Practitioner's Guide

Shellfish-Based Living Shorelines for Salt Marsh Erosion Control and Environmental Enhancement in the Mid-Atlantic

Laura Whalen, Partnership for the Delaware Estuary
Danielle Kreeger, PhD, Partnership for the Delaware Estuary
David Bushek, PhD, Rutgers' Haskin Shellfish Research Laboratory
Joshua Moody, Rutgers' Haskin Shellfish Research Laboratory
Angela Padeletti, Partnership for the Delaware Estuary

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I. Introduction

I.1 Problem: Eroding Marshes

In the Delaware Estuary, tidal marshes are extensive (Figure 1) and vital to the overall health of the system but are eroding at a rapid pace (Figure 2). To date, we have already lost 44% of salt marshes and 56% of freshwater marshes from human causes in the United States (USEPA Coastal Wetlands Initiative, 2010). The Delaware Estuary also has about a 40-50% reduction of our wetlands from historical levels since the 1790s (Dahl 1990). Due to their diversity and sheer extent across the Delaware Estuary, tidal wetlands are considered a hallmark habitat feature that is crucial for sustaining fish, shellfish and wildlife populations, helping maintain water quality, and providing protective barriers and buffers from flooding of coastal communities.

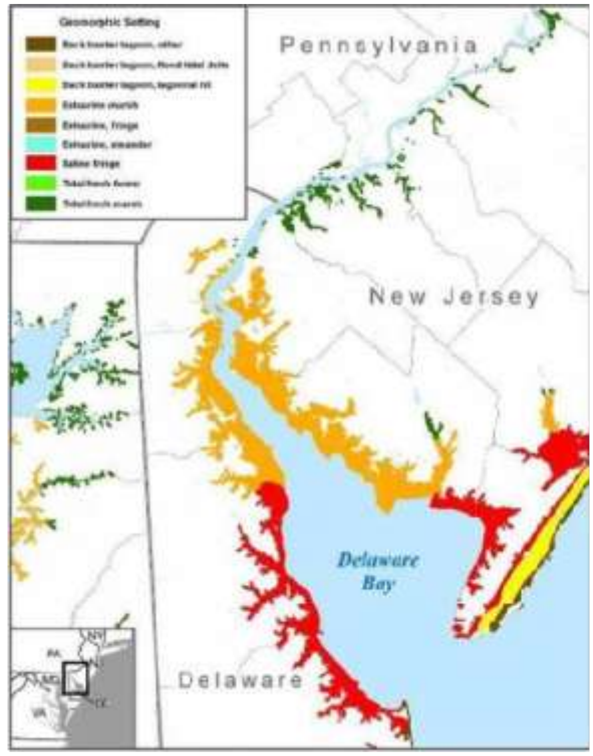

Figure 1. Configuration of Delaware Estuary Wetlands (red= tidal, green= non-tidal).

The Delaware Estuary's tidal marshes are being lost or degraded due to a variety of factors. One of these is erosion along seaward edges associated with sea level rise and boat wakes. Marshes often cannot keep pace or are increasingly eroded by higher wave energies from boat traffic and increasing fetch. Another widespread problem is the development or degradation of interior marsh areas resulting in their conversion to open water. Additional stressors that might exacerbate these problems include excess nutrients, insufficient sediment, impoundments and tidal restrictions, mosquito ditching, and invasive species.

As tidal heights and the estuary's volume increase in response to sea level rise and system alterations, the extent of tidal inundation along coastal areas will also increase, leading to successional shifts in habitat types as tidal wetlands encroach into non-tidal wetlands and forests. However, this natural migration (a.k.a., "transgression") is impeded in many areas by development or attempts to manage fixed coastlines in place. Meanwhile, erosion appears to be increasing along seaward margins of tidal wetlands. Taken together, the seaward loss and restricted landward gain leads to a net loss of coastal wetland acreage. PDE recently calculated that more than 2% of tidal emergent wetlands were lost in the Delaware Estuary between 1996 and 2006, and models project a minimum of 25% net loss this century (PDE, 2010). Therefore, proactive restoration and management tactics that either facilitates the

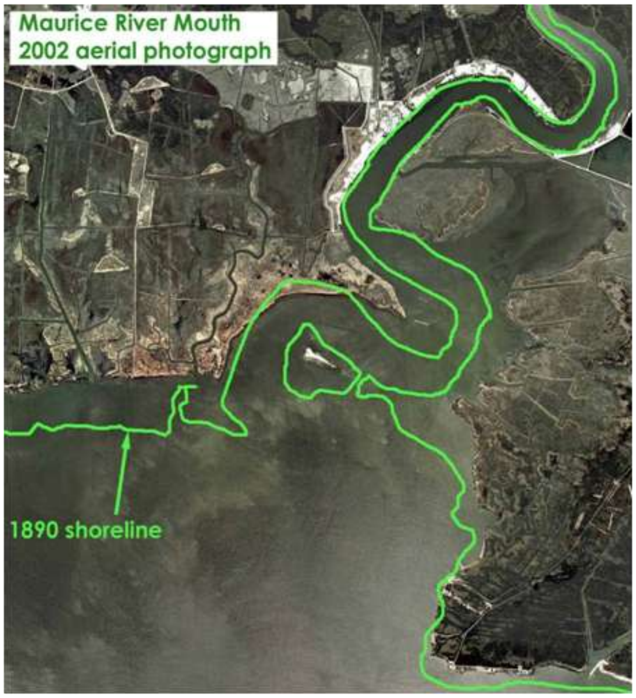

Figure 2. Erosion in the mouth of the Maurice River, Cumberland County, NJ.

horizontal, landward migration or the vertical, accretion of tidal wetlands are expected to become increasingly important to sustaining these critical coastal habitats, which are among the most productive in the world.

The objective of this report is to provide a "how-to" guide for a promising new living shoreline approach which can be used to help stem seaward edge erosion along mid-Atlantic salt marshes while also furnishing additional environmental benefits. This "climate adaptation" tactic was developed jointly by PDE and Rutgers to take advantage of the native community of plants and animals that live along intertidal salt marsh edges of the Delaware Estuary. The tactic is best suited for low energy areas, and it would need to be paired with more aggressive measures along high energy coastlines.

This report is organized as a manual for installing our bio-based living shoreline. To provide a context for how this tactic compares to other existing approaches, Appendix A provides an inventory of other approaches. Erosion control can take many forms, ranging from hard structures such as rock revetments (rip rap) and bulkheads to more natural communities that offer their own resilience. Mixed tactics are referred to as hybrids. Some of these tactics not only help stem erosion but can also encourage vertical accretion of tidal marshes. Appendix B consists of a project summary and research results from the Delaware Estuary Living Shorelines Initiative (DELSI), which was the R&D effort that led to the tactic described in this report. This effort is currently being expanded to include multiple on-the-ground tactics which are being matched to local needs, within a GIS context. Tech transfer and educational programs are also in the works to build awareness and expand the use of living shorelines to encourage vertical accretion of tidal marshes. Erosion control can take many forms, ranging from hard structures such as rock revetments (rip rap) and bulkheads to more natural communities that offer their own resilience, together with an array of mixed tactics referred to as hybrid designs. For our purposes, we herein focus on measures that are known to boost, rather than degrade, environmental integrity.

I.2 Definition of Living Shorelines

"Living Shorelines" have been defined as shoreline stabilization techniques that use natural habitat elements to protect shorelines from erosion while providing critical habitat for bay/ river wildlife (Smith 2006). They are a creative approach to protecting estuarine shorelines from erosion by using engineered structures to also maintain, restore, or enhance the shoreline's natural habitats. These approaches can include: restoring, enhancing, or protecting existing wetland/riparian vegetation, construction of a marsh sill, and/or using other engineered structures to maintain, restore, enhance or create a natural shoreline (Hardaway et. al. 2010).

Living shorelines typically incorporate biological elements instead of hardened structures with stone or wooden bulkheads. Hardened shorelines alone protect against erosion, but may prevent habitat benefits and important ecological connections of upland and water. Instead, a variety of natural structures may be used in living shorelines including: shellfish reefs, riparian plants, and strategically placed organic material. The use of living material reduces wave action in marshes, slowing erosion, and buying more time for marshes to accumulate in place (vertical accretion) or move inland. Some biological communities also act as levee builders, whereas, hardened structures cannot elevate themselves and keep pace with sea level rise.

As with any type of habitat alteration project, the habitat tradeoffs of living shorelines should be weighed carefully relative to project goals and the primary ecosystem goods and services being sought. In some cases, the protection of coastal communities and essential infrastructure will necessarily take precedence over ecological goals such as fish and wildlife enhancement or water quality maintenance. However, most types of shoreline stabilization projects can be designed in environmentally beneficial ways consistent with living shoreline concepts.

One way to do this is to incorporate natural materials and species such as shellfish reefs and planted

Table 1. Summary of U.S. Living Shorelines History

DATE	Living Shoreline History
1980s	"Living shorelines" term coined in MD
2003	North Carolina passes Living Shoreline Law (HB 1028)
early 2000s	Delaware puts "no bulkhead" policy in place
2005	Dauphin Island, Alabama- Living shorelines used to mitigate storm events
2006	National Academies undergoes Sheltered Coasts study
2006	Chesapeake Living Shoreline Summit held
2007-8	Florida state government begins Living Shoreline Initiative
2008	Maryland passes Living Shoreline Protection Act
2008	CBT and NOAA begin to quantify ecological impacts of LS
2008	PDE and Rutgers launch the Delaware Estuary Living Shoreline Initiative
2008	Georgia Department of Natural Resources and TNC begin oyster reef living shorelines projects
2009	CICEET funds NC work on engineered shorelines
2010	NOAA funds Smithsonian work on shoreline value
2010	CBT and NOAA fund VIMS to evaluate engineering value
2010	President Obama's Ches. Bay Exec. Order includes LS goal
2010	Rhode Island begins living shoreline effort
2011	NJ considers ways to ease living shoreline permit restrictions

vegetation into the design, where those species exist. Such communities are often capable of binding inert materials together with natural cement or fibers, thereby helping to buffer marshes from wave action, slowing erosion, and buying more time for marshes to accumulate in place (vertical accretion) or move inland (horizontal relocation). Other natural materials can include shrubs and trees, low profile sills, strategically placed organic material, and other techniques that recreate the natural functions of a shoreline ecosystem. In other cases, breakwater projects can be constructed in ways to enhance fish and shellfish communities, such as by arranging rock breakwaters in segments interspersed with sills; thereby providing habitat complexity while also creating low energy protected shorelines for passive sediment trapping and marsh expansion.

