LIVING SHORELINES IN THE DELAWARE ESTUARY:

  

Best Practices from Lessons Learned and Information Collected by the Partnership for the Delaware Estuary and the Rutgers Haskin Shellfish Research Laboratory, 2008 - 2012

A publication of the
Partnership for the Delaware Estuary;
a National Estuary Program
in partnership with
Rutgers Haskin Shellfish Research Laboratory

June 2013
PDE Report Number 13--04

PARTNERSHIP FOR THE DELAWARE ESTUARY INC.

RUTGERS
New Jersey Agricultural Experiment Station

Compiled by:

Sari Rothrock, with material from Danielle Kreeger, Ph.D., Jennifer Adkins, and Laura Whalen.

Acknowledgements:

This work was made possible through funding from the EPA's Climate-Ready Estuaries Program. We are grateful to Dr. David Bushek and his team at Rutgers Haskin Shellfish Research Laboratory for their continued partnership (for DELSI and beyond) and for his review of this piece. Thank you, too, to Jennifer Adkins and Dr. Danielle Kreeger for review of this document. We are also grateful to the municipal officials, community members, and agency staff that attended our workshops and asked thought-provoking and insightful questions. A final thank-you goes to PDE staff for their help in all aspects of the DELSI.

Recommended Citation for this Material:

Partnership for the Delaware Estuary. 2013. Living Shorelines in the Delaware Estuary: Best Practices from Lessons Learned and Information Collected by the Partnership for the Delaware Estuary and the Haskin Shellfish Research Laboratory, 2008 -2012. PDE Report No. 13-04

PARTNERSHIP FOR THE DELAWARE ESTUARY INC.

Established in 1996, the Partnership for the Delaware Estuary is a non-profit organization based in Wilmington, Delaware. The Partnership manages the Delaware Estuary Program, one of 28 estuaries recognized by the U.S. Congress for its national significance under the Clean Water Act. PDE is the only tri-state, multi-agency National Estuary Program in the country. In collaboration with a broad spectrum of governmental agencies, non-profit corporations, businesses, and citizens, the Partnership works to implement the Delaware Estuary's Comprehensive Conservation Management Plan to restore and protect the natural and economic resources of the Delaware Estuary and its tributaries.

RUTGERS
New Jersey Agricultural Experiment Station

The Haskin Shellfish Research Laboratory is a New Jersey Agriculture Experiment Station within the School of Environmental and Biological Sciences at Rutgers, The State University of NJ. With roots dating back to 1888, an important component of its overall mission is to provide interdisciplinary opportunities for long-term research in marine and coastal systems of southern New Jersey, especially the Delaware Bay.

PREFACE

This booklet was written as a reader-friendly repository for our findings from living shoreline research, installations, monitoring, and community workshops from 2008-2012. It was envisioned that this document would provide background on the Delaware Estuary Living Shoreline Initiative (DELSI) and related workshops, and that it could offer some insight and guidance for interested practitioners.

While the information contained herein remains useful and practicable, please note that our understanding of living shorelines and particularly of the DELSI method has continued to evolve in recent years. For more up-to-date information on our program, please visit our website at http://delawareestuary.org/living-shorelines, or contact Restoration Coordinator Josh Moody at JMoody@DelawareEstuary.org.

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Introduction

This document is meant to provide the reader with insight into the lessons learned and processes developed by the Partnership for the Delaware Estuary (PDE) and the Rutgers Haskin Shellfish Research Laboratory (HSRL) for the Delaware Estuary Living Shoreline Initiative (DELSI). The document is organized in sections by 'best practice,' which refers to the successful strategy used by PDE and HSRL to achieve desired results. (Desired results will vary, and are dependent upon the interests of a given organization and the goals of a particular project.)

Background

The Delaware Estuary stretches from Trenton, New Jersey, and Morrisville, Pennsylvania, south to Cape May, New Jersey, and Cape Henlopen, Delaware, and includes all of the Delaware Bay and the tidal reaches of the Delaware River. A majority of the Estuary's five million people live in one of the region's three largest cities-- Philadelphia, Camden, or Wilmington. This highly commercialized area hosts the largest freshwater port in the world, accommodates the second-largest petrochemical port, and is home to five of the largest East Coast refineries, with over 42 million gallons of crude being transported on the Delaware River every day.

Much of the Estuary, however, is rural or undeveloped, especially a large portion of the tidal wetlands. As a result, the Estuary remains a vital ecosystem, providing habitat for more than 130 species of finfish, as well as clams, oysters, and crabs. The second largest concentration of migrating shorebirds in the Western Hemisphere is found in the Estuary, along with habitat for 15 different species of waterfowl, which total more than half-a-million individuals who either migrate through or spend the winter there. The Delaware Estuary also has largest population of spawning horseshoe crabs in the world, and sustainable fish, oyster, and blue crab fisheries that depend on the system's extensive coastal wetlands.

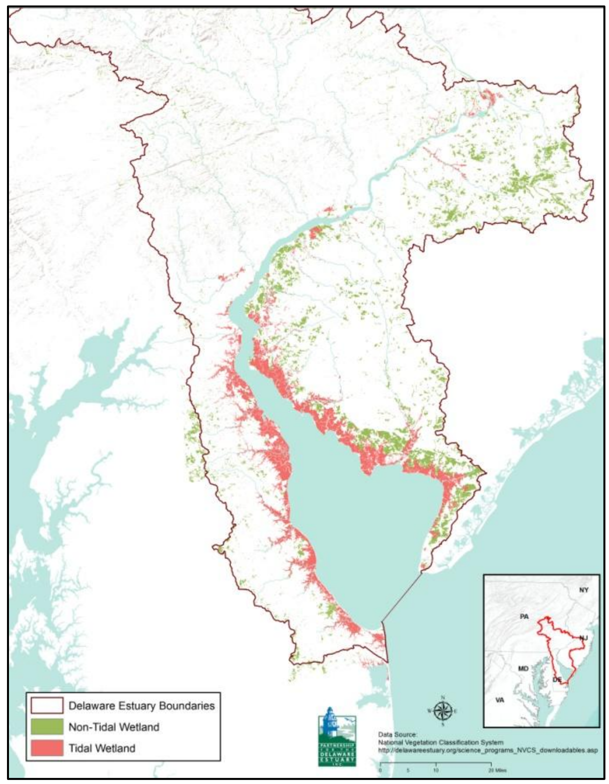


Figure 1. Tidal and nontidal wetlands of the Delaware Estuary watershed.

Coastal wetlands are arguably the Delaware Estuary's most important and characteristic habitat. There are two traits that distinguish this system from others. First, there is a near contiguous border of more than 370,000 acres of tidal wetlands that fringe Delaware Bay and the lower estuary region. Second, the system has the largest freshwater tidal prism in the world, and the extended salinity gradient leads to a rich diversity of marsh types (Kreeger, et al., 2010).

Wetland loss

Unfortunately, across the estuary, more than 6,500 acres of both coastal and inland wetlands were lost between 1996 and 2006 alone. Some of the most significant losses have been to salt marshes along the Delaware and New Jersey bayshores, where the impacts of sea level rise and erosion are widespread. In fact, in this area, coastal wetland loss exceeds an acre per day. While these recent losses are considerable, studies indicate that future losses are expected to occur faster and be more extensive than recent losses (Partnership for the Delaware Estuary, 2012).

Aside from the more obvious direct filling and degradation issues, the reason for the loss is two-fold: wetlands are impeded from moving inland as sea levels rise, and they are also eroding or drowning on the coastal edge. As tidal heights and the estuary's water volume increase in response to sea level rise and system alterations, the extent of tidal inundation along coastal areas will also increase. This will lead to successional shifts in habitat types, with tidal wetlands encroaching into non-tidal wetlands and forests. However, this natural migration (also called "transgression") is impeded in many areas by development, or attempts to maintain fixed coastlines in the same place. As a result, models predict that losses in the future will be twice any gains from landward migration.

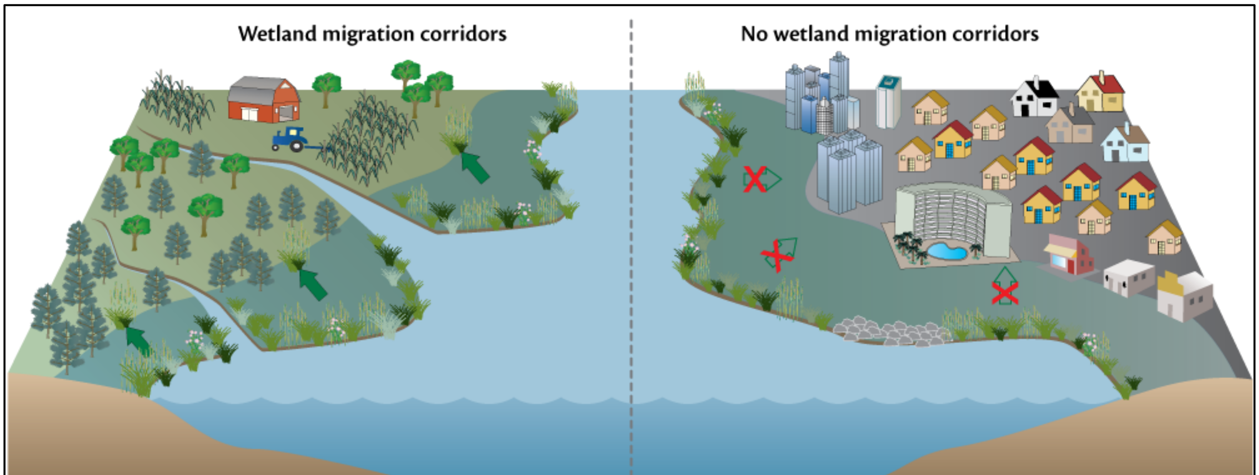


Figure 14. As sea level rises, wetlands may migrate into open spaces such as forests and fields. However, wetlands cannot migrate into areas with man-made barriers such as hardened shorelines and heavy development such as urban, commercial, and residential areas.

Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Enviromental Science. Source: Boesch, D.F. (editor). 2008. Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change Phase I: Sea-level rise and coastal storms. Report of the Scientific and Technical Working Group of the Maryland Commission on Climate Change. University of Maryland Center for Environmental Science, Cambridge, Maryland. This report is a component of the Plan of Action of the Maryland Commission on Climate Change, submitted to the Governor and General Assembly pursuant to Executive Order 01.10.2007.07.

Figure 2. Hard infrastructure impedes wetland transgression. Image courtesy of Jane Thomas, Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/).

Simultaneously, erosion appears to be increasing along seaward margins of unprotected tidal wetlands. Since wetlands are unable to transgress and erosion is increasing, the seaward loss and restricted landward gain is leading to a substantial net loss of coastal wetland acreage. This net loss is projected to exceed 50,000 acres by 2100, or possibly much more, with concomitant declines in ecosystem services (as these marshes are more productive than any potential replacement habitat (Knox, 1980)).

Possible Strategy to Combat Erosion

One potential strategy is to increase the rate of vertical accretion of sediment on coasts, stabilize erosion, and prevent coastal wetland edges from drowning. "Living Shorelines" are herein defined as engineered structures that utilize natural habitat elements to strengthen resilience of marsh edges and protect estuarine shorelines from erosion. In addition to protecting shorelines from erosion, living shorelines are also used to maintain, restore, or enhance the shoreline's natural habitats (Hardaway, Milligan, & Duhring, 2010), benefitting fish, birds and water quality. The installation of "living shorelines" along eroding marsh eduges could help stabilize the edges to help tidal marshes to build elevation and accrete vertically at a pace that matches sea level rise.

