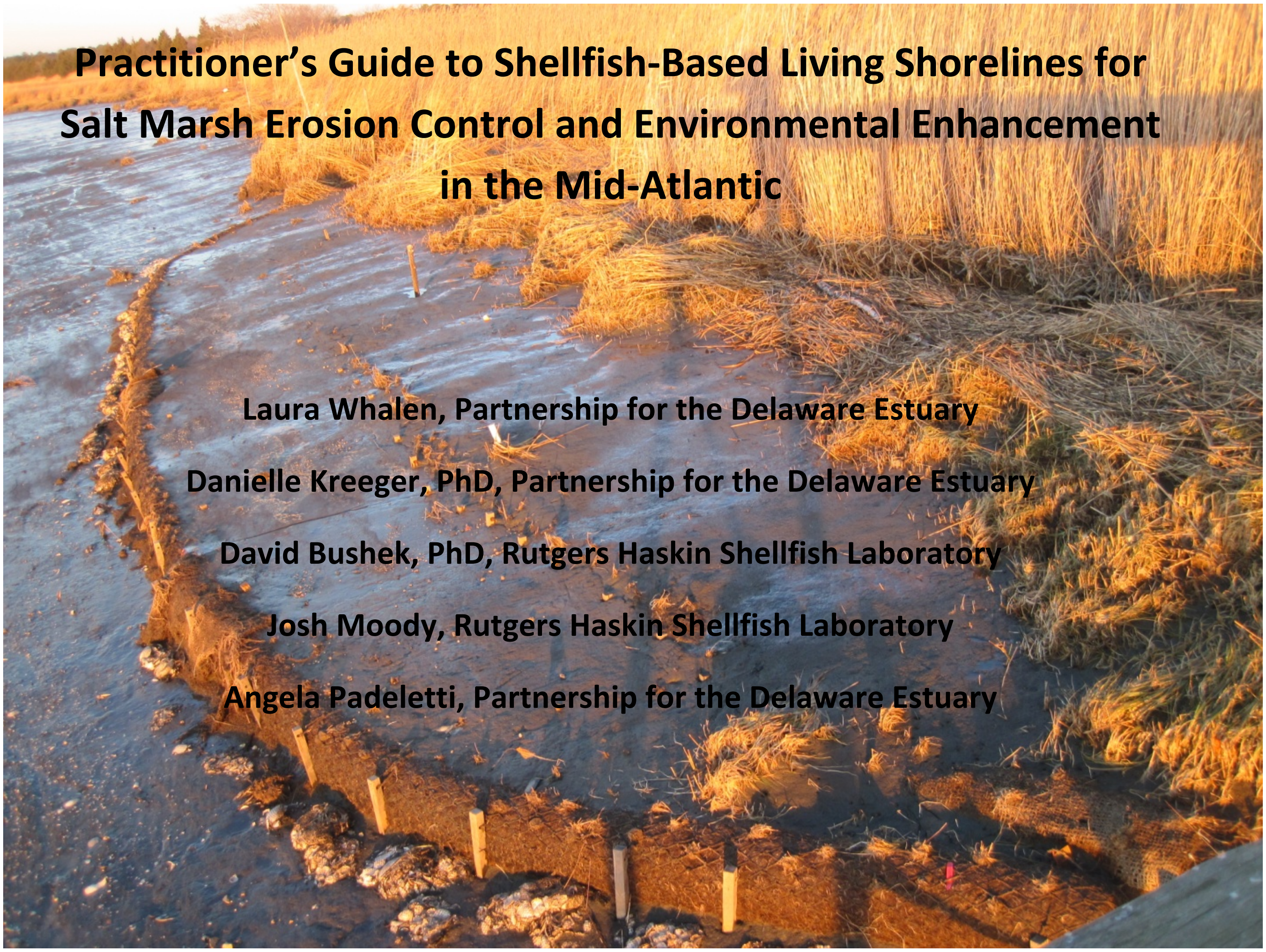

Practitioner's Guide to Shellfish-Based Living Shorelines for Salt Marsh Erosion Control and Environmental Enhancement in the Mid-Atlantic

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Table of Contents

Tables and Figures List

I. Introduction

I.1 Statement of problem and definition of living shorelines

In the Delaware Estuary, tidal marshes are vital to the overall health of the system but are eroding at a rapid pace (Figure 1). To date, we have already lost 44% of salt marshes and 56% of freshwater marshes from human causes (USEPA Coastal Wetlands Initiative, 2010). Marshes struggle to keep pace with erosion from sea level rise and boat wakes, while also suffering from degradation of interior areas. Tidal marshes have little room left to move inland because of development along shorelines. Wetland loss should be prevented because these are nature's kidneys filtering water, and nature's feeding and nursery grounds for fish, birds, and animals. When waters rise, marshes act like sponges, retaining floodwaters and buffering against powerful storm surges.

Living shorelines are a creative approach to protecting shorelines by using engineered stabilization techniques with natural habitat elements. These protect against erosion while providing critical habitat for wildlife (Smith 2006). Living shorelines deviate from the sole use 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.

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
- The location of shoreline in relation to prevailing winds
- Other energy factors such as boat wake and tidal currents
- Evidence of existing marsh grasses or submerged aquatic vegetation near the project site
- Erosion rate trends
- Shallow water depth near the shoreline
- Amount of sunlight

<u>Wave Energy</u>

Wave Energy is the first factor to consider for selecting a shore protection method. Low energy wave environments are the easiest to install bio-based tactics; shorelines in medium and high energy wave environments can be a much more difficult task. Higher wave energy typically requires more structural components to hold together other bio-based treatments. Approaches in high energy require a balance of protection and viable habitat for land-water exchange and processes (Smith 2006).

<u>Slope</u>

Bank height or slope is also important, and living shorelines need to be designed with a gentle gradient to allow for structural stability and a good surface for vegetation to establish.

<u>Organic Material Placement</u>

Living shoreline projects often use rock, fibers, and other natural materials. In high energy, rock can 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, creating habitat. This is combination of materials is often referred to as a “hybrid” design (Duhring 2006). These hybrids must be designed carefully as to not cause erosion of newly created marsh or beach habitat (Priest 2006).

Tidal Gates

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. The sill breaks enhance tidal flushing and connectivity, though to date no quantitative gate effectiveness studies have been done. If exchange is not facilitated, the areas landward of the sill may become ‘dead’ zones for aquatic species that cannot exit as the tide ebbs. Appropriate window locations and sizes should be governed by the suite of aquatic organisms likely to utilize the area as well as wind, wave, and tidal conditions specific to each site. More work to establish specific guidance based on ecological and engineering needs is needed in window design (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 area. Living shorelines may not provide the same level of erosion protection as other more structural practices. However, living shoreline techniques should 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 (Davis 2011). The VIMS’s Center for Coastal Resources Management has an online database of permit records (http://ccrm.vims.edu/perms/newpermits.html) that show what shore stabilization strategies have been proposed in different locations and could be a good reference tool.

I.2 Purpose and Benefits of Living Shorelines

The advantages of the Living Shoreline over the traditional riprap or bulkhead are well-documented. Recent studies have shown that hardened shorelines (bulkheads, rock revetments) have a lower abundance of bottom-dwelling organisms offshore and lower numbers of juvenile fish and crabs when compared to shorelines with vegetated marsh. Seitz et al. (2010) concluded that benthic abundance and diversity 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.

Other major benefits of living shorelines include lower construction costs, maintaining a link 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.

While there are many benefits associated with living shorelines, they are not effective in all conditions, especially in high energy environments. Other drawbacks include low numbers of knowledgeable marine contractors and the lack of information on the science behind the effectiveness of living shorelines for different types of shores and under different energy regimes and storm conditions.

Ecosystem services associated with living shorelines:

Productivity

The net primary productivity of the salt marsh exceeds that of most ecosystems. Tidal marshes provide the primary food sources for the Bay's living aquatic resources. Above-ground biomass in created *Spartina alterniflora* marshes on the Atlantic Coast or in Chesapeake Bay quickly reaches parity with natural marshes if basic conditions for marsh establishment and survival are employed.

Habitat 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.
• Nearly all of the 190 species of amphibians in North America depend on coastal wetlands for breeding.
• The cost benefit for a living shoreline is significant. 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.

Water Quality

The salt marsh traps silt and pollutants, including nitrogen and phosphorus contained in stormwater runoff and receiving waters. However, only 30% of the nitrogen load is from surface runoff; the balance moves unimpeded to the Bay's waters via sub-surface flow and groundwater. When this flow encounters a salt marsh, denitrification will likely occur. Denitrification is an important but little known marsh process. Simply stated, high productivity plants such as salt marsh vegetation move large amounts of biomass (carbon) below ground to provide electrons necessary to drive a process which converts elemental nitrogen to N2 (an inert gas), thereby dampening coastal eutrophication.