Restoring shoreline with "living shorelines" is not necessarily a new concept. For example, in the early 1970's, Environmental Concern Inc. constructed a salt marsh channel ward of an eroding shoreline at a low-energy cove in Talbot County, Maryland. The marsh thrived, and shoreline erosion was reversed. Over the next two decades, scientists and engineers at EC refined and expanded the initial design, creating sustainable salt marshes in highly erosive environments. Living shorelines are now increasingly becoming a more internationally accepted approach for dealing with shoreline erosion instead of strictly using hardened, man-made structural shoreline stabilization such as sea walls and bulkheads. Many states and organizations are now working on developing living shoreline initiatives. A brief history with some of these initiatives is found in Table 1. Shellfish reefs are one example out of a growing spectrum of tactics that can be considered as living shorelines restoration.

As summarized in Appendix A, living shoreline tactics are diverse, and selecting the appropriate type is important. Several studies on living shorelines around the United States have determined that the following basic site characteristics should be used to initially evaluate the appropriate living shoreline approach:

- The distance in miles of open water ("fetch") should be 3 miles or less
- Orientation of shoreline in relation to prevailing winds
- Presence of other energy factors such as boat wake and tidal currents
- Presence of existing marsh grasses or submerged aquatic vegetation on or near the project site
- Erosion rate trends
- Shallow water depth near the shoreline- slope
- Amount of sunlight

Examples follow:

As an example, the following sections describe factors that guided our selection of suitable sites for our Delaware Estuary Living Shoreline (DELSI) tactics (Section II).

Wave Energy

Wave Energy is the first factor to consider for selecting a shore protection method. Low energy environments are the easiest to maintain bio-based tactics; shorelines in medium and high energy environments can be more difficult to stabilize. Higher wave energy typically requires some hard structural components than simple bio-based approaches, although they can be used together. Shorelines with high energy require a balance of protection and viable habitat for land-water exchange and processes (Smith 2006). Unfortunately, no uniform measures of what constitutes high, moderate or low energy are currently available. Site inspections and comparisons with nearby areas demonstrating varying degrees of erosion presently provide the best guide. In this study, Plaster of Paris balls were used to measure relative wave energy at different sites in the salt marsh by calculated their loss of mass after 24 hours. The method was developed from Yokoyama

Slope

Bank height or slope is also important, and a gentle gradient more easily supports a living shoreline than a steep bank to allow for structural stability and a good surface for vegetation to establish. Our tactic relies on sediment trapping between installation and vegetated edge, and gradual slopes can increase space for this.

Natural Material Placement

Living shoreline projects often use rock, natural fiber products, and other natural materials selected based on energy and slope. In high energy, rock can be placed seaward of marsh to function as a breakwater or sill when oriented to dampen action from winds and waves. With the rock in place, marsh or beach is typically created landward of the sill structure in new sediment trapped by the more protected marsh. This allows for fish and wildlife passage, plus sometimes increases the diversity of habitat type (e.q. beach, marsh, SAV bed, oyster reef). This combination of materials is often referred to as a "hybrid" design (Duhring 2006). Hybrids must be designed carefully to achieve desired habitat enhancement without erosion elsewhere (Priest 2006).

Tidal Gates

Breakwaters or sills can be designed with gaps (also called windows or tidal gates), hypothesized to be effective in providing for habitat and maintenance of shoreline processes. Presumably, perforated sills/ breakwaters enhance tidal flushing and connectivity, though to date no quantitative gate effectiveness studies have been done. The size and frequency, and height of gaps can be adjusted to achieve design goals. More work to establish specific guidance based on ecological and engineering needs is needed (Takacs 2011).

Design Considerations

The skill in designing and building functional living shorelines often has to do with determining the fine line between adequate structural placements (e.g., rock, reefs, sills) balanced with desired habitat enhancement. Some types of living shorelines may not provide the same level of erosion protection as other more structural practices or they might require maintenance or adaptive management. However, living shorelines are believed to be more resilient in other cases because they provide for mobility of shoreline and near-shore sediments which may cause seasonal changes to shoreline configuration. As a result, there may be more of a marsh area or beach in one time of the year than another. The systems are dynamic by nature and appropriate living shoreline applications will act as part of the natural system, not against it. Stability in these living shorelines should be viewed much like the ebb and flood of tides or as a seasonal progression of sedimentary processes and accompanying habitat forms (Slear 2011).

I.3 Purpose and Benefits of Living Shorelines

The environmental advantages of living shorelines over traditional riprap or bulkheads are becoming better documented. Recent studies have shown that hardened shorelines (bulkheads, rock revetments) have a lower abundance of bottom-dwelling organisms nearby and lower numbers of juvenile fish and crabs, compared to shorelines with vegetated marsh. Seitz et al. (2006) concluded that the abundance and diversity of benthic organisms were higher in habitats adjacent to natural marsh than those adjacent to bulkheaded shorelines, and abundance and diversity were intermediate in riprapped shorelines. Predator density and diversity tended to be highest adjacent to natural marsh shorelines, and density of crabs was significantly higher in natural marshes than in bulkheaded habitats, suggesting a crucial link between marshes, infaunal prey in subtidal habitats, and predator abundance. This is of great importance as miles of Maryland and Virginia shorelines are hardened each year, thereby increasing the vulnerability of shorelines to storm damage and loss of valuable habitat for fish, crabs, and waterfowl (Davis et. al. 2006). In the Barnegat Bay Estuary in New Jersey, 45% of the estuarine shoreline is bulkheaded (Barnegat Bay Partnership, http://bbp.ocean.edu/pages/147.asp)

Other major benefits of living shorelines include lower or at least comparable construction costs, retention of links between aquatic and upland habitats, restoring or maintaining critical spawning and nursery areas for fish and crabs, maintaining natural shoreline dynamics and sand movement, reducing wave energy, absorbing storm surge and flood waters, and filtering nutrients and other pollutants from the water (Davis et. al. 2006).

While there are many benefits associated with living shorelines, designs are diverse and some will not be as effective in all conditions, specifically in high energy environments. Other drawbacks include low numbers of knowledgeable marine contractors and the lack of scientific information on the long-term the effectiveness of living shorelines for different types of shores and under different energy regimes and storm conditions.

The following ecosystem services have been associated with living shorelines, especially those designed to build or benefit marshes:

Shoreline Stabilization

The main reason for which living shorelines are installed is to stabilize erosion along valued coastal and estuarine habitats. The type of tactic and the design should be selected to ensure that the treatment can withstand the wave and current energies that contribute to the erosion. Reduction of wave height (wave attenuation) and thus the severity of the impact at the upland bank is a function of wave interaction with the bottom, wave interaction with any breakwater structure such as sill, shellfish reef, etc., and wave interaction with biota (marsh vegetation, oyster/mussel reefs, SAV beds). Knutson *et al.* (1982) report that *Spartina alterniflora* (SA) marshes significantly reduced wave height and erosional energy. Wave height was reduced by 50% within the first 5 m of marsh and 95% after crossing 30 m of marsh.

Productivity

Natural habitats such as tidal wetlands are far more ecologically productive than hard-armored shorelines. The net primary productivity of salt marshes exceeds that of most ecosystems worldwide. Tidal marshes also provide the food sources for many of the important living resources of the Delaware Estuary, even species that are not marsh residents. Above-ground biomass in created or restored marshes can be as productive as biomass in natural marshes if basic conditions for marsh establishment and survival are employed. When protected in their natural state or reestablished through restoration efforts, these shoreline areas trap sediment, filter pollution, and provide important habitat for both aquatic and terrestrial wildlife, such blue crabs and fishes in their critical early life-history stages.

Habitat and Economic Enhancement

80% of America's breeding bird population relies on coastal wetlands, 50% of the 800 species of protected migratory birds rely on coastal wetlands, and nearly all of the 190 species of amphibians in North America depend on coastal wetlands for breeding (Slear 2011). Facts like these demonstrate the importance of tidal wetlands as habitat. This is another important reason to protect wetlands from erosion. The cost/benefit ratio for a living shoreline is impressive. For every dollar spent to construct vegetative shoreline stabilization, as much as $1.75 is returned to the economy in the form of improvements to resources, including submerged aquatic vegetation (SAV), fish, benthic organisms, shellfish, waterfowl, and wetland habitat (Priest 2006).

Water Quality

Tidal wetlands are viewed as net sources of carbon (production) and sinks for nutrients and suspended solids. Nutrients are removed through burial and biogeochemical transformations (e.g. denitrification). At the watershed scale, the extensive tidal wetlands in the Delaware Estuary are therefore considered essential to maintaining water quality. Moreover, the seaward edges of salt marsh shorelines are some of the most productive areas as evidenced by tall form *Spartina alterniflora* and rich faunal communities with filter-feeding mussels as ecological dominants. Therefore, any project that either stems the loss of tidal wetlands or enhances the functionality of their edge habitats will make positive contributions to water quality and help safeguard against eutrophication.

II. Installation Guide

This meant to give step-by-step instructions for installing the DELSI ribbed mussel/plant tactic at an appropriate site with the proper salinity and energy. The steps for installation include:

1) Site Selection

- Elevation

The critical elevations to know for tidal wetlands establishment are the mean low water (MLW), the average low water at the site, the mean high water (MHW), the average high water level at the site, the mean tide level (MTL), roughly halfway between MLW and MHW, and the upper limit of wetlands (ULW), approximately 1.5 times the mean tide range at the site. These are the important elevations that will dictate the various planting zones within the new marsh. In general, plants will fare best roughly between mid-tide and MHW; however, optimal growth elevations vary and it's best to examine existing vegetation at the site as a guide (see below). If the marsh is on the verge of drowning, the current elevation that plants may be growing may be lower than their optimum growth range. In such cases, the planting elevation should be set above that of the existing plants at the site.

