South Carolina Department of Natural Resources

2019

Summary of Living Shoreline Research to Inform Regulatory Decision-Making in South Carolina

Acknowledgements

The South Carolina Department of Natural Resources' (SCDNR) ACE Basin National Estuarine Research Reserve (NERR) and Marine Resources Division, along with the North Inlet-Winyah Bay (NI-WB) NERR, collaborated with the South Carolina Department of Health and Environmental Control's Office of Ocean and Coastal Resource Management (SCDHEC OCRM) to undertake this research project.

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Executive Summary

Coastal marsh habitats are at risk due to sea level rise, increased storm intensity, coastline development, and shoreline hardening. Living shorelines are a powerful tool to proactively protect estuarine shorelines. Because of its extensive estuarine shoreline habitat, South Carolina is in an excellent position to take advantage of living shorelines to protect its salt marshes and improve coastal resiliency.

Living shorelines have been a part of the South Carolina Department of Natural Resources' (SCDNR) coastal management, conservation, and education strategies for over 20 years. Constructing living shorelines began as a habitat enhancement tool to increase the amount of oyster reefs and essential fish habitat. The co-benefits of living shorelines, including shoreline stabilization and salt marsh expansion, quickly became evident to SCDNR staff and to coastal property owners seeking to proactively protect the shoreline and marsh habitat adjacent to their upland private property. Based on property owners' increasing interest in living shorelines and the benefits to the coastal environment, the South Carolina Department of Health and Environmental Control's Office of Ocean and Coastal Resource Management (SCDHEC OCRM) is pursuing a regulatory pathway to easily and effectively permit them. To ensure that the resulting regulations and project standards developed are based on sound science, SCDNR, the North Inlet-Winyah Bay National Estuarine Research Reserve (NI-WB NERR), and SCDHEC OCRM embarked on a joint multi-year project to evaluate the effectiveness of a variety of greener living shoreline technologies under a number of coastal environmental conditions.

This joint effort included monitoring older, pre-existing living shorelines, as well as installing and monitoring new and previously used technologies under a range of environmental conditions. The technologies tested at the new sites included bagged oyster shell, manufactured wire reefs (MWRs), and natural fibers. The results and guidance contained herein are intended to provide SCDHEC OCRM with the science-based information for creating a regulatory pathway and developing project standards for living shorelines in South Carolina. This document will be updated as the science continues to develop, particularly with continued monitoring as living shorelines age.

Ultimately, the goal is for South Carolinians to have effective options to proactively protect marsh habitat using living shorelines. This proactive approach will not only help to maintain or increase the salt marsh footprint of the state, but it may also reduce the need for bulkheads or other hardened structures along uplands, which can compromise coastal environments. This represents a step towards improving coastal resiliency and sustainability in South Carolina.

1.0 Introduction

Coastal estuarine marsh health and stability are a growing concern for South Carolinians as the coastal zone changes due to sea level rise and increasing development. There is, however, great potential for nature-based solutions, such as living shorelines, to address these concerns. 'Living shorelines' is a broad term that refers to diverse shoreline stabilization techniques ranging from marsh grass plantings to sills and breakwaters, which are structural features placed parallel to the shoreline (Figure 1.1). In general, living shorelines are intended to reduce wave energy and encourage sediment accretion behind them. In this way, the marsh edge stabilizes and will often accrete to the point that it connects with the sill or breakwater.

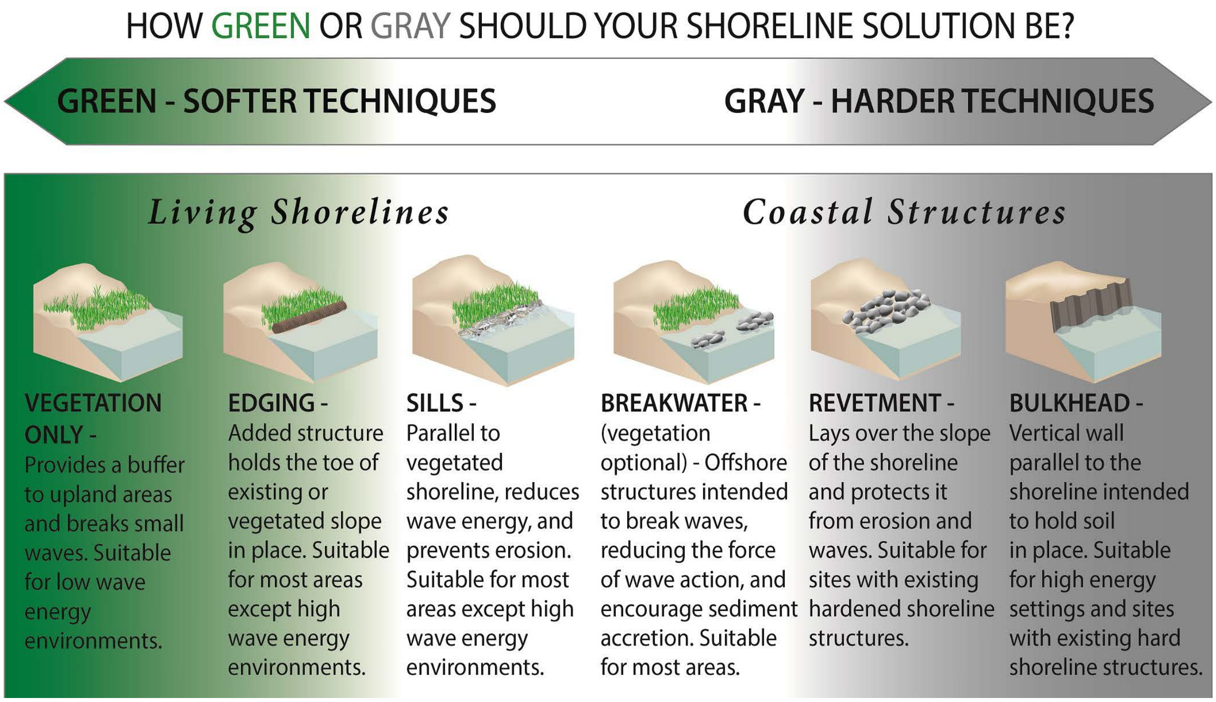


Figure 1.1. NOAA's "Coastal Shoreline Continuum and Typical Living Shorelines Treatments" (https://www.fisheries.noaa.gov/insight/understanding-living-shorelines).

For the purposes of this document, 'living shorelines' refers to techniques intended to stabilize estuarine shorelines at the marsh-water interface and facilitate the growth of marsh vegetation. These techniques generally incorporate materials (e.g., oyster shells or coir logs) that serve as sills or sediment-trapping devices and may or may not include marsh grass plantings. Because living shorelines have the potential to be effective for shoreline stabilization as well as provide additional ecological benefits, state agencies and others involved in coastal management and restoration encourage the use of living shorelines where they are appropriate and would likely be effective.

Living shorelines are a particularly effective tool when used proactively to protect salt marshes (Figure 1.2). As defined in this document, they are placed at the marsh-water interface, buffering the marsh edge against wave energy and increasing its resiliency and stability. There is tremendous environmental variability across this interface. Substrate may range from soft mud to hard sand. Energy associated with currents and waves varies from low-energy environments (e.g., inside bend of a waterway) to high-energy environments (e.g., Intracoastal Waterway). This project focused on the softer, greener side of the living shoreline spectrum (Figure 1.1), which may not be appropriate or effective in all situations. For instance, the living shoreline techniques tested in this study may not be appropriate in the face of an eroding upland, where the salt marsh is nonexistent and the shoreline slope is high. However, other living shoreline techniques may be appropriate for such circumstances. This project addressed the marsh-water interface and is not intended to address the upland-water interface (Figure 1.2).

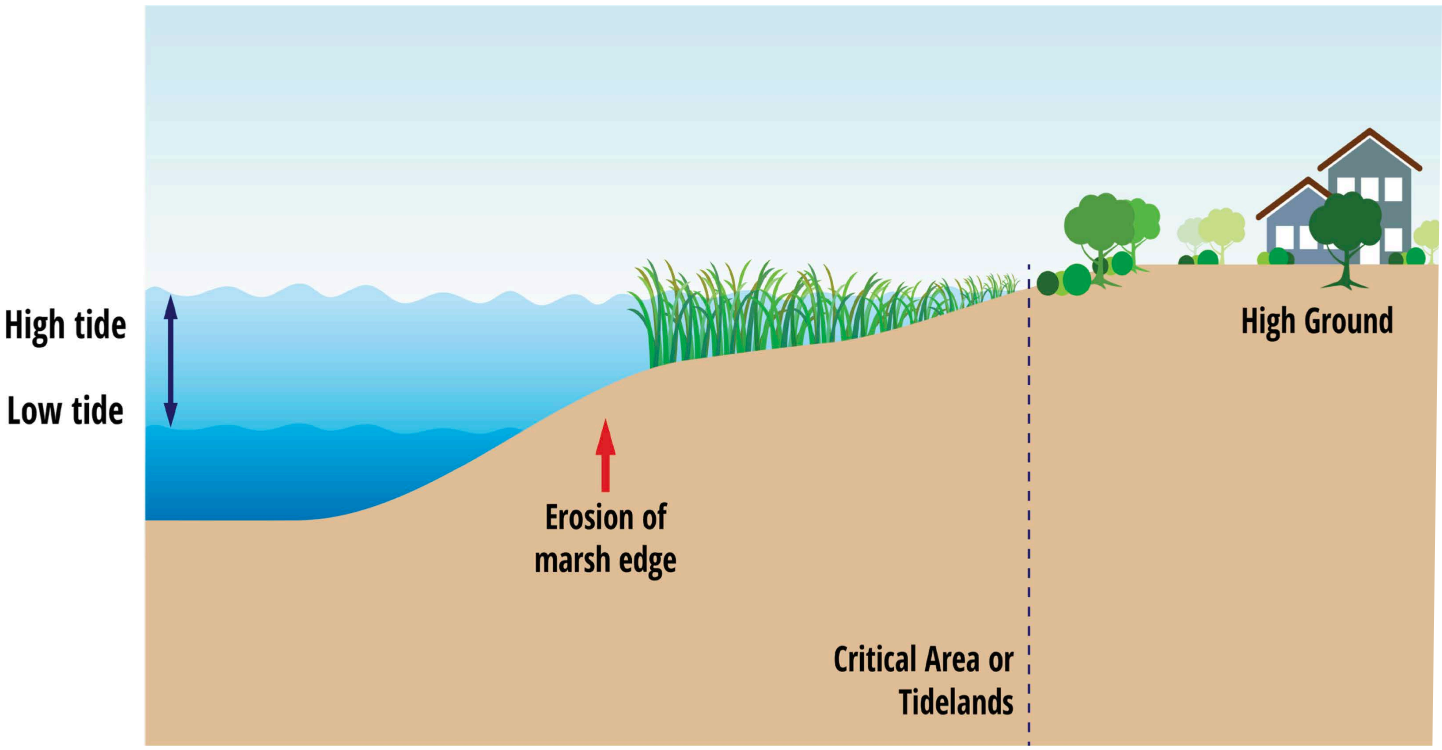


Figure 1.2. An example shoreline and area of concentration for this project (red arrow).

Living shoreline techniques are being used throughout the United States, with many agencies and nonprofit organizations developing data and information. The National Oceanic and Atmospheric Administration (NOAA) developed guidance for using living shorelines in 2015 (NOAA, 2015). Since environmental conditions and state regulations vary tremendously across the United States, a number of states, such as North Carolina (North Carolina, 2006), Virginia (Hardaway et al., 2017), and New Jersey (Miller et al., 2016), have developed guidance documents appropriate for their local conditions. The information from many of these other documents aided in the development of the framework for this document.

Co-Benefits of Nature-Based Solutions

There are a number of ecosystem benefits from living shorelines. Living shorelines are a management tool that not only provides shoreline protection benefits, but also creates habitat, promotes marsh growth, withstands storms, may have the ability to keep pace with sea level rise, and may filter the water. These benefits, provided by natural solutions, or free ecosystem services, enhance the health and resilience of our coasts.

Living shorelines are great habitat creators. In South Carolina, living shoreline construction often utilizes oysters to form a sill. The oyster reefs themselves provide important habitat for a multitude of species. More than 83 species of finfish and invertebrates are associated with intertidal oyster reefs in South Carolina, including all 22 managed by the Atlantic States Marine Fisheries Commission (ASMFC, 2007). Within the southeastern U.S. region, the South Atlantic Fishery Management Council recognizes oyster reefs as essential fish habitat, which as defined by Congress includes “those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity.” Furthermore, oyster reefs are well documented in their ability to improve water quality and clarity through their removal and deposition of suspended particles via filter feeding (e.g., Dame, 1999; Dame et al., 2001).

Living shorelines, whether oyster-based or not, promote the growth of the marsh. They create additional marsh habitat as sediment and marsh vegetation fill in behind them. Salt marshes are one of the most biologically productive and ecologically valuable habitats in the coastal region (Peterson et al., 2007). They are highly effective at capturing and holding carbon from the atmosphere, acting as carbon ‘sinks,’ which help to mitigate the effects of climate change caused by increasing carbon dioxide levels (NOAA, 2019). Marshes also remove excess nutrients from the water and reduce flooding by slowing and absorbing water (Tiner, 1993).

In terms of storm protection, natural marshes and those with a constructed living shoreline offer better protection to shorelines than bulkheads from significant storm events (Gittman et al., 2014). Many property owners assume that bulkheads provide superior protection from erosion and storm damage (Fear & Currin, 2012; Scyphers et al., 2014); however, studies to support this, particularly under storm conditions, are lacking (Shepard et al., 2011). Furthermore, studies show that bulkheads experience considerable damage during extreme storm events, compared with more natural systems that exhibit both greater resilience and recovery following such weather events (Currin et al., 2008; Gittman et al., 2014).

In addition to storm protection, living shorelines that are oyster-based may offer a buffer against the threat of sea level rise. As sea level rises, oyster reef heights will naturally increase; therefore, the reefs persist as natural, growing breakwaters which adjust to the change in tidal elevation (e.g., Rodriguez et al., 2014).

The co-benefits of living shorelines stand in contrast to the harder, grayer structures like revetments and bulkheads. Harder structures convey none of the additional benefits that living shorelines provide and can be detrimental to coastal environments. They isolate the estuary from the upland, disrupting the land-water continuum and restricting sediment supply to the marsh (Redfield, 1972; Chauhan, 2009). They also restrict the ability of coastal marshes to migrate upland or increase in height as sea levels change (Peterson et al., 2008b; Titus, 1988). Hard structures reflect wave energy, which increases the potential for erosion and sediment scour (National Research Council, 2007). Essentially, the presence of a bulkhead eliminates the intertidal zone, transforming a formerly gently sloped shoreline into a steep vertical structure (see Currin et al., 2010 and references within). As a result, bulkheads are associated with reduced abundances of upland coastal marsh plants, benthic infauna, and fish and crustaceans (Bozek & Burdick, 2005; Seitz et al., 2006; Bilkovic & Roggero, 2008).

Summary of Science Collaborative Project

Over the last 20 years, SCDNR, the US Fish and Wildlife Service (USFWS), and The Nature Conservancy (TNC) have implemented a large number of oyster-based living shorelines. In particular, the SCDNR has constructed oyster-reef based living shorelines adjacent to public lands since 2001. Through the South Carolina Oyster Restoration and Enhancement (SCORE) Program (Hadley et al., 2010) and ongoing research by the Shellfish Research Section of the SCDNR’s Marine Resources Research Institute (MRRI), more than 200 oyster-based living shoreline projects have been constructed, using several restoration methods known to be successful in coastal South Carolina. These methods have included installing loose oyster shell, bagged oyster shell, ‘oyster castles®’ produced by Allied Concrete Inc., cement-coated derelict and repurposed crab traps (RCT), and cement-coated manufactured wire reefs (MWRs).

Many of these oyster-based living shorelines were constructed in highly visible locations to serve as demonstration sites. Coastal property owners over the years witnessed the shoreline stabilizing effect at these sites; many became interested in using living shorelines to address shoreline issues associated with their own properties. However, SCDHEC OCRM does not currently have regulations specific to living shorelines, making permitting them a sometimes lengthy and challenging process (see Appendix A: 2017-2018 survey of private property owners interested in living shorelines).

SCDHEC OCRM recognized the need for new scientific information specific to the South Carolina environmental conditions on which to base new regulations and a streamlined permitting process for living shorelines. While SCDNR had data on the effectiveness of oyster-based living shorelines for over 200 locations, these data had not been comprehensively analyzed to establish relationships between site conditions and living shoreline performance and effectiveness. The SCDNR study sites were constructed at sites carefully selected to maximize their success at creating oyster habitat, including optimal salinities for oyster growth and recruitment as well as ideal bank slope and substrate type. SCDHEC OCRM and SCDNR, along with NI-WB NERR, worked together to define information needs and data gaps to develop a robust assessment of living shorelines applicable to all of the South Carolina coastal zone.