Shoreline Stabilization

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 the sill structure, and wave interaction with marsh vegetation. Knutson *et al.* (2006) 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. A properly engineered living shoreline will provide as much or more protection than riprap or a bulkhead and will improve water quality and enhance habitat as well. Engineering is site specific. Additionally, SA living shoreline design does not always fit neatly into the regulatory guidelines. This can be frustrating for the landowner who wants to protect the shoreline as quickly and as inexpensively as possible.

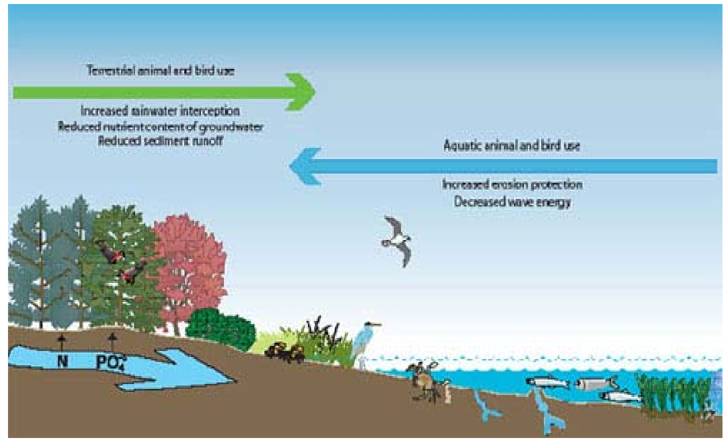
When protected in its natural state or reestablished through restoration efforts, these shoreline areas trap sediment, filter pollution, and provide important habitat for both aquatic and terrestrial wildlife, such as blue crabs and fishes in their critical early life-history stages. In an attempt to combat erosion, many shorelines have been hardened over time with artificial shoreline armor such as riprap revetments and bulkheads. In many cases, these artificial structures are not fully effective at protecting shorelines from erosion. In addition, these artificial structures decrease the ability of a shoreline to provide natural habitat and to serve other roles beneficial to the health of the Bay and its rivers, for example coping with problems associated with sea level rise.

II. Living Shorelines Inventory

"Bio-Based" Design Options

Riparian Vegetation Management

The purpose of this tactic is to increase vegetation, both in number 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.

This brief summary 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.

III. The Delaware Estuary Living Shoreline Initiative (DELSI)

DELSI is one type of living shoreline designed to combat erosion along tidal marsh edges. Marshes are an imperiled and critical habitat in the Del Estuary, as elsewhere in the Mid-Atlantic region. The principal goal of DELSI is marsh habitat enhancement and stabilization, using living shellfish reefs to "soft armor" shorelines and arrest erosion. In many areas, 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 is used to give living shorelines the time and means to "set up" ahead of the erosion rate. The primary objective of the DELSI project was to develop and evaluate methods to enhance mussel populations along marsh edges for habitat restoration. We will continue to broaden the range of tactics available and develop standard, cost-effective methodologies for widespread use. Ultimately we hope the DELSI method will help to conserve important habitat and strengthen overall ecosystem services throughout the Delaware Estuary.

The objectives of DELSI:

- to demonstrate the effectiveness of selected natural products to temporarily control or reduce erosion in order for naturally armored shorelines to develop
- to demonstrate the ability of selected natural products to encourage natural recruitment of mussels and marsh grasses along erosion zones in New Jersey marshes of the Delaware Bay.
- to evaluate the usefulness of seeding selected natural products with mussels and grasses to expedite establishment of 'soft-armored' living shorelines.
- to survey use of developing living shorelines by motile fauna

This practitioners' guide describes each step of the process for creating a mussel-based 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.

DELSI Methodology

Three study sites at the mouth of the Maurice River in southern New Jersey were selected (Figure 3). The three represent areas with varying levels of erosion exposure from wind driven wave action, boat wakes, and tidal currents. High energy resulting from a long open fetch combined with shallow waters made access to a fourth site (originally designated site A) too difficult to include in this study. Energy was quantified by measuring the dissolution rate of plaster of paris clods placed at the same intertidal height, overnight at each site. Results were summarized to evaluate which treatments had the greatest benefits in terms of stabilizing marsh edge erosion and aiding the establishment of shellfish populations along the energy gradient. All sites had prevailing salinities above 8 psu, varying denisities of ribbed mussels, *Spartina alterniflora* and evidence of erosion along the seaward margin. Shoreline materials were installed in various arrays and replicated with unaltered control areas at each site along the mouth of the Maurice River (see examples in Figure 4). In total, 43 coconut fiber (coir) bio-logs (20 ft long and 12 or 16 inch diameter) were positioned in the high, mid or low intertidal zone, seven coir mats (150 x 6 ft) were also positioned in the mid intertidal zone, 16 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 creating 47 experimental units with 5 controls interspersed among the treatments. To determine 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.

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 2007). Coir products are routinely used in erosion control, but have not been used in salt water marshes nor as a substrate to attract mussels. Previously, we demonstrated that ribbed mussels will readily attach to coir fabric within 24 hours. 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).

Throughout this study, various configurations of the living shorelines materials were tested. Figure 3 shows how the materials were set up and installed in the intertidal marsh. 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. This second method was the most successful and is described in detail in the Installation Guide section.

In this project, our team tested a variety of techniques for establishing a stable shoreline that can produce a mussel-dominated assemblage along eroding edges of marshes in the brackish region of the Delaware Estuary. Mussels (*Geukensia demissa*) are a functionally dominant species in the ecology of most salt and brackish marshes of Delaware Estuary. Dense shoreline assemblages enhance intertidal habitats and likely provide many benefits to the marshes behind them. A variety of approaches were used to stabilize shorelines and catch recruitment of mussel spat using natural fiber products. Installations were enhanced 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 stimulates more rapid colonization and improves overall stability.

We also used bagged oyster shell cultch to stabilize the foreshore immediately seaward of eroding marsh vegetation. Meyer et al. (1997) reported that using oyster cultch in North Carolina stabilized areas immediately upland of marsh edges and showed positive accretion of sediment, whereas noncultched areas lost sediment. Both shell bags and coir logs produced positive stabilization and accretion in the Maurice River. Although oyster shell was primarily used to enhance stability in this project, it did attract recruitment of oyster spat. Hence, 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 grass margin. Findings from this work guide our continued efforts and can be used to guide other efforts throughout the state and region. Additional work 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), and (4) identify the most efficient means to create or enhance ribbed mussel communities.

DELSI Study Results and Recommendations

Treatments installed during 2008 showed varying levels of survival and success after evaluation. Regardless of site, important variables for success included the treatment type, orientation of logs relative to prevailing boat wakes, currents, and other shoreline features. Mats were largely ineffective except as supporting material beneath logs. Cement coated stakes were also ineffective, although up to ten oysters did recruit to some stakes it was no where sufficient to replicate the results that work in the southeast. Logs survived best if oyster shell bags were placed in front of them as a barrier to wave action. Logs at sites B and C did not work if tucked against the marsh which we attribute to wave action against the marsh edge. Some logs sank into the mud, whereas others lost all of the inner stuffing, leaving behind a deflated shell. Some logs were lifted and moved from the stakes and others were not recovered. Overall, treatments survived best at site D, followed by B then C, which corresponds to the relative energy gradient measured by dissolution of plaster of paris clods at each site (Figure 7).

Successful log treatments yielded rapid sediment-trapping benefits with back-filling behind logs often becoming evident within days (Figure 6). Double log treatments produced the deepest sedimentation and logs that connected the points of a scalloped margin were most effective. Sedimentation also occurred behind shell bags that remained in place (wave action moved some shell bags at sites B and C indicating the intensity of energy exposure at those sites). Wherever sediments accumulated a rich microphytobenthic mat formed was observed that likely helped retain the accumulating soft sediments (Figure 6). Microphytobenthic communities remove nutrients from the water column and provide an important energy source for many organisms foraging along the marsh edge.

Mussels and grass planted into logs survived and grew well on the few treatments where this strategy was attempted in 2008 (Figure 6). Furthermore, mussels and oysters colonized logs and shell bags of virtually all surviving treatments with highest densities occurring at sites closer to the mouth of the river. While oysters recruited in good numbers to shell bags, mussel recruitment was generally low to logs and mats and rarely exceeded 50 per log. It was not clear if we missed a recruitment window or if this was an unusually low recruitment year. In any case, additional efforts were put forth into seeding treatments with mussels during 2009 and there is a need to develop efficient mussel seeding methods.