When used to finalize project designs, elevations should be based on a tidal datum such as the National Ocean Service (NOS) MLW and not strictly on a geodetic datum like the North American Vertical Datum of 1988 (NAVD 88). Tidal datums are based on water level observations over a 19 year period (a tidal epoch) where all of the high tides and low tides are averaged to determine MHW and

MLW. NAVD 88 is based on the elevation of a fixed point in Canada and is not directly related to tidal elevations. Relationships between tidal and geodetic datums have been established for many locations but can vary widely. The NOS MLW datum used should also be based on the 1983-2001 tidal epoch to help ensure recent sea level rise has been taken into account. More information on tidal elevations and datums can be found at http://tidesandcurrents.noaa.gov/
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Photo 1: **Optimum DELSI Tactic:** Double-log, cusp-shaped design, with mat underneath and shellbags in front (photo taken before planting with marsh grass and ribbed mussels).

Biological benchmarks (BBM) are elevations established by surveying the elevations of representative plant communities in an adjacent reference marsh, and these are often used to set target planting elevations rather than use of tidal datams (see examples from MD and NC). These elevations can then be corroborated with the tidal datum to cross reference the elevations for the wetland. The advantage of incorporating biological benchmarks into the project design is that these elevations integrate any vagaries in the local hydrology that might influence the distribution of plant zonation. For example, if there is a hydrologic constriction that prevents the area from draining completely, it can result in a perched mean low water and a concomitant compression of the tide range that will affect the success of the plantings. As noted above, one should also consider whether the existing vegetation might be sitting low in their optimal growth elevation range if the marsh platform is not keeping pace with sea level rise; in such cases, a higher planting elevation is warranted to "buy more years" for the treatment to keep pace.

- **Energy**

A major critical criterion to living shoreline placement is fetch, a measure of the exposure of the site to wave action. Generally when the fetch exceeds one mile, the chances of success without some type of structural protection are limited. Between one and 0.5 miles, chances improve but some minimal structure, such as biologs, is advisable to help the marsh become established. When the fetch is <0.5 mile, chances of success without structural toe protection, such as a rock sill, are good. Average fetch is calculated by determining the distance to the far shore along five transects. The main transect is perpendicular to the shore orientation and two transects 22.5 degrees apart are located on either side. The five measurements are then averaged. Shore morphology and depth offshore are also important criteria. The nearshore gradient will influence incoming waves.

- **Slope**

Flat or gentle slopes in the new marsh are important because they help maximize the plantable area within the intertidal zone and, where applicable, help dissipate wave energy and reduce erosion potential. Very often the slopes will be dictated by the size of the site, but, where possible they should at least 10:1 (H:V), preferably flatter if possible. In some situations, the intertidal area can be maximized by creating a bench between the creek and the upland that is very flat from MTL to MHW followed by a steeper slope from MHW to the adjacent upland. The slope of this transition zone should also be kept as flat as site conditions will allow. In higher wave energy sites where there is steep upland transition, some type of structure may be necessary to stabilize this slope. It is also important for the slopes to provide positive drainage for the site at low tide. If the site does not drain completely and there are large areas of standing water within the area to be planted, plant survival can be compromised. Hardaway et al. (2010) recommends that areas of standing water greater than 100 square feet be avoided unless they are an intentional feature of the design to increase habitat diversity.

- Hydrology

Hydrology is one of the most important factors in successfully establishing a wetland. Hydrology can also be affected by elevation and slope (see above). In a tidal wetland, Most marsh plants will survive best if the hydroperiod (duration of immersion per tidal cycle) is less than 50%.

Being dry at low tide is just as important as being wet at high tide. The reason that vegetation only grows down to MTL instead of MLW is that the roots need to breathe at low tide in order to survive. The dominant salt marsh plants do not grow well in permanently standing water. If the elevations and drainage, i.e. hydrology, in a planted marsh mimic the hydrology in the connecting waterway, the plants will adjust accordingly.

If the tidal connection to your site is highly convoluted or constricted by culverts, it can produce a phase lag in the hydrology. A phase lag usually results from having too much friction in the discharge channel which does not allow the site to drain effectively. Imagine a typical tidal cycle. At high tide because of the force of the incoming tide, the water levels within the site and those of the connecting waterway are equal. As the tide ebbs, it ebbs more slowly within the site because friction slows down the flow of water to the creek. Consequently, when it is low tide in the creek, there might still be a considerable amount of water waiting to drain from the site. As the tide begins to flood in the creek, it will rise to the level of the still ebbing water from the marsh. This level effectively determines the low water elevation because, from this point, the water begins to rise again within the marsh. The ultimate result of this situation is a higher MLW and a compressed tide range in the new marsh. This can have a dramatic impact on the survivability of the plants if the tidal levels from the adjacent creek, and not the site itself, are the main determinants for the planting elevations.

- Substrate

When constructing a new marsh, one needs to consider substrate, first and foremost, as the medium for growing plants. There are other factors such as the amount of organic carbon in the soil that govern functions, like denitrification. However, in the beginning, it is more important to establish the vegetation as rapidly as possible. To do this, the best medium is sand. It provides a good anchor for the plants, allows for rapid root growth and effective drainage. In exposed conditions, coarser sand should be used to minimize transport by wave action. Silt-clay and peat can work but they make planting more difficult and are not as effective at anchoring the plants. Heavy plastic clays should be avoided because of planting difficulties and the impediments to root growth. Likewise, organic amendments, topsoil, and mulch should be avoided in brackish tidal marshes. Once they become wet, they are difficult to plant because they often do not effectively anchor the plants which naturally float and tend to be dislodged by tidal and wave action.

Table 3. Example of Species Inundation Zone Salinity Range

Species	Planting Range	Salinity
Spartina alterniflora	MTL-MHW	5-30 ppt
Spartina patens	MHW-MHHW	5-30 ppt
Spartina cynosuroides	MHW-MHHW	0-5 ppt
Distichlis spicata	MHW-MHHW	10-30 ppt
Scirpus americanus	MHW-MHHW	0-15 ppt
Juncus roemarianus	Above MHW	10-25 ppt
Iva frutescens near	MHHW	5-30 ppt
Baccharis halimifolia	Near MHW	0-30 ppt

- Shade

Most wetland plants require a minimum of six hours of direct sun per day during the growing season. They require large amounts of energy to cope with the stress of salinity and inundation twice a day. When planting fringing areas, this may require the judicious pruning of the lower branches of adjacent trees to allow for additional sunlight. Trees should only be removed when absolutely necessary. The project design should also take into consideration shading from nearby structures and north facing shorelines which can induce unwanted shade. North facing shorelines, particularly when heavily forested, tend to receive less sunlight because of the low angle of the sun during the winter, spring, and fall.

- Zonation and Salinity Regimes

A general overview of planting zones and salinity tolerances for some of the more commonly planted species is provided in Table 3. The important elevations for determining where plants will grow in tidal wetlands are mean low water (MLW), which is the average low water at the site, mean high water (MHW), which is the average high water level at the site, mean tide level (MTL), which is roughly halfway between MLW and MHW, and mean higher high water (MHHW), which the average of the higher high water or upper limits of the wetlands. MTL is used instead of MLW to determine optimum plant growth because the roots of intertidal plants need to breathe as well during the tide cycle. This is neither exhaustive nor definitive and should be only used as a guide to be tempered by local conditions. Many will find exceptions to these recommendations, but they will work in a vast majority of situations. It is critical to the success of a project to effectively match plant material, planting zones, and salinity regimes.

Photo 2. Plants and ribbed mussels grow and survive best at certain elevations and salinity.

- Use of Local Biota (Plants/Mussels)

If the possible site location already has mussels and spartina alternifora, this will be a good indication that this particular tactic will be successful. Also, this helps when planting the site because eroded clumps of grass and mussels can be salvaged and planted in the living shoreline.

2) Timing of Project

The best time to install is early spring before mussel recruitment and plant growing season. You want the logs to be in place and seeded with mussels to improve recruitment and grass to take advantage of the growing season. Planting times are also discussed below. Also, it is important to figure out how long it will take to acquire permits and land-owner permission and obtain all necessary materials, crew, and equipment like boats, etc.

3) Permit Considerations

We found that it can be difficult to permit non-traditional tactics such as living shorelines compared with hard approaches such as bulkheads and rip rap, but the permitting landscape is evolving. One issue is that living shoreline installations should be adapted on site to take advantage of natural features of the shoreline that may not be apparent from initial surveys used during permitting. This means living shorelines often require greater variances to allow more flexibility for the project. This is counter to the traditional paradigm that expects exact positioning of every piece of material. Actual permits for specific sites will need to balance permit requirements with flexibility. Considerations must also be made to avoid impacting sensitive species (e.g., eagles, terrapins, etc.) and preventative measures may be needed to avoid trapping other species such as the horseshoe crab *Limulus polyphemus*. Permits typically are required from Army Corps of Engineers (unless they are a partner) and the state, and these can include fees. Letters of approval will also be needed from private landowners and public land managers. Some states will arrange for a single point of contact for permit review. Sufficient staff resources and time needs to be budgeted to navigate the permit process.

Changing the current practice of armoring sheltered coasts will require a change in the shoreline management framework. Decision makers should appreciate the costs and benefits of the spectrum of potential solutions to shoreline erosion problems, including potential cumulative impacts on shoreline features, habitats, and other amenities. The management framework should encourage approaches that minimize habitat loss and enhance natural habitats in environments where such methods offer effective stabilization.

Overcoming the obstacles associated with the current regulatory environment will require a number of societal and institutional changes in the following areas:

- Improving knowledge of sheltered shoreline processes and ecological services;
- Improving awareness of the choices available for erosion mitigation;
- Considering cumulative consequences of erosion mitigation approaches;
- Revising the permitting system; and
- Improving shoreline management planning.