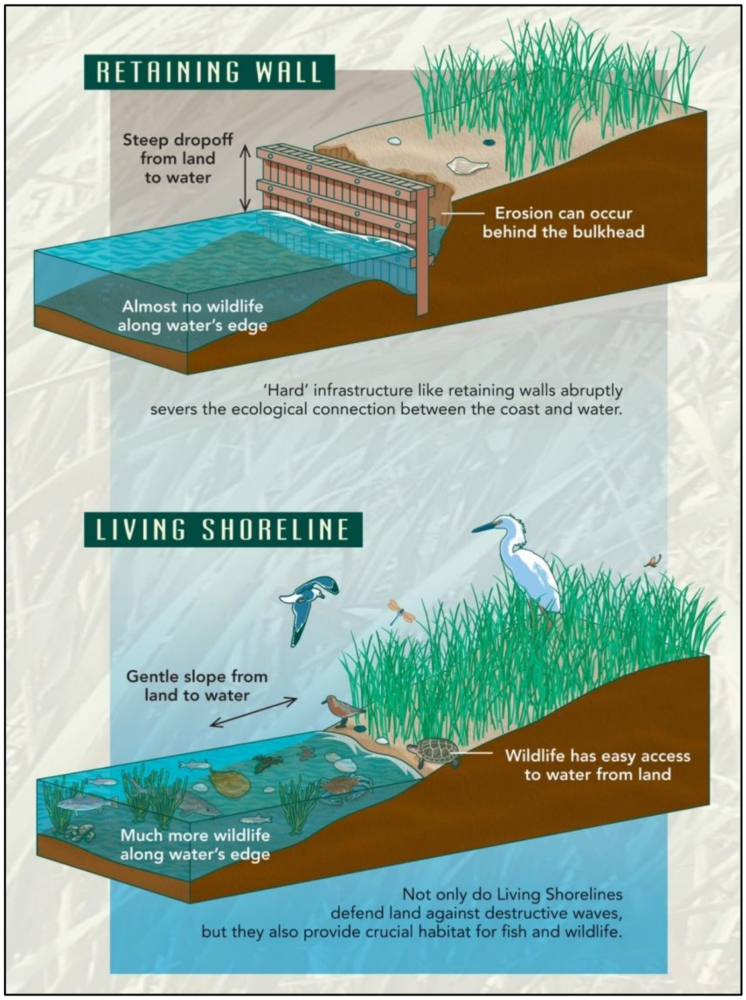


Figure 3. Graphic illustrating the difference between a severed ecological connection due to a retaining wall and the maintained one as with a living shoreline. Illustration by Frank McShane.

Traditionally, erosion is controlled using hard structures like bulkheads and seawalls that abruptly sever the ecological connection between the coast and water. While bulkheads and seawalls prevent erosion, they cannot elevate themselves to keep pace with sea level rise, and they contribute to degraded fish habitat. Living shorelines are an alternative to these 'hard' and inflexible techniques. A variety of natural structures can be used in living shorelines, including shellfish reefs, submerged grass beds, and native wetland vegetation. Such natural structures are often capable of binding inert materials together with natural cement or fibers, which helps to attenuate wave action and slow erosion, thereby "buying time" for marshes to accumulate in place (vertical accretion) or move inland (horizontal transgression). By providing tidal wetlands with the critical time they need to build themselves up or retreat, living shorelines can be an effective means to help wetlands adapt to sea level rise.

In some cases, breakwater projects can also be constructed to enhance fish and shellfish communities by arranging rock in segments interspersed with sills or slots, thereby providing habitat complexity while also creating low-energy, protected shorelines for passive sediment trapping and marsh (and beach) expansion. Combinations of nearshore and onshore (subtidal and intertidal) tactics are referred to as hybrid living shorelines, and these can further boost both resilience and ecological outcomes.

Even though a living shoreline is a stabilization tactic that incorporates natural elements, living shorelines should not be mistaken for natural shorelines. Living shorelines are designed and engineered similar to other erosion control or restoration projects, resulting in manipulated environments rather than undisturbed natural environments. Living shorelines differ from traditional stabilization methods by emphasizing both ecological and non-ecological outcomes. Living shorelines are also usually designed to be less confined in time and space in order to allow for natural dynamic processes. In short, living shorelines are designed to work with and enhance nature, rather than resist nature.

Living shorelines are designed to work with and enhance nature, rather than resist nature.

Hard structures typically reflect waves, potentially causing scouring or other flooding problems, whereas living shorelines typically absorb wave energy, allowing it to dissipate. A common example of a traditional tactic to hold the shoreline fixed in place is a stone revetment. This solution can provide long term shoreline protection, but provides little, if any, habitat benefits or connections between the upland and the water bodies. By restoring hydrological connectivity and using softer, natural materials (often arrangements of biological communities themselves), living shorelines can be more environmentally friendly than bulkheads and seawalls.

PDE/HSRL Plant-Mussel Tactic and the DELSI

In 2007, Dr. Danielle Kreeger from the Partnership for the Delaware Estuary and Dr. David Bushek from the Rutgers Haskin Shellfish Research Laboratory began research to design and create a living shoreline tactic that took advantage of plant and animal communities found in the Mid-Atlantic. This effort was the beginning of the Delaware Estuary Living Shoreline Initiative, or DELSI.

DELSI was conceived in an effort to replicate successful oyster-based living shoreline projects elsewhere (e.g., North Carolina, South Carolina, Alabama, and Louisiana). 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, Townsend, & Thayer, 1997). Unfortunately, oysters do not form extensive intertidal reefs in Delaware Bay (Taylor & Bushek, 2008). Ribbed mussels, though, are a functional dominant animal of Mid-Atlantic tidal marshes, and they are most numerous along the intertidal edges that are most prone to erosion. Ribbed mussels bind tightly to one another as well as plants with a network of fibers that attach with a natural 'superglue.' In a 2012 thesis (Moody, 2012), the author documented reductions in erosion whenever mussels were present, even at low abundance.

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 salt marshes in the Maurice River, a tributary of the Delaware Bay, in southern New Jersey. 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 treatments have been adaptively managed since 2008.

PDE and HSRL learned a number of lessons regarding the variables that led to successful installations. These variables included the type of natural materials installed and the orientation of installation relative to prevailing boat wakes, currents, and other shoreline features. The methods prescribed in Best Practices #5-8 of this document led to the best outcomes, but please note that every site will have local conditions that are likely to require tailored tactics and adaptive management (Whalen, Kreeger, Bushek, Moody, & Padeletti, 2011).

While the project was tested in marshes experiencing erosion along the New Jersey coast of the Delaware Estuary, PDE and HSRL 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. Current and imminent installations of this tactic are underway in the Forsythe National Estuarine Research Reserve along New Jersey's Atlantic Coast, as well as in the Nantuxent watershed along New Jersey's Bayshore, and in the Broadkill watershed, Mispillion Watershed, and Inland Bays in Delaware. When adapted for local conditions (e.g. energy and salinity), the technique should also be especially useful in concert with other tactics (e.g. hybrid living shorelines and maintenance activities undertaken by community groups).

The tactic emerging from DELSI is now referred to as the plant-mussel tactic. For more information on this tactic and its development, please visit http://delawareestuary.org/Living_Shorelines. A practitioner's guide has been created to provide more information about the origination and implementation of the tactic (Whalen, Kreeger, Bushek, Moody, & Padeletti, 2011).

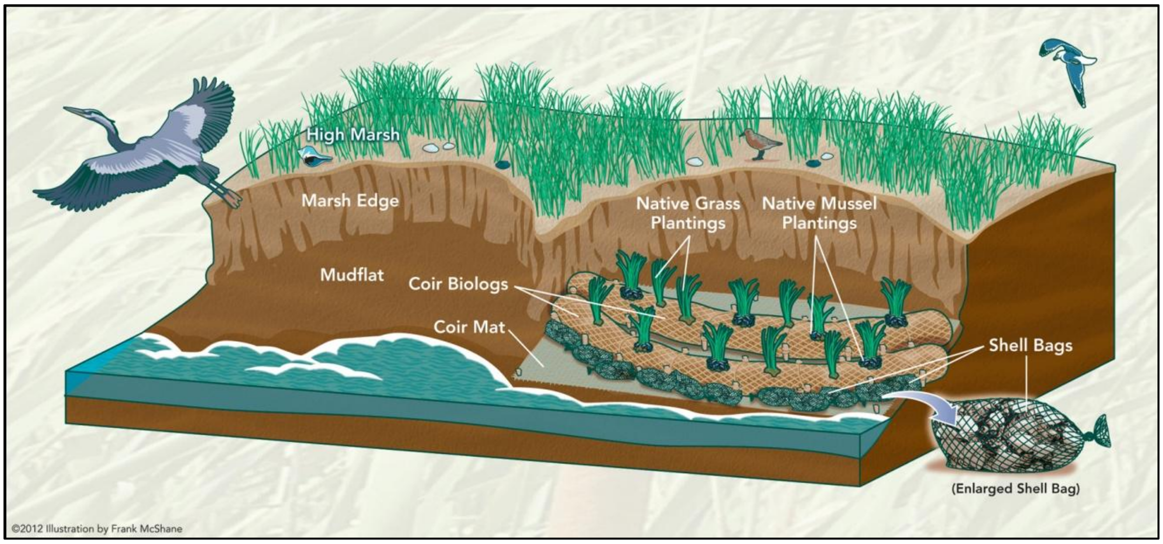


Figure 4. An illustrated representation of the PDE/HSRL DELSI plant-mussel tactic. Image by Frank McShane.

In general, though, the plant-mussel tactic uses staked coir (coconut fiber) biologs, coir mats, and bags of oyster shells to trap sediment in eroding marsh edges, recruit mussels, and reestablish *Spartina alterniflora* and other marsh species at the site.

Lessons learned from the pilot demonstrations included:

- Coir fiber mats help support coir fiber logs and shellbags, but are ineffective by themselves.
- Oyster shellbags placed in front of logs increases log stability.
- Logs should not be tucked against vertical erosion faces (cut banks) where waves are abruptly reflected.
- 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 installed end-to-end, tying them tightly and reinforcing the breaks by placing shellbags around them.
- Plantings of mussel seed and plant plugs can accelerate establishment of marsh and build resilience quickly if done in early spring. Salvaging marsh clumps from nearby eroded banks is an effective means of backfilling that also adds locally collected native plants and often mussels as well.
- The elevation of the new sediment surfaces behind the treatment should target the optimal growing range of the plants and mussels.
- The faster sediments fill in behind treatments, the less likely an installation will be to fail. Backfilling should be considered if the natural supply of sediments is low and accumulation is slow.

When these guidelines were followed, DELSI treatments usually yielded rapid sediment trapping, often fully backfilling to the top of the logs within two weeks; how fast this occurs at other sites will be dependent upon site specific sediment supply and deposition characteristics. Double log and overlapping treatments produced the deepest sedimentation. Wherever sediments accumulated, a rich microphytobenthic mat was observed that likely helped retain the accumulating soft sediments. The team also found that, after new sediments are compacted, a second vertical log tier can be added if additional elevation is needed to promote best biological colonization.

Common Hurdles

Despite the success that PDE and HSRL experienced with the plant-mussel tactic and the process of communicating and permitting the tactic, there were a number of hurdles that the team had to surmount in order to implement projects and continue to expand the initiative. Three hurdles that PDE and HSRL faced were insufficient information, the permitting process, and the public's general lack of exposure to living shorelines. These hurdles will likely be shared by most practitioners that initiate a living shoreline project until these tactics become more broadly recognized and long term results are proven.

Insufficient Information

Before installing a living shoreline, the project team must collect information and data to boost chances of success and select an appropriate tactic and design. Available options must be clarified and site data must be collected. Some of the basic questions are:

- What are the project's goals?
- What candidate sites and tactics exist to address the project's goals?
- What information and datasets exist to characterize current conditions at prospective sites (energy, distance to opposite bank [fetch], slope, vegetation, soil type, soil firmness, boating activity)?
- Which types of living shorelines would be most successful at the site (a softer tactic or a harder tactic)?
- If the installation is successful, how much new habitat would need to be created to reach stated goals? How many acres of tidal wetlands would be protected by the installation?
- Is there a particular time of year to target to minimize risks or maximize biological stability?
- Are there potential downsides or habitat tradeoff issues to address?

Information must be thoroughly collected and analyzed to ensure a successful project.

Permitting Process Challenges

Once an installation site has been selected, permits must be obtained to proceed with the installation. There are many questions to answer before embarking on procuring a permit:

- Are living shorelines a permitting option in the location of interest?
- Is installation of a living shoreline practical and feasible?
- Is the application process clearly defined and is guidance provided?
- Is it costly? (Does the application require site evaluations, inspections, testing plans, etc.?)

Without the proper permits, the installation cannot move forward. Regulation can be frustrating, but it is important to prevent projects from being improperly implemented in areas that are sensitive or where they might conflict with environmental management priorities. Typically, permitting agencies will answer early questions and provide some unofficial suggestions if approached prior to a formal permit application, potentially saving time for everyone involved later. Practitioners new to living shorelines should seek to understand all of the requirements and why they are there. The purposes of requirements are not always intuitive and are often constrained by multiple policies and management goals derived from different agencies.

The technique is not well-known

Perhaps the project team has collected detailed information about the site and managed to obtain a permit through a streamlined process. But if the project team is interested in promoting living shorelines as an alternative to bulkheads or other hard infrastructure, available data and a streamlined process can only go so far. How can a team spread the word out to communities and municipal leaders, who may be asked to support the effort? And, if a project's goals include research and design, how can a sound monitoring plan ensure that lessons are learned and communicated to others?