Collectively, these findings indicated that measurable reductions in erosion and lateral growth of the marsh edge may be achieved by the physical stabilization provided by some of the treatments employed and that these treatments may develop into living shorelines. Based on these observations, installation methods were refined to test an ‘optimized’ treatment across the energy gradient of sites B, C and D (Figure 7). The optimized treatment began by laying a mat in a convex arc from two points spanning one or more eroding scallops. Excess mat was laid across the grass line, tied with twine to bunch it up width-wise, and then staked in against the marsh edge. Five to six logs were then laid across the convex arc with a two foot overlap where two logs met. Overlaps were set up with the downstream log on the outside as this was generally the stronger direction of oncoming wave action and energy. Logs were secured in place with twine lashed across each log with ten pairs of stakes placed snugly on either side of the log. Stakes were not inserted through the logs as recommended by the manufacturer because prior experience indicated that doing so accelerated abrasion of the twine forming the log casing and ultimately the failure of the log. Twine was threaded through a quarter inch hole in the top of each stake and the casing on the top of each log. Half hitches were sufficient to hold twine securely. Once lashing was complete, stakes were depressed or pounded further into the mud until lashing was snug to the log. The structure was finally reinforced by placing shell bags along the logs, especially where two logs met and were more susceptible to wave action. These treatments began trapping sediments within days after installation. By December, when we could no longer access the sites, all were still secure and structurally sound at site D, but had failed at site B and all but one had failed at site C. These treatments will be re-assessed once weather permits us to launch our boat to access the sites again in spring.

Shellfish beds formed by mussels, oysters and clams are vital components of healthy estuarine ecosystems and have always been important in the Delaware Estuary. These organisms provide critical environmental services including the removal of nutrient-rich, turbidity-forming particles from the water column; supplying usable nutrients for marsh plants; and creation of essential habitat and food for fish and crabs. Intertidal species, such as the ribbed mussel (*Geukensia demissa*), are also thought to stabilize marsh edges and facilitate sediment accretion rates in brackish and salt marshes (Bertness 1984). In fact, increased sediment deposition along the edge of tidal marshes leading to build-up of natural levees is the result of physical processes (e.g., particles can precipitate when currents slow as flood tides encounter a vegetation canopy) as well as biological processes (e.g. filtration and biodeposition of suspended matter by filter-feeding mussels) acting synergistically in concert. This project was funded as a proof of concept toward rebuilding and stabilizing an eroded marsh edge with an intertidal, mussel-dominated community in brackish and saline regions of New Jersey tributaries of the Delaware Estuary.

While the project specifically targeted marshes experiencing erosion along the New Jersey coast of the Delaware Estuary, we are confident that the results will expand the arsenal of restoration tools that can be applied to combat wetland loss throughout New Jersey and the mid-Atlantic region, and that it will include activities that can be undertaken broadly 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 2007). 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 project is working to build on these efforts by considering the ecosystem benefits of restoring populations of other bivalve species throughout the watershed (Kreeger 2005).

Forty seven treatments of logs, mats, concrete coated stakes and shell bags indicated logs installed to connect points defining a short eroded cove that converted it from a concave to a convex shoreline were most effective. A two tiered structure was more effective than a single tier. Shell bags placed in front of logs provided structural integrity, especially near joints of overlapping logs. Cement coated stakes were not very useful, although they did collect oyster recruitment. Dissolution of plaster clods, which measures relative mass transfer among sites as a surrogate for erosional forces, was lowest at site D time and much higher at sites B and C. Mussel recruitment increased with energy following the naturally observed pattern. Preliminary tests with planted mussels showed good survival and plugs of *Spartina alterniflora* persisted when planted in logs. Coir mats alone were ineffective and only some survived at site D. Mats placed underneath logs prevented the logs from sinking and this proved to be a valuable strategy as the installation method was refined. Logs that failed were apparently destroyed when twine comprising the outer shell broke after rubbing against stakes. Based on these observations, three idealized treatment were installed or enhanced at each site. Specifically, five or six logs were placed on mats in an arc connecting two points protruding from the marsh shoreline. Shellbags were placed on the water side of the logs for additional stability. This strategy began trapping sediment within days at each site. By November, however, treatments at sites B and C were failing despite early evidence of rapid sediment trapping. Site D, in contrast, persisted well and will become a model for future efforts in similar energy regimes as we continue to monitor its success.

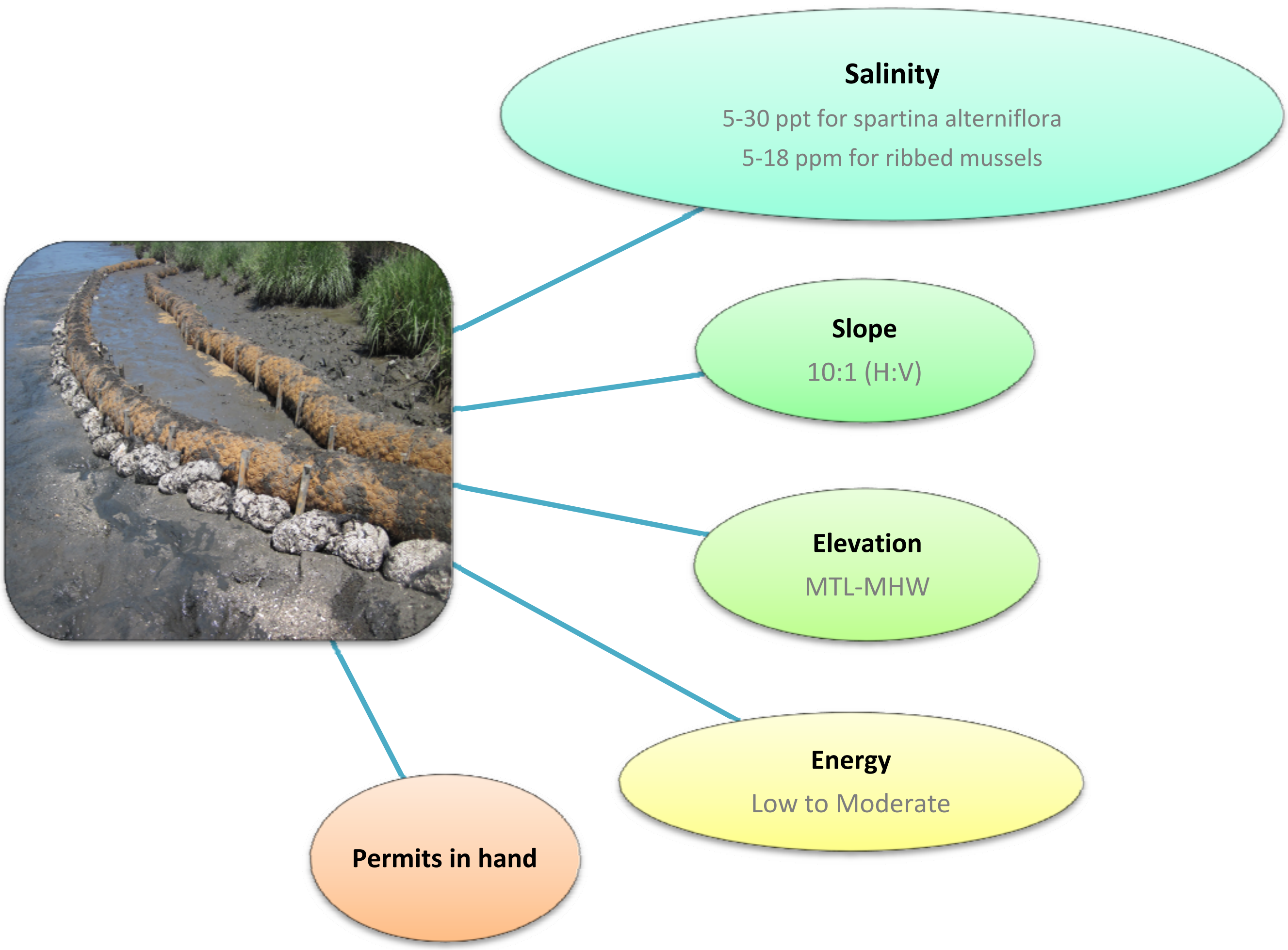
DELSI has identified a viable new approach for stemming salt marsh loss in some areas of Delaware Estuary. Shellfish-based living shorelines trapped sediment and appeared to decrease erosion at low to moderate energy sites, compared with untreated controls. Ribbed mussels (and oysters) successfully recruited onto natural substrates deployed in the intertidal zone along eroding salt marshes. While long-term outcomes have yet to be assessed, the overall strategy is producing the desired results. The most successful strategy identified involves installing coir fiber logs, coir mats; and shell bags in a convex array protruding from an eroding shoreline (Figure 4). As designed thus far, the DELSI treatment will work in areas not subject to significant wave action. In such areas it is a potentially useful alternative to bulk heading or the placement of rip rap. More substantial tactics will be needed in high energy locations. Continued monitoring is still needed to quantify sedimentation, shellfish and *Spartina* recruitment, changes in habitat usages, and changes in shoreline relative to control sites.