Each state in the Delaware Estuary has a slightly different set of permits to be obtained as indicated in the following table:

Table 4. Permit requirements for each state in the Delaware Estuary

Delaware	Pennsylvania	New Jersey
• The organization must complete the Basic Application, which can be found at **http://www.wr.dnrec.delaware.gov/Information/Permits/Pages/WetlandsandSubaqueousLandsPermittingInfo.aspx**. • In addition to the Basic Application, the organization must also complete the appropriate appendices. For Living Shorelines projects, organizations must fill out **Appendix J: Vegetative Stabilization**. If the LS project requires any type of fill, the organization must also fill out **Appendix H: Fill. These are found on the same webpage as the Basic Application.** • An application fee of $225 will cover the entirety of the process. • Organizations must verify with the Army Corps of Engineers that their project complies with **Nationwide Permit 13: Bank Stabilization and/or Nationwide Permit 27: Aquatic Habitat Restoration, Establishment, and Enhancement Activities.** Nationwide Permit information can be found here: **http://www.usace.army.mil/CECW/Pages/nw_permits.aspx**. To speak with the USACE to verify the correct Nationwide Permit for compliance, call the regulator of the day at (215) 656-6728.	• It is recommended for all first-time PA applicants to have a pre-application meeting (though not required). At the pre-application meeting, a DEP rep will discuss fees, what is needed for each section of the permit, and any questions from the agency. To schedule a pre-application meeting, call Govind Daryani at (484) 250-5165. • Applicants need to complete the Joint Permit Application, available with instructions at: http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-9531 • Fulfillment and approval of this application will provide both a PA Water Obstruction and Encroachment Permit and a USACE Section 404 permit. You would need to fill out the Standard Application. • The applicant also needs to get approval from the township where the project is located.	• The applicant needs to obtain permits from the U.S. Army Corps of Engineers and New Jersey Department of Environmental Protection (DEP) prior to initiation of work for state-owned land. • The State of New Jersey DEP permit is the Coastal General Permit from the Division of Land Use Regulation- www.state.nj.us/landuse • The Army Corp Permit is a Nationwide Permit 27: Stream and Wetland Restoration Activities • The State of New Jersey is currently working on revising the permit process for living shoreline projects. Check with NJ Coastal Zone Management or American Littoral Society for updates.

4) Purchase Materials

It is recommended that you find a nursery in your area that has grown or dealt with native wetland plants. PDE and Rutgers purchased materials from Pinelands Nursery in New Jersey.

Where to purchase/obtain materials:

DE and NJ
1) **Coir materials and plants:** Pinelands Nursery – 323 Island Road, Columbus, NJ 08022. Phone (609) 291-9486 e-mail: sales@pinelandsnursery.com www.pinelandsnursery.com/index.htm 2) **List of Plant Suppliers in DE and NJ:** http://www.plant-materials.nrcs.usda.gov/pubs/njpmcot9907.pdf

Materials needed per 40 m of shoreline to be treated (this is the typical size used in DELSI)

- 20 Premium 12’ coir fiber logs (Premium are stronger than standard)
- 1 coir fiber mat (6.6’ by 164’)
- 192 stakes (12 per log)- Pre-drill a hole for the twine in the top of the stakes before taking them to the site.
- 160 oyster bags (12 for each log in front cusp and extras used around joints)
- Coconut Fiber Twine (approximately 300’ for this size treatment)
- 640 Spartina plugs (~40 plugs per log) plus any salvageable plants and mussels

5) Installation

This section gives a step-by-step method for how to install an entire DELSI site.

1) Complete a site survey to determine elevations were the current vegetation is growing successfully. This could be done with an RTK GPS or Total Station.
2) Mark out with flags where logs are going to sit at the right elevation in a cusp shape
3) Install the Coir fiber mat:
   a. Carry mat to one end of the treatment site (about 200 lbs.) and unwrap plastic.
   b. Position mat so that it can be pushed and rolled out flat.
   c. Roll out the mat at the elevation where the logs will sit and in a cusp shape.

d. When you reach the end of the desired site, flip mat and roll back for second row of logs.

4) Carry logs and position in cusp shape on top of mat. The logs should be positioned end to end with the ends slightly overlapping. Tie logs ends tightly together with coir twine.

5) Lay out 12, 4' pre-drilled stakes per log, 6 on each side of each log parallel from each other. Put a flat side of the stake tightly against the log and push the stake through the mat under the log

and into the soil. Hint, don't drill the hole too close to the end of the stake or the stake may break when hammering it into the soil. A distance of 3- 4 inches down the end is sufficient.

6) Hammer in stakes tightly against logs (6 on each side of log) until pre-drilled holes are flush with top of logs.

7) Cut twine into 5 foot lengths and use one piece for every pair of stakes across from each other on the logs. Loop the twine through the hole of one of the stakes. On the first stake, tie a bowline or similarly secure knot around the stake. Then thread the twine through the outer mesh at the top of the log, pull the twine tight, thread it through the second stake and tie a few half hitches to secure it. Then hammer the stake down until they twine is snug against the log.

8) Reinforce with shell bags lined up end to end in front of each log and place extra shell bags at edges and at joints between logs. Shellbags are made by filling plastic mesh bags with oyster

shell and tying off each end of the plastic bag with overhand knots. An easy way to fill the bags with shell is to use a long PVC pipe as shown and put bag around it. Then pull the PVC out when bag is full and tie of the second end of the bag. The oyster bags are laid in a row in front of the seaward log and extras are placed at the joints between the logs.

6) Planting

Plants and animals require various conditions and the types of target communities for a particular site and project will need to be chosen based on sustainable conditions for the target assemblage. The Delaware Estuary Natural Vegetation Classification System (NVCS) could be one tool to find the native plant communities at a particular site: http://www.delawareestuary.org/science_programs_plant_communities.asp .

Spartina alterniflora plugs were planted into the logs and grass/mussel clumps salvaged from the surrounding shoreline was planted behind the logs.

The focus for DELSI was the common salt marsh cord grass *Spartina alterniflora*. Two considerations are the timing of planting and source of grass for planting.

1.) Timing of planting
   a. Spring is the best time to plant grasses because it gives the plants an entire growing season to become established and take a firm hold before winter sets in.
   b. Wait until sediment has accumulated behind logs and in logs, which can vary from weeks to months. If sediment accumulation is slow and the project permit allows (consider this potential need in your permit application), fill that matches local sediments may be added.
2.) Source of marsh cord grass
   a. Once sediments have accumulated, clumps of marsh grass that have eroded from nearby marsh edges and fallen below the intertidal zone for grass survival can be salvaged and planted in the accumulated sediments. Place the clumps behind logs and push the roots into the accumulated sediments. For DELSI, about 16-20 bushel baskets of salvaged clumps were used per site.
   b. Plugs of *Spartina alterniflora* can be purchased from a wholesale native plant nursery (e.g., Pinelands Nursery in Columbus, New Jersey) and planted directly into the logs. Insert 2-4 plugs per foot on each log and secure them under the coir fiber netting. After trying several techniques we found that two foot sections of ¾" pvc pipe cut at an angle on one end easily created small holes in the logs in which plugs could be planted. Once planted, the twine forming the outer log was pulled over the plug to help secure it in place. Although the Spartina plugs can be planted immediately upon installation of the logs, we found that it was much easier to plant plugs into the logs after the logs had

been in place for a couple weeks, which allowed them to become waterlogged from repeated high tides and to accumulate sediment between the fibers.

Before and during planting Spartina alterniflora plugs.

Before and during planting Spartina alterniflora salvaged clumps.

7) Mussel Application

The ribbed mussel *Geukensia demissa* naturally attaches to the roots of *Spartina alterniflora.* This association provides refuge to the mussels from predators, nutrients to the grass from mussel waste, stability to the marsh edge, and increased biological diversity. Hatchery production methods for ribbed mussels are being developed so juvenile seed is not readily available from nurseries. We hope to resolve this problem soon. Until then the best source of mussels is from adjacent habitats where they exist in such high abundance that harvesting a small fraction of the population will not harm the population or the habitat. The best method that we developed for attaching mussels to logs was as follows and worked for juveniles as well as large adults. Larger mussels will be less susceptible to predators.

Mussels attached to the coir mat in the lab overnight.

Coir fiber log with attached mussels. They migrate together in clumps.

1) Cut sections from a coir mat into strips 1-2 ft wide by 3-6 ft long.
2) Soak sections in a water table with mussels laid on top for a minimum of 24 hours. Longer is better, but will require feeding the mussels using a flow through system or the addition of phytoplankton (live microalgae or a commercial shellfish diet will work). The mussels will attach to the coir fiber with their byssal threads overnight, but the longer they are left in the water table, the stronger they will attach.
3) Roll mats with mussels on the inside for transportation to living shoreline. Unroll the mats on the top and front (waterside) of logs comprising the living shoreline and tie each mat to the log with coir twine. If the weave of the mat is tight, cut holes in the mat to ensure adequate flow of water to the mussels.

Carrying the attached mussels and mat to the site.

Tying the mats with attached mussels to the log with cable ties or twine.

4) A second method we are testing that holds promise and may be more efficient, is to place juvenile mussels at the base of the *Spartina alterniflora* plugs in the lab for several days before planting the plugs in the logs. The mussels attach to the plants with their byssal threads.

Juvenile mussels attached to roots of Spartina alterniflora plugs.

Coir mat eventually breaks down leaving mussels securely in logs.

Salvaged clumps of Spartina may provide another source of mussels to add. Mussels in salvaged clumps should be left attached to the clumps and can help become attractants for natural recruitment. We did find that mussels recruited to the coir logs as well as the stakes used to hold the logs down.

In some states (or regions within states), oysters may also be included in the design. Oysters would be targeted towards the lower intertidal and shallow subtidal zone with mussels used in the mid to high intertidal zone. Planting oysters is currently forbidden in waters closed to shellfish harvesting in NJ and was not part of our DELSI project. To date oysters that have naturally recruited onto shell bags used in the treatments have not survived to adulthood.

III. Estimated Costs

The average cost per linear foot of mussel-based living shorelines with coir fiber logs is approximately $50-$100 including log, mat, shellbag, and plant material costs. This is relatively inexpensive when compared to bulkhead costs which can be $500-$1500 per linear foot. Labor and materials may benefit from economy of scale for larger projects. For large-scale projects, contractors would need to be hired for installation.

A protected shoreline may stem the loss of much larger areas of marsh that are landward of the edge and are often situated lower in the tidal prism, which makes them more vulnerable to drowning from sea level rise or simply loss of the natural shoreline levee. Economic evaluations of ecosystem services such as flood protection are just beginning to be tallied, and we merely list these benefits qualitatively here.

Table 5. Cost comparisons of bio-based living shorelines materials vs. bulkheads

	Materials and Supplies	Cost Range (does not include labor costs)
MUSSEL & PLANT TACTIC	Plants- Spartina alterniflora plugs	$1.00-$2.00 per linear foot
	Coir Fiber Logs 16"X12' Premium	$16-$20 per linear foot
	900 COIR MAT 120SY (6'6" x 164')	$2- $3 per linear foot
	COIR Twine (approx. 1 bundle for 3 logs)	$25.00 per bundle
	2"X2"X48" Stakes (12 per log)	$1.75 each
	Oyster Shell Bags	$5.00 per linear foot
MARSH SIll or BREAKWATER	Rip Rap	$18-$35 per cubic yard
	Wave Attenuation Device	$180- $250 per linear foot
	Reef Balls	$44 per linear foot
	Reef Block	$150 per linear foot
BULKHEAD	Vinyl	$125-$285 / linear ft.
	Wooden	$115-$265 / linear ft.
	Concrete	$500-$1000 / linear ft.
	Sheetpile	$700-$1200 / linear ft.
	Rip Rap	$18-$35 / cubic yd.

