SPRING 2021

Living Shoreline Training
for Marine Construction Professionals

TRAINING PARTNERS

Tracy Skrabal is the Southeast Regional Manager and Coastal Scientist with the **North Carolina Coastal Federation**, a citizens-based conservation group working with partners to ensure clean water and natural resource protection in NC's 20 coastal counties. Tracy has been with the Coastal Federation since 1997, and has over 35 years of experience in education, design and construction of living shorelines. Tracy has an undergraduate degree in Geology from the College of William and Mary in Virginia, and a M.S. degree in Geological Oceanography from the School of Marine Science, College of William and Mary (Virginia Institute of Marine Science).
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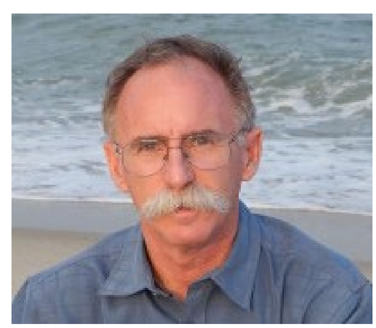
Erin Fleckenstein joined the **North Carolina Coastal Federation** in February 2008 and manages the federation's regional office in Wanchese. She holds a Master of Science in marine biology from the University of North Carolina at Wilmington and a Bachelor of Science in marine and freshwater biology from University of New Hampshire. Erin leads a variety of initiatives to restore wetlands, create oyster sanctuaries and living shoreline and build rain gardens. Contact: erinf@nccoast.org or 252-473-1607

Lexia Weaver joined the **North Carolina Coastal Federation** in April 2007. Her background is in estuarine water quality and plant ecology and she has conducted over 12 years of research in estuarine environments in Florida, Delaware and North Carolina. Lexia holds a Master of Science and a Ph.D. in Marine Studies from the University of Delaware and a Bachelor of Science in Biology with a specialization in Marine Biology from Barry University in Miami Shores, Florida. Lexia manages coastal restoration projects within the central region of North Carolina and supervises the central regional office. Contact: lexiaw@nccoast.org or 252-393-8185



Spencer Rogers joined **North Carolina Sea Grant** in 1978, where he helps property owners, builders, designers, and governmental agencies to develop hurricane-resistant construction methods, understand shoreline erosion alternatives, and implement marine construction techniques. He also is recognized as an expert on rip current science and outreach. Spencer serves on the faculty at the University of North Carolina at Wilmington's Center for Marine Science, and as adjunct faculty in the department of civil, construction, and environmental engineering at North Carolina State University. He holds a Master's in coastal and oceanographic engineering from the University of Florida and a Bachelor's in engineering from the University of Virginia.
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Ted Wilgis joined the **North Carolina Coastal Federation** in 1997. He leads the education program in the federation's southeast office, and he designs and implements oyster habitat restoration, living shoreline, and stormwater reduction projects. Previously, he served as the Cape Fear Coastkeeper® for five years and as the federation's education director. Ted holds a Bachelor of Arts in zoology from Connecticut College and a Coast Guard captain's license, and he is currently enrolled in the marine biology graduate program at the University of North Carolina at Wilmington.
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Lora Eddy works on the Coastal Resilience project, a program led by **The Nature Conservancy** to examine nature's role in reducing coastal hazards. She is working with stakeholders to develop tools like the Living Shorelines and Restoration Explorer apps, which incorporate science and spatial mapping data to make shorelines naturally resilient. Lora is a licensed Professional Geologist who has spent her career working with coastal communities in Florida, Oregon, Washington and North Carolina on environmental permitting, regulation, planning, and stormwater issues.
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Whitney Jenkins has been the coordinator of the North Carolina Coastal Training Program since 2002. The goal of the program is to promote informed coastal decisions through science-based training for professionals. Training programs focus on sustainable development, water quality protection, and coastal hazards. Whitney has a Master of Environmental Management from Duke University and a B.S. from the University of Florida. Whitney is based at the **North Carolina Coastal Reserve & National Estuarine Research Reserve**'s headquarters in Beaufort, but coordinates training across North Carolina's 20 coastal counties. Contact: whitney.jenkins@ncdenr.gov or 252-838-0882

ORTON FOUNDATION

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SPRING 2021

Living Shoreline Training

for Marine Construction Professionals

Training Description: To increase the knowledge of living shoreline construction practices among marine contractors, engineers, environmental consultants, and regulatory staff, the N.C. Coastal Reserve, North Carolina Coastal Federation, and North Carolina Sea Grant are partnering to offer a new training course. This course will focus on living shoreline design for typical structures in residential settings along North Carolina's estuarine shorelines. The training combines three classroom sessions with on-the-ground field training.

"The Division of Coastal Management encourages construction professionals to attend this training to become familiar with living shoreline construction practices," said Braxton Davis, division director. "Living shorelines are growing in popularity as an alternative to bulkheads because they work well, can be adapted from low to high energy settings, and provide a range of environmental benefits. This training comes at a great time, since the division recently streamlined the permitting process for marsh sills, a common type of living shoreline."

Training Objectives - Participants will be able to:

- Identify and describe the benefits, costs, and longevity of living shorelines projects for potential clients;
- Respond to client questions and concerns about different types of shoreline stabilization, including living shorelines;
- Understand living shoreline permitting process for North Carolina;
- Conduct analyses of site factors to design living shoreline projects;
- Implement non-structural (grading, vegetation) and hybrid (structural, vegetation) living shoreline projects;
- Understand how to secure materials and determine equipment needs for living shoreline projects;
- Create business opportunities to monitor and maintain living shoreline projects post-construction; and
- Provide instructions to property owners on basic maintenance and how to evaluate project success.

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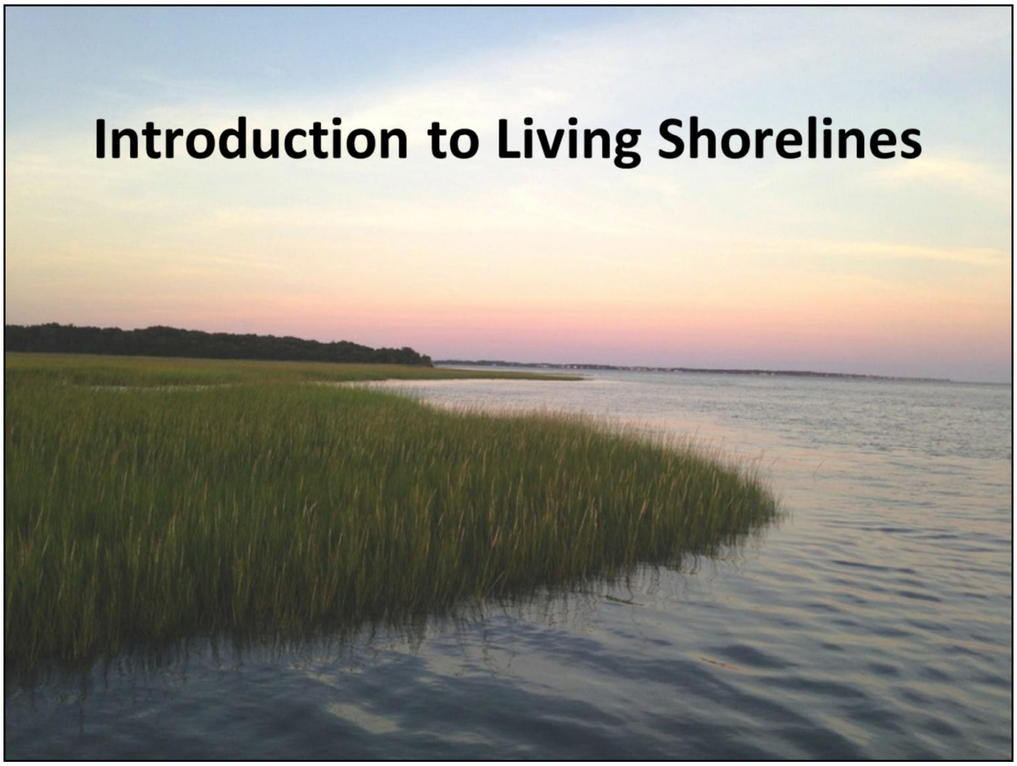
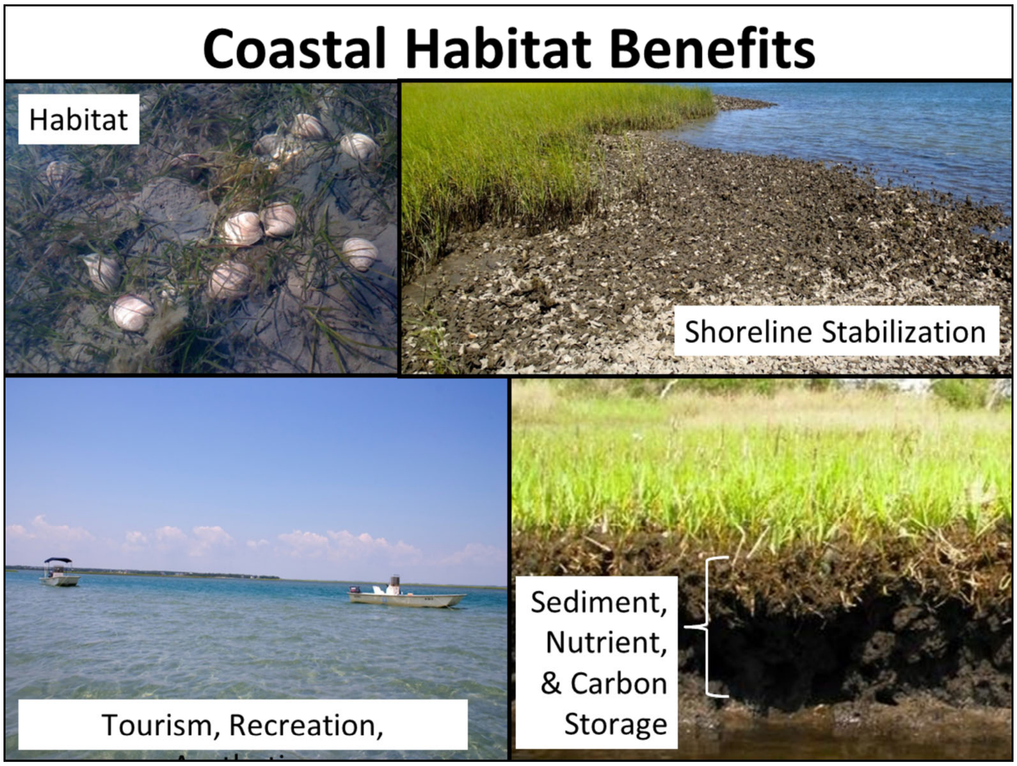

Introduction to Living Shorelines

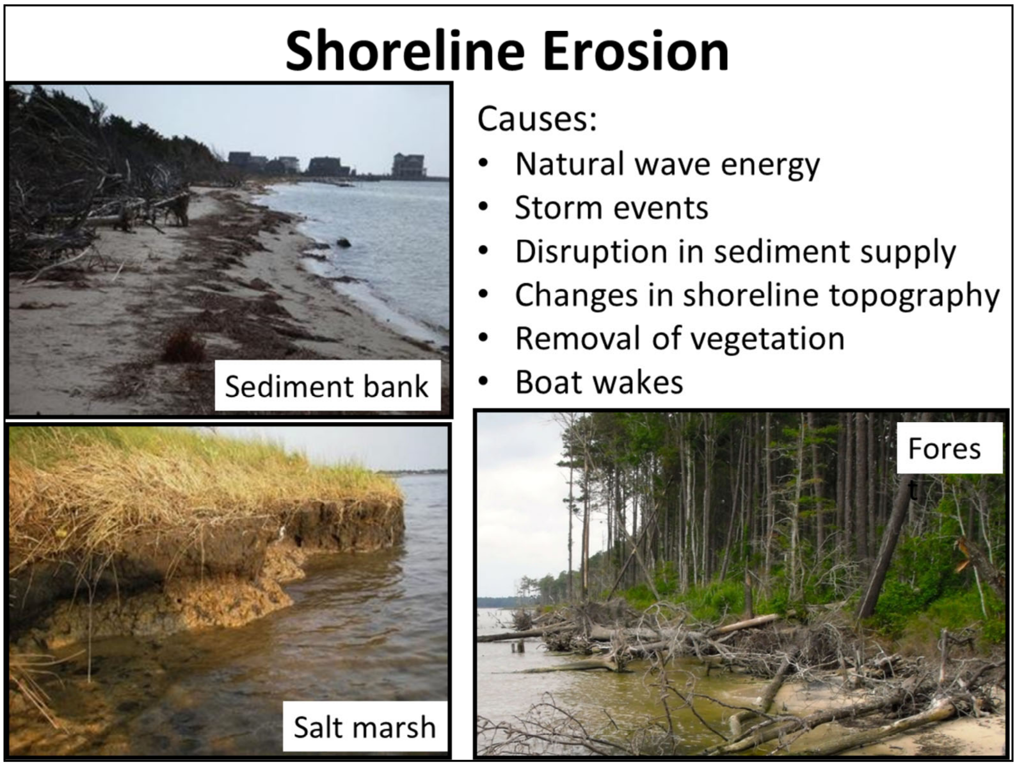
Saltmarshes, oysters, mud/sand flats, and seagrass beds are all important coastal habitats in North Carolina. And all can be incorporated into living shorelines design



Coastal habitats provide us with ecosystem services or nature's benefits, that is they provide us things that we value that are hard to put a dollar amount on.

- Habitat for commercially and recreationally valuable fish, crustaceans and shellfish
- Stabilize sediment and prevent erosion,
- Protect water quality by removing excess nutrients like Nitrogen and filtering pollutants
- They can remove carbon dioxide from the air and bury it in sediment.
- These systems also bring in billions of dollars from tourism and recreation.

All of these habitats and services can be found in the back yards of North Carolina's residents. The challenge is to maintain waterfront properties while maintaining beautiful and very valuable shoreline habitats. This shoreline is a fringing saltmarsh with an oyster reef in front. Many valuable ecosystem services occur right at this marsh edge. And the marsh itself is effective at dampening wave energy. How can we have both protected property and thriving habitats? You'll hear throughout this training how living shorelines provide erosion control while maintaining shoreline ecosystem services.



One major threat to waterfront property and to coastal habitats is erosion. Erosion is caused by:

- Natural wave energy. The amount of fetch in front of a shoreline determines this wave energy. Fetch is distance over which the wind blows over water.
- Storm events
- Disruption in sediment supply, such as the damming of rivers or dredging that removes sediment from the system
- Changes in shoreline topography, mainly from development
- Removal of vegetation
- Boat and ship wakes

When coastal properties and infrastructure are located on a coastline that is experiencing erosion, we typically resort to hardening the shoreline. Shoreline hardening includes any kind of artificial, permanent or semi-permanent structure placed on the shoreline to prevent erosion. The problem with hardening is that our coastal habitats are not able to co-exist with these structures.

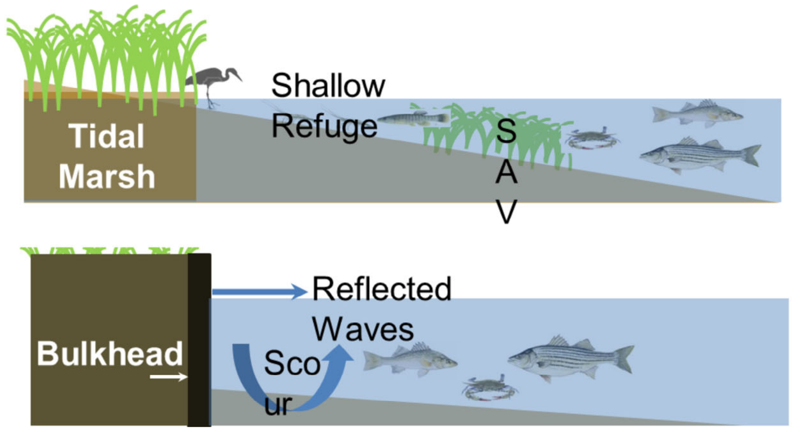


Fig. courtesy T. Jordan

Changes occur **BELOW** the MHW line:

- Sediment transport & particle-size change
- Vegetation loss
- Animal abundance reduced
- Ability to remove nitrogen is reduced

…all of which are negative impacts to our public trust resources.

What happens when you harden a shoreline? What do you lose?

- ~90% of commercially and recreationally important seafood will spend part of their lives in this shallow water area – it's a refuge or nursery area. Place to hide from predators and to find food.
- When we harden the shoreline
    - We lose the vegetation
    - Waves are no longer absorbed by the marsh
    - Waves hit the bulkhead (or other hard structure), bounce back out, scour the shoreline and deepen the sediment.
    - We lose the shallow water refuge and important nursery area
- Bulkheads are put in at or above mean high water (that's the state's rule), but these habitat changes are occurring below mean high water in the public trust area

What's the alternative?

Living shorelines are erosion control methods that includes a suite of options

Living shorelines are erosion control methods that include a suite of options. They can be non-structural (ie. grading, plantings, etc.) or some combination of non-structural and structural elements, such as stone, oyster shells or other innovative measures.

Living Shoreline Types

Marsh Plants

They include marsh grasses, and in many cases, other native grasses, shrubs and trees, either as existing or restored areas– hence the term "living shorelines." This pictures shows trays of Spartina alterniflora plugs ready for planting on a shoreline with orange dibble bars.

Living Shoreline Types

Marsh Plants

Here is Spartina alterniflora that has matured from plugs

Marshes Dampen Wave Energy

Marshes dampen wave energy and protect a shoreline from erosion. As the waves move through the grass, sediment is removed from the water column and deposited on the marsh surface. If there is enough sediment in the system, this increases the elevation of the marsh and enables marshes to keep up with sea level rise.

Living Shoreline Types – Sills

Living shorelines can include sills made of stone, oyster shell, wood or vinyl, or any of a number of innovative pre-cast structures. Sills can be linear or curved structures placed just offshore that serves to break down the energy of the waves, which protects the marsh and shoreline.

Living Shoreline Types

Oyster Bag Marsh Toe Revetment

Living shorelines can be a very low profile revetment that protects against further erosion of the scarped edges of eroding marshes. These marsh toe revetments are made of bagged oyster shells.

Living Shoreline Types

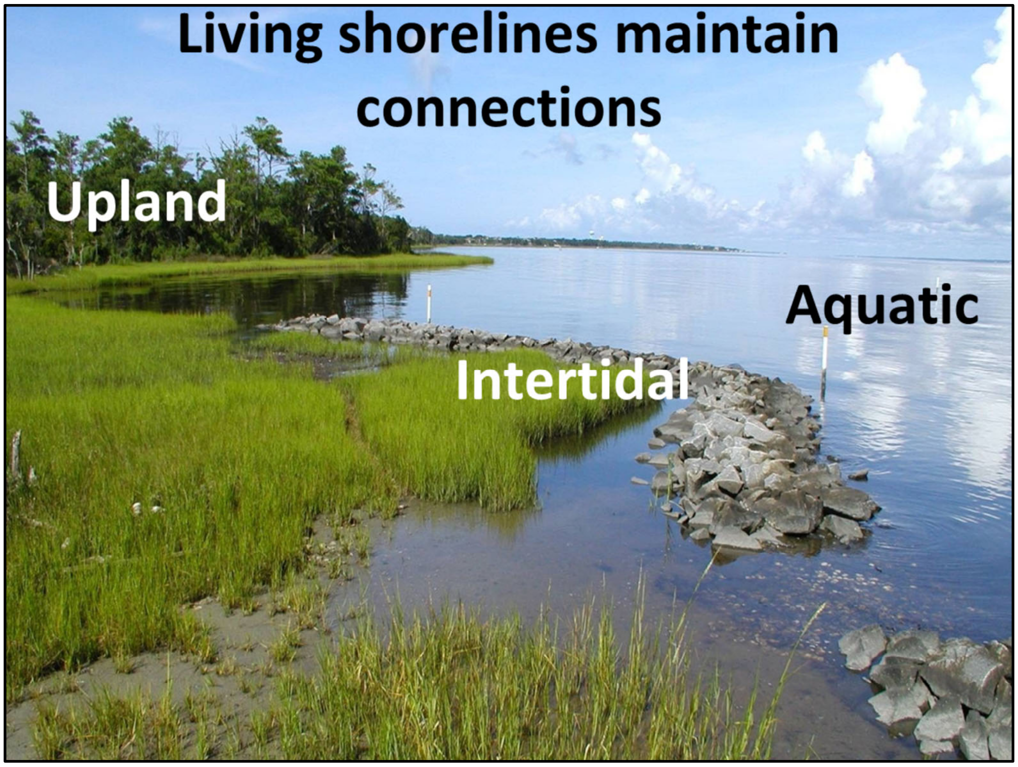
Loose Oyster Shell

Loose oyster shells can also be used in living shoreline designs and placed off barges using a front end loader or water jet method, such as those used to place dock pilings.

Living Shoreline Types

Oyster Shell

The goal of using oysters, either bagged or loose in living shoreline designs, is to create substrate for spat, or oyster larvae that has settled and attached. This creates an oyster reef, which provides erosion control and habitat for a whole suite of estuarine organism, including recreational and commercially important fish and shellfish species.



Unlike bulkheads or seawalls, living shorelines maintain connections between upland, intertidal and aquatic areas. These connections are necessary to protect water quality, ecosystem services (or nature's benefits) and coastal habitats. Living shorelines have proven to be just as effective, if not more effective, than bulkheads for erosion control during hurricanes. You'll hear more about this and see many examples of living shorelines throughout the training

SELLING POINTS

Module One

Benefits of living shorelines

Relative costs of shoreline stabilization options

Client questions and concerns

Module Objectives

Training participants will be able to:

- Identify and describe the benefits of living shorelines;
- Compare relative costs and longevity among different types of shoreline stabilization; and
- Respond to client questions and concerns about different types of shoreline stabilization, including living shorelines.


Module 1.1 Benefits

Why Do We Stabilize Shorelines?

- "Do Nothing" approach is no longer working, and you cannot retreat
- Need to control shoreline erosion
- Need to protect coastal properties and habitats
- Need to reduce the wave energy from boat wakes and storm surge
- Past practices (bulkheads, revetments, etc.) need repair or replacement and/or are increasing erosion

Photo from Environmental Concern, Inc.

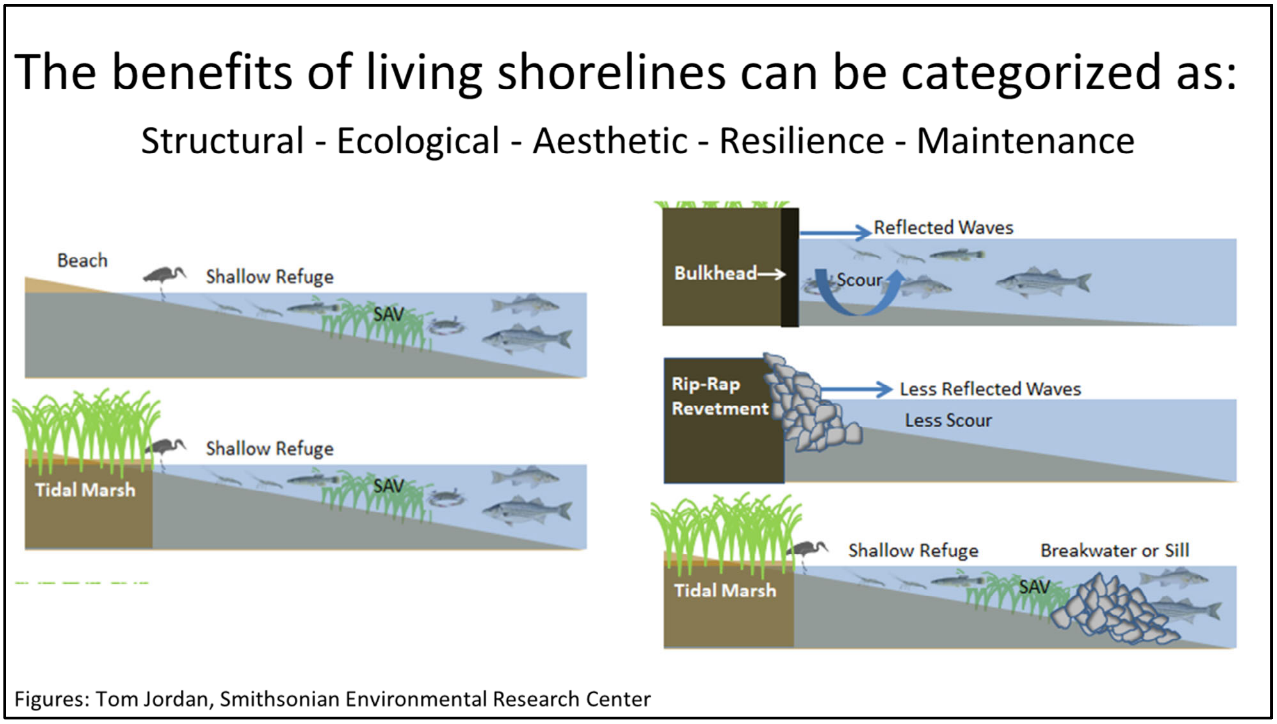
- As contractors/consultants, you fill the role of problem solver of coastal erosion for your clients, usually when coastal erosion is at the point where they can no longer "do nothing." Some sort of action needs to happen to protect a home, business, property, or cultural resource, and your clients have little knowledge of their options.
- Your role is to provide solutions to control the erosion—often by reducing wave energy from boat wakes or storm surge. However, traditional hardening methods such as bulkheads can fail or create additional erosion and harm ecosystems in a number of ways:
  - The vertical face of bulkheads reflects wave energy, which often results in erosion along the toe of the structure or where the structures end *(U.S. Army Corps of Engineers 1981, Bozek and Burdick 2005, National Research Council 2007).*
  - Shoreline hardening from structures like bulkheads can cause adverse impacts to coastal habitat, including the loss of shallow intertidal or shallow water fisheries habitats, loss of fringing marshes, decline of submerged aquatic vegetation (SAV) or seagrass, and a decrease in benthic abundance and diversity *(Douglass and Pickel 1999, OSTP 2015, Patrick et al. 2014, Seitz et al. 2006).*
  - Treated wood bulkheads may also contain chemicals that can leach into the coastal environment *(Weis and Proctor 1998).*
  - Hardening shorelines can halt the natural adaptation of shorelines to keep pace with local changes in sea level.
  - Vertical bulkheads, revetments, etc. can fail or receive severe damage during the frequent hurricanes or other severe storms common in North Carolina.

Why consider living shorelines?

A Living Shoreline constructed at Pine Knoll Shores Aquarium, North Carolina. Photo from North Carolina Coastal Federation.

- Living shorelines provide a cost-effective option for erosion control that will stabilize shorelines and not increase erosion elsewhere.
- Living shorelines allow for natural processes and mimic natural shorelines.
- Living shorelines can protect or restore coastal habitats
- Living shorelines enhance clients' recreational opportunities (i.e. fishing, bird watching, natural views)

- Living shorelines serve as a successful, cost- effective alternative to traditional erosion control practices and very often require little long term maintenance, repairs, and replacements. They have also been shown to withstand hurricanes and other major storm energy with little damage to the shoreline, other than debris clean up.
- Often times, living shorelines are more cost-effective to install and maintain than traditional erosion-control practices. Once established, many living shoreline projects require no additional repairs and will stabilize eroding shorelines for decades. This leads to greater satisfaction by customers, positive referrals, etc.
- Encouraging clients to choose a living shoreline can allow for:
    - Stabilization of eroding shorelines also maintains natural shorelines, marshes, and sandy beaches.
    - The protection or restoration of eroded coastal habitats for fishes, birds, vegetation, oysters, and many other important estuarine animals.
    - Enhancement of recreational and aesthetic opportunities for your clients. They could maintain or develop kayak launches, pier access, fishing opportunities, wildlife viewing, and create or preserve a beautiful view.



Living shorelines have a variety of benefits that can easily be categorized into five main categories including: structural benefits, ecological benefits, aesthetic benefits, resilience benefits, and maintenance benefits.

Some of these benefits can be understood by the visual comparison in this slide between the different erosion control measures. Where the structures are emplaced, how the structures function and their interaction with the natural environment are all important factors in understanding the relative benefits of living shorelines. We will go into more detail on each of these benefits in the following slides.

Structural Benefits of Living Shorelines

Benefits	Traditional Erosion Control	Living Shorelines
Reduces immediate shoreline erosion	+	+
Reduces/ prevents future shoreline erosion	+	+
Maintains ecosystem processes including providing sediment to coastal habitats	−	+
Protects, restores, and enhances wildlife habitats	−	+
Improves water quality (settling sediments, filters pollutants)	−	+
Decreases nutrient runoff	−	+
Maintains water access to public/ homeowners	−	+
Natural aesthetic	−	+
Absorbs wave energy and storm surge	−	+
Becomes more stable over time	−	+
Can adapt to sea level rise	−	+

This table provides a visual comparison between traditional erosion control practices and living shorelines. Highlighted in orange box are "structural benefits."

Structural Benefits of Living Shorelines

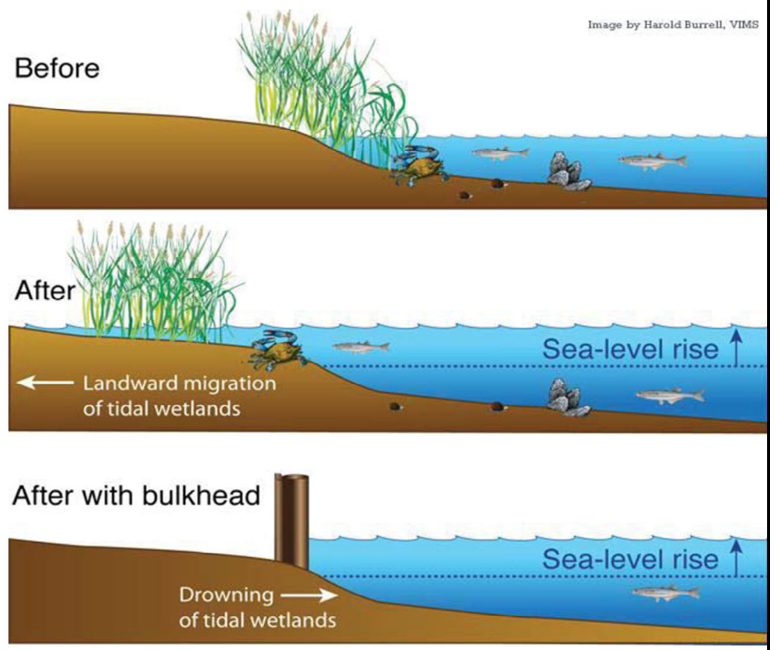
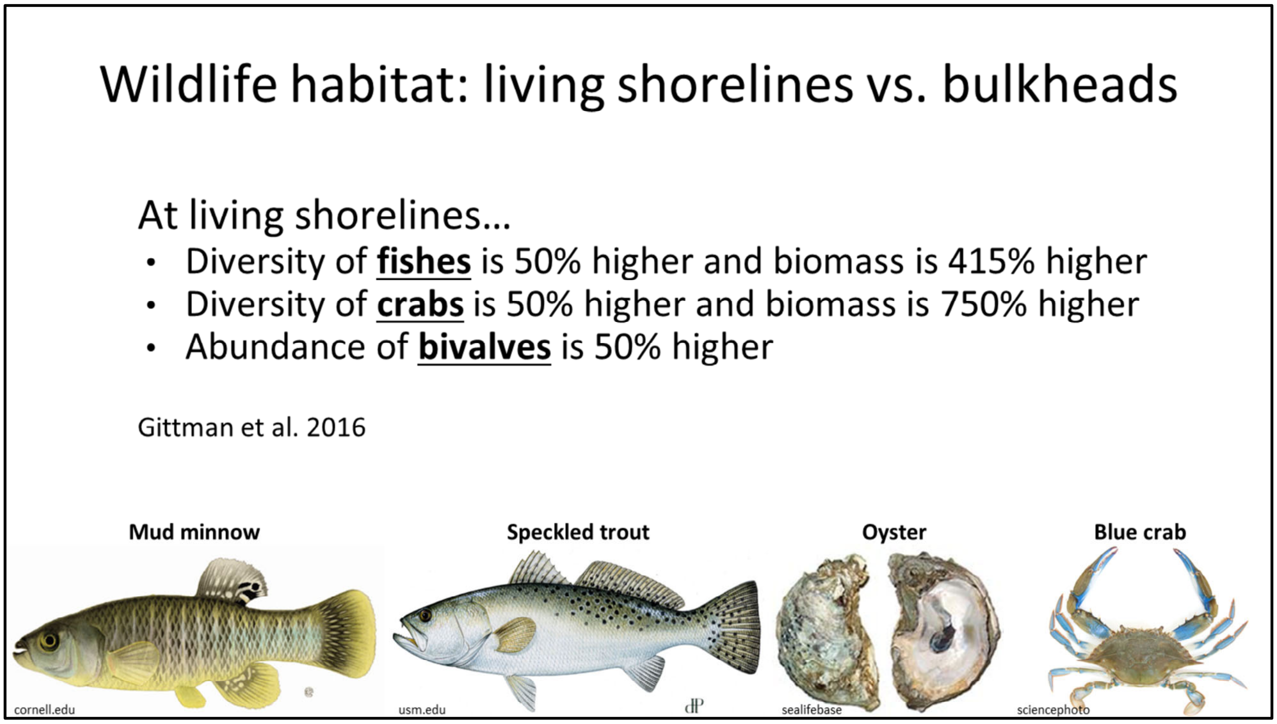


Image from ©Harold Burrell, Virginia Institute of Marine Science (VIMS)

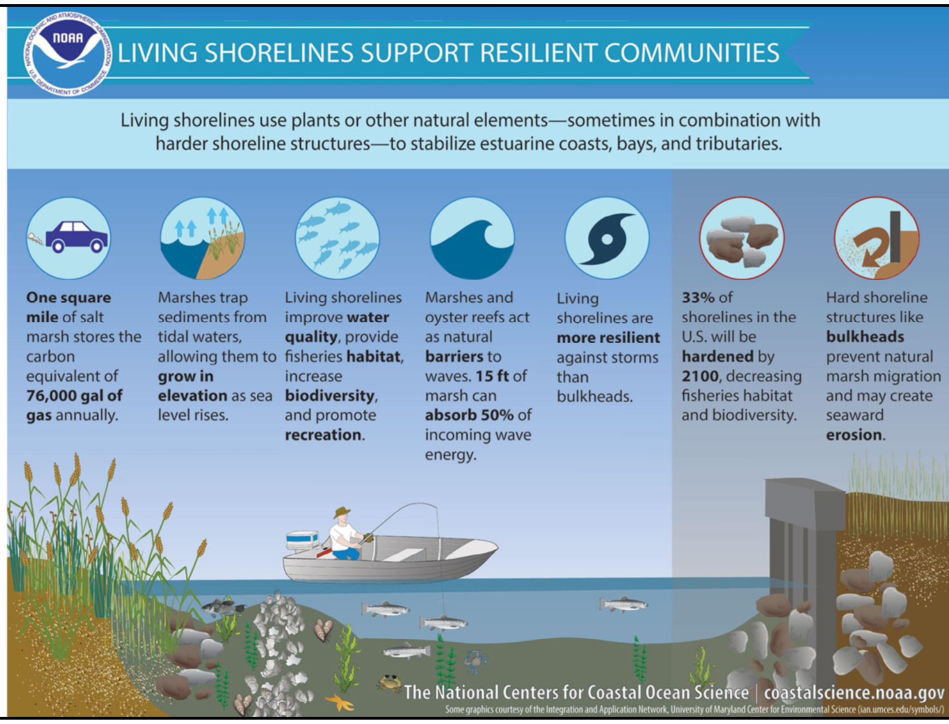
Environmental Benefits of Living Shorelines

Benefits	Traditional Erosion Control	Living Shorelines
Reduces immediate shoreline erosion	+	+
Reduces/ prevents future shoreline erosion	+	+
Maintains ecosystem processes including providing sediment to coastal habitats	−	+
Protects, restores, and enhances wildlife habitats	−	+
Improves water quality (settling sediments, filters pollutants)	−	+
Decreases nutrient runoff and stores Carbon	−	+
Maintains water access to public/ homeowners	−	+
Natural aesthetic	−	+
Absorbs wave energy and storm surge	−	+
Becomes more stable over time	−	+
Can adapt to sea level rise	−	+

Highlighted in orange are "environmental or ecosystem benefits."



- If we focus on some of the ecological benefits, such as wildlife effects, it is apparent that living shorelines are very beneficial for the environment.
- When we compare the number (i.e., diversity) of species and the combined weight of those species (i.e., biomass) between living shorelines and more traditional approaches such as bulkheads, we see the following from research conducted along the central coast of North Carolina (Gittman et al. 2016):
  - Living shorelines supported 50% higher diversity of fishes and 415% higher biomass of fishes. This includes species such as mud minnows, which spend their entire life cycle in estuaries, and species such as speckled trout, which spend only a portion of their life cycle in estuaries.
  - Living shorelines supported 50% higher diversity of crabs species, such as blue crabs. Also, crab biomass was 750% higher at living shorelines than adjacent to bulkheads.
  - Abundance of filter feeding bivalves, such as oysters, was 50% higher at living shorelines than nearby bulkheads.