Best Tactic=

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

Suitability Criteria

The following decision tree will help determine if a site is suitable for a mussel-based living shoreline with vegetation planting.



IV. Installation Guide

Materials needed per 10 m of shoreline to be treated

- 4 premium 20’ coir fiber logs
- 1 coir fiber mat
- 48 stakes (12 per log)
- 80 oyster bags
- Twine
- Spartina plugs (40 plugs per log)

Where to purchase/obtain materials

NJ	PA	DE
Pinelands Nursery – 323 Island Road, Columbus, NJ 08022. Phone (609) 291-9486 e-mail: sales@pinelandsnursery.com www.pinelandsnursery.com/index.htm		

When to install

The best time to install is early spring before mussel recruitment and plant growing season. Mussel recruitment typically happens in early spring as well, so you want the logs to be in place and seeded with mussels to improve recruitment. Planting times are also discussed below.

1) Install mat by rolling it out at the elevation where the logs will sit

2) Place logs in cusp shape on top of mat

3) Hammer in stakes (6 on each side of log) about 3 feet apart and tie down with twine using double hitch knot

4) Reinforce with shell bags as shown above and place extra shellbags at edges and at joints between logs

Planting Considerations

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.

1.) 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.

2.) Salvage clumps of grass that have already fallen off marsh edge. Place the clumps behind logs into the thick mud

3.) Purchase plugs of *Spartina alterniflora* and insert 2 plugs per foot on each log and secure them under the coir fiber netting.

Elevation

The critical elevations for tidal wetlands establishment are mean low water (MLW), the average low water at the site, mean high water (MHW), the average high water level at the site, 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.

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/ .

Biological benchmarks (BBM) are elevations established by surveying the elevations of representative plant communities in an adjacent reference marsh. 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.

Slope

Flat 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 the most important factor in successfully establishing a wetland. Several of the other important factors, e.g., elevation and slope, can have a direct influence on hydrology as well. To put it simply, to effect wetland hydrology in a tidal wetland, the area must be under water at high tide and dry at low tide. This may sound overly simplistic but it is the essence of tidal wetland hydrology. It is also the easiest way to explain the grading plan to an equipment operator.

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 culverted, 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 think of the 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.

Example of Species Inundation Zone Salinity Range

Species	Planting Range	Salinity
Spartina alterniflora	MTL – MHW	5 – 30 ppt
Spartina patens	MHW – ULW	5 – 30 ppt
Spartina cynosuroides	MHW – ULW	0 – 5 ppt
Distichlis spicata	MHW – ULW	10 – 30 ppt
Scirpus americanus	MHW – ULW	0 – 15 ppt
Juncus roemarianus	above MHW	10 – 25 ppt
Iva frutescens near	ULW	5 – 30 ppt
Baccharis halimifolia	near ULW	0 – 30 ppt
Panicum virgatum	above ULW	0 – 25 ppt
Myrica cerifera above	ULW	0 – 30 ppt

Shade

Most wetland plants require a minimum of six hours of direct sun 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 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 the list below. This is neither exhaustive nor definitive and should be only used as a guide to be tempered by local conditions. Almost anyone will be able to 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.

Mussel Application

In some states, oysters can also be included in design, targeting low intertidal and shallow subtidal zone with mussels in mid to high intertidal zone.) Oysters are not permitted in NJ based DELSI, and to date oysters that have naturally recruited onto shell bags used in the treatments have not survived to adulthood.

V. Monitoring and Maintenance

The detailed contours and elevations of grass lines, treatments, and other features provided baseline information (i.e. before treatment) to help evaluate treatment performance (Figure). Flora and fauna were documented along transects that ran perpendicular to the shoreline through treatment and control areas. Transects extended from the high marsh through the treatments to the water. Measurements included quadrat photos, percent plant cover, blade height, and fauna counts of oysters, mussels and fiddler crab holes (Figure).

Monitoring Treatments and Substrate Conditions

Initial locations and configuration of deployed treatments were assessed relative to stationary benchmarks installed on the marsh surfaces. Benchmarks of 5-foot, 2-inch pvc pipe and wooden stakes were pounded into the marsh surface until only 6-inches remain exposed. Each pipe was located with GPS coordinates and used to measure marsh edges and contours at no more than 1-m contours. Total station equipment was used to determine sediment elevations along the shoreline at marked transects and at least three locations along each transect from the marsh-line towards the water-line where the elevation changes. Sediment accretion rates were contrasted among treatments and marsh areas by monitoring elevation changes in the sediment surface, relative to initial scores on marker poles. The proximity of the high-marsh edge to fixed zero lines was assessed to track whether the marsh edge moves landward or seaward. At various points in time, the sediment horizon monitoring described above was repeated along the various shoreline locations, and compared back to stationary benchmark conditions installed on the marsh surfaces.

Biological Monitoring of Fauna and Flora

Direct sampling and digital photography was used to document standing stocks (i.e., productivity) of marsh grasses and associated fauna along the same fixed quadrats used to document substrate conditions changes. At least three $1m^2$ quadrats were placed along each transect starting at the high-marsh line and extending through the treatment (or control). Aerial photos (15 feet above ground) were taken of each quadrat, enabling flora and fauna percent cover data to be photo-documented and later assessed for various parameters (such as percent plant cover, blade height, bivalve shell density, and fiddler crab burrows). A subset of quadrats and transects were intensively sampled for belowground and aboveground biomass of various plant and animal species. Mussel populations were mapped along the marsh edge using 1 and 0.25 m^2 quadrats.

Recruitment Monitoring. Bivalve recruitment (mussels and oysters) and population standing stocks were assessed. Additional monitoring of new recruitment was performed in late spring and fall 2009 with particular focus on whether recruitment is enhanced by the presence of pre-existing bivalves that are seeded. Recruitment for many species of bivalves is directed to where adult populations already exist. New recruitment of mussels or oysters was examined quarterly, and when detected, 0.25 m^2 quadrat techniques or densities per unit weight/volume of shell techniques were used to determine mussel and oyster spat densities.

Ecosystem Function Assessment. Total intertidal bivalve biomass per linear meter of marsh shoreline was quantified with transect/quadrat methods and compared among unrestored and different types of restored marsh edges, including those seeded with mussels. Ecosystem processing by bivalve populations will be estimated by integrating bivalve biomass and abundance data with published weight-specific physiological processing rates (e.g., particle filtration rates), and these estimates will then be contrasted among treatments and study sites.

Fish Sampling- colonization and use of reef structures by other organisms such as fish, blue crabs, and horseshoe crabs are monitored with fish sampling materials used along the treated and control edges. Fish monitoring involves setting seine nets and minnow pots during one tide cycle and weighing and measuring the catch. We are also processing data collected from the fish monitoring, and we collected several species including flounder, eel, perch, and blue crab. The next fish monitoring sample will be taken in early spring 2011.

Maintenance

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 *Phragmites*.

In areas with populations of the common reed *Phragmites australis*, extraordinary measures are often necessary to eliminate existing stands and prevent recolonization. While there are no guarantees, there are a number of techniques which can help limit the risk. Whenever possible, existing stands should be sprayed with an appropriate herbicide prior to construction. During construction, every effort should be made to excavate and remove from the site as much of the *Phragmites* as possible. This should include over-excavation of at least a foot of material and backfill with clean sand. It is also 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.

Herbivory or the unwanted consumption of newly planted marshes is an emerging problem due to the burgeoning populations of resident Canada geese. These animals relish new stands of *Spartina alterniflora* and can quickly devastate plantings. They can, however, be effectively excluded by intensive fencing practices.

The accumulation of debris, flotsam and jetsam, as well as wrack material, *Spartina* stems, and eelgrass leaves, 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.

VI. Other DELSI Considerations

Estimated Costs and Benefits (Ecosystem Services)

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 costs are scalable, with economy of scale for larger projects. For large scale projects, contractors would need to be hired for installation. Figure 6 shows the labor and boat needed to complete a DELSI site.