IV. Resources

Environmental Concern Living Shoreline Restoration Projects

http://www.wetland.org/restoration_home.htm

North Carolina Living Shoreline Restoration and Education

http://www.nccoast.org/restoration-education/living-shorelines.asp

Center for Coastal Resources Management (CCRM) at VIMS

CCRM Presentations: Putting Nature to Work: How to Design and Build Living Shoreline Projects - October 24, 2008 A daylong workshop concerning Living Shorelines with all presentations online. http://ccrm.vims.edu/education/seminarpresentations/fall2008/index.html

Living Shorelines at Center for Coastal Resources Management/VIMS

Excellent resource page about Living Shorelines with multiple links to other sources concerning design options, definitions, projects, documents, agencies, photo gallery, etc. http://ccrm.vims.edu/coastal_zone/living_shorelines/index.html

Education: Living Shoreline Design - A class for marine contractors

Center for Coastal Resources Management at VIMS with funding from the Chesapeake Bay Restoration Fund, has developed curriculum to educate shoreline project designers and contractors about the use of "Living shoreline" designs. The course stresses the recommended design criteria and the interactions between upland riparian zones, wetlands and the aquatic system. http://ccrm.vims.edu/education/ls_design_class/index.html

Living Shorelines Summit

This document contains information designed for coastal managers, policy-makers, landowners, marine contractors, engineers, scientists, and regulators on the practice of, construction of, and case studies for living shorelines. http://www.vims.edu/cbnerr/coastal_training/recent_workshops/ls_summit.php

NOAA Restoration Portal – Living Shorelines

Information about the description, implementation, projects, publications and resources for living shorelines and federal and state contacts. https://habitat.noaa.gov/restorationtechniques/public/shoreline_tab1.cfm

Coastal Issues: Shoreline Management - Living Shorelines at VA DEQ

Lists information and sources about Living Shorelines related to Virginia. http://www.deq.virginia.gov/coastal/livingshore.html

Chesapeake Bay Trust

Source of grants to perform construction of Living Shorelines and projects to protect the Bay. http://www.cbtrust.org/site/c.enJIKQNoFiG/b.2020005/k.BD51/Home.htm

Gloucester Master Gardeners Living Shorelines Page

Excellent source of information, web sites, guides, books about living shorelines and a tremendous shoreline glossary, etc.
http://www.gloucesterva.info/ext/mastergardener/LivingshorelinesLinks.htm

In Your Backyard: Resources by the Chesapeake Bay Foundation

Contains information about BayScapes, living shorelines, native plants, shoreline protection, resources and many other similar topics.
http://www.cbf.org/Page.aspx?pid=525

Maryland Shorelines Online

Information about Living Shorelines in the State of Maryland. It includes frequently asked questions, locations of living shorelines, etc.
http://shorelines.dnr.state.md.us/living.asp

"Living Shorelines" Offer Protection, Habitat along Bay's Edge

Information about an alternative option to shoreline hardening that protects properties while also preserving habitat and clean water in the Chesapeake Bay. Mentions that living shorelines have been installed for more than 20 years in the Chesapeake region.
http://www.chesapeakebay.net/news_livingshorelines08.aspx?menuitem=31276

V. Frequently asked questions

-The marsh near my house is being battered by big waves from Delaware Bay and seems to be washing away quickly – can DELSI help?
-If the existing marsh edge has mussels and plants and is still eroding, isn't it just a matter of time before it washes away anyway?
-Do you need to plant with marsh plants and mussels?
-If permitting is easier for hard tactics, why should I use a LS approach?
- Do I have an erosion problem?
- What kind of living shoreline project is most suitable for my property?
- Do I need permits for a living shoreline project?
- What if my property is currently defended by a revetment or bulkhead?
- What plants are suitable for living shorelines and where can I buy them?
- How do I plant tidal marsh grasses along my shoreline?
- How do living shorelines perform during a nor'easter or hurricane?
- How much does a living shoreline project cost?
- Are there photographic or on-the-ground examples of various kinds of living shoreline treatments?

The marsh near my house is being battered by big waves from Delaware Bay and seems to be washing away quickly – can DELSI help? Probably not by itself. DELSI is best applied to shorelines that are suffering mild to moderate erosion from the effects of sea level rise. For high energy locations, shoreline stabilization might require more aggressive tactics such as installation of nearshore breakwaters combined with DELSI onshore.

If the existing marsh edge has mussels and plants and is still eroding, isn't it just a matter of time before it washes away anyway? Yes and no. If nothing further is done after a DELSI installation, the marsh is likely to still wash away, but it will take much longer to do so. Since DELSI is cheaper than traditional hard tactics, it might be necessary to repeat the treatment periodically to sustain the shoreline configuration and this still might be cheaper than maintenance of hardened shorelines (while also yielding other environmental benefits).

Do you need to seed living shorelines with marsh plants and mussels? In areas where there is high recruitment of mussel spat and plants are healthy, it might be possible to rely on natural colonization. However, we recommend that even in this case that the installations be seeded to expedite establishment and stabilization of plant and animal communities, which bind the sediments together. The presence of adult mussels might also attract and enhance recruitment.

If permitting is easier for hard tactics, why should I use a LS approach? The benefit to cost ratio is likely to be higher for mussel-based LS as long as the criteria are met and there exists a long-term commitment to maintaining a site. Soft shorelines are more environmentally friendly than hardened shorelines which are generally not good fish and wildlife habitat. Under ideal conditions, mussel-based living shorelines also have the potential to naturally build up their elevation as sea level rises, whereas hard structures will gradually become submerged and less effective.

Do I have an erosion problem?

Erosion is a natural process occurring along most Delaware Bay shorelines. Bare soil areas without vegetation, numerous fallen trees, collapsing banks, and gradual shoreline retreat are all signs of erosion. Not all erosion is a problem that needs to be corrected. If the erosion rate is very slow and the risk is low if the erosion continues, then consider leaving the shoreline in a natural condition. If the erosion cannot be tolerated and needs to be reduced, then first consider if a living shoreline method could be effective.

What kind of living shoreline project is most suitable for my property?

The best project type depends on location and the type of erosion. Look for existing natural buffers, such as bank vegetation, tidal marshes, and sand beaches. These features indicate suitable growing conditions for plants and they can be enhanced to improve erosion protection. Click here for an **alternatives analysis** to help you decide what stabilization method is most suitable for your situation (VIMS Decision Tree).

Do I need permits for a living shoreline project?

Yes, most shoreline projects require at least one permit. Any shoreline alteration has the potential to impact the environment or adjacent property owners. The permit process is required by laws designed to balance the need for shoreline management with environmental protection.

What if my property is currently defended by a revetment or bulkhead?

Even if your property is already protected from erosion, you can enhance the existing vegetation buffers near the shoreline, most simply by not mowing frequently close to the water. You can also capture rainwater and re-direct stormwater runoff away from the shoreline. Failed bulkheads on quiet tidal creeks can be replaced with bank grading and restored vegetation buffers. A decision tree on how to **evaluate currently defended shorelines** is being developed.

What plants are suitable for living shorelines and where can I buy them?

There are many native plants adapted to the conditions along Delaware Bay shorelines. Waterfront landscape designs should include plants that can tolerate high winds, salt water flooding and salt in the air. There are several **native plant nurseries** that provide these plants or you can ask your local nursery to find them for you.

How do I plant tidal marsh grasses along my shoreline?

The first thing to consider is the presence or absence of tidal marsh grass in the vicinity. If the shoreline has no existing marsh grasses, then the growing conditions may not be suitable. The water may be too deep during high tide and/or there is not at least 6 hours of full sun on the shoreline every day in the summer. If there is existing marsh and plenty of sunlight, then growing conditions may be suitable.

How do living shorelines perform during a nor'easter or hurricane?

Severe storms cause catastrophic erosion in a short period of time. All shoreline stabilization structures have a limited tolerance for storm damage, including revetments and bulkheads. Living shoreline projects with gradual slopes and integrated vegetation buffers are surprisingly resilient. It is important to know what to expect at your location and to properly design a project for the expected conditions.

How much does a living shoreline project cost?

The construction costs for living shoreline projects and other stabilization methods vary widely depending on the shoreline length, level of protection needed, and the costs for materials and labor. Non-structural methods cost an average \$50 - \$100 per foot, such as beach nourishment and planted marshes. Projects with sand fill and/or stone structures typically cost \$150 - \$500 per foot. This does not include permitting costs. Upfront construction cost is only one factor to consider. The value of ecosystem services provided by living shorelines help offset these costs indirectly over time.

Appendix A. Case Study: The Delaware Estuary Living Shoreline Initiative (DELSI)

The Delaware Estuary Living Shoreline Initiative consists of a broad array of activities, including: the development and testing of new living shoreline approaches, regional planning for living shorelines, preparation of tailored recommendations that match tactics with local needs, and educational programs to build awareness of living shoreline options. Led by the Partnership for the Delaware Estuary (PDE) and Rutgers Haskin Shellfish Research Laboratory (Rutgers), DELSI began in 2008 as a R&D project to test whether some form of intertidal, shellfish-based living shoreline could be developed for use in the Delaware Estuary, similar to oyster-based tactics developed in warmer areas of the United States where oysters can survive in the intertidal zone. This report summarizes the new tactic that was developed, which encourages native mussels and smooth cordgrass to colonize coconut fiber products used to stabilize intertidal erosion along salt marshes edges. As a resource for restoration practitioners and managers, we also summarize the main attributes of living shorelines and provide an inventory of other living shoreline tactics currently available or in development, which we expect to be useful in stabilizing erosion in the Delaware Estuary. Currently, the expanded DELSI (R&D, planning, outreach) is engaging diverse partners throughout the region, including outside the Delaware Estuary, in a shared effort to advance living shorelines as an example strategy to combat coastal flooding (i.e., climate adaptation, PDE 2010) and to sustain and enhance water quality and fish and shellfish production (PDE 2011). If eventually enacted on a large scale, living shorelines also have promise for sediment trapping, which might help stem maintenance dredging costs and benefit regional sediment management goals.

