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.

### 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, 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.

---

### Acronyms and Definitions

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CY</td>
<td>Cubic yards; one cubic yard equal 27 cubic feet. Project materials are often measured in cubic yards.</td>
</tr>
<tr>
<td>MHW</td>
<td>Mean High Water: The average of all the high water (i.e. high tide) heights observed over a period of time.</td>
</tr>
<tr>
<td>MTL</td>
<td>Mean Tide Level: The average of mean high water and mean low water.</td>
</tr>
<tr>
<td>MLW</td>
<td>Mean Low Water: The average of all the low water (i.e. low tide) heights observed over a period of time.</td>
</tr>
<tr>
<td>SAV</td>
<td>Submerged aquatic vegetation, which includes seagrasses such as eelgrass (Zostera marina) and widgeon grass (Ruppia maritima).</td>
</tr>
<tr>
<td>Sediment</td>
<td>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.</td>
</tr>
</tbody>
</table>
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.

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 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

<table>
<thead>
<tr>
<th>Selection Characteristics</th>
<th>Definitions and Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES</td>
<td>Energy State</td>
</tr>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>EE</td>
<td>Existing Environmental Resources</td>
</tr>
<tr>
<td></td>
<td>Coastal Bank</td>
</tr>
<tr>
<td></td>
<td>Coastal Dune</td>
</tr>
<tr>
<td></td>
<td>Coastal Beach</td>
</tr>
<tr>
<td>SR</td>
<td>Nearby Sensitive Resources</td>
</tr>
<tr>
<td></td>
<td>Endangered/Threatened Species</td>
</tr>
<tr>
<td></td>
<td>Shellfish</td>
</tr>
<tr>
<td>TR</td>
<td>Tidal Range</td>
</tr>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>EL</td>
<td>Elevation</td>
</tr>
<tr>
<td></td>
<td>Above MHW</td>
</tr>
<tr>
<td></td>
<td>MHW to MLW</td>
</tr>
<tr>
<td></td>
<td>Below MLW</td>
</tr>
<tr>
<td>IS</td>
<td>Intertidal Slope</td>
</tr>
<tr>
<td></td>
<td>Steep</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Flat</td>
</tr>
<tr>
<td>BS</td>
<td>Bathymetric Slope</td>
</tr>
<tr>
<td></td>
<td>Steep</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Flat</td>
</tr>
<tr>
<td>ER</td>
<td>Erosion</td>
</tr>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Low</td>
</tr>
</tbody>
</table>
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. 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.

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.

Project Information

<table>
<thead>
<tr>
<th>Project Proponent</th>
<th>Ferry Beach Park Association (FBPA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>Completed 2009</td>
</tr>
<tr>
<td>Permitting Insights</td>
<td>Permit-by-Rule needed from Maine DEP</td>
</tr>
<tr>
<td>Construction Notes</td>
<td>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 (&gt;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.</td>
</tr>
<tr>
<td>Maintenance Issues</td>
<td>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.</td>
</tr>
<tr>
<td>Final Cost</td>
<td>$25,000 and volunteer hours</td>
</tr>
<tr>
<td>Challenges</td>
<td>Trucking 90 dump-truck loads of sediment through the community. Construction and planting timing windows associated with piping plover nesting. Continued erosion.</td>
</tr>
</tbody>
</table>

Overview of Technique

Materials
Sediment is brought in from an offsite source, such as a sand and gravel pit or coastal dredging project. Planting the dune with native, salt-tolerant, erosion-control vegetation (e.g., beach grass Ammophila breviligulata) with extensive root systems is highly recommended to help hold the sediments in place. Sand fencing can also be installed to trap windblown sand to help maintain and build the volume of a dune.

Habitat Components
Dunes planted with native beach grass can provide significant wildlife habitat.