- This graphic from NOAA highlights why living shorelines would be a great addition to the services that you are able to provide your clients. Graphic from: https://www.fisheries.noaa.gov/insight/understanding-living-shorelines
- CIRCLE 1: An acre of salt marsh has been calculated to have a value from $981 to $6,471 (Barbier et al. 2011). The ecosystem benefits of living shorelines are also projected to increase over time as the living components of the shoreline establish themselves, compared to a hard shoreline that will need to be replaced (Seitz et al. 2006).
- CIRCLE 2: Salt marshes—a main component of many living shorelines designs—are known to trap sediment and organic matter and may also increase surface elevation through production of below-ground biomass, which is incorporated into the sediment (Morris et al. 2002, Cahoon et al. 2004, Currin et al. 2008, Currin et al. 2010).
- CIRCLE 3: When shoreline functions are considered at a system level, the cumulative ecosystem effects of hardened shorelines can be seen. Armoring of a few small sections of shoreline may have only local adverse impacts, but as more and larger areas of shoreline become armored, changes can occur to the coastal ecosystem and services they provide (National Research Council 2007). For example, hardened shorelines negatively affect benthic infauna—organisms burrowed in the sediment, like clams and worms—in subtidal habitat adjacent to the shoreline stabilization. This could be due to a loss of nutrients from the marsh that deposit-feeding infauna would consume. Reduced infauna densities adjacent to bulkheads can lead to diminished predator densities and

less productivity in the shoreline system (Seitz et. al. 2006).

- CIRCLE 4: Living shorelines can be successfully used on sheltered coasts to dampen wave energy and reduce erosion (Swann 2008). Even narrow marshes—a frequent component of living shoreline designs—have been shown to slow waves and reduce shoreline erosion (Currin et al. 2015). Specifically, Spartina spp. salt marshes have been shown to dissipate wave energy by 50 percent within the first 2.5 meters (Knutson et al. 1982).
- CIRCLE 5: On sheltered coasts along the North Carolina outer banks, marshes (with and without sills) outperformed bulkheads during Category 1 Hurricane Irene in 2011. Those marshes accreted sediment, while 75% of regional bulkheads surveyed were damaged (Gittman et al. 2014). Along the South Carolina coast near Charleston, 58% of bulkheads were destroyed during Hurricane Hugo in 1989 (Thieler and Young 1991).

Aesthetic Benefits of Living Shorelines

Benefits	Traditional Erosion Control	Living Shorelines
Reduces immediate shoreline erosion	+	+
Reduces/ prevents future shoreline erosion	+	+
Maintains ecosystem processes including providing sediment to coastal habitats	−	+
Protects, restores, and enhances wildlife habitats	−	+
Improves water quality (settling sediments, filters pollutants)	−	+
Decreases nutrient runoff	−	+
Maintains natural and desirable aesthetic of shorelines ($$$)	−	+
Self sustaining living shorelines more visually appealing	−	+
Absorbs wave energy and storm surge	−	+
Becomes more stable over time	−	+
Can adapt to sea level rise	−	+

Highlighted in orange are our “aesthetic benefits.” Having stabilized shorelines that are also beautiful and natural is a great selling point and increases property owner satisfaction and associated property values.

Highlights and Examples: Natural Shorelines

Living shorelines can provide aesthetic beauty to properties and stabilize shorelines, which add value to the property

This private shoreline highlights one of the largest selling points of living shorelines: the aesthetic beauty that they offer.

In this example, the eroding bank was first re-graded to allow for a slope suitable for planting. The bank was planted with native marsh plants, and the base was protected with a soft structure called a biolog until the marsh plants became well established (more on these and other living shoreline techniques in Module 2).

This type of shoreline provides great habitat for birds, fish, and other wildlife. It also provides the landowner with suitable shoreline stabilization, a more desirable and aesthetically pleasing shoreline, and an increase in property value.

Resilience Benefits of Living Shorelines

Benefits	Traditional Erosion Control	Living Shorelines
Reduces immediate shoreline erosion	+	+
Reduces/ prevents future shoreline erosion	+	+
Maintains ecosystem processes including providing sediment to coastal habitats	−	+
Protects, restores, and enhances wildlife habitats	−	+
Improves water quality (settling sediments, filters pollutants)	−	+
Decreases nutrient runoff	−	+
Maintains water access to public/ homeowners	−	+
Natural aesthetic	−	+
Absorbs wave energy and storm surge	−	+
Becomes more stable over time	−	+
Can adapt to sea level rise	−	+

Highlighted in orange are "resilience benefits." North Carolina's estuaries are experiencing a number of changes due to climate change and the associated increase in storms, sea-level, and erosion. Living shoreline projects have positive benefits over traditional approaches for a number of reasons, including their ability to continue to provide effective erosion control and ecosystem benefits despite these effects of climate change.

Maintenance Benefits of Living Shorelines

Benefits	Traditional Erosion Control	Living Shorelines
Reduces immediate shoreline erosion	+	+
Reduces/ prevents future shoreline erosion	+	+
Maintains ecosystem processes including providing sediment to coastal habitats	−	+
Protects, restores, and enhances wildlife habitats	−	+
Improves water quality (settling sediments, filters pollutants)	−	+
Decreases nutrient runoff	−	+
Maintains water access to public/ homeowners	−	+
Natural aesthetic	−	+
Absorbs wave energy and storm surge	−	+
Becomes more stable over time	−	+
Can adapt to sea level rise	−	+

Highlighted in orange are "maintenance benefits." The maintenance benefits of living shorelines are directly related to the resilience of living shorelines. Living shorelines are intended to absorb wave energy, maintain their stability over time, and adapt to changing sea levels. Thus, long term maintenance is reduced and complete failure, as in the case of bulkheads, is rare.

The State of Maryland provides some useful information regarding maintenance of various shoreline erosion options in this document: https://mde.state.md.us/programs/Water/WetlandsandWaterways/DocumentsandInformation/Documents/www.mde.state.md.us/assets/document/WetlandsWaterways/Shoreline_maintain.pdf

Longevity of Bulkheads vs. Living Shorelines

- Bulkheads will "hold the line" in a stationary location for a finite length of time
- Living shorelines can restore lost shorelines and provide greater resiliency during changing conditions, such as sea level rise

- Bulkheads are strongest when first constructed, but require maintenance and replacement over time. Living shorelines require care and maintenance when first constructed, then become self-sustaining and resilient over time.
- Bulkheads: Industry estimates state the longevity is 20-25 years for a normally constructed and maintained bulkhead, or less for one frequently subjected to high energy or storm effects. The best-case scenario is 30-50 years for a properly built or maintained bulkhead, which assumes relatively low energy, no major storm damages, and routine maintenance.
- Living Shorelines: Once established, a properly designed and constructed living shoreline can provide shoreline stabilization indefinitely, but will require care, including possible re-planting until the marsh and other plants are established. It will also take time for oyster shell bags (if part of the design) to be colonized with living oysters. Routine maintenance, such as removal of debris that can raft in during hurricanes or other storms, ensures marsh plants are protected. In addition, living shoreline allow for upward growth of the planted marsh to keep pace with local sea level rise, and a gradual landward migration of the protective marsh.

Pre- and Post-Hurricane Matthew, Morris Landing, NC

Photos: L. A. Jansen

By design, living shoreline features, such as loose or bagged oyster shells placed along existing or restored marshes, mimic the slope of natural estuarine shorelines. During most coastal storms, the energy is absorbed by this slope, resulting in a more stable and storm resilient shoreline.

Pre- and Post-Hurricane Matthew, New River, Sneads Ferry

Compared to living shorelines, vertical wall bulkheads often experience damage or destruction during hurricanes and other strong coastal storms. Wave energy associated with strong storms reflects off the walls, creating scour, damage to the structure, greater erosion at the ends of structures, and possible structural failure. In addition, storm surge often overtop these walls, which can create scour, increased pressure, and often failure of the structure as the water retreats. Vertical walled structures placed in open fetch areas or subject to constant boat wakes and strong currents can experience the same effects over time.

Highlights and Examples: Offshore Sills

A number of living shoreline methods include the combination of relatively low-profile structures constructed waterward of the existing marsh, or waterward of the area that will be restored with newly planted marsh plants. These structures, called sills, may be constructed as low profile, stand alone walls from bagged oyster shells, stone, or other materials. We will discuss the design and placement of these structures in more detail in Module 2.

Highlights and Examples: Repair/Replacement of Failing Bulkhead

Photo: Jon Guerry Taylor & Associates, Inc. Mt. Pleasant, SC

In some scenarios, a bulkhead may be in good structural condition, but is in danger of failing from a loss of waterward substrate or deepening of the water adjacent to the wall from erosion. These might be stabilized with the addition of a suitable stone structure such as a rip-rap revetment, as pictured above.

Highlights and Examples: Repair/Replacement of Failing Bulkhead

Photos: from NC Coastal Federation

In other scenarios, a bulkhead may be in poor structural condition in addition to experiencing waterward erosion. In this case, it may be possible to replace the failing wall with one of a number of living shoreline techniques. Although most living shoreline methods require more distance between the water's edge and any upland structures, in many cases, the living shoreline can provide greater long term stability with fewer maintenance requirements, as well as protecting the local ecosystem.

Structural Vs. Nonstructural Living Shorelines

- Softer living shoreline techniques such as bank re-grading and/or plantings may be successful for lower energy settings with low to moderate erosion effects, short fetch, gentle slopes, sheltered coasts
- Combination living shoreline options that include structural and non-structural elements may be ideal for higher energy settings with moderate to higher erosion effects, longer fetch, over-steepened banks, more open exposed coastlines.

Take home message: Every site requires consideration of risks and benefits for the different living shoreline options.

- It is important to evaluate the level of risk for continued erosion with the level of protection that is acceptable at a particular site.
- Decision-makers should keep in mind that no shoreline stabilization technique is guaranteed to prevent the loss of infrastructure during the most severe storms. By design, a living shoreline can be more resilient than a bulkhead in storms with high storm surge, because storm surge can roll over the living shoreline structure inundating the land and then leave the shoreline minimally impacted. In contrast, the wave energy from that can reflect off of the vertical bulkheads and from the retreat of the surge can undermine the channelward side of the bulkhead and/or cause damage or failure from the landward side.
- This emphasizes the point that each site will be different and all will require individual site assessments– which will be reviewed later in the training. Not all sites will allow for you to be completely green- there may need a hardened structure of some sort, but there will always be an opportunity to incorporate some “green” component.

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Module 1.2 Costs

Factors Affecting Costs

- Location of Site and Access
- Physical Properties
- Extent and Nature of Erosion
- Energy Setting of the Shoreline
  - High Energy: 5 or more miles of fetch
  - Medium Energy: 1-5 miles of fetch
  - Low Energy: < 1 mile of fetch
- Market Forces, Supply & Demand

Photo: North Carolina Coastal Federation

The total cost of any shoreline stabilization project depends on a number of factors. Larger projects, projects in high energy settings, or projects with challenging site conditions will typically cost more than more straightforward projects in low energy settings. Costs for design, materials, and labor varies geographically and are based on the demand in an area. Permitting fees and initial and long-term maintenance costs should be considered for every shoreline project. Where allowing natural erosion to occur is not an option, protecting or restoring an eroding shoreline can avoid the loss of much larger areas of marsh and uplands, which can be more expensive to replace. The economic value of estuarine ecosystems are often overlooked and undervalued.

- Location of Site and Access: The geographic location of the site and relative access for materials and equipment will affect the overall costs of the project.
- Physical Properties: The topography (surface shape and features) of the site and extent of the erosion effects will influence the project cost. For example, a gently sloping shoreline that needs minor grading and minimal planting will likely be less expensive than a high bluff project with steep or undercut banks.
- Extent and Nature of Erosion: Existing erosion rates and their causes can affect project costs. Since North Carolina is within a region that experiences frequent powerful storms such as hurricanes, the expected size and costs of shoreline structures would be higher than in some other coastal regions. In

addition, some relatively low wave energy sites may be impacted by man-made influences, such as consistent boat wakes, proximity to dredged channels or additional structures. These situations can warrant larger or more complex projects, driving up the potential costs.

- Energy Setting of the Shoreline: The location and physical properties of a site will influence the cost of a shoreline stabilization project. One of the most important factors is the energy setting of the shoreline. Sites with greater open exposure to wind and waves will tend to have higher erosion rates. Depending on a site's fetch (the distance wind travels across the water before arriving at a shoreline), shorelines are generally classified into three energy types:
    - High energy: 5 or more miles of fetch
    - Medium energy: 1-5 miles of fetch
    - Low energy: less than 1 mile of fetch

The longer the fetch, the greater the potential need for larger or more complex projects, which can increase the cost of any shoreline stabilization project.

According to Coastal Systems International, depending on the local construction market and bulkhead design requirements, repairs may cost $100-$400 per linear foot of wall. Bulkhead replacement, depending upon height, anchoring and associated drainage components, may cost $400-$1,500 per linear foot.

Factors Affecting Costs

- Design Considerations
- Expertise and Labor

Design Considerations: The cost of a shoreline stabilization project will vary with project design. The site conditions, degree and type of erosion, and project goals will determine the scope and complexity of the design. More complex designs will require more time, materials, and labor, driving up the cost of the erosion control project. Costs associated with non-structural designs typically include labor (see below) and material costs associated with bank re-grading, placement of fill (if needed) and planting of vegetation.

Projects with structural components will include costs for labor, materials, potential equipment, and access associated with the placement of the structural components. These structures typically include stone, concrete, recycled loose shells or bags of shells, wood, or vinyl.

Expertise and Labor: The level of expertise needed will influence the cost of the project. Hired professionals should be able to provide property owners with all available options and their associated costs and to supervise and/or prepare all aspects of the project, including design, permitting, site preparation, construction, planting, and cleanup.

Shoreline stabilization projects most often require a qualified contractor. Some projects will also require a consulting team, which can potentially include of an engineer, a coastal scientist, drafting staff, field staff, or project manager.

North Carolina Erosion Control Costs Estimates*

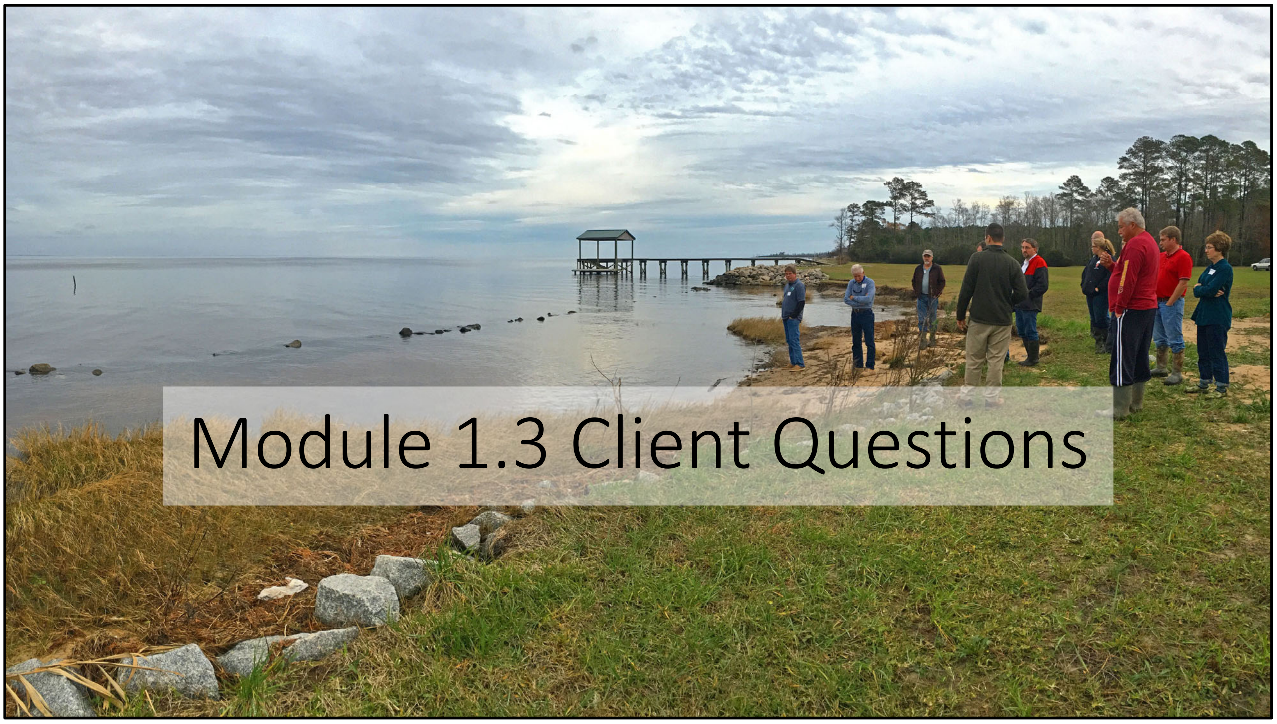
*Costs vary across regions, material costs and market conditions

- **Oyster Sills** (Including Marsh Toe Revetments) with Marsh Plantings
  $100-$250/ linear foot
- **Stone Sills** (Marsh Toe Revetments)
  $125-$300/ linear foot
- **Vertical Wall Sills** (Wood or Vinyl)
  $125-$300/ linear foot
- **Rip-Rap Revetments**
  $150-$500/linear foot
- **Bulkheads**
  $150-$500/linear foot

Costs are based on typical residential settings and conditions

Factors that can affect cost ranges can include market demands/competition, fluctuating costs and availability of materials, access to the site, equipment and mobilization/demobilization costs, time/travel requirements, site conditions and constraints, linear footage of project, and erosion rates and other environmental conditions.

More cost estimates will be provided in Module 3, which presents specific project designs, photos and costs (presented as current at the time of construction).


Module 1.3 Client Questions

Client Concerns

Concern: Do living shorelines work?

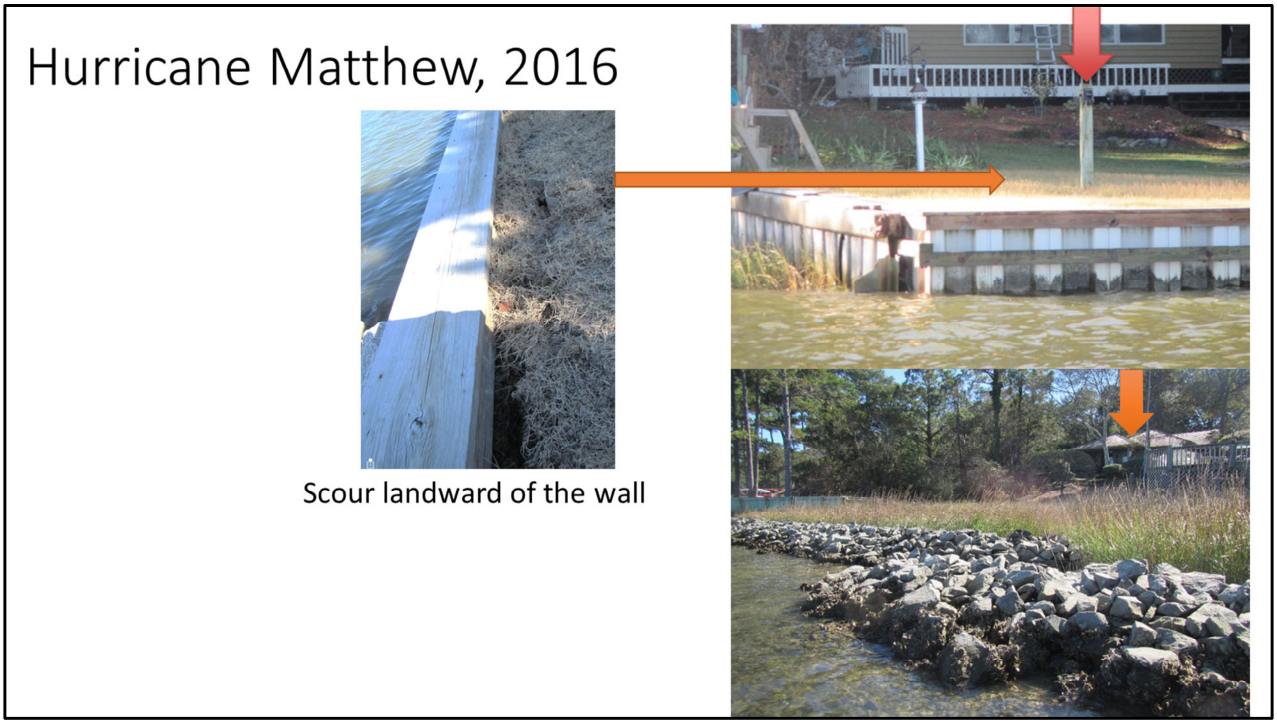
The short answer: Yes! Living shoreline methods can provide equal or greater erosion control over traditional hardening approaches, while protecting or restoring natural coastal marshes.

Your clients will have questions about how living shorelines hold up to storm conditions, boat wakes, and other events that may confront their shorelines. How do we know that this approach will work?

Traditional approaches to shoreline stabilization followed the assumption that larger, vertical structures would better protect against erosion, especially during higher energy events, than lower profile approaches with natural elements like plants and oysters. Long term monitoring and experience with living shoreline approaches over the past 40+ years shows us that designing to more closely mimic the natural shorelines can be as or more successful in stabilizing estuarine shorelines. In addition, these approaches protect or restore the natural marshes, which themselves are critical to protecting adjacent properties and ensuring that a shoreline remains stable over time. Living shorelines dampen, rather than reflect wave energy. Reflected wave energy results when wave and current energy are applied to a vertical bulkhead, can actually increase erosion adjacent to the walls and/or on adjacent shorelines.

Experience has also shown that for the vast majority of low to high energy settings, living shorelines can be designed to provide resilient, highly effective protection for both adjacent properties and the intertidal zone from uplands through marshes and the shallow underwater areas.

There are some great examples of living shorelines outperforming walls during storms. A paper published in 2014 documented a case study of two shorelines in North Carolina that received a direct hit from Category 1 Hurricane Irene. **The two shorelines in the images were only 500m away from each other and therefore encountered the same conditions during the storm.** As you can see, the living shoreline weathered the storm with minimal impacts, while the bulkhead suffered catastrophic damage. Twenty-two dump truck loads of sand were required to refill site after bulkhead failed after Hurricane Irene



That failed bulkhead was replaced with another bulkhead, despite researchers trying to convince the property owner to install a living shoreline. Hurricane Matthew comes through in 2016. It doesn't destroy bulkhead, but significant scour occurs landward of the wall, after storm surge overtopped the structure. Meanwhile, once again, the nearby living shoreline suffered no damage in Hurricane Matthew.

Additional resources to share with clients:

- Scientific America: Rebuilt Wetlands Can Protect Shorelines Better Than Walls
- Marshes with and without sills protect estuarine shorelines from erosion better than bulkheads during Category 1 hurricane (Gittman et.al, 2014)

Client Concerns

- Concern: What about maintenance?

- Recommendation
  - Bulkheads may need little maintenance at first, but eventually most often need repairs and will all require replacement.

  - Living shorelines require maintenance (e.g. plants replanted) in the first 1-2 years, but are more resilient and require little maintenance over time (beyond storm debris removal).

Photos: Savanna Barry, UF/IFAS

What about maintenance?

Bulkheads = compounding costs

Walls are guaranteed to need maintenance and eventual repair and replacement. This will increase with the climate change effects of sea level rise and increases in strong storms.

Living shoreline = compounding gains

Over time, living shorelines become mature, self-sustaining and are more resilient to storms and rising seas.

Client Concerns

- Concern: Will we lose our water views?
- Recommendation
  - There are a variety of native coastal marsh and riparian plants and structures that can be used to maintain water views.
  - North Carolina's native marsh plants are most often used in living shoreline projects, and provide natural views of the estuaries and excellent protection.

Photo: Biologs and native salt marsh living shoreline project, Bradley Oaks, Wilmington, NC (photo by NC Coastal Federation)

Note: Several references on native plants found along North Carolina's coast and supply resources will be provided in later training modules.

Client Concerns Exercise

For each of the following scenarios, develop a positive response that will address common client concerns about erosion control options, including living shoreline measures:

- Customer has a high energy shoreline, with erosion primarily resulting from boat wakes.
- Customer is concerned about the costs of solutions.
- Customer is concerned about the amount of effort needed to maintain the shoreline measures after installation.
- Customer questions the amount of time for establishment of living shorelines versus traditional hardening approaches.

FEASIBILITY

Module Two

Site assessment

- Desktop/Office Analysis
- Living Shoreline Explorer App
- Field/Site Analyses

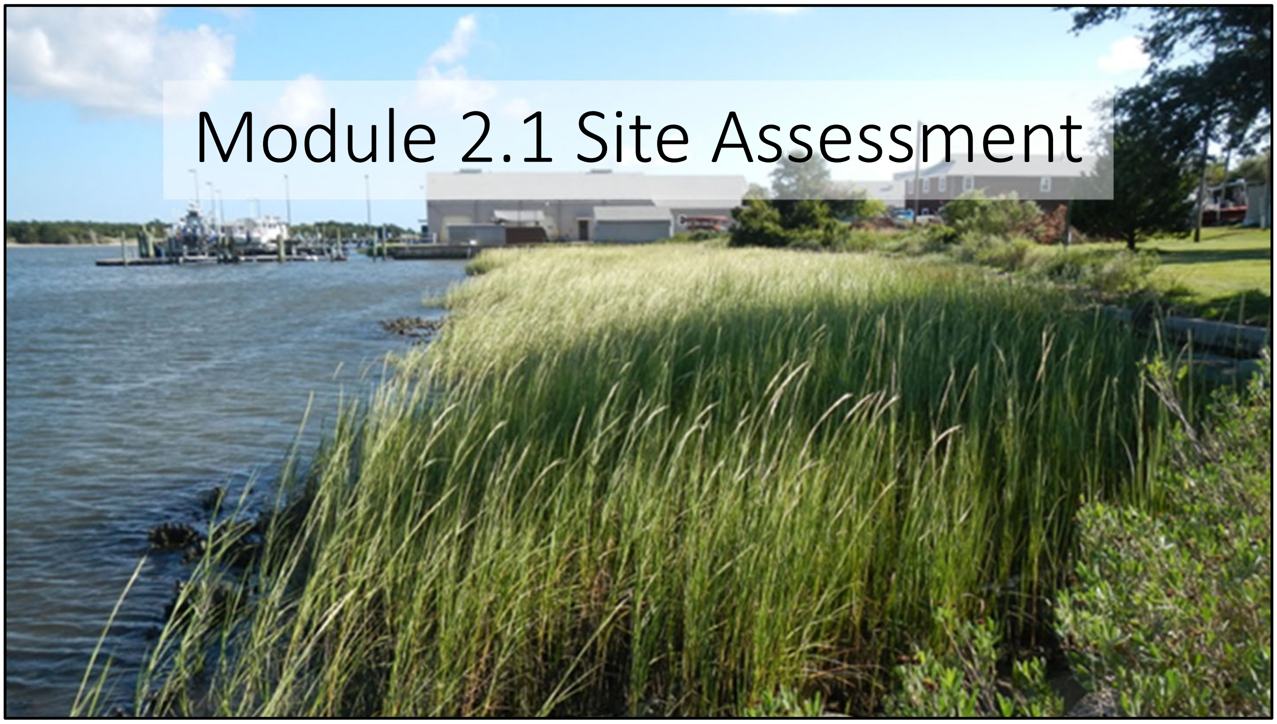
Site design options

Permitting

Module 2 Objectives

Training Participants will be able to:

- Conduct desktop (pre-field) and physical (field) analyses of site factors to design living shoreline projects;
- Differentiate among types of shoreline stabilization options and understand when each is appropriate;
- Plan design based on site analyses and application of appropriate methods; and
- Understand living shoreline permitting and what information is necessary for permit applications/approvals in NC.


Module 2.1 Site Assessment

Technical Definitions

• Slope	Bank angle from upland into water = uniform & steepness
• Orientation	Shoreline facing direction related to wave energy
• Topography	Map of the natural and artificial features of the shoreline
• Bathymetry	Underwater depth profile
• Sediment	Characteristics of solid material that settles in the water
• Currents	Rate of movement in the water (speed and direction)
• Wave Types	Wind driven verses boat/ship wakes
• Fetch	Distance over water that wind blows in a single direction

- Slope: Can vary between bank, marsh, and nearshore areas. Also, stabilization structure slope varies with design and site conditions.
- Orientation: Affects the design options. What is orientation relative to dominant erosion forces, such as wind, currents, wave heights, etc? Is the orientation uniform, or does it vary from exposed to sheltered areas within the same property?
- Topography: The contours and relative elevations of the property leading into the adjacent waters is critical in determining design options, access, etc. for construction.
- Bathymetry : The depths of the bottom offshore of a property can greatly affect the erosion of a shoreline, as they affect wave heights, direction and strength along a shoreline.
- Sediment: The type of bottom sediment determines what type of structure will be successful in a given site. Sandy bottoms will better support heavier structures, such as stone sills, whereas softer sediments may be better for planting approaches or vertical wall sills.
- Prevailing Currents: The volume and strength of tidal or stream/river currents must be considered, as they may affect material staying in place
- Waves: Includes wind driven waves, boat wakes, and ship wakes. Also need to consider if heavy boat traffic exists in this area. All these influence the design options
- Fetch: Large fetch equates to higher energies. Also consider prevailing wind directions and seasonality when designing energy dissipation features

Site Analyses & Design Considerations

What would we like to know about the site?

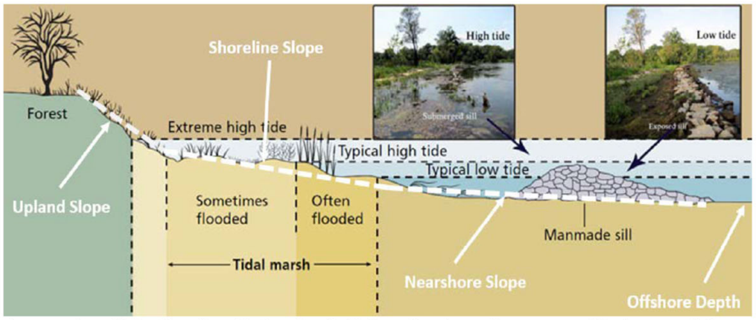
- Is the shoreline eroding
- Severity of erosion
- Causes of erosion (storm waves, boat wakes, stormwater, etc.)
- Upland and nearshore slopes
- Shoreline orientation, topography, bathymetry
- Existing bank and shoreline conditions (i.e., height, soils, scarping, etc.)
- Location of existing structures and shoreline modifications
- Shoreline type, associated habitats, and ecosystem functions

What can we learn from a desktop and an onsite analyses?

Site evaluation and design for any erosion control project includes two parts for success: consideration of conditions that can can be done prior to the site visit (desktop analyses) and the consideration of conditions that can be done on-site (field analyses). The goal is to fully understand the site conditions (present and from an historic perspective) and the forces of erosion and other shoreline changes.

Each of these items must be assessed and considered as part of the design process. The information gathered will inform the design for your site and help ensure a successful, long-term erosion control structure. Combine the site analysis with the desktop analysis to provide a more complete picture of the shoreline's conditions. Personal interviews with property owners can be very helpful in understanding the existing conditions, erosion history, wave energy vulnerability, as well as their goals for the project, etc.

Desktop Analysis & Design Considerations



Site features- from ***Living Shorelines Engineering Guidelines,*** New Jersey Department of Environmental Protection

- What is the long-term rate of shoreline erosion?
- What is the wave exposure?
- What is the tide range?
- What is the potential storm surge?

Some of this information can be determined during the desktop analysis and/or a 1-day visit, some can be informed by the property owner or neighbors, and some may require some additional time in the field during varying conditions.

Although many details needed for design and construction can be determined from a field inspection, some details can be best determined from your computer. Useful details include the rate of long-term erosion, the wave exposure, and potential storm surge elevations.

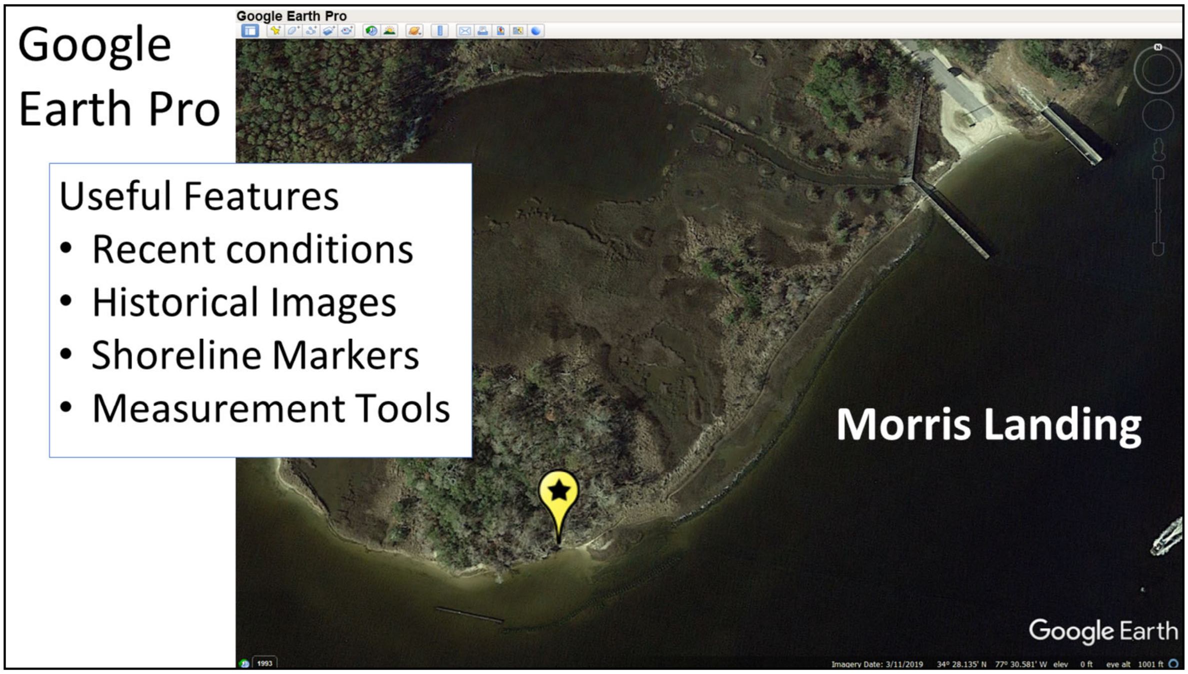
Desktop Analysis: Long-term Erosion Rate

- Ask the property owner
  - Property surveys
  - Historical ground photography
- Aerial imaging software like Google Earth Pro
- Earlier aerial photography
- State, federal, or local agencies

A single site visit can offer guidance on the long-term erosion but can also be misleading. Recent erosion from an infrequent but more severe storm may cause rapid erosion but can be quite different from the long-term trend.

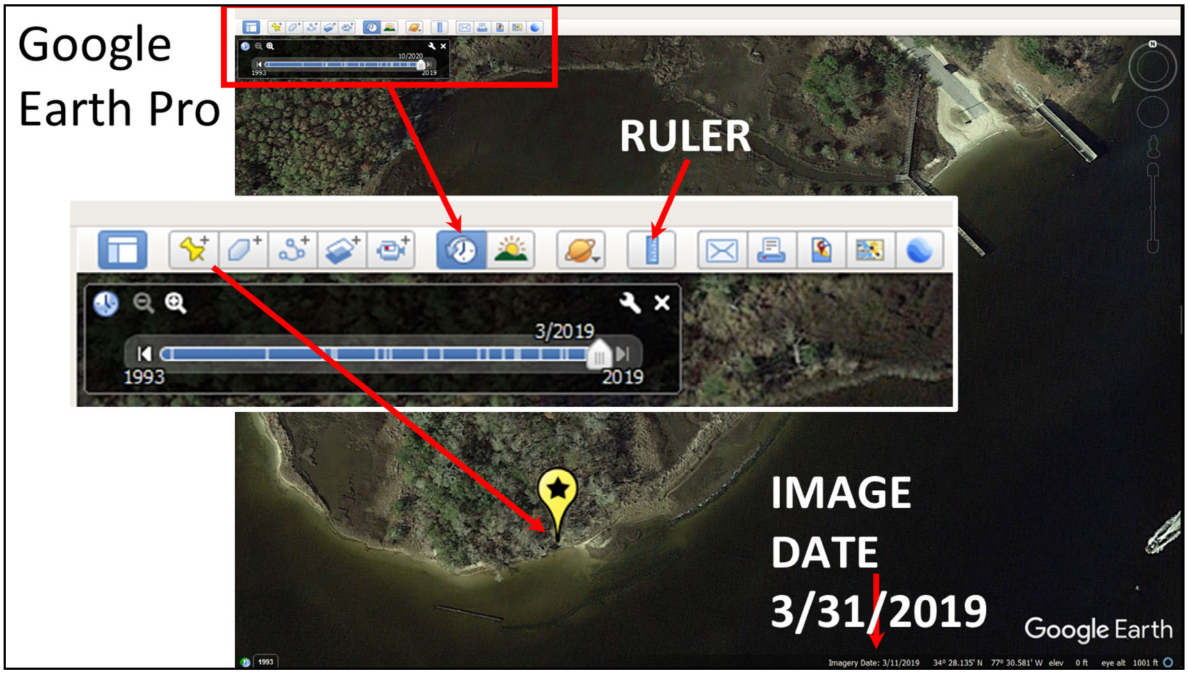
Historical property surveys or ground photographs, and verbal information may be available from the owner or neighbors that can be compared to the present conditions.

Google Earth Pro and other similar applications allow direct comparison of shoreline changes using aerial images. Earlier aerial photographs may be available from other local resources. State, local or federal agencies (like NC Department of Transportation) are most likely to have earlier images.



Google Earth Pro and similar applications offer useful tools to identify shoreline changes. Recent aerial images of all coastal North Carolina shorelines are readily available. This image is of Morris Landing, one of our nearby field sites.