A protected shoreline may stem the loss of much larger areas of marsh that sit landward of the edge and which tend to sit lower in the tidal prism and be more vulnerable to drowning (due to past land use practices like diking and haying) or natural processes. Economic evaluations of ecosystem services such as flood protection are just beginning to be tallied, and we merely list these benefits qualitatively here.

In temperate climates around the world, bivalve shellfish arguably represent the most ecologically important animal group. The myriad ecological goods and services furnished by three example bivalve shellfish in the Delaware Estuary are summarized in Table 3.

Habitat Enhancement. Similar to coral reefs in tropical latitudes, bivalves can build their own habitats or significantly enhance the structural complexity of aquatic habitats. As habitat-forming animals (a.k.a., ecosystem engineers) they create biological hot-spots for fish and wildlife and enrich bottom communities through filter-feeding and biodeposition. In estuarine areas, the SW mussel-dominated LS will offset erosion from SLR, boat wakes, and increase wind effects from ever-widening open water. Their nutrient rich biodeposits enhance vegetation production and carbon sequestration, protecting vital salt marsh habitat due to the tightly bound and dense mussel-plant association. The shellfish beds themselves create nutrient-rich, three-dimensional complexity (ideal habitats for fish & wildlife).

Biofiltration. As filter-feeding animals processing large volumes of water, bivalves are known for their beneficial effects on water quality. Even though most bivalve populations are depressed in the Delaware Estuary watershed, they collectively filter tens of billions of liters every hour during the summer (see Fig. 1, Supplemental Documents; Kreeger and Gatenby 2007). The current kingpin of the Delaware Estuary is the estuarine mussel (~60 billion L/h); however, this important animal is threatened by the loss of its tidal marsh habitats due to SLR and other factors. We are only now beginning to study how the past loss of bivalve population abundance in the watershed may have exacerbated declines in water quality associated with stormwater, nutrients, contaminants and pathogens (Goldman 2007).

Other Values. As noted in Table 3, bivalves are also important worldwide as sentinel bioindicators of water and habitat quality because filter-feeders efficiently accumulate many classes of contaminants, are sensitive to degraded conditions, and are sessile and therefore indicative of site-specific conditions. Because they are long-lived (lifespan up to 100 years), their fitness is indicative of long-term conditions integrated over seasons, years and sometimes decades, making them culturally and historically significant.

Resources and where to go for help and services

http://ccrm.vims.edu/decisiontree/index.html

http://www.vims.edu/cbnerr/resources/resources_coastal_training.php

Regulatory and Permitting 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 DELSI should be adapted on a micro scale to take advantage of natural contours of the shoreline, which evolve almost daily. This is counter to the traditional paradigm which expects exact positioning of every stake. Actual permits for specific sites will necessarily need to balance permit requirements with changing Also, need to discuss avoidance of sensitive species (eagles, terrapins, etc) and preventative measures to avoid trapping other species (HSCs). Permits typically are required from ACOE (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 and meeting 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.

PDE staff secured appropriate permits from the U.S. Army Corps of Engineers and New Jersey Department of Environmental Protection prior to initiation of this work in June 2008 (CENAP-OP-R 2007-1483-46 (NWP 27) and 0600-07-0002.1 CAF 070001, respectively). Each state in the Delaware Estuary has a slightly different set of permits to be obtained, including:

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 that we have. To schedule a pre-application meeting, call Govind Daryani at (484) 250-5165. • Need to complete the Joint Permit Application. The following website provides instructions for filling out the Joint Permit, as well as the actual Joint Permit application: http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-9531 • Fulfillment and approval of this application will get us both a PA Water Obstruction and Encroachment Permit and a USACE Section 404 permit. We would need to fill out the Standard Application. • Also need to get approval from the township where the project is located.	• Need to obtain permits from the U.S. Army Corps of Engineers and New Jersey Department of Environmental Protection prior to initiation of this work in June 2008 (CENAP-OP-R 2007-1483-46 (NWP 27) and 0600-07-0002.1 CAF 070001, respectively) for state-owned land

VII. Tables and Figures

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	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 begins living shoreline initiative

Table 2. Comparison of Living Shoreline Benefits, Constraints, and Costs

Comprehensive overview of Living Shoreline Tactics		Living Shoreline Types	Issues Addressed						Constraints							Costs
			Reduce Erosion	Provide Habitat	Uptake Nutrients	Filter Sediments	Improve Water Access	Dissipate Waves	Fetch	Other energy- i.e. boat wake	Water Depth	Erosion Rate	Salinity	Slope	Tide Range	
Single Tactics	Low energy- Soft armoring	Coir Fiber Logs & Plants	√	√	√	√	√	√	0.5 mile		1ft	2 ft/yr or less	5-30 ppt (spartina)	10:1 (H:V)	MTL-MHW	$100-$200/L.F
		Coir Fiber Logs, Plants, & Ribbed Mussels	√	√	√	√	√	√	0.5 mile		1ft	2 ft/yr or less	5-18 ppm	10:1 (H:V)	MTL-MHW	$100-$200/L.F
		Floating marsh		√	√	√		√					NA			
Multiple (Hybrid) Tactics	Medium to High energy hybrids of Soft armoring with Sills/ Revetments/ Breakwaters	Marsh Creation with Stone Sill	√	Yes, if gaps in	√	√	√	√	1- 1.5 mile		1-4ft	2- 8ft/yr	5-30 ppt (spartina)	10:1 (H:V)	MTL-MHW	$250-$400/L.F
		Stone Groin with Sand & Marsh	√	√	√	√	√	√	1- 1.5 mile		1-4ft	2- 8ft/yr	5-30 ppt (spartina)	10:1 (H:V)	MTL-MHW	$250-$400/L.F
		Nearshore Oyster Reefs	√	√	√	√		√					10-21 ppm			
		Stone Breakwaters or Revetment	√	Minor unless hybrid					2 or more		4-15ft	8-20ft/yr	NA			$450-$650/L.F.
		Bulkhead	Yes, but may cause						2 or more		4-15ft	8-20ft/yr	NA			$500-$1500/L.F.

Table 3. Ecosystem services of bivalve shellfish

Importance of Shellfish to the Delaware Estuary Watershed			Oysters *Crassostrea virginica*	Marsh Mussels *Geukensia demissa*	FW Mussels *Elliptio complanata*
Natural Capital Value	Commercial	***Dockside Product + Secondary Value***	✓✓✓		
	Ecological	***Structural Habitat*** biological hot spots, bottom-binding	✓✓	✓✓	✓✓
		Prey	✓	✓	✓✓
		Biofiltration top-down grazing, TSS removal, light)	✓✓	✓✓✓	✓✓
		Biogeochemistry enrichment/turnover, benthic production	✓	✓	✓
		Shoreline Protection - nearshore reefs	✓		
		Shoreline Stabilization - living edges	✓	✓✓	
	Cultural-Historical	***Waterman Lifestyle, Ecotourism***	✓✓		
		Native American - jewelry, dietary staple	✓		✓✓
	Bioindicator	***Watershed Indicators*** hallmark resource status/trends	✓✓	✓	✓
		Site-specific Bioassessment NS&T, caged sentinels	✓	✓	✓✓
	Conservation	**Biodiversity** fw mussels most critically impaired biota			✓✓✓