This document endeavors to help practitioners address these three common hurdles and understand the steps for physically installing a plant-mussel living shoreline. The document is divided into sections by best practice, beginning with equipping the reader with information about possible options, walking the reader through community and partner engagement, and providing details about the physical installation of a living shoreline. The information in this document is based solely on the lessons learned by the PDE and HSRL through the DELSI process, and will need to be altered depending upon the local conditions and needs of a given group.

Please be aware that living shorelines are new methods that do not yet have a long track record of proven effectiveness. Compared to some traditional (hard) tactics, living shoreline installations might need to be adaptively managed and possibly augmented more frequently than hard tactics. Therefore, monitoring is recommended for all projects. If you are planning to implement (or have implemented) a living shoreline, please contact PDE and HSRL at restoration@delawareestuary.org to share your lessons learned and help us to refine future designs.

Best Practice #1: Understand the Options Available

Before thinking about an eroding site, the community of people involved, or even budgetary considerations, it is important to have an inventory of options available. Being familiar with multiple living shoreline options can help a practitioner to better appraise a site and discern the type of intervention that might be worthwhile.

Living Shorelines Inventory

Below is a brief summary of the types 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 (Partnership for the Delaware Estuary and Rutgers Haskin Shellfish Research Laboratory, 2012).

"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 that slopes to a shoreline. This includes trimming overhanging tree branches to increase sunlight, selectively choosing desirable plants for natural regeneration, or planting. Vegetated buffers can be used to intercept stormwater runoff and control invasive species that degrade habitat or destabilize it. Most tidal shorelines are suitable for some type of riparian vegetation management and enhancement activities along their landward margins.

Beach Nourishment and Dune Restoration

Beach nourishment is the addition of sand to a beach or dune 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*.

Figure 5. One type of sand dune restoration tactic. Image retrieved from MRD Associates, "Gulf Dunes GeoTubes and Dune Restoration in Walton County, Florida," http://www.mrd-associates.com. 11 March 2013.

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 Nourishment and Enhancement

Tidal marsh enhancement includes adding new marsh plants to barren or sparsely vegetated marsh areas. Sand or mud fill (e.g. ‘beneficial use’ of dredge material) 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. Existing marshes that appear to be drowning in their interior areas, evidenced by widening open water and sparse, leggy plants, may be candidates for sediment application to build elevation.

Figure 6. Image of tidal marsh enhancement. Image retrieved from Santa Clara Valley Water District, “Islands Pond Tidal Restoration,” www.valleywater.org. 11 March 2013.

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 existing vegetation and 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 sometimes be applied where a natural marsh does not exist. In this tactic, non-vegetated intertidal areas are 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 to engineer a wider and higher intertidal zone. The plant species chosen will depend on the local salinity range plus the depth and duration of tidal flooding (hydroperiod). 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; therefore, the wave climate and the frequency and size of boat wakes must also be considered (Perry, et al., 2001). Marshes are difficult and costly to create where none have ever existed; as a result, more net gain can usually be realized by stemming the loss of existing wetlands through enhancement.

Bank Grading

Bank grading physically alters the slope of a shoreline segment in order to ease shorelines with steep slopes and reconnect ecological systems. Immediately after regarding, vegetation that will form dense and deep root mats should be planted. 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.

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. In urban areas, past land use, fill, and potential contaminants may need to be considered.

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. In soft substrates, they may need to be placed on fiber mats. Fiber logs are particularly useful to create quieter areas protected from waves where suspended sediments can drop out of the water. As soon as sediment is trapped or added, vegetation should be planted.

Figure 7. Credit: PDE. Coconut fiber logs, called 'coir logs' are used in the PDE/HSRL living shoreline tactic.

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. In some cases, logs can themselves be armored with bags of oyster or clam shell, as demonstrated by the PDE/Rutgers DELSI tactic.

"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. Like fiber logs, they are designed to break waves to prevent erosion, while allowing sediments to settle out of the water in the quieter areas behind the treatments.

Figure 8. Image of a marsh toe revetment. Retrieved from North Carolina Division of Coastal Management, "Stone Sill Photo," http://www.nccoastalmanagement.net/estuarineshoreline/options.html. 11 March 2013.

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 installed in shallow nearshore areas adjacent to marshes or near the low tide line. Sills can be backfilled with clean sand to create a suitable elevation and slope for planted tidal marsh vegetation, or they can be allowed to trap sand and other sediments. Like marsh toe revetments, the height of the sill can be adjusted between the mean low and high water elevations to minimize interruption of tidal exchange and encourage vigorous growth of wetland plants.

Marshes with broad, shallow mudflats or eroding banks without a tidal marsh present are candidate sites for marsh sills, particularly if marshes exist in the general vicinity or were present on the site historically. 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. In low energy areas, other types of finer sediments might be trapped or added if vegetated quickly to stabilize the substrate.

Marsh with Groins

Groins are short stone structures placed perpendicular to the shoreline to support a planted marsh, often on 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 and where longshore currents are a contributor to erosion. Sills, though, 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 structures strategically positioned offshore to dampen wave energy that reaches the shore and causes erosion. Some tactics encourage the creation of a stable beach profile with embayments. Even though they tend to be large and costly projects, offshore breakwater systems are sometimes included in living shoreline approaches where erosion energy is high because nothing else is capable of dealing with high energy currents and waves of large water bodies. If breakwaters are segmented, the resulting living shoreline behind them can be a habitat mosaic that includes sand beaches, marshes, and subtidal submerged aquatic vegetation (SAV) and reefs. Non-vegetated beach areas can be encouraged by breakwater systems and 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 shallow water areas.

Figure 9. Oyster domes accumulate sediment and attract spat. Retrieved from Southeast Aquatic Resources Partnership, "Oyster Reef for Shoreline Stabilization," http://southeastaquatics.net/projects/habitat-projects-2007/oyster-reef-for-shoreline-stabilization. 11 March 2013.

Suitable sites for offshore breakwater systems are medium and high-energy shorelines where sand beaches, banks, marshes, and bluffs show a historic trend for rapid 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 waiting for natural accretion of sand, and this can minimize any downdrift sediment starvation.

Other Considerations

This brief inventory includes methods for erosion protection and habitat restoration collectively referred to as the "living shoreline" approach for stabilizing and building resilience along vulnerable 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 paired in some places with bivalve shellfish can be applied to many low energy shorelines that have 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.

Hybrid types of living shoreline design options have several characteristics in common. Properly designed, hybrid projects can minimize disruption to tidal exchange and sediment transport. Effective hybrid projects provide enough protection on their own, eliminating the need for harder erosion control structures at the riparian-wetland habitat interface (since hybrid tactics focus on reducing or attenuating energy along the subtidal-intertidal interface, instead). 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.

Every project needs to be tailored to local conditions and designed to address specific goals.

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 or other 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. In the upper Mid-Atlantic region that includes the Delaware Estuary, oysters will eventually be able to survive in the intertidal zone (like in Virginia and other coastal southern states), which will allow practitioners to pursue more living shoreline tactics in the future.

“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. Professional design and engineering assistance will be necessary to ensure that the installation is likely to be successful. Local knowledge or predictions of tide range, predominant wind direction, and wave height will help to design successful projects. The amount of sand fill needed for sills, groins, and breakwater systems has to be accurately calculated to prevent adverse downdrift effects. In some cases, living shoreline projects can be designed to take advantage of nearby dredging operations, such as by using dredged sediments beneficially to build elevation (marsh or beach nourishment) or backfill behind shoreline treatments. In areas where suspended sediments are high in the water, passive trapping of fine sediments could in turn benefit navigation interests by reducing maintenance dredging costs.

Wider acceptance of the living shoreline approach with its inherent limitations could help shift the current trend for shoreline armoring, particularly in very low energy settings. The guiding principles presented here can assist with the selection of suitable tactics, but every project needs to be tailored to local conditions and designed to address specific goals. Importantly, projects should be science-based and monitored to ensure they do in fact promote ecological conditions while also achieving stabilization or enhancement goals.

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.

Best Practice #2: Engage the Community

Before working to implement a project, it is critical to engage the local community, the state regulatory community, and partner organizations in order to properly consider how the project may affect other users or resources at the site.

Without the support of local communities, partner organizations, and regulatory agencies, a project team may miss critical pieces of information that could help to make the project successful, or that could ensure they don't unknowingly blunder into difficult territory. For example, during discussions with local groups at one of the PDE/HSRL prospective living shoreline project sites, scientists learned about a potential conflict with a bald eagle nest. At another project site, PDE and HSRL contemplated a nearshore oyster reef to reduce waves, but locals said that installing an oyster reef would create conflicts with crabbers that actively fish the area. Engaging with regulatory agencies is also important, since working with regulators in advance of submitting a permit can help to ensure that the project application includes the necessary details.

Figure 10. A workshop participant adds a sticky note to a map of the NJ Bayshore at a 2012 workshop.

Engage the local community

Whether a location has been selected for a living shoreline installation or a general area of interest for study has been identified, engaging the local community is imperative. The community should be engaged in order to:

1. Gain support for the project.
2. Get local information.
3. Provide information to the community about living shorelines.

Once a team has selected a general area of study, speaking with local residents will help to further focus the area of interest. Local residents will know the places on their shores that are facing erosion, the locations that have the highest and lowest wave energy, and the places that have suffered the greatest amount of tidal wetland loss in the past years. Residents can help an organization to select a site where an installation can stem tidal wetland loss and simultaneously provide benefit to community assets (like marinas, roads, or houses).

By engaging the local community early, a project team may also pinpoint key partners that will help to link their organization to property owners, businesses interested in donating materials, or volunteers interested in donating time. This is especially true if the project's goals help locals to address their priorities, too.

Engaging a community early builds an understanding between the organization and the neighborhood. Creating an open process allows residents to ask questions and understand why the organization is there and what they are doing. Building good faith can help the community and regulators to support the work and installation regardless of the outcome (this is particularly important if the installation is experimental). If community officials are aware of the installation and projected outcomes, they can help to educate others and support the project. Building a good reputation among towns will help the organization in future work in that area.

PDE/HSRL Experience

In order to engage communities, PDE held large central workshops for community leaders in two regions where living shorelines could potentially provide benefit in the future. Community leader workshops were held for the South Jersey Bayshore (at the Cumberland County College in Vineland, NJ) and for the Delaware Bayshore (at the town library in Delaware City, DE).

The purpose of the community leader workshops was to introduce coastal leaders to the concept of living shorelines, to learn about new places where tidal wetlands are eroding, and to learn whether a living shoreline approach might be a feasible way to address the issue.

Both agendas contained the following elements:

- Welcome and workshop context
- Group introductions
- Living Shorelines 101: an overview of what living shorelines are and what they are not
- Case Studies of existing or proposed living shoreline installations
- Mapping exercise -- participants added sticky notes to a map to indicate where they
    - Saw erosion
    - Thought a living shoreline would help sustain a wetland, or
    - Thought a living shoreline installation would provide some other type of benefit
- Discussion of results of participant mapping exercise

Figure 11. Participants of our 2012 Delaware community workshop participate in the mapping activity.

PDE found that workshops that attracted elected officials and longtime community residents were more productive than those that did not. It was helpful when residents brought personal stories and historical pictures to the workshop. PDE scientists were able to ask specific questions of people with personal narratives, which helped them to decide if the locations discussed were areas that might benefit from installations. 'Benefits' were defined as both ecological benefits to the region and benefits important to local groups, including fishermen and boaters. For example, in some areas there was high interest in using living shorelines to protect roads that traverse marshes to access towns by stabilizing the marshes themselves, rather than bulkheading.

Participants in communities that were seeing erosion were particularly involved attendees, and had many questions for PDE scientists. While PDE scientists could not answer all questions (e.g., questions regarding state capacity and funding), they did their best to answer the questions they could. Participants were also able to meet with concerned residents from other, nearby towns, and learn that they were having similar issues. PDE believes that the networking afforded by our workshops was important for future collaboration between towns, while also building awareness and local interest in living shoreline tactics.

The participant counts by attendee type are as follows:

Workshop	Total Attendees	Non-profit attendees	Municipal attendees	Agency attendees	Corporate attendees	Academic attendees
New Jersey	46	18	19	5	2	2
Delaware	23	7	6	7	3	0

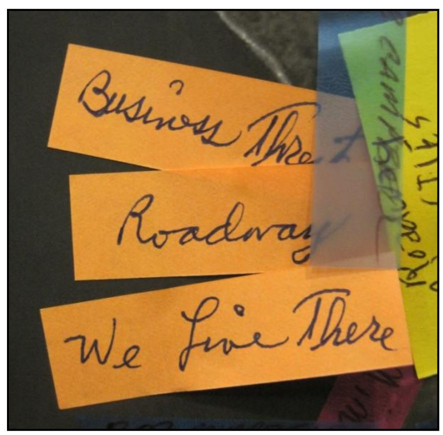


Figure 12. At left- image of map following sticky note activity at NJ community workshop. Note how sticky notes cluster in certain areas. Above- close-up of sticky notes placed on map of Cumberland County, NJ. Participants were asked to list what resources were being impacted by coastal erosion.