To obtain the scientific information to effectively permit and provide guidance for construction of living shorelines, SCDHEC OCRM, SCDNR, and NI-WB NERR partnered on a project funded by the NOAA National Estuarine Research Reserve System (NERRS) Science Collaborative Program. The goal of this research project was to generate the science-based information that SCDHEC OCRM needed to make effective policy decisions regarding living shorelines. This project experimentally tested the performance of softer, greener shoreline stabilization materials, including bagged oyster shell, MWRs, and natural fibers, under a broad range of conditions found in the South Carolina coastal zone (Tweel et al., in prep). Existing oyster-based living shoreline sites spanning a wider range of ages were monitored to provide an understanding of the performance over time (Kingsley-Smith et al., in prep). Monitoring of the new installation sites had only occurred for 1-2 years at the time this summary was developed.

Results of the joint project have improved the understanding and potential of living shorelines within the South Carolina coastal zone. As the chief end user of the information, SCDHEC OCRM has identified the development of a living shoreline regulatory definition and project standards as a priority for the coming years and will be directing funding to this initiative using their Coastal Zone Management Act (CZMA) Section 309 strategy. Through that funding, this document will be updated with the results from additional monitoring of recently created living shorelines sites, scheduled for the spring of both 2019 and 2020.

Purpose and Audience

The purpose of this document is to provide SCDHEC OCRM with research findings and science-based guidance as the basis for permitting living shorelines. The science-based guidance provided here is intended for SCDHEC OCRM staff who are responsible for the evaluation and permitting of living shorelines and who are involved in the development of policy and regulatory standards for living shorelines. The information provided may inform the regulatory and permitting framework. Entities, including the general public, seeking to implement a living shoreline may also find the information contained in this document useful; however, it does not contain detailed design specifications or maintenance protocols.

2.0 Regulations and Permitting Requirements

Contributed by SCDHEC OCRM

The South Carolina Coastal Tidelands and Wetlands Act (CTWA) was passed in 1977 by South Carolina's General Assembly. The CTWA created the South Carolina Coastal Council which would eventually become the SCDHEC OCRM. Through the CTWA, SCDHEC OCRM is tasked with the protection and preservation of coastal resources while promoting sound development practices within the coastal zone. The Coastal Division Regulations (S.C. Code Ann. Regs. 30-1 et seq.), promulgated pursuant to the CTWA, provide standards for evaluating activities that utilize the critical areas of the state. Over the years, these regulations have been amended to provide additional guidance to the regulated public and to reflect the progression of coastal management in the state. The increased interest in living shorelines highlights the need for specific project standards and guidance for the permitting and construction of living shoreline projects. Currently, the lack of specific project standards, or even a regulatory definition, for living shorelines results in longer permit review times, loose design requirements, and potentially ineffective projects.

The current regulations for shoreline stabilization only address traditional erosion control structures including bulkheads and rip-rap revetments. Per the existing regulations, erosion control structures are prohibited at sites that have an adequate marsh buffer which serves to protect the upland shoreline from tidally induced erosion (R. 30-12(C)(1)(c)). Where permissible, erosion control structures are required to conform to the critical area line (upland boundary) with allowances for up to 18 inches of channel ward extension when construction at the critical line is not feasible (R. 30-12(C)(1)(a)and(b)). All erosion control structures, including living shorelines, are authorized through an individual Critical Area Permit. Due to the complexities of living shorelines, these installations are subject to more rigorous review under the current regulatory framework.

Using information gathered by SCDNR, SCDHEC OCRM will consider regulatory options to streamline and simplify authorization of living shoreline installations. This may encourage property owners to use living shorelines as an alternative to hardened erosion control structures, which has the potential benefit of creating marsh and reducing the negative impacts that can result from hardening estuarine shorelines. SCDHEC OCRM coordinates closely with the U. S. Army Corps of Engineers on projects such as living shorelines which alter the critical areas. This study will inform state permitting decisions. Any individual property owner wanting to install a living shoreline must coordinate with the U.S. Army Corps of Engineers to determine if federal authorization is required.

3.0 Evaluated Living Shoreline Options

Over the last two decades, multiple organizations (e.g., SCDNR, USFWS, and TNC) have implemented oyster-based living shorelines in South Carolina. The purpose of most of these living shoreline installations was the creation of oyster habitat. Shoreline stabilization emerged as a secondary benefit. Therefore, a subset of these previously constructed living shorelines was assessed to better understand their long-term performance in the context of shoreline stabilization (Figure 3.1).

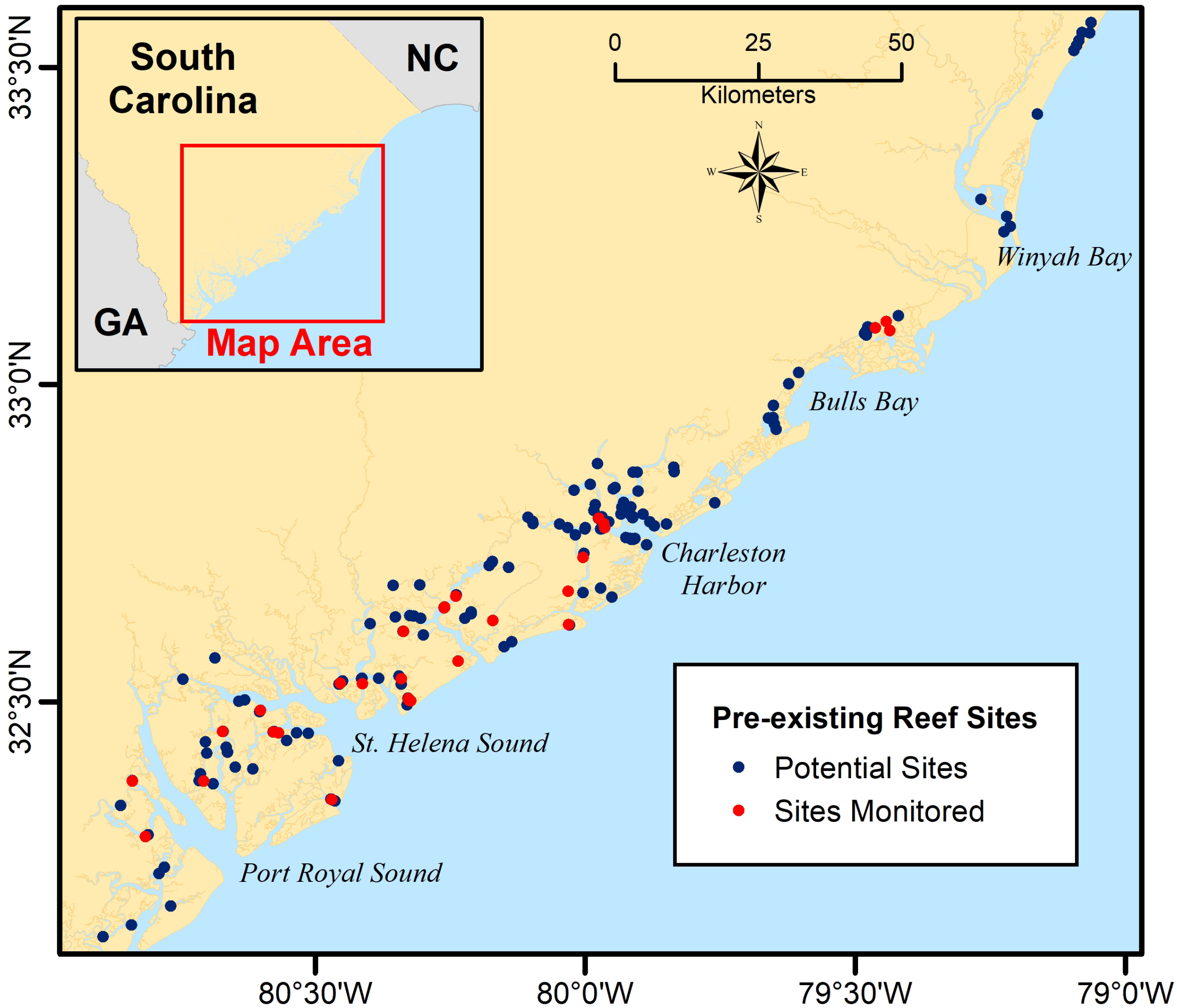


Figure 3.1. Map of existing South Carolina reef locations from 2001-2016 (blue and red symbols). A subset of reefs from this project were selectively monitored for this project (red symbols), representing a range of reef ages (0 to 16 years).

In addition, an experimental approach was utilized to better understand the relative performance of various oyster- and non-oyster-based living shoreline materials when installed at sites representing typical shoreline conditions occurring in coastal South Carolina. Experimental living shorelines were installed at a total of 16 locations (Figure 3.2). The techniques tested included oyster shell bags, manufactured wire reefs (MWRs), coir logs, and Curlex® Blocs. These do not represent the full spectrum of living shoreline materials but were considered suitable green approaches for application in South Carolina. Control areas immediately adjacent and equivalent in size to the living shoreline treatments were also established and monitored as part of the experimental approach at each site. Curlex® Blocs (American Excelsior Company), made of aspen fiber wrapped in a biodegradable sock, were included as a previously untested material in the marine environment. Curlex® Blocs, as purchased, degraded too quickly (<1 year) to provide a shoreline stabilization benefit. Therefore, this material is not discussed further within this document.

The success of a living shoreline technique at a particular site was related to a number of site attributes, such as energy level from waves and currents, width and slope of the bank, sediment firmness, sediment composition, which are discussed in Section 4.0. Techniques at various sites were evaluated using two lines of evidence, including 1) whether the material remained intact at the site for longer than one to two years, and 2) the success of measured performance metrics for each treatment at each site. Performance metrics included changes in sediment type, vertical accretion of the sediment behind the material, lateral movement of the marsh toward the materials, and the coverage of the material by oysters for oyster-based techniques. Therefore, site examples are provided to illustrate the variation in performance for each technique.

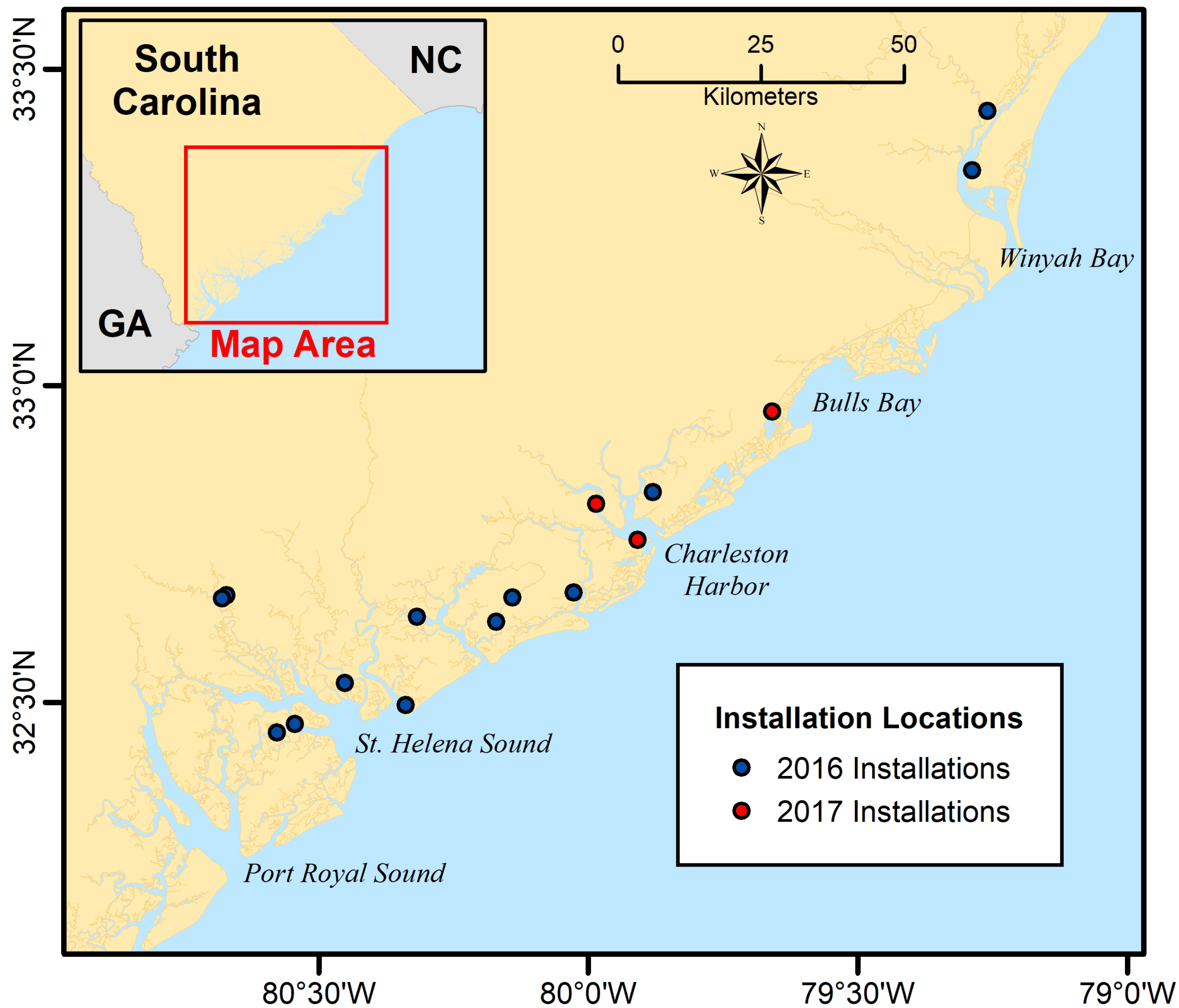


Figure 3.2. The 16 locations where experimental living shorelines were installed for this project.

In South Carolina, we find ourselves in the fortunate position of being able to utilize oyster-based techniques for many of our living shorelines. This is because in South Carolina, oysters are primarily intertidal; therefore, when they form reefs, those reefs serve as natural breakwaters, sheltering the shoreline from wave energy and promoting growth of the marsh. Additionally, between April and September, South Carolina waters are teeming with oyster larvae seeking an appropriate place to settle. Oyster recruitment is substrate-limited, so when an appropriate substrate is added in an area with oyster-supporting salinity conditions, it will likely recruit young oysters. The potential for non-oyster-based techniques was also of interest. The information provided below summarizes the conditions and success of the three materials utilized in this study.

Oyster Shell Bags

Oyster shell bag reefs have been used as a basis for living shoreline projects to increase habitat diversity and provide shoreline protection in South Carolina since the early 2000s. This method is most successful at locations conducive to oyster recruitment and growth. Oyster shell bag reefs consist of nontoxic, UV-stabilized mesh bags filled with substrate (primarily oyster shell) that facilitates the recruitment and development of oyster larvae. These bags are placed in the intertidal zone at the midpoint between the eroding bank and the mean low water (MLW) line. Placing the shell into bags creates a stable reef structure that buffers incoming wave energy and facilitates accumulation of fine sediment on the shoreward side of the reef. Design modifications can be made to oyster shell bag reefs to increase their chance of success at sites with challenging environmental conditions. Shell bags do not perform well at sites where the sink depth is more than 4 in (10 cm) into the sediment or in portions of a creek system with large amounts of sediment deposition. At these sites, shell bags sink into or become covered in sediment, resulting in oyster recruitment failure. Problems with soft sediment or high sedimentation conditions can be mitigated by installing a footprint of wood pallets on the intertidal bank beneath the shell bags. This helps to distribute the weight and increases the elevation of the reef, thereby preventing the reef from sinking into the sediment. The resulting higher profile helps to maintain the shell bags above the soft sediment so that oyster recruitment and growth can occur. Shorelines with steep intertidal banks (>16% slope), especially at sites where the sediment is soft (>10 cm sink depth) and fine (>70% silt/clay and <30% sand), have a higher incidence of individual shell bags dislodging or of the entire reef footprint sliding downslope. Caution should be taken before installing oyster shell bag reefs at sites with high-slope and soft/fine sediment. Additional staking may be required to ensure the reef does not shift.

Oyster shell bags are typically arranged in a rectangular footprint, with a width of 8 ft (2.4 m) and the length determined by the amount of shoreline to be protected (Figure 3.3). Shell bags are oriented perpendicularly to the shoreline and staked every 5 in (12.7 cm) with 30-in L-shaped rebar along the waterward row of shell bags, as well as along both sides of each reef. The rebar helps to hold the structure in place.
SCDNR uses Duronet mesh (www.swmintl.com) bag netting to make oyster shell bags. The mesh is purchased in 2,000- or 3,000-ft (610- or 914-m) rolls. The length of an unfilled bag is 4 ft (1.2 m). Roughly two-thirds of a bushel (five gallons) of oyster shell are placed into each bag, making the final dimensions approximately 2 ft (0.6 m) long, 8 in (20.3 cm) wide, and 8 in (20.3 cm) tall (Figure 3.3).