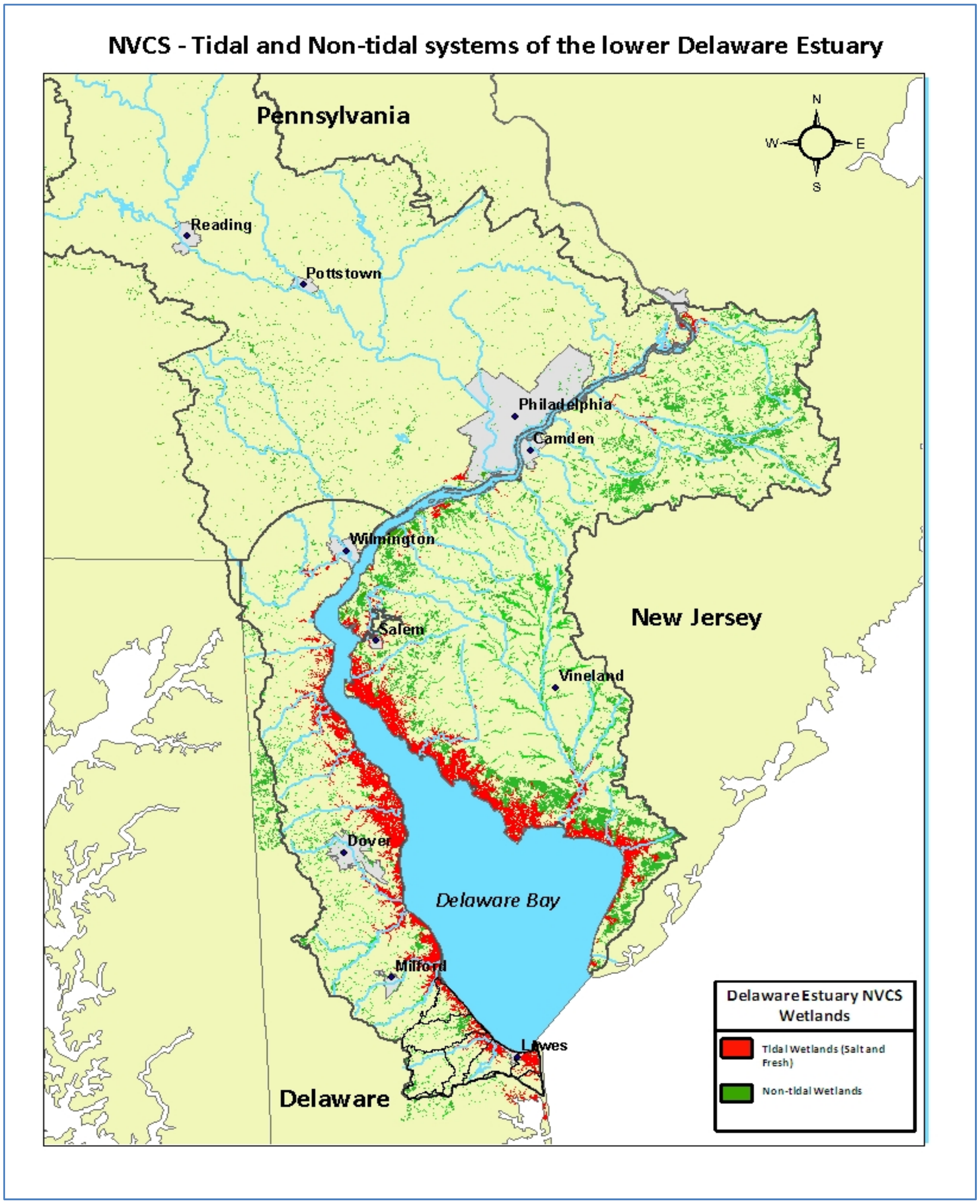


Figure 1. Configuration of Delaware Estuary Wetlands.

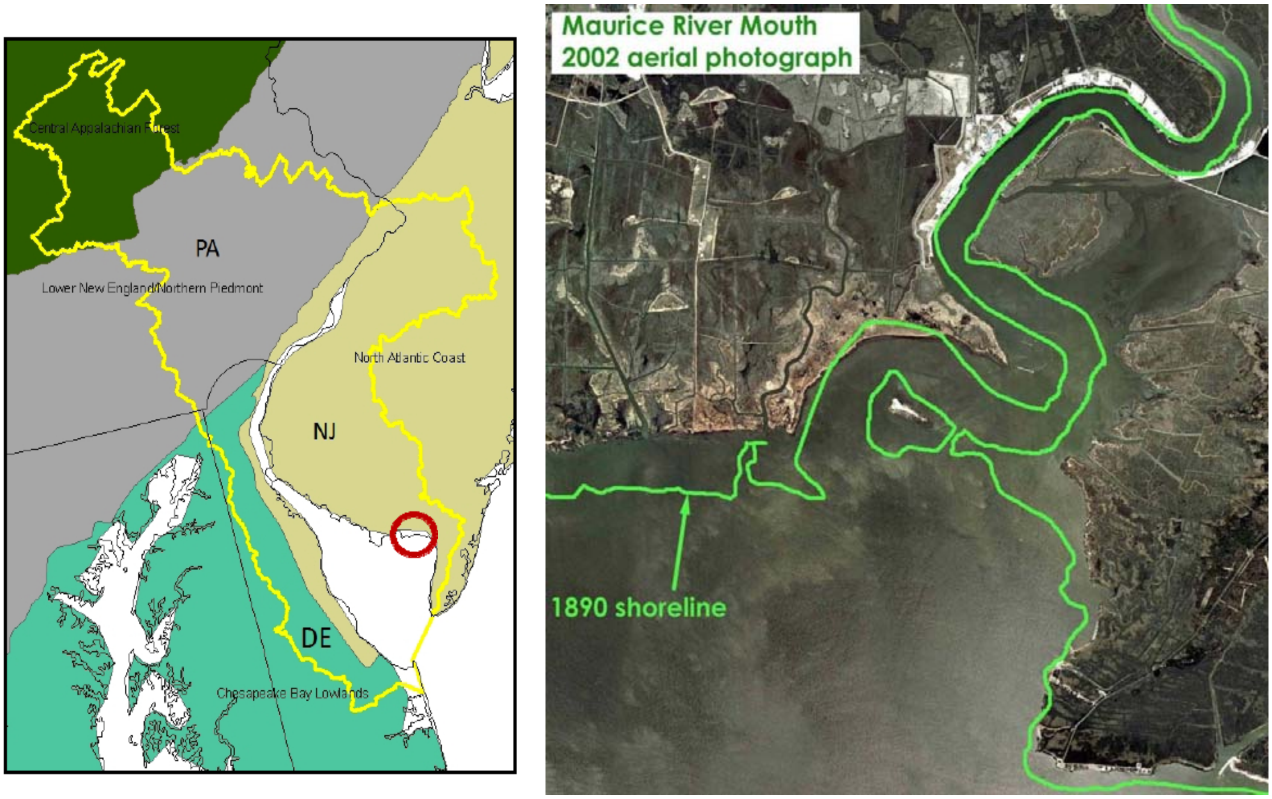


Figure 2. Location of study sites in the mouth of the Maurice River, Cumberland County, New Jersey. Site A (not shown) was dropped due to difficulty in accessibility.

Figure 3. Three test sites over a gradient of energy and erosion.