As illustrated by the images above, some of the most compelling information received from the community workshops came from mapping activities and personal narratives.

Engage the regulatory community

It is often difficult to obtain a permit for a project type that is new to a region. Living shorelines are new to many places (even though the term was coined in the 1980s).

PDE/HSRL Experience

In order to facilitate advancement of living shorelines permitting in the estuary region, PDE held three events for permitting agencies and environmental practitioners to discuss permitting challenges to living shorelines. The first was a workshop held for permitting agency representatives and practitioners in Dover, DE. The second was a meeting held with partner organizations in Bridgeton, NJ. The third was a workshop held for permitting agency representatives and environmental practitioners that work on the urban waterfronts of Philadelphia, PA, and Camden, NJ. It was held at the Adventure Aquarium in Camden.

DELAWARE WORKSHOP: PDE hosted a workshop at the St. Jones Reserve in Dover, DE in December 2011.

PDE (and partners) had been informed by practitioners that the Delaware permitting process for living shorelines installations was slow and expensive. In December 2011, with funding from Delaware Coastal Programs (DCP) and the Delaware Department of Natural Resources and Environmental Control (DNREC), PDE hosted a workshop at the Delaware National Estuarine Research Reserve at St. Jones, just outside of Dover, DE.

Figure 13. Greg Breese of USFWS talks about habitat trade-offs at our 2011 Delaware practitioner workshop.

The goals of the workshop were three-fold: share interest with decision-makers (federal and state regulatory agencies and environmental practitioners), identify barriers to living shoreline installations, and find ways to navigate challenges to installing living shorelines. The day was designed to provide a brief overview at the beginning, progress into policy matters in the middle, and stimulate significant discussion at the end. The discussion was divided into two portions—in the first, four key questions about living shorelines were introduced by professionals (in agencies and corporations) who were familiar with them. The questions (and introductions) were designed to help the audience grapple with the permitting and policy questions that routinely block expedient permitting. In the second part of the group discussion, participants were asked to use sticky notes to mark areas on a map where a living shoreline might be a feasible method of stemming coastal erosion. They could also mark other issues on the map, like areas in need of contaminant containment. After marking areas on the map, attendees discussed the areas that were targeted for concern.

The agenda included:

- Welcome and workshop context
- Living Shorelines 101: an overview of what living shorelines are and what they are not
- Case Studies from New Jersey and Maryland
- Local Needs presentation with information from initial field reconnaissance analysis
- Facilitated Group Discussion about the following topics:
    - Permitting barriers and solutions to living shorelines
    - Costs and maintenance costs of living shorelines
    - Habitat trade-offs of current habitat to living shorelines
    - Technical limitations of living shorelines
- Living Shorelines and upcoming municipal outreach
- Mapping exercise -- participants add sticky notes to a map to indicate a potential location for a future installation
- Discussion of results of participant mapping exercise

The workshop attracted forty participants from environmental nonprofits, corporations, and federal and state agencies.

Workshop	Non-profit attendees	County-level attendees	State-level attendees	Federal-level attendees	Corporate attendees	Academic attendees
Delaware Practitioner Workshop	9	2	18	4	6	1

Participants responded particularly well to the case studies and information imparted from permitting practitioners in other states. The speaker from Maryland Department of Natural Resources was able to answer questions regarding the evolution of the state's living shoreline policies as well as questions regarding differences and similarities between current practices and programs in Maryland and Delaware.

Figure 14. Kevin Smith from Maryland DNR spoke at the 2011 Delaware workshop.

One of the most useful products of the workshop was a table on barriers and solutions to living shorelines that PDE created from stories and information collected at the workshop. While the workshop gleaned a Delaware-specific perspective, the information collected in this table is applicable to other area locations, as well.

Existing Barrier	Potential Solution	Evidence?
Lack of political will	Look at the social and political drivers in the state to boost interest in living shorelines. Find a political sponsor.	This drove the installation in New Castle, DE. In MD, 5th graders were brought to the state legislature to lobby for living shorelines
No demonstration projects/don't know what the barriers are	Raise funds to launch a demonstration project to determine actual barriers.	This is what helped in New Jersey.
Do not know who the partners/interested non-profits are	Launch a demonstration project to determine partners	This is what helped in New Jersey.
Groups do not speak the same language/use the same jargon	Hold meetings for all agencies/groups involved to determine definitions	PDE experience with the USACE
Private owners coming in piecemeal (no coordinated or state-led efforts)	Education, state leadership?	Strong landowner interest in PDE living shoreline brochure
Lack of understanding/importance of cumulative impacts of hardened projects	Hardened projects should be scrutinized as much as LS. USACE nationwide permit should consider cumulative impacts	MD policy places burden of proof on applicant to prove that a LS will not manage erosion at the location
People are unfamiliar with living shorelines/regulations do not exist to promote them	Slowly phase in policies, regulations, and then law.	This is how the process began in Maryland.
Application fees	Waive the application fee for living shoreline projects, charge a fee for hardened stabilization projects to offset this	This happened in Maryland—fee for hardened projects was created through legislation (a bill went through the state assembly)
USACE and state permitting difficulties	Get the USACE on board as a partner, possibly through beneficial reuse of dredge materials	PDE experience

The information in the table addresses issues likely common in all states that do not have a living shoreline permitting process.

NEW JERSEY MEETING

As a result of the momentum that had already recently been generated around living shorelines in NJ (including the American Littoral Society workshop "Advancing Living Shorelines in New Jersey" held in March 2011 and press from the PDE-HSRL living shoreline installation), PDE decided that a more targeted permitting agency/partner meeting would be more productive than a workshop. New Jersey state and U.S. Army Corps of Engineers permitting was the single greatest challenge experienced by the PDE-HSRL living shoreline installation, and, at the time, revisions to living shoreline permit rules were being considered but did not seem to be progressing.

PDE held the partner update meeting in January 2012 at the JCNERR David Sheppard House in Bridgeton, NJ. The meeting provided an opportunity for all partners (non-profits and agencies alike) to share information regarding the latest efforts to ease living shorelines permitting impediments. The meeting also provided PDE with an opportunity to ask partners for help in recruiting attendees for a second New Jersey workshop for community leaders. New Jersey efforts were funded by the Geraldine R. Dodge Foundation.

At the onset of PDE and HSRL planning for this phase of living shorelines, New Jersey had already begun to engage in a process whereby it would make the criteria to obtain these permits less onerous. A white paper for discussion by the New Jersey Coastal Management Office had been posted in November 2009 (Frizzera & Wood, 2009). The white paper was prepared "in response to the permitting experience of the first living shorelines pilot project implemented by the Partnership for the Delaware Estuary," and was

> developed to help the NJDEP and the CMO examine pilot project opportunities that explore the technical and science knowledge necessary to expand the universe of living shorelines projects and to make this knowledge and methodology available to the general public in response to climate adaptation, sea level rise and shoreline erosion (Frizzera & Wood, 2009).

The white paper goes on to provide basic information about living shorelines and difficulties in obtaining permits for them in New Jersey. The writers also provided comments on existing relevant permits, specifying places where information on soft infrastructure could be inserted for ease of permitting living shoreline approaches. White paper co-author Dorina Frizzera was present at the meeting to confirm forward movement on living shorelines permitting, and to provide additional details regarding envisioned long range plans.

'LIVING URBAN SHORELINES' WORKSHOP: PDE hosted a Living Urban Shorelines workshop for environmental practitioners and state and federal regulatory agencies in Camden, NJ in October 2012.

Since urban waterfronts face different challenges than their suburban and rural counterparts, PDE focused this workshop on the importance of shoreline stabilization and ecological restoration along already-hardened shorelines. The workshop attracted agency staff and practitioners from

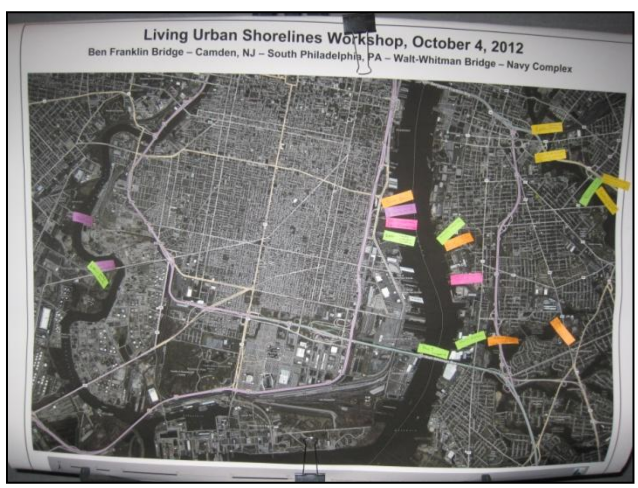


Figure 15. One set of mapping results from the living urban shorelines workshop in late 2012.

Philadelphia and Camden, among other interested parties.

The agenda included:

- Welcome and workshop context
- Urban Waterfront Ecological Opportunities
- Case Studies on Philadelphia initiatives, New Jersey's Harrison Avenue Landfill project, and Stabilizing and Restoring Contaminated Waterfront Shorelines
- Local Needs presentation with information from field reconnaissance analyses
- Facilitated Group Discussion on the following topics:
    - Permitting barriers and solutions to living shorelines
    - Costs and maintenance costs of living shorelines
    - Habitat trade-offs of current habitat to living shorelines
    - Technical limitations of living shorelines
    - Social justice opportunities that accompany restoration of urban waterfront sites
- Mapping exercise -- participants add sticky notes to a map to indicate a potential location for a future installation
- Discussion of results of participant mapping exercise

The workshop attracted fifty participants from environmental nonprofits and state, local, and federal agencies.

Workshop	Total Attendees	Non-profit attendees	Municipal attendees	Agency attendees	Corporate attendees	Academic attendees
Living Urban Shorelines	47	10	6	23	3	5

The workshop attracted a range of practitioners and interested parties, and demonstrated that, along the urban waterfront, there is significant interest in living shorelines as modes for contaminant stabilization, water quality improvement, *and* the more traditional ecological uplift. The workshop helped to communicate the difficulties faced by staff of permitting agencies, who described all waterfront projects being approached in the same way, regardless of project type (i.e. development projects are treated the same as green infrastructure projects). Staff communicated the belief that their agencies are evolving, and hope for movement on living shorelines permitting in the future.

Engage partners

The PDE is a regional entity, working in New Jersey, Pennsylvania, and Delaware to support its mission of leading science-based and collaborative efforts to improve the tidal Delaware River and Bay, which spans Delaware, New Jersey, and Pennsylvania. As a result, when PDE wants to do work in communities, it relies heavily on its partner organizations for help.

Engaging partner organizations in the community and the regulatory agency outreach process will help to make workshops more productive. Partner organizations that have staff with in-depth knowledge of particular communities and their needs can be very helpful allies during this process.

PDE/HSRL Experience

PDE engaged the South Jersey Bayshore Coalition (SJBC), and asked for their help to inform South Jersey communities of the upcoming workshop. SJBC is comprised of roughly twenty nonprofit organizations, five of which assisted PDE with workshop recruitment. These five organizations sent representatives to local communities to speak at planning board or environmental commission meetings about the upcoming workshop and why it would be beneficial to attend. As a result of our partner organizations' work in recruitment, the South Jersey workshop attracted nearly fifty participants who shared valuable information about their towns. As a result, PDE was able to build deeper relationships with specific towns and property owners that were interested in pursuing living shoreline installations.

Engaging partner organizations in the outreach process is a strategy that will make the greatest difference to the attendance and productivity of a workshop.

Partner organizations and staff were also important participants of workshops, as well. Partner organizations have local knowledge from working closely with bayshore residents, and from having to navigate municipal regulations in the past. Partner organization staff can suggest new ideas and can quickly synthesize and pass along information learned from the workshop. Partners that live and work with communities possess local knowledge and have local contacts to help sidestep thorny issues, pinpoint places of specific concern, and provide a support network of boats, storage facilities, contractors, and businesses that can be engaged to generate local support and ensure success.

Best Practice #3: Listen to the Science/Data

Ensure that your process is firmly rooted in science by collecting and analyzing any appropriate data regarding the geospatial landscape, proximity and size of adjacent water bodies (fetch, wave field, currents), elevation and slope (survey data), geotechnical foundation and sediment type, and existing dominant biota (vegetation, SAV, bivalves).