Although living shorelines can help stabilize diverse types of coastal landscapes, DELSI targets tidal wetlands for stabilization and ecological enhancement. Tidal wetlands are a critical habitat and increasingly imperiled in the Delaware Estuary, as elsewhere in many areas of the Mid-Atlantic region where sea level is expected to rise quickly than most other parts of the world. Hence, the principal focus of the DELSI tactic described here is marsh habitat stabilization and enhancement, using living shellfish communities and vegetation to “soft armor” shorelines and arrest erosion.

In many areas of the Delaware Estuary, tidal marsh edges are eroding so rapidly that natural shellfish communities do not have sufficient time to recruit and establish themselves. Deployment of natural substrates combined with directed seeding with bivalves and planting of vegetation is used to give living shorelines the time and means to “set up” ahead of the erosion rate. The primary innovation of the DELSI tactic is to foster healthy communities of ribbed mussels and smooth cordgrass, which naturally live in mutualism along intertidal marsh edges for habitat restoration. Dense beds of mussels and plants bind together and form a natural levee system. DELSI takes advantage of this relationship by enhancing or restoring mussel/plant assemblages along marsh shorelines. The purpose of this report is to describe DELSI as a standard, cost-effective methodology for more widespread use. Ultimately, we hope that DELSI method will help to conserve important habitat and strengthen overall ecosystem services throughout the Delaware Estuary, along with other living shoreline tactics (See Appendix A).

Advantages of the DELSI bio-enhancement tactic for salt marshes include:

- **Uses only natural products** to temporarily control or reduce erosion in order for naturally armored shorelines to develop
- Attracts natural recruitment of mussels and **encourages expansion of marsh grasses** along erosion zones of salt marshes.
- Can help mitigate erosion impacts associated with boat wakes or other activities that increase energy along shorelines from currents, waves, and sea level rise.
- **Can be combined with other tactics** such as hard structures, breakwaters, sills, and subtidal oyster reef enhancement where high energy or other local features warrant.
- **Cost is comparable to or lower** than traditional hard tactics to control erosion.
- Has the potential to vertically accrete with sea level rise due to natural levee-building processes associated with dense mussel/plant communities.
- Restores ecological and functions and habitat productivity lost in hard structural solutions.

Some disadvantages of the DELSI tactic are:

- Successful in low energy areas only, such as, along tributary systems where fetch is limited.
- New tactic - long term success/durability is uncertain and could require future augmentation. Requires testing in additional locations over longer periods of time.

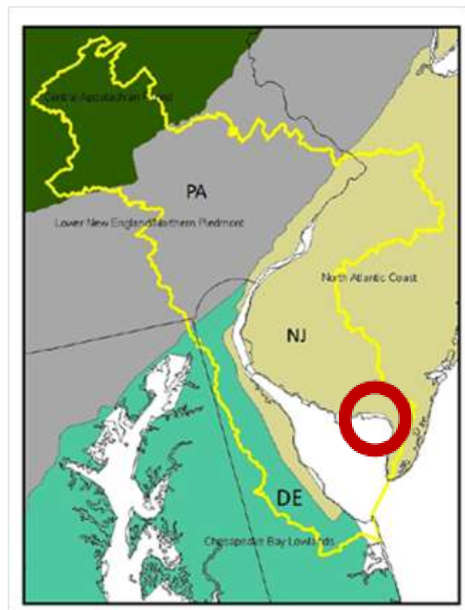

Figure 1. Location of study sites in the mouth of the Maurice River, Cumberland County, New Jersey.

We believe that the advantages far outweigh the disadvantages in low energy systems and recommend this DELSI bio-enhancement approach or a similar tactics wherever possible, even if in combination with more traditional tactics. This practitioners' guide describes each step of the process for creating mussel/plant/fiber enhanced enhance living shorelines from the initial design and materials to installation methods to monitoring. The permitting process and costs are also discussed and will hopefully aid future living shoreline project planning. The next section describes research and development of the strategy by the Partnership for the Delaware Estuary and Rutgers' Haskin Shellfish Research Laboratory over the last several years. The subsequent section provides a step-by-step guide to execute this particular type of living shoreline on your own. Stay tuned for future DELSI products from PDE, Rutgers and additional partners as this effort continues to expand.

DELSI Research and Development Project Overview

Figure 2. Four DELSI sites along the Maurice River.

DELSI was conceived jointly by shellfish ecologists, Dr. D. A. Kreeger (PDE) and Dr. D. Bushek (Rutgers), in 2007 in an effort to replicate successful oyster-based living shoreline projects elsewhere (e.g., North Carolina, South Carolina, Alabama, Louisiana, etc.). In the southeast oysters naturally form extensive, fringing intertidal reefs. Soft-armoring of eroding marsh edges with oysters has been found to help counteract marsh loss (Meyer et al. 1997). Unfortunately, oysters do not form extensive intertidal reefs in Delaware Bay (Taylor and Bushek 2008). Ribbed mussels are a functional dominant animal of Mid-Atlantic tidal marshes, where they are most numerous along the intertidal edges that are most prone to erosion.

Figure 3. Mussels attach to Coir fiber within 24 hours.

Working with others at the Partnership for the Delaware Estuary and Rutgers, Drs. Kreeger and Bushek received several research grants to develop a pilot test of their DELSI concept at eroding areas in the Maurice River tributary. Designed as a restoration research and development project, several tactics were tested alone and in combination along an energy gradient to identify an optimal strategy. The method described here is based on the best outcomes of this project.

Four study sites at the mouth of the Maurice River in southern New Jersey were selected areas with varying levels of erosion exposure from wind driven wave action, boat wakes, and tidal currents (Figure 1 and 2). Energy was quantified and compared among sites by measuring the dissolution rate of plaster of paris clods placed at the same intertidal height, overnight at each site. All sites had prevailing salinities above 8 psu, varying densities of ribbed mussels, *Spartina alterniflora* and evidence of erosion along the seaward margin.

At each site, a variety of DELSI treatments were installed beginning in 2008, and their performance was compared among sites and with controls at each site. Performance was assessed by evaluating which treatments best stabilized marsh edge erosion and aided establishment of shellfish and plants along the shoreline.

Figure 4. Storage of coir fiber products, boat usage and labor to install small scale living shoreline project.

Materials used to reduce erosion and attract shellfish were coir (coconut fiber) logs and mats, oyster shell bags, and cement coated wooden stakes. Shell bags have been successfully employed to build intertidal reefs in several states including New Jersey (Taylor and Bushek 2008). Coir products are routinely used in erosion control, but have not been used in salt water marshes nor as a substrate to attract mussels. We demonstrated that ribbed mussels will readily attach to coir fabric within 24 hours (Figure 3). In total, 71 coconut fiber (coir) bio-logs (20 ft long and 12 or 16 inch diameter) were positioned in the high, mid or low intertidal zone in various ways; 10 coir mats (150 x 6 ft) were also positioned in the mid intertidal zone under logs, 19 sets of 20 oyster cultch shell bags were positioned in the mid to low intertidal zone, and seven sets of 45 cement-coated wooden stakes were positioned in the low intertidal zone. Installation of living shoreline treatments began at each site along the Maurice River in June 2008 and continued into November. These efforts progressed more rapidly as we developed methods and skills to move and manipulate the logs and mats along the muddy shorelines (Figure 4). Through 2009 and 2010, these treatments were adaptively managed and augmented, sequentially building on lessons learned and testing new modifications. The logs were initially arranged in a single chain in a straight line. The next method tested was a double row configuration in a cusp shape with shell bag armoring (Figure 5). This second method was the most successful and is described in detail in the Installation Guide section III. To determine initial sediment elevation, each installation and control area was surveyed using a Sokkia Topcon Total Station with the USGS benchmark AA7224 in front of the Haskin Shellfish Research Laboratory as a reference.

Figure 5. Progression of log configuration.

One of our major goals was to enhance the mussel-dominated assemblage along eroding edges of marshes in the saline region of the Delaware Estuary. Ribbed Mussels (*Geukensia demissa*) are a functionally dominant species in the ecology of salt marshes along the Atlantic Coast (Kuenzler 1961, Jordon and Valela 1982). They attach to plants and each other with strong, hair-like byssel threads. Their filter feeding helps move suspended particles to the marsh surface, aiding in sediment capture and nutrient fertilization of the edge where they are most abundant. The interaction between mussels and marsh grasses synergistically elevates the marsh at the waters edge to create a natural levee. This "levee building" feature combined with our observation that marshes appeared to erode faster in areas without many mussels formed the basis of our premise that ribbed mussels were a suitable target shellfish species for DELSI. Moreover, ribbed mussels are not a commercial species, which alleviates problems associated with their potential harvest[1].

Once formed, dense shoreline assemblages enhance intertidal habitats and likely provide many benefits to the marshes behind them. In addition to using a variety of approaches and natural fiber products to stabilize shorelines and catch recruitment of mussel spat, treatment stabilization was facilitated by seeding with plugs of *Spartina alterniflora* and ribbed mussels recovered from marsh that had eroded and broken away, or from a hatchery. Adding ribbed mussels into a treatment should stimulate more rapid colonization and expedites overall stability.

Bagged oyster shell cultch was used to stabilize the foreshore immediately seaward of coir logs. Meyer et al. (1997) reported that using oyster cultch in North Carolina stabilized along marsh edges led to positive accretion of sediment, whereas non-cultched areas lost sediment. Both shell bags and coir logs produced positive stabilization and accretion in the Maurice River project. Although oyster shell was primarily used to enhance stability in this project, some treatments did attract recruitment of oyster spat. Hence, where allowed by NJ law, recruitment of oysters in the adjacent low intertidal and shallow subtidal areas may work in tandem with efforts to establish intertidal mussel beds along the vegetated margin.

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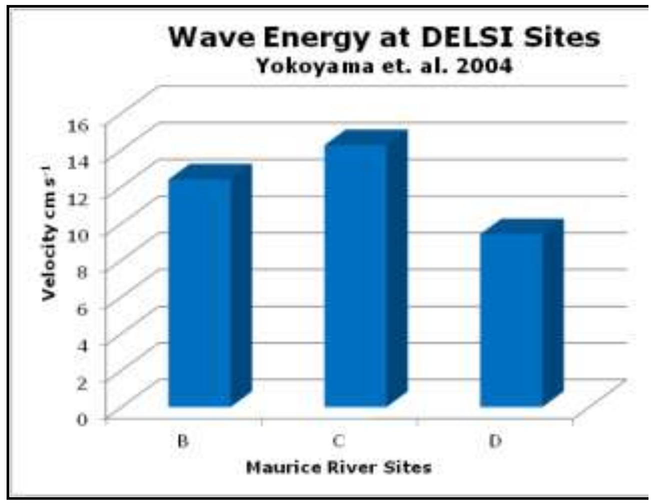
[1] In addition to the direct concern of harvest impacting a restoration project, in 2010, the state of New Jersey banned restoration of commercially harvested species of shellfish in waters closed to their harvest for shellfish sanitation reasons.

Findings from 2008-2011 continue to guide our efforts and guide other efforts throughout the state and region. For additional updates, please refer to the PDE website, http://www.delawareestuary.org/science_projects_living_shoreline.asp . The findings presented here are the first step in developing living shoreline strategies for the Delaware Estuary. Additional research is needed to (1) further establish the relationship between shoreline mussel assemblages and erosion (e.g., what densities protect under what conditions, etc.), (2) identify the habitat value/impact of forestalling erosion with these methods versus alternative methods, (3) quantify other ecosystem services provided by ribbed mussels along marsh shorelines (e.g., how do they impact phytoplankton and bacterioplankton), (4) identify the most efficient means to create or enhance ribbed mussel communities, and (5) assess the long-term outcomes.



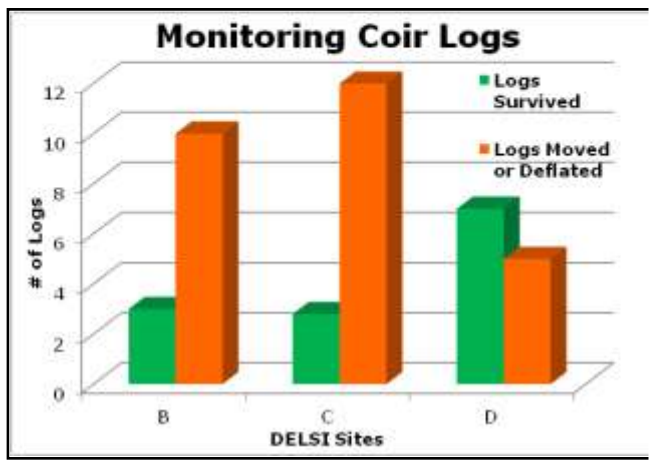


Figure 6. Energy impact on survival of logs from high energy sites (B and C) to low energy sites (D).

DELSI Study Results and Recommendations

As a research study, DELSI tested a variety of treatment approaches and materials combinations, leading to a variety of outcomes beginning in 2008. Thereafter, treatments were adaptively managed. Important variables for success included the type of natural materials installed and the orientation of logs relative to prevailing boat wakes, currents, and other shoreline features. The methods prescribed here led to the best outcomes, but please note that every site will have local conditions that are likely to require some adaptive management. As general rules of thumb, we found that:

- Mats help support logs and shellbags, but are ineffective by themselves
- Oyster shellbags placed in front of logs increases logs survival
- Logs should not be tucked against vertical erosion faces (cut banks) where waves are abruptly stopped

Photo 1. Successful sediment trapping behind logs.

- Log deployment plans were most successful when installed in a convex arc from two points spanning one or more eroding scallops, capturing approximately 50-100 feet of shoreline. Logs should be overlapped on their ends rather than installed end-to-end, and overlaps should be set up with the downstream log on the outside as this was generally the stronger direction of oncoming wave action and energy. Additional detailed guidelines are furnished in later sections. When these guidelines were followed, DELSI treatments usually yielded rapid sediment-trapping, often fully backfilling to the top of the logs within days (Photo 1). Double-log and overlapping treatments produced the deepest sedimentation. Wherever sediments accumulated, a rich microphytobenthic mat formed was observed that likely helped retain the accumulating soft sediments (Figure 7). Microphytobenthic communities remove nutrients from the water column and provide an important energy source for many organisms foraging along the marsh edge.

Figure 7. Results after log installation show sediment trapping with algal mats and survival of planted marsh grass and ribbed mussels.

Ribbed mussels and grass planted into logs survived and grew well on the treatments where this planting strategy was attempted (Figure 9). Furthermore, natural recruitment of mussels and oysters occurred on logs and shell bags; however, we recommend that natural recruitment by augmented with direct planting of live shellfish and plants because of patchy, unpredictable natural recruitment. Various options exist for planting mussel seed or salvaged adults, for example. Once smooth cordgrass and ribbed mussels are incorporated into the treatments, we found that they grew quickly so long as the elevation of the treatment within the tidal prism matched their needs.

While the project was tested in marshes experiencing erosion along the New Jersey coast of the Delaware Estuary, we are confident that the resulting method will work elsewhere in comparable eroding salt marshes of the Mid-Atlantic, thereby expanding the arsenal of restoration tools that can be applied to combat wetland loss. When adapted for local conditions (ex. energy and salinity), the technique should also be useful in concert with other tactics (ex. hybrid living shorelines and possibly also activities undertaken by community groups). As the ecological value of shellfish to coastal ecosystems is becoming more widely recognized, shellfish restoration efforts are also increasing in number throughout many areas of the nation. Recently, Brumbaugh et al. (2006) published a guide for establishing and monitoring shellfish restoration and the Atlantic States Marine Fisheries Commission recently published an extensive review of the importance of shellfish created habitats (Coen and Grizzle 2007). Oyster reefs, for example, have been found to provide refuge from predation, nursery grounds, and foraging areas for larval and juvenile fish species (Coen and Luckenbach 2000; Luckenbach et al. 2005). The species diversity and abundance of fish have also been shown to increase following shell additions to oyster reefs in the Chesapeake and Carolina regions (Luckenbach et al.2005; Coen and Luckenbach 2000; Breitburg et al.2000) and data is accumulating for Delaware Bay (Taylor and Bushek 2008). The oyster revitalization effort in the Delaware Estuary (e.g., Babb et al. 2005) exemplifies the increased national attention on shellfish restoration, and the DELSI tactic described here builds on these efforts by considering the full range of bivalve species that exist throughout the salinity gradient. As discussed above, the DELSI treatment may not work in areas subject to heavy wave action, currents, or

Table 2. Summary of findings from DELSI treatment experiments 2008-2011.

Premium COIR logs be installed in a linear sequence to form a continuous seaward cusp that encloses an eroding area of marsh	Logs should be anchored with the longest possible oak stakes and tied in as described below	The energy level should be mild to moderate, typically found along tributary creeks or in areas protected from severe wind and wave erosive forces	The elevation of installations should be set to take capture sediment and encourage marsh formation/stabilization in a zone that takes advantage of optimal growth conditions for plants, often at or slightly above the elevation of the existing marsh.	Installations should be planted with marsh plants and mussels as soon as possible to expedite stabilization and sediment capture. Plants and mussels can either be propagated in nurseries/hatcheries or salvaged from the foreshores of newly eroded marsh areas

steep slopes. More substantial tactics or hybrids (described in Appendix A) that include DELSI will be needed in high energy locations. Continued monitoring is also recommended in any installation to quantify sedimentation, shellfish and *Spartina* recruitment, changes in habitat usages, and changes in shoreline relative to control sites, thus helping us accumulate a body of evidence to further optimize future bio-based living shorelines in the Mid-Atlantic region.

Monitoring

Monitoring successful living shorelines installations is important and should ideally include vegetation surveys, mussel surveys, sediment deposition, and fish/nekton use. The success of any living shoreline is dependent upon adaptive management that requires regular monitoring of performance. To evaluate performance and eventual success, specific goals must be established prior to installation and the site must be described in detail before work begins. For the DELSI treatments on the Maurice River, our goals were (1) to quantify the effectiveness of for coir mats at trapping sediments and stabilizing erosion, and (2) to establish methods to seed biology based living shorelines with *Spartina alterniflora* and *Geukensia demissa*. One finding from the DELSI study found similar fish and crab abundance and species in treatments and controls, suggesting no impairment from the treatment.

Adaptive Management

Living shoreline structures can help contain large sediment loads and help modulate flows. However, they do need to be maintained to function effectively. It is very important to maintain effective erosion control in newly established wetlands due to wave action or upland erosion. The effects of a storm event on a newly planted marsh can easily be mitigated with additional plantings. Significant upland erosion that deposits large amount of sediments into a new established wetland can smother plantings. It can also cause hydrological modifications and alter elevations within the wetland that would alter vegetative communities and, perhaps facilitate the invasion of non-native plants such as *Phragmites*.

In areas with populations of the common reed *Phragmites australis*, extraordinary measures are often necessary to eliminate existing stands and prevent recolonization. It is important to design the majority of the site below MHW. In areas of moderate to high salinity, this can be a very effective deterrent. *Phragmites* control is an issue that requires continuing vigilance including at least semi-annual inspections and a comprehensive plan to treat future infestations.

The accumulation of debris, such as *Spartina* stems, eelgrass leaves, or even trash, can smother and devastate newly planted marshes. Care needs to be taken on any windward shore, particularly in coves facing the dominant wind direction. The only remedy is surveillance and removal.

If plants are not growing properly, it is possible that the correct elevation was not established for that species. We learned that we can increase the elevation of the site by adding another row of logs on top of the existing logs by laying a new mat and staking them into the mud that has accumulated behind the existing logs.

BEFORE: Marina in New Jersey's Heislerville Fish and Wildlife Management Area in April of 2010.

BEFORE: Day of installation of coconut-fiber (coir) logs and mats in New Jersey's Heislerville Fish and Wildlife Management Area in May of 2010.

AFTER: One year later, June 2011, native marsh grass can be seen flourishing in the soil that has collected behind the new "living shoreline." Not only does this defend land against destructive waves, but also it serves as fish habitat during high tides.

AFTER: September 2011- the site remained stable after Hurricane Irene and Tropical Storm Ike.

Appendix B. Living Shorelines Inventory

To provide a context for the tactic described in Sections II and III, we briefly summarize the diversity of living shoreline tactics being used today. This inventory is not meant to be comprehensive of all living shoreline types, but provides background information for the most common types of living shorelines.