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. To maintain an effective dune, sediment may need to be added regularly to keep dune’s height, width, and volume at appropriate levels. The seaward slope of the dune should typically be less steep than 3:1 (base:height). Dunes with vegetation perform more efficiently, ensuring stability, greater energy dissipation, and resistance to erosion. If plantings were included, plants should be replaced if they are removed by storm or die.

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. 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. Dunes dissipate rather than reflect wave energy, as is the case with hard structures. Dunes also act as a barrier to storm surges and flooding, protecting landward coastal resources and reducing overwash events. Sand dunes provide a unique wildlife habitat.

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 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.

**Siting Characteristics and Design Considerations**

<table>
<thead>
<tr>
<th>Selection Characteristics</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ES</strong> Energy State</td>
<td>Low to high</td>
</tr>
<tr>
<td><strong>EE</strong> Existing Environmental Resources</td>
<td>Coastal beach; coastal dune; coastal bank</td>
</tr>
<tr>
<td><strong>SR</strong> Nearby Sensitive Resources</td>
<td>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 smothers 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)</td>
</tr>
<tr>
<td><strong>TR</strong> Tidal Range</td>
<td>Low to high</td>
</tr>
<tr>
<td><strong>EL</strong> Elevation</td>
<td>Above MHW. Dune projects require a dry high tide beach to be successful.</td>
</tr>
<tr>
<td><strong>JS</strong> Intertidal Slope</td>
<td>Flat to steep</td>
</tr>
<tr>
<td><strong>BS</strong> Bathymetric Slope</td>
<td>Flat to steep</td>
</tr>
<tr>
<td><strong>ER</strong> Erosion</td>
<td>Low to high</td>
</tr>
</tbody>
</table>

**Other Characteristics**

| 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.\(^3\) 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.\(^10\) |

**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.

**Photos**

- Cow Bay Beach, Martha's Vineyard, MA (Photo courtesy of Woods Hole Group)
- Duxbury Beach, Duxbury, MA (Photo courtesy of Woods Hole Group)

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\(^1\) Bates, 2010
\(^2\) DiRienzo, 2010
\(^3\) DiRienzo, 2010
\(^4\) DiRienzo, 2010
\(^5\) DiRienzo, 2010
\(^6\) Bates, 2010
\(^7\) Bates, 2010
\(^8\) Bates, 2010
\(^9\) Bates, 2010
\(^10\) Bates, 2010
\(^11\) Bates, 2010
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.

### 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.

- **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 are 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 $14,650 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.

### Design Schematics

**Overview of Technique**

| Materials | Sediment is brought in from an offsite source, such as a sand and gravel pit or coastal dredging project. 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. Planting the dune with native, salt-tolerant, erosion-control vegetation (i.e. beach grass *Ammophila breviligulata*) with extensive root systems is highly recommended to hold the sediments in place. Sand fencing can also be installed to trap windblown sand to help maintain and build the volume of a dune.

| Habitat Components | Dunes planted with native beach grass can provide significant wildlife habitat.

| 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. To maintain an effective dune, sediment may need to be added regularly to keep dune's height, width, and volume at appropriate levels. The seaward slope of the dune should typically be less steep than 3:1 (base:height). Dunes with vegetation perform more efficiently, ensuring stability, greater energy dissipation, and resistance to erosion. If plantings were included, plants should be replaced if they are removed by storm or die.

| 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. 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. Dunes dissipate rather than reflect wave energy, as is the case with hard structures. Dunes also act as a barrier to storm surges and flooding, protecting landward coastal resources, and reducing overwash events. Sand dunes provide a unique wildlife habitat.

| 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.
**Regulatory and Review Agencies**

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

<table>
<thead>
<tr>
<th>State</th>
<th>Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maine</td>
<td>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.</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>Local Conservation Commission, NH Natural Heritage Bureau, NH Department of Environmental Services (Wetlands Bureau, Shoreland Program, and Coastal Program), and NH Fish &amp; Game Department.</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>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.</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>Coastal Resources Management Program.</td>
</tr>
<tr>
<td>Connecticut</td>
<td>Local Planning and Zoning Commission, and CT Department of Energy and Environmental Protection.</td>
</tr>
</tbody>
</table>