Once an organization has gathered all necessary data, it is imperative to process and analyze it appropriately. Proper analysis will facilitate design of appropriate living shoreline treatments and help determine an installation that can take best possible advantage of existing ecology and physical conditions. This can also be particularly valuable for organizations that need to use funding strategically—understanding the potential outcomes of several different options can allow for better prioritization of precious resources.

PDE/HSRL Experience

PDE/HSRL pursued a three step process: GIS mapping, field reconnaissance, and data analysis. When these steps were completed, PDE/HSRL worked on conceptual plans, and then engaged experts to draft formal site plans for the permitting process. (For information about conceptual plans, please see Best Practice #4: Plan for Success.)

GIS Mapping

In cases where living shoreline installations seek to promote ecological goals for large areas rather than specific site goals, then GIS analysis tools can be used to identify prime areas for potential projects that would yield greatest ecological outcomes.

PDE/HSRL Experience

The Delaware Estuary is a large system, with fringing tidal wetlands extending from the mouth of the Bay (around Cape May, NJ and Lewes, DE) all the way up to Trenton, NJ. PDE has documented widespread wetland losses and prioritized coastal wetland preservation and restoration.

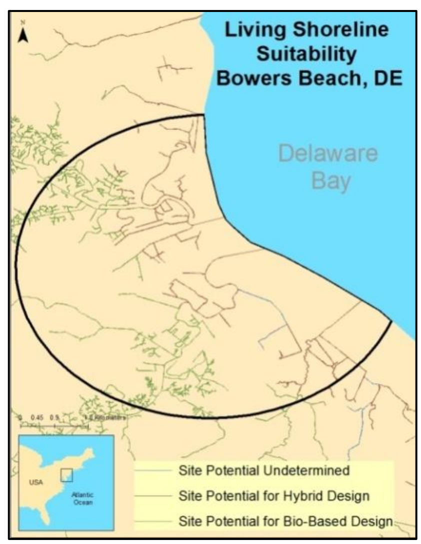


Figure 16. Example of GIS analysis showing tributaries with high and low energy.

To learn where various types of living shoreline installations might help stem these losses, PDE met with partners to identify a number of broad areas of interest. PDE scientists then used ArcMap, a Geographic Information System (GIS), to determine where a 'softer' or 'harder' living shoreline approach might be helpful within these broad areas of interest. Scientists initially gathered data on wave energy and fetch (among other considerations) to indicate the likelihood of a bio-based or hybrid living shoreline surviving in areas near eroding tidal wetlands (Partnership for the Delaware Estuary and Rutgers Haskin Shellfish Research Laboratory, 2012). This data was used to create living shoreline suitability maps like the one shown in Figure 15 above.

Field Reconnaissance

Once prospective areas are identified from either local knowledge or GIS analyses, trained scientists or engineers should examine areas on the ground, especially where they overlap with suggestions from other partner organizations, agencies, and community members. Ideally, for each identified site, scientists should plan to survey the site with a Real-Time Kinematic (RTK) Geographical Positioning System (GPS) to examine baseline slope, substrate, and elevation conditions. Biological characterization should include the presence and robustness of dominant biota.

Figure 17. RTK GPS surveying at Gandys Beach, NJ 2012

Mapping of sites generally consists of surveying along transects oriented perpendicular to the shoreline (for slope) *and* along natural contours parallel to the shoreline (for vegetated edges and other natural features). Point density and data logging should be dense and descriptive enough to allow generation of maps and GIS layers for topography, substrate variation, vegetation cover, and any other key habitats. Scientists should also record data for visible erosion and any hydrological or landscape features that could positively or negatively affect the success of a living shoreline. Scientists must also make note of other important features, like fauna (are there oysters or turtles?), ease of access (important to determine how to bring supplies to the site and the likelihood of public interaction) and whether there was some type of infrastructure or amenity that would be protected by the living shoreline (aside from the obvious habitat protection for tidal wetlands).

Figure 18. At left: Existing conditions at Lebanon Landing. Center: Vegetation at existing Lebanon Landing site. At right: predicted conditions at Lebabon Landing post-installation

Analysis

After completing the field work, point data from the RTK GPS are translated into a GIS data layer. Next, scientists perform an analysis to take into consideration how the vegetation and sedimentation would change if a successful living shoreline was installed. An important consideration is identifying the target elevation for biotic communities such as marsh grass, which will not grow if too low in the tidal prism.

Best Practice #4: Plan for Success

Select your site and carefully think through the things that will need to be accomplished prior to project implementation.

Whereas other steps are about collecting and analyzing information or asking others about best sites for installation, this step is about planning. You will need to think through non-technical considerations at your site; for example, it is important to ascertain whether it is possible in your area to procure the permits necessary for your chosen living shoreline. Other non-technical considerations include ensuring that the installation you've selected can be supported by your budget, and thinking through the inherent value judgments you make by proposing an installation. If the tactic isn't well-established or proven in your area, it is wise to plan to adaptively manage and consistently monitor the installation in order to allow for potential augmentation in the future.

Non-technical site considerations

Permitting

Organizations interested in installing a living shoreline must start thinking about permits early. Contact the appropriate permitting agencies in your state as soon as you have selected a site. For instructions on obtaining permits, see best practice #5 below.

PDE/HSRL Experience

The Delaware Estuary watershed spans three states (Pennsylvania, New Jersey, and Delaware), all of which have separate permitting systems. At the onset of the PDE living shorelines planning process, there were different levels of understanding of living shorelines built into each of these systems. Therefore, PDE devised a plan to engage each state on the permitting issue in a different way. For more information on these engagement tactics, please see best practice #2. The section includes information about potential barriers that may be present when an organization attempts to pursue a living shoreline permit.

In areas that have not yet adapted proactive living shoreline policies, changing the current practice of armoring sheltered coasts may 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. Ideally, 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;
- Improving shoreline management planning; and
- Sharing of lessons learned to validate efficacy of living shoreline pilots.

Ownership and Maintenance

Owning, or otherwise having responsibility for a living shoreline, is primarily about responsibility for maintenance. A living shoreline like the PDE/HSRL plant-mussel tactic is a type of 'soft' infrastructure, which means that it is made of biologically-based materials that respond to changing conditions. If a living shoreline is placed at a medium- or high-energy location, this can mean that some of the design elements used to create the installation will deteriorate more quickly than desired and may not allow the marsh time to reassert itself. If this is the case, the installation may need periodic maintenance. Depending upon the living shoreline tactic, periodic maintenance could range from planting *Spartina alterniflora* plugs to needing to repeat the treatment. Similarly, if marshes are not keeping pace with sea level rise, marsh enhancement to raise elevation might need to be repeated every few decades. Nevertheless, even repeated treatments could be cost-effective depending on the ecological and economic benefits of the site.

It is important to install the type of shoreline stabilization appropriate for the selected site in order to limit maintenance needs. Depending on the level of protection that is needed at a site (and the energy at the location), nonstructural and hybrid methods may not always be easier, less costly, or require less maintenance than rock revetments and bulkheads. However, if a living shoreline is appropriate for a given site, then maintenance options might be cheaper than maintenance of hardened shorelines (while also yielding other environmental benefits).

Habitat Tradeoffs

Regardless of the project type, any work to stabilize shorelines and improve ecological conditions will undoubtedly alter existing habitat in a given area. Projects should be assessed for habitat trade-offs on a case-by-case basis. For each site, practitioners should consider the purpose of the project, what it is meant to achieve, and what is being lost as a result. A group interested in protecting tidal wetlands might advocate for living shorelines to stem erosion, while a group interested in protecting mud flat habitat might embrace erosion/migration of tidal wetlands. In the Delaware Bay, some existing habitat types may be just as or more important than tidal wetlands. For example, juvenile horseshoe crab habitat is extremely important. An environmental practitioner might not want to install an oyster bed if the habitat that currently exists in a given location is important for horseshoe crabs. In general, coastal wetlands have very high stacked ecosystem benefits and so are a top priority for many projects.

Depending on a practitioner's values, there may be some tension between the person who wants to install a project and a person trying to support existing habitat. Some of these tensions may include:

- Submerged bottom lands vs. fill necessary for some living shorelines
- A biodiverse habitat vs. a habitat used by one species (perhaps a species of concern)
- Restoring historical uses vs. maintaining current use vs. planning for future sustainable uses
- Flood protection vs. navigation

Regardless of values motivating a project, considerations must 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 crabs and fish.

Education/Outreach goals

Depending on the nature of a living shoreline project, a project team may or may not have education or outreach goals associated with the installation. However, most projects will necessitate some type of education or outreach, if only to the property manager or landowner of the site on which the installation sits. If you are installing a living shoreline in a region where living shorelines are uncommon and difficult to obtain permits for, you might wish to expand your outreach efforts and proactively engage appropriate entities or people.

PDE/HSRL Experience

The goal of our efforts, overall, is to curb tidal wetland erosion by installing living shorelines in the Delaware Estuary watershed. The goal of our education/outreach, then, is threefold to address each of the previously-identified 'Common Hurdles.' The first desired outcome of outreach is to find where communities are seeing tidal marsh erosion or shoreline destabilization. The second desired outcome is to facilitate discussion between environmental practitioners and permitting agencies in order to create a more streamlined living shorelines permitting process. The third desired outcome is to educate impacted communities about living shorelines as a potential strategy that can be environmentally and budget-friendly alternative to sea walls or bulkheads.

In order to facilitate discussion between environmental practitioners and permitting agencies, PDE held workshops. In order to educate impacted communities about living shorelines, PDE held community workshops and created an introductory brochure. The brochure was intended to provide a property owner with enough information to talk to a consultant about living shorelines, but not enough information for the property owner to be able to do it themselves. The brochure offers explanations of living shorelines and basic terms and gives information on budget basics for installations.

Budget/Costs

The cost of a shoreline stabilization structure typically increases in proportion with the level of energy at the site. In other words—typically, a high energy site will cost proportionally more to stabilize than a low energy site. Many other variables, however, can also affect living shoreline pricing, such as slope and geotechnical base. 'Soft infrastructure' projects, like living shorelines, tend to be less expensive to install than traditional 'hard infrastructure' projects like bulkheads. The charts below provide some basic information for comparison.

The first table estimates a cost per linear foot for several types of shoreline stabilization tactics, as well as the general benefits afforded by each of the five types. Note that cost per linear foot includes the cost of materials and does not include any labor-related expenses, survey costs, field studies, modeling, design, permitting, special equipment rental fees or monitoring. Due to the wide variety of conditions that need to be taken into account, costs can vary significantly site to site.

Living Shoreline Types	BENEFITS						Costs per linear foot
	Reduce Erosion	Provide Habitat	Improve Water Quality	Filter Sediments	Improve Water Access	Slow Wave Energy	
Mussel and Plant Tactics	Yes	Yes	Yes	Yes	Yes	Yes	$100-$225
Marsh Creation with Stone Sill	Yes	Yes, if gaps in sill	Yes	Yes	Yes	Yes	$250-$700
Nearshore Oyster Reefs	Yes	Yes	Yes	Yes	No	Yes	$100-$1000
Breakwaters	Yes	Minor	No	No	No	Yes	$450-$1000
Bulkhead	Yes, but may cause erosion downstream	No	No	No	No	Yes	$500-$1500

The tables below provide a more specific cost breakdown for shoreline stabilization materials. The first is for the mussel & plant tactic, which is a soft tactic (suitable for low energy areas). The second is for a marsh sill and breakwater, which is a hybrid tactic (suitable for medium energy areas). The third is for a bulkhead (suitable for high energy areas), included here for comparative purposes only, as bulkheads are not living shorelines. Again, note that cost per linear foot includes the cost of materials and does not include any labor-related expenses, survey costs, field studies, modeling, design, permitting, equipment fees or monitoring. Due to the wide variety of conditions that need to be taken into account, costs can vary significantly site to site.

MUSSEL & PLANT TACTIC		
Materials & Supplies		**Cost Range**
Plants – Smooth Cordgrass		$1.00-$2.00 per linear foot
Plants – Saltmeadow Cordgrass, Sea Oats, Panic Grass		$.060-$1.60 per linear foot
Straw Blanket		$0.29 per square yard
Coconut Straw Blend		$0.52 per square yard
Coconut Fiber		$0.65 per square yard
Non-woven Geotextiles		$0.70-$1.35 per square yard
"Snow" Fencing		$45.00 per 100 feet
Coir Log		$57.25 per 10 feet
Geotextile Tube	15' circumference	$115-$175 per linear foot
	22' circumference	$175-$225 per linear foot
	30' circumference	$140-$200 per linear foot

MARSH SILL & BREAKWATER

Materials & Supplies	Cost Range
Oyster Shell (loose shell)	$50-$60 per cubic yard
Oyster shell (bags)	$5 (or $30 per bag with spat)
Concrete Bags	$4-$6 per bag (approx. $12-$16 per linear foot)
Limestone Rock	$125-$200 per linear foot
Reef Balls	$44 per linear foot (installed)
Reef Block	$150 per linear foot (installed)
Wave Attenuation Device	$180-$250 per linear foot
Rip Rap	$18-$35 per cubic yard

BULKHEAD (4-8 feet in height)	
Materials & Supplies	**Cost Range**
Vinyl	$125-$200 per linear foot
Vinyl (with toe protection)	$210-$285 per linear foot
Wooden	$115-$180 per linear foot
Wooden (with toe protection)	$200-265 per linear foot
Concrete	$500-$1000 per linear foot
Sheetpile	$700-$1200 per linear foot
Revetment	$25-$45 per cubic yard

Depending upon the energy level at the project site, each of these might be an appropriate strategy to combat shoreline erosion. However, the cost per linear foot for a softer infrastructure approach (as per the plant and mussel tactic) is likely to be less expensive than installing a bulkhead, as shown here. As mentioned earlier, some treatments may need to be adaptively managed and augmented, and those costs are not represented in the tables above.

Develop a conceptual plan

Once candidate sites are selected based on the data and analysis, these sites must be vetted with partner organizations familiar with a particular area. If partner organizations agree that the site is a good area of interest, scientists or engineers can create a basic site plan. The basic site plan should show the type of living shoreline needed at the site, as well as the configuration, amount, and extent of materials needed to achieve it.

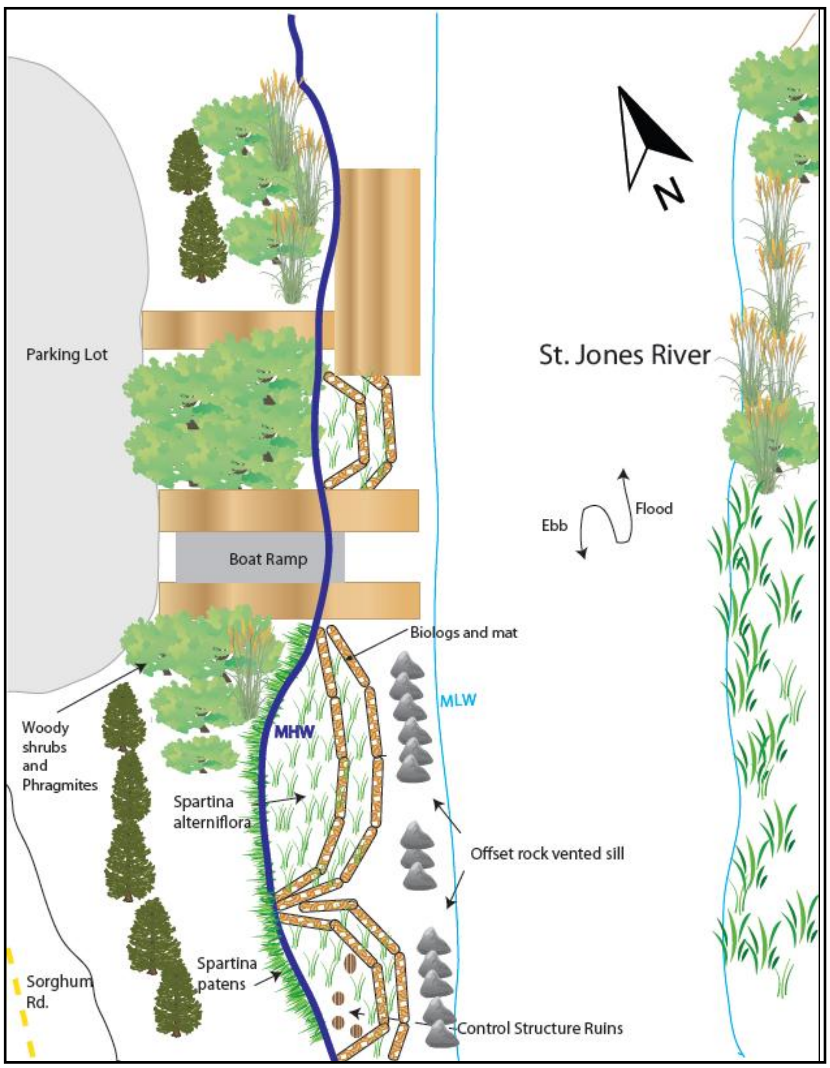
PDE/HSRL Experience

At PDE, we typically began by preparing a conceptual plan for the sole purpose of discussion and fundraising. These conceptual plans show existing site conditions and summarize our suggested tactic for addressing project goals. Conceptual plans are not formal site plans needed for typical permit applications (which often require very specific measurements and drafted plot layouts). Once funding and support is arranged, PDE works with partners to prepare site plans, which sometimes requires collaboration with engineers.

The following are conceptual plans for areas of interest (AOI) in Delaware and New Jersey that have been identified by PDE as possibilities for living shoreline demonstration projects. These AOIs (and others, not shown) were initially determined through GIS analysis to pinpoint sites on public lands where living shorelines were feasible based on energy and existing erosion. The initial AOIs were narrowed down through information gathered from field reconnaissance and workshops. For each site, scientists created an aerial view of the site, pre- and post- restoration contour maps showing vegetation and substrate, a summary of the data obtained during field reconnaissance, and a conceptual plan for the living shoreline installation that can be used for discussion and planning purposes when seeking funds for these demonstration projects. Again, conceptual plans are not engineering plans. They are to be used only for discussion and planning purposes.

Lebanon Landing

This site is located on the St. Jones River, at Lebanon Landing in Magnolia, DE near the Dover Air force Base. The site is very close to two fishing piers that are frequently used for both fishing and crabbing. Between the piers is a small boat ramp, which provides easy public access to the St. Jones River. The landing also has a water quality station that is owned by the Delaware National Estuarine Research Reserve System: http://nerrsdata.org/get/realTime.cfm?stationCode=DELSLWQ .

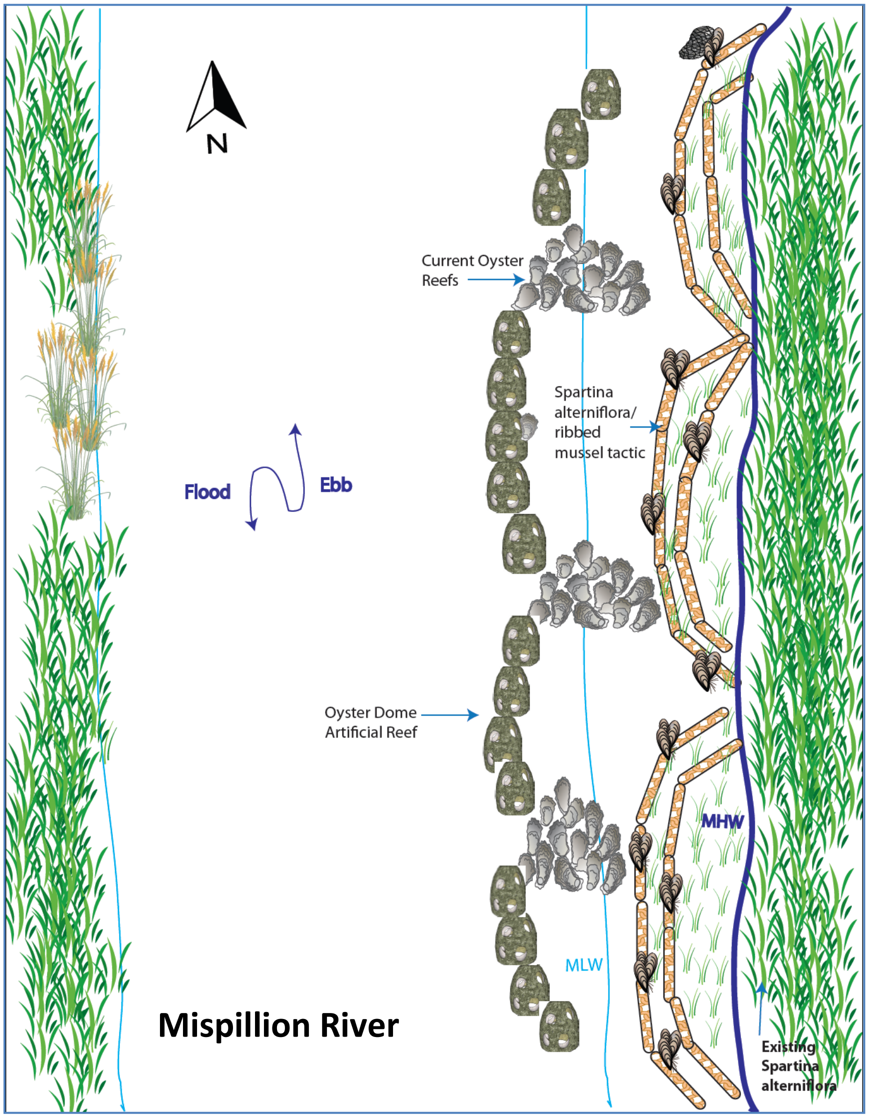


This is a highly ranked site for a living shoreline demonstration project because it is a low energy shoreline with great public access. The low salinity at this site prevents the use of marine bivalve shellfish (i.e., oysters or ribbed mussels) as a structural component of a living shoreline. The plan for this site is to use a hybrid living shoreline consisting of coconut fiber logs with native marsh vegetation planted behind the logs and a stone vented sill to divert energy in front of the logs. This living shoreline should reduce erosion and allow for the expansion of vegetated marsh. The conceptual plan shows two rows of coir fiber logs sitting on top of a fiber mat, which is necessary to stabilize the logs and prevent them from sinking into the sediment.

The cost estimate for this site was appraised at $79,284. This number includes site surveys, permitting costs, material prices, and monitoring needs. For a better cost break-out, please refer to the "Delaware Living Shoreline Possibilities" report by the Partnership for the Delaware Estuary and Rutgers Haskin Shellfish Research Laboratory (Partnership for the Delaware Estuary and Rutgers Haskin Shellfish Research Laboratory, 2012).

Mispillion

This site is located at the mouth of the Mispillion River in southern Delaware. The site is a high ranked site for a living shoreline demo project because intertidal oyster reefs present, ribbed mussels are abundant, it be easily seen by the public from the northern side of the river near an existing outreach center, and the *Spartina alterniflora* salt marsh behind this site is large and has little to no invasive plants. However, this site does have medium-high energy because of the water depth, proximity to the mouth of the river, and the presence of frequent boat wakes. The conceptual plans show a hybrid living shoreline consisting of expanded oyster reefs (subtidal) and mussel/plant augmentation (intertidal). Oyster domes or a comparable technology would be used as a breakwater to slow energy, protect the intertidal oyster beds, and provide more habitat for oysters. Oyster domes were chosen as opposed to oyster cultch based on the findings of Piazza et. al. 2005. The results of this study indicated that although oyster cultch can help protect salt marsh shorelines from erosion in low energy environments, the effectiveness of cultch is greatly diminished in environments that experience higher energy. A bio-based living shoreline consisting of two rows of coir fiber logs on a fiber mat would be used to trap sediment behind the oyster reefs and provide an attachment surface to facilitate mutualistic mussel and plant communities. At this site, the mussel/plant tactic developed by Rutgers and the Partnership on the Maurice River, NJ could be used to enhance stability and ecological function of the installation.

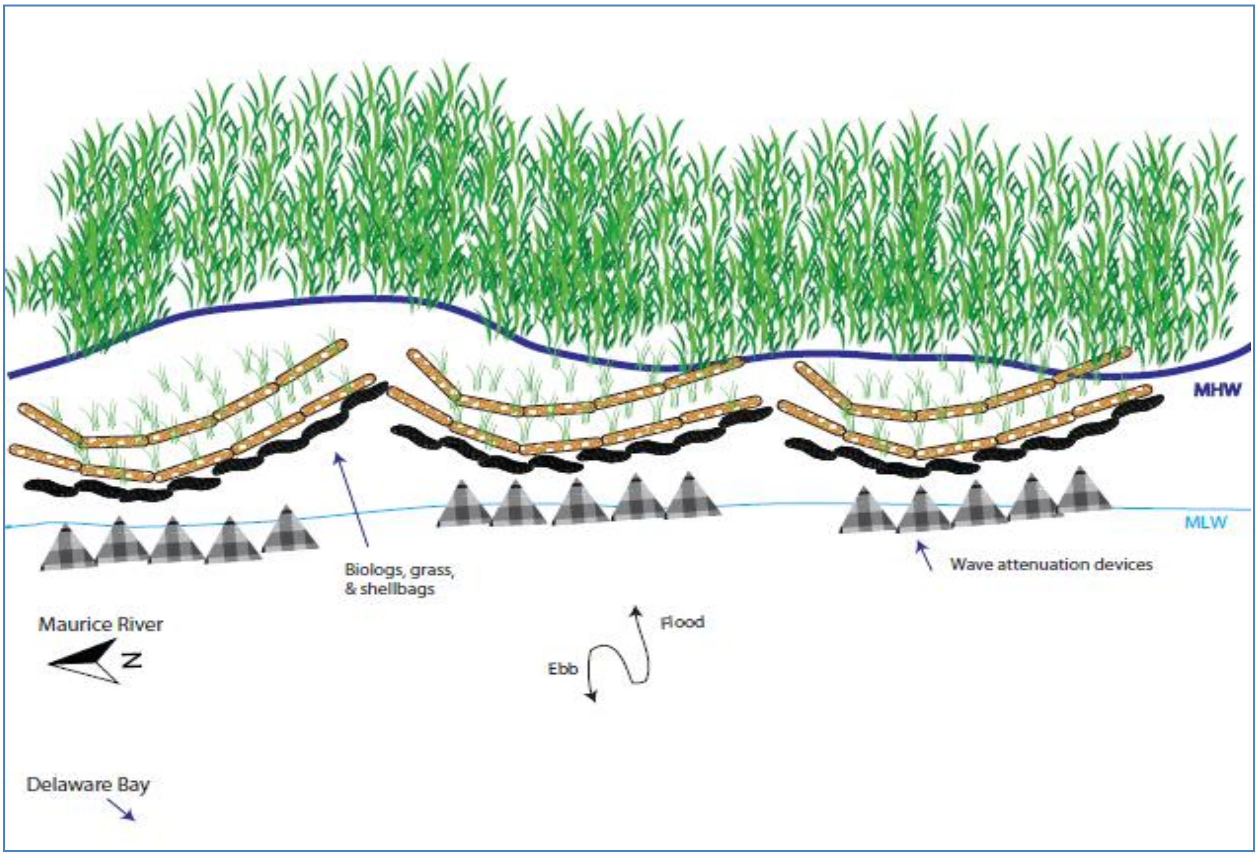


The cost estimate for this site was appraised at $233,309. This number includes site surveys, permitting costs, material prices, and monitoring needs. For a better cost break-out, please refer to the “Delaware Living Shoreline Possibilities” report by the Partnership for the Delaware Estuary and Rutgers Haskin

Shellfish Research Laboratory (Partnership for the Delaware Estuary and Rutgers Haskin Shellfish Research Laboratory, 2012).

Maurice River

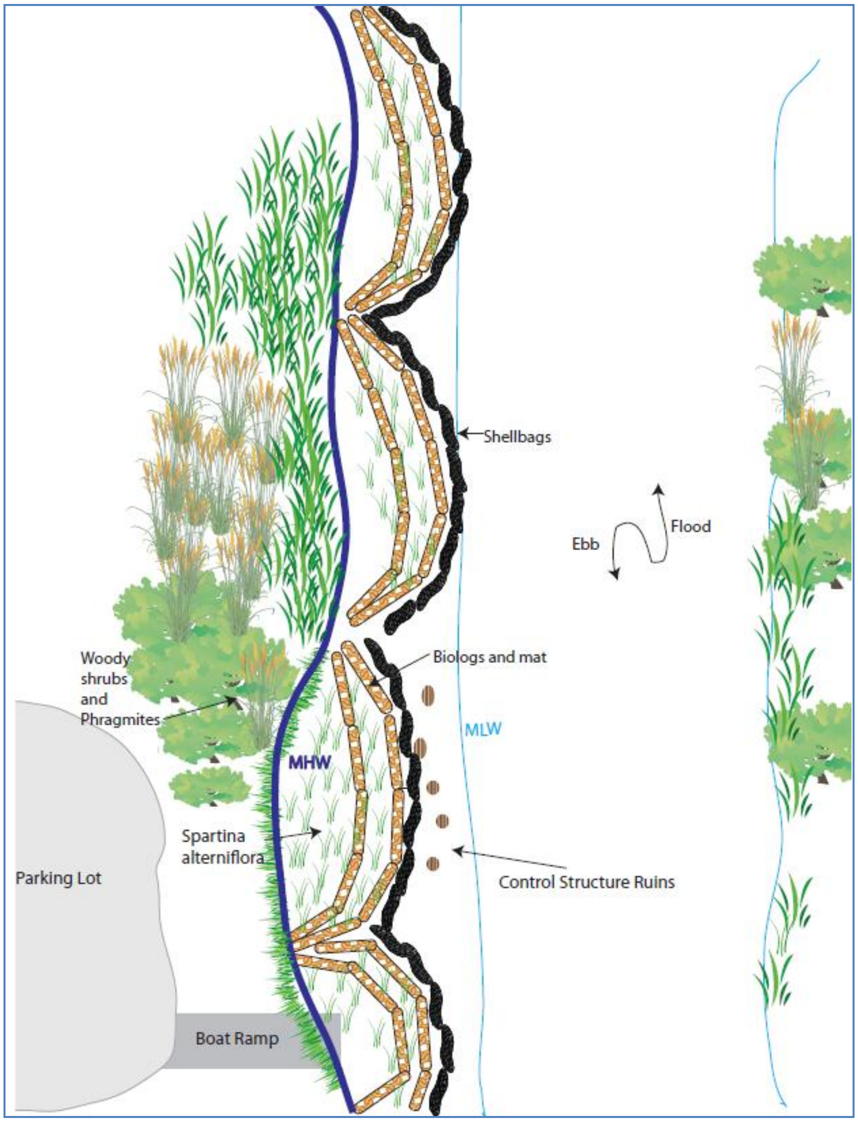
The Maurice River site is within the Heislerville Wildlife Management near Bivalve, NJ. The site is close to the mouth of the river and is eroding quickly. The Maurice River site is the subject of considerable focus by regional, state and local authorities, deemed an 'emergency situation,' especially post-Sandy. PDE proposed a multi-tiered effort to stabilize the river mouth, consisting of offshore breakwaters, nearshore sills, and hybrid living shorelines along inner margins and tributaries. The conceptual idea below depicts only one facet, designed to stabilize eroding salt marshes inside the mouth. This site is a possibility for a living shorelines demo project because it is an important area to protect before it becomes open water and affects the nearby towns. However, the Maurice River has high boat wake and energy. The idea for this site is intertidal mussel-plant (DELSI) treatments to stabilize erosion and expand the marsh edge. An offshore breakwater is suggested to reduce the energy at this site.



The cost estimate for this site was appraised at $233,309. This number includes field studies, permitting costs, material prices, and monitoring needs. For a better cost break-out, please refer to the "New Jersey Living Shoreline Possibilities" report by the Partnership for the Delaware Estuary and Rutgers Haskin Shellfish Research Laboratory (Partnership for the Delaware Estuary and Rutgers Haskin Shellfish Research Laboratory, 2012).

Greenwich

This site is located on Ragged Island Street near a boat ramp on the Cohansey River. The site is frequently used for both fishing and crabbing. There is a small boat ramp, which provides the public with easy access to the Cohansey River. This is a highly ranked site for a living shoreline demo project because it is a low-medium energy shoreline with great public access. The salinity at this site allows the use of marine bivalve shellfish (i.e. ribbed mussels) as a structural component of a living shoreline. The plan for this site is to use a bio-based living shoreline consisting of coconut fiber logs with native marsh vegetation planted behind the logs. This living shoreline should reduce erosion and allow for the expansion of vegetated marsh. The conceptual plan shows two rows of coir fiber logs sitting on top of a fiber mat, which is necessary to stabilize the logs and prevent them from sinking into the sediment. This arrangement is designed to trap sediments and increase elevation to a level that will support marsh plant growth and survival. *Spartina alterniflora* has an optimum growth range of about -0.4m to 0.9m, so the logs are placed at MSL to support plant growth, or just above if some settling is expected.



The cost estimate for this site was appraised at $38,097. This number includes site surveys, permitting costs, material prices, and monitoring needs. For a better cost break-out, please refer to the “New Jersey Living Shoreline Possibilities” report by the Partnership for the Delaware Estuary and Rutgers Haskin Shellfish Research Laboratory (Partnership for the Delaware Estuary and Rutgers Haskin Shellfish Research Laboratory, 2012).

Conceptual plans, like these, are important products that can only be created once all information has been collected, analyzed, and shared with partners. Conceptual plans are invaluable for developing the project as it moves to the engineering, funding, and ultimately implementation phases.

Best Practices #5-8: Implementation

Proper implementation is critical to a successful project. The following best practices are specifically for the PDE/HSRL DELSI plant-mussel tactic and is meant to provide the reader or user with information related to this tactic in the mid-Atlantic region only. The DELSI plant/mussel tactic is a 'bio-based' tactic, and this information may not apply to other types of living shoreline strategies. Hybrid tactics, in particular, will require much more engineering and planning ahead. The information below is for planning purposes only, and some of it is expected to change as the technology evolves.

#5: Get Appropriate Permits

Research and understand the permits you will need to procure for the installation, and ensure that you allocate enough time to complete the permitting process. Depending on the permitting agency's level of experience with living shoreline technology, the permitting process could be quite lengthy. Be prepared, be thorough, and be patient.

There are a several unique considerations for living shorelines installations that can trip up a permitting process. Normally, a project team applies for a permit for a project whose engineering plan is fixed and final. A living shoreline installation plan, though, needs to be adapted on site in order to take advantage of natural features or changing conditions of the shoreline that may not be apparent from initial surveys used for the permitting applications. Living shorelines require flexibility in a permitting process and in a final permit. As a result of these unique considerations, PDE found that it can be more difficult to permit an adaptively managed non-traditional tactic (such as a living shoreline) than a hard approach (such as a bulkhead or rip rap).

A living shoreline installation plan needs to be adapted on site in order to take advantage of natural features of the shoreline that may not be apparent from initial surveys used for the permitting applications.

Typically, permits are required from the Army Corps of Engineers and the state in which the installation will be located. These permits normally include fees. Regardless of whether the installation will be placed on public or private land, a letter of approval from the land manager or owner will be required. 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.

Each state in the Delaware Estuary has a different set of permits that need to be obtained in order to move forward with a living shoreline installation:

Pennsylvania

In Pennsylvania, there is no specific permit or process for installing a living shoreline. It is recommended for all first-time Pennsylvania applicants to have a pre-application meeting (though it is not required). At the pre-application meeting, a Department of Environmental Protection (DEP) representative 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 (484) 250-5165.

Applicants in Pennsylvania must complete a Joint Permit, which goes to both the PA DEP and the USACE. Fulfillment and approval of this application creates both a PA Water Obstruction and Encroachment Permit and a USACE Section 404 permit. Applicants must also complete the Standard Application. The applicant must procure appropriate approvals from the township where the project is located.

Delaware

In Delaware, there is more specificity in the living shorelines permitting process. Applicants must begin by filling out a Basic Application, followed by Appendix J: Vegetative Stabilization. If the living shoreline project requires any type of fill, the organization must also fill out Appendix H: Fill. An application fee of $225 will cover the entirety of the process. Following this, applicants 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. To speak with the USACE to verify the correct Nationwide Permit for compliance, call the regulator of the day at (215) 656-6728. (At the time of the writing of this report, an effort is underway to streamline and centralize living shoreline permits in Delaware, so this information is subject to change.)

New Jersey

In New Jersey, the state code acknowledges the need and desire for living shorelines (Code 7:7-7.21 Coastal general permit for the stabilization of eroded shorelines). Accordingly, applicants must obtain a coastal general permit from the Division of Land Use Regulation. Additionally, applicants must obtain a USACE nationwide permit 27: Aquatic Habitat Restoration, Establishment, and Enhancement Activities. These must be obtained prior to initiation of work for state-owned land. Since the time of the DELSI installation, however, NJ living shoreline permitting rules have changed. We advise you to check with NJ DEP for updates.

#6: Purchase Materials

It is important to acquire materials appropriate for the geographic location, elevation, and characteristics of the site. In order to do so, a project manager should become familiar with the site's flora, fauna, and sediment characteristics, then work with a reputable nursery or hatchery. Without the proper information or contact, plants or materials may be purchased that are not suited for the site's specific conditions, wasting precious time and resources. Physical characteristics such as slope, salinity, and wave energy are all very important.

In order to learn more about the types of native species at a site within the Delaware Estuary system, a project manager could use the Delaware Estuary Natural Vegetation Classification system. The Natural Vegetation Classification system "provides a complete, standardized listing and description of all the vegetation types that represent the variation in biological diversity at the community level" (Westervelt, et al., 2006). Using the maps and other information available at the PDE website (http://www.delawareestuary.org/downloadable-nvcs-products), the project manager can discern the site's ecological system and sub-habitat type. Once these are determined, the manager can use the accompanying Guide to the Natural Communities of the Delaware Estuary to identify the most characteristically abundant species for a given site.

Once the native species to be used at a site are identified, the project team should look for a nursery in the area of the project site that grows or deals with native wetland plants. PDE and Rutgers purchased materials (coir logs and plants) from Pinelands Nursery in New Jersey. Pinelands Nursery is located at 323 Island Road, Columbus, NJ 08022. Their phone number is (609) 291-9486, and they can be found online at www.pinelandsnursery.com/index.htm. For a more extensive list of plant suppliers in Delaware in New Jersey, you can check here: http://www.plantmaterials.nrcs.usda.gov/pubs/njpmcot9907.pdf. If bivalve shellfish are to be seeded into the treatment, check with the Rutgers Haskin Shellfish Research Laboratory for a source of seed.

The following materials are needed per 40 meters of shoreline (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 oak stakes (12 per log) 5 ft long - 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

#7: Installation and Planting

Installation must be carried out in the manner determined by the analysis and with respect to conditions at the site. Without submitting to observed conditions, the installation will not function properly.

The following steps prescribe how to install the plant/mussel living shoreline tactic.

1) Complete a site survey to determine elevations where the current vegetation is growing successfully. This could be done with an RTK GPS, Total Station, or simply a line level referencing nearby growing marsh grasses. Design the treatment so that vegetation will be expected to grow within a comparable elevation zone (or slightly above if settlement can be expected on soft sediments). Note: the elevations where vegetation grows are relative to the site specific tidal prism and this varies as one moves around the estuary.

Figure 19. Carrying a coir fiber mat to the project site. Picture credit Priscilla Cole, 2012.

2) Use survey flags to mark the location where logs will be placed

to ensure placement at the correct tidal elevation in a cusp shape. The ends of the installation should reach back to the existing marsh shoreline.

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 tied tightly together with coir twine.
5) Lay out six pairs of 4 or 5 ft pre-drilled stakes per log (stake lengths can be shortened or lengthened to account for sediment firmness), 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.

Figure 20. Laying out the stakes. Picture credit Priscilla Cole, 2012.

6) Hammer in stakes tightly against logs through mat (6 on each side of log) until pre-drilled holes are flush with top of logs. (Hint: it helps to widen mat mesh openings with fingers to insert stakes through mesh and prevent stakes from pulling mat into sediment.)
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 mesh bags with shell is to slip the bags over a 3-4ft section of 6" diameter PVC pipe after tying off one end of the bag with an overhand knot. Once full, remove the pipe and tie off the other 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.

Further details are available at the PDE website, at www.DelawareEstuary.org. Amendments to this method (knot types, log arrangements, staking) are often needed to maximize resilience and adapt to softer bottoms. The orientation to prevailing waves and currents is also important.

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 (and animals) because it gives the biota 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 that supports grass survival can be salvaged and planted in the accumulated sediments. Some of these might already have mussels attached—a bonus. Place the salvaged clumps behind logs and push the roots into the accumulated sediments. For DELSI, up to 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 alterniflora* 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.

Figure 21. These plugs of marsh grass were purchased from a local nursery. Picture credit: Priscilla Cole, 2012.

Figure 22. Planting *Spartina alterniflora* in the coir logs. Picture credit Priscilla Cole, 2012

#8 Other Biota

In the PDE/HSRL tactic, scientists sought a local intertidal bivalve. Since there are few intertidal oysters in the Delaware Estuary, scientists chose mussels. Mussels have unique ecological needs (e.g. substrate and salinity); therefore, projects should consider all of the ecological needs of dominant species being targeted, including key animals.

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. Juvenile seed for ribbed mussels is starting to be produced experimentally at the Rutgers Aquaculture Innovation Center and may soon be commercially available. Until then, the best source of mussels is 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. Grass plugs and mussel clumps can often be found washing up on the foreshore. Larger mussels will be less susceptible to predators, though all mussels are susceptible to blue crabs. As a result, protecting the mussels with coir mesh is advised. The PDE method of attaching mussels to logs, as detailed below, worked for juveniles as well as adults:

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.
4) A second method tested by PDE and HSRL involves placing 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. Salvaged clumps of *Spartina alterniflora* 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. When PDE and HSRL tried this method, they found mussels recruited to the coir logs as well as to the stakes used to hold the logs down.

Figure 23. Mussels attaching to coir mats in Rutgers Haskin Shellfish Research Lab. PDE, 2011.

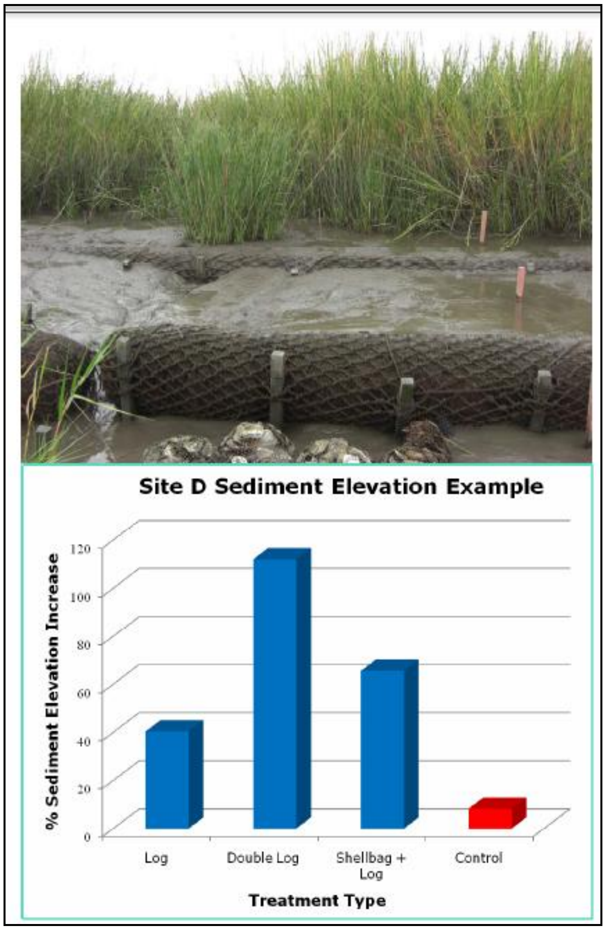
In some states (or regions within states), oysters may also be included in the design. Oysters would be targeted towards the lower intertidal and shallow subtidal zone with mussels used in the mid to high intertidal zone. Planting oysters is currently forbidden in waters closed to shellfish harvesting 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. Interestingly, we have found high recruitment of ribbed mussels into oyster shell bags, and they continue to thrive.

Best Practice #9: Evaluate Success

Without data to compare preexisting conditions with post-installation conditions, it is difficult to evaluate the success of a project. Monitoring is crucial to understanding whether a project is working or how to alter it if it is not. This is especially true in areas where living shoreline applications are new and/or experimental.

Monitor sedimentation/erosion

For PDE, the ultimate goal of living shorelines was to stem tidal marsh erosion. In order to find a living shoreline that was best-suited for this purpose, in 2008 PDE and the Rutgers Haskin Shellfish Research Laboratory installed a number of different types of bio-based living shorelines in different energy systems in different configurations in order to learn what worked best. Adjacent control sites were also identified and monitored. All sites were positioned around the mouth of the Maurice River near Bivalve, NJ.



Credit: PDE, 2009. The most sediment accreted behind double log configurations.

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. 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. The detailed contours and elevations of grass lines, treatments, and other features provided baseline information (i.e. before treatment) to help evaluate treatment performance. 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.

Treatments installed during 2008 showed varying levels of survival and success after evaluation in 2009. Regardless of site, treatment type and the orientation of logs relative to prevailing boat wakes, currents and other shoreline features appeared to be important variables. The most successful treatments had coir logs in low energy areas. Successful log treatments yielded rapid sediment-trapping benefits with back-filling behind logs often becoming evident within days. Treatments with two parallel rows of logs produced the deepest sedimentation and logs that connected the points of a scalloped margin were most effective.

Credit P. Cole, 2011. Monitoring the Matts Landing living shoreline.

PDE and Rutgers Haskin Shellfish Research Lab's 2010 installation at Matts Landing in Commercial Township, NJ used the lessons learned from these previous trials to ensure success. Installations at Matts Landing used double log treatments in a concave pattern. PDE and Rutgers Haskin Shellfish Research Lab have continued to monitor and learn from this site. To date, the Matts Landing installation has survived both Hurricane Irene in 2011 and Hurricane Sandy in 2012, thanks to the thorough research and appropriate site plan created by scientists at PDE and the Rutgers Haskin Shellfish Research Lab.

In June 2013, PDE scientists returned to some of the sites that had been installed in moderate energy areas in 2009 and 2010, and had not been augmented since. Although rigorous surveying is needed there, marsh edges in untreated adjacent controls had receded 10-20 feet landward, whereas the living shoreline cells either remained in place or experienced much less retreat.

Monitor biological activity

Monitoring plant and mussel growth was critical to appraising the health and success of the PDE/HSRL living shoreline installation. Revisiting the site over the course of several seasons to survey the area and take pictures will help to provide scientific data and photographic evidence in support of the installation's success.

PDE and Rutgers Haskin Lab Living Shoreline Installation. At left: April 2010. Center: June 2010. At right: June 2011.

The success of the PDE and Rutgers Haskin Shellfish Laboratory installation at Matts Landing is clearly charted in pictures (as above), as well as in data sets.

Monitor fish/aquatic life use

To help assess the quality of habitat provided by the new installation, scientists measured abundance and biodiversity of fish and aquatic life at the site and at a nearby control (an unaltered wetland edge). They did this by deploying seines in spring, summer and fall. They found 17 species present at the installation and 20 species present at the control site.

Credit: PDE, 2009. Two part fish monitoring samples at each treatment and control: Seining (Left side photo) and Minnow Pots (Right side photo)

Seine Catch Data

Species	Control	Treatment
Grass Shrimp	1482	2080
Blue Crab	746	577
Bay Anchovy	323	39
Mummichog	235	245

White Perch	93	55
Silverside	51	39
Weakfish	16	15
Striped bass	14	8
Black drum	12	6
Windowpane flounder	12	
Silver Perch	9	26
Hogchoker	5	
American Eel	3	2
Spot	2	1
Unidentified	2	2
Summer Flounder	2	5
Common Carp	2	
Atlantic Menhaden	1	8
Naked Gobi	1	
Diamondback Terrapin	1	1
Toadfish		1

Scientists also deployed minnow pots in spring, summer, and fall. They caught 8 species at the control site, and 9 species at the installation. Notably, they caught almost three times the number of mummichog at the installation as at the control site.

Minnow Pot Catch Data

Minnow Pot Species	Control	Treatment
Grass Shrimp	749	771
Mummichog	558	1592
American Eel	29	22
Blue Crab	13	10
Atlantic Menhaden	2	
White Perch	1	10
Spotfin Mojarra	1	2
Striped Bass	1	
Silver Perch		6
Diamondback Terrapin		1
Bay Anchovy		1

Monitoring the abundance and diversity of aquatic life is also helpful to track the performance of an installation, and can help to guide the management of the site.

Best Practice #10: Know the FAQs

The following are a list of frequently asked questions and answers developed by the PDE about our experience in the Delaware Estuary.

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 (in spring) 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 (where some areas erode while other areas accrete). There are many places, however, where erosion is outpacing accretion. 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 energy 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. Visit the Virginia Institute of Marine Science Coastal Resource Management decision tree website for help deciding what stabilization method is most suitable for your situation. The website can be found here: http://ccrm.vims.edu/decisiontree/index.html (Virginia Institute of Marine Science, 2013).

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 can be found at http://ccrm.vims.edu/decisiontree/index.html (Virginia Institute of Marine Science, 2013).DELSI has also been successfully used to 'green up' dilapidated bulkheads and rip rap, instead of full replacement.

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 in the Delaware Estuary region 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, partly because they help dissipate waves instead of amplifying or reflecting wave energy. 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. Factoring maintenance costs over larger time spans (25-50 years) is usually prudent.

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