In addition to viewing the recent conditions we can view earlier historical images, set markers to compare shoreline changes and measure the changes over time.
(Image from: Google Earth Pro 3/11/2019)

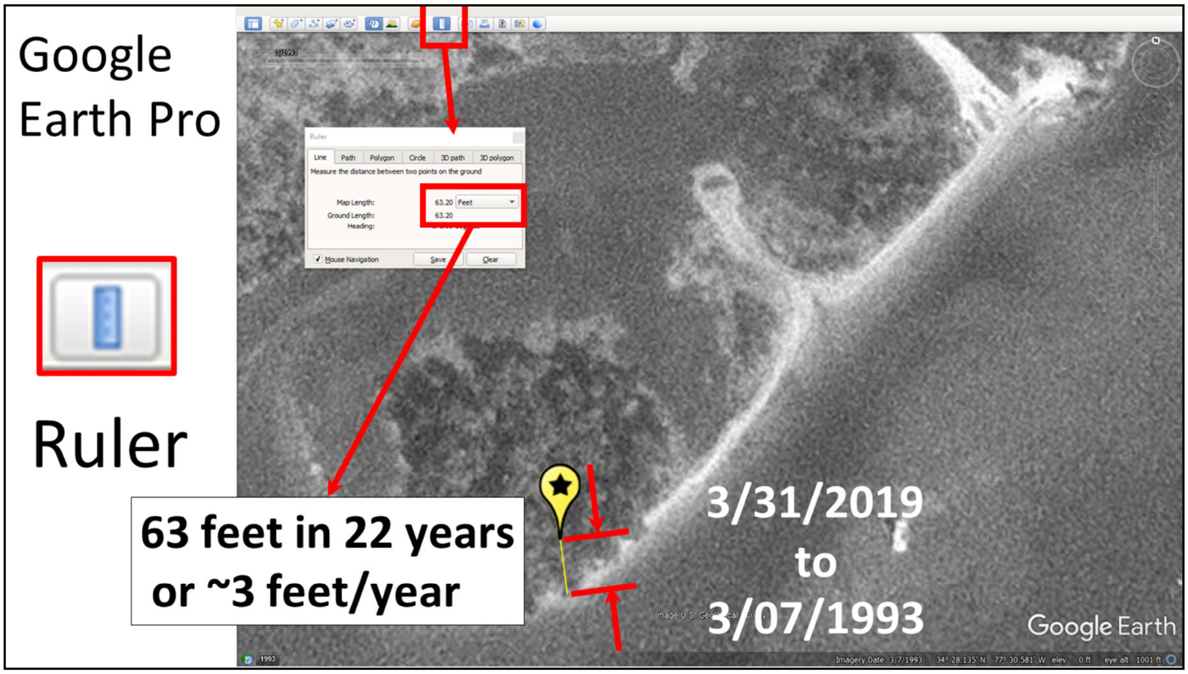


Google Earth can be used on your computer or mobile device to view a recent aerial image. The free, downloadable version for your computer is now called Google Earth Pro has the most useful features. For those not familiar with all of Google Earth Pro's features, the menu bar at the top of the screen is the place to start.

- Zoom to your area of interest using the mapping navigation features or by entering a street address.
- The date of the recent image is shown and the bottom of screen
- The clock button opens a sliding scale that allows you to go back in time to older aerial images.
- The pushpin button allows you to put a marker on the shoreline to compare with older images.
- The ruler tool allows you measure the shoreline change over time and calculate a long-term erosion rate.

(Note: The historical images are only available in the free, downloadable version of Google Earth Pro. The web and mobile versions of GE do not include the historical images.)

(Image from: Google Earth Pro 3/11/2019)



Clicking the Ruler button opens menu to measure the change in the shoreline position. The image overlays are not always perfect but with a little adjustment effort you can usually get a reasonable estimate of the shoreline change. (Image from: Google Earth Pro 3/7/1993)

Desktop Analysis: Wave Exposure

- What is the open water fetch?
- What is the dominate storm wind direction?
- Design wave heights?
  - Gage measurements
  - Wind speed prediction

In most cases, measuring the fetch, or distance of open water over which the wave heights continue to grow before reaching the shoreline, can be used as a surrogate for wave height. The fetch distances can be measured using readily available maps, navigation charts or mapping software.

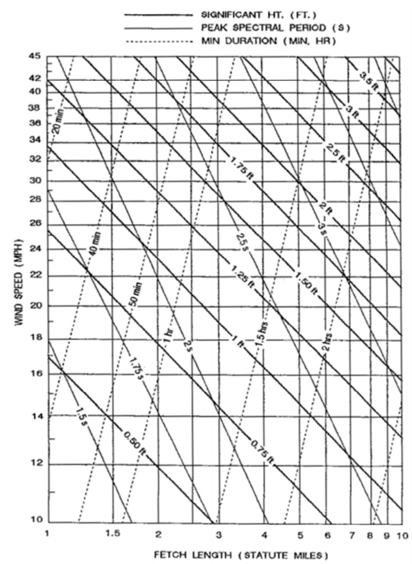
For any wind speed, the longer the fetch the bigger the potential wave. There are often dominate storm wind directions that make those fetch directions the most important. You'll hear more about fetch later in the design section of the training.

At the Morris Landing site on the Intracoastal Waterway, the average fetch is short, less than 0.5 miles. The longest fetch from the northeast direction is close to 1 mile. (Image from: Google Earth Pro 3/11/2019)

Design Wave Conditions

Estimate using several methods or models:

- Fetch
- Wind speed
- Wave height & period



(from HEC 11)

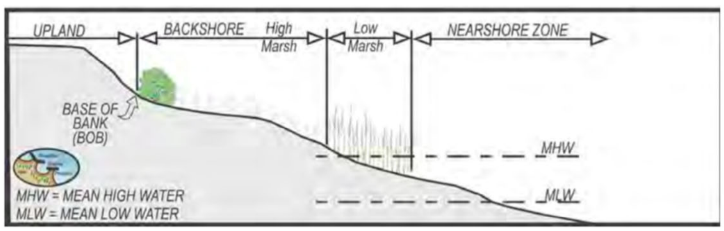
In most cases fetch will be used in the design process that follows. If design wave conditions are needed, they can be determined using a variety of models or other methods. Some methods are as simple as tables, such as this table from [Federal Highway Administration (1989). Design of Riprap Revetment, (HEC 11), FHWA-IP-89-016, US Department of Transportation.]

The Nature Conservancy's Living Shoreline Explorer is another tool that can be used to determine the level of wave exposure, will be described later.

Tide Conditions

Needed for design

- Marsh plant growth range
- Structural component elevations & depths



From ***Living Shoreline Design Guidelines for Shore Protection in Virginia's Estuarine Environments***, Virginia Institute of Marine Science, September 2017

Determining several tide parameters will be important for most designs. The most useful marsh species like to get wet, but can be finicky on how long they stay wet during the day. For example, smooth cordgrass will typically thrive as high as mean high water but does not do well below mid tide, staying wet for half the day. Those elevations will be needed for planting guidance.

Structural components in living shoreline alternatives such as shell bags or sills, are most cost-effective when designed with the lowest possible crest elevation to perform their needed marsh protection function. Tidal parameters may also be necessary to comply with permit conditions limiting how high or distant from the shoreline living shoreline features may be allowed, referenced to tidal parameters.

Tidal Data

Needed for design

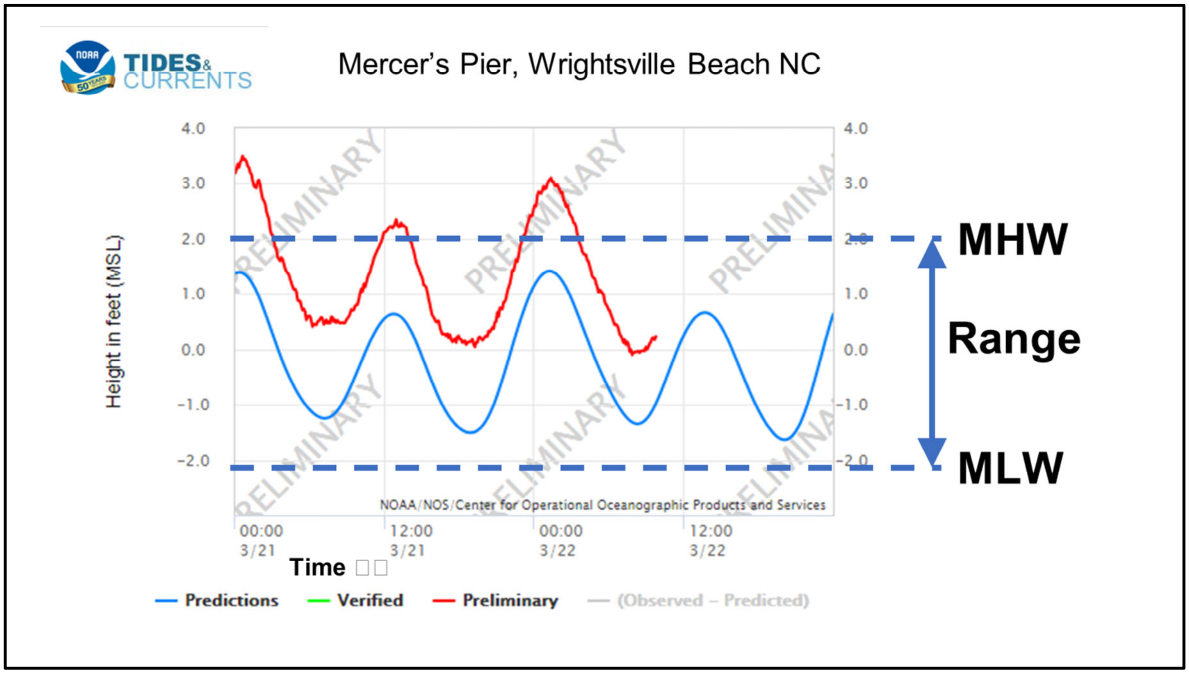
- Mean High Water (MHW)
- Mean Low Water (MLW)
- Tide Range

TIDES & CURRENTS

tidesandcurrents.noaa.gov/tide_predictions.html

- Primary stations: real-time reporting
- Secondary stations: high/low predictions

For design, local estimates of Mean High Water and Mean Low Water elevations, providing the tide range, will be needed. The place to start is NOAA's closest primary station which will include real-time reporting. Tide elevations can vary over short distances, particularly from ocean to bay, so look for the closest secondary station for a better estimate of local tidal factors.



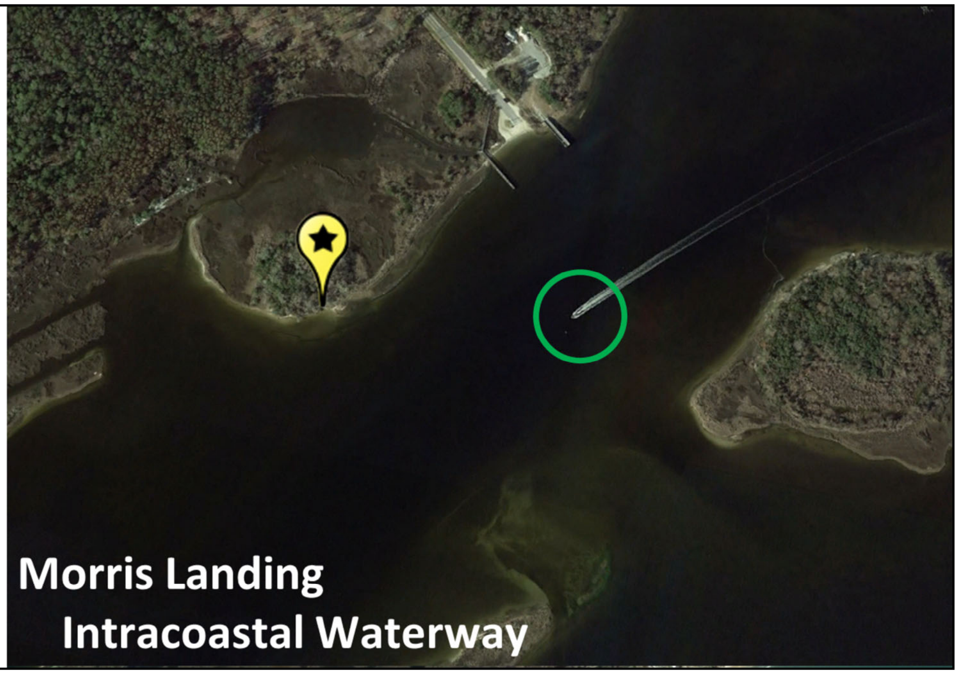
Part of the tide can be predicted from Lunar and Solar gravity but other factors like wind speed and direction can raise or lower the water level above or below the predictions. In the case shown a moderate northeast storm has added more than a foot to the ocean tide. South of Cape Lookout the estuarine tides will be similar in elevation but lag behind the ocean timing at times by hours. In the Albemarle/Pamlico Sounds, distant from the ocean inlets the tide range shrinks to a few inches, and the water level is control by the wind direction and velocity.

You can use the tide predictions to help select the best time to schedule your site visit. Generally, the lower the water level the more vegetation and bottom features you will be able to see.

The desktop analysis can off guidance, but site visit should be used to confirm the local tide parameters.

Near navigation channels

Design Wave = Boat Wake



Near navigation channels boat wakes may be larger than storm wind-waves, making them the primary cause of the erosion. However, Morris Landing and most of the Intracoastal Waterway shorelines have design wave heights dominated by boat wakes. The steep, short-period wakes are particularly likely to induce erosion. Closer channels to the shoreline, higher numbers of boat use and larger boats make wakes the more likely to be the primary cause of erosion, as along the Morris Island shoreline on the Intracoastal Waterway.
(Image from: Google Earth Pro 3/11/2019)

Desktop Analysis:
Potential & Historical Storm Surge Elevations

- NC Floodmapping & FEMA
  - 100 & 500-year storm surges
- U.S. Geological Survey
  - Flood Event Viewer by storm or flood date
- Other historical flood elevations
  - Army Corps of Engineers, FEMA, N.C. Emergency Management

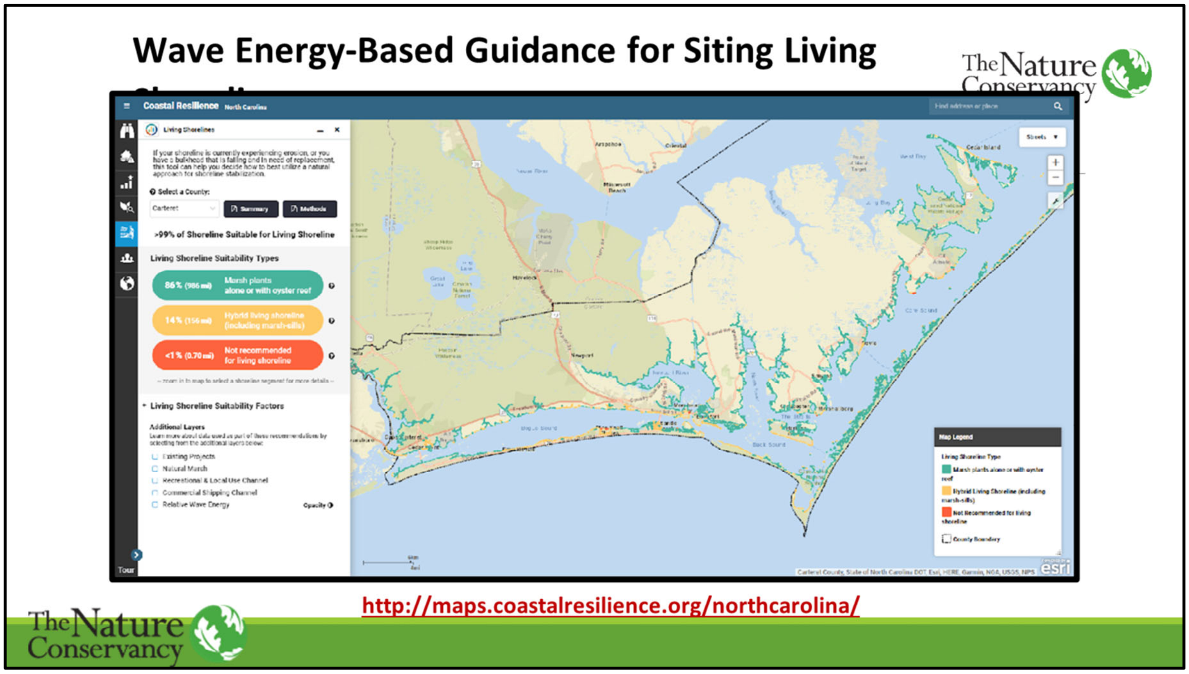
Living shoreline methods can be widely applied to address long-term erosion problems along most of North Carolina's estuarine shorelines. However, these shorelines are also subject to much higher storm surges during infrequent but more severe events like hurricanes. Living shoreline methods are most effective during conditions with shallow flooding. As living shorelines are more deeply flooded their effectiveness in protecting the upland property is gradually diminished. Particularly along shorelines with high bank elevations or bluffs, Living shorelines may need to be combined with bank grading, groundwater management, or other higher elevation solutions may be needed higher storm surge-induced erosion events.

Desktop Analysis Resources

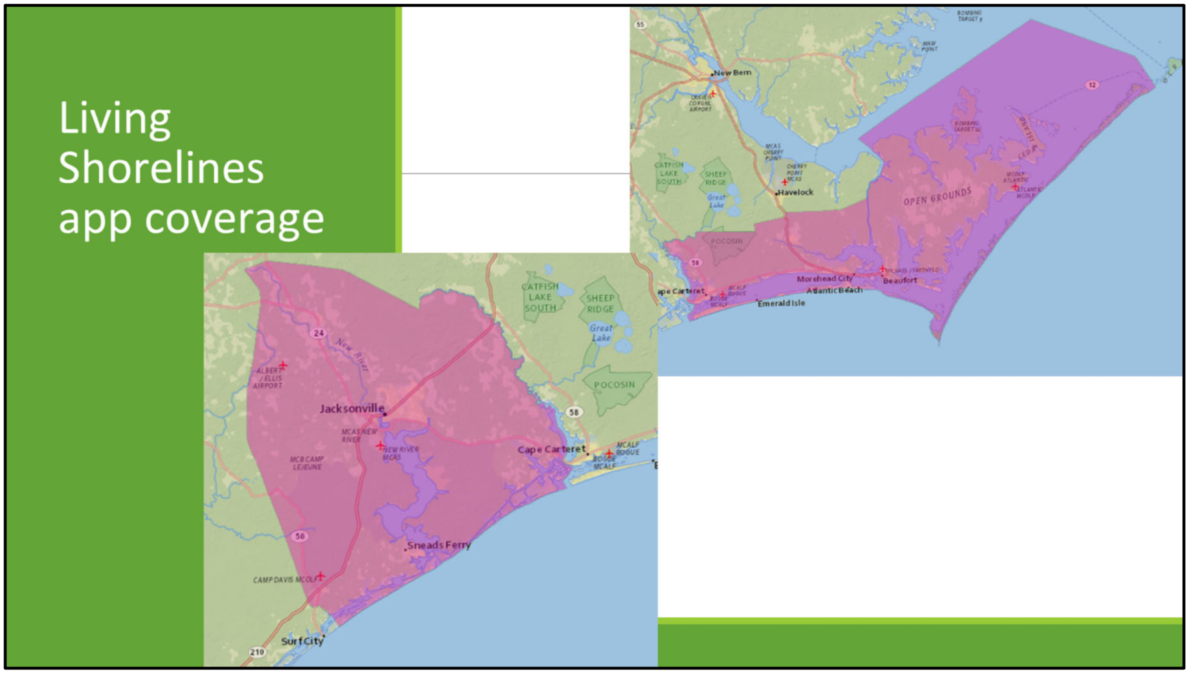
Resource	Link
Aerial Photography	Google Earth Pro, Historic imagery, etc.
Land surveys	From property owner or local surveyor
Historical water levels	https://stn.wim.usgs.gov/FEV/
Tides	https://tidesandcurrents.noaa.gov/tide_predictions.html
N.C. Floodmapping	https://flood.nc.gov/ncflood/; https://fris.nc.gov/fris/
FEMA flood maps	https://msc.fema.gov/

Listed are some of desktop resources available to assess site conditions.

- Historic aerials are worth their weight in gold, especially if you have a succession of images, as one can note the changes in the shoreline over time.
- Use Google Earth Pro to view historical photos, typically back to the 1990s
- USGS posts storm surge and stream gage records for specific storm events as early as 2005.
- NOAA Tides & Currents posts tidal predictions and annual analysis summaries for many locations.
- NC Floodmapping and FEMA both post the National Flood Insurance Rate maps with 100 and 500-year flood elevations.



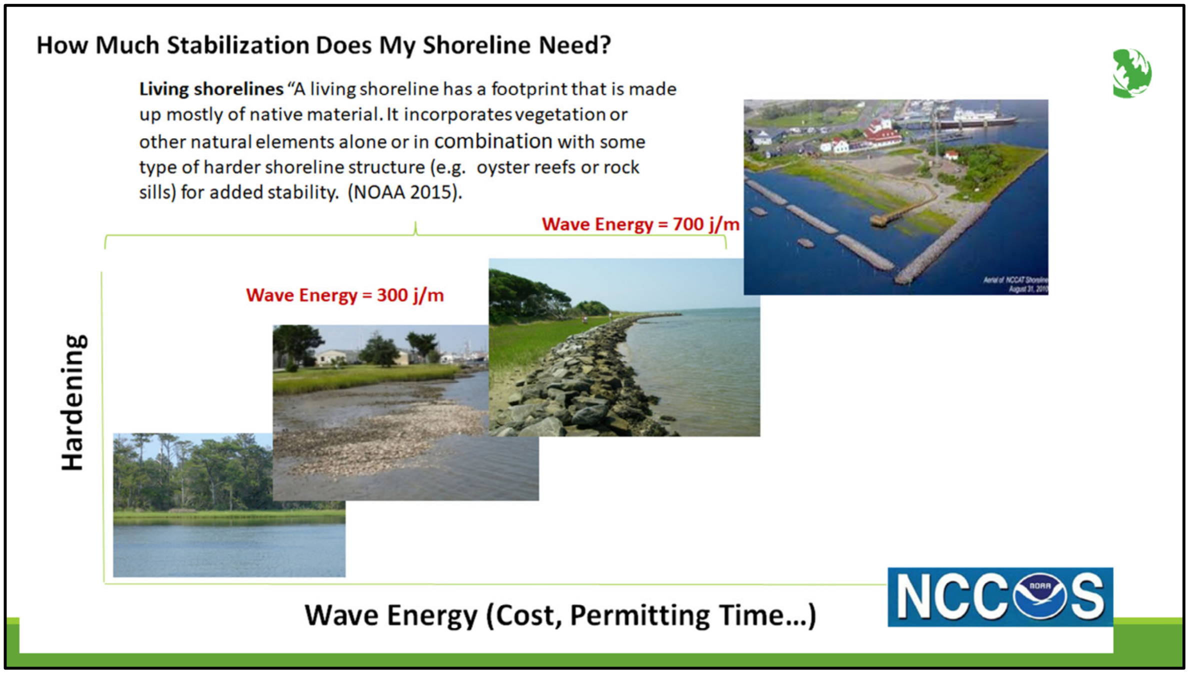
The Nature Conservancy will discuss and demo a new online guidance tool, *the Living Shoreline Explorer.* This tool helps users identify where shoreline conditions are suitable for a living shoreline. This quick screening tool can help you determine a site's wave exposure or energy conditions as well as provide guidance on what living shoreline design may be suitable to address potential erosion concerns.



Currently only Carteret and Onslow counties are included in the tool. If your project site is in these counties, it will be helpful to consult this tool before you invest time walking through the desktop site analysis for wave exposure, as this tool can provide part of that analysis

The Nature Conservancy is interested in improving this tool and encourages you to reach out with feedback. Email Lora Eddy at lora.eddy@tnc.org.

This tool can help you assess the homeowner's perception of erosion risk against a scientific regional analysis of shoreline wave energy. And this tool can help you determine what amount of protection the site will need slow shoreline erosion.

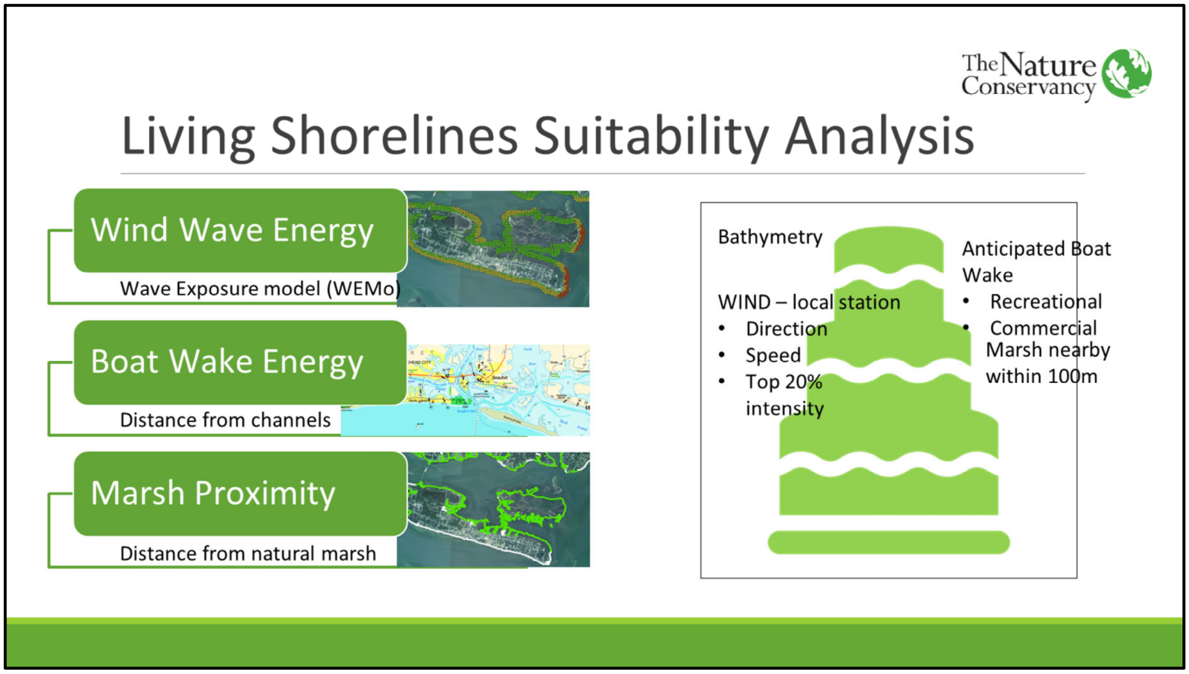


This tool is based on work by scientists Drs. Jenny Davis and Carolyn Currin from NOAA's Beaufort Lab on Pivers Island. This tool brings their research on shorelines in the southern Pamlico Sound and the New River Estuary into this streamlined regional analysis which based on shoreline wave energy exposure. The guidance provided by this tool is supported by their decade-long research program that's monitored changes in vegetation, shoreline position or erosion, and surface elevation in natural fringing marshes and created living shorelines.

This long-term research evaluated the site conditions where marshes or living shoreline are stable and then compared that to their nearshore wind-wave energy value (which is calculated by a model), and estimated boat wake energy. The presence of nearby marsh was also determined to predict where shoreline energetics will support the use of living shoreline techniques.

We know that physical processes (such as boat and wind wave energy) dictate where a living shoreline approach will be effective as represented by this visual in the lower left corner. Shorelines with very low energy support natural shoreline features. However, as wave energy increases, more and more structure is needed.

Researchers have documented that the width of natural shoreline marshes is markedly decreased when wave energy is greater than 300 joules per meter and that natural marshes don't occur when wave energy is greater than 700 joules per meter. In between 300 - 700 joules per meter for living shorelines with a structural element will be most suitable, which you can determine through site evaluation, experience, etc.



The tool includes three factors. 1 - Wind Wave Energy; 2 - Boat Wake Energy; and 3 - Proximity to Marsh.

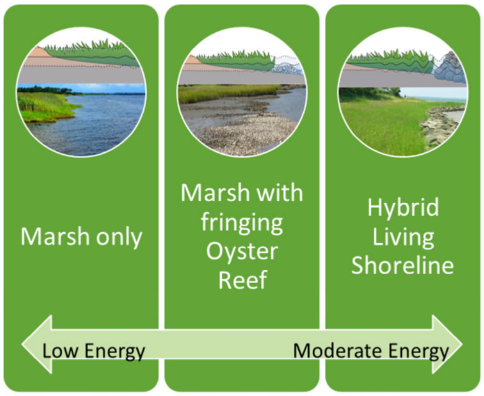
- NOAA's Wave Exposure Model (WEMo) was used to determine shoreline wind-wave energy at 50 meter points along the shoreline. Then scored based upon previous thresholds or wind wave energy values (covered in previous slide) along stable natural marsh shorelines, oyster fringed shorelines and sill based (or hybrid design) living shorelines. Bathymetry, or the contour mapped bottom, is used and adjusted by 1 meter to account this region's tides. Wind data from the local station at Cape Lookout National Seashore, including direction and intensity, is used to determine wave size and frequency. Then the maximum shoreline wave energy for each 50 meter point along the shoreline is determined.
- The impact of boat wakes was incorporated based upon distance of shoreline from marked navigation channels. Existing research on wave heights was generated from recreational sersus commercial vessels to determine wave impact on the shoreline.
- Presence of marsh on nearby shorelines indicates suitable conditions for marsh survival.

For more information about the living shorelines suitability analysis and the factors and methods that went into it, see the methods link and the information icons in the tool.

The intent is to streamline the site evaluation process so that you don't have to walk all of these steps themselves at each site. This analysis has done the calculations (WEMo output) and analyzed the relationship between wave energy model results, salt marsh distribution, and erosion rates, and provided the guidance based on this in a map. Use of the tool does not require knowledge of wave energy calculations or metrics, but simplifies these steps. Using this tool you can remove this technical barrier to implementation of living shoreline projects and provide a level of confidence to satisfy your client's concerns.

The Nature Conservancy

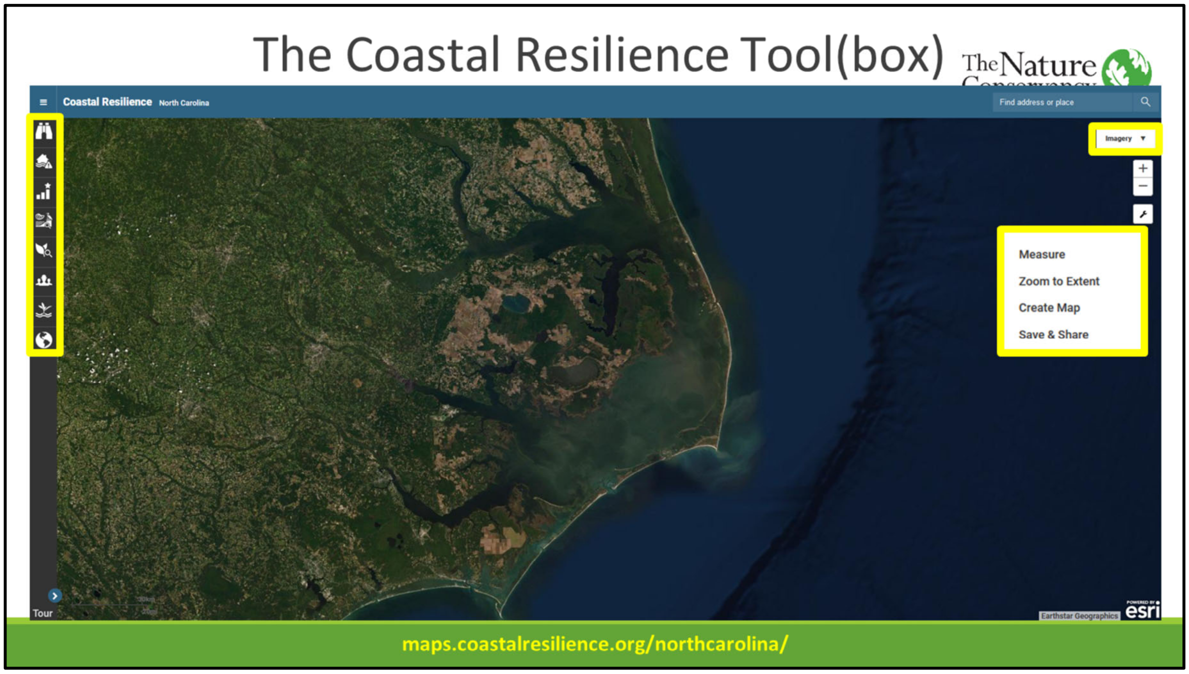
Living Shorelines app



- Users
  - Permitting staff
  - Practitioners
  - Shoreline property owners
- Maps areas where a living shoreline can be a suitable erosion control strategy.
- To locate and target living shoreline restoration locations and to match living shoreline design to site specific shoreline wave energy conditions.

The Nature Conservancy

And now to the demonstration!

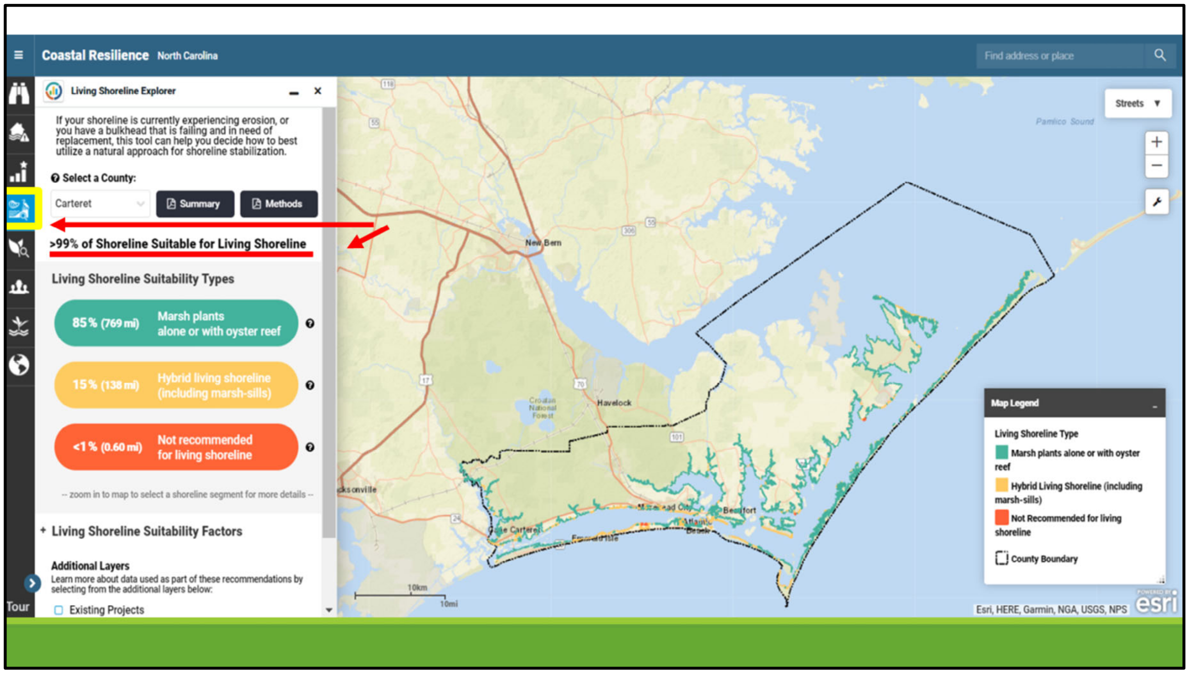


This new tool is part of The Nature Conservancy's Coastal Resilience web-based mapping platform.

This web-based tool can be used in most Internet browsers, including Chrome, Firefox, and Safari. However, NOT Internet Explorer. Click on Tour for a brief introduction to the mapping site or visit coastalresilience.org/tools/training/ for an online Try Me Tutorial.

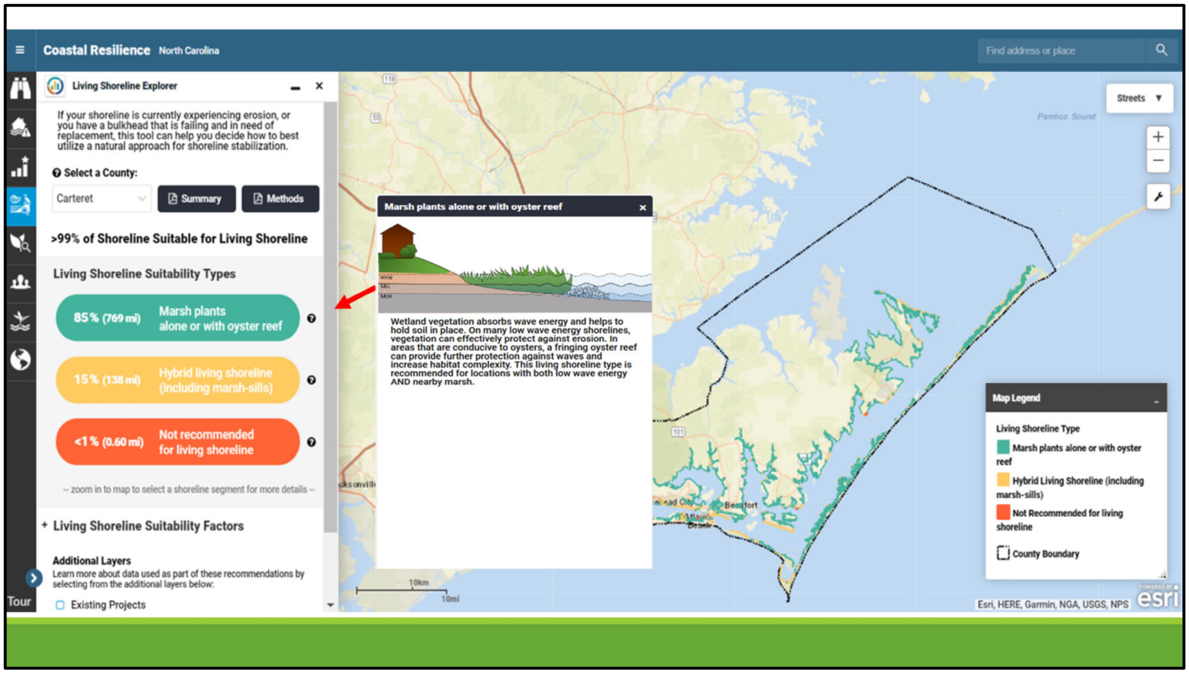
We call this mapping platform our Tool(box) because the map has special app or 'tools' on the left side. These various apps can be used together or on their own.

You can search the map by typing an address in the search bar in the upper right corner, like many other online maps. Also, you can switch the base map from an aerial photograph to a street map by using the highlighted pull-down menu. To share your map via PDF or a link, click on the wrench icon and another menu will pop up with those options.

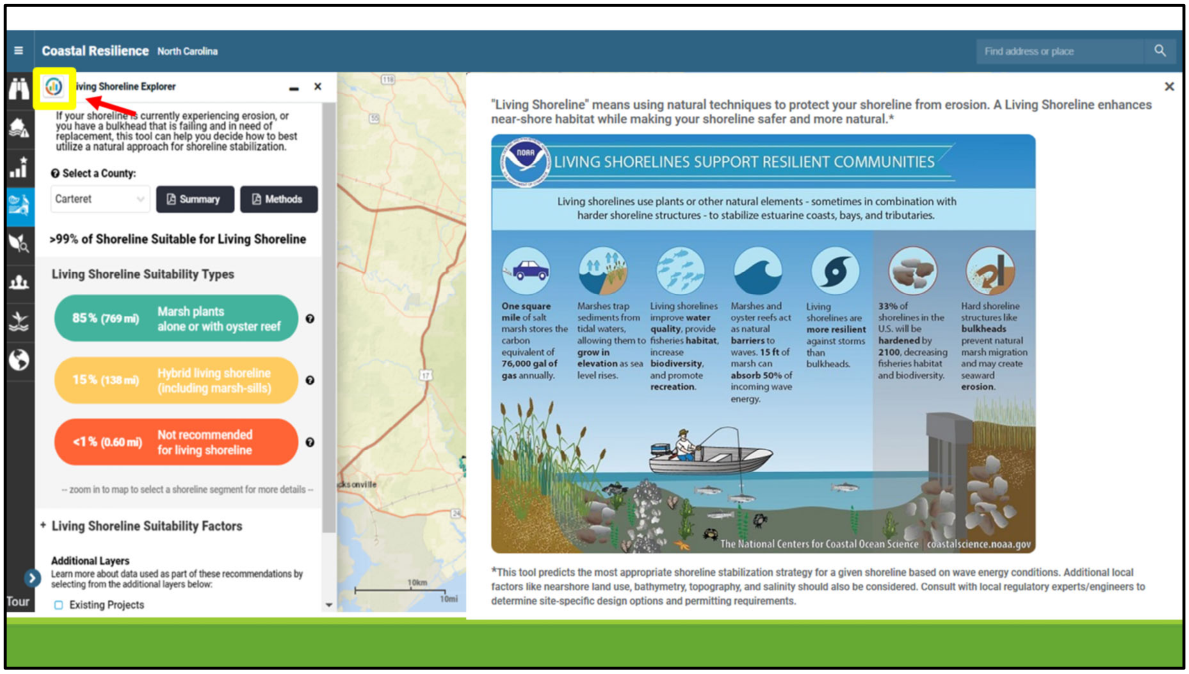


Activate the Living Shoreline app by clicking on the yellow highlighted app icon on the left edge of the map

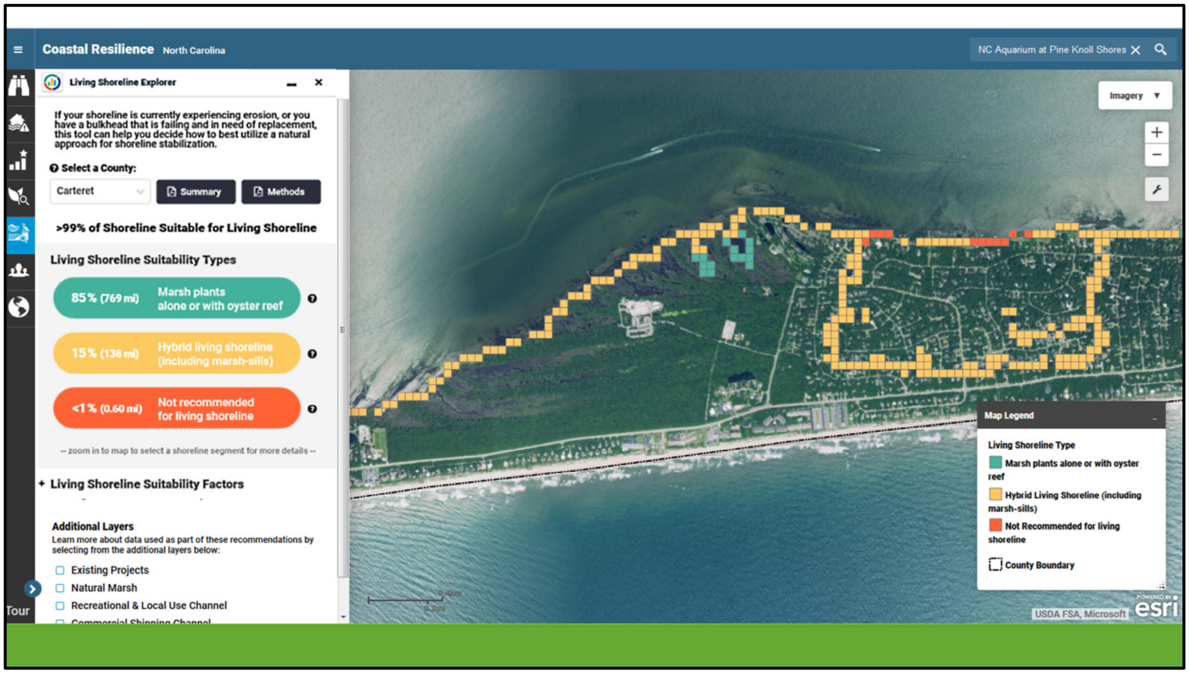
- The Living Shorelines app home window will appear
- The map zooms to Carteret County. Currently the tool's coverage includes Carteret and Onslow Counties
- Notice the Summary Statistic, 99% of shorelines in Carteret County are suitable for a Living Shoreline
- And 86% of the county's shoreline is suitable for marsh alone or with oyster reef, which means generally we might be over engineering our shoreline stabilization. How much unnecessary and <u>expensive</u> artificial and hardened materials are we putting into the water while unnaturally cutting off that land/water zone?



- Click on the info icons to find out more about the Suitability Types, this is the small question mark next to the green, yellow and red-orange buttons
- Another window pops up with a description of the type of living shoreline design recommended by the tool
- This tool was designed for a wide variety of audiences including shoreline property owners, feel free to encourage them to use the tool, their feedback would be valuable



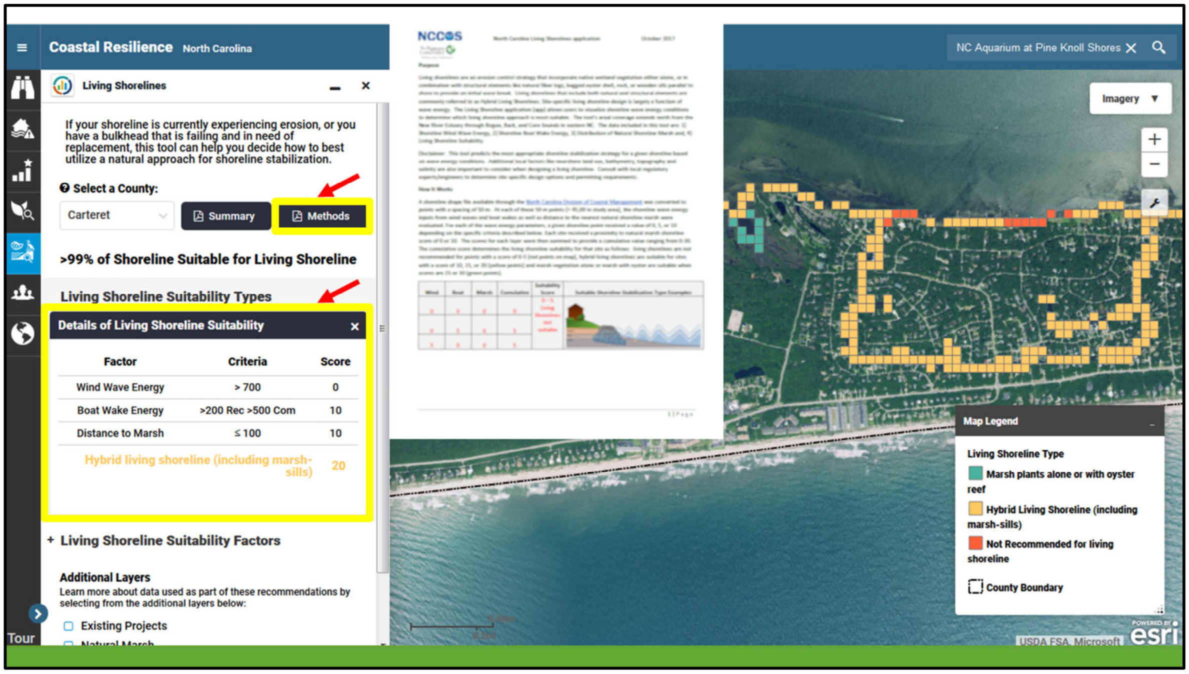
If you click on the bar graph icon in the top left corner of the app home window highlighted here in yellow, an infographic pops up on the benefits of living shorelines. There is also a disclaimer regarding the tool's use – which describes the need for onsite visits and professional judgement to make final determination when selecting the best shoreline stabilization method.



This is an exercise to demonstrate the tool’s functionality.

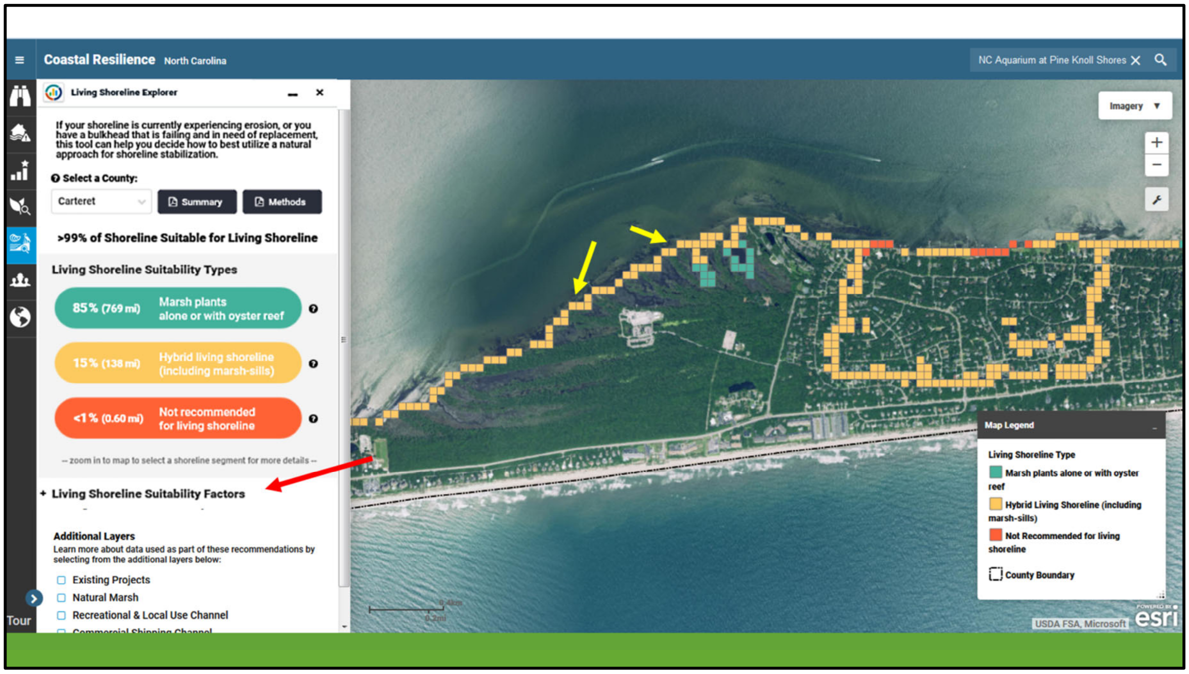
Let’s identify areas near the NC Aquarium at Pine Knoll Shores that are suitable for a living shoreline project using only marsh vegetation. Navigate to Pine Knoll Shores, NC. You can scroll in with your mouse, double-clicking over the area OR by typing NC Aquarium at Pine Knoll Shores in the search bar.

As the map zooms in you can see the suitability analysis grids along the shoreline. As you click through the three different suitability types, the data on the map changes to show only that specific type.

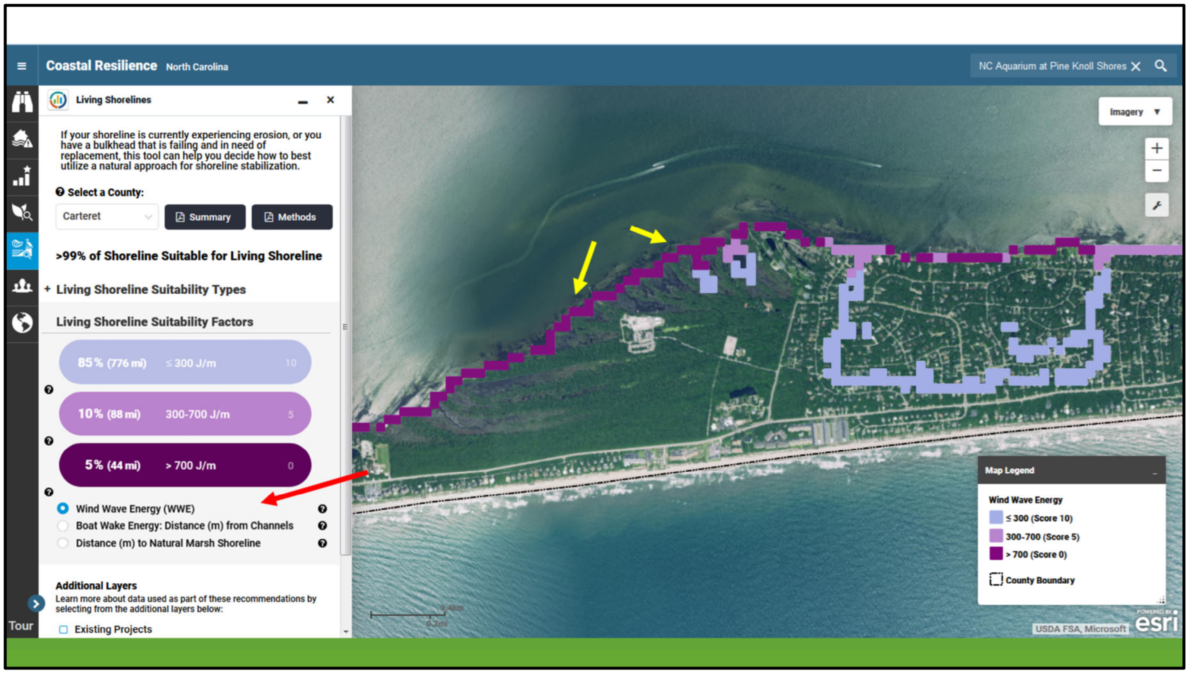


- Click on a yellow shoreline grid
- A window pops up detailing the shoreline grid's specific suitability analysis score
- In this window you can view the model values of the three factors: 1) wind wave exposure, 2) boat wake energy, and 3) distance to marsh

It may be helpful to have the methods document open to understand the suitability types and the data and rational for each. Find the methods document by clicking on the methods button at the top of the app home window.



To look at the shoreline wave energy and other data that went into the tool's recommendations at this location, click on the Living Shoreline Suitability Factors to expand this section of the tool



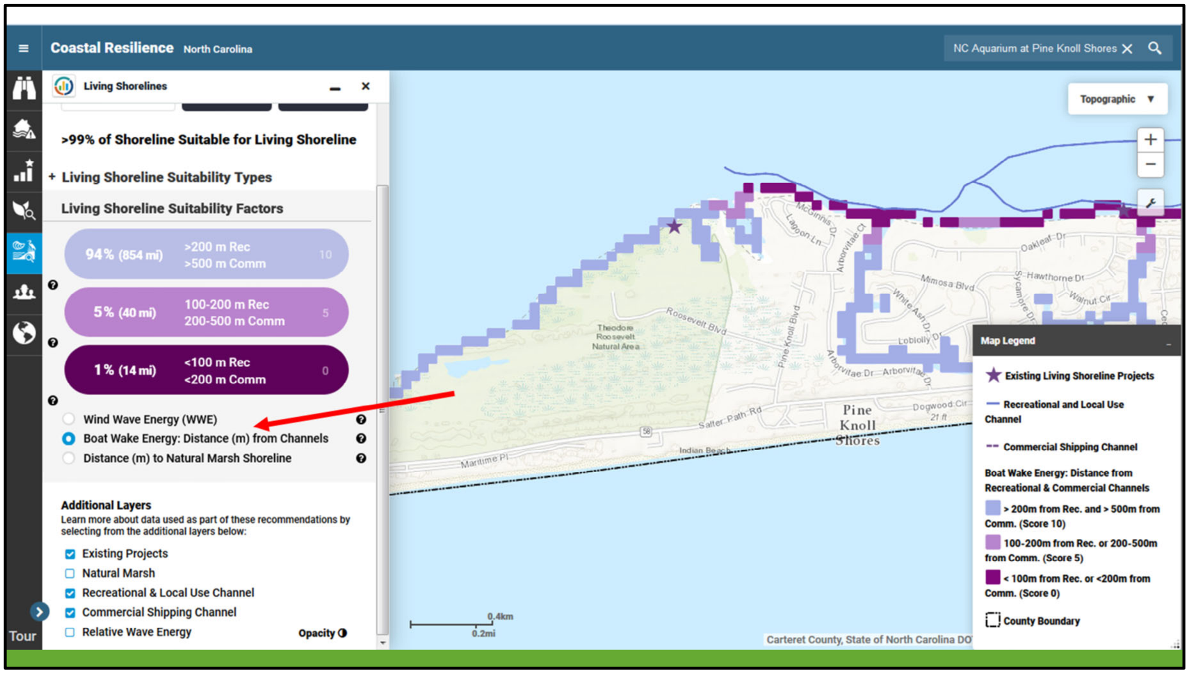
The map and legend change to display Wind Wave Energy values.

*Notice the aquarium's shoreline is exposed to high wind wave energy. This is the limiting factor that prevents this location from being suitable for marsh alone or marsh with oyster reef living shoreline project. This publicly accessible site has both natural marsh and a marsh shoreline protected by stone sills and constructed oyster reefs.

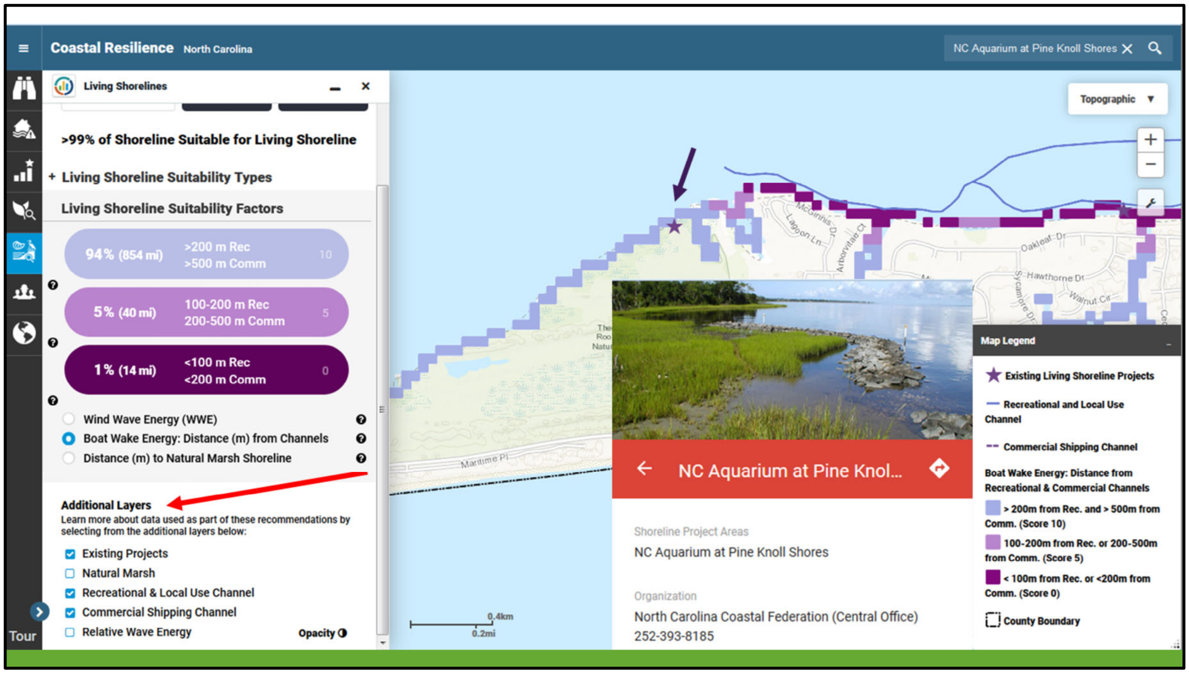
At a recent site visit here, researchers saw that:

- The natural unprotected marsh has eroded by 5-15 meters over the last 10 years.
- The stone sill is protecting the marsh, but there are large bare areas, which appear to lined up with the sill drop downs.
- Field monitoring here shows sediment deposition behind the sill, but as noted the marsh behind the sill drop downs are void of vegetation. This is likely due to the marsh's low tolerance for high wind/wave exposure.
- Newer oyster reef installations look a little better, and are a little more sheltered, but sections of them have been knocked down and the oysters are blown back into the marsh

All of these findings are indicative of the high wind/wave exposure at this site. As this tool indicates, this high wind/wave exposure is driving shoreline changes in this area.

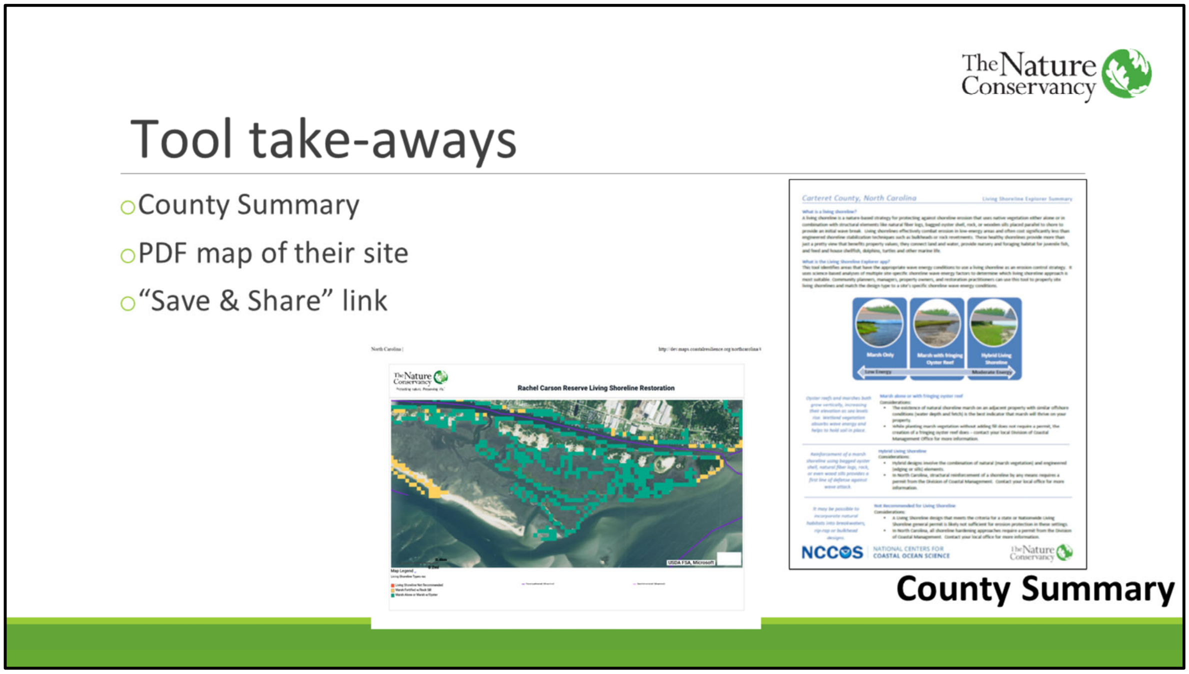


Lets the look at Boat Wake Energy. Click on the button by Boat Wake Energy: Distance (m) from Channels, the map will change. This shoreline is not heavily impacted by boat wake.

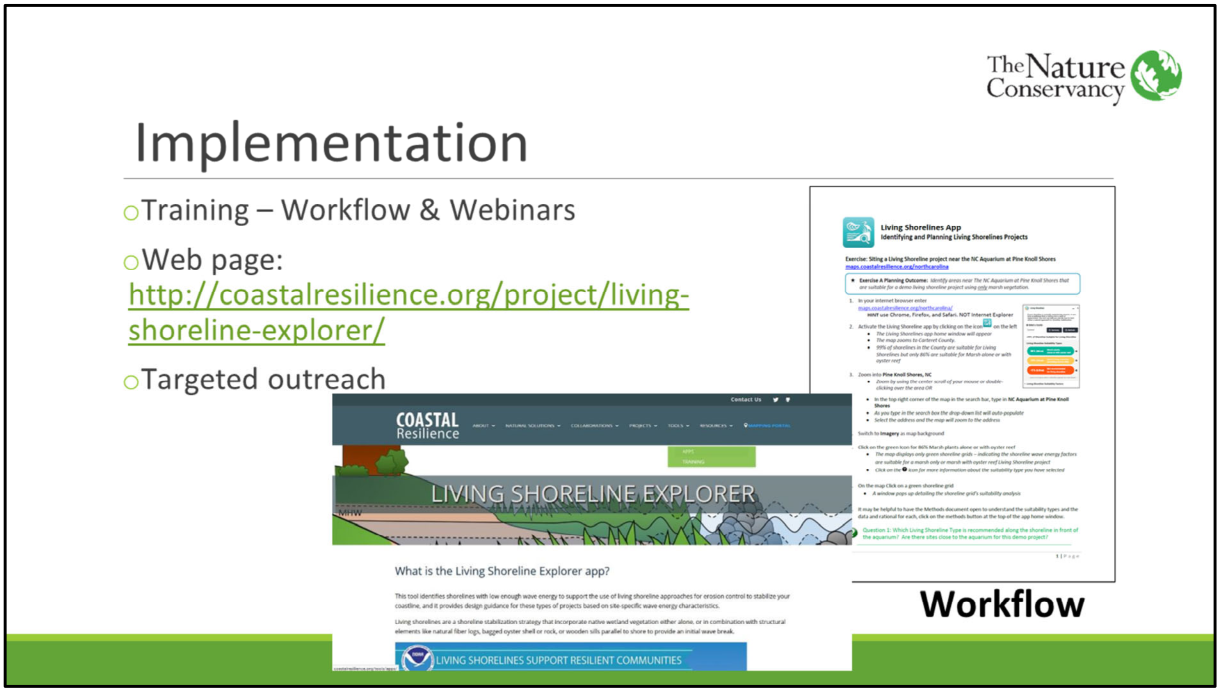


You can verify this under Additional Layers, turn on the Navigational channels' datasets by clicking on the box.

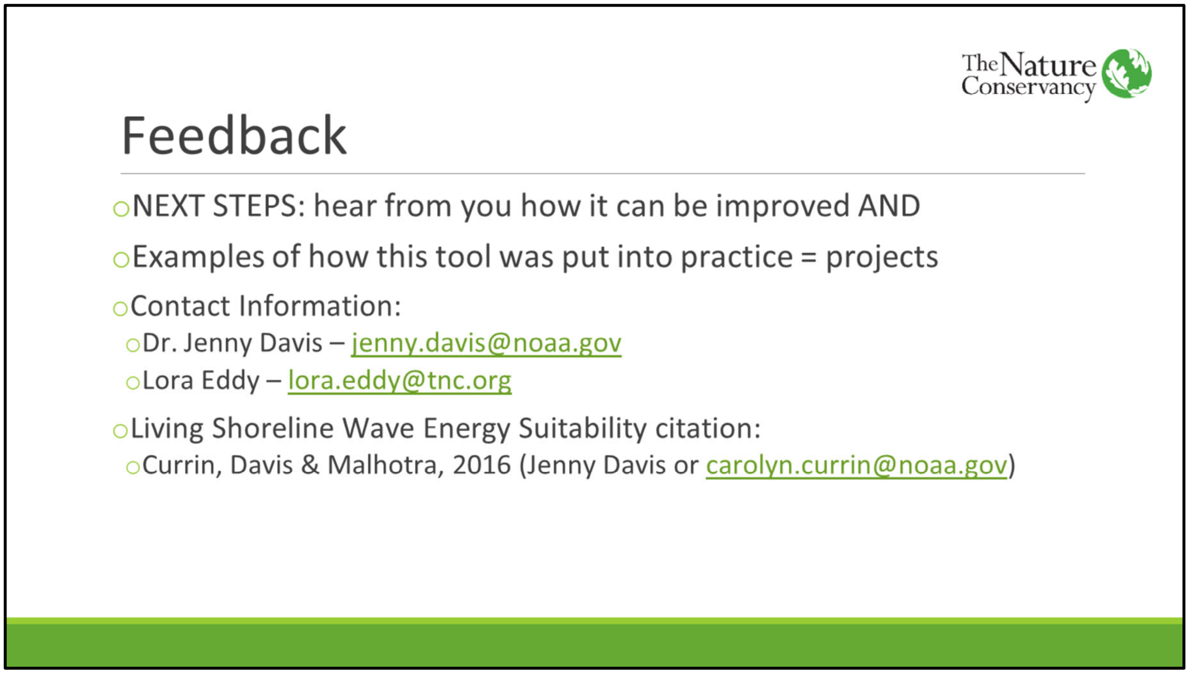
And explore whether there are existing Living Shorelines projects close by, click on the box beside Existing Projects. See that there is a Hybrid Living Shoreline project as recommended by the tool's suitability analysis.



What does the user walk away with? A Living Shoreline County Summary with graphic about living shorelines including different types, its benefits, and links to resources and next steps for a living shoreline project. You can create a PDF map of the site or use the Save & Share feature to share a link and collaborate with others on the tool’s suitability recommendations.



To aid in implementation, there is a Living Shoreline workflow to guide a user through using the app with a scenario-based lesson. The Nature Conservancy is available to host training webinars on the tool and the science behind it.



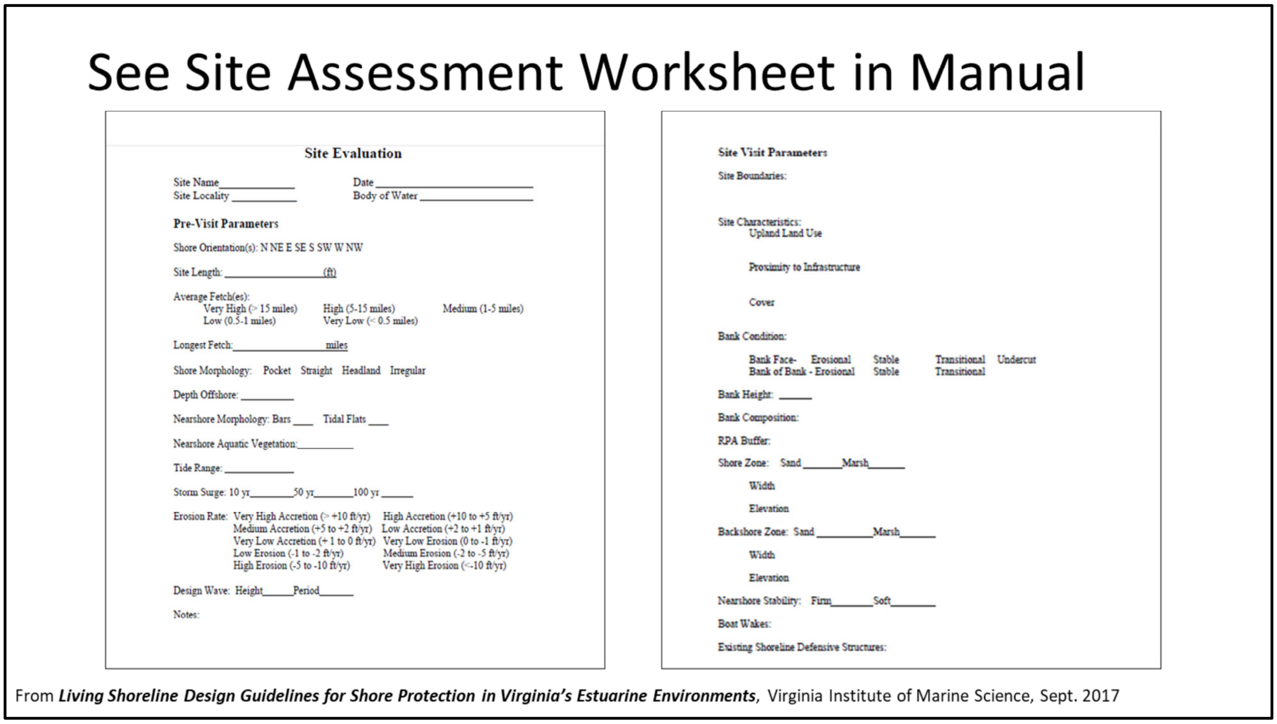
These tools are meant to assist with the applied science of conservation. We would like to hear from you how it maybe be improved and look forward to examples of how this tool was put into practice.

Field Visit – Site Assessment

Once the site history and desktop analysis has been completed, it is time to conduct the field visit/site assessment. Depending on the site, this might include a one-day visit or multiple visits to understand the erosion forces during different times (storms, heavy rains, etc.).

Each of these items must be assessed and considered as part of the design process. The information gathered will inform the design for your site and help ensure a successful, long-term erosion control approach. It is very valuable to combine the site analysis with the desktop analysis to provide a more complete picture of the shoreline's conditions. Personal interviews with property owners can be very helpful in understanding the existing conditions, erosion history, wave energy vulnerability, as well as their goals for the project, etc.



Site Assessment Worksheet

Creating a personal site assessment worksheet is a good way to organize your site visit. There are a number of good examples available, or you can create your own. Benefits of using a standard site assessment worksheet:

- Streamlines initial site assessment
- Facilitates design process
- Helps analyze whether a living shoreline approach is feasible
- Documents existing conditions for design and permitting of a living shoreline project

Site Evaluation

Site Name______________ Date ________________________________
Site Locality ____________ Body of Water ______________________

Pre-Visit Parameters

1. Shore Orientation(s): N NE E SE S SW W NW

Site Length: __________________(ft)

2. Average Fetch(es):
   Very High (> 15 miles) High (5-15 miles) Medium (1-5 miles)
   Low (0.5-1 miles) Very Low (< 0.5 miles)

Longest Fetch:__________________miles

3. Shore Morphology: Pocket Straight Headland Irregular
4. Depth Offshore: __________
5. Nearshore Morphology: Bars ____ Tidal Flats ____
6. Nearshore Aquatic Vegetation:___________
7. Tide Range: _____________
8. Storm Surge: 10 yr________ 50 yr_______ 100 yr _________
9. Erosion Rate:

   Very High Accretion (> +10 ft/yr) High Accretion (+10 to +5 ft/yr)
   Medium Accretion (+5 to +2 ft/yr) Low Accretion (+2 to +1 ft/yr)
   Very Low Accretion (+ 1 to 0 ft/yr) Very Low Erosion (0 to -1 ft/yr)
   Low Erosion (-1 to -2 ft/yr) Medium Erosion (-2 to -5 ft/yr)
   High Erosion (-5 to -10 ft/yr) Very High Erosion (<-10 ft/yr)

10. Design Wave: Height______Period______

Notes:

Site Visit Parameters

1. Site Boundaries:

2. Site Characteristics:
   Upland Land Use

   Proximity to Infrastructure

   Cover

3. Bank Condition:

Bank Face-	Erosional	Stable	Transitional	Undercut
Bank of Bank -	Erosional	Stable	Transitional	

4. Bank Height: ______

5. Bank Composition:

6. RPA Buffer:

7. Shore Zone: Sand _______Marsh_______

   Width

   Elevation

8. Backshore Zone: Sand __________Marsh_______

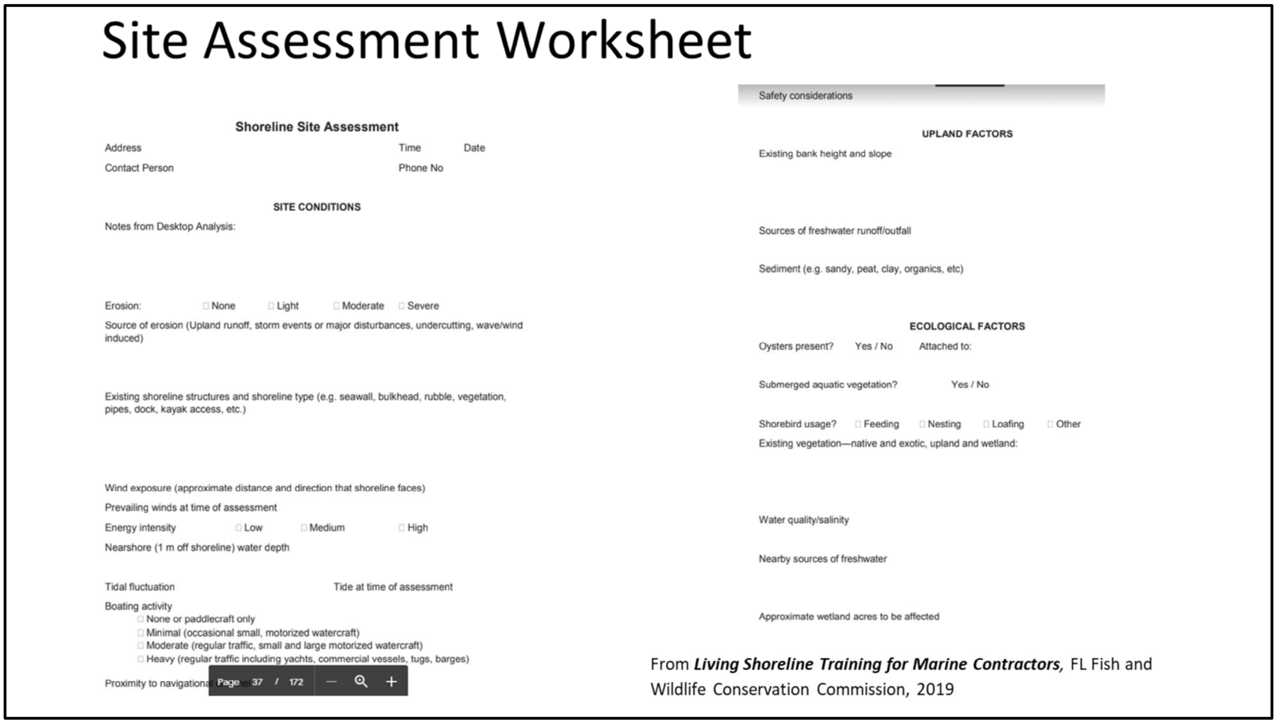
   Width

   Elevation

9. Boat Wakes a Problem:

10. Existing Shoreline Defensive Structures:

11. Nearshore Stability: Firm ________Soft________



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Shoreline Site Assessment

Address Time Date

Contact Person Phone No

SITE CONDITIONS

Notes from Desktop Analysis:

Erosion: ☐ None ☐ Light ☐ Moderate ☐ Severe

Source of erosion (Upland runoff, storm events or major disturbances, undercutting, wave/wind induced)

Existing shoreline structures and shoreline type (e.g. seawall, bulkhead, rubble, vegetation, pipes, dock, kayak access, etc.)

Wind exposure (approximate distance and direction that shoreline faces)

Prevailing winds at time of assessment

Energy intensity ☐ Low ☐ Medium ☐ High

Nearshore (1 m off shoreline) water depth

Tidal fluctuation Tide at time of assessment

Boating activity

- ☐ None or paddlecraft only
- ☐ Minimal (occasional small, motorized watercraft)
- ☐ Moderate (regular traffic, small and large motorized watercraft)
- ☐ Heavy (regular traffic including yachts, commercial vessels, tugs, barges)

Proximity to navigational channel

Safety considerations

UPLAND FACTORS

Existing bank height and slope

Sources of freshwater runoff/outfall

Sediment (e.g. sandy, peat, clay, organics, etc)

ECOLOGICAL FACTORS

Oysters present? Yes / No Attached to:

Submerged aquatic vegetation? Yes / No

Shorebird usage? ☐ Feeding ☐ Nesting ☐ Loafing ☐ Other

Existing vegetation—native and exotic, upland and wetland:

Water quality/salinity

Nearby sources of freshwater

Approximate wetland acres to be affected

Appropriate Conditions for Various Living Shoreline Approaches

	Marsh Sill	Breakwater	Revetment	Living Reef	Reef Balls
System Parameters					
Erosion History	***Low-Med***	***Med-High***	***Med-High***	***Low-Med***	***Low-Med***
Relative Sea Level	Low-Mod	Low-High	***Low-High***	Low-Mod	Low-Mod
Tidal Range	***Low-Mod***	Low-High	Low-High	***Low-Mod***	Low-Mod
Hydrodynamic Parameters					
Wind Waves	***Low-Mod***	***High***	***Mod-High***	***Low-Mod***	***Low-Mod***
Wakes	***Low-Mod***	***High***	***Mod-High***	***Low-Mod***	***Low-Mod***
Currents	Low-Mod	Low-Mod	Low-High	Low-Mod	Low-Mod
Ice	***Low***	***Low-Mod***	***Low-High***	***Low***	Low-Mod
Storm Surge	Low-High	***Low-High***	***Low-High***	Low-High	Low-High
Terrestrial Parameters					
Upland Slope	Mild-Steep	Mild-Steep	***Mild-Steep***	Mild-Steep	Mild-Steep
Shoreline Slope	***Mild-Mod***	***Mild-Steep***	**Mild-Steep**	***Mild-Mod***	Mild-Steep
Width	***Mod-High***	***Mod-High***	Low-High	***Mod-High***	***Mod-High***
Nearshore Slope	***Mild-Mod***	***Mild-Mod***	Mild-Steep	***Mild-Mod***	***Mild-Mod***
Offshore Depth	Shallow-Mod	Mod-Deep	Shallow-Deep	Shallow-Mod	Shallow-Mod
Soil Bearing	Mod-High	***High***	***Mod-High***	Mod-High	***Mod-High***
Ecological Parameters					
Water Quality	Poor-Good	Poor-Good	Poor-Good	***Good***	***Poor-Good***
Soil Type	***Any***	Any	Any	Any	Any
Sunlight Exposure	***Mod-High***	Low-High	Low-High	Mod-High	Low-High

From ***Living Shorelines Engineering Guidelines***, Prepared for New Jersey Department of Environmental Protection, February 2016

Resources such as this one from New Jersey Department of Environmental Protection may provide useful guidance on how to assess conditions for various living shoreline approaches. However, this should be viewed as general guidance, since every site is unique and more than one approach may be appropriate or successful.

Field Visit/Site Assessment

Land/ Water Interface:

- Source of erosion (i.e., boat wakes, storms, etc.)
- Severity of erosion
- Existing bank and shoreline conditions (i.e., height, soils, scarping, etc.)
- Slope
- Shoreline orientation, topography, bathymetry
- Location of existing structures and shoreline modifications
- Existing condition/presence of sandy beach, wetlands, SAV, riparian zones
- Shoreline type, associated habitats, and ecosystem functions
  - -Water quality
  - -Soils
  - -Buffers, sunlight

Photo: North Carolina Coastal Federation

Field Visit/Site Assessment

Hydrodynamics include:
- Storm waves
- Boat wakes
- Currents (velocity/direction)
- Potential storm surge
- Stormwater runoff effects
- Tidal effects

Photo: North Carolina Coastal Federation

Evaluating the hydrodynamic effects at a site involves understanding both the forces that occur from the water side (storm surge, waves, tides, currents, etc.) and effects that occur from land-based forces (ie. concentrated flow from runoff, oversteepened banks, etc.)

Field Visit/Site Assessment

Space limitations and land uses

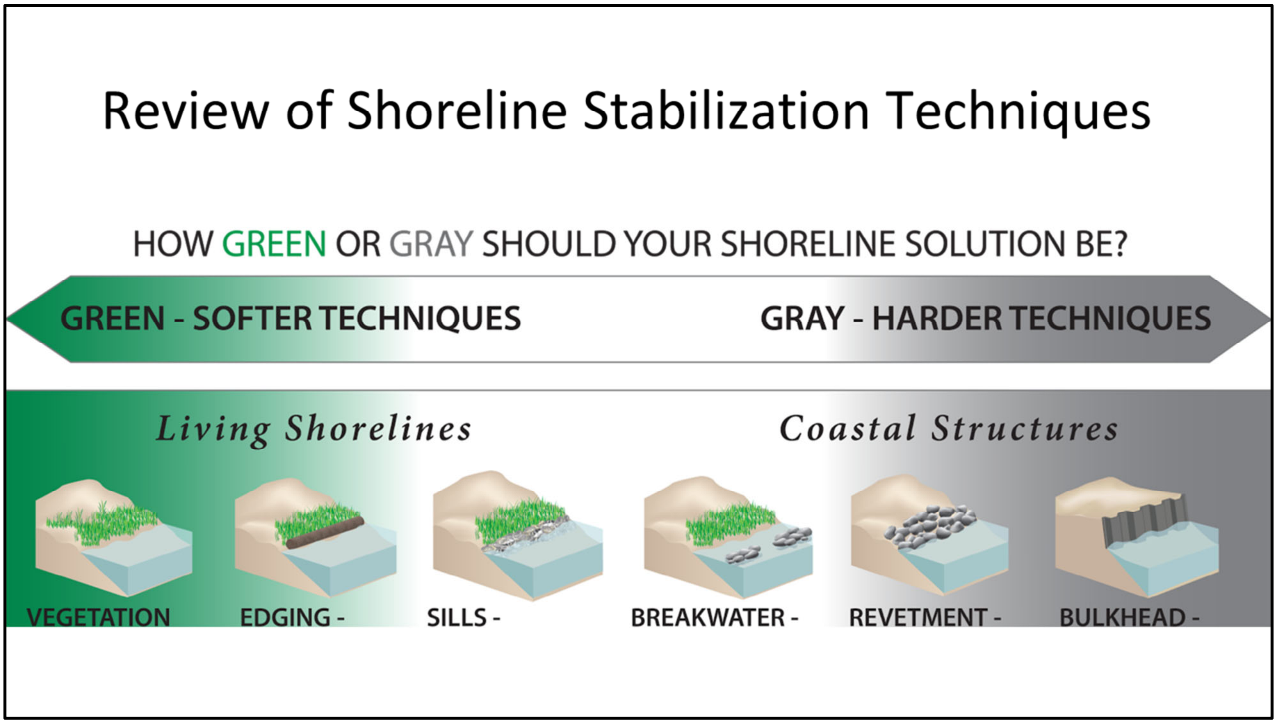
- Can we re-grade upland?
- Do we protect existing or restore lost marsh?
- Do we need to extend the shoreline into the waterway?
- What are the adjacent land uses and structures?
- How close are the existing/future structures?
- Do we have proper access for construction equipment?
- Are there other erosion control structures on the property or nearby?

Photo: North Carolina Coastal Federation

Additional Resources for Site Assessment & Design:

- **Living Shoreline Design Guidelines for Shore Protection in Virginia's Estuarine Environments.** Virginia Institute of Marine Science (VIMS), 2010. An excellent resource for marine professionals wanting more extensive information on the design of living shoreline projects. https://www.vims.edu/research/departments/physical/programs/ssp/_docs/living_shorelines_guidelines.pdf
- **The Living Shoreline Academy (website).** Provides many references and resources for property owners and professionals, including training modules tools for site assessment and design of living shorelines. livingshorelinesacademy.org
- The Center for Coastal Resources Management (Part of VIMS) has developed an **online course to educate shoreline project designers and contractors about the use of living shoreline designs.** The course stresses the reasoning behind the recommended design criteria and the interactions between upland riparian zones, wetlands and the aquatic system – three areas that are functionally integrated and tend to be impacted by shoreline projects. http://ccrm.vims.edu/education/ls_design_class/
- **Living Shorelines Engineering Guidelines.** Stevens Institute of Technology; Davidson Laboratory. Prepared for New Jersey DEP, February 2016. https://www.nj.gov/dep/cmp/docs/living-shorelines-engineering-guidelines-final.pdf


Module 2.2 Site Design Options



Many eroding shorelines could be stabilized using one of a number of erosion control strategies. They range from vegetation, or softer techniques, to shorelines protected by engineered structures, such as sills, revetments, and bulkheads. Living shorelines can be adapted to most shoreline types and energy levels, combining native plantings with structural elements where needed.

A good resource for considering different options is the "Systems Approach to Geomorphic Engineering" or "SAGE" website: http://sagecoast.org/. The SAGE brochure (in your packets) highlights the different levels of "green" and "gray." The highlights include:

- Structural options for various environments and site conditions
- Material options
- Benefits
- Disadvantages

It also indicates price ranges for initial construction costs as well as the operations and maintenance costs. It is available online to print and distribute to your staff and/or clients.

Hierarchy of Erosion Control Options

Photo: by North Carolina Coastal Federation

- No Action
- Relocation of Threatened Structures
- Non-Structural Stabilization Measures
- Combination Approaches
- Hardening Structures

- No Action
- Relocation of Threatened Structures

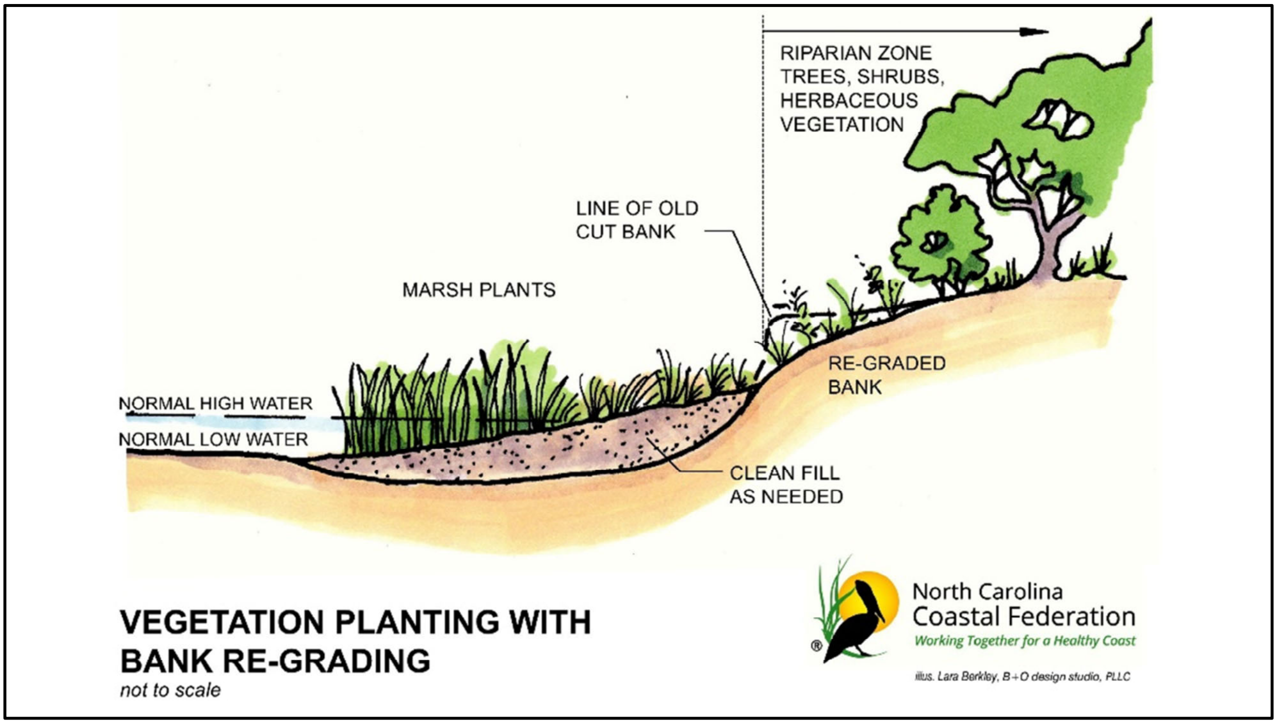
- Non-Structural Stabilization Measures - includes slope grading, marsh creation, native plantings, and beach nourishment
- Combination Approaches - includes sills, oyster reefs, stone containment cells, breakwaters with plantings
- Hardening Structures includes groins, revetments, gabions, and bulkheads

Some strategies can provide adequate upland protection, but may result in loss of valuable estuarine ecosystems, in either the short or long term. The process of designing living shoreline projects involves the evaluation of each site to determine the best approach for erosion control that also protects, enhances, or restores the natural estuarine environment. This is critical for maintaining the shoreline's ecosystem services, including preserving good water quality and fish habitat, and providing nutrient cycling, and carbon sequestration.

Beach Nourishment at Cape Lookout Lighthouse

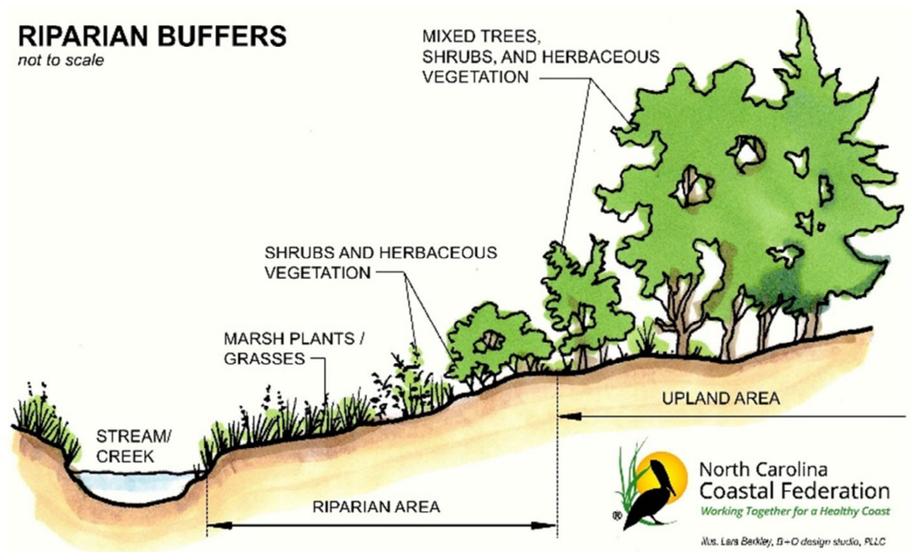
Photo: North Carolina Coastal Federation

In some very specific sites, the addition of clean beach sand may be the preferable choice to address shoreline erosion and potential loss of property. These sites would include areas which were historically characterized by sandy beaches, without marsh fringes, oyster reefs or submerged aquatic vegetation (SAV), or seagrass. The nourishment of the beaches does nothing to change the sources of erosion, but it can “buy time” by moving the shoreline offshore of its current location.

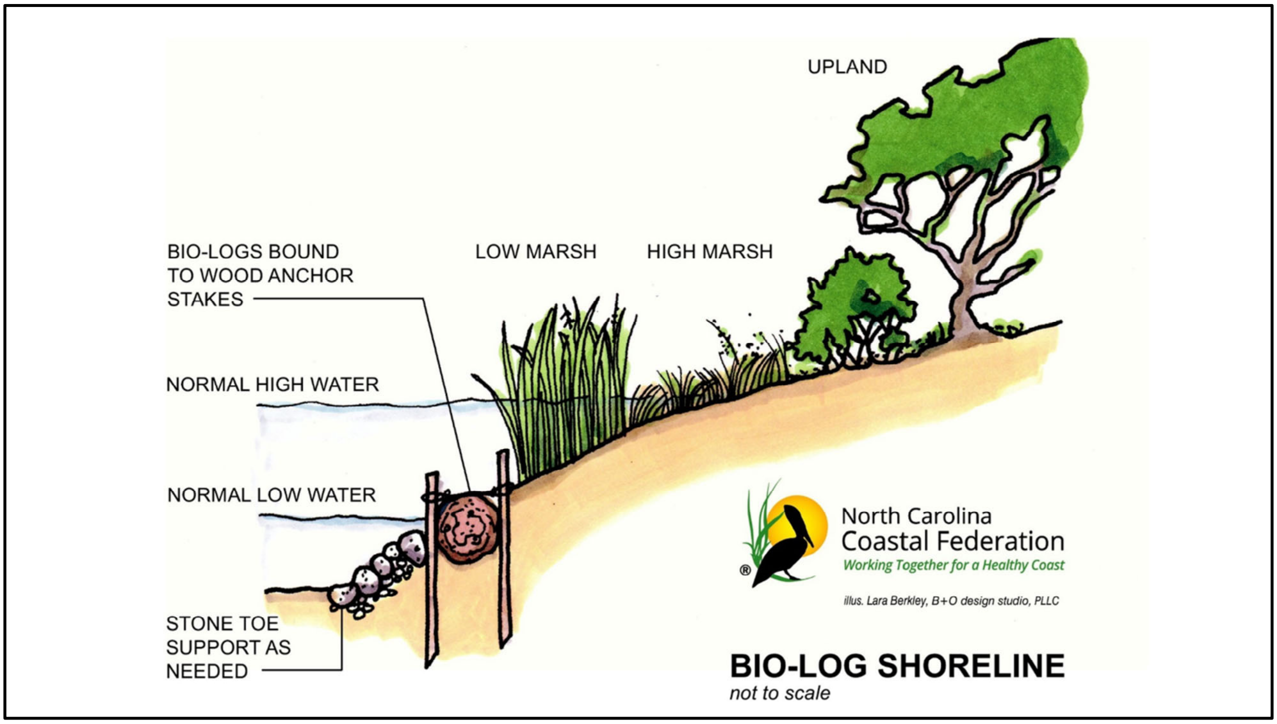


For lower energy regimes, the easiest and least expensive option is often re-grading the eroded slope and planting with native vegetation, such as marsh and/or dune grasses. However, for any eroding shoreline, the predicted energy levels and the cause of the erosion must be addressed (e.g. minimum wake zone enacted or wave energy protection installed) before selecting re-grading and/or plantings as the preferred approach along the shoreline.

Riparian Buffer Restoration with Marsh Creation



In many locations, it is possible to restore or protect both the lower elevation zones and the upland, often forested buffers. The connection of these two areas is critical habitat for many estuarine species, but it is also very effective in reducing flooding and erosion from stormwater runoff and from high water surges and waves associated with hurricanes and other coastal storms.



In areas with minimal to moderate wave energy, plantings with temporary protection, in the form of coconut fiber logs (often called biologs) can provide temporary protection while the plants are growing. This approach works best in brackish and freshwater areas, but can be successful in saltwater environments. To extend the life of the logs and the upper energy threshold for application of this technique, a small amount of stone can be used as toe protection channelward of the line of biologs.

Plants with Biologs

- Works in areas with minimal wave energy
- Can be combined with other measures
- Biologs provide temporary protection for juvenile plants
- Need initial monitoring and minimal maintenance to ensure plants are growing

Photo: Chesapeake Bay Foundation Staff (cbf.org)

In most cases, biologs are designed to provide energy dissipation for up to 18 months, which should allow the plants the time necessary to become established. These applications do need initial monitoring and potentially some maintenance to ensure that the plants are growing and expanding as anticipated, and the structure remains intact.

Plants with FibreCoir® Logs (Biologs)

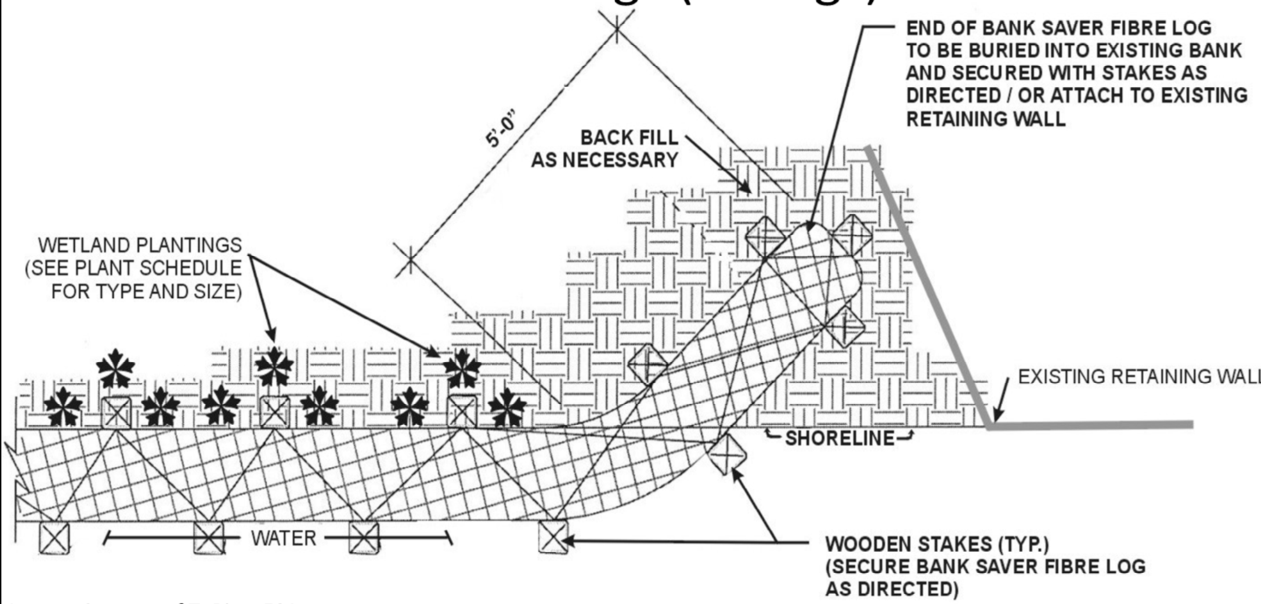


Image: Coutesy of T. Ries, ESA

Plants with Biologs

Photo: North Carolina Coastal Federation

Biologs can be placed in succession to create a terraced effect, which can provide better stability for properties with steeper banks.

Plants with Biologs

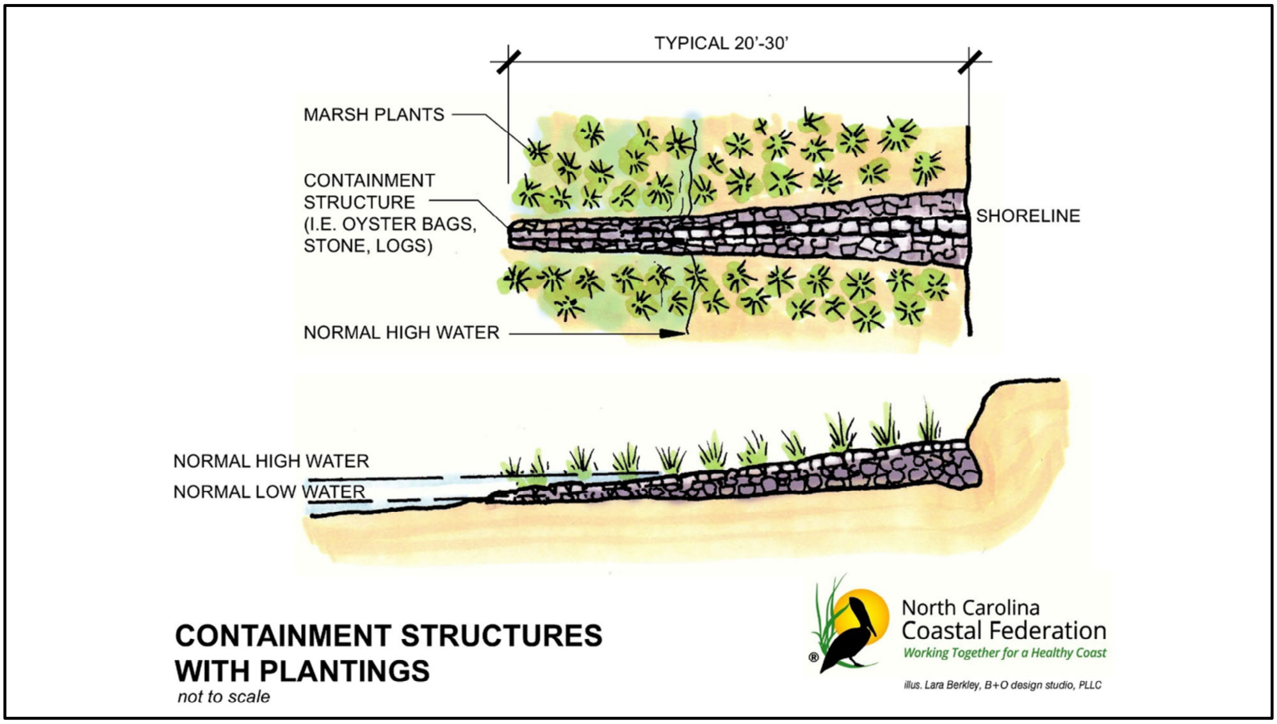
Photo: North Carolina Coastal Federation

After ~18 mos, the biologs remain in place, and the banks planted with native marsh and other coastal plants have become well established, providing excellent erosion control and maintaining the benefits of a natural shoreline.

Combination or Hybrid Projects

Photo: North Carolina Coastal Federation

As energy levels and the resultant potential for erosion increases, so might the need to design projects that include both structural and non-structural elements. There are many design options for these “hybrid” living shoreline projects, however, all living shoreline projects should include some vegetation, which is either existing, restored, or enhanced.



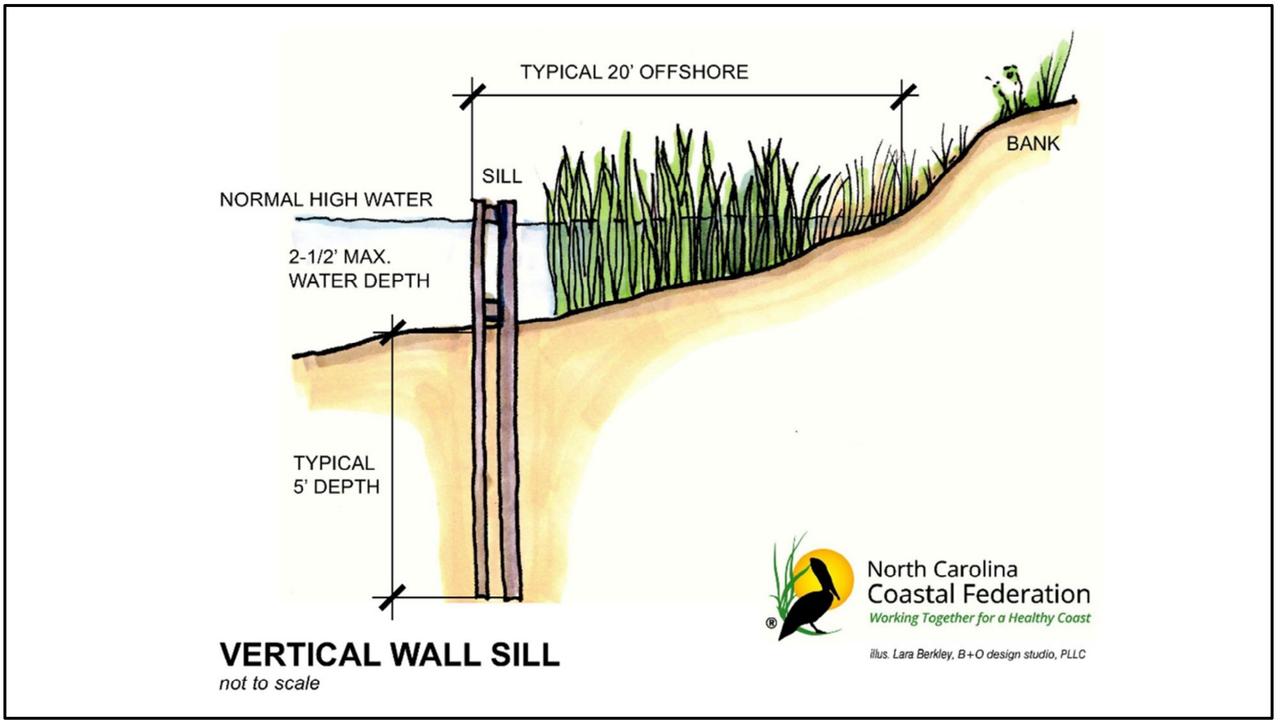
For fetch-limited settings where the forces of erosion energy may be due to boat wakes and alongshore currents, the use of stone containment structures with marsh plantings can be a successful approach. The containment structures slow the alongshore energy and hold the existing soil in place until the marsh can become established. This approach provides great access for fishes and other animals who rely on marsh habitats for their survival.

Stone Containment Structures

Stone Containment Structure

Stone Containment Structure

At this relatively narrow tidal creek site in Maryland, an eroded, oversteepened bank was re-graded to establish a suitable shoreline for marsh restoration, which included the placement of stone containment structures to hold the soil in place, giving stability to the shoreline until the marshes became established and mature.



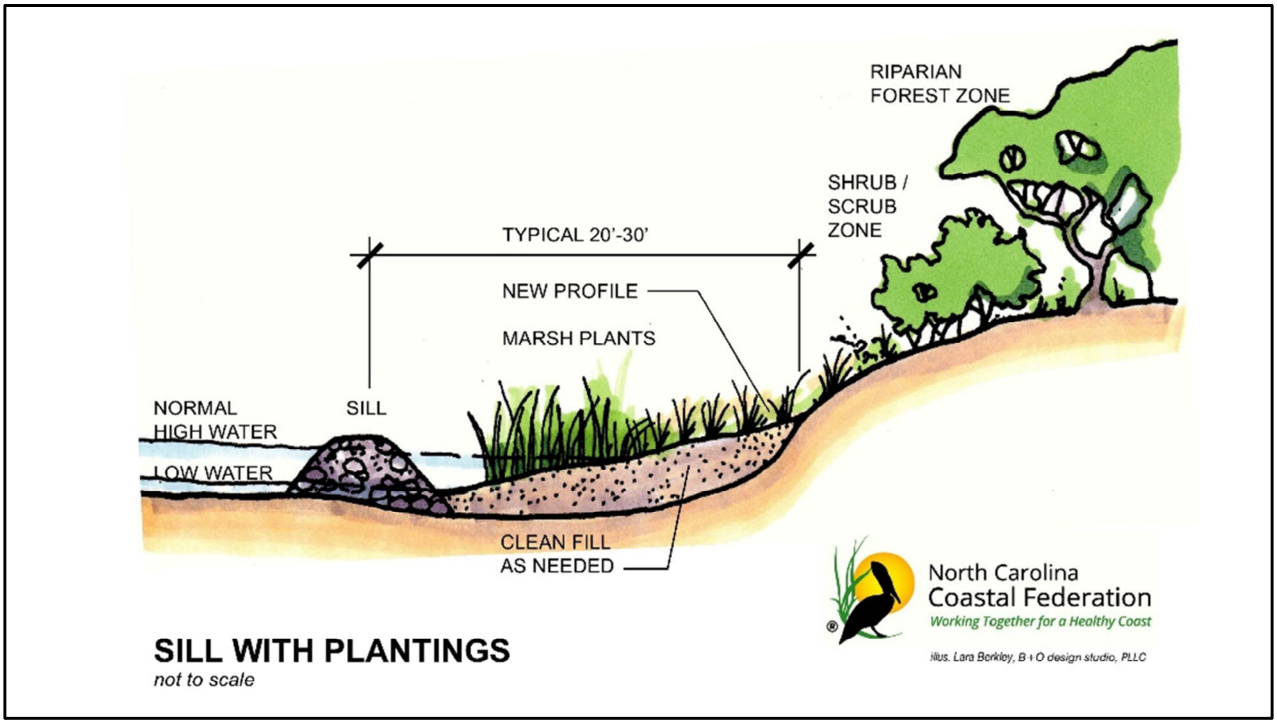
Unlike bulkheads and revetments, sills are designed to be placed channelward of the existing or restored marsh and shallow intertidal zones, providing both erosion control and a resilient estuarine ecosystem. Vertical wall sills are often a great option adjacent to narrow channels, where oysters or other shellfish exist, and where access to the site may be limited for equipment. They are most often constructed as gapped wooden or vinyl structures.

Vertical wall sills are designed to allow some water to pass through the structure, while still dissipating wave and current energy. As with any piling supported structure placed in estuarine conditions, it is critical to design and size the structure to withstand the expected energy forces at that site.

Vertical Wall Sills

Photo: North Carolina Coastal Federation

This vertical wall sill is constructed along a relatively high energy site adjacent to Albemarle Sound near Nags Head. The construction materials are wood, and the design encouraged the protection of the shoreline and the restoration of a sandy shoreline and marsh fringe (primarily black needlerush) and riparian buffer.



For certain moderate to higher energy sites, stone sills may be the best design option to ensure adequate erosion control and long term resilience. These trapezoidal shaped structures break down wave energy from storms or boat wakes, but are pervious, allowing waters to flow through and over them at higher tides, which sustains the landward marsh. Longer structures often have constructed gaps, that allow for better fish passage around and through the sills.

Stone Sills with Marsh Plantings

Columbia, North Carolina (Albemarle Sound)

Pivers Island, Beaufort, North Carolina
(Beaufort Channel)

Photo: North Carolina Coastal Federation

Stone Sills with Marsh Plantings

Photo: North Carolina Coastal Federation

Stone Sills with Marsh Plantings/Riparian Buffer

Photo: North Carolina Coastal Federation

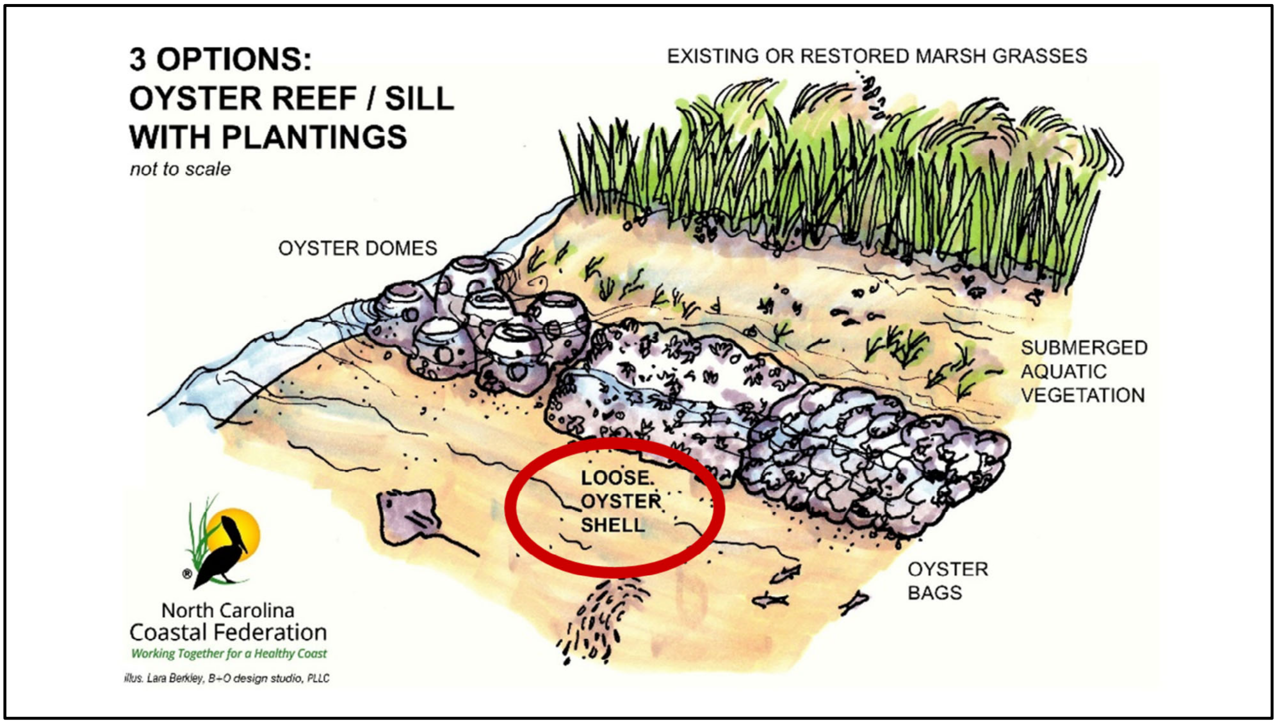
Stone sills are effective for higher energy sites in both saltwater and freshwater environments. Sill projects can often be designed to allow for a shallow unvegetated zones, marsh plantings, and adjacent buffers of upland grasses, shrubs, and trees. This project is located on the Chowan River at the state wildlife boat ramp located at the base of the bridge in Edenton, NC. The project involved removal of a failing bulkhead, re-grading of the bank, construction of a stone sill, and planting of freshwater wetlands plants, shrubs and native trees.

Stone Sills with Marsh Plantings

November 2020

Photo: North Carolina Coastal Federation

The project is continuing to thrive and provide excellent shoreline stabilization, as seen in these photos from November 2020.



In areas of North Carolina’s estuaries where oysters grow naturally, but may be limited by lack of structures on which to attach, loose oyster shells, or bagged oyster shell reefs may be a great living shoreline option. Recycled and bagged oyster shells can be stacked in various ways to create a sill structure, which provides shoreline stabilization and a reef structure for new oyster settlement and growth. As with all living shoreline structures, marshes are a critical component of this approach.

In selecting this living shoreline option, it is critical to ensure that oysters are naturally occurring in the area. Varying salinities, water circulation and sedimentation are key factors in the successful growth of oysters on constructed oyster sills or mounds.

Oyster Shell Patch Reefs & Sills

Photo: North Carolina Coastal Federation

Loose Oyster Shell Methods- Morris Landing, NC

Loose oyster shell sills during construction

Loose oyster shell sill after Hurricane Matthew

Photo: North Carolina Coastal Federation

Photo: L. A. Jansen

Where conditions are appropriate (eg. lower energy, low boat wakes, firm bottoms, naturally occurring oyster reefs) loose oyster shell patch reefs can be “hand” placed or washed into place using commercial water jet systems. It is critical to design and place the shell to closely mimic the natural oyster reefs in the area.

With loose oyster shell sills/reefs, the material is often “overbuilt” which allows for waves, tides and currents to redistribute the material into a more natural, sustainable structure. During Hurricane Matthew, some loose shell was lost into the marsh, but the overall structure was maintained and functioning adjacent to the tidal marsh.

Living Shorelines with Oyster Domes

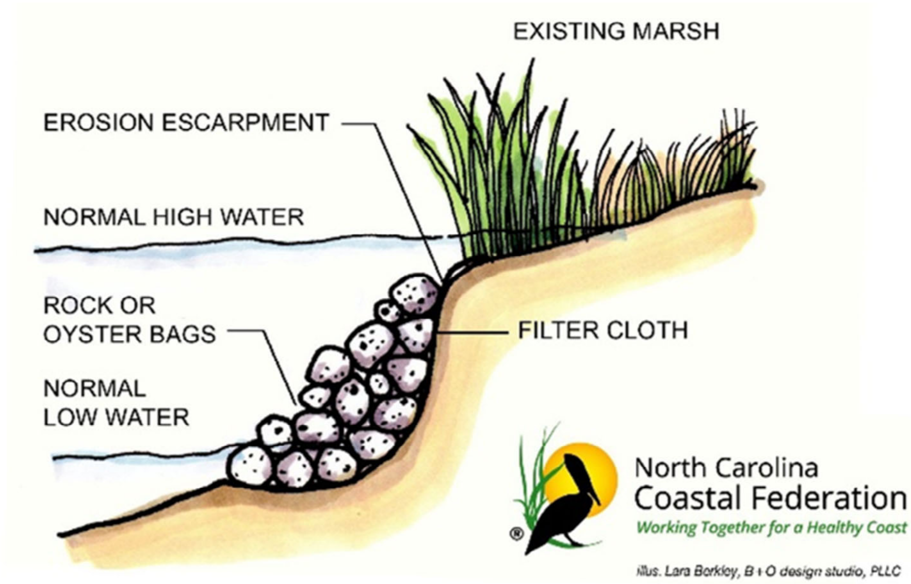
Photo: North Carolina Coastal Federation

In many areas of the country, the use of prefabricated pre-cast oyster domes have been used as a successful erosion control and oyster reef restoration projects. They can be placed in a variety of designs and alignments. For this design, it is important to understand the natural oyster growing ranges for each site, and place them accordingly to ensure maximum oyster establishment.

Oyster domes are sold commercially and available regionally throughout the United States. Some organizations, such as the non-profit conservation organization Tampa Bay Watch (https://tampabaywatch.org/) have built forms to create oyster domes with volunteer or student assistance.

Living Shorelines with Oyster Domes

Photo: North Carolina Coastal Federation



MARSH TOE REVETMENT
not to scale

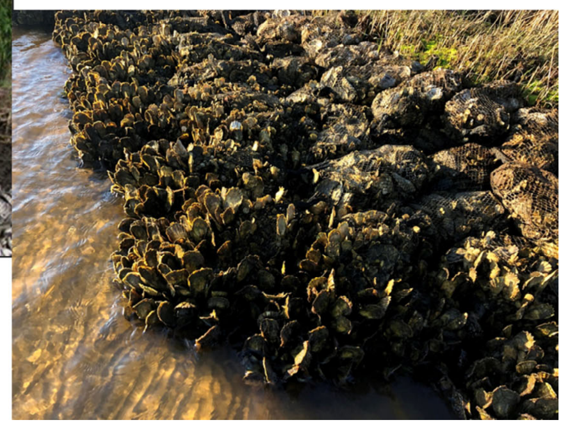
Similar in function and relative design to sills, marsh toe revetments can provide excellent erosion control and oyster reef restoration. These structures are placed directly adjacent to the scarped edges of eroding marshes, and are designed with a maximum crest elevation of 0.5' above the existing marsh grades.

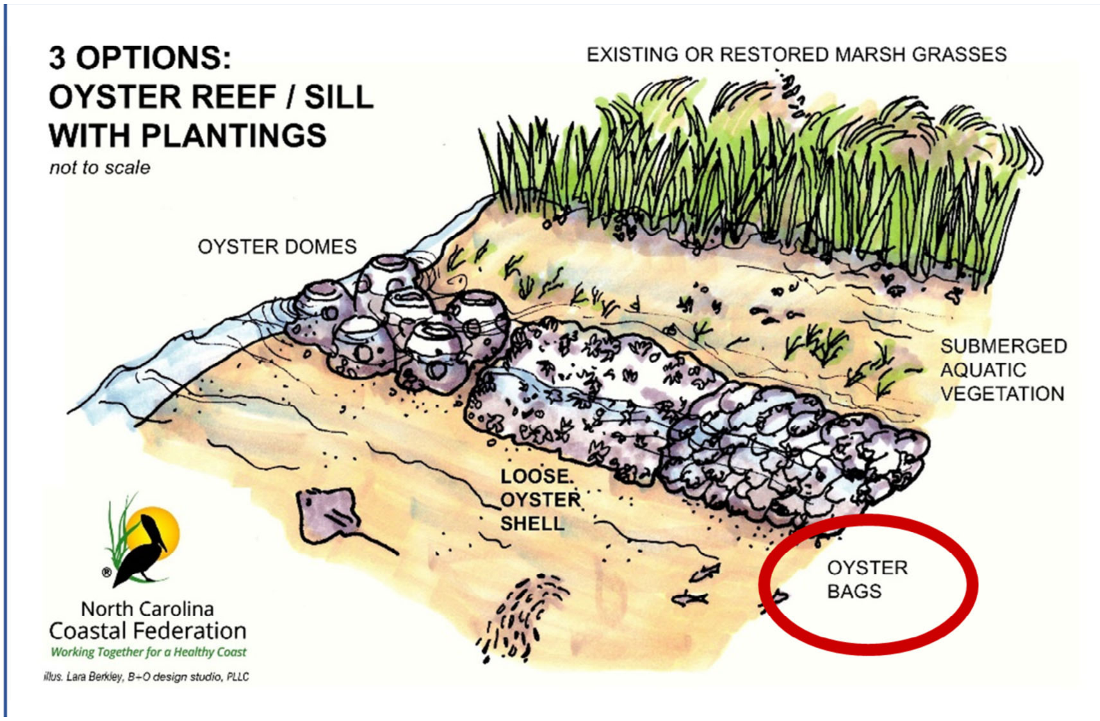
Marsh Toe Revetments

Photo: North Carolina Coastal Federation

Marsh Toe Revetments

Photo: North Carolina Coastal Federation





Bagged oyster shells can be used to create full sized sill structures. Depending on site conditions, energy levels, and natural oyster growing ranges, the elevations and dimensions of the structure can be highly variable. In addition, bagged marl is often used as base layers, over which bagged oyster shells can be placed, as oyster shell is a limited resource. Design details will be provided in Module 3.

Oyster Shell Bag Sills

Photo: North Carolina Coastal Federation

Oyster Shell Bag Sills at Jones Island

Before

Photo: North Carolina Coastal Federation

After

At Jones Island, an island located in the White Oak River, over 1,350 linear feet of oyster shell bag sills have been used to stabilize eroding shorelines. The first created sill was 150 linear feet long by about 4 feet wide and was built in one day by over 65 volunteers that were recruited by the local public radio station. As you can see, this sill has been very successful in stabilizing the shoreline and marshes, and creating a thriving oyster reef in the White Oak River.

Oyster Shell Bag Sills at Jones Island

Photo: North Carolina Coastal Federation

The left photo shows oyster bags shortly after placing them in the water. The right photo is of the same oyster bag sill after two years. After two years you can barely see the mesh bags and new oysters have settled on the bagged shell. Many organisms including stone crabs, mud crabs, hermit crabs, worms, sea squirts, mussels, clams, barnacles, and a variety of fish have also taken residence in and around the sill.

Innovative Materials Sills and Hybrid Designs

“Oyster Catcher™” from Sandbar Oyster Company

“Oyster Castles® from Allied Concrete alliedconcrete.com

There is a great deal of innovation in living shoreline design, with new businesses, products and designs emerging throughout the United States. These represent two of the innovative living shoreline designs currently in use in North Carolina. Many of these design approaches are adaptable to a range of energy, erosion and substrate conditions.

Bulkhead & Rip-Rap Revetment Enhancement Projects

- Bulkhead or revetment enhancement projects can be utilized when existing structures are already in place or if there are infrastructure conflicts
- Elements such as rip-rap, marsh plantings, or other shoreline plants can provide wave dissipation and habitat
- These features can mitigate the effects of erosion on the existing structures and extend the life of the structure

Photo: North Carolina Coastal Federation

Bulkheads will always exist due to the location of some existing structures or infrastructure, property owner preferences, the limitations of existing bulkheads along man made canals, or other circumstances. In those cases, bulkhead enhancement projects may provide an option to dissipate wave and current energy, which can extend the life of the wall and provide habitat and water quality benefits. There are numerous design options, from placing rip-rap at the toe of the wall to prevent scour to construction of sills placed waterward of restored or existing marsh.


Module 2.3 Permitting

North Carolina Living Shoreline Permitting

Tara MacPherson
District Manager
Wilmington Regional Office

Division of Coastal Management

Marsh Sills (Living Shorelines)

~Constructed out of sloping riprap stone including granite, marl, oyster shell or broken concrete

~Placed offshore and parallel to shore to reduce wave energy to protect existing and or newly planted wetland/marsh grasses.

Marsh Sills are defined for permitting reasons as wetland enhancement and shoreline stabilization in estuarine and public trust waters. They are shore-parallel structures built in conjunction with existing, created or restored wetlands.

Division of
Coastal Management

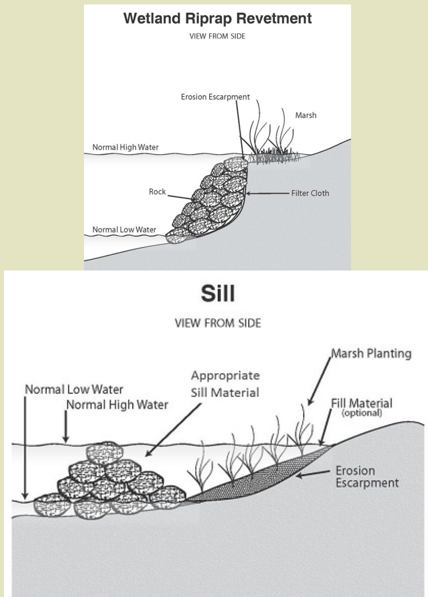
Shoreline Stabilization Permitting

General Permits (GPs): issued by DCM field staff and are streamlined major permits for routine projects. GP 7H .2700

Major permits: reviewed by 10 state & 4 federal agencies and are issued at the Division headquarters (permit issuance averages 75-90 days).

If the proposed project exceeds the specific conditions of the General Permit, it will be elevated to a Major Permit for Review.

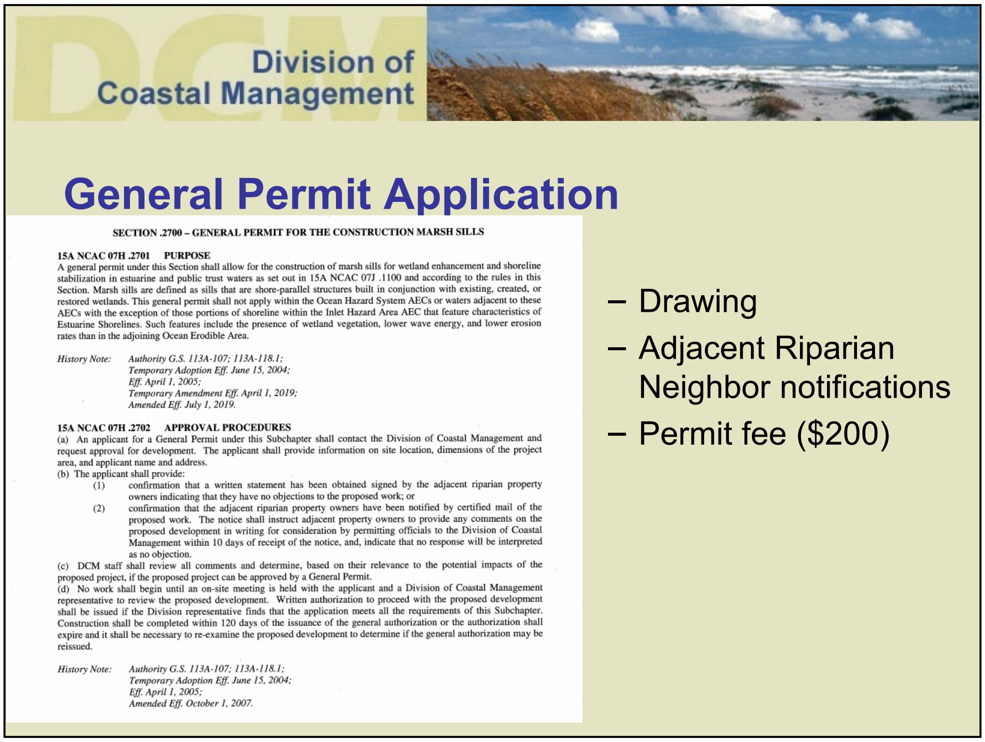
Division of Coastal Management



- Two Types of General Permits
  - Riprap revetment for Wetland Protection GP (.2400)
  - Marsh Sill for Wetland Enhancement GP (.2700) – **AKA Living Shoreline GP**

The Riprap Revetment is for marsh protection and must be installed immediately adjacent to and waterward of the wetland toe. The escarpment must not be great than 3 ft.

The Marsh Sill is installed waterward of the existing or marsh or shoreline and is planted. If backfill is required, this would be elevated to a major permit.



A field representative will conduct a site visit and review the submitted proposal to make sure it qualifies for a General Permit (GP). The permit drawings will be sent to both adjacent riparian property owners via certified mail. If the proposed sill is within 15 ft. of an adjacent riparian line a waiver will be required. The permit fee is submitted with the notifications and drawings. The permit is good for 120 days from issuance.

Division of
Coastal Management

General Permit for Living Shorelines

- Limited to 30’ past normal high water or 5’ past existing wetlands, whichever is greater
- Cannot exceed 1’ above normal high water
- Slope cannot exceed 1.5’ horizontal distance over a 1’ vertical rise
- Max length 500’ with a 5’ openings every 100’, max base width of 12’
- Must be marked for navigational purposes
- Cannot construct over existing SAV or oyster beds
- **NO ASSOCIATED BACKFILL**

Division of
Coastal Management

General Permit for Living Shorelines

- USACE Regional General Permit for Marsh Sills became effective March 2019
- In turn, the DCM Living Shoreline GP became effective April 1, 2019

This streamlined GP is consistent with other GPs for shoreline stabilization and does not require further agency coordination if GP Special Conditions are met.

Division of
Coastal Management

Major Permit
used for Living Shorelines that don't meet GP

- Reviewed by 10 state & 4 federal agencies
- Permit issuance averages 75 days but can be issued within 30-45 days
- Application Requirements:

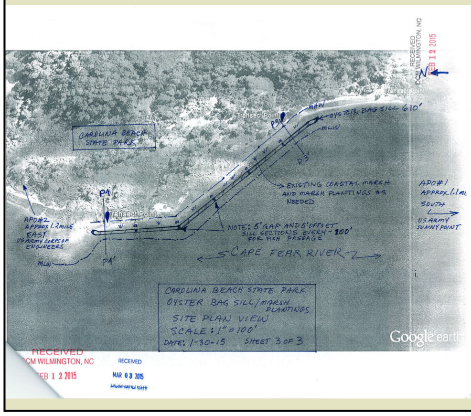
  Adjacent Property owner notification
  Deed (or other legal instrument)
  Top view drawing
  Cross section drawing
  Application forms (MP-1 and MP-2)
  $400.00 permit fee

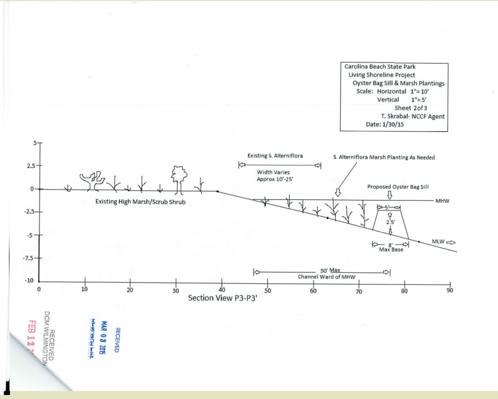
DCM provides coordination with other agencies on behalf of the applicant.

Division of Coastal Management

Major Permit Drawings

- Do not require surveyed or engineered drawings and can be hand drawn but must be to **SCALE**!





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Quick tips for expedited applications

- Discuss Navigational impacts
- Propose Marking (reflectors)
- Review possible submerged aquatic vegetation (SAV) impacts
- Discss oyster growing potential
- Review if area is Open or closed to shellfish
- Determine bottom type (mud or sand bottom)
- Propose gaps for marine animal movement

For questions about living shoreline permitting, contact your NC Division of Coastal Management field representative.

You can find your field representative at:

https://deq.nc.gov/about/divisions/coastal-management/about-coastal-management/staff-listing

IMPLEMENTATION

Module Three

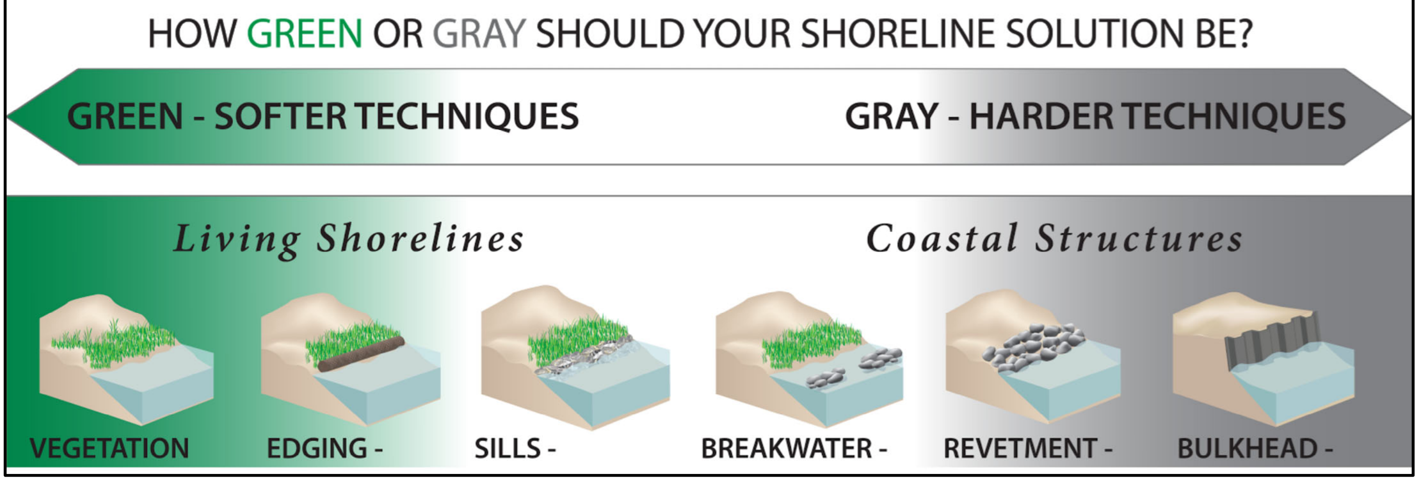
Constructing Living Shorelines:

- Planted marsh/buffers
- Shell bag sill
- Marsh revetment
- Stone sill
- Vertical sill

Module Objectives - Training participants will be able to:

- Understand how to implement non-structural (grading, vegetation) and hybrid (structural, vegetation) living shoreline projects; and
- Understand sources and process of securing materials, as well as equipment needs for living shoreline projects.

Implementation of Living Shorelines: Options, Construction, Materials and Equipment



Depending on the project location and goals, there are many living shoreline designs that can be considered. These range from “gray” or hybrid techniques in areas of higher vulnerability to the “green” and softer techniques in lower energy environments.

Other alternatives that have been used in North Carolina include loose or bagged oyster shell, oyster domes, native limestone, granite, wood or vinyl sills, or any number of innovative, commercially-available pre-casted designs/structural alternatives. This module will provide more information about these approaches.

Living Shorelines With Marsh Plantings: Choose Appropriate Vegetation

- Geographic Location: sun tolerance, drought tolerance, salinity tolerance
- Zonation: low marsh, mid marsh, high marsh
- Plants: use only healthy, native plants with established, actively growing roots

Graphic courtesy Burke Environmental Associates

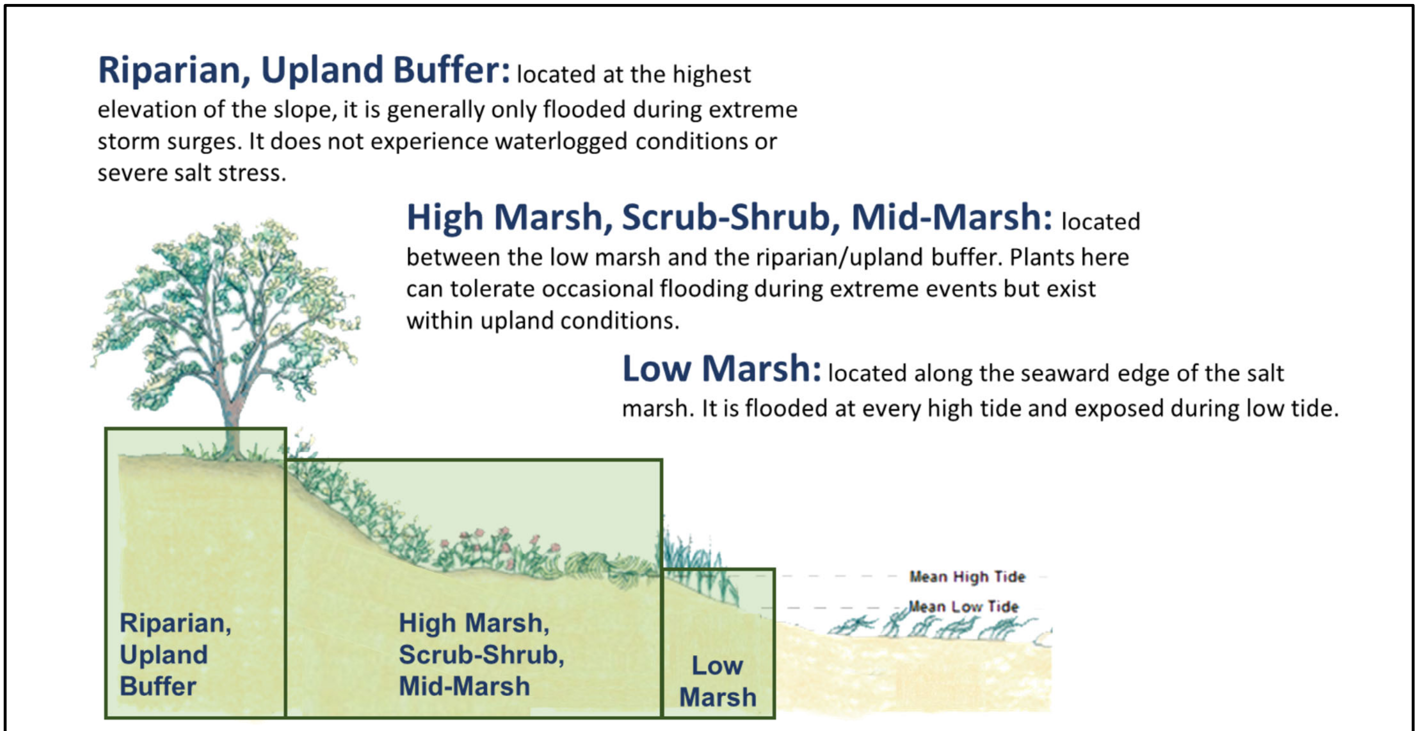
Use only native plants appropriate for the climate and conditions. Are the plants tolerant of full sun, partial sun, or shade? Are the plants drought tolerant? Can they be exposed to salinity for a length of time? The species selected should ideally be resilient and low maintenance. Plantings will be exposed to storms and experience saltwater or freshwater inundation, intense sunlight, and high winds. They must be able to adapt to drought and grow in sandy, nutrient poor soils.

Make sure that you are planting along the entire wetland-upland profile (graphic). The low marsh tidal zone occurs along the seaward edge of the salt marsh. It is flooded daily and usually exposed during low tide. In North Carolina, most saltwater marshes include smooth cordgrass and/or black needlerush species. In fresher marshes, you can find giant cutgrass or water millet, saw grass, arrow arum, or other swamp type freshwater species.

The mid- to high-marsh zone lies above the mean tide line. Plants that live here can tolerate flooding, although they prefer drier conditions. Species include: saltmeadow cordgrass, seashore saltgrass or spike grass, as well as sedges and rushes.

The high marsh zone is generally flooded only during above-average high tides. Plants that live here are adapted to avoid severe salt stress. Typical species include seaside asters, several species of panicum grasses, sea lavender, etc. Native shrubs such as yaupon holly, wax myrtle, and marsh elder (high tide bush) are found in this zone, and are effective for erosion control, storm resilience, and provide great habitat.

To ensure planting success, make sure you are using healthy, native plants with established, actively growing roots. Generally, it is recommended to plant in staggered rows with the plants about 1-3 feet apart, along the profile in the zone where the plants specific moisture/salinity requirements are met.



Modified from: http://ccrm.vims.edu/wetlands/livingshoreline_intro.html

In addition to a variety of salt- or freshwater-tolerant marsh plants, living shorelines can include the restoration or protection of riparian buffer vegetation, including native grasses, scrub-shrub plants and trees. The gradation between aquatic, marsh, and upland zones is important in providing erosion control, and in maintaining the estuarine ecosystem. In addition to the native shrubs already mentioned, trees such as bald cypress, live oaks, sand live oaks, pines, sweet gums, are found in the upland buffer.

Two good references for planting of estuarine and coastal species in North Carolina are *“Seacoast Plants of the Carolinas”,* Paul Hosier, University of North Carolina Press, 2018; and *“Common Plants of the Mid-Atlantic Coast”,* Gene Silberhorn, Johns Hopkins University Press, Rev. 1999.

Typical North Carolina Saltwater Marsh Plants

Spartina alterniflora
(smooth cordgrass)

Spartina patens
(saltmeadow cordgrass)

Juncus roemerianus
(black needlerush)

In North Carolina's saltwater marshes, three marsh grass species dominate the landscape, and are good choices for living shoreline projects.

Sporobolus alterniflorus, formerly known as *Spartina alterniflora* or smooth cordgrass, is an intertidal species that is planted below the high tide line, closer to the water. *Spartina patens*, or saltmeadow cordgrass grows above that high tide line. *Juncus roemerianus*, or black needle rush, grows close to the mean high water line.

Smooth cordgrass is most often planted along eroding, lower elevation living shoreline projects.

Common Shrubs and Trees Planted for Living Shorelines

Wax Myrtle

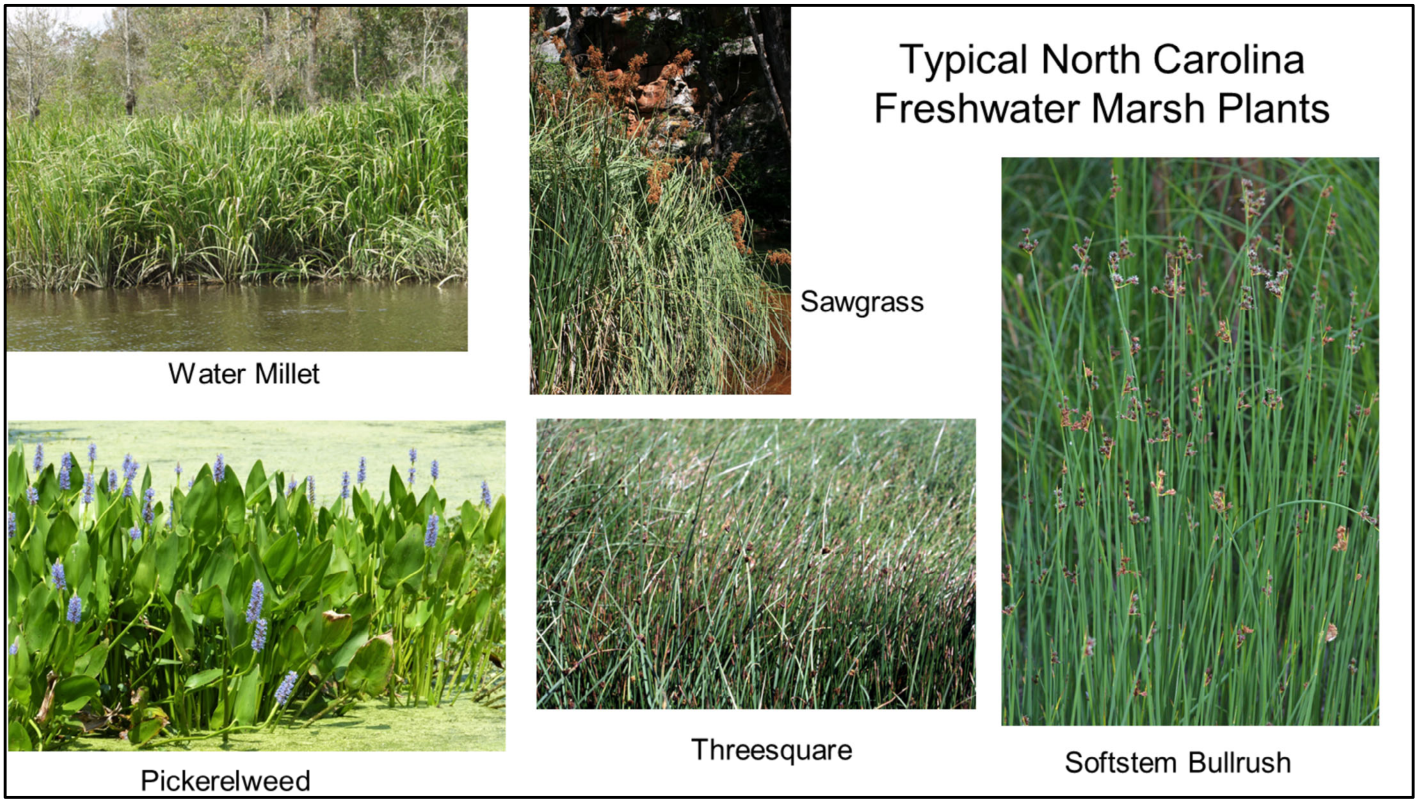
Marsh Elder

Bald Cypress

Yaupon Holly

Atlantic White Cedar

There are numerous native shrubs and trees that can be incorporated into living shoreline projects in both saltwater and freshwater environments. These species reduce flooding, stabilize soil, provide shade, maintain habitats, improve air and water quality, and offset the effects of climate change.



These freshwater marsh plants, along with several others, are available through commercial nurseries in North Carolina.

Plants for Living Shorelines in the Carolinas and Virginia

Brackish to seawater (Salinities of 5 to 35 parts per thousand or ppt)

Grasses that should make up at least 95% of the installed plants

- *Spartina alterniflora* (Smooth Cordgrass) between mid-tide and mean high tide
- *Spartina patens* (Saltmeadow Cordgrass) and/or *Distchlis spicata* (Saltgrass) between mean high tide and spring tide
- *Panicum amarum* (Bitter Panicum) above spring tide

A flower that can be used to add a bit of color

- *Borrichia frutescens* (Sea Oxeye) above mean high tide

Slightly brackish (Salinities 0.5 to 5 ppt)

Grasses that should make up at least 95% of the installed plants

- *Spartina alterniflora* (Smooth Cordgrass) between mid-tide and mean high tide, or in areas normally flooded by a few inches of water
- *Spartina cynosuroides* (Big Cordgrass) and/or *Juncus roemerianus* (Black Needlerush) between mean high tide and spring tide, or where soil is saturated but not normally inundated. Substitute Carex *hyalinolepis* (Shoreline Sedge) for shady areas.
- *Cladium mariscus spp. jamaicense* (Sawgrass) and *Spartina patens* (Saltmeadow Cordgrass) above mean high tide, or where soil is wet to moist but not normally flooded.
- *Panicum amarum* (Bitter Panicum) above spring tide, or where soil is only wet during storms in low nutrient sand
- *Panicum virgatum* (Switchgrass) above spring tide, or where soil is only wet during storms in richer soil

Flowers that can be used to add a bit of color

- *Hibiscus moscheutos* (Swamp Rosemallow) and *Kostelezkya virginica* (Saltmarsh Mallow) above mean high tide, or where soil is moist but not normally saturated

Freshwater

Grasses that should make up at least 95% of the installed plants

- *Zizaniopsis miliacea* (Water Millet) from wet soil to water up to 6” deep. Substitute *Carex hyalinolepis* (Shoreline Sedge) for shady areas.
- *Panicum virgatum* (Switchgrass) from moist to irregularly flooded areas. Substitute *Panicum amarum* (Bitter Panicum) if planting into low nutrient sand.

Flowers that can be used to add a bit of color, unless soil is low nutrient sand.

- *Hibiscus moscheutos* (Swamp Rosemallow) and *Kostelezkya virginica* (Saltmarsh Mallow) where soil is moist but not normally saturated.

Plants for Living Shorelines in the Carolinas and Virginia

Core Grasslike Species

Carex hyalinolepis (Shoreline Sedge)
- tolerates prolonged flooding of 3-6”
- <5 ppt salinity
- reserve for shady locations

Cladium mariscus spp. jamaicense (Sawgrass)
- above mean high tide
- <5 ppt salinity

Distchlis spicata (Saltgrass)
- between mean high tide and spring tide
- also high salinity wet depressions that are irregularly flooded
- tolerates full to hyper-salinity (up to 50 ppt)

Juncus roemerianus (Black Needlerush)
- between mean high tide and spring tide
- up to 25 ppt salinity.

Panicum amarum (Bitter Panicum)
- above spring tide
- tolerates full salinity (@35 ppt)
- performs well in dry or moist sterile sands as well as fertile sites

Panicum virgatum (Bitter Panicum)
- moist to dry soils
- <5 ppt salinity
- Needs fairly fertile soil

Spartina alterniflora (Smooth Cordgrass)
- between mid-tide and mean high tide
- tolerates full salinity (35 ppt)
- *Spartina alterniflora* is the ONLY salt marsh species that can be installed in areas that flood day after day

Spartina cynosuroides (Big Cordgrass)
- between mean high tide and spring tide
- up to 10 ppt salinity

Spartina patens (Saltmeadow Cordgrass)
- between mean high tide and spring tide
- tolerates full salinity (@35 ppt)
- often found with *Distichlis* at the lower elevations of its range

Zizaniopsis miliacea (Water Millet)
- from wet soil to water up to 6” deep
- freshwater only

Flowers to use as Accents

Borrichia frutescens (Sea Oxeye)
- mean high tide to upland
- tolerates full salinity (35 ppt)

Hibiscus moscheutos (Swamp Rose Mallow)
- above mean high tide
- <5 ppt salinity

Kosteletzkya virginica (Saltmarsh Mallow)
- above mean high tide
- <5 ppt salinity

Ordering and Planting Times

- Order in fall
- Plant in April-June
- Plant in spring for 2-3 years
- Trays or boxes
- Trim - “Haircut”
- Grow them in a greenhouse

The first step is to order your salt marsh plugs from nurseries. I am always asked if you can harvest them from other marshes and transplant them? Or maybe my neighbor could spare some? No, they cannot be harvested from other places and transplanted because they are wetland plants in areas of environmental concern and as such they are protected and regulated by the Coastal Area Management Act also known as CAMA. You don’t need a permit to just plant marsh grass from commercially grown nurseries.

Orders need to be placed with nurseries in the fall, September to October, as this is when the smooth cordgrass put out their seeds. The growers collect the seeds in the field, place them in the refrigerator until about February, then they are planted in soil in trays, and grown in a greenhouse. They are usually ready to plant in April and May, which is the best time to plant, as it’s the start of the growing season. It is possible to plant marsh grasses during the summer months, however, this shortens the time they have to establish their roots and increases the chance that they will need to be replanted if there is a strong storm season in the fall.

Like establishing new turf, marsh plants need to be managed and watched until they become established. It is common that additional plants need to be planted in years two and three, until the marsh becomes well established.

When they are delivered, depending on the nursery, your plants will arrive in either trays of 50 or 75 plugs or in boxes of 250 plugs. There are pros and cons to each of these delivery methods. When they are delivered in trays, they take up more space, but you have more time to plant them because you can care for them until you are ready to plant. When they are delivered in boxes, they take up less space, but you must plant them right away or they begin to wither within a day since they are cramped in the boxes and cannot be watered easily.

Sometimes the plant stems are too tall and top heavy when they come from the nursery. If that is the case you can give them a “haircut” with yard clippers, cutting off just enough so that when you plant them, they will be standing straight and not flopping over.

If you have a greenhouse, you can also grow the plants yourself.

Nurseries that Grow Salt Marsh Plugs

- Garner's Landscaping, Tree Farm & Plant Stand, Newport
- Wetland Plants Inc., Edenton
- Mellow Marsh Farm, Inc., Siler City
- Lumber River Native Plants, Gibson
- Mercer Nursery, Lockwoods Folly
- Greenlands Farm, Bolivia, NC

Note: prices will vary due to weather, availability, demand, shipping costs, and market variability.

Plugs of smooth cordgrass currently cost between \$0.50 and \$1.00 per plug depending on delivery costs. Less commonly grown marsh plants, such as black needlerush plugs are typically more.

Here are just a few nurseries that grow the plugs in North Carolina or that can get them for you.

Marsh Grass Suppliers
Smooth Cordgrass (Spartina alterniflora), Saltmeadow Cordgrass (Spartina patens) and Black Needlerush (Juncus roemarianus)

***Carry only Smooth Cordgrass (Spartina alterniflora)**

Carolina Home & Garden
4778 Highway 24 East
Newport, NC 28570
252-393-9004
carolinahomegarden.com

*Coastal Transplants
1509 George II Hwy SE
Bolivia, NC 28422
910-512-2204
coastaltransplants.com

Garner's Landscaping & Plant Stand
173 Sam Garner Rd
Newport, NC 28570
252-241-1184
garnerslandscaping.com

Lumber River Native Plants
7000 Livingston Rd.
P.O. Box 42
Gibson, NC 28343
336-601-8787
ncnativeplants.com

Mellow Marsh Farm
1312 Woody Store Road
Siler City, NC 27344
919-742-1200
Fax: 919-742-1280
mellowmarshfarm.com

Sunshine Garden Market
1700 Live Oak St.
Beaufort, NC 28516
252-342-6335
sunshinegardenmarket.com

Wetland Plants Inc.
812 Drummonds Point Road
Edenton, NC 27932
252-482-5707
wetlandplantsinc.com

Williams Farm and Garden Center
1309 Old Cherry Point Rd.
New Bern, NC 28560
252-638-1983
williamsfarmandgardencenter.com

Out of State:

Aquatic Plants of Florida
8305 Wauchula Road
Myakka City, FL 34251
800-266-1272
941-378-2700
apofl.com

Environmental Concern Inc.
P.O. Box P
201 Boundary Lane
St. Michaels, MD 21663
410-745-9620
wetland.org

Pinelands Nursery & Supply
323 Island Road
Columbus, NJ 08022
609-291-9486
pinelandsnursery.com

Note: The Division of Coastal Management does not endorse the vendors listed above and is only providing resources for marsh grass.

Created by: NC Sea Grant Revised March 2017

When and Where to Plant

- Plant in April-June for 2-3 years.
- If planting an unvegetated area:
  - Smooth cordgrass - below high tide line
  - Salt meadow cordgrass and black needlerush- at/above high tide line
- If planting area with existing marsh grass, plant where that species is already present
- Plant close together and close to existing grass

Plant in the Spring, April-June, ideally for a few years to ensure plant establishment.

If you are putting in a sill, it is best to wait until the sill is in place before planting the marsh. This significantly increases plant survivability as they are protected by the sill.

If you are planting a shoreline that has no existing salt marsh grass, where would you plant each species? The easiest way is to follow the high tide line. You also don’t want to plant them too far into the water where they are submerged all the time.

If you are planting in an area where marsh grass is already present, that is a bit easier, you should plant at the elevation where that species is already growing.

If you can only afford a few plugs, say 300, do you plant them all along the shoreline to cover the area, or do you plant them closer together and closer to the grass that is present?

You want to plant them as close as possible to the existing grass and to each other, about 6-12 inches apart. They survive better when they are closer to each other, like safety in numbers. Over time, that patch will get spread and get bigger. The following year I would plant another 300 plugs close to those and over time you will be able to cover the shoreline as they spread naturally and as you plant more plugs.

If you had a few thousand plugs to plant, then you could cover more shoreline.

Dibble bars are commercially available. We get them from Forestry Supplier for about $40.

When sediment is dry during planting, we include approximately one tablespoon per plant of slow-release fertilizer in each hole. You can also plant in the water, but plant deep to ensure the plugs don’t get washed away. You do not use fertilizer if planting in water.

It is also important to plant each plug deep enough to avoid losing them from tide and wave energy while the roots become established. Generally, it is recommended that each plug be planted at a minimum depth of approximately two inches above the plug/roots, i.e., at least two inches of the stems are covered.

If soils are very sandy and relatively free of roots, stones or heavy shell hash, it is also possible to plant marsh grass using battery power planting augers, choosing the diameter of auger bit to give plenty of room to plant the marsh plugs.

How to Plant Marsh Grass

Planting the marsh grass plugs close together, as opposed to the traditional method of planting them 2 feet apart, increases the success of the planting significantly. There is safety in numbers.

This photo shows a section of shoreline where the plants were planted very close together. These plants were taller and greener than the nearby plants that were planted further apart.

Planting can be done by groups, including volunteers, but guidance is needed.

Jones Island Shoreline

Before Planting

After 1 Year

Before and after planting pictures from Jones Island in the White Oak River near Swansboro. After one year you can see that the marsh has established itself quite nicely.

At this site, 9,000 plugs were planted along this 250 linear feet of shoreline. The more plugs you can plant the quicker your marsh will become established.

Marsh establishment varies between shorelines. This shoreline on the other side of Jones Island took longer to establish, as it was wider, and we had a greater area to cover. It was planted for multiple years with thousands of plugs.

Use Recycled Oyster Shell When Conditions Are Favorable

Oyster shell is the best, most natural material to use to build oyster reefs, but it's also in short supply. To save this ecologically important byproduct, the state of North Carolina and other organizations maintain oyster shell recycling programs. Using recycled shell is a great option as it takes a resource that would otherwise be disposed of in a landfill and puts in back in the water where it provides oyster reef habitat and erosion control. Where oysters grow naturally within North Carolina's estuaries, recycled shell should be considered as an option for living shoreline projects.

While oysters can grow throughout NC's coastal tidal regions, they are best adapted to higher salinity conditions, as opposed to lower salinity sounds or upstream creeks. As a rule of thumb, if oysters are visibly growing/thriving in the area of your project site, it is a good indicator that an oyster shell living shoreline project is appropriate. It is useful to look for oysters growing on rocks, docks/pier pilings and adjacent to existing marsh fringes.

Using Recycled Oyster Shells for Living Shorelines

- The shells of oysters that were harvested and consumed
- Reduces shoreline erosion and creates habitat

Recycled oyster shells are the shells of oysters that were harvested and consumed. Each oyster has two shells and once the organism is eaten, the leftover shells are collected at recycling centers. These recycled shells are eventually put back into the water to create habitat for more oysters, fish, and crabs, and to protect estuarine shorelines from erosion.

Oyster shell recycling drop off locations can be found throughout NC’s coastal regions. More information on oyster shell recycling in North Carolina and drop off locations can be found at https://www.nccoast.org/project/oyster-shell-recycling-program/.

Using Recycled Oyster Shells for Living Shorelines

Oyster shell bags

Sill

The oyster shells are used for living shorelines in several ways.

Place loose oyster shells in front of the marsh to stabilize your shoreline. You can also place them a bit offshore to create patch oyster reefs that will also help to reduce wave energy and protect your shoreline.

Oyster shells can be put in mesh bags and placed them right up against your eroding marsh as a marsh toe revetment or a few feet from your shoreline as a sill.

Please note that unlike planting your shoreline, the placement of oyster shells in the water does requires a permit from the Division of Coastal Management.

Not only do these oyster shells protect shorelines from erosion but the shells also provide a hard surface for other oysters to attach to. The new oysters help to improve water quality because as they feed, they filter the water. These living shorelines also form very productive reef habitat for fish and crabs.

In coastal North Carolina, the use of loose oyster shells for living shoreline projects may not be suitable along shorelines with higher energy conditions, such as heavy boat wakes, higher waves and frequent hurricanes/storm conditions. In these conditions, loose oyster shells can move before oyster settlement and reef establishment has occurred.

Obtaining the Recycled Oyster Shells

- Purchased from seafood companies/shucking houses**
  - Quality Seafood, Elizabeth City ($2.85/bushel)
- Purchased from trucking companies**
  - Roy Rogers ($2.48/bushel)
- Donated from oyster roasts
- Restaurants

**Note: prices current in 2020, but will vary by region, availability, and market conditions.

Currently, recycled oyster shells can be purchased from seafood companies such as Quality Seafood Company in Elizabeth City at $2.85 per bushel or at $2.48 per bushel from a trucker that delivers the shells from Virginia.

Most of the cost for the shells is not the shells themselves but the transportation costs.

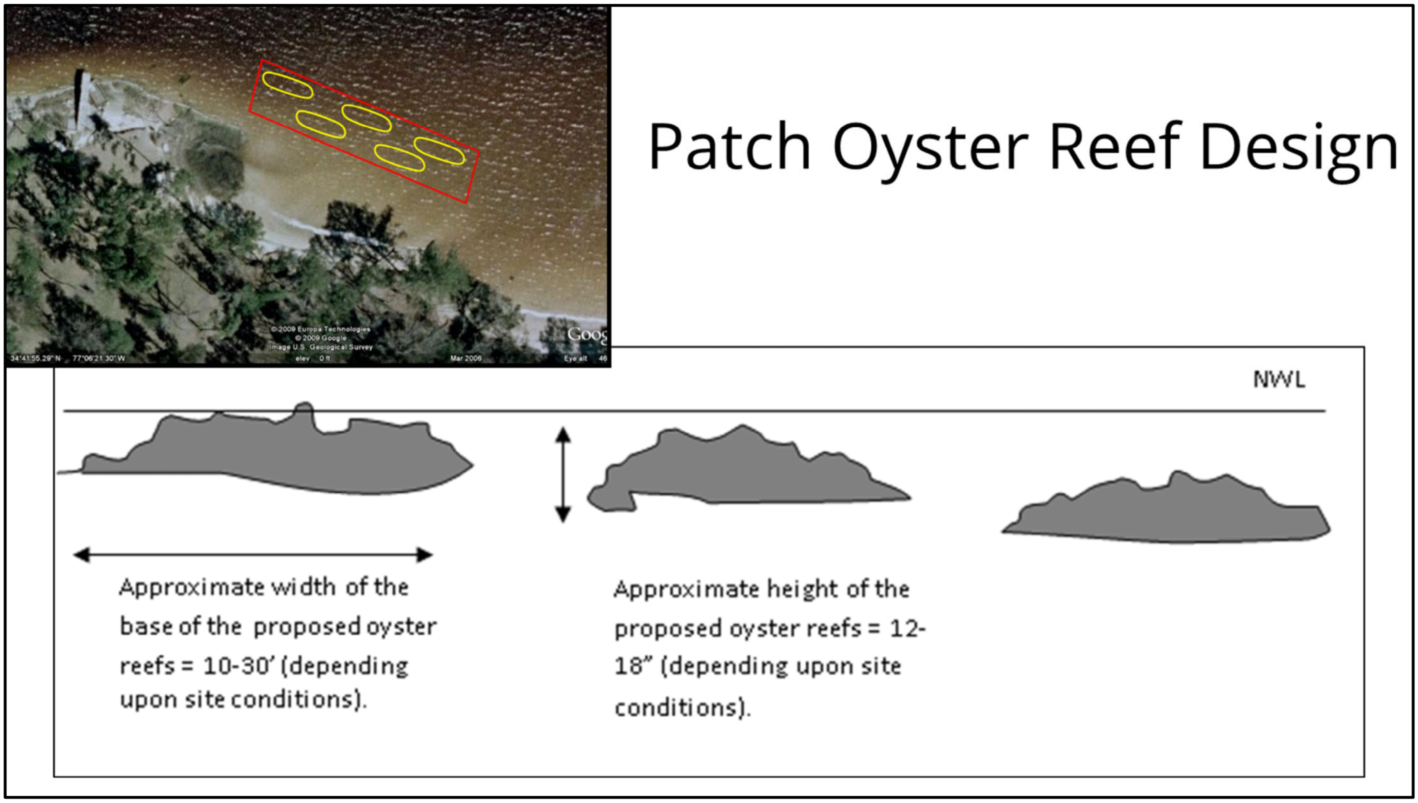
You can also get oyster shells from large oyster roasts that will donate them like the ones held by the local rotary clubs or they can be donated and purchased from restaurants.

Loose Shell Project, Morris Landing

For lower to moderate energy environments, loose oyster shells can be used for living shoreline projects. Recycled shells are placed along the shoreline, in shallow water adjacent to the marsh grass, and are placed to replicate the natural height and formation of naturally occurring reefs. Often, the restored reefs are created as mounded reefs, which are then "shaped" into a more natural reef from subsequent tides and erosion forces. To be successful, they must attract natural oysters to recruit along the newly established reefs, which anchors and structure in place and provides a sustainable natural element of a living shoreline.

As with all living shoreline methods, you need to consider your site conditions. If it is a high energy site with lots of sand movement, you need to build your reefs higher to prevent them from getting covered by sand. In areas with high wave and storm erosion potential, the use of loose oyster shells for establishment of reefs/living shorelines may not be suitable.

For oyster recruitment to occur, there is a sweet spot where the shells must be placed. Using existing low and high elevations of oysters growing in the area, i.e., along pier pilings or other hard structures, provides guidance for reef design and construction. In high salinity areas, you may not want to use oysters as boring sponges which exist in high salinity areas can bore into the shells and break them down over time.



Patch reefs require CAMA Major Permits. Above are several designs that are have been submitted with the permit applications.

For homeowner scale projects, these types of designs are sufficient. However, with larger and more complex shorelines, the plans may have to be engineered.

For this project, the design consisted of creating five staggered patch reefs, each approximately 1 foot in elevation. These reefs received about 1,500 bushels of recycled oyster shells each.

Loose shell can be placed along shoreline using small floating platforms or barges, and a power wash system such as those used by marine contractors for jetting in dock or pier pilings. Once placed, tides, waves, and currents will reshape the mounded shells into a shallower, broader shape, suitable for oyster recruitment and growth.

Using Oyster Shell Bags for Living Shorelines

Oyster shell bags sill

Marsh toe revetment

For higher energy settings, it is necessary to use bagged oyster shell, which are stacked in layers to create the shape and height of the structure. This design can be used to include a wide variety of alignments, widths, and heights to mitigate erosion. We will describe the process for creating oyster shell bags for marsh toe revetments and sills.

Making Oyster Shell Bags

To make the bags, we use this mesh and a specially designed bagging frame. The mesh costs about $125 per roll and the bagging frame can be built using wood or metal and PVC.

Making Oyster Shell Bags

Step 1: Create mesh bags

Step 2: Pull bags over PVC tubes

Step 1 – Cut the mesh, which come in a roll, into 3 to 4-foot-long sections. The bags are either crimped at one end using hog rings or you can simply tie a knot at the end.
Step 2 – Place bags onto PVC tubes, pull them over the tubes like a sock.

Making Oyster Shell Bags

Step 3: Fill bags with shell

Step 4: Remove bags from PVC and close

Step 3 - The tubes are then placed in the bagging frames and then filled with the recycled oyster shells.
Step 4 - The tubes are then removed, and the filled bags are crimped or knotted on the other end.

Making Oyster Shell Bags:
The Final Product

Use of Limestone Marl for Living Shorelines

Because of the short supply of oyster shells, we may substitute oyster shells with marl in part of the oyster bag sill. Marl can be obtained from local suppliers, such as septic companies. Marl bags are used as the bottom layer of the oyster shell bag sills. This bottom layer is typically buried with sediment. By using marl underneath, where oysters won't settle, we provide structure for the sill valuable without wasting valuable oyster shells.

Transporting the Bags

Ideally you would want to make the bags at the site where you will be using them, to minimize the number of times that the bags are moved.

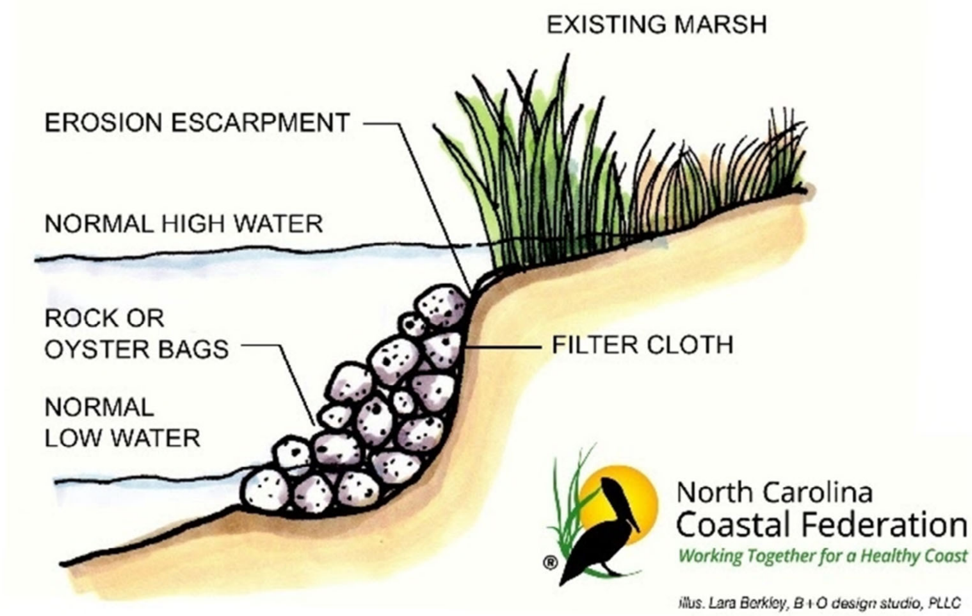
However, sometimes that is not possible and sometimes they need to be transported to your site either by trailer or boat.

Stockpile Sites

If you are not going to place the bags in the water right away, you also need to find a good stockpile location, as close to your site as possible.

Oyster Shell Bag Marsh Toe Revetments

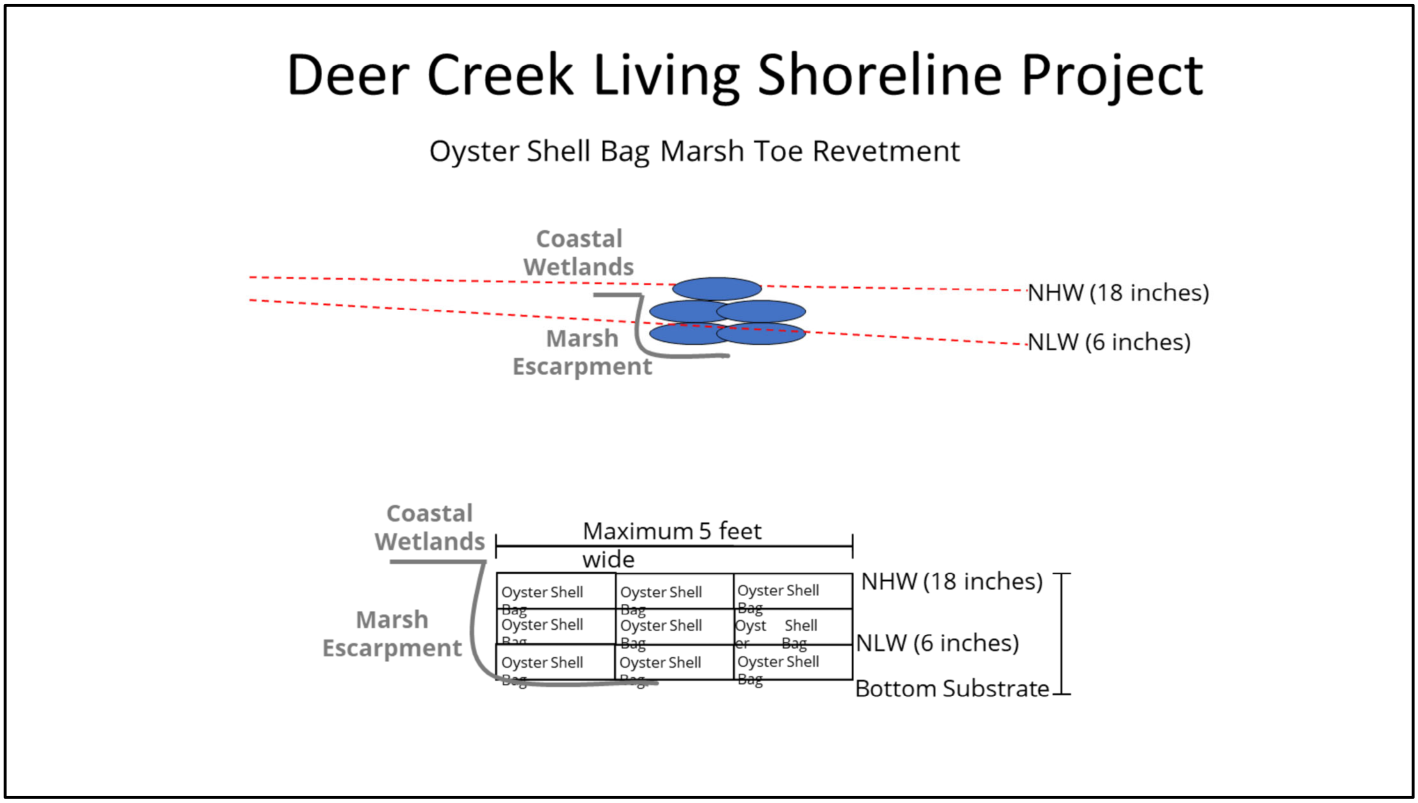
Here are eroding marshes that are excellent candidates for oyster shell bag marsh toe revetments. They are lower in elevation, fairly uniform, and actively eroding. You can see how they have a clear erosion escarpment where you would place the bags to protect your existing marsh. With these structures, oyster shell bags are placed directly against the cut bank, so this design is not optimal when marsh reestablishment or enhancement is needed.



MARSH TOE REVETMENT
not to scale

This site plan depicts a typical marsh toe revetment project, which qualifies for an existing CAMA General Permit for marsh toe revetments. This structure could be constructed from stone or oyster shell bags.

Deer Creek Living Shoreline Project
Work Plat Drawing 1 of 2: Oyster Shell Bag Marsh Toe Revetment Design - Plan View
Date: February 5, 2015
The location of the proposed oyster shell bag marsh toe revetment is shown (yellow line). The total length of the revetment will be approximately 86 linear feet. The revetment will be constructed by layering oyster shell bags perpendicular to the shoreline, no more than five feet waterward of the erosion escarpment and no higher than six inches from the elevation of the existing marsh substrate.



Permit drawings do not have to be done on the computer. They may be submitted for approval with a hand sketch, or using a standard design template, such as this one.

Deer Creek Living Shoreline Project
Work Plat Drawing 2 of 2: Oyster Shell Bag Marsh Toe Revetment Design - Cross-Section View
Date: February 5, 2015

The revetment will consist of layers of oyster shell bags placed perpendicular to the shoreline, no more than five feet waterward of the erosion escarpment and no higher than six inches from the elevation of the existing marsh substrate. Each oyster shell bag is approximately 2 feet long, 6 inches wide and 6 inches high.

This marsh toe revetment, constructed from bags of loose oyster shell, was built by volunteers.

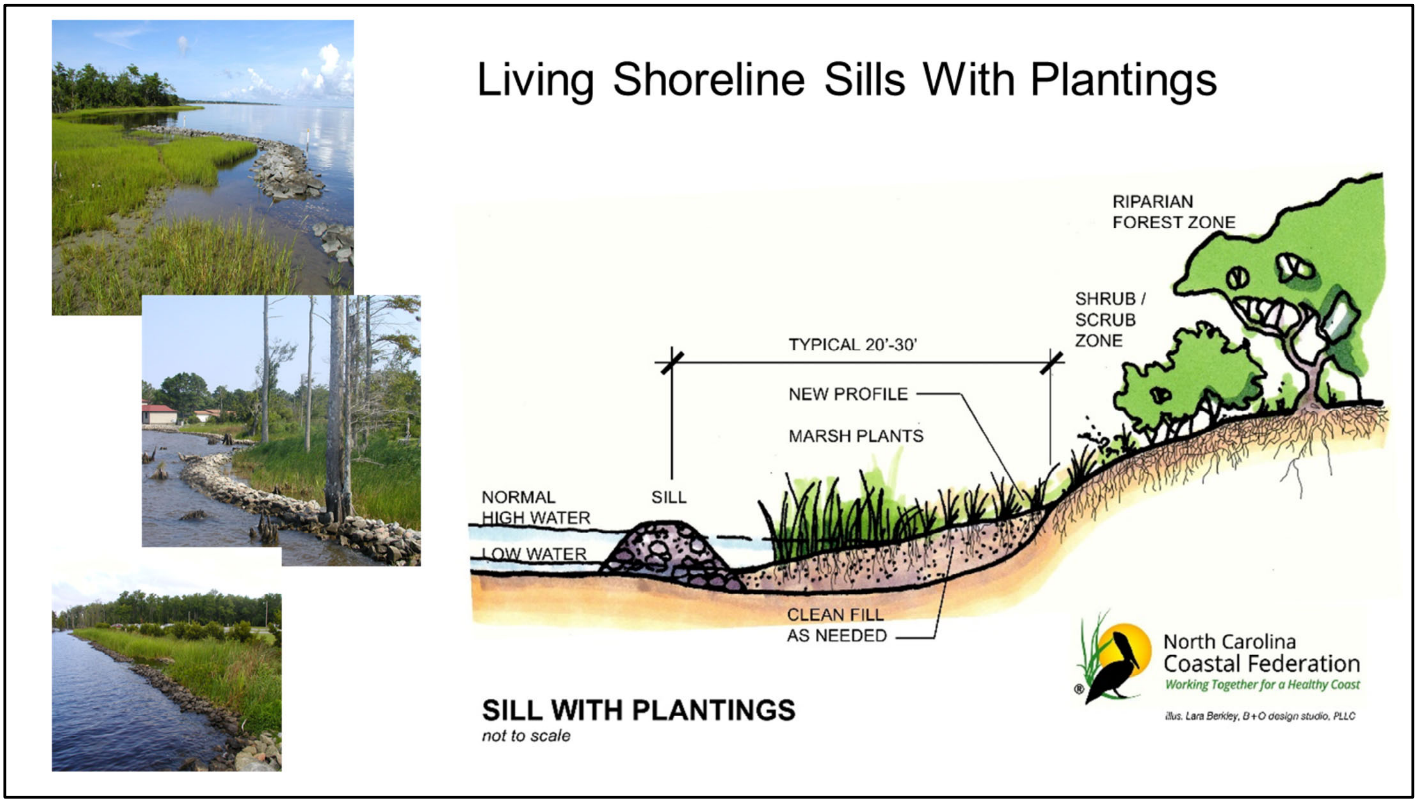
Local Fishermen

This work can also be done by marine contractors, consultants, fishermen, etc. such as this project at Beacon Island, which was created by local fisherman.

Oyster Shell Bag Marsh Toe Revetments

For structural integrity and stability, it is important that the bags be placed lengthwise perpendicular to the shoreline.

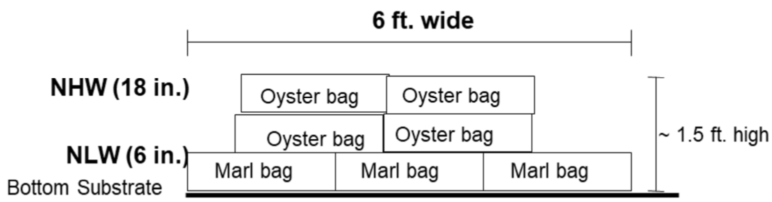
For the project pictured here, a total of 4,785 bags of oyster shells were placed along a total of 393.5 linear feet of shoreline. Construction took 17 days in August through November.



For areas where oysters are not found naturally, or in very high energy environments, construction of a sills or marsh toe revetments from stone may be the most appropriate design option. In North Carolina, stone sills are constructed from either granite or marl. Stone sill designs can be adjusted for low to very high energy environments, with changes to base widths, elevations, stone size, slopes, and orientation important parameters in sill designs.

The top project in this slide is of a stone sill at the Pine Knoll Shores Aquarium, located in a relatively higher energy location on Bogue Sound. The sills allowed for the protection of existing and restored tidal salt marsh plants. The other two projects pictured here are sill projects locate along relatively higher energy shorelines adjacent to the Albemarle Sound (middle) and the Chowan River (bottom). In these settings, the stone sills provided erosion control and protection of existing and restored freshwater wetlands, shrubs, and trees. Each of these projects included gaps in the design to allow for fish and other estuarine animals to access the adjacent marshes.

Oyster Shell Bag Sill Design



Oyster bag sills are designed to be placed offshore of an eroding marsh shoreline, sloping sandy beach, or higher banks. Like stone sills, the design is trapezoidal in shape, which is effective in breaking down wave energy, while allowing water to flow through and over the structure. The design can be modified to be effective in low to high energy regimes. For most residential settings, sills can be designed to qualify for a CAMA General Permit.

To create an oyster shell bag sill, three marl bags were first laid end to end perpendicular to the shoreline as shown in this diagram. Then two layers of oyster shell bags were then placed on top of the marl bags. This was continued until the desired length of the sill was reached.

With the existing marsh sill general permit, a small gap was created every 100 feet of sill to allow for fish and other marine animal passage access to the marsh.

This sill is 150 linear feet long by six feet wide and was built in one day by over 65 volunteers that were recruited by the local public radio station. Volunteers included marines from Cherry Point and at Camp Lejeune.

The shells inside the bags provide a hard surface for natural oyster larvae to attach to and provide habitat for fish, crabs, and other shellfish. These sills will eventually become large oyster reefs, filtering the water of the White Oak

Once established, the sills function as both erosion control measures and restored oyster reefs. Oysters continue to grow through the bags and then on the previously established oysters. The reef breaks down wave, current, and boat wake energy approaching the shoreline, protecting the existing or restored marshes landward of the structure.

As the water passes over and through the structures, it provides needed oxygen and food for the growing oysters. Many organisms including stone crabs, mud crabs, hermit crabs, polychaetes, sea squirts, juvenile mussels and clams, barnacles and a variety of fish will find a home in and around the sills.

Typical Costs for Oyster Shell Bag Sills and Marsh Toe Revetments

For 50 linear feet*

- 700 bags, 175 bushels @ $3.00/bushel = $525
- 3 rolls of mesh @ $125/roll = $375
- Bagging frame = $100
- Labor, $5.00 per bag = $3,500
- Plantings, 1,500 plants @ $1.00 = $1,500

Total cost = $6,000 or $120/linear ft.

Photo: Restoration Systems, Inc.

* Note: Costs of stone sills vary significantly by size of structure, mobilization/demobilization costs, location, availability/transport of material, and market conditions.

Typical Costs for Stone Sills and Marsh Toe Revetments

For 50 linear feet of stone sill*

- Stone installed (materials + labor) @ $150-$200/linear foot= $7,500-$10,000
- Plantings, 1,500 plants (1,500 square feet) @ $1.00/per = $1,500

Total cost = $9,000- $11,500

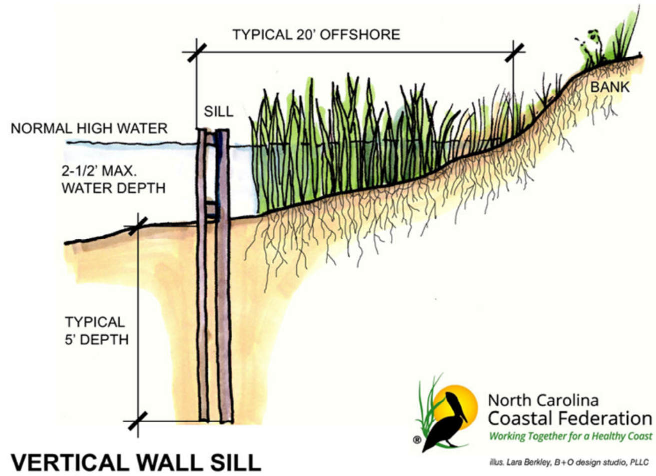
*Note: Costs of sills vary significantly by size of structure, mobilization/demobilization costs, location, availability/transport of material, and market conditions.

Typical Costs for Vertical Wall Sills

For 50 linear feet of vertical wall sill*

- Vertical sill installed (materials + labor) Estimate includes 8' vinyl sheeting panels, marine treated whalers, galvanized hardware
- $120-$140/linear foot= $6,000- $7,000
- Plantings, 1,500 plants (1,500 square feet) @ $1.00/per plant = $1,500

Total cost = $7,500- $8,500



VERTICAL WALL SILL
not to scale

* Note: Costs of sills vary significantly by size of structure, mobilization/demobilization costs, location, availability/transport of material, and market conditions.

Typical Costs for Oyster Dome Project, Morris Landing, NC

For 150 linear feet*:

- Plantings: 1,500 plants @ $1.50 = $750
- Domes: 200 @ $90/dome= $18,000
- Delivery of domes (from VA): $1,500
- Installation of domes: $7,000

Total cost = $27,250, or $182/ft.

* Note: Costs of sills vary significantly by size of structure, mobilization/demobilization costs, location, availability/transport of material, and market conditions.

Oyster domes, which are also known as reef balls, are commercially available pre-cast structures that are available from suppliers throughout the United States. They were originally designed to create fish habitat but have been expanded for use as innovative and effective living shoreline projects.

Oyster domes can be designed into effective sill structures, placing them waterward of eroding sandy and/or marsh shorelines. Oyster domes are available in many sizes and can be staggered or placed in multiple rows to increase wave dissipation. It is important to place the oyster domes in the location and at the elevations that will maximize oyster settlement and growth on the domes.

The Morris Landing Clean Water Preserve provides an opportunity to experiment with living shoreline designs and study the long-term effects of various living shoreline techniques along the shoreline adjacent to Stump Sound. More information about the living shorelines constructed at Morris Landing can be found at http://www.nccoast.org/project/morris-landing.

Morris Landing: Five Living Shoreline Projects

Phase I 2005

2013

Phase I: In 2005, a 600 feet by six feet stone sill was established to protect and restore the eroding estuarine shoreline and salt marsh habitat. The protection afforded by the sill coupled with plantings of Spartina alterniflora (smooth cordgrass) seedlings behind the sill resulted in the restoration of a vibrant salt marsh habitat. Funding for the project was provided by the NOAA Restoration Center's Community-based Restoration Program and Restore America's Estuaries.

Morris Landing: Five Living Shoreline Projects

Phase II 2008

2013

Phase II: In 2008 the federation constructed 200 linear feet of a shoreline restoration project along the eastern shoreline of the property. The purpose of the project was to restore oyster and saltmarsh habitat and provide protection for the existing eroding shoreline. The project consisted of a 150 feet by eight feet oyster shell bag sill and a 150 feet by 25 feet salt marsh restoration project, and an additional 50 linear feet of shoreline re-grading and marsh restoration.

Morris Landing: Five Living Shoreline Projects

Phase III 2010

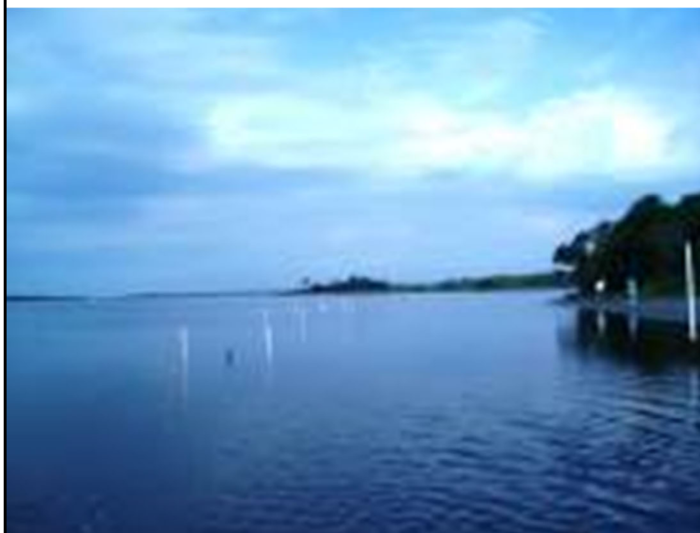
2013

Phase III: In 2011, a 225-foot-long living shoreline project including salt marsh restoration was constructed along the northeastern shoreline of Morris Landing. The project consisted of two 75 feet by six feet oyster reef and sills made up of concrete oyster domes, one 75 feet by eight feet oyster reef and sill made up of oyster shell and marl bags and 225 feet by 25 feet of salt marsh restoration.

Morris Landing: Five Living Shoreline Projects

Phase IV 2013

2016



Phase IV: In 2013, a 305-foot-long living shoreline was constructed along the southwestern shoreline of Morris Landing. The project included: an eight feet by 104 feet oyster shell bag and marl bag sill; two 6 feet by 100 feet to 120-feet-long oyster dome sills, one 80-foot-long vertical wall sill. The project included restoration of salt marsh habitat through marsh plantings an area 305 feet long with an average width of 25 feet behind the sills.

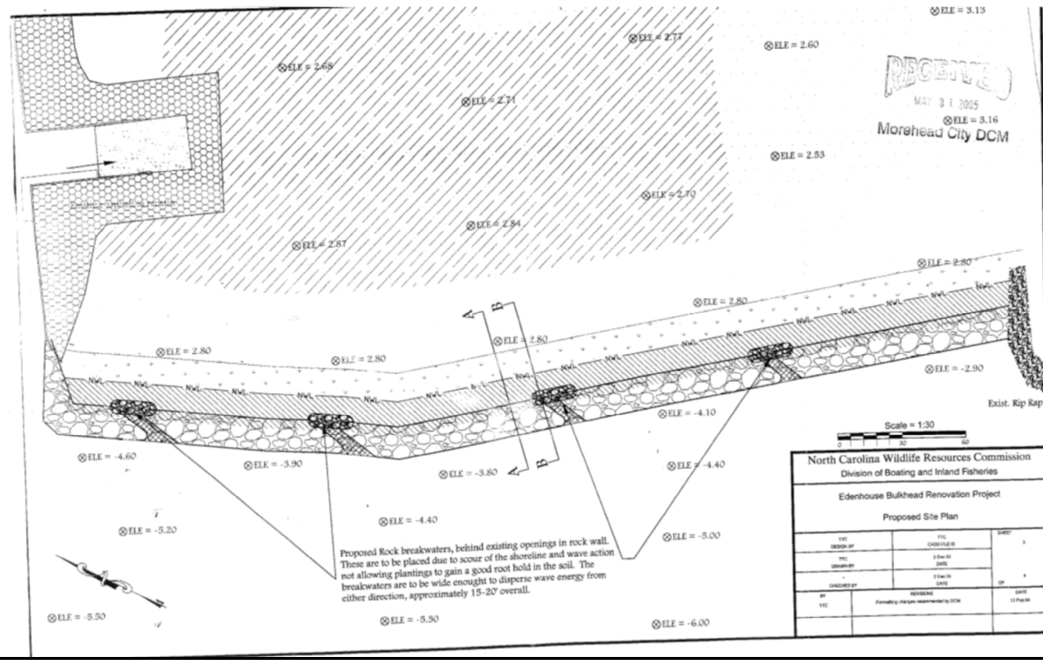
Morris Landing: Five Living Shoreline Projects

Phase V 2016

2016

Phase V: In 2016, three loose oyster shell sills, 100 feet long with a 10-foot-wide base and a 6 feet-8 feet crest, were constructed. Salt marsh plantings were done in an area 310 feet long with an average width of 15 feet behind the sills. The first 100-foot-long sill and marsh restoration was completed in February 2016.

Stone Sill Living Shoreline in Freshwater Environment
Edenhouse Boat Ramp, Chowan River, Edenton, NC (2004-2005)

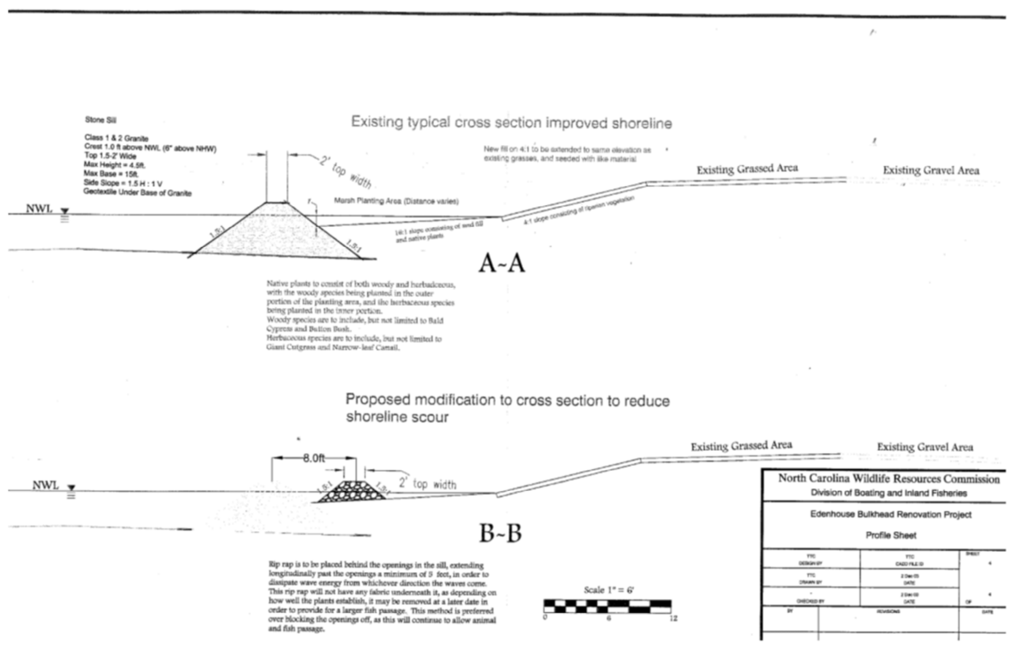


Edenhouse Living Shoreline: 450’ of stone sill with small offset sill structures for gap openings.

- Text on the drawing: Proposed rock breakwaters, behind existing openings in rock wall. These are to be placed due to scour of the shoreline and wave action not allowing plantings to gain good root hold in the soil. The breakwaters are to be wide enough to disperse wave energy from either direction, approximately 15-20 feet overall.
- ~1.2 tons riprap per linear foot
- Stone costs (in 2004 dollars) $27 per ton. Class I and II riprap.
- Engineering and construction provided by NC Wildlife Resources Commission
- NC Wildlife Resources Commission estimates for labor ($38,000) and equipment costs ($6,000) totaled approximately $44,000

Living shorelines can provide very effective stabilization in high energy areas, such as this project on the Chowan River. In addition, many shorelines can be enhanced to include zones of restored marsh grasses, higher marsh shrub/scrub, and native riparian tree buffers. In higher energy freshwater sites such as the Edenhouse project site, a stone sill was designed, along with regrading and restoration of a scarped shoreline following removal of a failing bulkhead.

Stone Sill Living Shoreline in Freshwater Environment
Edenhouse Boat Ramp, Chowan River, Edenton, NC (2004-2005)



The Edenhouse Wildlife Boat Ramp project was designed for a higher energy environment, including removal of a failing bulkhead, re-grading of a cut bank, placement of a stone sill, and marsh and riparian buffer plantings. See cross-sectional views above.

Edenhouse Boat Ramp, Chowan River, Edenton, NC

This compilation of photos shows the project progression from removal of the aging bulkhead, through construction and planting efforts. It should be noted that the project required some repair of the shoreline and additional plantings after a hurricane passed over in 2006, but the stone sill was virtually unchanged.

At this site, freshwater/brackish plant species were included in the planting design including wetland plants, shrubs, and trees. The planted and naturally occurring species included:

- Shallow/inundated zone: *Zizaniopsis miliacea* (Water Millet), *Pontederia cordata* (Pickerelweed), *Cladium jamaicense* (Sawgrass), *Sagittaria latifolia* (Duck Potato), *Schoenoplectus tabernaemontani* (Softstem Bulrish), and Lilaeopsis spp.
- Frequent but not continuous inundation: Scirpus americanus (Threesquare), Juncus effusus (Softrush), Impatiens capensis, and Polygonum spp.
- Occasionally inundated higher marsh/upland: *Spartina patens* (Saltmeadow Cordgrass), *Platanus occidentallis* (Sycamore) and *Taxodium distichum* (Bald Cypress).
- Upper berm/riparian buffer: *Morella cerifera* (Wax Myrtle), *Rosa palustris* (Swamp Rose), *Callicarpa Americana* (American Beautyberry), *Rhus copallina* (Dwarf Sumac) and *Aronia arbutifolia* (Red Chokeberry)

Edenhouse Boat Ramp, Chowan River, Edenton, NC

November 2020

These photos show the shoreline's current condition, approximate 15 years after completion. As a result of the project, this relatively high energy shoreline is very stable, and the freshwater marsh and riparian shrubs and trees have matured, creating into a resilient, cohesive zonation from shallow subtidal through a mature upland buffer.

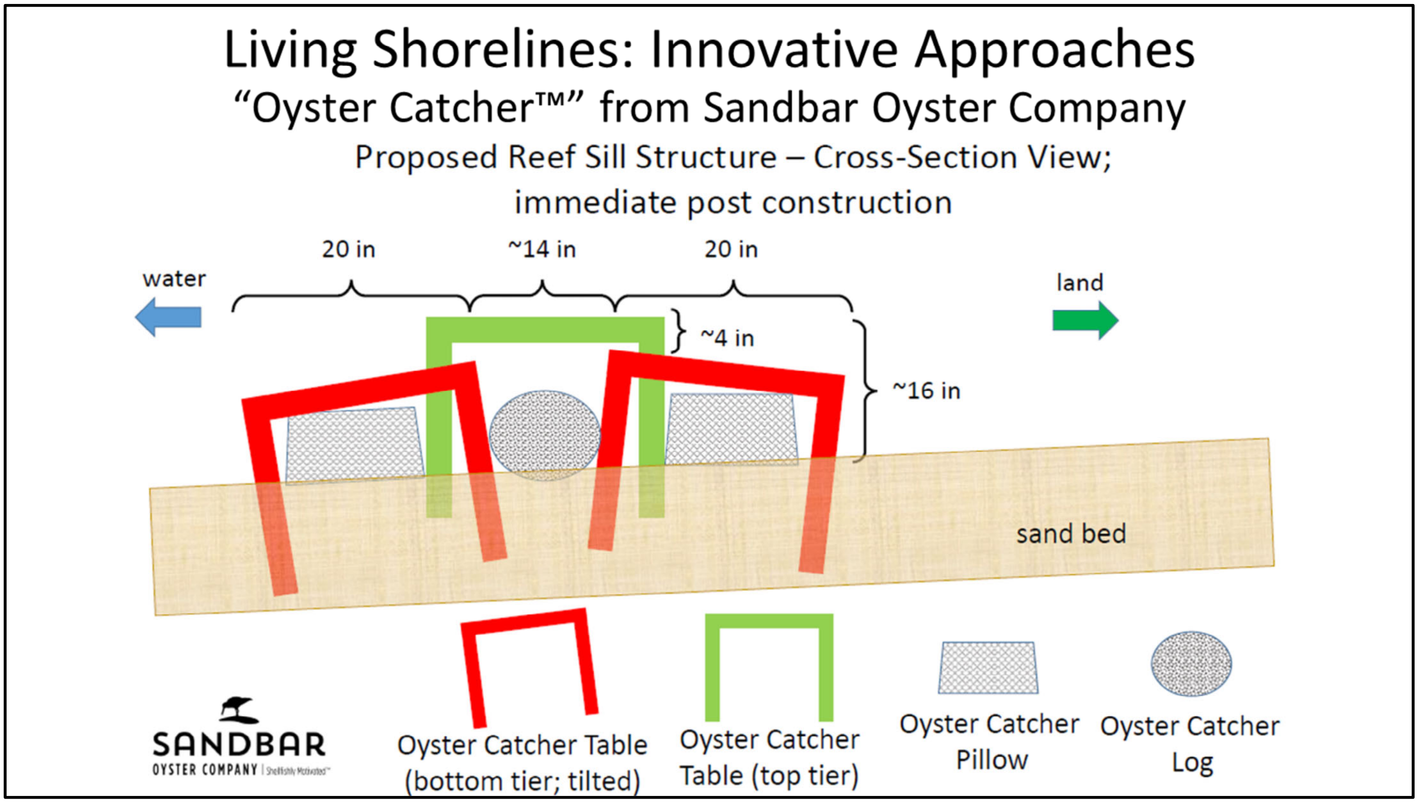
Living Shorelines: Innovative Approaches
“Oyster Catcher™” from Sandbar Oyster Company

As the demand for living shoreline projects grows nationwide, so has innovation in living shoreline design and materials. In North Carolina, several companies are marketing new materials and approaches commercially.

NOTE** Before selecting any innovative approach, contractors and other design professionals and/or property owners should ask for references, design and cost information, and performance monitoring results of existing projects for areas with similar site and energy level conditions.

Living Shorelines: Innovative Approaches
"Oyster Catcher™" from Sandbar Oyster Company

Pine Knoll Shores Aquarium
April 2019 - October 2020

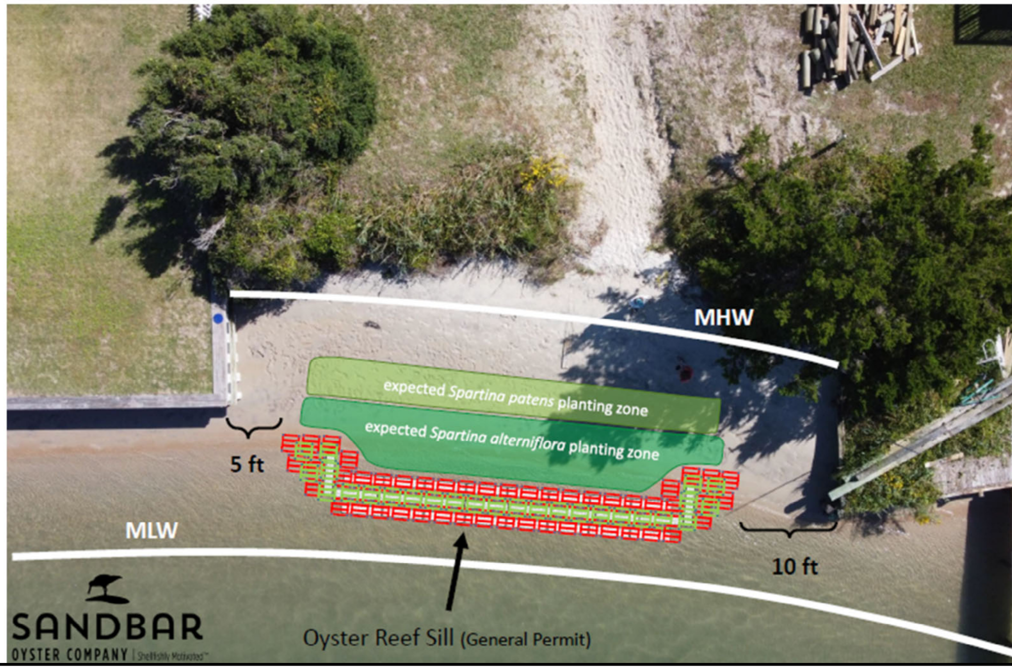


Innovative approaches allow for combining materials, structure shapes, alignments, and "stacking" of layers to create a successful design for varying site and energy conditions. This shoreline sill structure includes several different structures and a site design created for the location and site conditions.

*Note: Typical or specific costs for materials and designs should be requested from Sandbar Oyster Company™.

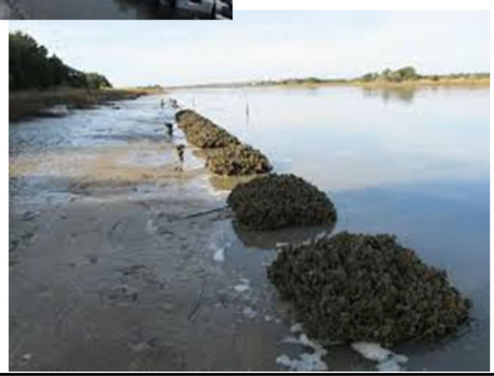
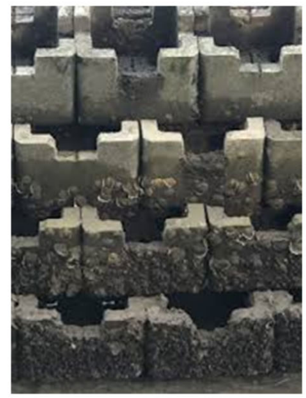
Living Shorelines: Innovative Approaches

"Oyster Catcher™" from Sandbar Oyster Company



Living Shorelines: Innovative Approaches- Oyster Castles®
“Oyster Castles® from Allied Concrete alliedconcrete.com



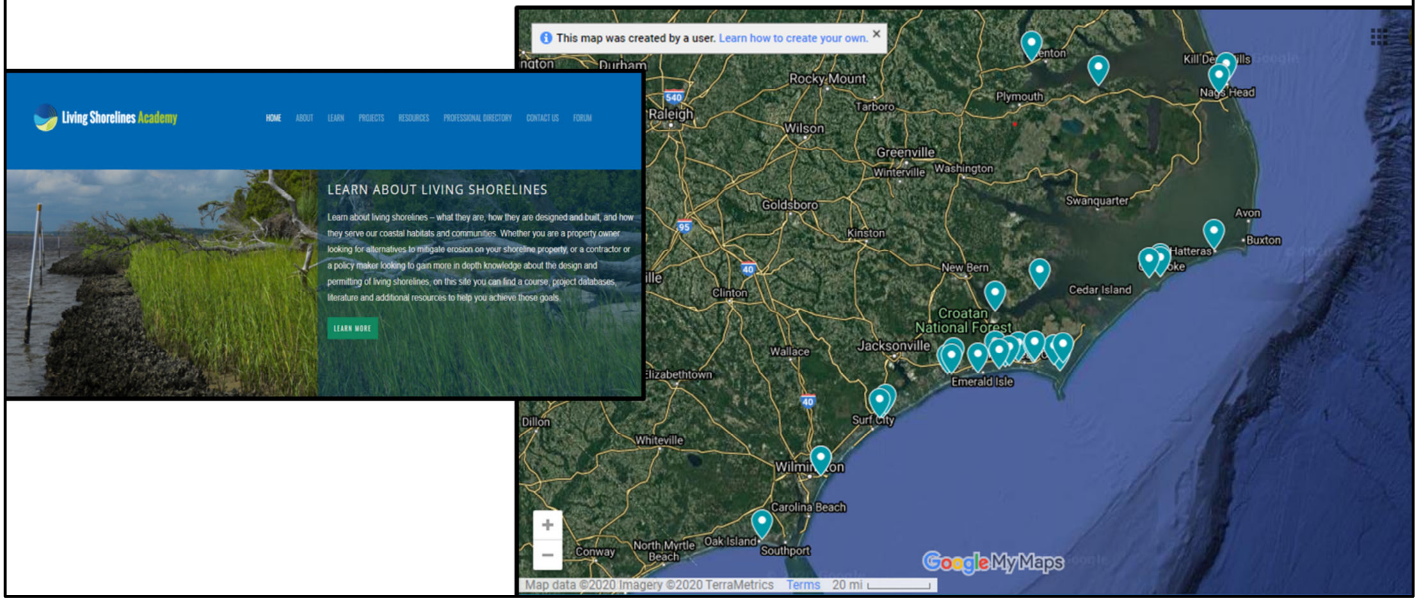
Pre-cast concrete structures, such as the Oyster Castles®, provide flexibility in design widths and heights, with a focus on interlocking modules to increase stability. The relatively portable and lightweight nature of the modules allow for “hand” construction of the structure, where conditions are optimal.

NOTE** Before selecting any innovative approach, contractors and other design professionals and/or property owners should ask for references, design and cost information, and performance monitoring results of existing projects for areas with similar site and energy level conditions.

*Note: Typical or specific costs for materials, design and installation of Oyster Castles® should be requested from Allie Concrete.

Additional Case Study Resources: Living Shorelines Academy

www.livingshorelinesacademy.org/index.php/projects-databases



Today, many online resources and state by state websites contain living shoreline project information and databases. The national Living Shorelines Academy website (livingshorelinesacademy.org) provides a great deal of information about living shorelines, including self-guided trainings and several databases of state and regional living shoreline projects, including North Carolina.

MAINTENANCE

Module Four

Evaluation and maintaining project success

Maintenance as a business opportunity

Module Objectives

Training participants will be able to:

- Monitor and maintain living shoreline projects post-construction;
- Provide instructions to property owners on basic maintenance and how to evaluate project success; and
- Understand opportunities that can provide additional income, continued education, and adaptive management of shoreline projects.

This module includes:

- Identification of post-installation monitoring and maintenance services that may be used as a business opportunity, continued education, and adaptive management
- How to provide instructions for property owners to evaluate and maintain the success of their living shoreline investment, including:
    - Understanding conditions that could be mimicked by living shorelines
    - Basic maintenance needs and who is responsible
    - Basic monitoring permit requirements and who is responsible
- Understanding different opportunities that can add value to a project, and maintenance income for professionals. This follow-up may include networking with prospective clients. Neighbors are always interested in what's happening next door, which provides a valuable potential for future jobs.

Photos from Carolina Beach State Park

Planning for Long-Term Success

Create a maintenance plan from project goals:

- Shoreline protection
- Habitat enhancement
- Access for recreation
- Potential maintenance needs from storms

- Think long-term for some components
- Planning creates maintenance needs, i.e., service opportunities

Project goals should be established during planning (pre-construction) stages

- What erosion issues does the client want addressed that require short- and long-term approaches?
- What additional values would your clients like to see? For example, wildlife use, fishing, natural beauty, oysters (harvestable only in open shellfish waters), recreational access
- Are there any funding (grant/ cost-share) and/or permit reporting requirements for monitoring/maintenance
- What questions do your clients (and their neighbors) have about the project maintenance/monitoring?
- Much better to discuss realistic maintenance/monitoring needs during the planning process between contractors/consultants and property owners. Also creates ongoing maintenance/ business opportunities.

Maintenance

- Pre-project: Identification of potential issues
  - Movement/displacement of materials
  - Maintain project footprint
  - Compliance with permit conditions
  - Invasive species encroachment
  - Additional materials/plants needed
  - Adaptive management to natural conditions

- Follow-up instructions for homeowners
  - Post-storm inspections; clean out debris
  - Identify any concerns early
  - Quarterly photos to show changes

Monitoring should occur so that maintenance needs are identified and addressed. It is important to establish a maintenance plan with the client prior to installing the living shoreline. Maintenance plans can help you to create and build new partnerships with additional firms if needed.

Maintenance is critical for the success of a living shorelines project, including replanting vegetation as needed, trimming tree branches (depending on the native vegetation's sunlight requirements), removing debris, and removing any interfering invasive species. Traditional hard stabilization also requires maintenance, such as bulkhead repairs, replacement, and rock movement and replacement.

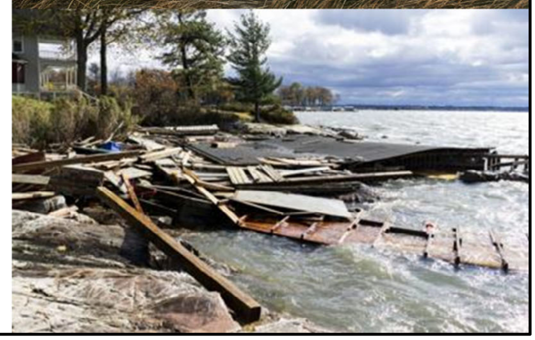
Again, revisit the goals of the project. What made the client approach you in the first place? During initial assessment and planning stages, think about how project will mature. What are foreseeable issues that should be discussed? For example:

- Invasive species encroachment: invasive species maintenance might be necessary, and this could be another opportunity for partnering with an environmental company.
- Additional materials needed: Clients may decide they need more of a particular component, or additional plants to enhance look of shoreline – always encourage natives species.
- Follow up instructions: Post-storm inspections and quarterly photos provided to the property owners and/or project contractor for this files provide opportunities to enhance work and build new clientele.

Create some type of ongoing maintenance plan with your clients.

Maintenance - Structural

- Scheduled maintenance
  - Replace missing/moved materials
  - Check for scouring, subsidence
  - Ensure gaps/drop downs remain in place
- Post-storm
  - Check integrity; repair/replace
  - Remove debris
  - Repair/replace navigation markers



Contractors or other professionals can establish a regular maintenance schedule for living shoreline projects. This might include quarterly or semi-annual visits in the first 1-2 years, with annual visits as needed for maintenance, removal of debris, etc. It is also a good idea to schedule regular post-hurricane or coastal storm visits to ensure the project is in good shape and/or remove debris that can harm any structures and marsh areas. Most debris removal, replanting etc. can be done without additional permits, however any changes to the structures)ie footprint, alignment, etc. should not be done prior to consultation with the appropriate permit agencies.

Maintenance - Vegetation

- Scheduled maintenance
  - Check survival, growth, coverage
  - Supplemental planting
  - Adding compatible species
  - Invasive species removal
  - Remove deposited debris
- Post-storm
  - Post-storm inspections
  - Clean out debris deposits
  - Assess survival, plan repairs

Maintenance of planted/restored marshes may need to occur until the plants become well established and function much as a natural marsh. Evaluations should be done more often in the first 1-2 years, and after any potentially damaging storm.

Monitoring of Living Shoreline Projects

- Evaluation on a regular basis can provide property owners with peace of mind and a point of pride
- Visual observation such as a quarterly set of photographs is very helpful
- Monitoring parameters such as deposition or erosion of sediments, success of vegetation, growth of oysters, and fish biodiversity are important indicators but require a professional skill set.

Monitoring the effectiveness and habitat function of living shorelines is important for the adaptive management of these structures. Learning more about how living shorelines protect shorelines from erosion and sustain fish habitats is important to evaluate whether the use of moreliving shorelines is appropriate.

Living shoreline designers/property owners may be required to provide monitoring of their sites, particularly for projects that are part of cost share programs or other governmental projects. Even when not required, routine qualitative monitoring (during routine maintenance trips, using quarterly photos, etc.) is valuable in talking with current and future clients.

Monitoring provides valuable information about long term effects, successes, challenges, etc. that is important for adaptive management (refining designs and construction based on monitoring of projects with specific conditions, sites, etc.) of future projects and for communicating with potential clients about the performance of these projects.

Performance of Natural and Marsh-Sill Living Shorelines

Dr. Carolyn Currin, NOAA

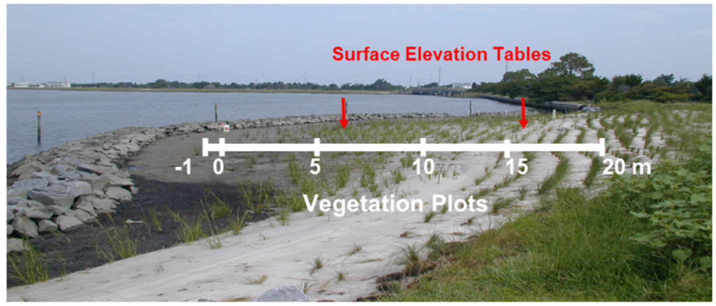
One of four paired monitoring sites in Carteret County

Dr. Carolyn Currin, an ecologist at the NOAA Beaufort Lab, conducted a 15-year study to monitor changes in the lower marsh edge. This included monitoring vegetation cover and species and surface elevation. Four paired natural marshes and marsh sill sites in Carteret County were part of the study. Permanent research plots were established at the marsh shoreline and transects were established to the upper edge of the marsh. Elevation benchmarks were also established, we'll describe these in more detail shortly. Dr. Currin states that surface elevation and plant distribution drive the ecosystem services (or nature's benefits) along a shoreline. These benefits include wave attenuation, fish habitat, water quality, the burial of carbon from the atmosphere into sediments.

These aerial photos are of natural marsh and marsh-sill on Pivers Island, Beaufort NC. Both have served as monitoring sites since 2004. Note transition from S. alterniflora to high marsh vegetation at both sites. Foot paths and wrack lines mark the transition at approximate mean high water. The far right photo shows layout of transects to measure vegetation density and cover, and location of Surface Elevation Tables (SETs) used to measure elevation change in the study.

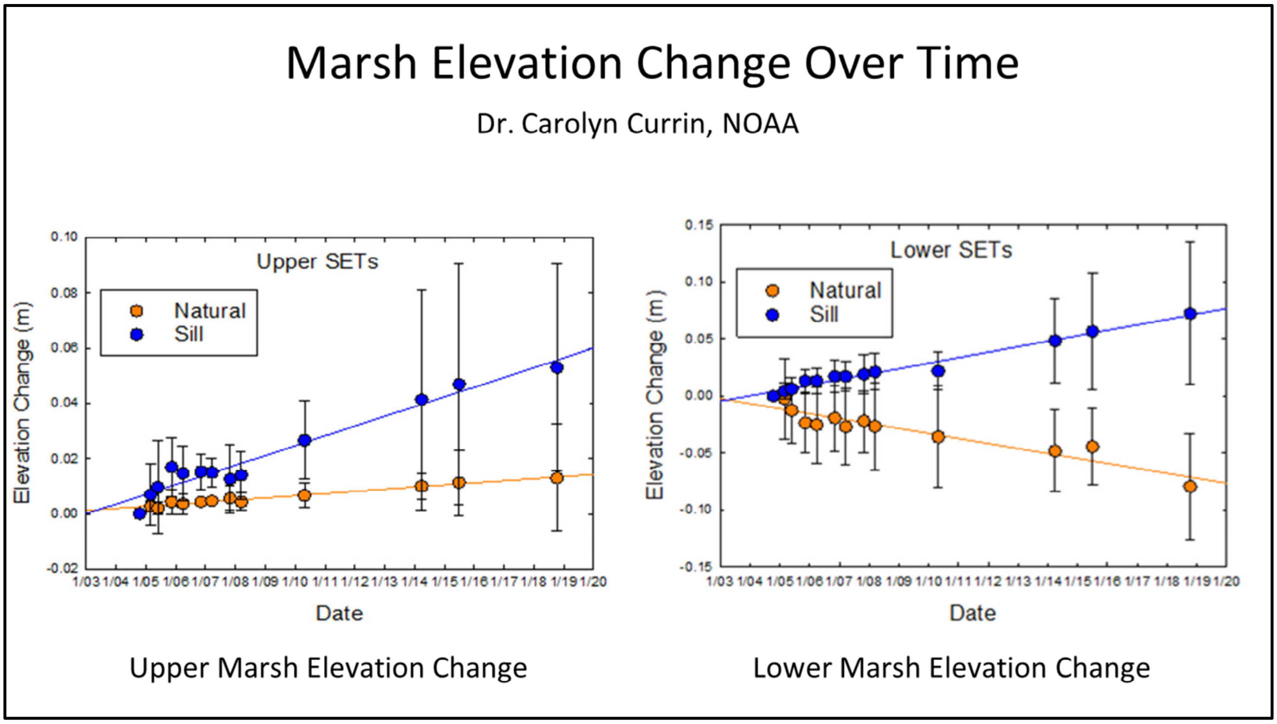
Performance of Natural and Marsh-Sill Living Shorelines

Dr. Carolyn Currin, NOAA



The top image shows the layout of transects to measure vegetation density and cover, and location of Surface Elevation Tables (SETs) used to measure elevation change in the study. You'll see these vegetation plot numbers on a subsequent graph related to *Spartina alterniflora* stem density.

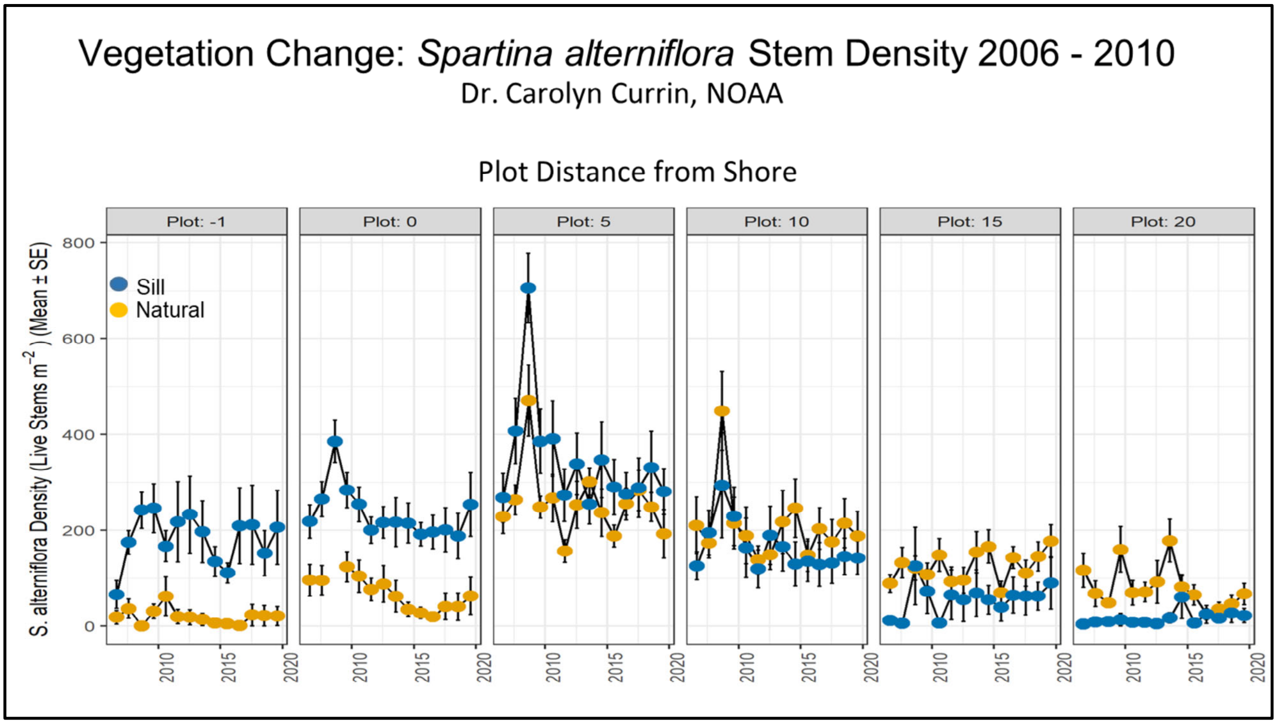
Elevation benchmarks can be as simple as a nail in a dock or piling, long piece of rebar driven into ground, or other fixed point to provide reference point for tracking changes in sediment and surface elevation (bottom left image) and should be established during living shoreline project installation. We installed Class C benchmarks (SETs) to monitor small changes (+/- 2mm) in surface elevation over time. The image on the right is Carolyn measuring the marsh elevation with the SET. Measuring those removable pins allows for monitoring of small changes. It is important not to trample this area, as it will affect your measurements.



Over 15 years, all of the natural fringing marshes lost elevation at the lower edge of the marsh (graph on right, orange dots/line), and in some places also lost vegetation (next slide). Data from other sites suggest that oyster reefs waterward of the marsh can reduce elevation and vegetation loss at fringing marshes. Dr. Currin's data shows that the lower natural marshes are not keeping up with sea level rise, while the upper marsh is accreting near long-term relative sea level rise. Marsh sills increase sediment accretion, particularly in high energy settings and in lower marsh.

Since these are not static systems, design shoreline stabilization methods for change. Water levels will get higher, and the mean high water/S.alterniflora line will move landward.

We found that hurricanes (Irene, Matthew, and Florence) had either no or a small impact on fringing marshes. Hurricanes often delivered sediment to the marshes, and erosion occurred rarely during low water levels. Vegetation showed little change and recovered quickly. Debris was the biggest storm-related problem. Salt marshes behind sills accreted sediment and gained surface elevation at a higher rate than natural fringing marshes, although elevation at sill sites also trailed SLR during the study period (2004-2018).



Spartina alterniflora stem density increased at shoreward edge of sill marshes, in contrast to natural marshes where vegetation declined on this edge. Natural fringing marshes have greater *Spartina alterniflora* density 15 and 20 m landward of shoreline. Sill marshes transition to upper marsh species (*S. patens, Juncus*), as *Spartina alterniflora* declines.

Spartina alterniflora stem density in the middle sections (5-10 m from shore) of both natural and sill marshes was consistent through the study, and this part of the marsh provides excellent wave attenuation. The decline in *Spartina alterniflora* at the upper edge of sill marshes may be due to the higher elevations in these created shorelines. At the upper edges, *Spartina alterniflora* was often replaced by upper marsh species (*S. patens* and *Juncus*) in sill marshes. This gives the sill marshes resiliency to SLR, and also demonstrates the landward movement of fringing mashes.

Dr. Currin established permanent PVC poles at lower and upper edges of marsh plantings to track erosion and changes in marsh distribution.

Vegetation Change *S alterniflora* Stem Density 2006 - 2010

Dr. Carolyn Currin, NOAA

Natural marsh on 0m plot, Pine Knoll Shores

Sill, Pine Knoll Shores

Sill, Harkers Island

- The left picture from Pine Knoll Shores illustrates how most natural fringing marshes saw a decline or loss of marsh vegetation at the lower shoreline.
- In contrast, the middle picture also from Pine Knolls Shores, shows how the higher sediment accretion see behind sills led to marsh grasses growing out over the rock sill.
- The right picture from Harkers Island shows that at the upper edges, *Spartina alterniflora* was often replaced by upper marsh species in sill marshes, including *Juncus* and *S. patens*.
- Many years of fish monitoring demonstrate that if you build a healthy marsh, the fish will come, so spend living shoreline monitoring time on elevation and marsh plant success.