**Siting Characteristics and Design Considerations**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Selection Characteristics</strong></td>
<td></td>
</tr>
<tr>
<td><strong>ES</strong> Energy State</td>
<td>Only applicable in moderate to high energy environments. Natural dune projects are preferred whenever possible.</td>
</tr>
<tr>
<td><strong>EE</strong> Existing Environmental Resources</td>
<td>Coastal beach; coastal dune; coastal bank</td>
</tr>
<tr>
<td><strong>SR</strong> Nearby Sensitive Resources</td>
<td>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. In addition, plantings may need to be thinned for dune projects in nesting habitat for protected shorebird and turtle species.</td>
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<tr>
<td><strong>TR</strong> Tidal Range</td>
<td>Low to high</td>
</tr>
<tr>
<td><strong>EL</strong> Elevation</td>
<td>Above MHW. Dune projects require a dry high tide beach to be successful.</td>
</tr>
<tr>
<td><strong>IS</strong> Intertidal Slope</td>
<td>Flat to steep</td>
</tr>
<tr>
<td><strong>BS</strong> Bathymetric Slope</td>
<td>Flat to steep</td>
</tr>
<tr>
<td><strong>ER</strong> Erosion</td>
<td>Moderate to high</td>
</tr>
</tbody>
</table>

**Other Characteristics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grain Size</strong></td>
<td>It is important to utilize sediment with a grain size and shape compatible to the site. The percentage of sand-, gravel-, and cobble-sized sediment should match, or be slightly coarser than, the existing dune sediments. Mixed sediment dunes may be appropriate and necessary for some locations. The shape of the material is also important, especially for larger sediment, and should be rounded rather than angular.</td>
</tr>
<tr>
<td><strong>Impairment Level</strong></td>
<td>Consideration should be given to invasive species, level of existing armoring, and extent of public use.</td>
</tr>
<tr>
<td><strong>Climate Vulnerability</strong></td>
<td>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 storm and sea level rise in the future.</td>
</tr>
<tr>
<td><strong>Surrounding Land Use</strong></td>
<td>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. Dune restoration will be most successful if it is located where the natural dune line should be and, if possible, tied into existing dunes. 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.</td>
</tr>
</tbody>
</table>

**Notes:**

1. The shape of the material is also important, especially for larger sediment, and should be rounded rather than angular.
2. Mixed sediment dunes may be appropriate and necessary for some locations.
3. The percentage of sand-, gravel-, and cobble-sized sediment should match, or be slightly coarser than, the existing dune sediments.
4. Consideration should be given to invasive species, level of existing armoring, and extent of public use.
5. 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.
6. 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.
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 Overview

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sediment is brought in from an offsite source, such as a sand and gravel pit or coastal dredging project.¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat Components</td>
<td>Beaches nourished with compatible sediments can provide significant wildlife habitat.⁵,⁶</td>
</tr>
<tr>
<td>Durability and Maintenance</td>
<td>A coarser sand may erode more slowly than a finer sand.⁴ To maintain an effective beach berm, sediment may need to be added regularly to 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.⁵</td>
</tr>
<tr>
<td>Design Life</td>
<td>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.</td>
</tr>
<tr>
<td>Ecological Services Provided</td>
<td>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</td>
</tr>
</tbody>
</table>

### 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 cu y 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.

### 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 aesthetics.

### 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.

---

¹ Revere Beach, MA

² Long Beach, Barnstable, MA

³ Photo courtesy of MA CZM

⁴ Photo courtesy of MA CZM

⁵ Massachusetts Division of Conservation and Recreation (DCR)

⁶ Phase 1: 2013; Phase 2: 2014

⁷ Permitting Insights

⁸ Construction Notes

⁹ Maintenance Issues

¹⁰ Final Cost

¹¹ Challenges
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.

Regulatory and Review Agencies

<table>
<thead>
<tr>
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Siting Characteristics and Design Considerations

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<tr>
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<tbody>
<tr>
<td>Energy State</td>
<td>Low to high</td>
</tr>
<tr>
<td>Existing Environmental Resources</td>
<td>Coastal beach; subtidal</td>
</tr>
<tr>
<td>Nearby Sensitive Resources</td>
<td>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. 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.</td>
</tr>
<tr>
<td>Tidal Range</td>
<td>Low to high</td>
</tr>
<tr>
<td>Elevation</td>
<td>Above MHW to Below MLW. When designing beach berm elevations, consider increasing elevation above existing berm elevation.</td>
</tr>
<tr>
<td>Intertidal Slope</td>
<td>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.</td>
</tr>
<tr>
<td>Bathymetric Slope</td>
<td>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.</td>
</tr>
<tr>
<td>Erosion</td>
<td>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.</td>
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Other Characteristics

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<tr>
<td>Grain Size</td>
<td>It is important to utilize sediment with a grain size, shape and color compatible to the site. The percentage of sand-, gravel-, and cobble-sized sediment should match, or be slightly coarser than, the existing sediments. The shape of the material is also important, especially for larger sediment, and should be rounded rather than angular.</td>
</tr>
<tr>
<td>Impairment Level</td>
<td>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.</td>
</tr>
<tr>
<td>Surrounding Land Use</td>
<td>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. 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. 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.</td>
</tr>
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</table>
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.

**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.

**Overview of Technique**

**Materials**

<table>
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<tr>
<th>Material</th>
<th>Description</th>
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<tbody>
<tr>
<td>Sediment</td>
<td>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&quot; 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. 2 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.)</td>
</tr>
</tbody>
</table>

**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, 4 Coir logs must be securely anchored to prevent wave and tidal current-induced movement. 1, 12 Invasive species management should be incorporated into the project. 1 Runoff and groundwater management will also be crucial to project success. 5

**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 water 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.
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.

**Siting Characteristics and Design Considerations**

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<thead>
<tr>
<th>Selection Characteristics</th>
<th>Detail</th>
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</thead>
<tbody>
<tr>
<td><strong>ES</strong> Energy State</td>
<td>Low to moderate. Coir rolls can be used on both sheltered sites and sites exposed to wave energy. 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. 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.</td>
</tr>
<tr>
<td><strong>EE</strong> Existing Environmental Resources</td>
<td>Coastal bank; vegetated upland.</td>
</tr>
<tr>
<td><strong>SR</strong> Nearby Sensitive Resources</td>
<td>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. 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.</td>
</tr>
<tr>
<td><strong>TR</strong> Tidal Range</td>
<td>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.</td>
</tr>
<tr>
<td><strong>EL</strong> Elevation</td>
<td>Above MHW</td>
</tr>
<tr>
<td><strong>IS</strong> Intertidal Slope</td>
<td>Flat to steep. Although, flat to moderate slopes are preferred; steeper slopes may require armoring, which would result in a non-living shoreline.</td>
</tr>
<tr>
<td><strong>BS</strong> Bathymetric Slope</td>
<td>Flat to steep</td>
</tr>
<tr>
<td><strong>ER</strong> Erosion</td>
<td>Low to moderate</td>
</tr>
</tbody>
</table>

**Other Characteristics**

<table>
<thead>
<tr>
<th>Impairment Level</th>
<th>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.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Vulnerability</td>
<td>Both horizontal and vertical loss to a coastal bank is permanent.</td>
</tr>
<tr>
<td>Surrounding Land Use</td>
<td>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. 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.</td>
</tr>
</tbody>
</table>

**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.

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- **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.
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.

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.

<table>
<thead>
<tr>
<th>Project Proponent</th>
<th>City of Cranston, RI, Edgewood Waterfront Preservation Association (EWPA), Save The Bay, Natural Resources Conservation Service (NRCS).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permitting Insights</td>
<td>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.</td>
</tr>
<tr>
<td>Construction Notes</td>
<td>A key component of this project was reggrading the bank from a vertical cut to create a more gradual slope. Once the slope was regressed, sand filled coir envelopes were installed, covered with soil and planted with salt tolerant vegetation.</td>
</tr>
<tr>
<td>Maintenance Issues</td>
<td>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.</td>
</tr>
<tr>
<td>Final Cost</td>
<td>Permitting: No permit fee for municipalities Construction: $59,006 plus volunteer labor.</td>
</tr>
<tr>
<td>Challenges</td>
<td>Funding and coordination with partners and volunteers.</td>
</tr>
</tbody>
</table>

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 onsite 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. Invasive species management should be incorporated into the project. Runoff management and groundwater will also be crucial to project success.

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.
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.

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<tr>
<td>Energy State</td>
<td>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</td>
</tr>
<tr>
<td>Existing Environmental Resources</td>
<td>Coastal bank; vegetated upland.</td>
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<tr>
<td>Nearby Sensitive Resources</td>
<td>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.</td>
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<td>Tidal Range</td>
<td>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.</td>
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<td>Elevation</td>
<td>Above MHW</td>
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<td>Intertidal Slope</td>
<td>Flat to steep. Although, flat to moderate slopes are preferred; steeper slopes may require armoring, which would result in a non-living shoreline.</td>
</tr>
<tr>
<td>Bathymetric Slope</td>
<td>Flat to steep</td>
</tr>
<tr>
<td>Erosion</td>
<td>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.</td>
</tr>
</tbody>
</table>

Other Characteristics

| 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. 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. |

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.
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.

Objectives: dissipates wave energy, habitat creation, shoreline stabilization

Design Schematics

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Objectives: dissipates wave energy, habitat creation, shoreline stabilization

Design Schematics

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.

Materials
Native marsh plants appropriate for salinity and site conditions. Plugs of marsh grass can be planted to augment bare or sparse areas. 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. Bird exclusion fencing may be necessary to avoid predation while plants develop.

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. 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. The extensive root systems of marsh vegetation help to retain the existing soil, thus reducing erosion while plants attenuate wave energy. A healthy salt marsh may reduce wave energy. Marshes provide habitat for many species of plants and animals, and maintain the aquatic/terrestrial interface. Marshes also provide natural shore erosion control, better water quality, recreation and education opportunities, and carbon sequestration (blue carbon).

Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold tems)
Including roughened surfaces, such as emergent vegetation can help break up ice sheets. 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. 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.
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.

### Natural Marsh Creation/Enhancement

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

Fringing Marsh Project, Indigo Point, Barrington, RI  
Photo courtesy of Janet Freedman

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<td><strong>Selection</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Energy State</strong></td>
<td>Low to moderate. Works best in low energy sites (i.e. less than 2 feet of short waves, low current and low storm surge). Sites with a fetch &gt;5 miles are not recommended.</td>
</tr>
<tr>
<td><strong>Existing Environmental Resources</strong></td>
<td>Coastal beach; mud flat; salt marsh</td>
</tr>
<tr>
<td><strong>Nearby Sensitive Resources</strong></td>
<td>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 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.</td>
</tr>
<tr>
<td><strong>Tidal Range</strong></td>
<td>Low to high</td>
</tr>
<tr>
<td><strong>Elevation</strong></td>
<td>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. Tidal buffer should be planted above highest observable tide.</td>
</tr>
<tr>
<td><strong>Intertidal Slope</strong></td>
<td>Flat. With slopes 5:1 (base:height) and flatter, plants can be utilized without additional erosion control. Between 5:1 and 3:1, marsh projects may not work without additional toe stabilization. The wider the intertidal zone, the more effective the marsh is at dissipating wave energy. A minimum width of the planting should be 10 feet.</td>
</tr>
<tr>
<td><strong>Bathymetric Slope</strong></td>
<td>Flat to moderate</td>
</tr>
<tr>
<td><strong>Erosion</strong></td>
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<td><strong>Boat Traffic</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Ice Sensitivity</strong></td>
<td>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. Plant in the spring to allow plants to become established well before ice becomes a concern.</td>
</tr>
<tr>
<td><strong>Climate Vulnerability</strong></td>
<td>Planted marsh areas may have a difficult time adapting to sea level rise. If there is space on a project site, designs should anticipate marsh migration in response to sea level rise.</td>
</tr>
<tr>
<td><strong>Surrounding Land Use</strong></td>
<td>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. Marshes require sunlight to thrive; trees must be pruned or removed to allow for at least four to six hours of sunlight a day; this will increase vegetation growth. 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.</td>
</tr>
</tbody>
</table>

### Additional Notes

- Natural Marsh
- Fringing marsh
- Living shoreline
- Projects
- Successful
- Protective structures
- Sheltered waterways
- Low natural wave action
- Boating activities
- Marshes
- Endangered species
- Tidal range
- Elevation
- Intertidal slope
- Bathymetric slope
- Erosion
- Boat traffic
- Ice sensitivity
- Climate vulnerability
- Surrounding land use
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 Overview**

<table>
<thead>
<tr>
<th>Materials</th>
<th>Native marsh plants appropriate for salinity and site conditions. Plugs of marsh grass can be planted to augment bare areas. 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 silt materials. Bird exclusion fence to avoid predation while plants develop.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat Components</td>
<td>Salt marsh; Tidal buffer landward of the salt marsh; Coastal beach; Mud flat.</td>
</tr>
<tr>
<td>Durability and Maintenance</td>
<td>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. Coir logs must be securely anchored to prevent wave and tidal current-induced movement. Ongoing maintenance of invasive species and runoff issues will be important to the long-term success of the project.</td>
</tr>
<tr>
<td>Design Life</td>
<td>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.</td>
</tr>
<tr>
<td>Ecological Services Provided</td>
<td>Increases water infiltration, uptake of nutrients, filtration, denitrification and sediment retention. The extensive root systems of marsh vegetation help to retain the existing soil, thus reducing erosion while plant stems attenuate wave energy. Marshes provide habitat for many species of plants and animals, and maintain the aquatic/terrestrial interface. Sill mitigates erosive waves and stabilizes shoreline. Marine animals can access the marsh through gaps in the sill. Marshes also provide better water quality, recreation and education opportunities, and carbon sequestration (blue carbon).</td>
</tr>
<tr>
<td>Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)</td>
<td>Including roughened surfaces, such as logs, stones or emergent vegetation can break up ice sheets. Fringing marsh projects will respond better to ice if designed with gentler slopes (6:1-10:1) and by incorporating shrubs. Planting in the spring will allow vegetation to become established before it has to withstand ice. Hardy, salt-tolerant shrubs are well-suited shorelines that are affected by ice. Need to consider where in the tidal range oysters will be placed if they’re used: too high may result in freezing.</td>
</tr>
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</table>

**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).
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 creates greater tidal exchange. Toe protection is particularly important where there is higher wave activity or threat of boat wakes.

**Regulatory and Review Agencies**

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### Siting Characteristics and Design Considerations

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<th>Selection Characteristics</th>
<th>Detail</th>
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<tr>
<td><strong>ES</strong> Energy State</td>
<td>Moderate. A sill may be necessary in medium energy sites (2-5 foot waves, moderate currents and storm surge).[6]</td>
</tr>
<tr>
<td><strong>EE</strong> Existing Environmental Resources</td>
<td>Coastal beach; mud flat; salt marsh</td>
</tr>
<tr>
<td><strong>SR</strong> Nearby Sensitive Resources</td>
<td>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. [7] 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.</td>
</tr>
<tr>
<td><strong>TR</strong> Tidal Range</td>
<td>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.[7,11,15]</td>
</tr>
<tr>
<td><strong>EL</strong> Elevation</td>
<td>MLW to MHW; Above MHW. For low marsh, the lowest grade should be MLW and extend up to MHHW. High marsh plantings should extend between MHW and MHHW.[7]</td>
</tr>
<tr>
<td><strong>IS</strong> Intertidal Slope</td>
<td>Moderate. With slopes between 5:1 and 3:1 (base:height), sills should be added to the toe of the marsh.[3]</td>
</tr>
<tr>
<td><strong>BS</strong> Bathymetric Slope</td>
<td>Flat to moderate</td>
</tr>
<tr>
<td><strong>ER</strong> Erosion</td>
<td>Low to moderate</td>
</tr>
</tbody>
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### Other Characteristics

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<tr>
<td>Boat Traffic</td>
<td>If boat wakes are expected to be the dominant force the sill should be designed accordingly.[7]</td>
</tr>
<tr>
<td>Ice Sensitivity</td>
<td>Gentle slopes and intermixed shrubs will handle ice the best.[6] Plant in the spring to allow plants to become established well before ice becomes a concern.[6]</td>
</tr>
<tr>
<td>Climate Vulnerability</td>
<td>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]</td>
</tr>
<tr>
<td>Surrounding Land Use</td>
<td>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.[13,15] 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.[13]</td>
</tr>
</tbody>
</table>
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

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

Design Overview

<table>
<thead>
<tr>
<th>Materials</th>
<th>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.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat Components</td>
<td>Shellfish reef. Complex structure for fisheries habitat.</td>
</tr>
<tr>
<td>Durability and Maintenance</td>
<td>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.</td>
</tr>
<tr>
<td>Design Life</td>
<td>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.</td>
</tr>
<tr>
<td>Ecological Services Provided</td>
<td>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.15 Because shellfish are filter feeders, oyster/mussel reefs can improve water quality.21 As the living breakwaters become colonized with marine species, they provide recreational benefits such as fishing and snorkeling.21</td>
</tr>
<tr>
<td>Unique Adaptations to NE Challenges (e.g. ice, winter storms, cold temps)</td>
<td>Reef Balls installed in Stratford, CT withstood significant icing during the 2014-2015 winter.11 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.</td>
</tr>
</tbody>
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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
DABDA 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.
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.

Living Breakwater

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

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

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<tr>
<td><strong>Energy State</strong></td>
<td>Moderate to high. Suitable for most areas, except those in the highest wave energy environments. 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%. Using additional rows of Reef Balls can decrease this even more.</td>
</tr>
<tr>
<td><strong>Existing Environmental Resources</strong></td>
<td>Coastal beach; mud flat; subtidal</td>
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<td><strong>Nearby Sensitive Resources</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Tidal Range</strong></td>
<td>Low to middle. In areas with a large tidal range, these structures would have to be extremely large to continue to provide protection functions, or could be sited closer to shore. Best suited for low to medium tidal range areas.</td>
</tr>
<tr>
<td><strong>Elevation</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Intertidal Slope</strong></td>
<td>Flat to steep. The breakwater itself will not be impacted by the intertidal slope, but other project components, such as a marsh planted behind the breakwater, may have specific slope requirements.</td>
</tr>
<tr>
<td><strong>Bathymetric Slope</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Erosion</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Ice Sensitivity</strong></td>
<td>Current guidance suggests sizing stone so that the median stone diameter is two to three times the maximum expected ice thickness. In colder climates, oysters/mussels should be submerged (below MLW) to prevent them from freezing during the winter months.</td>
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<td><strong>Climate Vulnerability</strong></td>
<td>The effectiveness of a breakwater will be reduced over time as sea level rise gradually reduces the maximum expected wave height. Reef Balls could reduce wave heights by 60% using additional rows of Reef Balls can decrease this even more.</td>
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<td><strong>Surrounding Land Use</strong></td>
<td>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.</td>
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<tr>
<td><strong>Climate Vulnerability</strong></td>
<td>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.</td>
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