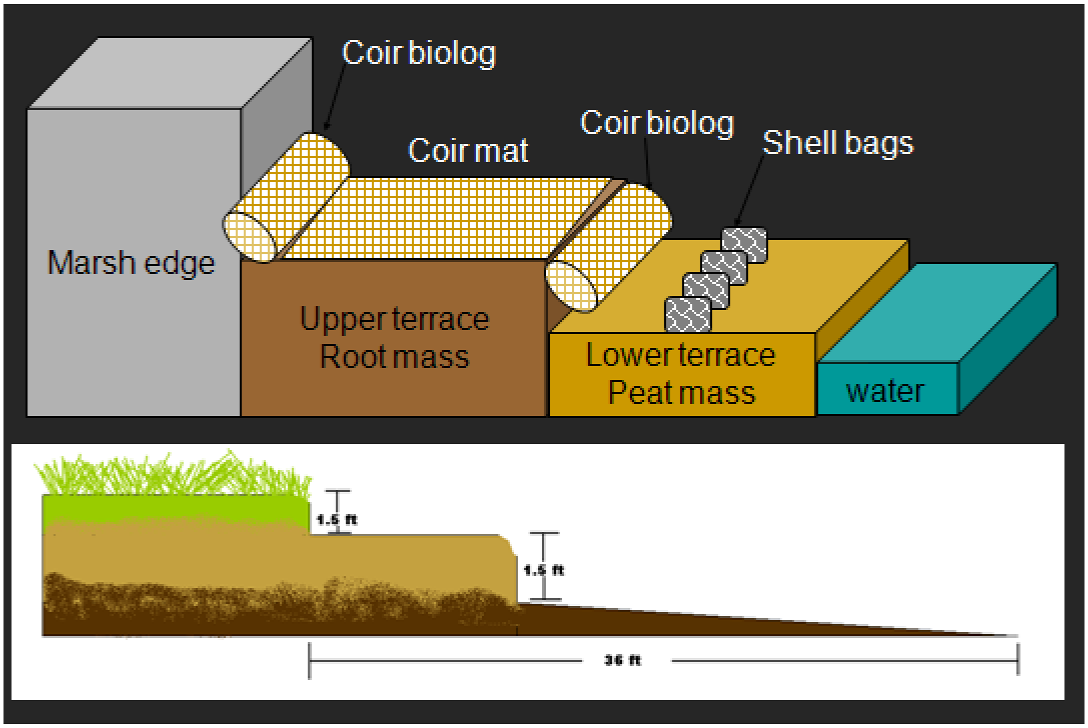


Figure 4. Materials needed and configuration of DELSI sites

Figure 5. Boat usage and labor to install small scale living shoreline project

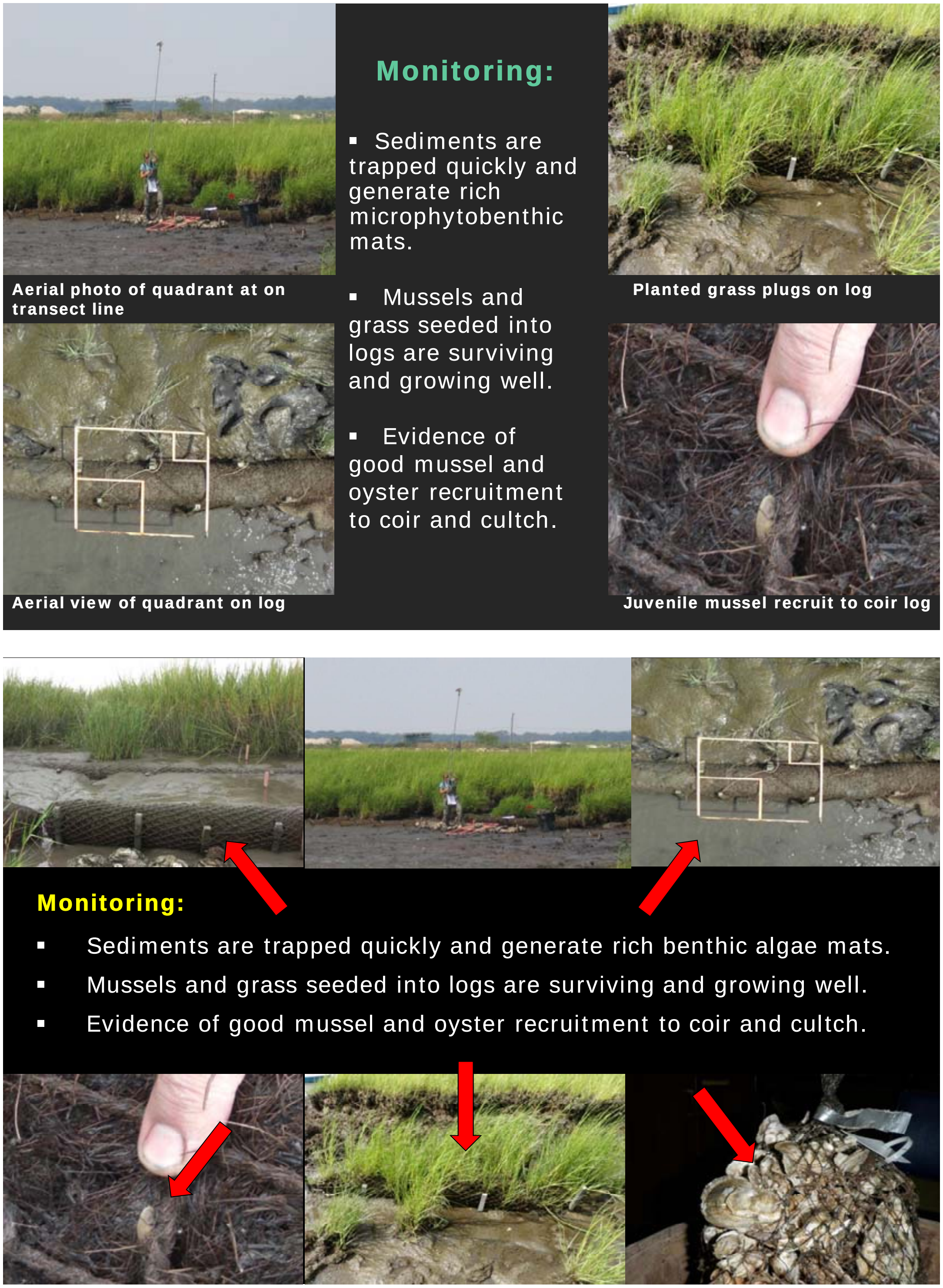


Figure 6. Monitoring plan for DELSI

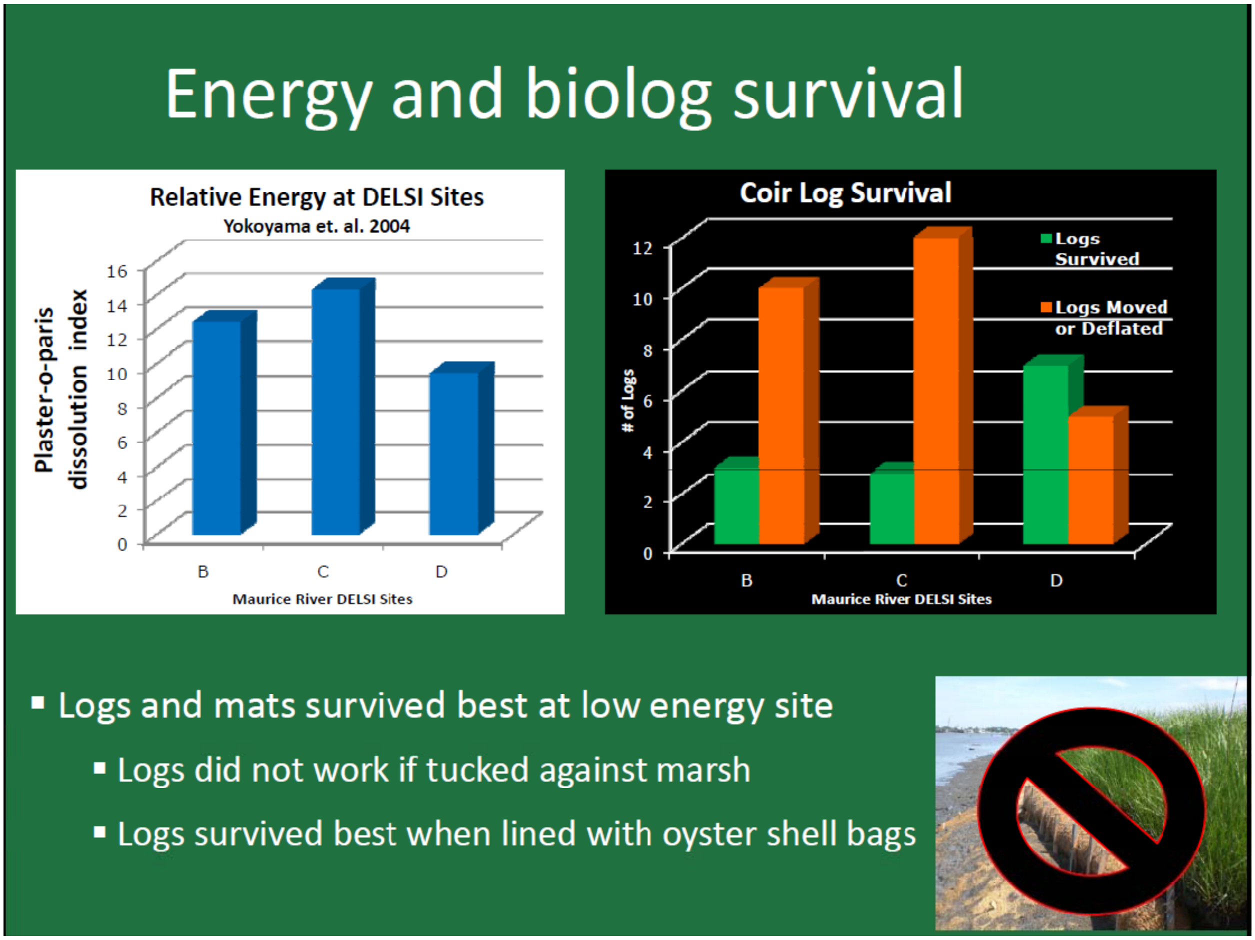


Figure 7. Energy impact on living shorelines

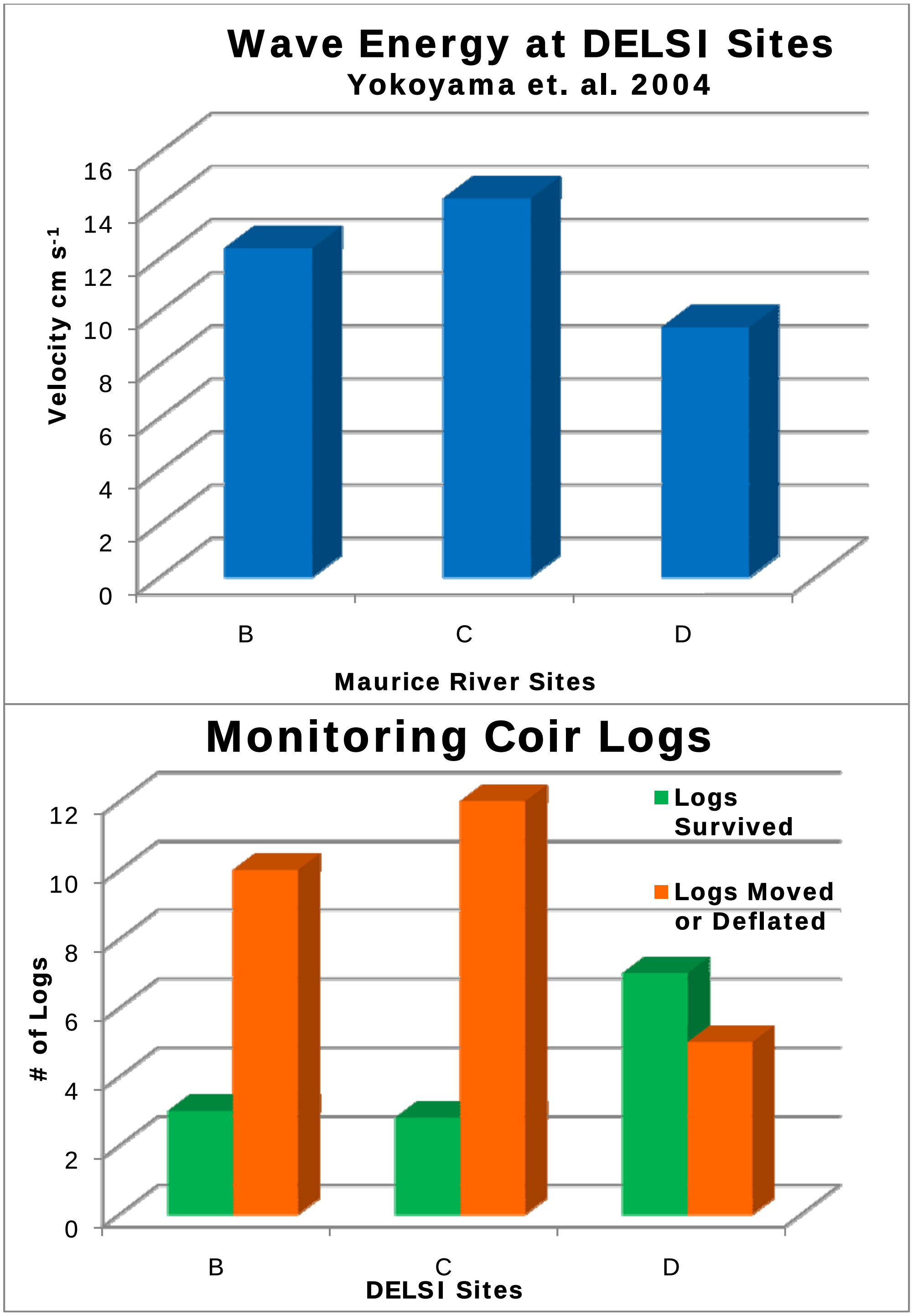


Figure 8. Log survival comparison at DELSI sites

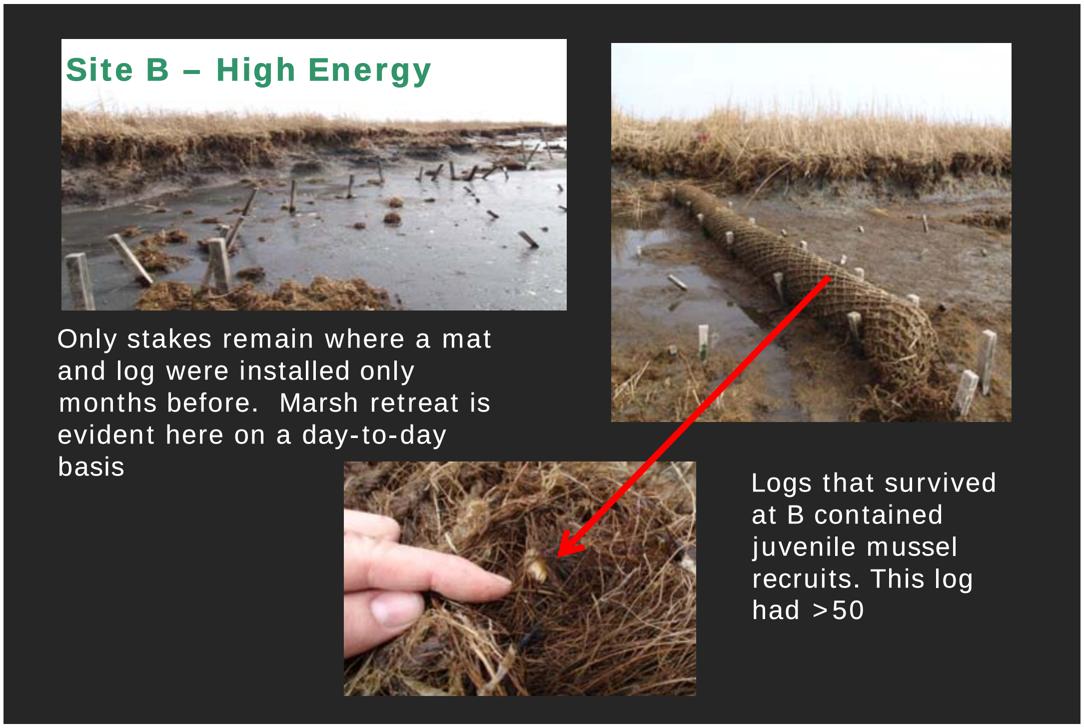
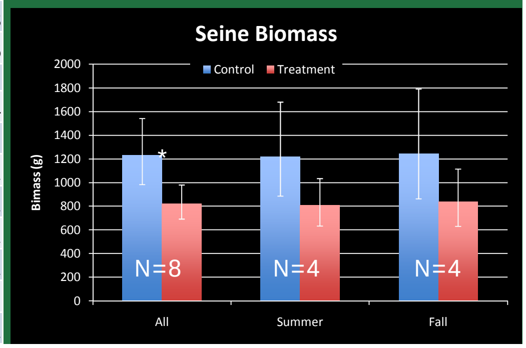


Figure 9. Example of log deflation at high energy site and mussel recruitment on log.

Figure 10. Fish monitoring plan with seines and minnow pots

Seine Catch Data

Seine Species	Control	Treatment
Grass Shrimp	1037	1536
Blue Crab	647	501
Mummichog	221	229
Bay Anchovy	251	26
White Perch	89	52
Silverside	50	38
Silver Perch	9	26
Weakfish	16	15
Striped bass	14	8
Black drum	12	6
Window pane flounder	12	
Atlantic menhaden	1	4
Hogchoker	5	
American eel	2	1
Spot	2	1
Unidentified	2	1
Summer Flounder	1	1
Naked Gobi	1	
Toadfish		1



Minnow Pot Catch Data

Minnow Pot Species	Control	Treatment
Mummichog	544	1564
Grass Shrimp	458	424
American eel	14	6
White Perch	1	9
Blue Crab	6	2
Silver Perch	3	3
Spotfin mojarra	1	2
Bunker	2	
Striped Bass	1	

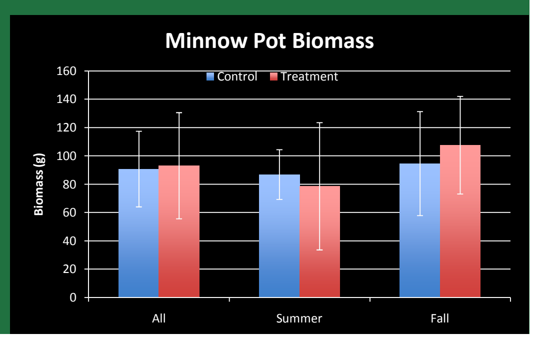


Figure 11. Initial results of fish monitoring.

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, 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.

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IX. 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 plant 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 Chesapeake 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 may 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. Here is an **on-line course** with more information to guide you through the choices.

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. Click here for more information about the **living shorelines permit process**

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 and do not mow 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 harsh conditions along Chesapeake Bay shorelines. Waterfront landscape designs should include plants that can tolerate high winds, salt water flooding and salt in the air. Look here for suitable **native plants for upland, wetland and beach areas** of living shoreline projects. 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. Click here for more information about **planting tidal marshes**.

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. Click here for **living shorelines technical design guidance**

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.

Are there photographic or on-the-ground examples of various kinds of living shoreline treatments?
Please see the **public demonstration area map** to visit areas with living shoreline treatments. There is also a gallery of photographs containing before and after pictures of living shorelines

Funders: