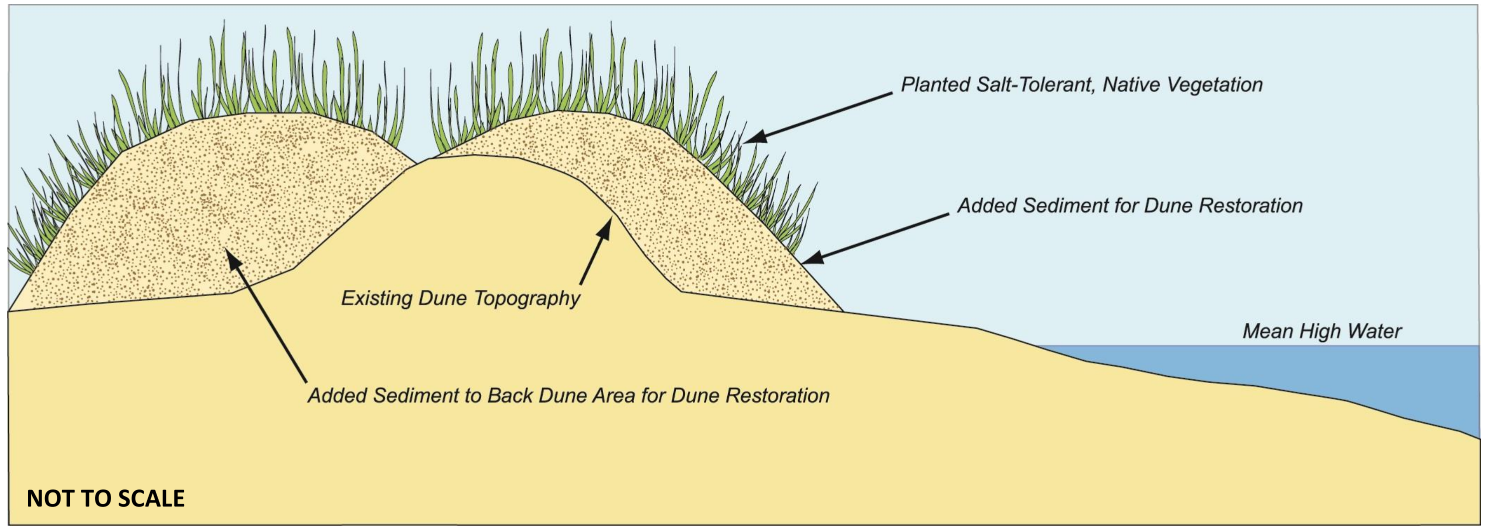
Selection Characteristics	Definitions and Categories
ES Energy State	A measure of the wave height, current strength and storm surge frequency of a site that would be suitable for a particular living shoreline project type. **High**: Project site has waves greater than 5 feet, strong currents, high storm surge **Moderate**: Project site has 2 to 5 foot waves, moderate currents, moderate storm surge **Low**: Project site has waves less than 2 feet in height, low current, low storm surge
EE Existing Environmental Resources	Existing environmental resources that a proposed living shoreline project is able to overlap with. **Coastal Bank** **Salt Marsh** **Vegetated Upland** **Coastal Dune** **Mudflat** **Coastal Beach** **Subtidal**
SR Nearby Sensitive Resources	Nearby sensitive resources that, with proper planning and design, may be compatible with a particular living shoreline type. **Endangered/Threatened Species** **Submerged Aquatic Vegetation (SAV)** **Shellfish** **Cobble or Rocky Bottom Habitat**
TR Tidal Range	The magnitude of tidal range at a site that would be suitable for a particular type of living shoreline design. **High**: Tide range at project site is more than 9 feet **Moderate**: Tide range at project site is between 3 and 9 feet **Low**: Tide range at project site is less than 3 feet
EL Elevation	The elevation, with respect to the tide range, where a particular living shoreline project type should be sited. **Above MHW**: Project footprint is entirely above MHW **MHW to MLW**: Project footprint is located within the intertidal zone **Below MLW**: Project footprint is located in subtidal areas
IS Intertidal Slope	The intertidal slope appropriate for siting a particular living shoreline project type. **Steep**: Project site has an intertidal slope steeper than 3:1 (base:height) **Moderate**: Project site has an intertidal slope between 3:1 and 5:1 (base:height) **Flat**: Project site has an intertidal slope flatter than 5:1 (base:height)
BS Bathymetric Slope	The nearshore bathymetric slope appropriate for siting a particular living shoreline project type. **Steep**: Project site has an bathymetric slope steeper than 3:1 (base:height) **Moderate**: Project site has an bathymetric slope between 3:1 and 5:1 (base:height) **Flat**: Project site has an bathymetric slope flatter than 5:1 (base:height)
ER Erosion	The rate of coastal erosion at a site that would be suitable for a particular living shoreline project type. **High**: Erosion at project site is high (>3 feet/year) **Moderate**: Erosion at project site is moderate (1-3 feet/year) **Low**: Erosion at project site is low (<1 foot/year)

Dune - Natural

Dune building projects involve the placement of compatible sediment on an existing dune, or creation of an artificial dune by building up a mound of sediment at the back of the beach.[1] This may be a component of a beach nourishment effort or a stand alone project.

Objectives: erosion control; shoreline protection; dissipate wave energy; enhanced wildlife and shorebird habitat.

Design Schematics



Case Study

Ferry Beach, Saco, Maine

Relatively high beach and dune erosion (approximately 3 feet per year) prompted the FBPA to undertake a dune restoration project to help protect roads and homes from flooding and erosion. Given the relatively high erosion rate, it was decided that placing sediment for restoration seaward of the existing dune would be short-lived. A secondary frontal dune ridge landward of the existing dune crest was constructed instead, allowing native vegetation to establish.

Ferry Beach, Saco, ME
Photo courtesy of Peter Slovinsky

Project Proponent	Ferry Beach Park Association (FBPA)
Status	Completed 2009
Permitting Insights	Permit-by-Rule needed from Maine DEP
Construction Notes	An 800 foot long secondary dune was built to 1 foot above the effective FEMA 100-year BFE. A secondary dune was built because erosion of the front dune was considered too high (>3 feet per year) to have a successful project. 1,800 cy of dune-compatible sediment was delivered via truck from a local gravel pit. Construction and planting occurred in early spring. Volunteers planted native American Beach grass.
Maintenance Issues	Sand fencing was used to help trap sediment in the constructed dune, and to help maintain the seaward edge of the original dune. However, shoreline erosion has continued; as of May 2017 the restored dune has started to erode.
Final Cost	$29,000 and volunteer hours
Challenges	Trucking 90 dump-truck loads of sediment through the community. Construction and planting timing windows associated with piping plover nesting. Continued erosion.

Overview of Technique

Materials	Sediment is brought in from an offsite source, such as a sand and gravel pit or coastal dredging project.[1] Planting the dune with native, salt-tolerant, erosion-control vegetation (e.g., beach grass *Ammophilia breviligulata*) with extensive root systems is highly recommended to help hold the sediments in place.[1,11] Sand fencing can also be installed to trap windblown sand to help maintain and build the volume of a dune.[1,11]
Habitat Components	Dunes planted with native beach grass can provide significant wildlife habitat.[9]
Durability and Maintenance	The height, length, and width of a dune relative to the size of the predicted storm waves and storm surge determines the level of protection the dune can provide.[1] To maintain an effective dune, sediment may need to be added regularly to keep dune's height, width, and volume at appropriate levels.[1] The seaward slope of the dune should typically be less steep than 3:1 (base:height).[1,9] Dunes with vegetation perform more efficiently, ensuring stability, greater energy dissipation, and resistance to erosion.[10] If plantings were included, plants should be replaced if they are removed by storm or die.[1]
Design Life	Dunes typically erode during storm events. In areas with no beach at high tide, dune projects will be short lived as sediments are rapidly eroded and redistributed to the nearshore.[1] Designs should consider techniques that enhance or maintain the dune (e.g. sand fencing and/or vegetation to trap wind blown sand).
Ecological Services Provided	The added sediment from dune projects supports the protective capacity of the entire beach system (i.e., dune, beach, and nearshore area). Any sand eroded from the dune during a storm, supplies a reservoir of sand to the fronting beach and nearshore area.[1,9] Dunes dissipate rather than reflect wave energy, as is the case with hard structures.[1] Dunes also act as a barrier to storm surges and flooding, protecting landward coastal resources,[9] and reducing overwash events.[10] Sand dunes provide a unique wildlife habitat.[9]
Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)	Shorter planting and construction window due to shorter growing season. Utilization of irrigation to establish plants quickly. Presence of sensitive species may require design (e.g. slope, plant density) and timing adjustments.

Dune - Natural

Dune projects may be appropriate for areas with dry beach at high tide and sufficient space to maintain dry beach even after the new dune sediments are added to the site, and can be done independently, or in conjunction with a beach nourishment project.

Duxbury Beach, Duxbury, MA
Photo courtesy of Woods Hole Group

Regulatory and Review Agencies

Maine	Municipal Shoreland Zoning, Municipal Floodplain, ME Dept. of Environmental Protection, ME Land Use Planning Commission, ME Coastal Program, ME Dept. of Marine Resources, ME Dept. of Inland Fisheries and Wildlife, and ME Geological Survey.
New Hampshire	Local Conservation Commission, NH Natural Heritage Bureau, NH Department of Environmental Services (Wetlands Bureau, Shoreland Program, and Coastal Program), and NH Fish & Game Department.
Massachusetts	Local Conservation Commission, MA Division of Fisheries and Wildlife (Natural Heritage and Endangered Species Program), MA Environmental Policy Act, and MA Office of Coastal Zone Management.
Rhode Island	Coastal Resources Management Program.
Connecticut	Local Planning and Zoning Commission, and CT Department of Energy and Environmental Protection.
Federal (for all states)	U.S. Environmental Protection Agency, and U.S. Fish and Wildlife Service.

Siting Characteristics and Design Considerations

Selection Characteristics	Detail
ES Energy State	Low to high
EE Existing Environmental Resources	Coastal beach; coastal dune; coastal bank
SR Nearby Sensitive Resources	All. Dune projects can be successfully designed even in the presence of sensitive resource areas. However, special consideration is needed near salt marsh, horseshoe crab spawning grounds, and other sensitive habitats. Sediment can smother plants and animals if it is eroded quickly and carried to these areas. Impacts can be minimized by placing dunes as far landward as possible and using compatible grain size.[1] In addition, plantings may need to be thinned for dune projects in nesting habitat for protected shorebird and turtle species.[1,9]
TR Tidal Range	Low to high
EL Elevation	Above MHW. Dune projects require a dry high tide beach to be successful.
IS Intertidal Slope	Flat to steep
BS Bathymetric Slope	Flat to steep
ER Erosion	Low to high

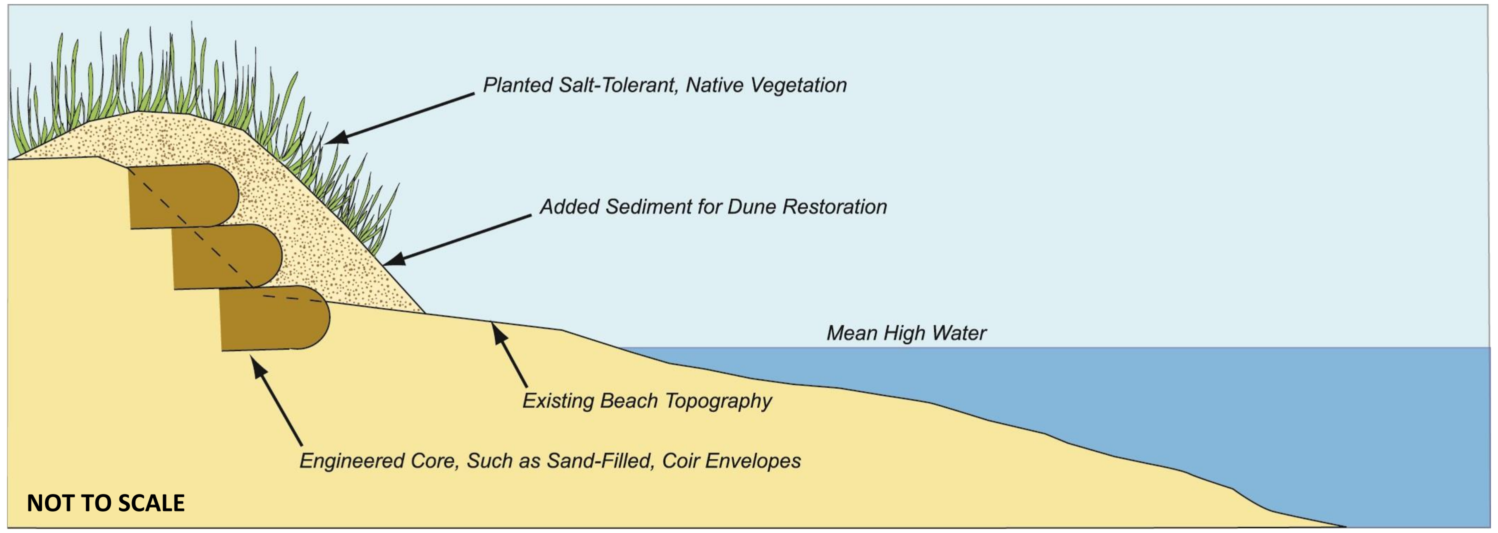
Other Characteristics	Detail
Grain Size	It is important to utilize sediment with a grain size and shape compatible to the site.[5] The percentage of sand-, gravel-, and cobble-sized sediment should match, or be slightly coarser than, the existing dune sediments.[1] Mixed sediment dunes may be appropriate and necessary for some locations.[5] The shape of the material is also important, especially for larger sediment, and should be rounded rather than angular. [1]
Impairment Level	Consideration should be given to invasive species, level of existing armoring, and extent of public use.
Climate Vulnerability	The long-term climate vulnerability of the restored dune will be influenced by a number of factors, including what is behind the landform; if the dune/beach is backed by natural landscape, it will be able to respond naturally to storms and overwash and migrate over time. Hard landscape, such as seawalls, parking lots, roads, and buildings will prevent this movement, and may ultimately cause narrowing or disappearance of these resources.
Surrounding Land Use	Shoreline armoring changes the lateral movement of sediment, thereby affecting sediment flows to nearby dunes. Therefore, any armoring adjacent to a dune restoration site needs to be taken into consideration during the planning process.[5] Dune restoration will be most successful if it is located where the natural dune line should be and, if possible, tied into existing dunes.[11] Dunes are not well suited for major urban centers or large port/harbor facilities because of space requirements and the level of risk reduction required.[10]

Dune - Engineered Core

Dune projects involving a core as a central design element covered with compatible sediment. This may be a component of a beach nourishment effort or a standalone project.

Objectives: erosion control; shoreline protection; dissipate wave energy; enhanced wildlife and shorebird habitat.

Design Schematics



Case Study

Jerusalem Dune, Narragansett, RI

Homeowners along an eroding shoreline were interested in increased shoreline protection. The houses were located 12 to 25 feet from the dune scarp. This shoreline has an average annual erosion rate (AAER) of just less than 2 feet per year.


Jerusalem Beach, Narragansett, RI
Photo courtesy of Janet Freedman
During construction (2011)


Current conditions (2017)

Project Proponent	Three private homeowners with contiguous properties
Status	Completed in November 2011; Maintained (added sand and plantings) after Sandy in 2012.
Permitting Insights	Using sand filled coir envelopes as the dune core is considered a non-structural technique in the RI Coastal Resources Management Program because the coir is biodegradable and sand compatible with beach and dune sediment, so allowed where revetments and bulkheads are not. Applicants required to maintain lateral beach access.
Construction Notes	The project extended 135 linear feet across 3 properties – 45 feet each. Ends of the coir structure were gradually returned to the slope of the feature in order to minimize erosion on adjoining properties.
Maintenance Issues	Significant repairs were necessary after Hurricane Sandy.
Final Cost	Permitting :$750 ($250 per property) Construction: $46,650 (2 properties each cost $14,950 and a third property cost $16,750) Maintenance: Costs are storm dependent
Challenges	The dune and coir core is not likely to withstand a major storm leaving the properties are at risk.

Overview of Technique

Materials	Sediment is brought in from an offsite source, such as a sand and gravel pit or coastal dredging project.[1] To be considered a living shoreline (or non-structural) project, an engineered core should be constructed using coir envelopes, which are coir fabric filled with sand.[1] Planting the dune with native, salt-tolerant, erosion-control vegetation (i.e. beach grass *Ammophilia breviligulata*) with extensive root systems is highly recommended to help hold the sediments in place.[1,11] Sand fencing can also be installed to trap windblown sand to help maintain and build the volume of a dune.[1,11]
Habitat Components	Dunes planted with native beach grass can provide significant wildlife habitat.[9]
Durability and Maintenance	The core should be kept covered to increase longevity. Some repairs to the fabric, or replacement of sand, may be necessary after a storm. The core essentially functions as a backup in the event that the rest of the dune fails during a high energy event. The height, length, and width of a dune relative to the size of the predicted storm waves and storm surge determines the level of protection the dune can provide.[1] To maintain an effective dune, sediment may need to be added regularly to keep dune's height, width, and volume at appropriate levels.[1] The seaward slope of the dune should typically be less steep than 3:1 (base:height).[1,9] Dunes with vegetation perform more efficiently, ensuring stability, greater energy dissipation, and resistance to erosion.[10] If plantings were included, plants should be replaced if they are removed by storm or die.[1]
Design Life	Dunes typically erode during storm events. In areas with no beach at high tide, dune projects will be short lived as sediments are rapidly eroded and redistributed to the nearshore.[1] Designs should consider techniques that enhance or maintain the dune (e.g. sand fencing and/or vegetation to trap wind blown sand).
Ecological Services Provided	The added sediment from dune projects supports the protective capacity of the entire beach system (i.e., dune, beach, and nearshore area). Any sand eroded from the dune during a storm, supplies a reservoir of sand to the fronting beach and nearshore area.[1,9] Dunes dissipate rather than reflect wave energy, as is the case with hard structures.[1] Dunes also act as a barrier to storm surges and flooding, protecting landward coastal resources,[9] and reducing overwash events.[10] Sand dunes provide a unique wildlife habitat.[9]
Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)	Shorter planting and construction window due to shorter growing season. Utilization of irrigation to establish plants quickly. Presence of sensitive species may require design (e.g. slope, plant density) and timing adjustments.

Dune - Engineered Core

Dune projects are appropriate for almost any area with dry beach at high tide and sufficient space to maintain some dry beach even after the new dune sediments are added to the site, and can be done independently, or in conjunction with a beach nourishment project.

Dune with an engineered core, South Kingstown, RI
Photo courtesy of Janet Freedman

Regulatory and Review Agencies

In general, coastal dunes with an engineered core are more difficult to permit than natural dunes.

Maine	Municipal Shoreland Zoning, Municipal Floodplain, ME Dept. of Environmental Protection, ME Land Use Planning Commission, ME Coastal Program, ME Dept. of Marine Resources, ME Dept. of Inland Fisheries and Wildlife, and ME Geological Survey.
New Hampshire	Local Conservation Commission, NH Natural Heritage Bureau, NH Department of Environmental Services (Wetlands Bureau, Shoreland Program, and Coastal Program), and NH Fish & Game Department.
Massachusetts	Local Conservation Commission, MA Division of Fisheries and Wildlife (Natural Heritage and Endangered Species Program), MA Environmental Policy Act, and MA Office of Coastal Zone Management.
Rhode Island	Coastal Resources Management Program.
Connecticut	Local Planning and Zoning Commission, and CT Department of Energy and Environmental Protection.
Federal (for all states)	U.S. Environmental Protection Agency, and U.S. Fish and Wildlife Service.

Siting Characteristics and Design Considerations

Selection Characteristics	Detail
ES Energy State	Only applicable in moderate to high energy environments. Natural dune projects are preferred whenever possible.
EE Existing Environmental Resources	Coastal beach; coastal dune; coastal bank
SR Nearby Sensitive Resources	All. Dune projects can be successfully designed even in the presence of sensitive resource areas. However, special consideration is needed near salt marsh, horseshoe crab spawning grounds, and other sensitive habitats. Sediment can smother plants and animals if it is eroded quickly and carried to these areas. Impacts can be minimized by placing dunes as far landward as possible and using compatible grain size.[1] In addition, plantings may need to be thinned for dune projects in nesting habitat for protected shorebird and turtle species.[1,9]
TR Tidal Range	Low to high
EL Elevation	Above MHW. Dune projects require a dry high tide beach to be successful.
IS Intertidal Slope	Flat to steep
BS Bathymetric Slope	Flat to steep
ER Erosion	Moderate to high

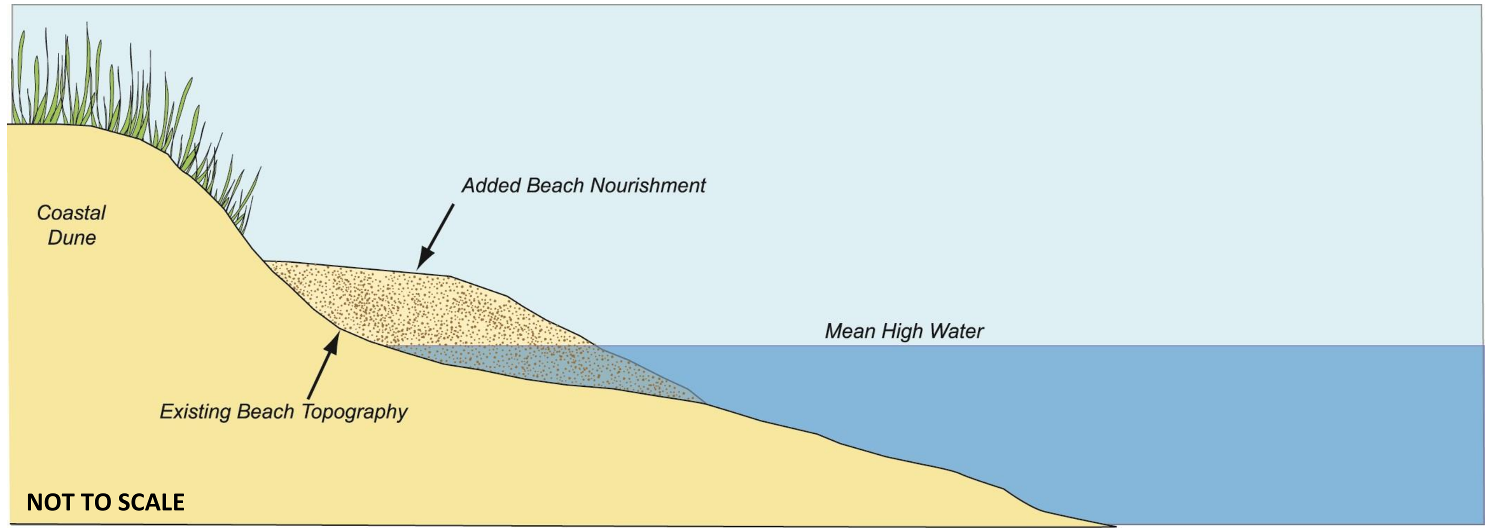
Other Characteristics	Detail
Grain Size	It is important to utilize sediment with a grain size and shape compatible to the site.[5] The percentage of sand-, gravel-, and cobble-sized sediment should match, or be slightly coarser than, the existing dune sediments.[1] Mixed sediment dunes may be appropriate and necessary for some locations.[5] The shape of the material is also important, especially for larger sediment, and should be rounded rather than angular. [1]
Impairment Level	Consideration should be given to invasive species, level of existing armoring, and extent of public use.
Climate Vulnerability	Dunes with an engineered core provide more stability and protection to landward areas in the short term, but do not allow the dune to migrate naturally, which may be necessary given increased storms and sea level rise in the future.
Surrounding Land Use	Shoreline armoring changes the lateral movement of sediment, thereby affecting sediment flows to nearby dunes. Therefore, any armoring adjacent to a dune restoration site needs to be taken into consideration during the planning process.[5] Dune restoration will be most successful if it is located where the natural dune line should be and, if possible, tied into existing dunes.[11] Dunes are not well suited for major urban centers or large port/harbor facilities because of space requirements and the level of risk reduction required.[10]

Beach Nourishment

Beach nourishment is the placement of sediment along the shoreline of an eroding beach from outside source. It widens and/or elevates the beach and usually moves the shoreline seaward, increasing the natural protection that a beach can provide against wave energy and storms. This may be a component of a dune restoration/creation effort or a stand alone project.

Objectives: erosion control; shoreline protection; enhance recreation; increased access; dissipate wave energy; enhanced wildlife and shorebird habitat.

Design Schematics



Design Overview

Materials	Sediment is brought in from an offsite source, such as a sand and gravel pit or coastal dredging project.[1]
Habitat Components	Beaches nourished with compatible sediments can provide significant wildlife habitat.[5,6]
Durability and Maintenance	A coarser sand may erode more slowly than a finer sand.[6] To maintain an effective beach berm, sediment may need to be added regularly maintain the desired beach profile.[6,11] The need to replenish the beach depends upon the rate of erosion at the particular site, but is typically once every 1-5 years.[6]
Design Life	To increase erosion and flooding protection, nourished beaches are frequently built higher and wider than would occur naturally.[11] Grain size (e.g. sand, gravel, cobble) drives appropriate design slopes; gentler slopes generally perform better than steep areas. However, coarser grain sizes allow for steeper project slopes.
Ecological Services Provided	A nourishment beach can provide additional beach habitat area. Added sediment used for the nourishment can also provide a sand source for surrounding areas. The increased width and height of the beach berm can help attenuate wave energy.[10]
Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)	Beach nourishment sites subject to ice impacts are generally most successfully stabilized with gentler slopes (e.g., 6:1-10:1).[13] Presence of sensitive species may require design (e.g. slope, plant density) and timing adjustments.

Case Study

Winthrop, MA Beach Nourishment

Applied Coastal Research & Engineering, Inc. designed the Winthrop Beach Nourishment Program to provide storm protection to an upland urban area fronted by a seawall originally constructed in 1899. The project utilized 460,000 cy of compatible sediment to nourish approximately 4,200 linear feet and to create the equilibrated designed berm width of 100 feet. Once the beach nourishment was completed in late 2014, the high tide shoreline was pushed more than 150 feet from the seawall, with a gradual slope extending approximately 350 feet offshore.

Winthrop Shores, Winthrop, MA
Photo courtesy of Applied Coastal Research & Engineering

Project Proponent	Massachusetts Division of Conservation and Recreation (DCR)
Status	Phase 1: 2013; Phase 2: 2014
Permitting Insights	Offshore sediment source was denied by Army Corps after a 12-year permitting process. Conservation Permit required from NHESP to address potential impacts to Piping Plovers.
Construction Notes	Upland derived mix of sand, gravel and cobble to match the existing beach sediments was required, where the nourishment was provided from two sources: sand borrow (80%) and naturally rounded cobble & gravel (20%).
Maintenance Issues	Cobble berms have begun forming along the beach, which conflicts with community recreation goals, requiring additional sand for aestheitcs.
Final Cost	Permitting: $2,000,000 (including attempt to permit offshore borrow site. Construction: $22,000,000 (included work on coastal engineering structures).
Challenges	Trucking through the community: urban community with two roads in and out, as well as roadway damage and air quality impacts associated with 16,000+ truck trips. Public perception of compatible sediment.

Revere Beach, MA
Photo courtesy of MA CZM

Long Beach, Barnstable, MA
Photo courtesy of MA CZM

Beach Nourishment

Beach nourishment projects are appropriate for almost any tide range or grain size, and can be done independently, or in conjunction with a dune restoration project.

Misquamicut Beach, RI
Photo courtesy of Janet Freedman

Western Scarborough Beach, ME
Photo courtesy of Peter Slovinsky

Regulatory and Review Agencies

Maine	Municipal Shoreland Zoning, Municipal Floodplain, ME Dept. of Environmental Protection, ME Land Use Planning Commission, ME Coastal Program, ME Department of Marine Resources, ME Department of Inland Fisheries and Wildlife, ME Geological Survey, and ME Submerged Lands Program.
New Hampshire	Local Conservation Commission, NH Natural Heritage Bureau, NH Department of Environmental Services (Wetlands Bureau, Shoreland Program, and Coastal Program), and NH Fish & Game Department.
Massachusetts	Local Conservation Commission, MA Dept. of Environmental Protection (Waterways and Water Quality), MA Division of Fisheries and Wildlife (Natural Heritage and Endangered Species Program), MA Environmental Policy Act, and MA Office of Coastal Zone Management.
Rhode Island	Coastal Resources Management Program, and RI Dept. of Environmental Management.
Connecticut	Local Planning and Zoning Commission, and CT Department of Energy and Environmental Protection.
Federal (for all states)	U.S. Army Corps of Engineers, National Marine Fisheries Service, U.S. Environmental Protection Agency, and U.S. Fish and Wildlife Service.

Siting Characteristics and Design Considerations

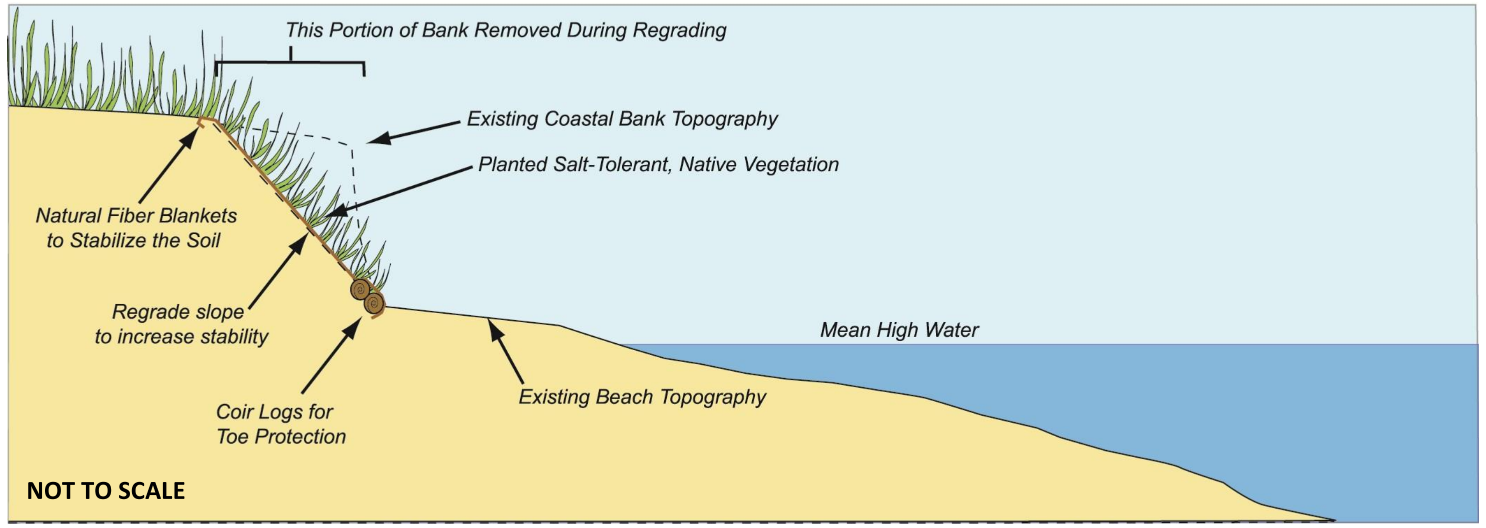
Selection Characteristics	Detail
ES Energy State	Low to high
EE Existing Environmental Resources	Coastal beach; subtidal
SR Nearby Sensitive Resources	Endangered and threatened species; shellfish. The added sand may result in shoaling of adjacent areas and increase turbidity during the placement of the sand, which can cause temporary adverse effects.[6] Nourishment can also bury native vegetation. Nourished sediment may also adversely affect nesting and foraging of shorebirds and other coastal animals, but can be avoided through a time of year restriction.[11]
TR Tidal Range	Low to high
EL Elevation	Above MHW to Below MLW. When designing beach berm elevations, consider increasing elevation above existing berm elevation.
IS Intertidal Slope	Flat to steep. Beach nourishment is most effective where a gently sloping shoreline is present, but it can also be appropriate for use on other slopes.
BS Bathymetric Slope	Flat to steep. However, areas with steep bathymetric slope may result in offshore transport carrying sediment past depth of closure. A steep bathymetric slope will also produce larger waves.
ER Erosion	Low to high. The erosion rate at the site is one of the most important elements when designing a beach nourishment project; if the rate is high then beach nourishment may not be appropriate.[6]
Other Characteristics	**Detail**
Grain Size	It is important to utilize sediment with a grain size, shape and color compatible to the site.[5] The percentage of sand-, gravel-, and cobble-sized sediment should match, or be slightly coarser than, the existing sediments.[1] The shape of the material is also important, especially for larger sediment, and should be rounded rather than angular.[1]
Impairment Level	Consideration should be given to invasive species, level of existing armoring, and extent of public use. Beach nourishment projects are more successful is they are located where there are already existing beaches. The longer and more contiguous the project is, the more resilient the project will be.
Surrounding Land Use	Beach nourishment is best suited where natural beaches have existed at a site and where there is a natural source of sand to help sustain the beach.[6] Beach nourishment is also suitable to help restore sediment supply to a sediment-starved system. Not generally well-suited for application to most major urban centers or areas with large port and harbor facilities because of the space requirements and the level of risk reduction desired. [10] Existing structures on site, like seawalls, may force beach nourishment projects to have a steeper slope than desirable. Steeper slopes leave little opportunity for wave energy dissipation.[13]

Coastal Bank - Natural

Coastal bank protection, including slope grading, and toe protection and planting of natural vegetation will reduce the steepness and protect the toe of the bank from further erosion. Coir logs, root wads protect bank toes from erosion, while planted vegetation develops strong root systems.

Objectives: erosion control; shoreline protection; dissipate wave energy; enhanced wildlife habitat.

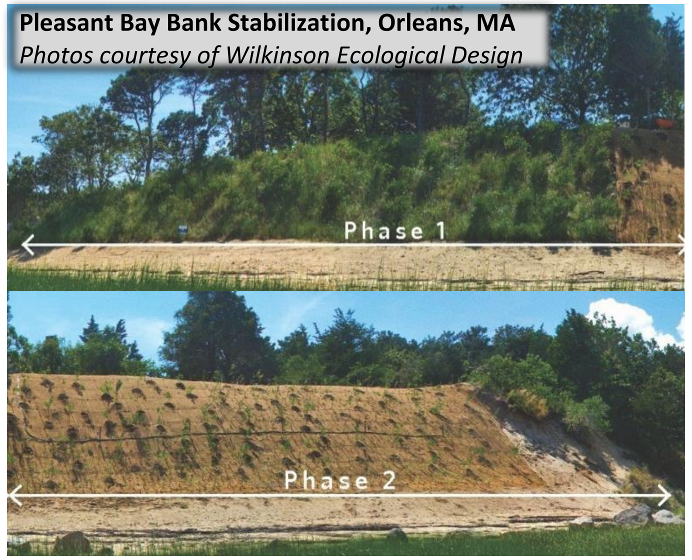
Design Schematics



Case Study

Coastal Bank Stabilization, Orleans, MA

Wilkinson Ecological Design developed a plant-focused coastal bioengineering project, determined not to be a coastal engineering structure by the local municipality and MA DEP. The project included a robustly anchored fiber roll array at the bottom of the bank and intensive planting and stabilization through the remainder of their coastal bank, which falls within a mapped FEMA Velocity Zone.



Pleasant Bay Bank Stabilization, Orleans, MA
Photos courtesy of Wilkinson Ecological Design

Project Proponent	Private property owners. The project spans three properties with multiple owners.
Status	Phase 1 constructed in 2010, Phase 2 constructed in 2013 and Phase 3 constructed in 2015.
Permitting Insights	The project involved one permit under the MA Wetlands Protection Act for each phase, three wetland permits in total.
Construction Notes	Regraded the over steepened bank, installed six rows of coir rolls at the toe of bank, installed natural fiber blankets on the bank face above the coir rolls, planted the bank face with native, salt-tolerant grasses and shrubs, and covered fiber rolls with sand.
Maintenance Issues	Monitor vegetation monthly throughout the growing season to ensure plant success; temp-orary irrigation for first three years; monitor coir rolls twice annually and after storms. Replant and retighten fiber roll anchoring system as needed.
Final Cost	Permitting: $10,000 Construction: $1,000/ linear foot Maintenance : $8,000/yr
Challenges	No substantial challenges in the permitting, construction or maintenance phases of work and has performed well through storms.

Overview of Technique

Materials	Sediment, if fill is needed, to establish a stable slope. Coir rolls or root wads from fallen trees to minimize erosion. Coir rolls, typically rolls 12-20” in diameter and 10-20 feet long, packed with coir fibers and held together by mesh.[1] (Coir rolls can be pre-vegetated to head start the growing process.) A high-density roll may be necessary at the toe, while lower-density rolls could be used above.[5] Wooden stakes for blankets, earth anchors for rolls, or a combination of the two are necessary to anchor the system.[1] Other naturally occurring woody material or root wads may also be utilized to stabilize the toe of the coastal bank in some sites. Salt-tolerant vegetation with extensive root systems are often used in conjunction with fiber rolls to help stabilize the site.[1] Natural fiber blankets can be used to stabilize the ground surface while plants become established.[1] (Blankets should be run up and down the slope rather than horizontally across it.)
Habitat Components	Because they are made with natural fibers and planted with vegetation, natural fiber blankets also help preserve the natural character and habitat value of the coastal environment.[1]
Durability and Maintenance	Installing coir rolls at the toe of a bank stabilization project can provide increased stability while the vegetation becomes established,[1] but bioengineering projects with coir rolls and vegetation require ongoing maintenance, such as resetting, anchoring, or replacement, to ensure their success.[1,6] Coir logs must be securely anchored to prevent wave and tidal current-induced movement.[11] Invasive species management should be incorporated into the project.[1] Runoff and groundwater management will also be crucial to project success.[6]
Design Life	As the coir rolls disintegrate, typically over 5-7 years, the plants take over the job of site stabilization.[1] The bank slope is extremely important. Often the existing condition of the slope is steep or undercut. Before installing coir logs or planting vegetation, the bank slope should be stabilized.[1] This is often done by regrading the bank slope by removal of sediment from the top of the bank rather than adding sediment to the toe of the slope.[1]
Ecological Services Provided	Upland plantings stabilize bluffs and reduce rainwater runoff.[11]
Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)	Shorter planting and construction window due to shorter growing season. Utilization of irrigation to establish plants quickly. Freeze and thaw processes can damage this design. Consideration should be given to the slope aspect and the implications on plant growth and microbiome from shading and sun exposure.

Coastal Bank - Natural

Natural coastal bank protection projects are appropriate for almost any tide range, topographic slope, or grain size, provided that the toe of the bank is situated above mean high water where it will not be regularly inundated.

Regulatory and Review Agencies

Maine	Municipal Shoreland Zoning, Municipal Floodplain, ME Dept. of Environmental Protection, ME Land Use Planning Commission, ME Coastal Program, ME Dept. of Marine Resources, ME Dept. of Inland Fisheries and Wildlife, and ME Geological Survey.
New Hampshire	Local Conservation Commission, NH Natural Heritage Bureau, NH Department of Environmental Services (Wetlands Bureau, Shoreland Program, and Coastal Program), and NH Fish & Game Department.
Massachusetts	Local Conservation Commission, MA Division of Fisheries and Wildlife (Natural Heritage and Endangered Species Program), MA Environmental Policy Act, and MA Office of Coastal Zone Management.
Rhode Island	Coastal Resources Management Program.
Connecticut	Local Planning and Zoning Commission, and CT Department of Energy and Environmental Protection.
Federal (in all states)	U.S. Environmental Protection Agency, and U.S. Fish and Wildlife Service.

Siting Characteristics and Design Considerations

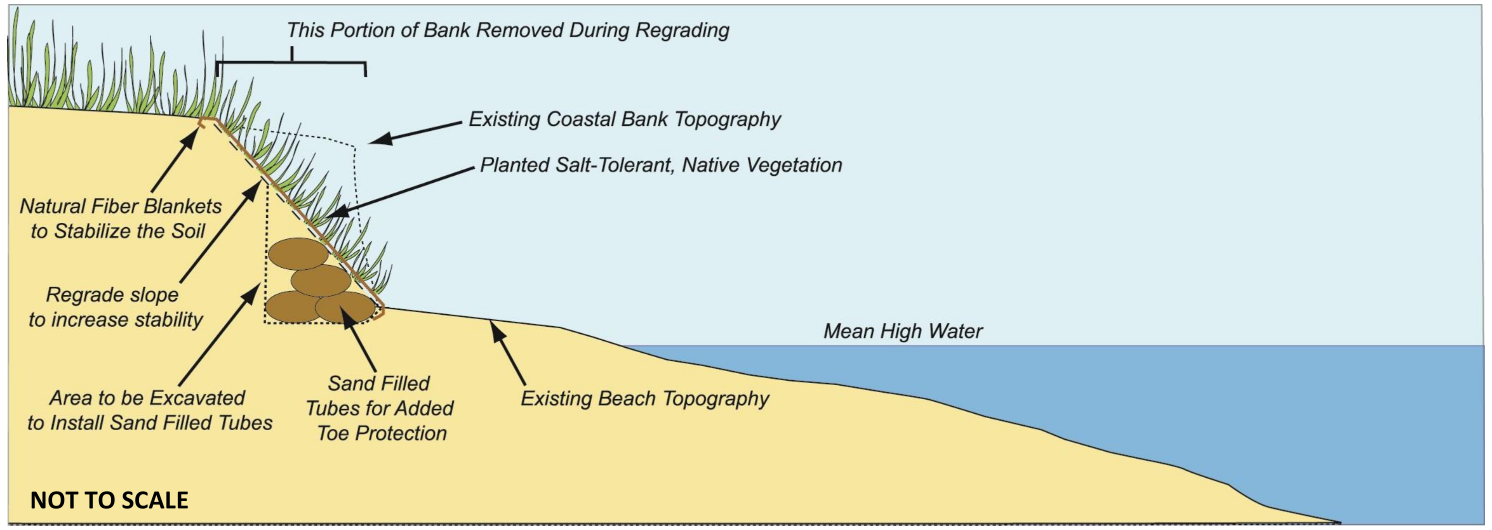
Selection Characteristics	Detail
ES Energy State	Low to moderate. Coir rolls can be used on both sheltered sites and sites exposed to wave energy.[1] However, they are most effective in areas with higher beach elevations with some dry beach at high tide, where the rolls are not constantly subject to erosion from tides and waves.[1] Naturally occurring fringe protection (e.g. bedrock outcrop, salt marsh or higher beach elevations with some dry beach at high tide), will also help protect the project.
EE Existing Environmental Resources	Coastal bank; vegetated upland.
SR Nearby Sensitive Resources	All. If the project is proposed in or adjacent to habitat for protected wildlife species or horseshoe crab spawning areas, there may be limitations on the time of year that the project can be constructed.[1] Mudflats, clam flats and other adjacent habitat are dependent on eroded habitat; this loss in sediment source to adjacent habitat must be accounted for. If trees are removed during construction, replanting is required; the removed trees can also be used to stabilize the toe of the bank.
TR Tidal Range	Low to high. Natural coastal bank protection projects can be designed for all tidal ranges, provided the toe of bank is above the mean high water line and will not be regularly inundated.
EL Elevation	Above MHW
IS Intertidal Slope	Flat to steep. Although, flat to moderate slopes are preferred; steeper slopes may require armoring, which would result in a non-living shoreline.
BS Bathymetric Slope	Flat to steep
ER Erosion	Low to moderate
Other Characteristics	**Detail**
Impairment Level	Groundwater can be the cause of slope failure (particularly when clay is the base material), but wave exposure can be the dominant driver of loss.
Climate Vulnerability	Both horizontal and vertical loss to a coastal bank is permanent.
Surrounding Land Use	The ends of a coir roll project should be carefully designed to minimize any redirection of waves onto adjacent properties. Tapering the rolls down in number and height so that the project blends in to the adjacent bank helps address this problem. [1] If pavement or lawn extends all the way to the edge of the top of the bank, or if forests are cut to the edge of the top of the bank, coastal bank loss is more likely; maintenance or creation of a vegetated buffer will mitigate loss.

Coastal Bank – Engineered Core

Coastal bank protection, including slope grading, terracing, and toe protection and vegetation planting will reduce the steepness and protect the toe of the bank from further erosion. Engineered cores, of sand filled tubes, provide added protection from future bank erosion.

Objectives: erosion control; shoreline protection; dissipate wave energy; enhanced wildlife habitat.

Design Schematics



Design Overview

Design Overview	
Materials	An engineered core could be constructed using coir envelopes, which are coir fabric filled with sand. Cutback/excavated material should be used to fill the coir envelopes but supplemental offsite material may be required. Anchors are necessary to secure the envelopes. Native vegetation with extensive root systems are often used in conjunction with coir envelopes to help stabilize the site. Also, natural fiber blankets can also be used to stabilize the ground surface while plants become established. (Blankets should be run up and down the slope rather than horizontally across it.)
Habitat Components	Because they are made with natural fibers and planted with vegetation, natural fiber blankets also help preserve the natural character and habitat value of the coastal environment.
Durability and Maintenance	A veneer of sand/sediment should be maintained over the sand filled tubes to prolong their lifetime. Regular maintenance, such as resetting, anchoring, replacement, or recovering, can increase the effectiveness of the project.[6] Invasive species management should be incorporated into the project. Runoff management and groundwater will also be crucial to project success.[6]
Design Life	As the sand tube material and natural fiber blankets disintegrate, typically over 5-10 years, the plants take over the job of site stabilization.
Ecological Services Provided	Upland plantings stabilize bluffs and reduce rainwater runoff.[11]
Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)	Shorter planting and construction window due to shorter growing season. Utilization of irrigation to establish plants quickly. Freeze and thaw processes can damage this design. Consideration should be given to the slope aspect and the implications on plant growth and microbiome from shading and sun exposure.

Case Study

Stillhouse Cove, Cranston, RI

Stillhouse Cove is the site of a public park and a previous salt marsh restoration project that was completed in 2007. Restoration of the coastal bank was initiated after Superstorm Sandy caused extensive erosion which over-steepened the bank and washed fill and soil into the adjacent marsh. Save The Bay and EWPA, working closely with the USDA Natural Resources Conservation Service, developed a design to reinforce and protect the eroding bank by reconfiguring the slope and using natural materials and vegetation.


Construction at Stillhouse Cove, RI
Photos courtesy of Janet Freedman

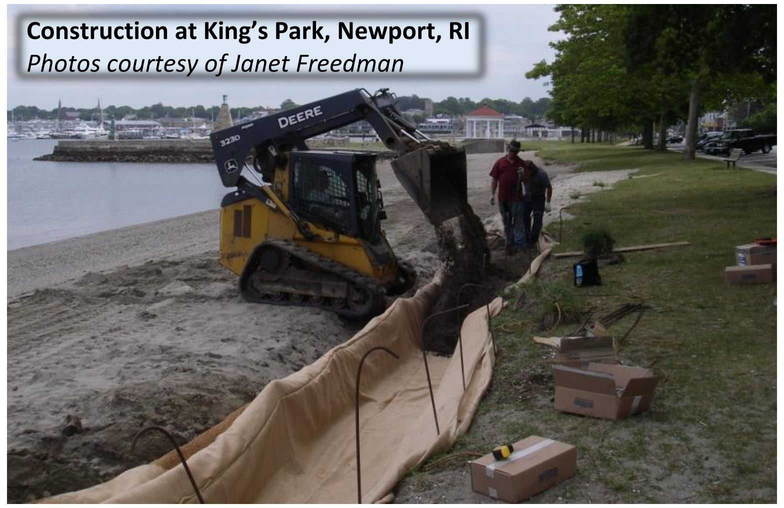
Project Proponent	City of Cranston, RI, Edgewood Waterfront Preservation Association (EWPA), Save The Bay, Natural Resources Conservation Service (NRCS).
Status	Completed in 2013. Maintained in 2014 (added coir logs and plantings).
Permitting Insights	The project had several iterations but was finally permitted as a Sandy Emergency Assent. An extension was required due to challenges of securing funding within the permit time frame.
Construction Notes	A key component of this project was regrading the bank from a vertical cut to create a more gradual slope. Once the slope was regraded, sand filled coir envelopes were installed, covered with soil and planted with salt tolerant vegetation.
Maintenance Issues	3 coir logs were installed at the southern end of project and planted with warm season grasses as part of the Dept. of Interior Hurricane Sandy Relief Grant Program. The base of the bank will be more frequently inundated as sea levels rise.
Final Cost	Permitting: No permit fee for municipalities Construction: $59,006 plus volunteer labor.
Challenges	Funding and coordination with partners and volunteers.


Completed Stillhouse Cove Project (RI)
Photo courtesy of Janet Freedman


Construction at Allin's Cove, Barrington, RI
Photo courtesy of Janet Freedman

Coastal Bank – Engineered Core

Engineered coastal bank protection projects are appropriate for almost any tide range, topographic slope, or grain size, provided that the toe of the bank is situated above mean high water where it will not be regularly inundated.



Construction at King's Park, Newport, RI
Photos courtesy of Janet Freedman

Regulatory and Review Agencies

Maine	Municipal Shoreland Zoning, Municipal Floodplain, ME Dept. of Environmental Protection, ME Land Use Planning Commission, ME Coastal Program, ME Dept. of Marine Resources, ME Dept. of Inland Fisheries and Wildlife, and ME Geological Survey.
New Hampshire	Local Conservation Commission, NH Natural Heritage Bureau, NH Department of Environmental Services (Wetlands Bureau, Shoreland Program, and Coastal Program), and NH Fish & Game Department.
Massachusetts	Local Conservation Commission, MA Division of Fisheries and Wildlife (Natural Heritage and Endangered Species Program), MA Environmental Policy Act, and MA Office of Coastal Zone Management.
Rhode Island	Coastal Resources Management Program.
Connecticut	Local Planning and Zoning Commission, and CT Department of Energy and Environmental Protection.
Federal (in all states)	U.S. Environmental Protection Agency, and U.S. Fish and Wildlife Service.

Siting Characteristics and Design Considerations

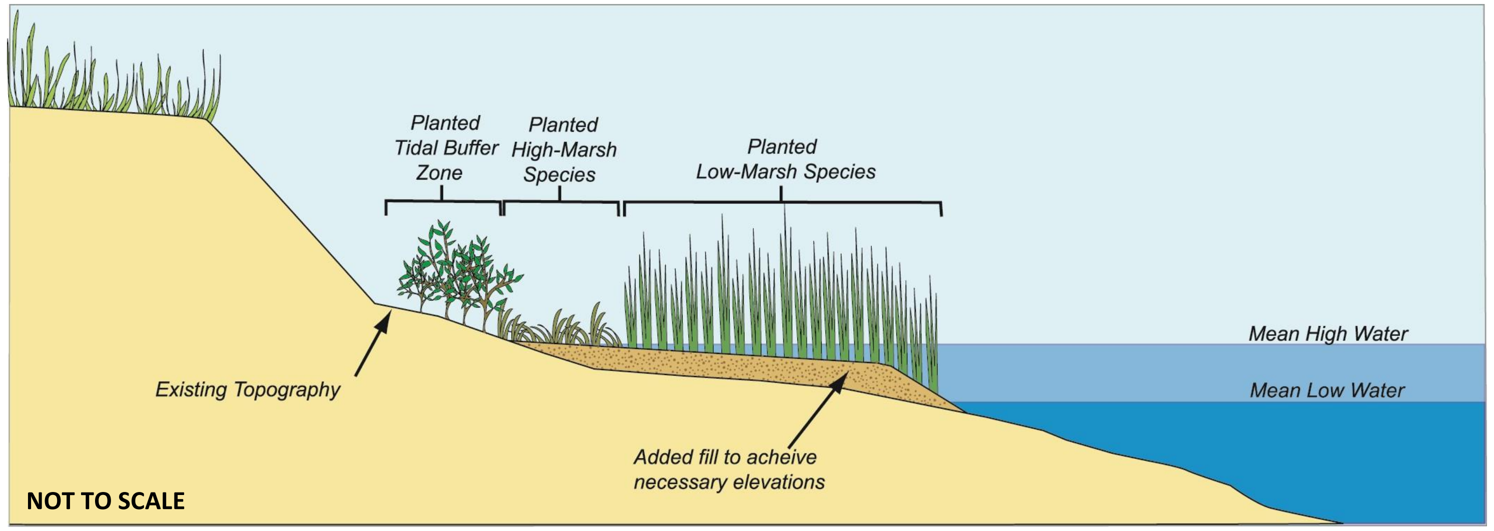
Selection Characteristics	Detail
ES Energy State	Low to high. Engineered cores, as part of a coastal bank protection project, can be used on both sheltered sites and sites exposed to wave energy. Additionally, they are most effective in areas with naturally occurring fringe protection (e.g. bedrock outcrop, salt marsh or higher beach elevations with some dry beach at high tide), where the toe of the bank is not constantly subject to erosion from tides and waves.[1]
EE Existing Environmental Resources	Coastal bank; vegetated upland.
SR Nearby Sensitive Resources	All. If the project is proposed in or adjacent to habitat for protected wildlife species or horseshoe crab spawning areas, there may be limitations on the time of year that the project can be constructed.[1] Mudflats, clam flats and other adjacent habitat are dependent on eroded habitat; this loss in sediment source to adjacent habitat must be accounted for. If trees are removed during construction, replanting is required; the removed trees can also be used to stabilize the toe of the bank.
TR Tidal Range	Low to high. An engineered coastal bank protection projects can be designed for all tidal ranges, provided the toe of bank is above the mean high water line and will not be regularly inundated.
EL Elevation	Above MHW
IS Intertidal Slope	Flat to steep. Although, flat to moderate slopes are preferred; steeper slopes may require armoring, which would result in a non-living shoreline.
BS Bathymetric Slope	Flat to steep
ER Erosion	Low to high. Steeper slopes may be more likely to erode, i.e. less stable. Coastal bank protection projects with engineered cores are preferred in areas of widespread erosion.
Other Characteristics	**Detail**
Impairment Level	Groundwater can be the cause of slope failure (particularly when clay is the base material), but wave exposure can be the dominant driver of loss.
Climate Vulnerability	Both horizontal and vertical loss to a coastal bank is permanent.
Surrounding Land Use	The ends of the sand tubes for an engineered coastal bank protection project should be carefully designed to minimize any redirection of waves onto adjacent properties. Tapering the tubes down in number and height so that the project blends in to the adjacent bank helps address this problem. [1] If pavement or lawn extends all the way to the edge of the top of the bank, or if forests are cut to the edge of the top of the bank, coastal bank loss is more likely; maintenance or creation of a vegetated buffer will mitigate loss.

Natural Marsh Creation/Enhancement

Marsh vegetation, such as native low (*Spartina alterniflora)* and high marsh (*Spartina patens*) species, can be planted along the shoreline. Roots help hold soil in place, and shoots will break small waves and increase sedimentation – vegetation projects such as this are a minimally invasive approach.

Objectives: dissipates wave energy, habitat creation, shoreline stabilization

Design Schematics



Case Study

Sachuest Point Restoration, Middletown, RI

The U.S. Fish & Wildlife Service and The Nature Conservancy developed this project at the Sachuest Point National Wildlife Refuge to help the area better withstand the impacts of sea-level rise and coastal storm surge. Storm surge and wave erosion, combined with the lack of sediment replenishment from estuaries whose rivers have been dammed, left the existing salt marsh at a point where it could not keep up with sea-level rise. With little opportunity to migrate, due to being constrained by Third Beach, the best solution to protect Sachuest Point was to raise the elevation of the marsh itself.

Sachuest Point, Middletown, RI
Photo courtesy of Jennifer White

Project Proponent	USFWS, The Nature Conservancy, Save The Bay, Town of Middletown, Norman Bird Sanctuary
Status	Initial construction and planting: Spring 2016.
Permitting Insights	Care was taken to prevent sediment plumes from entering the Sakonnet that could negatively affect winter flounder. Testing was done to ensure material was clean and of appropriate grain size. Ensured that elevations remained within the tidal marsh elevation range.
Construction Notes	Sand was trucked to the site and placed on the marsh with machines. The surface was contoured to create high and low marsh elevations. Salt tolerant grass plugs grown out from local seed sources were planted in the spring following sediment placement.
Maintenance Issues	Fencing was used to protect plant plugs from winter grazing by Canada Geese. Additional planting will occur in 2017.
Final Cost	$634,000 for sediment placement; $36,100 for growing of plant plugs.
Challenges	A drought during the growing season of 2016 caused mortality of some plant plugs, and maintenance of anti-grazing fencing during/after winter storms to prevent damage by geese.

Design Overview

Materials	Native marsh plants appropriate for salinity and site conditions. Plugs of marsh grass can be planted to augment bare or sparse areas.[11] Sediment may be necessary if the project area needs to be filled to obtain appropriate elevations, to provide a suitably gradual slope for marsh creation, or to enable a marsh to maintain its elevation with respect to the sea-level rise.[11] Bird exclusion fencing may be necessary to avoid predation while plants develop.[16]
Habitat Components	Salt marsh; Tidal buffer landward of the salt marsh; Coastal beach; Mud flat.
Durability and Maintenance	Plants that are removed or die during the early stages of growth must be replaced immediately to ensure the undisturbed growth of the remaining plants. The removal of debris and selective pruning of trees is also a good maintenance practice to ensure that sunlight reaches plants. Protection measures, such as fencing, must be taken to keep waterfowl from eating the young plants.[6] Ongoing maintenance of invasive species and runoff issues will be important to the long-term success of the project. After significant growth has occurred only periodic inspections may be necessary.
Design Life	It is important to recognize that design life may be shorter in the future given changes in sedimentation rates, accelerating sea-level rise and other climate change impacts.
Ecological Services Provided	Increases water infiltration, uptake of nutrients, filtration, denitrification and sediment retention.[2,3] The extensive root systems of marsh vegetation help to retain the existing soil, thus reducing erosion while plant stems attenuate wave energy.[11] A healthy salt marsh may reduce wave energy. Marshes provide habitat for many species of plants and animals, and maintain the aquatic/terrestrial interface.[2] Marshes also provide natural shore erosion control, better water quality, recreation and education opportunities, and carbon sequestration (blue carbon).[12]
Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)	Including roughened surfaces, such as emergent vegetation can help break up ice sheets.[4] Marshes can respond better to ice if gentler slopes (6:1-10:1) are used and by incorporating shrubs. Planting in the spring will allow vegetation time to become established before it has to withstand ice.[8,13] Consider using pre-planted mats to compensate for a shorter growing season. Hardy, salt-tolerant shrubs (e.g., *Iva frutescens* and *Baccharis halimifolia*) are well-suited for shorelines affected by ice.[13]

Natural Marsh Creation/Enhancement

Fringing marsh living shoreline projects have proven successful with or without protective structures such as fiber rolls or sills, but projects without protective structures are most likely to be successful on sheltered waterways where there is low natural wave action and limited wave action from boating activities.

Allin's Cove, Barrington, RI
Photo courtesy of Janet Freedman

Fringing Marsh Project, Indigo Point, S. Kingstown, RI
Photo courtesy of Janet Freedman

Regulatory and Review Agencies

Maine	Municipal Shoreland Zoning, Municipal Floodplain, ME Dept. of Environmental Protection, ME Land Use Planning Commission, ME Coastal Program, ME Department of Marine Resources, ME Department of Inland Fisheries and Wildlife, ME Geological Survey, and ME Submerged Lands Program.
New Hampshire	Local Conservation Commission, NH Natural Heritage Bureau, NH Department of Environmental Services (Wetlands Bureau, Shoreland Program, and Coastal Program), and NH Fish & Game Department.
Massachusetts	Local Conservation Commission, MA Dept. of Environmental Protection (Waterways and Water Quality), MA Division of Fisheries and Wildlife (Natural Heritage and Endangered Species Program), MA Environmental Policy Act, and MA Office of Coastal Zone Management.
Rhode Island	Coastal Resources Management Program, and RI Dept. of Environmental Management.
Connecticut	Local Planning and Zoning Commission, and CT Department of Energy and Environmental Protection.
Federal (for all states)	U.S. Army Corps of Engineers, National Marine Fisheries Service, U.S. Environmental Protection Agency, and U.S. Fish and Wildlife Service.

Siting Characteristics and Design Considerations

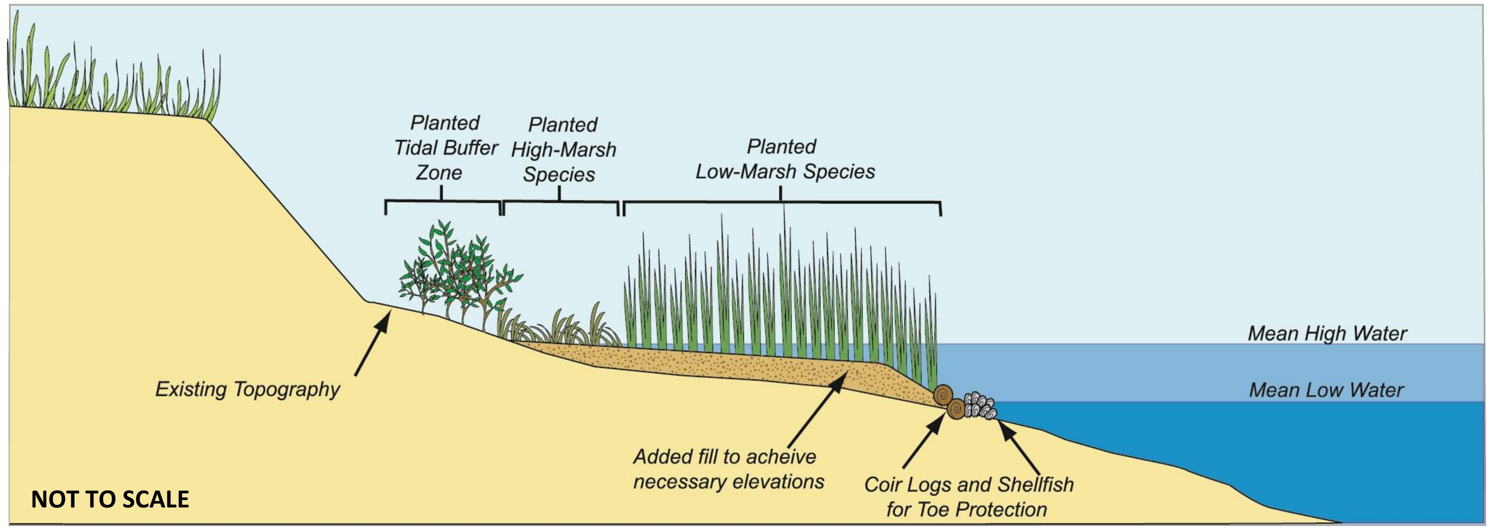
Selection Characteristics	Detail
ES Energy State	Low to moderate. Works best in low energy sites (i.e. less than 2 feet of short waves, low current and low storm surge).[3] Sites with a fetch >5 miles are not recommended.[15]
EE Existing Environmental Resources	Coastal beach; mud flat; salt marsh
SR Nearby Sensitive Resources	Endangered and threatened species. If the project is proposed in or adjacent to habitat for protected wildlife species or horseshoe crab spawning areas, there may be limitations on the time of year for construction.[1] Shellfish beds and essential fish habitats will restrict where a marsh can be extended. Construction may produce short term habitat impacts, but in the long term, the marsh area should provide enhanced wildlife and fisheries habitat.
TR Tidal Range	Low to high
EL Elevation	MLW to MHW; Above MHW. For low marsh, the lowest grade should be MTL and extend up to MHW. High marsh plantings should extend between MHW and MHHW.[5] Tidal buffer should be planted above highest observable tide.
IS Intertidal Slope	Flat. With slopes 5:1 (base:height) and flatter, plants can be utilized without additional erosion control.[3] Between 5:1 and 3:1, marsh projects may not work without additional toe stabilization.[3] The wider the intertidal zone, the more effective the marsh is at dissipating wave energy.[7] A minimum width of the planting should be 10 feet.[15]
BS Bathymetric Slope	Flat to moderate
ER Erosion	Low to moderate
Other Characteristics	**Detail**
Boat Traffic	If boat wakes are perceived to be a significant problem, the site should be treated as a higher energy site and may be more suitable with a sill or other toe protection.
Ice Sensitivity	Planted marsh areas with gentle slopes and intermixed shrubs will handle ice the best. Shrubs have a significant advantage over other types of vegetation because they have deep fibrous root systems and a structure that remains in place throughout the winter months.[8] Plant in the spring to allow plants to become established well before ice becomes a concern.[8]
Climate Vulnerability	Planted marsh areas may have a difficult time adapting to sea level rise.[7] If there is space on a project site, designs should anticipate marsh migration in response to sea level rise.[13]
Surrounding Land Use	Existing structures on site, like seawalls, may force living shoreline projects to have a steeper slope than desirable. Seawalls will limit the inland migration potential of the salt marsh in the future. Steeper slopes leave little opportunity for wave energy dissipation.[13] Marshes require sunlight to thrive; trees must be pruned or removed to allow for at least four to six hours of sunlight a day;[6] this will increase vegetation growth.[11,15] Although it is possible to create a marsh on most shorelines, marsh creation is not recommended for sites where they are not a natural feature along comparable natural shorelines.[11]

Marsh Creation/Enhancement w/Toe Protection

Marsh vegetation that is planted along the shoreline often benefits from toe protection to assist with marsh stabilization. Toe protection materials may include natural fiber rolls, shell bags or, in some cases, stone. The toe protection may also allow the design to achieve the appropriate grade in lieu of seaward fill, thereby decreasing the project footprint.

Objectives: dissipates wave energy, habitat creation, shoreline stabilization

Design Schematics



Case Study

North Mill Pond, Portsmouth, NH

This project involved restoration of low and high marsh along North Mill Pond, with about half of the area consisting of new marsh creation, and the other half of the area consisting of restoration of degraded low and high marsh through sediment addition (thin layer deposition).

North Mill Pond Marsh Restoration, Portsmouth, NH
Photo courtesy of David Burdick (UNH)

Project Proponent	City of Portsmouth, Stantec (wetlands consultant), UNH (assisted plan development)
Status	Construction complete May 2016. Beginning year two of monitoring in 2017.
Permitting Insights	NHDES and USACOE permits needed for drainage outfall into pond. Project impacted 600 sf of coastal wetland. Salt marsh restoration was compensatory mitigation.
Construction Notes	Imported fill to raise 12,060 sf to suitable elevation for salt marsh (low marsh); planted 3,055 sf of high marsh area. Created micro-topography and interior drainage channels. 12-in diameter coir logs staked at seaward edge of marsh to stabilize toe. Placed large boulders to break-up winter ice sheets.
Maintenance Issues	Long term monitoring and maintenance efforts are scheduled. Survival of low marsh plants is good; survival of high marsh salt hay is fair to poor. Survived 2016-2017 winter well.
Final Cost	$60,000 (construction, monitoring & maintenance)
Challenges	Construction did not have a provision for within plot drainage; many plants were washed out by runoff gullies in the first year. More time needed for filled sediment to settle before planting.

Design Overview

Materials	Native marsh plants appropriate for salinity and site conditions. Plugs of marsh grass can be planted to augment bare areas.[11] Sediment may be necessary if area needs to be filled to obtain appropriate elevations. Toe protection materials may include natural fiber rolls, oyster/mussel shells bags, or in some cases, stone. Filter cloth placed prior to added fill and/or sill materials.[16] Bird exclusion fence to avoid predation while plants develop.[16]
Habitat Components	Salt marsh; Tidal buffer landward of the salt marsh; Coastal beach; Mud flat.
Durability and Maintenance	Plants that are removed or die during the early stages of growth must be replaced immediately to ensure the undisturbed growth of the remaining plants. The removal of debris and selective pruning of trees is also a good maintenance practice to ensure that sunlight reaches plants. After significant growth has occurred only periodic inspections may be necessary. Protection measures, such as fencing, can keep water-fowl from eating the young plants. Toe protection materials should also be replaced or re-installed if they are moved by a storm.[6] Coir logs must be securely anchored to prevent wave and tidal current-induced movement.[11] Ongoing maintenance of invasive species and runoff issues will be important to the long-term success of the project.[10]
Design Life	It is important to recognize that design life may be shorter in the future given changes in sedimentation rates, accelerating sea-level rise and other climate change impacts.
Ecological Services Provided	Increases water infiltration, uptake of nutrients, filtration, denitrification and sediment retention.[2,3] The extensive root systems of marsh vegetation help to retain the existing soil, thus reducing erosion while plant stems attenuate wave energy.[11] Marshes provide habitat for many species of plants and animals, and maintain the aquatic/terrestrial interface.[2] Sill mitigates erosive waves and stabilizes shoreline.[10] Marine animals can access the marsh through gaps in the sill.[12] Marshes also provide better water quality, recreation and education opportunities, and carbon sequestration (blue carbon).[12]
Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)	Including roughened surfaces, such as logs, stones or emergent vegetation can break up ice sheets.[4,10] Fringing marsh projects will respond better to ice if designed with gentler slopes (6:1-10:1) and by incorporating shrubs.[9,13] Planting in the spring will allow vegetation to become established before it has to withstand ice.[8] Hardy, salt-tolerant shrubs are well-suited shorelines that are affected by ice.[13] Need to consider where in the tidal range oysters will be placed if they're used: too high may result in freezing.

Marsh Creation/Enhancement w/Toe Protection

A toe protection structure holds the toe of an existing, enhanced or created marsh platform in place, and provides additional protection against shoreline erosion. A gapped approach to the toe protection structure allows habitat connectivity, and greater tidal exchange. Toe protection is particularly important where there is higher wave activity or threat of boat wakes.

Marsh Enhancement w/Coir Toe, Chatham, MA
Photo courtesy of Wilkinson Ecological Design

Regulatory and Review Agencies

Maine	Municipal Shoreland Zoning, Municipal Floodplain, ME Dept. of Environmental Protection, ME Land Use Planning Commission, ME Coastal Program, ME Department of Marine Resources, ME Department of Inland Fisheries and Wildlife, ME Geological Survey, and ME Submerged Lands Program.
New Hampshire	Local Conservation Commission, NH Natural Heritage Bureau, NH Department of Environmental Services (Wetlands Bureau, Shoreland Program, and Coastal Program), and NH Fish & Game Department.
Massachusetts	Local Conservation Commission, MA Dept. of Environmental Protection (Waterways and Water Quality), MA Division of Fisheries and Wildlife (Natural Heritage and Endangered Species Program), MA Environmental Policy Act, and MA Office of Coastal Zone Management.
Rhode Island	Coastal Resources Management Program, and RI Dept. of Environmental Management.
Connecticut	Local Planning and Zoning Commission, and CT Department of Energy and Environmental Protection.
Federal (for all states)	U.S. Army Corps of Engineers, National Marine Fisheries Service, U.S. Environmental Protection Agency, and U.S. Fish and Wildlife Service.

Siting Characteristics and Design Considerations

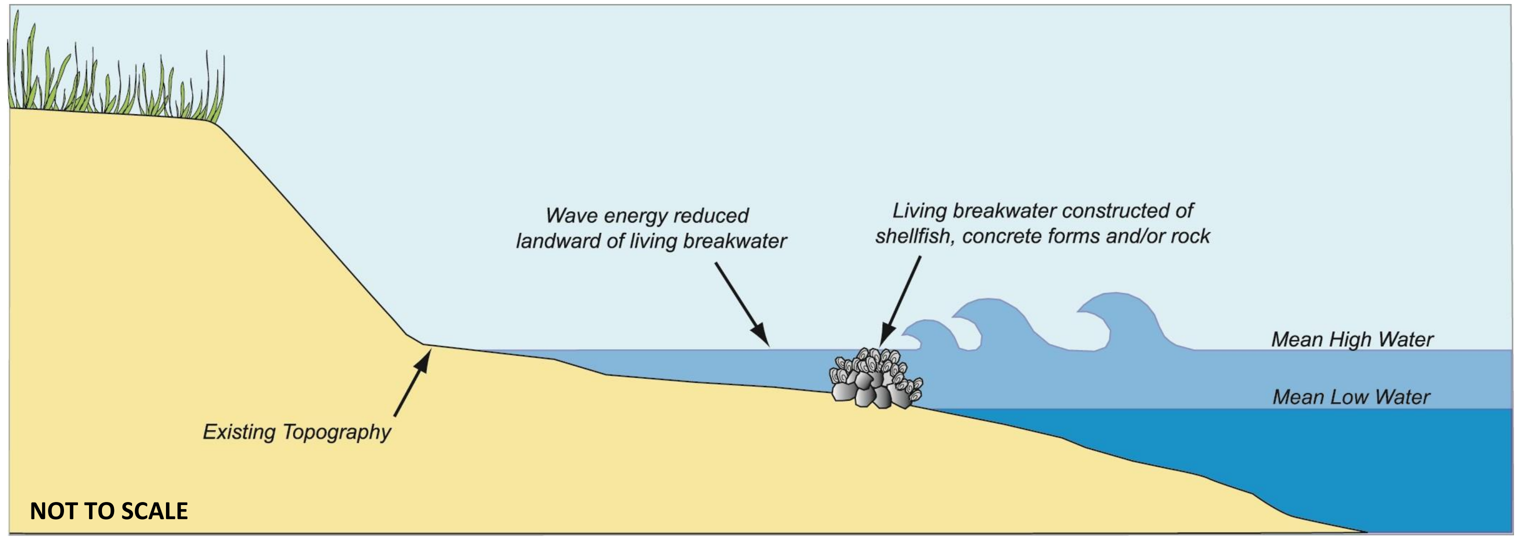
Selection Characteristics	Detail
ES Energy State	Moderate. A sill may be necessary in medium energy sites (2-5 foot waves, moderate currents and storm surge).[3,6]
EE Existing Environmental Resources	Coastal beach; mud flat; salt marsh
SR Nearby Sensitive Resources	Endangered and threatened species. If the project is proposed in or adjacent to habitat for protected wildlife species or horseshoe crab spawning areas, there may be limitations on the time of year for construction.[1] Shellfish beds and essential fish habitats will restrict where a marsh can be extended. Construction may produce short term habitat impacts, but in the long term, the marsh area should provide enhanced wildlife and fisheries habitat.
TR Tidal Range	Low to moderate. Sills are more suited to sites with a small to moderate tidal range, and are intended to be low-crested structures with a freeboard of between 0 and 1 ft above MHW.[7,11,16] However, shellfish sills should have a crest height at or near MLW since oysters and mussels can only remain out of the water for between 2 and 6 hours depending on the weather conditions.[7]
EL Elevation	MLW to MHW; Above MHW. For low marsh, the lowest grade should be MTL and extend up to MHW. High marsh plantings should extend between MHW and MHHW.[5] Tidal buffer should be planted above highest observable tide.
IS Intertidal Slope	Moderate. With slopes between 5:1 and 3:1 (base:height), sills should be added to the toe of the marsh.[3]
BS Bathymetric Slope	Flat to moderate
ER Erosion	Low to moderate
Other Characteristics	**Detail**
Boat Traffic	If boat wakes are expected to be the dominant force the sill should be designed accordingly.[7]
Ice Sensitivity	Gentle slopes and intermixed shrubs will handle ice the best.[8] Plant in the spring to allow plants to become established well before ice becomes a concern.[8]
Climate Vulnerability	If implemented carefully, this design can allow for inland migration. Planting higher, outside of the normal elevation range for the marsh grasses, may be useful in anticipation of sea level rise. It is important to recognize the uncertainty in future elevations. The effectiveness of a sill will be reduced over time as sea level rise gradually reduces the freeboard of the structure.[7]
Surrounding Land Use	Existing structures on site, like seawalls, may force living shoreline projects to have a steeper slope than desirable. Seawalls will limit the inland migration potential of the salt marsh in the future. Steeper slopes leave little opportunity for wave energy dissipation.[13] Marshes require sunlight to thrive; trees must be pruned or removed to allow for at least four to six hours of sunlight a day;[6,] this will increase vegetation growth.[11,15] Although it is possible to create a marsh on most shorelines, marsh creation is not recommended for sites where they are not a natural feature along comparable natural shorelines.[11]

Living Breakwater

Living breakwaters are constructed nearshore to break waves on the structure rather than on the shoreline to reduce erosion and promote accumulation of sand and gravel landward of the structure. They are typically larger than sills and constructed in deeper water in more energetic wave climates, and have the potential to enhance habitat.

Objectives: break waves, dissipates wave energy, erosion control, habitat creation

Design Schematics



Case Study

Stratford, CT Reef Balls

Beginning in 2010, the Stratford Point project has focused on restoring and managing 28 acres of coastal upland and 12 acres of intertidal habitat using an integrated whole ecosystem approach. The creation of a 1,000-foot living shoreline started with the construction of an artificial reef, using pre-cast reef balls, at mean tide elevation (~ 75 ft. offshore), in conjunction with restoration of low and high marshes and dune shoreward of the artificial reef. In addition, upland shrub, coastal forest and meadow mosaic is being restored to improve bird and pollinator habitat.

Reef Ball Breakwater, Stratford, CT
Photo courtesy of Jennifer Mattei

Project Proponents	Sacred Heart Uni.(Project Lead), Audubon Society (Site Manager); DuPont Company (Site Owner)
Status	In Progress (Reef construction: Complete; Marsh & Dune Restoration and Upland work: Continuing
Permitting Insights	DABA had concerns about 'wild' oysters settling on the reef and possibly harboring diseases that might affect the aquaculture industry of Long Island Sound. So far, this has not been a problem.
Construction Notes	A restoration team of land managers, restoration ecologists and environmental engineers is key for designing and deploying a living shoreline. The study of local bathymetry, storm wind and wave trajectory, sediment loads and causes of erosion are imperative for proper placement of artificial reefs used to protect newly restored saltmarshes.
Maintenance Issues	Previous attempts of dune restoration prior to artificial reef construction highlight the importance of comprehensive restoration planning, and construction sequencing.
Final Cost	To be determined
Challenges	Initial dune installation (2012) was eroded by storms before the artificial reef and saltmarsh were installed. Slight field modifications to reef ball placement due to natural rock outcroppings.

Design Overview

Materials	Living reef materials (oysters/mussels). Shellfish reefs can be constructed with bagged or loose shell to provide the same erosion control as rock sills but with additional ecosystem benefits.[11] Precast concrete forms or stone.
Habitat Components	Shellfish reef. Complex structure for fisheries habitat.
Durability and Maintenance	Concrete reefs or living resources (e.g. shell bags) will break down over time, while precast concrete forms and stone will last longer. The degradation of the shell bags over time is often a desired characteristic if they are being used to temporarily break waves while a system behind it is reestablishing or a natural living system is establishing itself on this substrate.
Design Life	Shell bags, concrete forms, and stone provide the foundation for living breakwaters; concrete forms and stone provide more time for natural recruitment of shellfish and marine algae.
Ecological Services Provided	Can become valuable substrate for marine organisms, as well as provide shelter and habitat for many fish, crab and other mobile species.[14] Can dampen wave energies and increase sediment retention.[10] Because shellfish are filter feeders, oyster/mussel reefs can improve water quality.[11] As the living breakwaters become colonized with marine species, they provide recreational benefits such as fishing and snorkeling.[11]
Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)	Reef Balls installed in Stratford, CT withstood significant icing during the 2014-2015 winter.[14] Need to consider where in the tidal range shellfish will be placed if they're used: too high in the intertidal area may result in freezing and loss of shellfish.

Reef Ball Breakwater, Stratford, CT
Photo courtesy of Jennifer Mattei

Living Breakwater

Although breakwaters are often considered coastal engineering structures, a gapped living breakwater allows habitat connectivity and greater tidal exchange and can be used in combination with other living shorelines practices to reduce the wave energy allowing the establishment of a beach or vegetated (typically marsh) shoreline in its lee.


Oyster bags for a living reef at Gandy's Beach NJ
Photo courtesy of Mary Conti, TNC NJ

Regulatory and Review Agencies

Maine	Municipal Shoreland Zoning, Municipal Floodplain, ME Dept. of Environmental Protection, ME Land Use Planning Commission, ME Coastal Program, ME Department of Marine Resources, ME Department of Inland Fisheries and Wildlife, ME Geological Survey, and ME Submerged Lands Program.
New Hampshire	Local Conservation Commission, NH Natural Heritage Bureau, NH Department of Environmental Services (Wetlands Bureau, Shoreland Program, and Coastal Program), and NH Fish & Game Department.
Massachusetts	Local Conservation Commission, MA Dept. of Environmental Protection (Waterways and Water Quality), MA Division of Fisheries and Wildlife (Natural Heritage and Endangered Species Program), MA Environmental Policy Act, and MA Office of Coastal Zone Management.
Rhode Island	Coastal Resources Management Program, and RI Dept. of Environmental Management.
Connecticut	Local Planning and Zoning Commission, and CT Department of Energy and Environmental Protection.
Federal (for all states)	U.S. Army Corps of Engineers, National Marine Fisheries Service, U.S. Environmental Protection Agency, and U.S. Fish and Wildlife Service.

Siting Characteristics and Design Considerations

Selection Characteristics	Detail
ES Energy State	Moderate to high. Suitable for most areas, except those in the highest wave energy environments.[2] Concrete forms are generally stable under most wave conditions due to the size and weight of the units, and have been shown to attenuate wave energy and reduce erosion in a low to moderate wave energy locations; one study found that Reef Balls could reduce wave heights by 60%.[7] Using additional rows of Reef Balls can decrease this even more.[7]
EE Existing Environmental Resources	Coastal beach; mud flat; subtidal
SR Nearby Sensitive Resources	Endangered and threatened species. If the project is proposed in or adjacent to habitat for protected wildlife species or horseshoe crab spawning areas, there may be limitations on the time of year for construction. Shellfish beds, submerged aquatic vegetation, and essential fish habitats will restrict where a living breakwater can be constructed.
TR Tidal Range	Low to middle. In areas with a large tidal range, these structures would have to be extremely large to continue to provide protection functions,[2] or could be sited closer to shore. Best suited for low to medium tidal range areas.
EL Elevation	MLW to MHW; subtidal. Located intertidally or subtidally, but typically designed with crest elevation at MHHW, therefore quickly overtopped during storms; not effective at dealing with storm surge events.[10]
IS Intertidal Slope	Flat to steep. The breakwater itself will not be impacted by the intertidal slope[7], but other project components, such as a marsh planted behind the breakwater, may have specific slope requirements.
BS Bathymetric Slope	Flat to steep. The bathymetric slope will influence the size and type of waves that impact the structure, and thus should be considered in the wave analysis. [7]
ER Erosion	High to low. Assuming wave energy is the primary driver of coastal erosion at the site, an appropriately sized and placed breakwater should be capable of mitigating the erosional problem under most conditions.[7]
Other Characteristics	**Detail**
Ice Sensitivity	Current guidance suggests sizing stone so that the median stone diameter is two to three times the maximum expected ice thickness.[7] In colder climates, oysters/mussels should be submerged (below MLW) to prevent them from freezing during the winter months.[7]
Climate Vulnerability	The effectiveness of a breakwater will be reduced over time as sea level rise gradually reduces the freeboard of the structure. Living reef breakwaters have some capacity to adapt to changing conditions, as long as sea level rise is relatively slow.[7]
Surrounding Land Use	Projects need to be planned alongside other competing water uses such as boating, fishing, shellfishing, and aquaculture. Consideration should be given to potential conflicts with existing navigable waters.

4.0 APPLICABILITY INDEX

The Team developed a framework for users to explore and learn about the different site characteristics important for selecting a LS design. Appropriately siting LS designs is essential to the success and longevity of a project. Variations in existing site-specific resources, topographies and tidal ranges can greatly impact project success. In fact, experts report that LS projects that fail, often fail because the design was not well matched to the site characteristics. Not all LS types are appropriate in all locations. Recognizing the challenge of properly siting LS designs, we developed a Living Shorelines Applicability Index.

This Excel-based tool provides a series of pull-down menus that can be used to define a particular site's characteristics (e.g. elevation, slope, existing resources, etc.). Based on the requirements of each LS type, the Applicability Index tool then scores and categorizes each living shoreline type as "Likely", "Possible" or "Unlikely" to be suitable for that location. The index is an informational tool and draws on professional opinions collected to set the scores for each LS type for each criterion. The final categorizations were based on professional judgement, as well as the maximum possible score. These designations are meant to be comparative, rather than absolute, and are designed to highlight particular sets of LS types that would likely be more suited to a particular site than others. As a result, the Applicability Index is provided as an informational planning level tool only and should not be used to make final project designs. However, it is designed to provide a useful foundation from which to begin to narrow the focus of the site assessment and project planning steps that will ultimately lead to implementation of a final design implemented by an experienced LS professional. More details about the Applicability Index are provided in Appendix A.

Link to Living Shorelines Applicability Index tool.

Living Shorelines Applicability Matrix	
Living Shoreline Type	Living Shoreline Type is Applicable to Site?
Dune - Natural	Unlikely
Dune - Engineered Core	Unlikely
Beach Nourishment	Likely
Coastal Bank - Natural	Likely
Coastal Bank - Engineered Core	Possible
Natural Marsh Creation/Enhancement	Likely
Marsh Creation/Enhancement w/Toe Protection	Likely
Living Breakwater	Possible

Figure 1. Example results from the Living Shorelines Applicability Matrix.

5.0 SUMMARY

The profile pages add to the resources available to those charged with regulating, designing, implementing and monitoring LS in New England. More importantly, they are also an important communication tool for reaching those considering a LS solution for a specific coastal challenge. The profiles provide important details about the different designs, but ultimately those working with LS will need to develop site-specific design plans. The authors expect that the profiles will continue to be updated as new information becomes available.

6.0 ACKNOWLEDGEMENTS

The Team would like to acknowledge the contributions of a large group to the content of this report. Contributors included workshop participants, experts interviewed for this work and those who prepared reports and compilations that served as key resources for this project. Those interviewed included experts from:

NOAA Restoration Center Narragansett, RI	Chesapeake & Coastal Service Maryland Department of Natural Resources
New England District Corps of Engineers, Department of the Army	University of Connecticut and Connecticut Sea Grant
DEP Southern Maine Regional Office	Coastal Resources/Land And Water Resources CT DEEP
New England Environmental A Division of SWCA Environmental Consultants	New Hampshire Coastal Program Pease Field Office Portsmouth, NH
Save The Bay	Massachusetts Office of Coastal Zone Management
Maine Geological Survey Bureau of Resource Information and Land Use Planning Dept of Agri., Cons. and Forestry	RI Coastal Resources Management Council
Applied Coastal Research and Engineering	Massachusetts Division of Marine Fisheries

A smaller subset of Team members participated in multiple workshops, conference calls and review rounds, including two workshops focused on reviewing every part of each profile page. They include:

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Chris Boelke, National Oceanic and Atmospheric Administration

Bruce Carlisle, Massachusetts Office of Coastal Zone Management

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Steve Kirk, The Nature Conservancy

Julia Knisel, Massachusetts Office of Coastal Zone Management

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Ru Morrison, Northeastern Regional Association of Coastal Ocean Observing Systems

Peter Slovinsky, Maine Geological Survey

John Torgan, The Nature Conservancy

Ted Wickwire, Woods Hole Group

Jeff Willis, Rhode Island Coastal Resources Management Council

We are grateful for the support of the talented contributors to this project and NROC, NERACOOS and NOAA.

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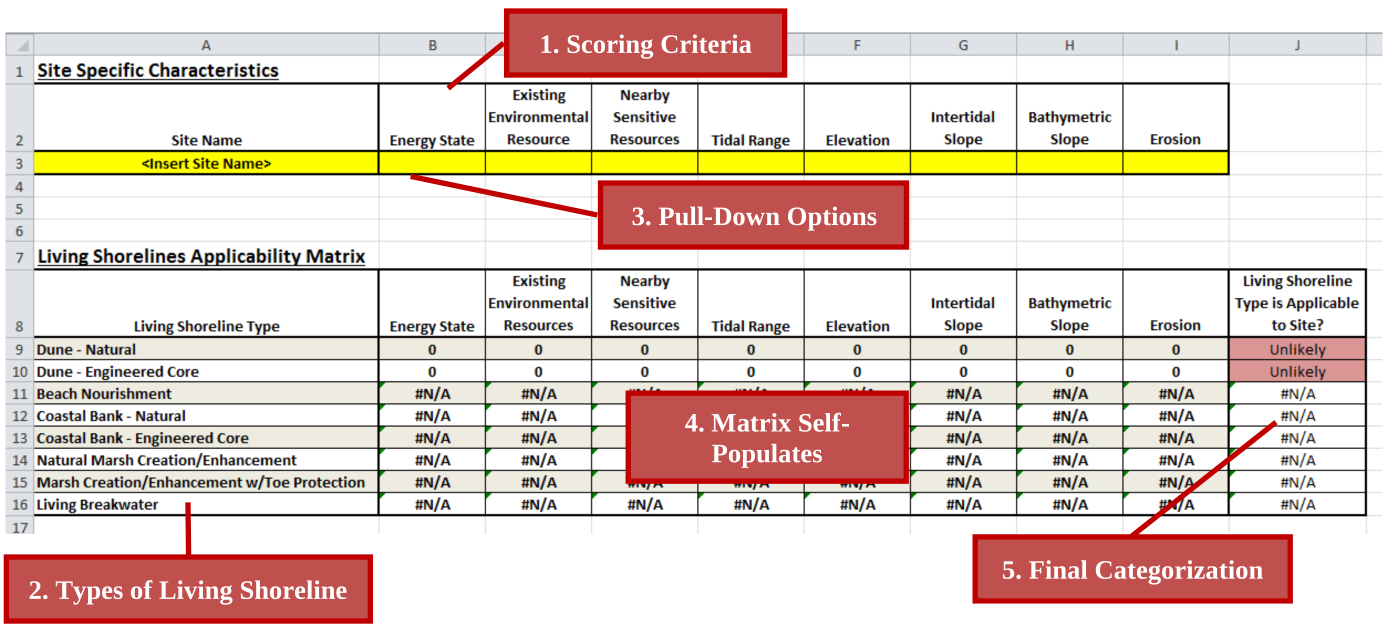
APPENDIX A: APPLICABILITY INDEX SUPPORTING MATERIAL

The Living Shorelines Applicability Index was designed using an Excel spreadsheet. This method has multiple benefits. First, it is a program that many users are generally familiar with, so very little additional training or instruction is necessary to operate it. Second, cells within the Excel sheet can be locked or unlocked. By locking the cells that contain equations and connections to other data, and leaving only pull down selection options for the user to change, there is very little risk of users unintentionally altering any of the criteria weightings or spreadsheet connections. On the other hand, because these cells can be unlocked, it allows more advanced users to edit criteria scores, add additional living shoreline types, or add additional selection criteria categories.

Figure A-1 below shows the blank, unscored Living Shoreline Applicability Index. There are eight scoring criteria listed in row 4 (1) (e.g. Energy State, Existing Resources, Nearby Sensitive Resources, etc.) and eight different types of LS under consideration are listed in column A (2). For each LS type, as a selection is made for all eight of the scoring criteria in row 4 using pull-down menu options in each cell of row 5 (3), the main matrix will automatically populate with a score (4), and the overall ranking for each LS type will be computed based on the user's entered scoring criteria (5).



	A	B	C	D	E	F	G	H	I	J
1	Site Specific Characteristics									
2	Site Name	Energy State	Existing Environmental Resource	Nearby Sensitive Resources	Tidal Range	Elevation	Intertidal Slope	Bathymetric Slope	Erosion	
3	<Insert Site Name>									
4										
5										
6										
7	Living Shorelines Applicability Matrix									
8	Living Shoreline Type	Energy State	Existing Environmental Resources	Nearby Sensitive Resources	Tidal Range	Elevation	Intertidal Slope	Bathymetric Slope	Erosion	Living Shoreline Type is Applicable to Site?
9	Dune - Natural	0	0	0	0	0	0	0	0	Unlikely
10	Dune - Engineered Core	0	0	0	0	0	0	0	0	Unlikely
11	Beach Nourishment	#N/A	#N/A	[illegible]	[illegible]	[illegible]	#N/A	#N/A	#N/A	#N/A
12	Coastal Bank - Natural	#N/A	#N/A	[illegible]	[illegible]	[illegible]	#N/A	#N/A	#N/A	#N/A
13	Coastal Bank - Engineered Core	#N/A	#N/A	[illegible]	[illegible]	[illegible]	#N/A	#N/A	#N/A	#N/A
14	Natural Marsh Creation/Enhancement	#N/A	#N/A	[illegible]	[illegible]	[illegible]	#N/A	#N/A	#N/A	#N/A
15	Marsh Creation/Enhancement w/Toe Protection	#N/A	#N/A	[illegible]	[illegible]	[illegible]	#N/A	#N/A	#N/A	#N/A
16	Living Breakwater	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
17										

Figure A-1. Living Shoreline Applicability Index layout.

Scores for each of the potential answers for each of the eight (8) selection criteria were developed by consensus with the Team. The numerical scores for each potential answer range from 1 to 5, with 1 indicating a poor fit between that site-specific condition and that LS type, and 5 indicating a good fit between the LS type and the site conditions. The scoring reference sheet is provided in the "Scoring" tab of the Excel workbook.

To utilize the Living Shoreline Applicability Index users need only to select one choice from each of the eight (8) drop down menus (yellow cells) below the selection criteria.

Table A-1 below lists all the available options for each of the selection criteria, and Table A-2 defines each choice to give users a better understanding of what each option means. Based on the individual scores for each site characteristic, a total score will be computed for each LS type, and each LS type will be categorized as "Likely", "Possible", or "Unlikely" in terms of its suitability for that project location. This tool is meant only as an information planning level tool to start the discussion about what LS design types might be appropriate for a site, and no final decisions should be made based on this tool.

Table A-1. Living Shoreline Applicability Index scoring categories.

Energy State	Existing Resources	Nearby Sensitive Resources	Tidal Range	Elevation	Intertidal Slope	Bathymetric Slope	Erosion
High; Moderate; and Low;	Coastal Bank; Coastal Dune; Coastal Beach; Salt Marsh; Mudflat; Subtidal; and Vegetated Upland	Endangered/ Threatened Species; SAV; Shellfish; Cobble/Rocky Bottom; and None	Low; Moderate; and High	>MHW; MHW – MLW; and <MLW	Steep; Moderate; and Flat	Steep; Moderate; and Flat	High; Moderate; and Low

Table A-2. Definitions for scoring categories for Living Shoreline Applicability Index.

Energy State	
High	project site has waves > 5 feet, strong currents, high storm surge
Moderate	project site has 2 - 5 foot waves, moderate currents, moderate storm surge
Low	project site has waves < 2 feet in height, low current, low storm surge
Existing Resources	
Coastal Bank	project will occur where there is an existing coastal bank
Coastal Dune	project will occur where there is an existing coastal dune
Coastal Beach	project will occur where there is an existing coastal beach
Salt Marsh	project will occur where there is an existing salt marsh
Mudflat	project will occur where there is an existing mudflat
Subtidal	project will occur in an existing subtidal area
Vegetated Upland	project will occur where there is an existing vegetated upland area
Nearby Sensitive Resources	
Endangered/Threatened Sp.	project site is near or in habitat of endangered or sensitive resources
SAV	project site is near or in an area that contains submerged aquatic vegetation (SAV)
Shellfish	project site is near or in an area that has significant shellfish populations
Cobble/Rocky Bottom	project site is near or in an area with cobble or rocky substrate
Tidal Range	
Low	tide range at project site is less than 3 feet
Medium	tide range at project site is between 3 and 9 feet
High	tide range at project site is more than 9 feet
Elevation	
>MHW	location where project is to be built is above MHW
MHW - MLW	location where project is to be built is between MHW and MLW
<MLW	location where project is to be built is below MLW
Intertidal Slope	
Steep	slopes 3:1 (base:height) and steeper
Moderate	slopes between 3:1 and 5:1 (base:height)
Flat	slopes 5:1 (base:height) and flatter
Nearshore Bathymetry Slope	
Steep	slopes 3:1 (base:height) and steeper
Moderate	slopes between 3:1 and 5:1 (base:height)
Flat	slopes 5:1 (base:height) and flatter
Erosion	
High	erosion at project site is high (>3 feet/year)
Moderate	erosion at project site is moderate (1-3 feet/year)
Low	erosion at project site is low (<1 foot/year)

APPENDIX B: EXPERT INTERVIEW RESPONSE SUMMARIES

1. <u>What is your opinion regarding the state of living shorelines in the Eastern U.S? In New England (and other colder weather climates)? Trends</u>?

Figure B-1. Response word cloud for Question #1: What is your opinion regarding the state of living shorelines in the Eastern U.S? In New England (and other colder weather climates)?

1a. <u>Do you think they're being implemented</u>?

- There is general agreement that living shorelines (LS) are being designed and implemented in New England although the approaches are still early in development compared to LS projects in the Mid-Atlantic. However, there are not many examples that have been in place long enough to identify trends and monitoring is limited.
- LS have been used in mid-Atlantic for 40 years. They are clearly gaining traction and higher visibility in New England in recent years.
- The topic of LS is raised in meetings more frequently, but the discussions do not necessarily translate into projects.
- Those working in the field disagree about the following terminology: LS vs green infrastructure and design names and classifications. For example, dune construction and restoration has been done for years, but there is disagreement about whether dunes are a LS.
- There are non-experts that are not using engineering principles and peer reviewed approaches claiming to be implementing LS.

- Permitting is driving the use of LS in some areas because hard structures are not allowed unless they are in danger of failure (CT).
- Examples of approaches that are implemented in New England include: dune restoration, sacrificial dunes, beach nourishment, coastal bank protection with vegetation, natural fiber blankets and coir rolls, and marsh creation/restoration (primarily without protection).

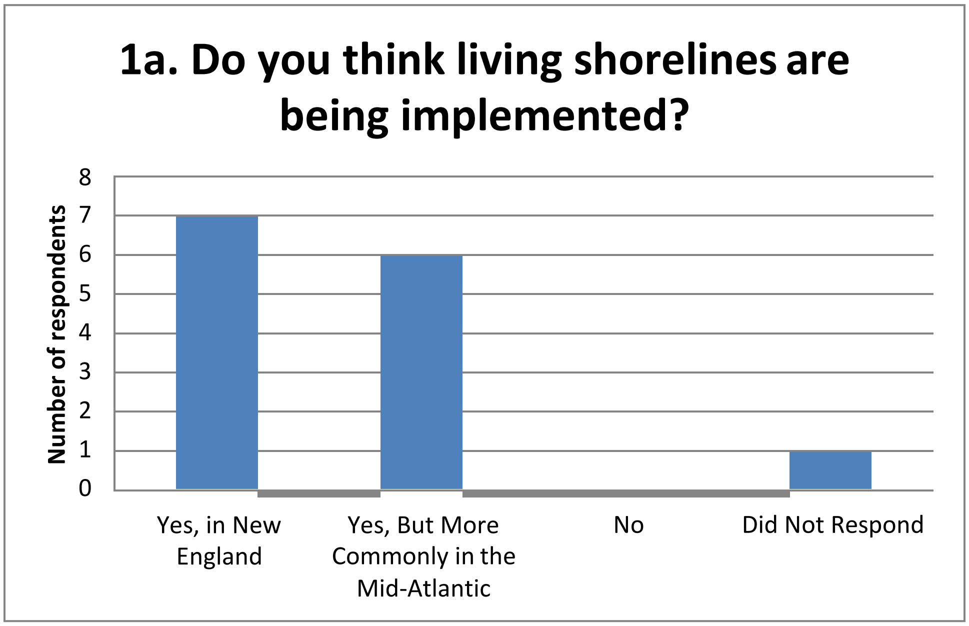


Figure B-2. Responses to Question #1a.

1b. <u>Do you think LS should be implemented more frequently</u>?

- Yes. There is general consensus that LS should be applied more frequently. There is some hesitation by homeowners because there is not enough long-term monitoring to show how well LS work in New England.
- There is agreement that there needs to be more thought put into the siting process and fitting an approach to site characteristics.
- LS are an important alternative to gray infrastructure because they not only provide protection but also add habitat services.
- There is an opportunity to implement LS more frequently, but science, guidelines, training, incentives, and general knowledge about the approaches are all lacking.

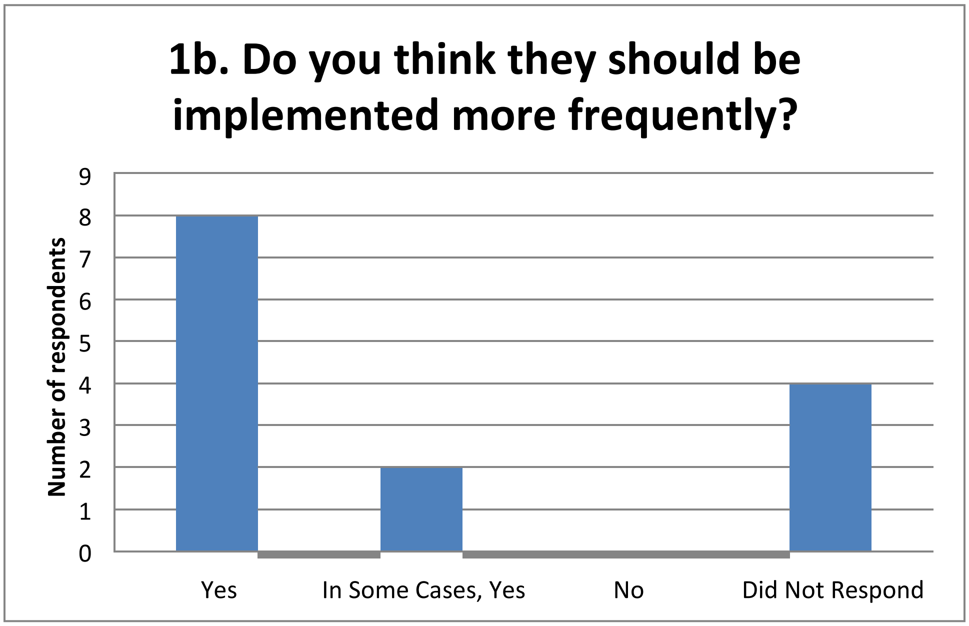


Figure B-3. Responses to Question #1b.

1c. <u>Do you think the LS that have been implemented are working? What needs to change</u>?

- This is largely an open question in New England because of a combination of few long-term examples and lack of monitoring of those examples.
- In some specific cases, e.g. reef balls in CT and dune restoration in MA, they have worked quite well.
- There is a lack of consensus about appropriate monitoring metrics (and a lack of money to fund the monitoring for appropriate time periods).
- There is a clear need to reach consensus on site assessment criteria because not all sites can be restored or made more resilient using LS designs and only certain designs will fit with specific site characteristics. The LS projects that do not work tend to have not been sited appropriately.
- There is a need to compile best practices based on experience as more LS designs are implemented.
- There is a need for practitioner training opportunities.
- To increase acceptance and use, the regulatory process needs to be more predictable and transparent.
- Care should be taken to avoid overselling the approach.
- Routine maintenance should be required on LS projects.

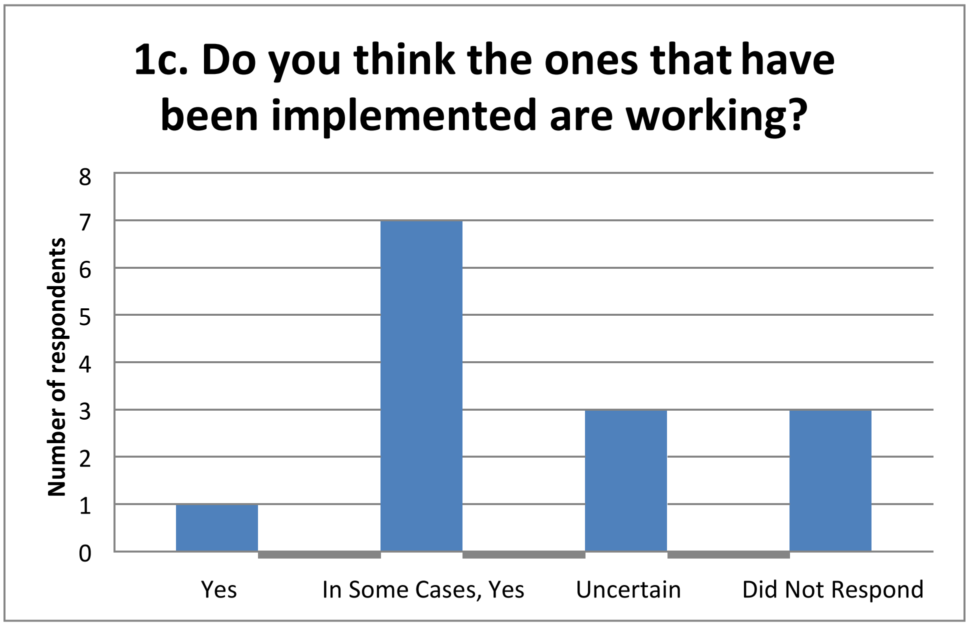


Figure B-4. Responses to Question #1c.

1d. For Practitioners – have you seen an uptick in interest and application of living shoreline project types?

- There is definitely interest, but also some concerns. The LS project process from gathering data to design through permitting is uncertain and can take much longer than implementing the more predictable and tested gray designs.
- There is a sense that regulators are driving the push into LS, and the paying public is most interested in the 'tried and true' approach.

2. What are the benefits of using a living shoreline approach compared to a gray design to shoreline protection?
   - The ecological services provided by LS exceed those of gray designs and include not only protection, but habitat creation, restoration/improvement, extension, stabilization and aesthetic improvements. If completed correctly, the ecological processes continue naturally, i.e. there is no significant interruption and the ecology of the system is more resilient.
   - LS have fewer impacts on neighbors.
   - Costs can be lower than gray designs in some cases.
   - LS can be easier to permit than gray designs in some cases.
   - If well designed, they are self-sustaining/maintaining.
   - Living shorelines can provide better erosion protection and in some cases flood/storm protection/surge mitigation (less costly up front, less costly to maintain/repair, with fewer secondary erosive/flood impacts to neighboring properties), higher quality habitat for fish, birds and other species, more carbon sequestration and storage, better water pollution (nitrogen and

sediment) filtration/uptake/capture, higher aesthetic benefits, and greater adaptive capacity to long-term sea-level rise (Howard, 2016).

- LS can preserve and enhance intertidal habitat.

Figure B-5. Response word cloud for Question #2: What are the benefits of using a living shoreline approach compared to a gray design to shoreline protection?

3. <u>What are the challenges or drawbacks of using a living shoreline approach compared to a gray design to shoreline protection? Obstacles</u>?
    - There is a lack of site suitability metrics, a lack of performance metrics and a limited track record in New England because they are so new. Unlike gray designs, LS are much less of a one-size fits all and the performance criteria can be confusing given the many different services a LS can provide.
    - Challenging coastal issues often lead to a gray design default rather than exploring LS options. For example, ice rafting and large tidal ranges. In some cases, given site conditions, LS will not work.
    - LS have not been in place long enough to assess how well they hold up. In contrast to some gray designs, LS require regular maintenance.
    - Regulatory landscape can be confusing.
    - The site and design assessments, data collection and permitting are time intensive and the unpredictability of the process can reduce attractiveness of LS options.

- Even if the LS design is the same, different sites require different site assessments, i.e. there is some efficiency in repeated applications, but every site requires a certain level of data collection and analysis.
- There is a misperception that only gray designs really work. This is reinforced if LS designs are not properly designed/sited and developed. Because they are new and there are limited best practice compilations, poorly sited projects do occur and can mislead the public about the potential for LS.
- Cost can be prohibitive for LS in some states/locations.
- In some cases, a LS design may require consideration of land for retreat over time – landowners can be reluctant to give up more of their property.
- Impact of some designs on surrounding natural systems – e.g. Agriculture Department expressing concerns about shellfish reefs because of the potential spread of disease. Even if there would be an overall net benefit, if there are existing natural resources (e.g. wetlands) at a site, permitting can be difficult.
- There are limited training opportunities for practitioners including overview of construction techniques, designs, site characterization, permits and costs. Documentation of actual case studies is also essential.

4. <u>Have you developed or observed living shoreline designs that are particularly well-suited to the challenges of the New England climate, e.g. snow, ice, winter storms? (specific sites/examples?)</u>
   - There haven't been enough examples applied for a long enough time period to reach final conclusions.
   - There has been some success with marsh restorations, and dune restoration with revegetation. Also natural slope protection with coir materials and/or vegetation is a widely used LS design in New England.
   - LS designs must be well matched to conditions at each site.

   4a. <u>In your opinion, what are the Best Practices in cold climates</u>?
   - Some LS experts take specific steps, but many argue that as long as a design fits a site well (i.e. based on key site characteristics such as matching the site geology) unique steps do not need to be taken to protect against ice or cold weather. Nature will tell you what works the best.
   - Appropriate project preparation and installation timing can protect against cold climate issues. For example, installing vegetation in the spring so it will have time to establish before the winter. Some practitioners will pre-establish vegetation over the winter and plant early in the spring.
   - Sills have been used to deal with the elevated tidal range, but there is limited data regarding the most effective protective sill elevation. There is a need to balance biological needs with protection against damage.
   - The use of gradual slopes can protect against ice damage.
   - Reef balls have been constructed with special concrete to withstand ice.
   - Rock structures can be used to break wave energy. The most effective structures include stones contacting other stones at three points to minimize

freeze-thaw issues. Using a range of grain sizes in placed material can also build resiliency.

- Designs that incorporate trapezoidal shapes are the most stable.
- Modify designs based on position in tidal zone, for example, if using reef balls and they are too high in the intertidal they may freeze.

4b. Do you specifically design around ice?

- See above.
- Ice is not a factor for all LS designs (e.g. beach and dune nourishment or coir and vegetated banks which are above high tide line).

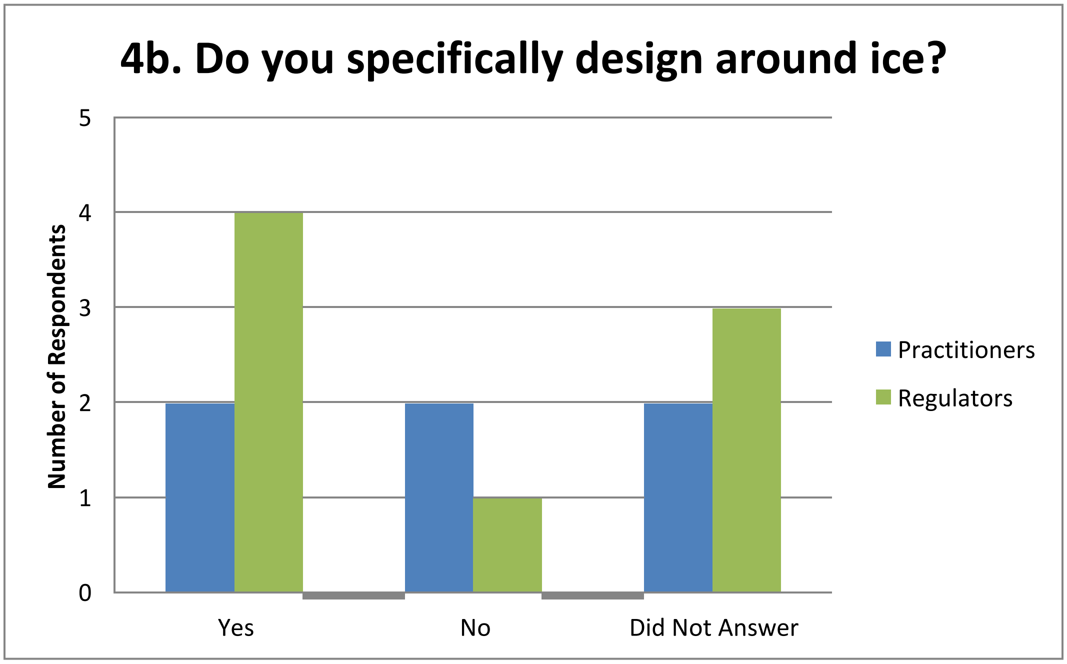


Figure B-6. Responses to Question #4a.

4c. What are your favorite LS designs in this area? Best materials? What do you avoid in your designs?

- Some experts mentioned dune and beach nourishment, coir and vegetative stabilization of banks, and salt marsh restoration/creation. Hybrid designs, such as a protected toe or sill with a wetland, work well.
- Designers should avoid synthetic fabrics in designs because they can restrict root growth.

4d. What are the property owners favorite living shoreline design types?

- They prefer the aesthetics of a natural shoreline, but if erosion and storm threats are elevated, they prefer gray designs because of track record.

4e. Are there specific techniques or design elements that help to increase the resiliency of a design in New England's climate?

- Engineered sill
- Reef balls with cement
- Managing runoff can help stabilize LS designs.

5. In your work on Living Shorelines, how have habitat/environmental services (e.g. habitat, carbon sequestration, runoff controls, water quality, sedimentation/ erosion control) been accounted for in these designs (compared to gray designs)? How do we prove what services are present and quantify them? What are the primary environmental services you consider or promote when recommending a living shoreline adaptation? How do these habitat benefits vary across living shoreline types?
    - One of the most frequently mentioned ecological services is the protection or expansion of Essential Fish Habitat (EFH) through the use of LS designs. The presence of bait fish can help to confirm the quality of the new habitat.
    - Interviewees did not list specific ecological services by LS design type.
    - It is difficult to compare multiple LS design types because they are site specific and there are so many different components for any given design.
    - Ecosystem services are often viewed in terms of what could be lost in a LS conversion rather than the potential positive gain of ecosystem services.
    - Dissipation of energy is an important function of LS.
    - A before and after comparison can be a valuable approach, considering the tradeoffs of the status quo versus LS implementation. Characterizing and understanding baseline conditions is necessary to properly evaluate trade-offs.
    - A net benefit analysis can be conducted. Rather than examining tradeoffs, respondents suggested that LS designers should focus on characterizing what is present at the start of a project, adjust a LS design to incorporate what is already present, and at the end of the project evaluate the net gain in habitat through a comparison to the baseline.
    - A challenge arises when a LS design will lead to a natural system that differs from what is already there, e.g. a shift from a subtidal area to a marsh wetland. In general, however, a design that fits in with what is or was already there will last longer.
    - Sediment distribution is an important habitat consideration. There is a need for a greater focus on quantifying negative impacts to local sediment budgets from gray designs and identifying the influence of LS on sediment movement.

5a. How do you assess or monitor the effectiveness of your designs? Are there specific metrics?

- In most cases, a well-sited and designed LS will have a positive influence on habitat.

- The primary focus should be on whether the implementation of a LS has met the project goals. In most cases the goal is to reduce coastal erosion. This can be assessed through comparative, multi-time period monitoring.
- Other measures might include: changes in marsh area over time, changes in species diversity, comparison to the same LS at other locations; percent of beach fill remaining; # of viable plants after a certain period.
- Periodic observations to determine if new erosion is occurring or if a wetland behind a sill is washing out can help limit long-term failures. In some cases, monitoring can be required by a property owner. Photo tracking can also be a useful approach to evaluate change over time.
- The appropriate monitoring period is not well defined. There is no standard. Generally, a minimum monitoring time is 5 years.

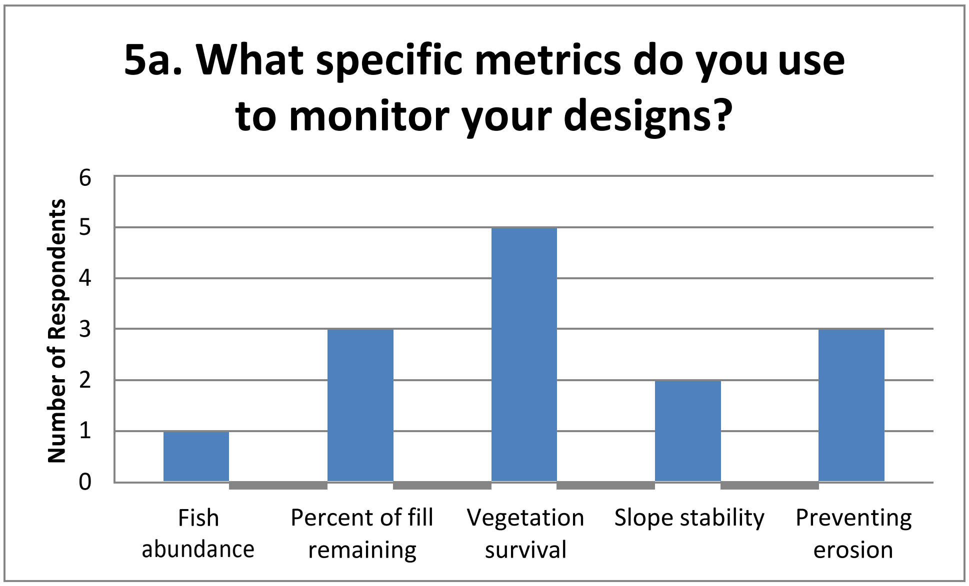


Figure B-7. Responses to Question #5a.

6. <u>Are there compilations of Living Shoreline designs that you use and/or developed</u>?
    - References are included in Report References.

7. <u>Do you know of any case studies that we could use to illustrate how well these designs perform? Or the challenges associated with them? And the costs? We need to identify the actual practitioners to gather project details</u>.
    - Case studies are included in the Profile Pages.

8. <u>What is your sense of living shorelines in terms of the regulatory community – whether in that community or part of a regulated group? Do the regulations in your</u>

state (or those in other New England states for which you have knowledge) encourage use of living shoreline approaches, restrict their use or influence in some way which designs can be used and at which sites? Can you provide examples of incentives for use? Is there a sense that living shorelines are accepted and/or promoted and if so why? What are the specific regulatory requirements (opportunities and challenges) for living shorelines (as a group) and for specific design types in your state or federal jurisdiction?

- NOTE: Specific regulatory considerations are discussed on the profile pages and a report that summarizes the regulatory landscape in New England in detail is available (Willis et al. In Press).
- Regulations vary among the New England states. State regulations are evolving and each state is at a different step in the development process. LS are required to be considered in some states, but are more difficult to permit in others. Some states are just starting to develop regulatory specifically concerning LS. Depending on the project location, practitioners must deal with local, state and/or Federal regulators.
- There is a lack of consistency between agencies, among and within states and even from one community to the next. The review process and permit applications are not always predictable. There is a need to streamline the process, increase transparency and provide an efficient method to assess sites.
- In many cases regulators are driving LS designs by tightening restrictions on gray designs, but there are not always clear incentives for choosing a LS design.
- Regulatory concerns include: does the net benefit of the project outweigh the impact of development; and is fish habitat lost, expanded or threatened by the project?
- Engineers, homeowners, municipal leaders all want to shift to LS.
- There is a definite shift in favor of LS. Historically in Maine, for example, under 'Permit-by-Rule,' placing rip rap fell under an abbreviated permit process. Now the permitting process is more holistic and requires consideration of natural resources.
- Endangered species habitat can restrict the use of LS (and gray designs). Conversions from one system to a new LS design are often discouraged by marine fisheries regulators.
- A regulatory challenge is the limited number of regulators familiar enough with LS to review, manage and permit. Many regulators have not seen the designs and need to be trained.

9. Is climate change/sea level rise considered in your work with living shoreline designs? If so, in what ways – e.g. design life, maintenance activities?
    - Responses varied from not at all, the focus is on current conditions to climate is considered in the site characterization and design processes.

- Considerations of the sustainability of a project, storm frequency and vulnerability of LS designs are increasingly required in solicitations, but not specifically required by regulations.
- There is a general expectation (emphasized by regulators) that climate impacts should be considered in the design and siting process. LS designs are more flexible in terms of migration compared to gray designs.
- On the ground, there are not many examples of direct design actions to accommodate changing sea levels and storm inundations. One example includes LS designs with a migration corridor included to accommodate shifting of the LS elements as sea levels rise.
- LS designs should consider potential impacts from changes in salinity with sea level rise changes.
- Designs should consider storms and to the extent storm predictions incorporate climate factors, the designs will account for climate impacts.
- Some designs are avoided because naturally occurring versions are stressed and degraded due to current sea level rise, e.g. marsh creation.

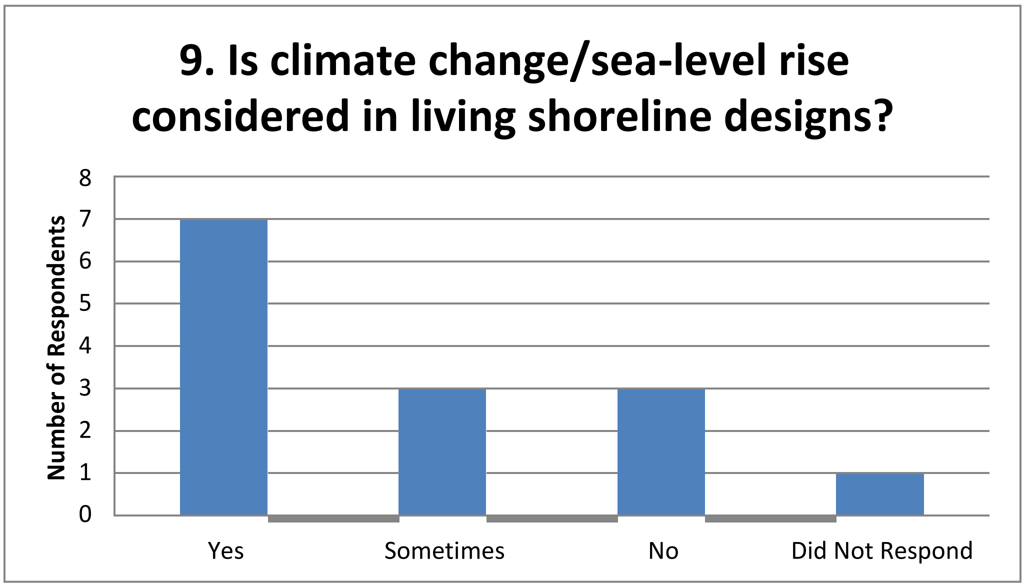


Figure B-8. Responses to Question #9.

Figure B-9. Response word cloud for Question #9: Is climate change/sea level rise considered in your work with living shoreline designs? If so, in what ways – e.g. design life, maintenance activities?

10. <u>What methods have been most successful for educating diverse audiences (contractors, regulators, engineers, public, homeowners, etc.) about living shorelines</u>?
    - Workshops have been held that bring together regulators, coastal engineers, academics and practitioners together and include discussions of actual case studies.
    - Outreach and education in Connecticut includes workshops with the University of Connecticut. These cover detailed examples and design standards, participation in developing a design for a model site, and a panel of regulatory experts from the State and Army Corps discussing LS issues.
    - Fact sheets have been and are being developed by many groups (e.g. MA CZM Storm Smart, University of CT).

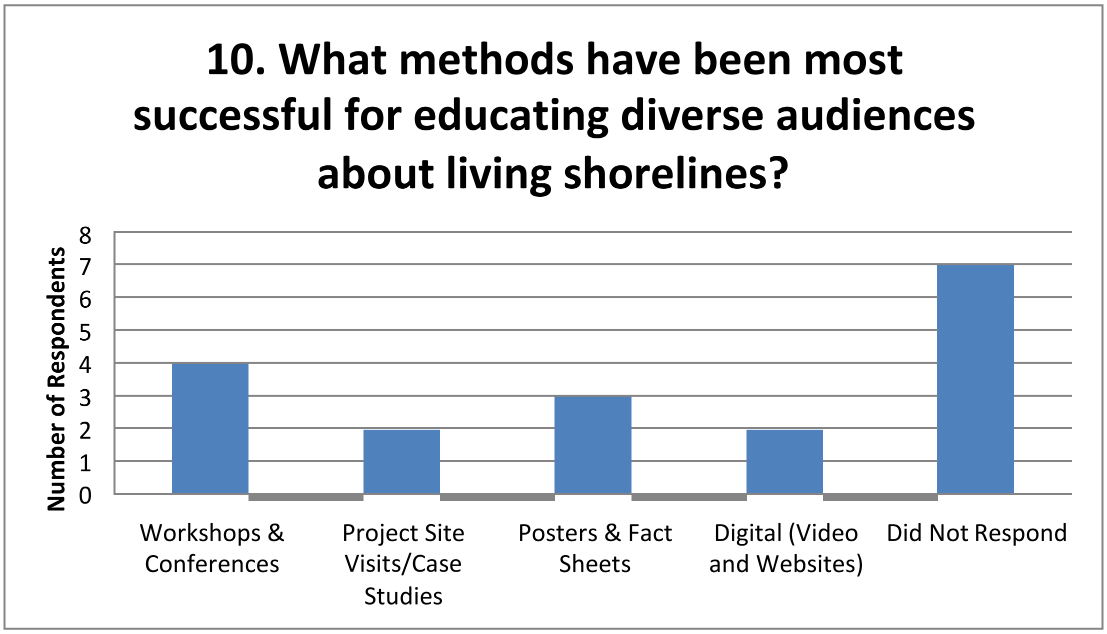


Figure B-10. Responses to Question #10.