"Bio-Based" Design Options

Riparian Vegetation Management

The purpose of this tactic is to increase vegetation, both in abundance and diversity, for the purpose of stabilizing a bank. This includes trimming tree branches overhanging a marsh to increase sunlight, selectively choosing desirable plants for natural regeneration, or planting. Using vegetation buffers can be used to intercept stormwater runoff and control invasive species that degrade habitat and stabilization. Most tidal shorelines are suitable for some type of riparian vegetation management and enhancement activities.

Beach Nourishment and Dune Restoration

Beach nourishment is the addition of sand to a beach to raise elevation and increase width to enhance its ability to buffer the upland from wave action. Dune restoration is the process of reshaping and stabilizing a dune with appropriate plants usually after a beach nourishment event. Common plant species for Chesapeake Bay beaches and dunes include *Ammophila breviligulata*, *Panicum amarum,* and *Spartina patens*.

These actions are best suited for gently sloping, sandy beach shorelines with low erosion. Beach and bank erosion may still occur during storms. Periodic replenishment is usually needed to maintain the desired beach profile. This method may not provide sufficient protection where no beach currently exists or where tidal currents and wave action remove sand rapidly.

Tidal Marsh Enhancement

Tidal marsh enhancement includes adding new marsh plants to barren or sparsely vegetated marsh areas. Sand fill can be added to a marsh surface to maintain its position in the tide range or to increase its width for more protection. Replacing marsh plants washed out during storms also fits into this category. Less mowing of wetland vegetation can also enhance the stabilizing and habitat features of a tidal marsh.

Suitability

Shorelines with existing marshes or where marshes are known to have occurred in the recent past may be suitable for this treatment. Water depth and the amount of sunlight available are key factors to consider. A wide, gently sloping intertidal area with minimal wave action also indicates suitability.

Tidal Marsh Creation

Tidal marsh creation can be applied where a natural marsh does not exist. Non-vegetated intertidal areas can be converted to a tidal marsh by planting on the existing substrate. Because a wide marsh is needed for effective stabilization, this method normally requires either grading (see next section) the riparian area landward or filling channelward into the subtidal area for a wider intertidal zone. The plant species will depend on the local salinity range plus the depth and duration of tidal flooding. Two common tidal marsh grasses used for this purpose are *Spartina alterniflora* and *S. patens*.

The most suitable shorelines for tidal marsh creation have wide, gradual slopes from the upland bank to the subtidal waters, a sandy substrate without anaerobic conditions, and plenty of sunlight. Extensive tree removal in the riparian buffer just to create suitable growing conditions for a tidal marsh should be avoided, especially if the forested bank is relatively stable (Smith 2006). Salt marsh plants have a limited tolerance for wave action. The wave climate and the frequency and size of boat wakes must also be considered (Perry 2001).

Bank Grading

Bank grading physically alters the slope of a shoreline segment, to ease shorelines with steep slopes. It is recommended to plant graded plots with vegetation which will form dense and deep root mats. Vegetation creates a buffer for upland runoff and groundwater seepage, and in the lower portion, provides stabilization in the wave strike zone. Bank grading can also be combined with planted tidal marshes and beach nourishment.

Suitability

Low eroding banks with only partial or no vegetative cover are particularly suited for bank grading. Confining layers in the bank material and the transition to adjacent shorelines may dictate the extent of possible grading. Surface and groundwater management measures may be needed.

Fiber Logs

Fiber logs are also known as coir logs or biologs. These biodegradable logs come in a variety of sizes and grades for different applications. They must be aggressively staked into place to prevent them from being lifted and moved by tidal currents and wave action. Fiber logs are particularly useful to temporarily contain sand fill and reduce wave action at planted marsh sites.

Suitability
Fiber logs decay in five years or less. They may need to be replaced if the planted marsh does not stabilize before the logs break down. They have also been placed along undercut banks where excessive shading prevents the growth of marsh vegetation. The effectiveness of using fiber logs to reduce the undercutting effect of tidal currents and boat wakes is still under investigation, but it is assumed that they must be inspected regularly and replaced periodically.

Hybrid Design Options

Marsh Toe Revetment
Marsh toe revetments are low profile structures typically constructed with quarry stone, and placed to stabilize the eroding edge of an existing tidal marsh.

Suitability: The most suitable sites for this treatment have existing tidal marshes with eroding edges. Ideal sites will be wide enough to provide upland erosion protection, and have a trend of landward retreat. Gaps can be used to facilitate tidal exchange if the structure height exceeds mean high water, or if the target shoreline requires a long continuous structure. Wave height and shoreline length will need to be examined.

Marsh Sill
Marsh sills are low stone structures used where no existing marsh is present. Sills are usually located near the low tide line, then backfilled with clean sand to create a suitable elevation and slope for planted tidal marsh vegetation. Like marsh toe revetments, the height of the sill should be near the mean high water elevation to minimize interruption of tidal exchange.

Suitability
Eroding banks without a tidal marsh present are candidate sites for marsh sills, particularly if marshes exist in the general vicinity. However, the physical alterations needed to create suitable planting elevations and growing conditions should not require major disturbance to desirable shoreline habitats, such as mature forested riparian buffers or valuable shallow water habitats (e.g., shellfish beds, submerged aquatic vegetation). If bank grading is appropriate to create target slopes, then the bank

material can possibly be used to backfill a marsh sill if it is mostly coarse-grained sand. Sand fill can also be imported from an upland source.

Marsh with Groins

Groins are short stone structures placed perpendicular to the shoreline to support a planted marsh with sand fill. This approach is similar to marsh sills, which are placed parallel to the shoreline. This method is suitable for lower energy shorelines where erosion of the unprotected marsh edge is expected to be minimal, while sills can be used where direct wave action and boat wakes need to be reduced. The potential effects on sediment transport and downdrift shorelines need to be considered before choosing a groin approach.

Nearshore or Offshore Breakwater System

An offshore breakwater system is a series of freestanding trapezoidal structures strategically positioned offshore to create a stable beach profile with embayments. Even though they tend to be large and costly projects, offshore breakwater systems are commonly included as a living shoreline approach because they include a dynamic, natural beach feature in the design. Non-vegetated beach areas within breakwater systems also provide habitat for terrestrial and aquatic wildlife, including shorebirds, turtles, terrapins, and the northeastern beach tiger beetle. Oysters, mussels, algae, and other reef-dwelling organisms may colonize the shallow water structures.

Suitability

Suitable sites for offshore breakwater systems are medium and high-energy sand beaches, banks, and bluffs without adequate sand for erosion protection and an historic trend for landward retreat. Like groins, offshore breakwater systems can interrupt longshore sediment transport and adversely affect downdrift shorelines. Beach nourishment and stabilizing beach and tidal marsh vegetation are usually included rather than allowing for natural accretion of sand.

Other Considerations

This brief inventory includes methods for erosion protection and habitat restoration collectively referred to as the "living shoreline" approach for tidal shorelines. If shoreline erosion must be stabilized, then choosing the least intrusive yet effective method is the main objective. Nonstructural methods that emphasize the use of dense riparian and wetland vegetation can be applied to many low energy shorelines with minimal wave action or boat wakes. They can also be combined with hybrid methods, such as a marsh sill combined with bank grading and a planted marsh.

The hybrid types of living shoreline design options have several characteristics in common. The structures should be necessary to support habitat enhancement, restoration, or creation. Important coastal processes are also minimally disrupted by properly designed hybrid projects, particularly tidal exchange and sediment transport. Effective hybrid projects provide enough protection without the need for erosion control structures at the riparian-wetland habitat interface if possible. This allows for the landward retreat of tidal marshes and sand beaches in response to rising sea levels. Connections between riparian and wetland habitats can enhance bank stability in the wave strike zone while also providing wildlife habitat value with food, cover, and vegetated corridors.

Some methods were not included in this summary of living shoreline design options because they are not widely practiced and their effectiveness is still under investigation. Oyster shell reefs can be designed to mimic marsh toe revetments or marsh sills, but it is not clear if uncontained oyster shell is sufficiently resistant to wave action and tidal currents. The placement of oyster shell adjacent to existing or planted marshes to support native oyster restoration efforts is most likely suitable even with limited erosion protection benefits. Pre-cast concrete structures in various shapes have also been deployed in intertidal and subtidal areas to provide wave dissipation as well as habitat for shellfish and other reef dwellers.

“Living walls” for steep bank stabilization is another method commonly applied to upland slopes, but only recently installed on tidal shorelines in Virginia. This engineered system of support structures with planted vegetation is intended to provide stabilization without extensive land disturbance and bank grading.

Depending on the level of protection that is needed, nonstructural and hybrid methods may not always be easier, less costly, or require less maintenance than rock revetments and bulkheads. While this may be the case with tidal marsh enhancement and creation projects, professional design and engineering assistance is usually required. Local knowledge or predictions of tide range, predominant wind direction, and wave height are required for effective designs. The amount of sand fill needed for sills, groins, and breakwater systems has to be accurately calculated to prevent adverse downdrift effects. Predicting how banks should be graded to achieve stable slopes and determining if the bank material is suitable for backfill also requires professional expertise.

Wider acceptance of the living shoreline approach with its inherent limitations could shift the current trend for shoreline armoring, particularly in very low energy settings. The guiding principles presented here can assist with the selection of possible alternatives, but site-specific design considerations are also required.

In summary, there are many different concepts that define a living shorelines approach. Living shorelines is a concept based on an understanding and appreciation of the dynamic and inherent ecological value that our natural shorelines provide. Living shoreline projects apply these natural principles in the design and construction of shorelines in order to enhance habitat and maintain shoreline processes.

The important aspects of this definition are: dynamic, function, habitat, and processes. Dynamic implies variable and changing; function is aggregated in inherent ecological value, that includes wave sediment-flora-fauna interactions at the shore and offshore and downstream of the eroding area; habitat includes the water-land interface (sediment size, water exchange, flora and faunal interactions) that permit use of the shore by a suite of bay plants and animals; and processes refers to the hydrology, chemistry, and biotic activities that typify this fluid water-land interface. These are the principles that need to be integrated into the development of living shoreline projects if they are to control erosion and function as sustainable living shorelines.

The goal of this Practitioner's Guide is to refer to living shoreline projects in other regions but focus on providing methods for establishing shellfish reefs as shoreline stabilization technique combined with other living shoreline tactics.

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VII. Funders

Partners