Under current SCDNR regulations, clean, cured, and dried oyster shell is the only approved substrate for oyster shell bags. If oyster shell is sourced from out of state (non-South Carolina oysters), the shell must be quarantined for a minimum of 6 months before it may be placed in South Carolina waters to avoid spreading shellfish diseases or introducing invasive species into South Carolina. Contact SCDNR at 843-953-9300 for detailed information on the quarantine verification process. SCDNR is testing alternative substrates, including mined shell and limestone, for use in mesh bags; results of these tests are expected in summer 2020.

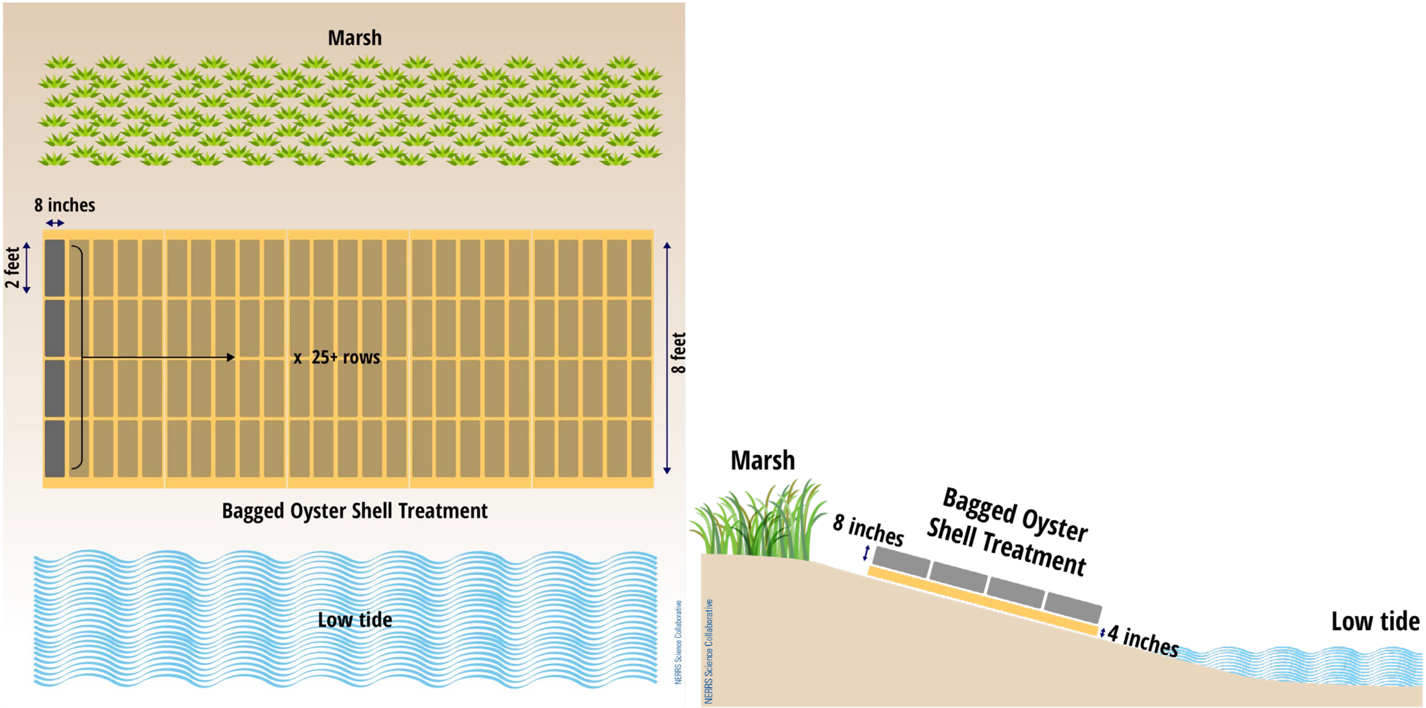


Figure 3.3. Overhead (left) and cross section (right) of a typical bagged oyster shell reef design with shell bags placed atop wood pallets.

Site Examples

Big Bay Creek, Edisto Island

The shell bag experimental treatment on Big Bay Creek (32.49352, -80.33596) was installed in July 2016 along an intertidal bank located on the inside bend of this creek (Figure 3.4). The waterbody width is 344 ft (105 m). This site is considered low energy due to the small waterbody width, the sheltered environment provided by an inside bend, and its placement within a No Wake Zone. The intertidal bank where the shell bags were placed had a slope of 26%, which is above the recommended 16% for a viable range for this type of treatment. Immediately prior to installation, the surface sediment was 65% sand and 35% silt/clay. The bank width was 15.7 ft (4.8 m) and the escarpment (i.e., the erosional area of shoreline that has some degree of vertical relief) height averaged 1.8 ft (55 cm). The 4-in (10-cm) sink depth (i.e., the depth to which a cinderblock sinks into the substrate) resulted in a sediment firmness classification of soft; thus, it was decided to place the shell bags on wooden pallets.

During the first two years following installation, a total of 10 in (26 cm) of fine sediment accumulated on the bank immediately upslope of the reef, and 9.4 in (24 cm) of sediment accumulated on the bank 30 cm (1 ft) upslope of the reef. During this same time period, the sediment surface elevation at a nearby control area decreased by 2.7 in (7 cm). Most of the sediment accumulation occurred during the first year after installation. In addition to sediment accumulating in the newly sheltered area behind the reef, sediment also collected on top of many of the shell bags located on the upslope portion of the reef, decreasing the available area for oyster recruitment and development (Figure 3.4). Percent oyster cover, measured at the mid-slope position of the reef, decreased from 26% one year after installation to 2% two years after installation. Oysters in the lower, non-sediment-covered portions of this reef are, however, growing well (Figure 3.4). Even though the slope is steep and the baseline sink depth was moderately high, the rebar has been successful at holding the treatment in position on the bank; this could be due to the fact that the sediment was 65% sand with relatively large sand grains (the other 35% was silt/clay). After two years, marsh expansion was occurring at this location (Figure 3.4), likely facilitated by the sediment stabilized by and accumulating behind the shell bag reef.

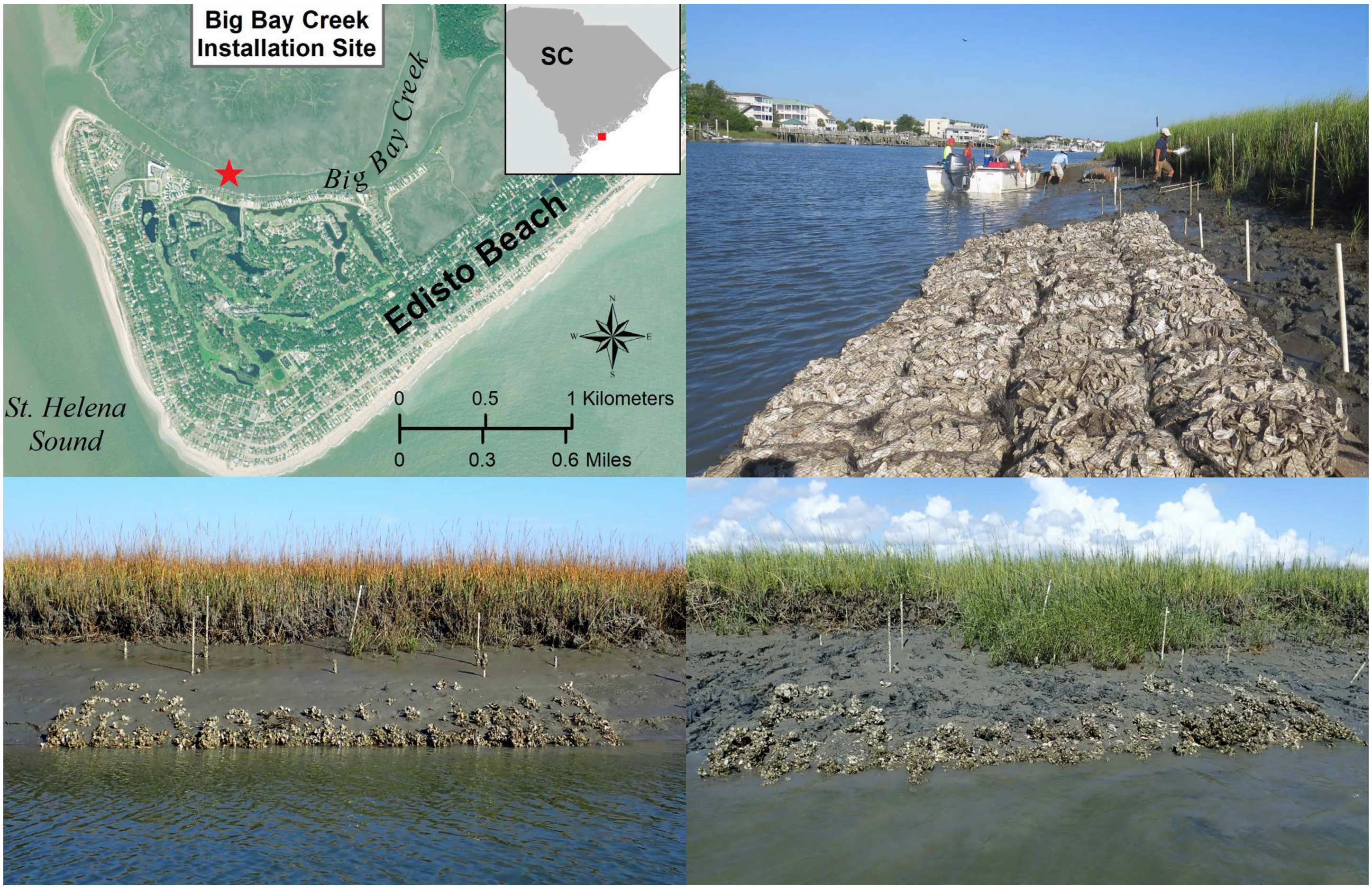


Figure 3.4. Aerial view of the living shoreline research site on Big Bay Creek (upper left). Shell bag reef constructed on wooden pallets in July 2016 (upper right). Oyster growth and sediment accumulation on reef at Big Bay Creek in November 2017 (one year post-install; lower left) and in September 2018 (two years post-install; lower right). Note marsh grass expansion (lower right).

Abbapoola Creek, Charleston

The shell bag experimental treatment on Abbapoola Creek (32.66956, -80.02127) was installed in June 2016 along an intertidal bank located on a straight section of the creek (Figure 3.5). The waterbody width at this location measured 253 ft (77 m), and this site is considered low energy due to its narrow water width and relatively low boat traffic. At baseline, the intertidal bank where the shell bags were placed had a slope of 16%, and 70% of the surface sediment was made up of silt/clay (the other 30% was sand). The bank width was 13.4 ft (4.1 m), and the escarpment height averaged 1.4 ft (43 cm). The baseline sink depth at this treatment (4.9 in; 12.5 cm) resulted in a sediment firmness classification of soft; therefore, the shell bags were placed on wooden pallets (Figure 3.5).

During the first two years following installation, a total of 11.5 in (29 cm) of silt/clay sediment accumulated on the bank immediately upslope of the reef. A greater amount of sediment accumulated during the first year (9 in; 23 cm) than during the second year (2.5 in; 6 cm). On the bank 1 ft (30 cm) upslope of the reef, 10.1 in (26 cm) of sediment accumulated, and during this same 2-year time period, the sediment surface elevation at a nearby control area decreased by 1.9 in (5 cm). Moderate sediment accumulation on top of the reef decreased the available area for oyster recruitment and development (Figure 3.5). Percent oyster cover, measured at the mid-slope position of the reef, was 41% one year post-installation and 35% two years post-installation. After two years, oysters were growing well on all non-sediment-covered portions of this treatment. One side of this treatment slid a moderate distance down the bank, likely because the slope was fairly steep and the sediment was muddy (70% silt/clay). A slight amount of marsh expansion has been observed behind the oyster sill at this location (Figure 3.5).

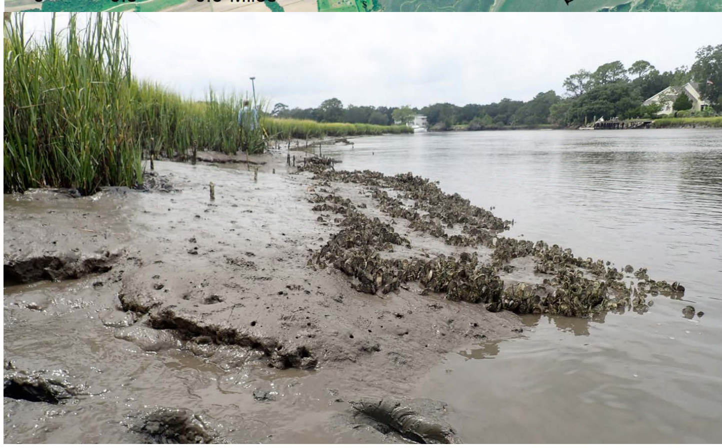


Figure 3.5. Aerial view of the living shoreline research site on Abbapoola Creek (upper left). Shell bag constructed on wooden pallets in June 2016 (upper right). The same reef in August 2018 (2 years post-install; lower left). The close side of the reef has slid a short distance down the bank, away from the monitoring PVC pole.

Morgan Island, St. Helena

The shell bag experimental treatment on Morgan Island (32.46485, -80.54217) was installed in July 2016 along an intertidal bank located on an outside bend shoreline along Parrot Creek, where it joins with the Morgan River (Figure 3.6). The waterbody width at this location measured 2,749 ft (838 m). This site is considered high energy because it is exposed to relatively high wind, wave, and tidal flow energy associated with its waterbody width and proximity to the Morgan River. At baseline, the intertidal bank where the shell bags were placed had a slope of 4%, and 92% of the surface sediment was made up of silt/clay (the other 8% was sand). The bank width was 85.3 ft (26.0 m), and the escarpment height averaged 2.1 ft (64 cm). The 8.2-in (20.9 cm) sink depth resulted in a sediment firmness classification of very soft; thus, it was decided to place the shell bags on wooden pallets (Figure 3.6).

During the first two years following installation, a total of 5.4 in (14 cm) of fine sediment accumulated on the bank immediately upslope of the reef. A greater amount of sediment accumulated during the first year (4.2 in; 11 cm) than during the second year (1.3 in; 3 cm). On the bank 1 ft (30 cm) upslope of the reef, 1.4 in (4 cm) of sediment accumulated, and during this same 2-year time period, the sediment surface elevation at a nearby control area decreased by 4.1 in (11 cm). Percent oyster cover, measured at the mid-slope position of the reef, was 4.3% one year post-installation and 4.5% two years post-installation (Figure 3.6). Low recruitment of oysters appears to be cause for the low percentage of oyster coverage, but not due to lack of substrate; the shell bags have not been covered by sediment. Although the sediment was muddy (92% silt/clay and 8% sand), this technique remained in place (i.e., it did not slide down the bank), likely because the slope was so gentle (4%). Marsh expansion has not yet been observed at this location.

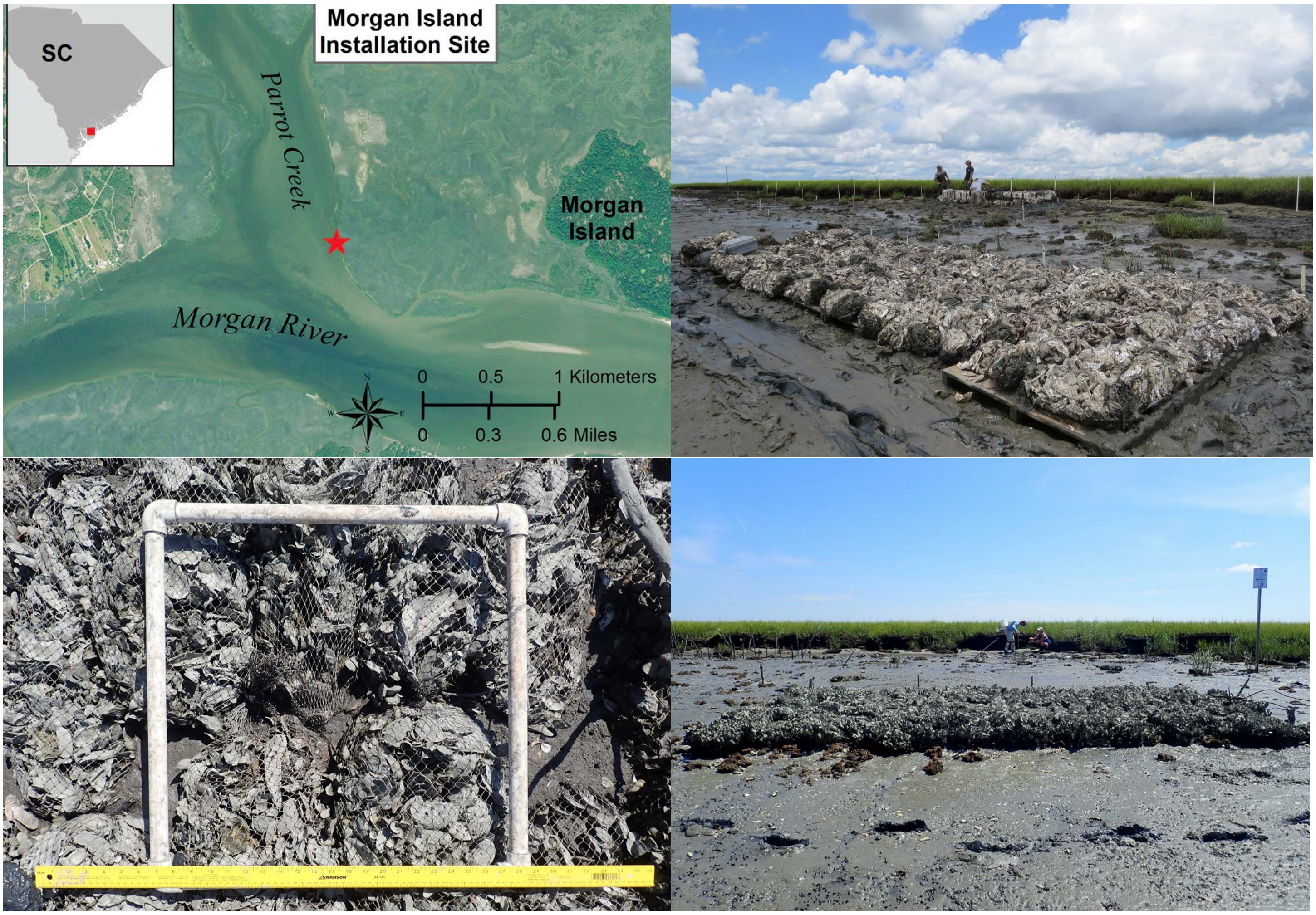


Figure 3.6. Aerial view of the living shoreline research site on Morgan Island (upper left). Shell bag constructed on wooden pallets in July 2016 (upper right). Percent oyster coverage (lower left) and shell bag reef (lower right) in August 2018.

Manufactured Wire Reefs (MWRs)

Repurposed crab traps coated in cement have been used in living shoreline projects to increase habitat diversity and provide shoreline protection in South Carolina since 2011. SCDNR has been successful in using cement-coated repurposed abandoned and donated crab traps that rapidly attract larval oysters, yielding high coverage supported by rapid growth. Private citizens, however, do not have access to large numbers of used crab traps. The State of South Carolina discourages anyone from removing crab traps from estuaries in case they are not actually abandoned. It is unlawful to “remove, willingly damage, or interfere with any fishing equipment belonging to another” [Section 50-5-105 (A)]. Crab traps that are suspected to be abandoned can be reported to crabtraps@dnr.sc.gov. More information on this topic is available at http://www.dnr.sc.gov/marine/crabtraps/.

Due to the success of the repurposed crab trap method – but limited availability for private citizen use – SCDNR began testing MWRs (Figure 3.7). MWRs can be manufactured for the purpose of creating an oyster-based living shoreline adjacent to private property. MWRs are constructed from the same wire mesh and have the general shape typically used for the construction of recreational and commercial crab traps. Raw materials and tools can be purchased online. At this time, these structures are not currently available for purchase “off the shelf” from any retailer, but customized orders can be made through crab trap suppliers. The galvanized wire mesh can either be uncoated or coated with vinyl. The mesh is coated in a thin layer of cement to serve as an attractive substrate for the settlement of larval oysters. A thinset tile mortar is typically used, since it adheres relatively well to the wire mesh and is cost effective. The mortar is mixed with water in a cement mixer to the proper consistency and then placed in a cement sprayer. A thin layer is applied to the entire surface of each MWR unit and then left to cure for at least two weeks prior to use in the construction of a living shoreline.

Figure 3.7. Manufactured wire reefs (MWRs) were developed as an option similar to repurposed crab traps.

MWRs are 4 ft (1.2 m) long, 2 ft (0.61 m) wide, and 18 in (45.7 cm) high. They are manufactured with these dimensions to create more surface area for larval oyster recruitment compared with crab traps (2 ft x 2 ft x 2 ft; 0.61 m x 0.61 m x 0.61 m). MWRs are installed on the intertidal bank halfway between the waterward marsh edge and the mean low water line to provide optimal conditions for oyster survival and productivity (Figure 3.8). SCDNR tested MWRs in a staggered checkerboard-like pattern to maximize surface area while creating one contiguous structure. They are secured to the sediment using #3 J-bar rebar that is at least 24 inches long and has a 4-inch candy cane bend, which is placed into the sediment through the mesh of the reef at four points (two on each side), holding the reef in place on the bank. These structures are well-suited for sites where the sediment is too soft for traditional reef materials such as bagged oyster shell. MWR units are also much lighter than bagged shell, take less effort to install, and, due to the finite supply of oyster shell, are likely to be a more viable option for installing oyster-based living shorelines at a commercial scale.

It appears that the vinyl-coated mesh may remain intact longer than the exposed wire; however, additional side-by-side assessment of the two versions of MWR units is required to evaluate this issue.
Recruitment of oysters on MWRs is not immediate. It may take 2-3 years before the MWR is well colonized by juvenile oysters. Juvenile oysters grow rapidly, but it takes up to 1-2 years for them to reach a size that effectively traps sediment. MWRs will take longer than bagged shell to achieve a similar percentage of oyster cover. Therefore, it will take longer for the MWRs to provide shoreline protection that is similar to traditional bagged-shell-based approaches. Once established, however, the top surface of MWRs will have a higher elevation than bagged shell or bagged-shell-on-wood-pallets methods, which will likely make MWRs less susceptible to being covered by sediment in high-sedimentation environments. Also, due to their higher profile, MWRs will have the capacity to trap a greater volume of sediment along the upslope portion of the bank after becoming fully colonized by oysters. A better understanding of the variation in recruitment and growth of oysters on the different types of MWRs could be achieved by future side by side comparisons.

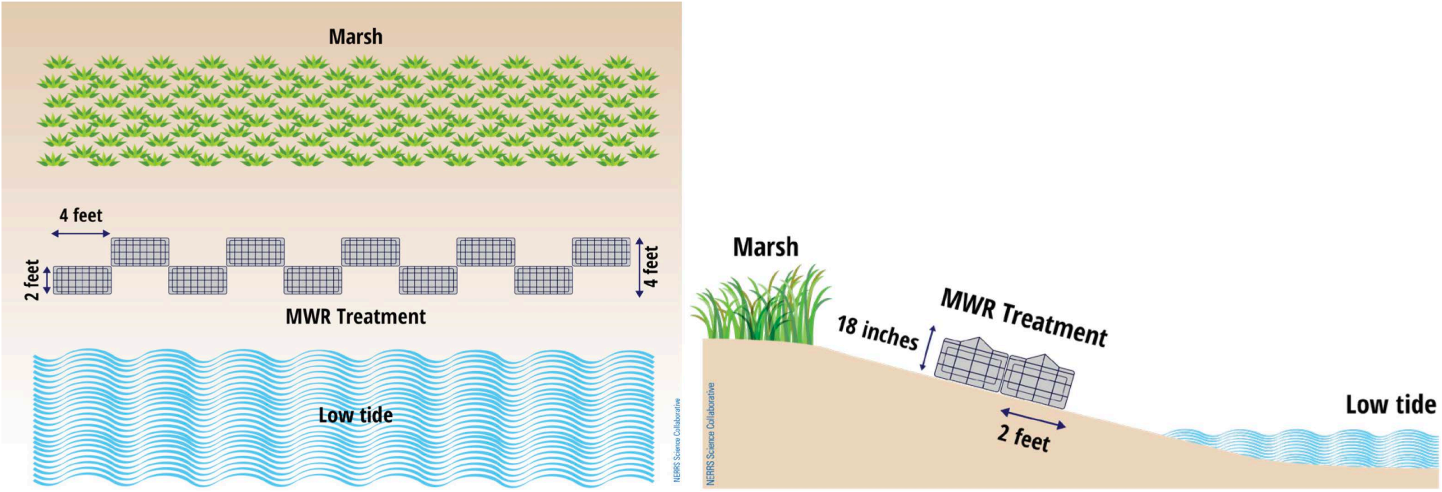


Figure 3.8. Overhead (left) and cross section (right) views of a typical manufactured wire reef (MWR) design in the intertidal zone used for this study.

Site Examples

Big Bay Creek, Edisto Island

The vinyl-coated MWR experimental treatment on Big Bay Creek (32.49354, -80.33606) was installed in July 2016 along an intertidal bank located on the inside bend of this creek (Figure 3.4). The waterbody width at this location measured 344 ft (105 m), and this site was considered low energy due to the small waterbody width, the sheltered environment provided by an inside bend, and its location within a No Wake Zone. At baseline, the intertidal bank where the MWRs were placed had a slope of 28%, and 35% of the surface sediment was made up of silt/clay (the other 65% was sand). The bank width was 15.7 ft (4.8 m) and the escarpment height averaged 2.3 ft (70 cm). The 4.1-in (10.3 cm) sink depth resulted in a sediment firmness classification of soft.

During the first two years following installation, a total of 3.7 in (9 cm) of fine sediment accumulated on the bank immediately upslope of the reef, and 4.8 in (12 cm) of sediment accumulated on the bank 1 ft (30 cm) upslope of the reef. During this same time period, the sediment surface elevation at a nearby control area decreased by 2.7 in (7 cm). This treatment has successfully maintained its location on the bank, with no sliding downslope. Oyster recruitment and growth, on the surface of the wire, increased markedly from 11% at one year post-installation (less than at the shell bag reef at this site) to 54% at two years post-installation (greater than at the shell bag reef at this site; Figure 3.9). As seen in a photo taken in May 2019, 34 months after installation, marsh expansion has started to occur at this location (Figure 3.10).

Figure 3.9. Live oyster coverage on MWRs at Big Bay Creek in October 2017 (one year post-install; left) and September 2018 (two years post-install; right).

Figure 3.10. Almost 3 years after installation of the MWR at Big Bay Creek, oyster cover and growth continue to increase, and marsh expansion was starting to occur. Photo taken in May 2019.

Orangegrove Creek, Charleston

The vinyl-coated MWRs experimental treatment on Orangegrove Creek (32.80887, 79.97745) was installed in August 2017 along an intertidal bank located on the inside bend of this creek (Figure 3.11). The water-body width at this location is 203 ft (62 m), and this site is considered low energy due to limited boat traffic, the sheltered environment offered by the inside bend position, and the narrowness of the creek. This was the narrowest waterbody width of any site monitored for this project. At baseline, the intertidal bank along this shoreline had a slope of 20%, very muddy sediment (97% silt/clay and 3% sand), and a sink depth (7.4 in; 21.3 cm) that resulted in a sediment firmness classification of very soft. The bank width was 10.8 ft (3.3 m), and the escarpment height averaged 1.5 ft (44.4 cm).

During the first 20 months post-installation, a total of 5.3 in (13 cm) of fine sediment accumulated on the bank 1 ft (30 cm) upslope of the reef. During this same time period, an average of 7.5 in (19 cm) of sediment elevation was lost at a nearby control area. Oyster recruitment and growth on the surface of the wire remains fairly limited at 20 months post-installation (Figure 3.11), but this treatment has only been in the environment for one full oyster recruitment season thus far. This treatment slid slightly down the bank, likely due to the relatively steep slope and very muddy sediment.

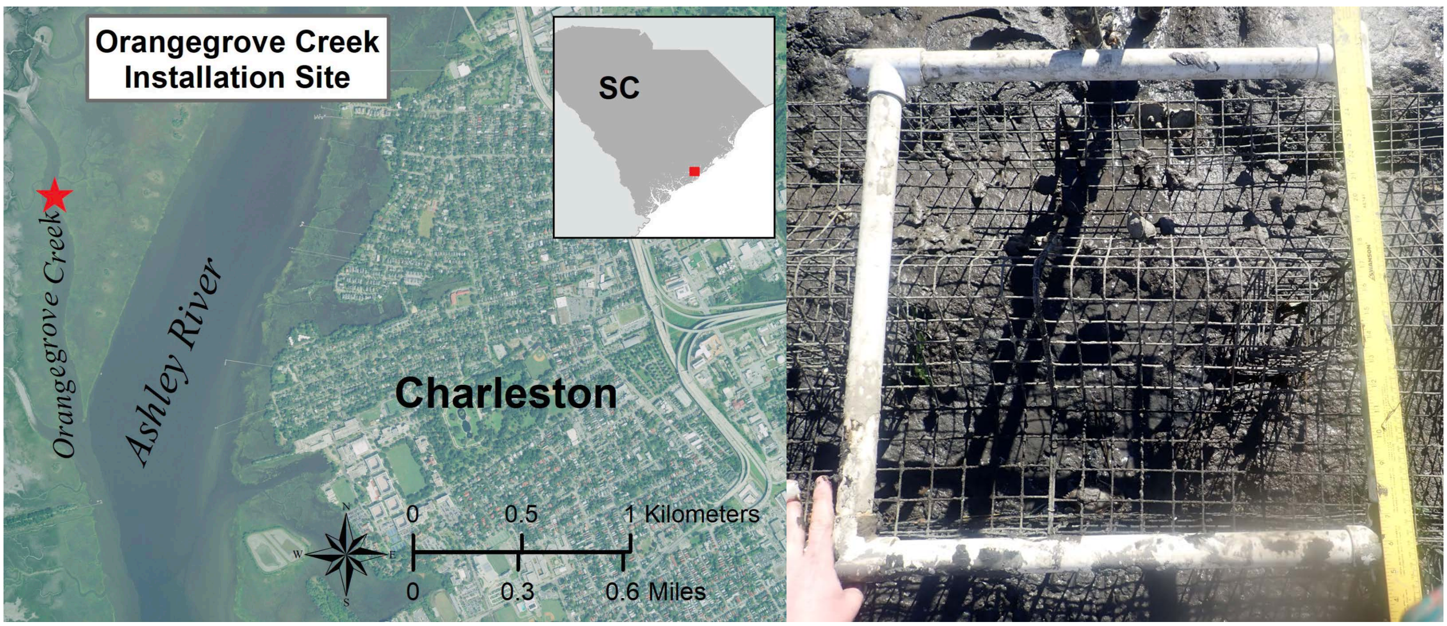


Figure 3.11. Living shoreline research site on Orangegrove Creek with an aerial view (left). Live oyster coverage on MWR at Orangegrove Creek in April 2019 (right) with limited recruitment and growth after 21 months.

Morgan Island, St. Helena

The vinyl-coated MWR experimental treatment on Morgan Island (32.46501, -80.54226) was installed in July 2016 along an intertidal bank located on an outside bend shoreline on Parrot Creek, where it joins with the Morgan River (Figure 3.12). The waterbody width at this location measured 2,749 ft (838 m). This site was considered high energy because it is exposed to relatively high wind, wave, and tidal flow energy associated with its waterbody width and proximity to the Morgan River. At baseline, the intertidal bank where the shell bags were placed had a slope of 10%, and 95% of the surface sediment was made up of silt/clay. The bank width was 85.3 ft (26.0 m), and the escarpment height averaged 2.3 ft (70 cm). The 8.2-in (20.9 cm) sink depth resulted in a sediment firmness classification of very soft.

On the bank 1 ft (30 cm) upslope of the reef, there was a net loss in sediment surface elevation of 4.0 in (10 cm) during the first two years after installation. During this same 2-year time period, the sediment surface elevation at a nearby control area decreased by 4.1 in (11 cm). Wind and wave energy from Hurricane Matthew, in October 2016, caused multiple MWR units to become dislodged (Figure 3.12). These MWR units and associated rebar were found less than 305 ft (100 m) away at the next site visit and were easily re-anchored to the remaining original reef structure. Percent oyster cover was 0.9% one year post-installation and 14.8% two years post-installation (Figure 3.12). Marsh expansion has not yet been observed at this location.

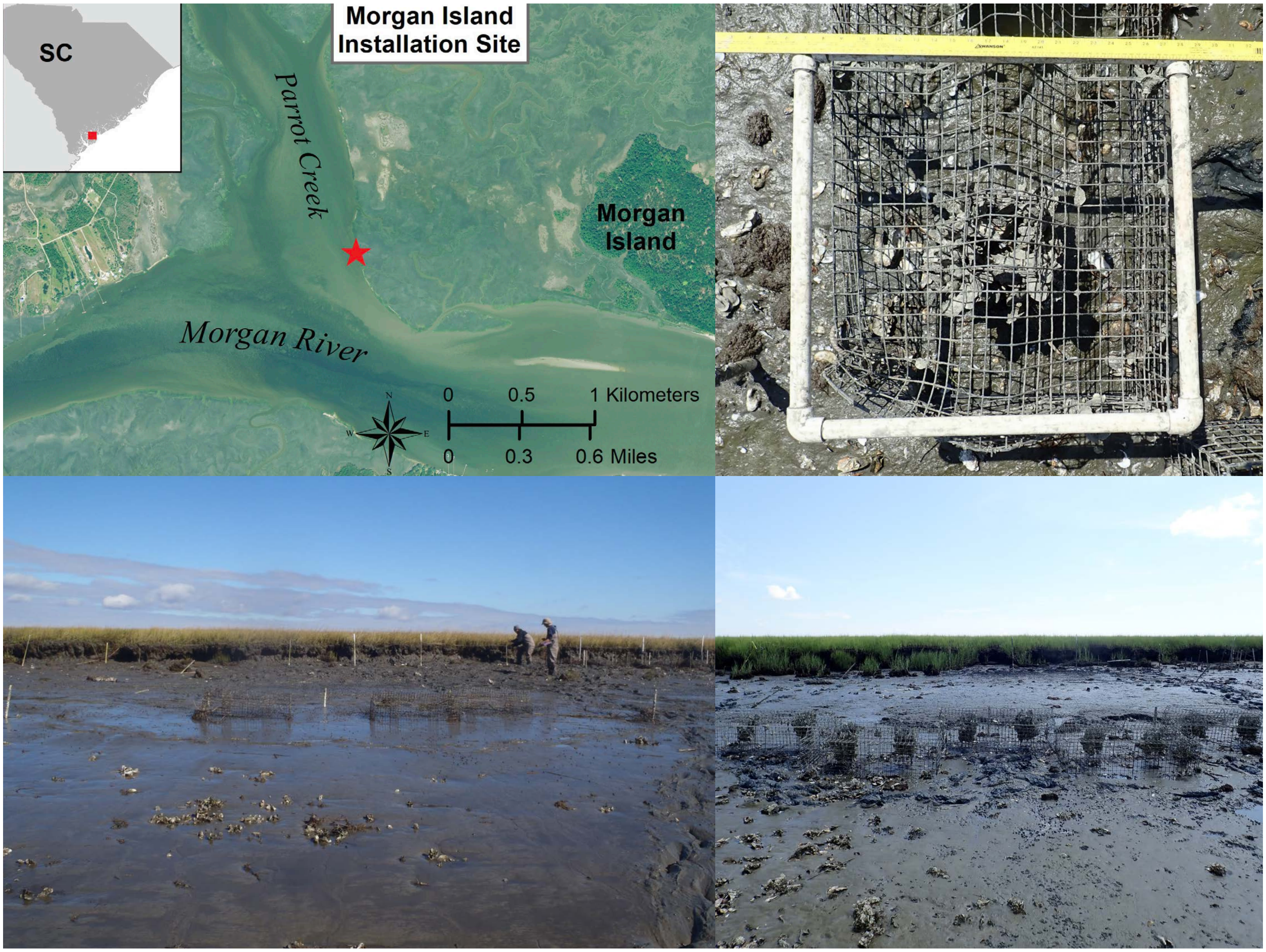


Figure 3.12. Aerial view of the living shoreline research site on Morgan Island Creek (upper left). Two MWR units were dislodged and relocated nearby by Hurricane Matthew (lower left) but were easily moved back into position. Live oyster coverage on MWR in August 2018 (upper and lower right).

Coir Logs

There are scenarios where oyster-based methods are not appropriate or potentially less effective than other alternatives. For example, if the salinity is too low or too variable to support oyster populations, or if someone wants to stabilize a shoreline for a short time period, then an alternative may be more suitable. Coir logs have been used in living shoreline applications in several states as an alternative to oyster-based shoreline stabilization and protection methods. These logs are used to combat erosion caused by wave energy and to trap sediment on the shoreward side of the log. As the coir log stabilizes and accretes sediment, marsh plants can colonize the portion of the bank on the shoreward side of the reef. Coir logs are a living shoreline option suited for lower salinity or freshwater environments and potential areas that are suitable for oyster growth but where oyster development is not of interest. The logs perform best in low energy environments, as they tend to dislodge or degrade too quickly at sites with frequent boat wakes or longer fetches. Coir logs will degrade over time and will need to be replaced on a periodic basis if the stabilization of the marsh has not been achieved.

Coir logs are biodegradable cylinders of compressed coconut husk fiber, also known as coir (Figure 3.13). They are available in a variety of lengths and widths but are typically sold in 10 ft (3.0 m) lengths. Coir logs are wrapped in a coir or jute netting that contains the compressed coir. SCDNR has found it useful to wrap the coir log in an additional layer of coir netting with smaller openings to better contain the compressed coir fibers and lengthen the life span of the coir logs in the estuarine environment (Figure 3.13). A folded underlayment of coir fabric is also beneficial at sites with soft or very soft sediment. This underlayment reduces the amount that the coir log sinks into the soft sediment.

Figure 3.13. Coir log (10 ft length x 16 in diameter; 3 m x 41 cm) with a single-layer tube of coir netting with smaller openings and additional netting placed under the coir log to reduce sinking of the log into the sediment.

Coir logs can be placed in a range of positions along the intertidal bank, extending from directly abutting the marsh edge to halfway between the marsh edge and the MLW line. Coir logs should be deployed in a gentle “U” configuration, with the inside bend of the U facing shoreward (Figures 3.14 and 3.15). Coir logs can be placed in single or double rows. When installing a double-row coir log treatment, the shoreward row may be placed at the marsh edge or pressed against an escarpment to shelter an eroding area from wave energy, with the waterward row running parallel, approximately 6.6 ft or 2 m downslope, in order to trap sediment between the rows of logs (Figures 3.14 and 3.15).

Regardless of their installation location, it is imperative that coir logs are securely staked and tied in place. This can be done using rot-resistant wooden stakes with a hole drilled a few inches from the top through which to pass coir twine. Stakes are pounded into the sediment through the folded coir mat resting under the log at 1-ft (0.3 m) intervals around the perimeter. Coir twine is laced through the stakes with care to ensure the stakes and coir twine are touching the log. Stakes are then pounded further into the sediment until the coir twine is pressed tightly into the top surface of the log in order to reduce potential vertical movement of the log (Figures 3.14 and 3.15). Additional stakes should be installed inward, in an A-frame configuration, where the stakes are touching the coir log near the top surface and coming in contact with each other in the air space over the top center surface of the coir log. A-frame stakes do not need eye holes for twine; the stakes themselves will hold the log against the bank. The combination of vertical and A-frame staking will prevent the log from sliding downslope (vertical stakes) and prevent vertical movement of the log in response to wave energy (A-frame stakes), which can lead to the twine wearing and breaking (Figures 3.14 and 3.15). Coir logs that are not properly secured to the bank can go missing within one tidal cycle regardless of the site conditions.

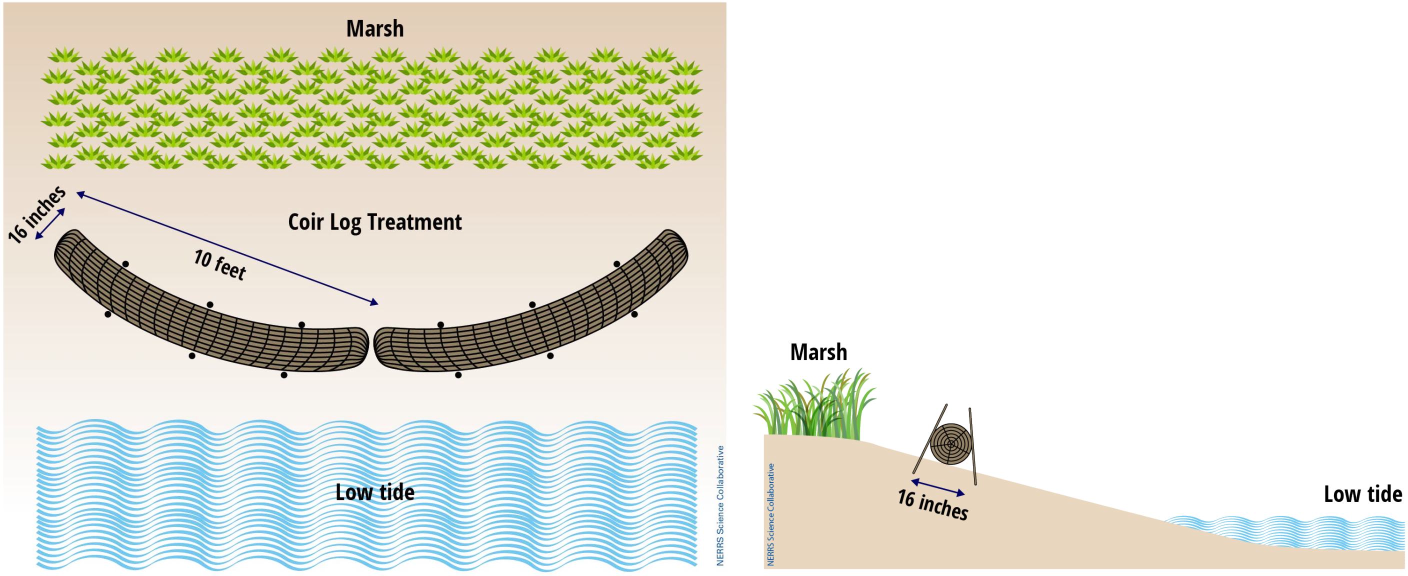


Figure 3.14. Overhead (left) and cross section (right) of a typical single row coir log design in the intertidal zone used for this study.

Figure 3.15. Coir rope laced through stakes and tied to secure log in place (upper left). Bagged oyster shell was used in front of some coir logs to prevent undercutting of the log but was later discontinued (upper right). Double-row coir log at Orangegrove Creek, with alternate A-frame staking, installed in August 2017 (lower left).

Coir logs are widely available and can be ordered through large home improvement stores or through numerous online companies. A subject of particular concern is the mesh that contains the coir. Some suppliers use a jute or coir netting that contains a monofilament line at its center. When the log inevitably degrades, the monofilament line remains, which can be severely damaging to many marine species. Therefore, the core of the mesh must consist of cotton twine and not monofilament line.

Site Examples

Big Bay Creek, Edisto Island

The coir log experimental treatment on Big Bay Creek (32.49347, -80.33576) was installed in July 2016 along an intertidal bank located on the inside bend of this creek (Figure 3.16). The waterbody width at this location measured 344 ft (105 m), and this site was considered low energy due the small waterbody width, the sheltered environment provided by an inside bend, and its location within a No Wake Zone. At baseline, the intertidal bank where the coir logs were placed had a slope of 20%, and 36% of the surface sediment was made up of silt/clay (the other 64% was sand). The bank width was 15.7 ft (4.8 m), and the escarpment height averaged 2.1 ft (65 cm). The 4.1-in (10.3 cm) sink depth resulted in a sediment firmness classification of soft.

During the first two years following installation, a total of 10.8 in (27 cm) of fine sediment accumulated on the bank immediately upslope of the reef, and 10.9 in (28 cm) of sediment accumulated on the bank 1 ft (30 cm) upslope of the reef. During this same time period, the sediment surface elevation at a nearby control area decreased by 2.7 in (7 cm). Most of the sediment accumulation occurred during the first year after installation (Figure 3.16). Even though the slope was steep and the baseline sink depth was high, the stakes and coir twine were successful at holding the treatment in position on the bank; this could be due to the relatively coarse sediment (65% sand) present on the intertidal bank at baseline. Approximately 3 years after installation (May 2019), natural (not planted) marsh grass has begun to colonize the bank behind the coir log (Figure 3.16, lower right).

Figure 3.16. A single-row coir log treatment at Big Bay Creek (Figure 3.4) in July 2016 (upper left), October 2017 (upper right), September 2018 (lower left), and May 2019 (lower right).

Orangegrove Creek, Charleston

The double-row coir log experimental treatment on Orangegrove Creek (32.80904, 79.97747) was installed in August 2017 along an intertidal bank located on the inside bend of this creek (Figure 3.17). The water-body width at this location measured 203 ft (62 m), and this site was considered low energy due to limited boat traffic, the sheltered environment provided by an inside bend, and narrow creek width. This was the narrowest waterbody width of any site monitored for this project. At baseline, the intertidal bank where the coir logs were placed had a slope of 24%, and 95% of the surface sediment was made up of silt/clay. The bank width was 10.8 ft (3.3 m), and the escarpment height averaged 1.2 ft (37 cm). The 8.4-in (21.3 cm) sink depth resulted in a sediment firmness classification of very soft. The coir log closest to the marsh was staked against the marsh grass and followed the contours of the escarpment, while the midpoint of the shoreward coir log was staked 5.5 ft (1.7 m) from the upper coir log (Figure 3.17).

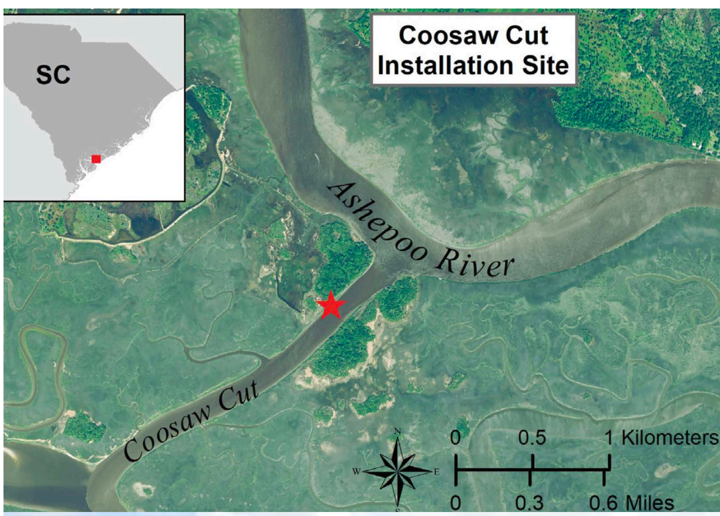
During the first 20 months post-installation, a total of 6.2 in (16 cm) of fine sediment accumulated on the bank 1 ft (30 cm) upslope of the bottom row of coir logs (Figure 3.17). During this same time period, an average of 7.5 in (19 cm) of sediment elevation was lost at a nearby negative control area. One of the coir logs in the escarpment edge row, at some point between monitoring in August 2018 and April 2019, broke away from its stakes and went missing (Figure 3.17). While a significant amount of sediment had accumulated at this treatment site, no marsh expansion has been observed to date.

Figure 3.17. Double-row coir log treatment at Orangegrove Creek in August 2017 (upper left), May 2018 (upper right), and April 2019 (lower). The upper left coir log went missing at some point between August 2018 and April 2019.

Coosaw Cut, Bennetts Point

The single-row coir log experimental treatment at Coosaw Cut (32.52894, -80.44922) was installed in June 2016 and re-installed in September 2017 along an intertidal bank located on the dredged, straight section of the Intracoastal Waterway (ICW) (Figure 3.18). The waterbody width at this location measured 427 ft (130 m), and this site was considered high energy due to the level of boat traffic on the ICW. At baseline, the intertidal bank where the coir log was placed had a slope of 17%, and only 16% of the surface sediment was made up of silt/clay (the other 74% was sand). The bank width was 24.1 ft (7.3 m), and the escarpment height averaged 0.7 ft (22 cm). The 1.5-in (3.9 cm) sink depth resulted in a sediment firmness classification of very firm. The waterward edge of the log was enforced with a single row of oyster shell bags, secured along the coir log with rebar, to prevent undercutting of the coir log by tidal currents and boat wakes (Figure 3.18).

Both coir log treatments, the 2016 installation and the 2017 installation, became dislodged before any scheduled post-installation monitoring occurred. Both installations were documented as failures. The single row of oyster shell bags installed adjacent to the coir log is still in place, and the oysters growing on these shell bags are continuing to provide minimal protection to this area (Figure 3.18). All coir log treatments installed at ICW sites for this project were considered failures. The use of coir logs at high-energy sites, including locations along the ICW or sites exposed to high wind and wave energy as a result of large water body widths, is not recommended.



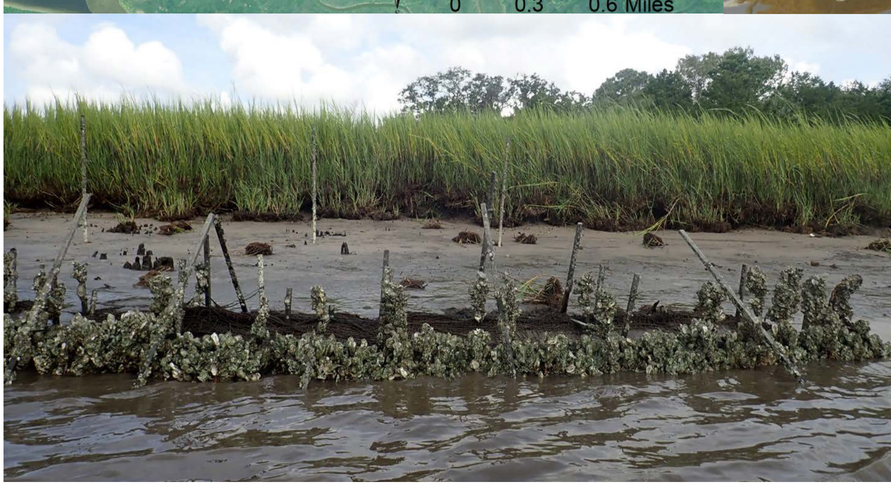


Figure 3.18. Aerial view of the Coosaw Cut experimental living shorelines site (upper left). Coir log treatment immediately after re-installation in September 2017 (upper right). At select sites, bagged oyster shell was used in front of the coir logs to prevent undercutting of the log (upper right). Missing coir logs with remaining oyster shell bags in September 2018 (lower left).

Salt Marsh Grass Planting

In addition to the erosion controls mentioned above, there are supplemental practices that can aid and enhance shoreline stabilization, primarily the planting of a marsh grass (e.g., *Spartina alterniflora* or smooth cordgrass). All of the above methods are intended to promote sediment accretion with the ultimate goal of marsh plant colonization. The root and rhizome network established by the growth and propagation of marsh plants serves as a long-term sediment stabilization network.

With successful shoreline stabilization, establishment of the root and rhizome network often happens naturally. In places where existing marsh plants are sparse, however, or in cases where an expeditious timeline is preferred, planting of marsh grass is an option. It is important to choose an appropriate species for planting. To determine the appropriate species of grass, the adjacent marsh grass should be identified. In most estuarine areas, smooth cordgrass will be the dominant marsh grass species; however, in lower salinity areas, another species may be more appropriate. Tools to assist with identifying native plant species include field guides, smartphone apps such as iNaturalist, and websites. In addition, *A Guide to the Salt Marshes and Tidal Creeks of the Southeastern United States* (www.saltmarshguide.org) provides information about common plants found along estuarine shorelines in South Carolina.

Smooth cordgrass and other native marsh plants can be acquired by contacting local plant nurseries that grow native wetland plants. SCDNR has only planted smooth cordgrass. The following best practices are for this species, but it is likely that the recommendations are relevant to other marsh grasses.

Mature plants can be successfully planted behind the living shorelines used in this project without requiring any further growth or care prior to installation. The hardiness of each plant will vary, but mature plants should have a developed root or rhizome network prior to planting. Proper planting is crucial to a successful installation. It is recommended that the living shoreline be left unplanted for at least one year post-installation, so that the sediment behind it has a chance to accumulate and stabilize. The elevation of the sediment should be high enough to be dry and completely exposed at low tide for smooth cordgrass to be successful. Smooth cordgrass will not survive at sites that are fully submerged. Findings from this study indicate smooth cordgrass should not be planted below 3.3 ft (1 m) mean high water (MHW).

The hole dug for each plant must be deep enough so that after planting, the roots are completely covered by the displaced sediment to a depth of at least one inch. The goal is to secure each plant to prevent the plug from floating away with the next tide. Success of the planting is measured in two phases; the first is that plants remain in place throughout the next few tidal cycles. The second is the regrowth of vegetation the following spring. Planted smooth cordgrass often lose a large portion of their leaf area to wave damage after installation, but if the rhizome network is intact, the leaves should rebound the following year.

Site Examples

Big Bay Creek, Edisto Island

Two single-row coir log treatments were installed in July 2016 along an intertidal bank located on the inside bend of Big Bay Creek (Figure 3.16). The waterbody width at this location measured 344 ft (105 m), and this site was considered low energy due to the small waterbody width, the sheltered environment provided by an inside bend, and its location within a No Wake Zone. At the time of installation, the slopes for the two treatments were 19% and 20%, and the sediment was relatively sandy (63% sand and 37% silt/clay). The bank width was 15.7 ft (4.8 m) and the escarpment heights for the two treatments averaged 2.4 ft (74 cm) and 2.1 ft (65 cm). The 4.1 in (10.3 cm) sink depth resulted in a sediment firmness classication of soft.

In April 2018, 21 months after installation (after allowing for sediment to accumulate and stabilize), one of the Big Bay Creek single-row coir log treatments was planted with smooth cordgrass (Figure 3.19). The other treatment was left unplanted. The purpose of the marsh planting was to test whether marsh expansion behind a living shoreline treatment occurs at a faster rate at a planted treatment in comparison with the same treatment type that is not planted.

Behind the planted coir log treatment, the majority of the planted smooth cordgrass survived the first growing season and winter. As of May 2019, the new marsh grass was growing well. At the planted coir log treatment, the area of the bank shoreward of the log had a higher percent cover of marsh grass than the equivalent bank area upslope of the unplanted coir log treatment. Although the planting accelerated marsh expansion along this shoreline, natural marsh expansion had started to occur behind the unplanted treatment by May 2019, and it is possible that the unplanted treatment could catch up to the planted treatment within 1-2 growing seasons (Figure 3.19).

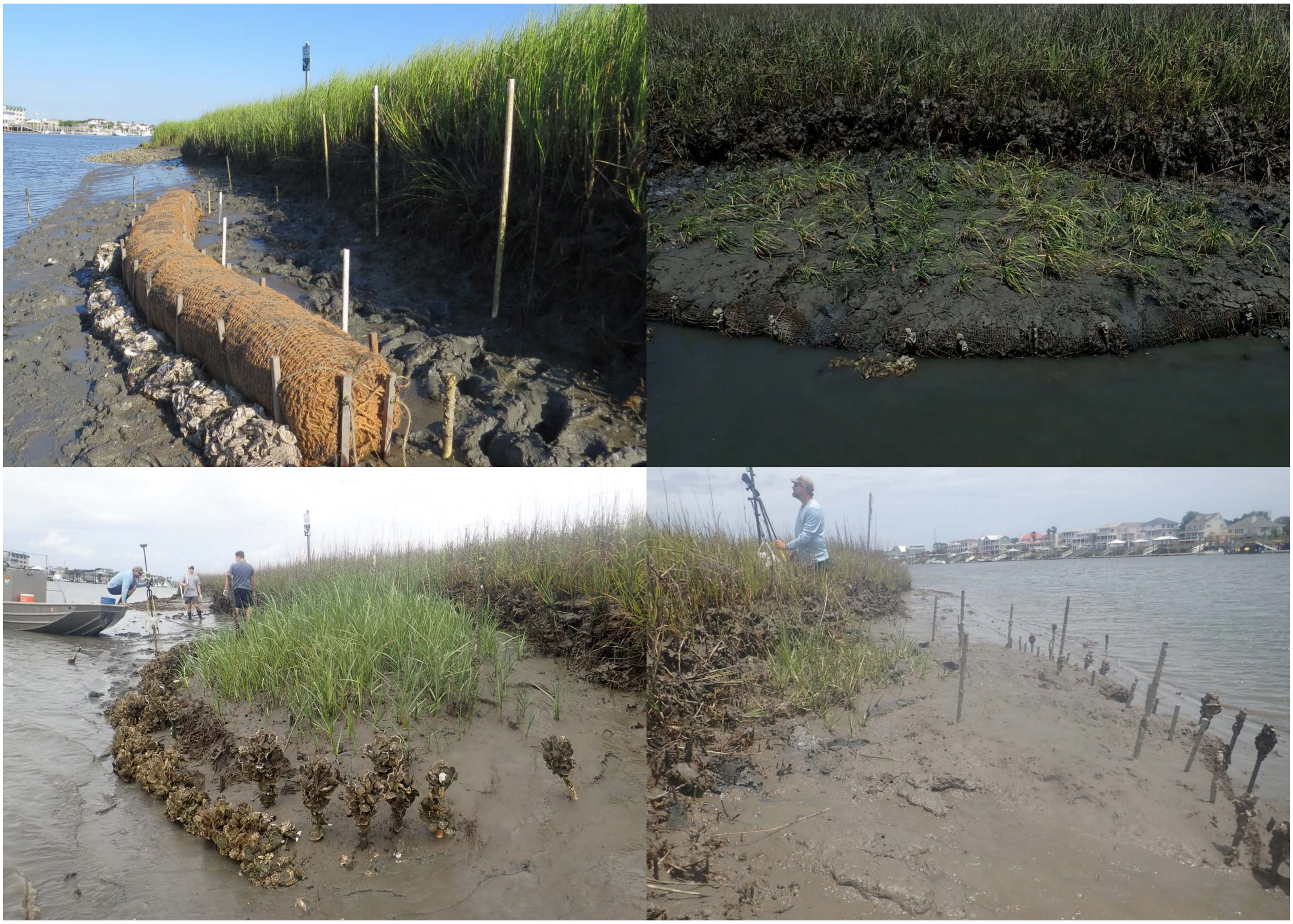


Figure 3.19. A single-row coir log treatment at Big Bay Creek in July 2016, with a single row of shell bags along the waterward edge (upper left). The same coir log treatment in April 2018, with smooth cordgrass planted behind the log (upper right). Replicate coir log treatments were installed at this site. The planted coir log treatment (lower left) demonstrated excellent smooth cordgrass cover on the bank upslope of the treatment in May 2019, one year after planting, as well as excellent oyster recruitment on the shell bags and stakes. In May 2019, natural marsh expansion was also occurring behind the non-planted coir log treatment (lower right).

Orangegrove Creek, Charleston

Two double-row coir log treatments were installed in August 2017 along an intertidal bank located on the inside bend of Orangegrove Creek (Figure 3.17). The waterbody width at this location was 203 ft (62 m), and the site was considered low energy due to limited boat traffic, the sheltered environment provided by an inside bend, and the narrowness of the creek. At the time of installation, the bank slope was 31% at the planted treatment and 24% at the non-planted treatment, and the sediment was extremely muddy (95-98% silt/clay). The bank width was 10.8 ft (3.3 m), and the escarpment height for the two treatments averaged 1.0 ft (30 cm) and 1.2 ft (37 cm). The 8.4 in (21.3 cm) sink depth resulted in a sediment firmness classification of very soft.

In May 2018, nine months after installation (after allowing for sediment to accumulate and stabilize), one Orangegrove double-row coir log treatment was planted with smooth cordgrass (Figure 3.20), and the replicate treatment was left unplanted (Figure 3.17).

By April 2019, 11 months after planting, most of the area between the rows of coir logs at the planted treatment did not have any smooth cordgrass present. Some smooth cordgrass, however, was growing adjacent to the downslope edge of the row of coir logs secured against the escarpment. Based on the location of these plants, it is difficult to tell whether they were survivors from the planting event or were growing naturally from rhizomes extending from the established marsh behind the log (Figure 3.20). There was no equivalent growth of smooth cordgrass at the unplanted treatment (Figure 3.17).

At the gap between the rows of coir logs on the left-hand side of the planted treatment, it appears that some of the sediment that had accumulated between the logs became destabilized and collapsed down the slope (Figure 3.20); this loss of sediment stability may have been associated with the loss of some of the planted smooth cordgrass or disturbance during monitoring. The steep slope (31%) and high silt/clay sediment (98% silt/clay and 2% sand) where the planted double coir log treatment was installed provided challenging conditions for a living shoreline installation. However, if the smooth cordgrass along the upper row of logs can establish and expand further downslope, this treatment may provide some level of shoreline stabilization.

Figure 3.20. A double-row coir log treatment at Orangegrove Creek in August 2017 (top). The same coir log treatment in May 2018, with smooth cordgrass freshly planted in the sediment trapped between the logs (middle); full view (bottom left) in April 2019.

Oyster Castles

While this study focused on the greener types of living shoreline alternatives (Figure 1.1), oyster castles have also been used in living shoreline projects along the South Carolina coast. These concrete structures fall more towards the gray end of the continuum; however, these treatment types were present at some of the existing monitoring sites and were therefore evaluated along with the other treatment types.

Oyster castles present an additional option for providing substrate that attract oysters and can trap sediment to create habitat and support shoreline stabilization. These concrete-based structures are produced by Allied Concrete Inc. and have been used by The Nature Conservancy in a number of states along the East Coast, including South Carolina in collaboration with SCDNR since 2011. The interlocking nature of oyster castles allows for flexible spatial configurations (including vertical stacking) along the shoreline (Figure 3.21). This vertical relief can be effective in buffering the shoreline from onshore wave energy associated with boat wakes, as well as natural forces (e.g., wind, tides, and currents). However, oyster castles can only be used in low-slope and firm shorelines. The interstitial spaces provided by these 3-dimensional structures are beneficial in providing habitat for a number of reef-associated organisms, such as blue crabs.

Figure 3.21. Oyster castle reef on Lucy Point Creek, near Beaufort, SC, shown during construction (left) and Coosaw River, near Beaufort, SC, shown 2 years after construction (right).

Due to the heavy nature of oyster castles, these structures do not require additional anchoring materials, such as rebar, and they are able to remain in place on firm shoreline substrates in environments with moderate to high levels of wave energy. The solid nature of these structures does create potential navigational hazards when submerged in shallow water at high tide in areas of high boat traffic. Additional signage is often required, however, even with effective signage in place, some locations may be considered unsuitable due to navigational hazard concerns.

Oyster castles were present as treatments at some of the existing sites and were evaluated along with the other treatments present. However, oyster castles were not chosen as a treatment for newly installed living shorelines as part of this study; they fall under the grayer options along the living shoreline spectrum of materials, and the current study focused on more green alternatives. Therefore, oyster castles are not included in the summary tree or table due to a limited sample size and limited site conditions for installation (i.e., primarily installed at sites with low slope and relatively firm substrate). The data associated with oyster castles can be found in Kingsley-Smith et al. (in prep).

4.0 Site Evaluation and Selection

Identification and selection of the appropriate living shoreline technique is highly site specific. Estuarine shorelines vary considerably across the South Carolina coast, and no single approach can be successfully applied to all shorelines. For property owners to attain successful living shorelines, multiple aspects of the target shoreline should be defined and measured to determine the most appropriate living shoreline approach. It is also important to note that living shorelines are biologically based solutions deployed in a constantly changing environment, and therefore some amount of uncertainty will persist throughout the maturation of a living shoreline installation.

The following section highlights site attributes thought to be the most important ones to consider prior to installing a living shoreline. These attributes should be considered in future efforts working with certified contractors and homeowners who are constructing living shorelines. These were identified based on SCDNR's prior living shoreline efforts. Criteria include property boundaries, geomorphic characteristics, vegetation characteristics, hydrologic characteristics, and human influences. These observations will help to determine which type of living shoreline technique will most likely be suitable for a given site.

A. Site Boundaries and Regulatory Considerations

Knowing the legal property boundaries in the vicinity of potential living shoreline sites is important to avoid infringing on neighboring properties or the adjacent intertidal areas. Legal property lines can be found on county tax maps. All South Carolina coastal counties have websites to assist with locating property boundaries and other associated information. Existing erosion control structures, such as bulkheads or revetments, should be identified. Planning should take these structures into account to ensure that they do not interfere with the living shoreline design and implementation. Additional legal and regulatory considerations include the required state and federal critical area permits, whether the planned installation is within a legal shellfish harvesting area, and whether it is located along a designated navigational channel such as the ICW.

B. Site Access

Site access should be considered in the context of how supplies and equipment will be transported to the installation site. At sites where marsh is present, access from the water is preferred to avoid trampling the marsh during construction. Water access can be provided using boat ramps, docks, or walking along the shoreline from an adjacent property.

C. Oyster Proximity or Salinity

Salinity can vary based on water-path distance to the Atlantic Ocean and the quantity of freshwater inputs. Freshwater has a salinity of 0 practical salinity units (psu), and the Atlantic Ocean has a salinity of approximately 36 psu. Sites closer to the ocean can have salinities that range from 20-35 psu, and salinity typically decreases as one travels upriver. In tidally influenced areas, salinity tends to be elevated near high tide each day and lessened near low tide. Significant rainfall leads to temporary decreases in salinity. Oyster-based living shorelines (shell bags and manufactured wire reefs) should only be considered at sites that rarely experience a salinity lower than approximately 15 psu. Based on prior SCDNR experience, sites with low average salinity (<15 psu) are not suitable for oyster-based living shoreline approaches. To determine whether oyster-based approaches may be suitable, observe the adjacent shoreline and dock structures for the presence of large (> 2 in or 5 cm) living oysters; keep in mind that oysters need a hard surface on which to attach in addition to appropriate salinity regimes. During drought periods, oysters may occur in upstream areas that do not normally support oysters, due to increased salinity levels. These oysters usually die once the salinity regimes return to normal or during wet years.

D. Energy Level

The level of potential erosive energy due to waterbody width (e.g., fetch), shoreline orientation, and boat traffic is an important factor to consider in determining an appropriate living shoreline approach. Wider waterbodies tend to be subject to higher levels of erosive wave energy formed by wind passing over open stretches of water. Sites located along dredged channels such as the ICW, or other sites with high levels of boat traffic, also experience more frequent and greater wave energy.

In addition to wind-driven waves and boat wakes, currents are another source of erosive energy. Sites located on the outside bend of a river or large tidal creek are subject to stronger currents, and therefore higher erosional energy, than sites located along straightaways or the inner bend of a river or creek (Figure 4.1).

A few examples of the potential living shoreline options are provided to underscore why energy is important. Coir logs are best suited to smaller, sheltered waterways, such as tidal creeks, and may not be successful when placed on the outer bend of larger creeks or rivers, due to the increased current. Oyster shell bag reefs and MWRs can be used in both low and high energy systems; however, in higher energy areas, oyster-based living shorelines benefit from extra staking and may require additional maintenance, including moving bags of oyster shell or wire reefs back into place.

E. Bank Slope and Width

Bank slope and width should be considered when selecting an appropriate living shoreline approach. A highly sloped shoreline can result in the materials sliding down toward the water. Slope is calculated as "rise" (vertical distance) divided by "run" (horizontal distance), multiplied by 100%, and should be calculated for the portion of the bank where the living shoreline will be installed (Figure 4.2). Bank width, the horizontal distance from the low water line to the marsh edge, is also important in determining where to place the materials. If the slope is high and the sediment composition is muddy (high silt/clay), then the potential for materials to slide down the bank appears to increase.

Oyster shell bag reefs worked best at sites where the bank slope was less than 16% and the bank width was less than approximately 16 ft (5 m). MWRs can tolerate a steeper slope and have been successful at slopes of up to 28%. Like oyster shell bag reefs, MWRs perform best at sites with a bank width of less than approximately 16 ft (5 m). Coir logs can be successful with bank slopes of up to 25%, but at higher slopes they require additional staking to prevent them from slipping downslope. Coir log functionality does not appear to be limited by bank widths. Further monitoring and research are needed to understand the outcomes of various materials on a range of bank widths. Therefore, bank width should be considered during site evaluation but is not included in the flow chart.

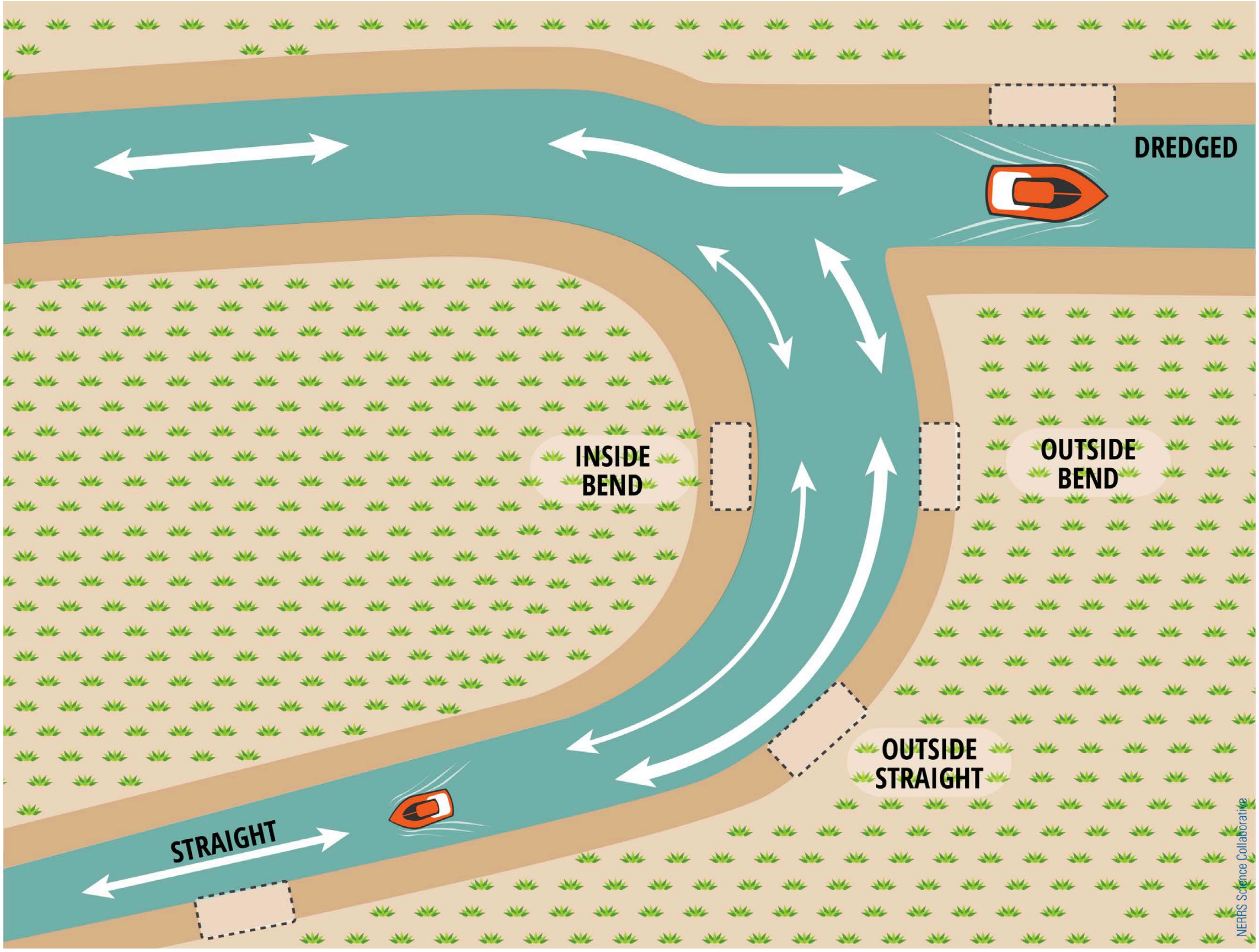


Figure 4.1. The wave and current energy at a site is affected by the amount of boat traffic and shoreline orientation is also important to consider in relation to energy levels in the system.

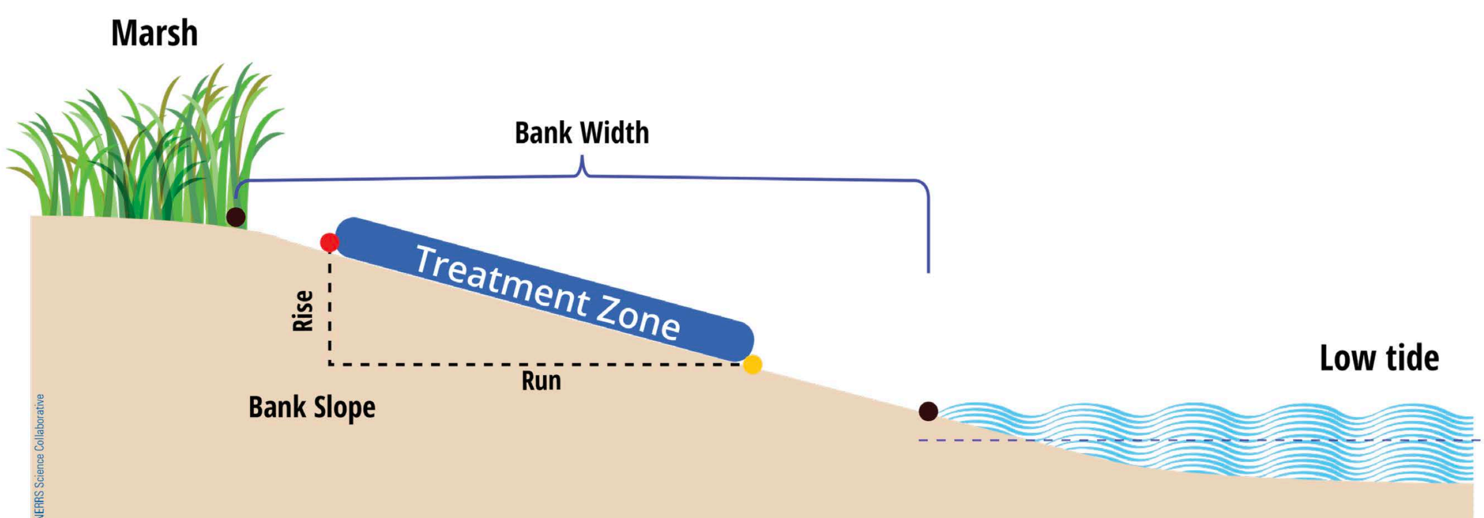


Figure 4.2. The rise over run method for calculating bank slope and determining bank width.

F. Sediment Firmness and Composition

Assessing the firmness of sediment will aid in selecting which living shoreline material will be most suitable. To assess sediment firmness or sink depth, researchers held a standard cinderblock approximately 3 ft (1 m) above the sediment surface at the intended living shoreline location and dropped it (Figure 4.3). At the upslope edge of the indentation made by the cinderblock, the vertical distance was measured from the bottom of the indentation to the top edge, providing the sink depth. Sink depth can be used to categorize sediment firmness as very firm (<1.97 in or 5 cm), firm (1.97-3.90 in or 5-9.9 cm), soft (3.94-5.91 in or 10-15 cm), or very soft (>5.91 in or 15 cm). For this study, a threshold of 10 cm was used for differentiating firm from soft.

Figure 4.3. An image of the sink depth method used for this study.

Another site attribute related to the substrate type and firmness is sediment composition. In this study, scientific methods were utilized in the laboratory. The sediment was classified into two categories: 1) sand (>30-40% sand or <60-70% silt/clay) and 2) silt/clay or mud (>60-70% silt/clay or <30-40% sand). Although there is often a close relationship between sediment firmness and composition, the research indicated that there were occasions where the composition of the sediment altered the performance at a site.

Oyster shell bag reefs, MWRs, and coir logs can all be installed on firm and very firm sediment. All of these materials may also be installed on soft and very soft sediment, but sites with those conditions will require the use of additional materials to prevent slippage down the bank or to prevent excessive sinking of materials. At soft and very soft sites, oyster shell bag reefs require the use of wooden pallets under the shell bags to ensure that the oyster shell remains above the sediment and available for oyster recruitment. MWRs and coir logs may require additional or longer rebar or wooden stakes to help ensure that they are anchored firmly in the softer sediment, especially at sites with relatively steep slopes.

G. Escarpment

An escarpment is the erosional area of shoreline that has some degree of vertical relief, often located at the marsh edge (Figure 4.4). This is the area of shoreline that needs stabilization using a living shoreline or other approach. The escarpment may be uniform across the entire project area or it may vary along the length of the shoreline. The height of the escarpment can be measured by placing a ruler at the base of the erosional area and measuring the vertical distance to the top of the escarpment. An escarpment generally indicates that the marsh is experiencing erosion which may be related to the overall energy in the system. The height of the escarpment appears to affect a treatment's performance in terms of its ability to retain sediment.

For escarpment heights of less than 23.6 in (60 cm), oyster shell bag reefs provided better marsh protection than in scenarios where the escarpment heights were greater than 23.6 in (60 cm). For coir logs, escarpment heights of 7.9-15.7 in (20-40 cm) may be associated with increased sediment accretion or retention. The escarpment height did not appear to influence the findings for MWR treatments.

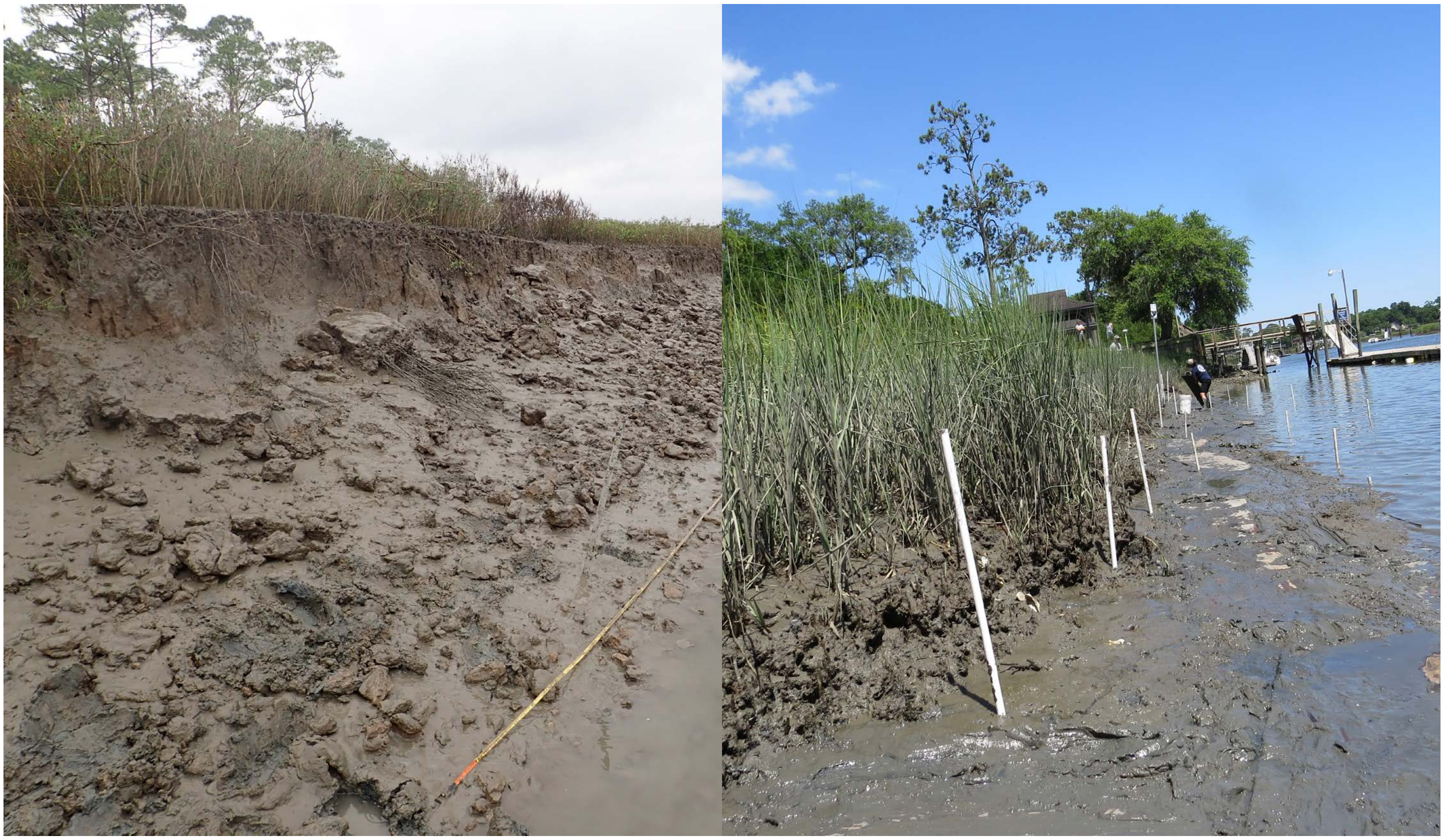


Figure 4.4. A view of a marsh with a pronounced escarpment on the Kiawah River (left) and without a pronounced escarpment on Hobcaw Creek (right).

H. Vegetation Characteristics

Documenting the type of vegetation present is a necessary step in determining which species of plants will colonize newly trapped sediment or will grow well if planted there. Plant types vary based on the salinity of the water at the site and site elevation. Tools to assist with identifying native plant species include field guides, smartphone apps such as iNaturalist, and websites. In its plants section, *A Guide to the Salt Marshes and Tidal Creeks of the Southeastern United States* provides information about common plants found along estuarine shorelines in South Carolina; it is available at www.saltmarshguide.org.

5.0 Identification of Options for Greener Living Shorelines

Based upon research findings, a flow chart and table are provided as a guide through the types of environments that are best suited for different living shoreline techniques (Figure 5.1, Table 5.1). The flow chart is meant to assist SCDHEC OCRM in the development of living shoreline guidelines and when reviewing living shoreline permit applications that utilize the techniques tested as part of this study. It is not meant to exclude or encourage certain types of materials but instead serve as a summary of the techniques tested for this study. The conditions in South Carolina are variable, and all factors need to be considered.

This study did not test all combinations of site conditions with each living shoreline technique (i.e., bagged oyster shell, MWR, and coir log). The summary of the results is based on the conditions and techniques evaluated. Consistency was not always found among the different sites tested. For example, the slope at installation of the Big Bay bagged shell reef was 26%, which is steeper than the recommended level for use with bagged oyster shell. The bagged shell reef placed there, however, was successful in that it trapped sediment, the marsh expanded, and the reef did not slide down the slope. This may be related to the low silt/clay sediment (35%) and moderate sink depth (4 in; 10.3 cm).

This study attempted to provide the best possible science-based information on the relative success of different living shoreline materials deployed under a variety of South Carolina-specific site conditions. If a technique is not listed based on one or more of the site attributes present at a given shoreline, then proceed with caution. Additional research and monitoring are needed to understand the success of different treatments over long time scales as well as to test new materials and techniques.

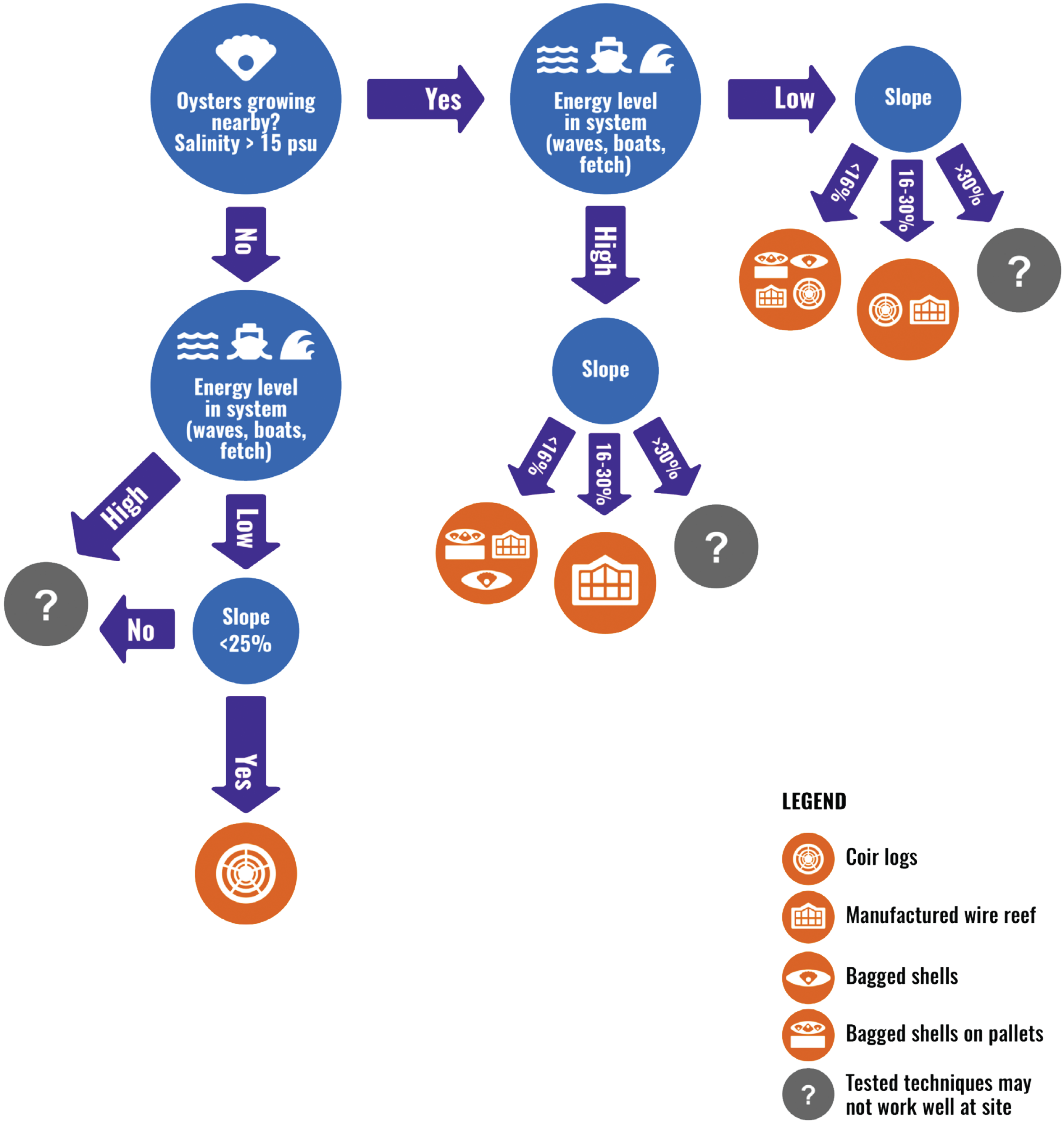


Figure 5.1. Flow chart of the conditions for which the study found successful living shoreline treatments over the course of the 1-2 years of monitoring of new sites and a single monitoring event for existing sites. The reader is referred to Section 4.0 to understand the different terms and how to measure them. Blue circles represent attributes and orange circles represent materials. In addition, bagged oyster shell should be placed on pallets if sink depth is greater than 3.94 in (10 cm; soft or very soft substrate).

Table 5.1. Three materials were tested for this study (bagged shell, manufactured wire reef (MWR), and coir logs) in a variety of site conditions relevant to the South Carolina coast. A summary of where success was achieved and additional comments are provided.

	Site Conditions	Bagged shell	MWR	Coir log
Salinity	High salinity (>15 ppt) or oysters naturally occur nearby	Successful during study.	Successful during study.	Successful during study.
Salinity	Low salinity (<15 ppt) or oysters do not naturally occur nearby	Not successful during study.	Not successful during study.	Successful during study. Only choice tested for non-oyster/ low salinity areas.
Energy	ICW/dredged	Successful during study. Recommend using extra stakes and checking placement as material may move. Reduced sediment accretion compared to non-ICW.	Successful during study. Recommend using extra stakes and checking placement as material may move. Reduced sediment accretion compared to non-ICW.	Not successful during study. Material moved or degraded quickly.
Energy	Open bay/exposed (wide water width)	Successful during study. Recommend using extra stakes and checking placement as material may move.	Successful during study. Recommend using extra stakes and checking placement as material may move.	Not successful during study. Material moved or degraded quickly.
Energy	Outside bend	Successful during study.	Successful during study.	Successful during study. Lower success rate on outside bend in larger tidal creek or river systems.
Energy	Straight shoreline	Successful during study.	Successful during study.	Successful during study. If low-energy system.
Energy	Inside bend	Successful during study. High sediment accretion potential.	Successful during study. High sediment accretion potential.	Successful during study. High sediment accretion potential.
Bank Slope and Width	High slope (>30%)	Not tested during study.	Not tested during study.	Not tested during study.
Bank Slope and Width	Moderate slope (16%-30%)	Not as successful during study. May exhibit greater sediment accretion at slopes >10%.	Successful during study. Tested up to 28%. Well-suited for high slope (tested up to 28%). High accretion potential at higher slopes (>10%).	Successful during study. Performs best in areas < 25%.
Bank Slope and Width	Low slope (<16%)	Successful during study. May exhibit greater sediment accretion at slopes >10%.	Successful during study. Well-suited for high slope (tested up to 28%). High accretion potential at higher slopes (>10%).	Successful during study. Performs best in areas < 25%.
Bank Slope and Width	Bank width	Successful during study. Performs best at widths <16 ft (5 m).	Successful during study. Performs best at widths <16 ft (5 m).	Successful during study. For range of bank widths, including banks >16 ft (5 m).
Sediment Firmness/Composition	High sinkability (>10 cm)	Successful during study. Recommend using pallets. High potential for sediment accretion.	Successful during study. Recommend using deep stakes or extra stakes. High potential for sediment accretion.	Successful during study. Recommend using extra stakes to prevent the log from sliding downslope. High potential for sediment accretion.
Sediment Firmness/Composition	Low sinkability (<10 cm)	Successful during study.	Successful during study.	Successful during study.
Sediment Firmness/Composition	Muddy substrate - silt/clay >60-70%	Successful during study. Recommend using pallets and extra stakes. Increased sediment accretion potential.	Successful during study. Good potential for sediment accretion, but may exhibit reduced oyster growth.	Successful during study.
Sediment Firmness/Composition	Sandy substrate -silt/clay <60-70%	Successful during study.	Successful during study.	Successful during study.
Escarpment		Successful during study. More likely to exhibit marsh protection up to 24 in (60 cm). Higher than 24 in (60 cm) uncertain or ineffective.	Successful during study.	Successful during study. Moderate escarpment heights (8-16 in, 20-40 cm) associated with increased sediment accretion.

Setting Expectations

Living shorelines may take several years to mature and mitigate erosion compared with upland shoreline erosion solutions. They are constructed with the intention that, over time, they will become a part of the natural environment. Unfortunately, the natural landscape is complex and can be unpredictable. Creating appropriate expectations for living shorelines is an important step in choosing a living shoreline material and technique.

Four main performance measures indicative of success were evaluated for this study: 1) increased amount of silt/clay or muddiness behind the living shoreline treatment, 2) increased sediment elevation behind the material, 3) marsh expansion or protection, and 4) oyster growth or development of habitat (Table 5.2). The methods used for the new experimental sites and the pre-existing sites varied slightly, but all of the information was used to develop these expectations. Each living shoreline material will be discussed separately in relation to the performance measures to shed light on expectations as the living shoreline matures.

Bagged shell oyster reefs quickly serve as a sill and begin to retain higher levels of silt/clay behind installed reefs. In general, a 5-15% increase in silt/clay occurred within the first year. If the reef is serving as a barrier, then one would expect the finer material (silt/clay) to settle out of the water column or trap silt/clay material from the eroding marsh behind the reef. Sediment elevational gains were greater when higher slopes and more silt/clay sediments existed at a site. Overall elevation behind the reef would be expected to increase within 1-2 years following an installation. Marsh expansion or protection was found to occur at some sites as early as 2-4 years and will continue to change over time. Oyster larvae are only present in the water column in the spring and early summer (typically April-September). SCDNR primarily installs oyster reefs in the spring to coincide with the beginning of the oyster recruitment period. Therefore, depending on the time of installation and treatment used, oyster recruitment may vary dramatically within the first 1-2 years. Once oyster recruitment has occurred, subsequent growth happens fairly rapidly at most locations. Rodriguez and colleagues (2014) found oyster reefs were able to keep up with changing sea levels. Therefore, oyster-based living shorelines are believed to be a good option in that regard.

MWRs are expected to have a delay in the sediment retention, sediment composition changes, and elevational changes until the material begins to recruit oysters. Once oyster growth is dense enough to fill in the wire frame, the structure should begin to trap silt/clay sediments and elevation should begin to increase behind the MWR. Greatest sediment accretion has been observed when the reef was placed in the lower 40% of the tidal frame. The greatest marsh protection occurred when MWRs were placed higher in the tidal frame (>40%). SCDNR has observed varying results related to oyster settlement on MWRs. Repurposed crab traps, which SCDNR began using several years ago, have shown the best oyster recruitment. The cement on newly created MWRs does not appear to adhere on the wire as well. Oyster recruitment on the MWRs is delayed approximately one year relative to the recruitment associated with the bagged oyster shell reefs. This may be because the plastic coating is weathered on the repurposed crab traps, allowing for better adhesion of the concrete. SCDNR has tested non-plastic-coated wire, but this appears to degrade (rust) quickly in South Carolina estuaries.

Table 5.2. Setting expectations regarding a living shoreline material is critical to homeowner satisfaction.

Performance Expectations	Bagged Shell	MWR	Coir Log
Sediment fining (becoming muddier)	Generally, silt/clay proportion increases 5-15% within a short time frame.	Increases in silt/clay proportion are smaller or delayed compared to bagged shell.	May initially lead to coarsening of sediments, but over several years returns to baseline sediment composition
Sediment elevation	More elevation gain in areas with higher slope and finer sediments. Expectation: 4-8 in (10-20 cm) within 1-2 yrs. Highest potential for sediment accretion likely to occur when placed lower in the tidal frame (10-30%).	May lose a few cm of elevation initially, prior to establishment of oysters. Greater sediment accretion observed when placed lower in tidal frame (<40%).	Highest potential for rapid increase in sediment elevation. Consider use in low energy (low current/ wave) environments. High position within tidal frame is associated with greater sediment accretion. Avoid placing low in tidal frame (<25%).
Marsh accretion/ protection	Marsh changes may occur as early as 2-4 yrs but more likely will take 4 yrs, and can continue to change beyond 10 years. Well-suited for marsh protection in high escarpment areas.	Placement higher in tidal frame (>40%) associated with greater marsh protection. Protection may be limited at lower positions within the tidal frame (<40%).	Where site attributes permit, offers comparable marsh protection to other treatments. Higher placement in tidal frame (>40%) associated with greater protection.
Oyster growth/ habitat	Fastest oyster growth option. Oysters may continue to develop for 5 yrs with minimal changes beyond 5 yr. Highest potential for oyster growth likely to occur when placed lower in the tidal frame (10-30%).	Eventually hosts oysters, but may be delayed ~1 yr vs bagged shell. Oysters may continue to develop for 5 yrs, with minimal changes beyond 5 yr. Greater oyster productivity occurs when placed lower in tidal frame.	

In places where coir logs were successful (low current/wave environments), they quickly served as a sediment-trapping sill. In some cases, there may be a short-term increase in sand behind them, but this is expected to return to normal after a couple years. Coir logs also have the highest potential for rapid increases in sediment elevation. A higher position in the tidal frame was associated with increased elevation gains. Early indications suggest that they provide marsh protection comparable to the other treatments in the short-term. Coir logs are not expected to last beyond 5 years; a 2-3-year life span is probably more realistic, since they degrade in salt water. It is not known if the marsh can be stabilized within the coir log life span and then maintain itself after the coir log degrades.

There is anecdotal information to indicate that combining coir logs with oyster shell bags or MWRs may be beneficial. Based on guidance from the mid-Atlantic region (Partnership for the Delaware Estuary), a single row of oyster shell bags (shell bolsters) were placed in front of a subset of coir logs with the goal of limiting undercutting of coir logs. No undercutting was observed at coir log treatments installed without shell bags in this study; however, it was noted that at higher salinity sites, a single row of shell bags often successfully recruited and grew oysters (Figure 5.2). Coir logs were effective at capturing sediment but are expected to have a limited lifespan (< 5 years) in the estuarine environment. It seems likely that the presence of an oyster reef along the downslope edge of a coir log could increase the likelihood that the sediment trapped by a coir log remains in place after the coir log degrades. Additionally, coir logs may improve the performance of shell bag reefs when certain site conditions are present. At sites with high slopes and soft sediment, shell bag treatments, even when placed on wooden pallets, often became partially covered with sediment (Figure 5.3), reducing the surface area for oyster recruitment and growth. At high slope sites, placing a row of coir logs immediately upslope of a shell bag reef may reduce sediment deposition on the top surface of the shell bags and thereby increase the proportion of the reef area covered in living oysters.

Although MWRs are not as susceptible as shell bag reefs to being covered in sediment, they do have delayed performance relative to shell bag reefs due to their slower timeline for oyster recruitment and growth. Therefore, adding a row of coir logs immediately upslope of an MWR at installation may accelerate the timeline at which sediment accumulation and marsh protection benefits are provided. Using coir logs in combination with oyster-based living shoreline methods may improve initial sediment retention and marsh protection performance, protect shell bags from being covered by sediment at some sites, and the ongoing growth of oyster reefs may provide long-term sediment retention after coir logs degrade.

Further research is warranted due to the relatively early stages of implementing living shoreline techniques to combat erosion in South Carolina. An evaluation of the combinations of materials discussed above is clearly warranted as well as an assessment of the various techniques in relation to mitigating the impacts of sea level rise. Research is needed into improving the performance of the oyster recruitment on MWRs to achieve results similar to repurposed traps (through techniques such as weathering the material or changing the cement formulation). New materials will continue to appear on the market, requiring testing.

Figure 5.2. Single-row coir log treatment with a single row of shell bags, installed in July 2016 along Big Bay Creek (left). This treatment was planted with smooth cordgrass in April 2018 and photographed in May 2019 (right)

Figure 5.3. Oyster shell bag treatment installed atop wooden pallets in July 2016 along Big Bay Creek (top). The same treatment, a little over a year later (October 2017), with much of its surface area covered with sediment (bottom).

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7.0 Glossary

Bank width – For the purposes of this living shoreline project, bank width is defined as the distance, on a line perpendicular to the shoreline, from the marsh edge to the estimated mean low water line.

Breakwater – “A structure which is designed to protect an area from wave action, is generally built parallel to the shore, may or may not be submerged, and may be built singly or in series. Breakwaters may interfere with natural wave action and wave-induced currents,” S.C. Code Ann. Regs. 30-1(D)(38).

Bulkhead – “A retaining wall designed to retain fill material but not to withstand wave forces on an exposed shoreline,” S.C. Code of Laws § 48-39-270(1)(b) (https://www.scstatehouse.gov/code/t48c039.php).

Coastal resilience – The ability of coastal ecosystems or coastal communities to withstand and recover from natural disasters and long-term changes to the atmosphere and oceans. Resilience has social, economic, and ecological components.

Erosion – Gradual loss of soil or substrate due to physical action of wind or water.

Escarpment – For living shoreline purposes in this document, escarpment refers to a local, very steep or vertical eroding edge of the marsh with a clearly evident top and bottom. An eroding face.

Estuary (estuarine) – An area where a freshwater river system meets the ocean. Estuaries are the transition zone between river and ocean environments.

Intertidal zone – Generally, the area of shoreline that is covered by water at high tide and exposed to air at low tide. May have more specific or formal definitions depending on use (e.g., state law may define an area as intertidal that is between the mean high and mean low water lines, with these lines defined to by specific datums, epochs, and survey methods).

Revetment – “A sloping structure built along an escarpment or in front of a bulkhead to protect the shoreline or bulkhead from erosion,” S.C. Code of Laws § 48-39-270 (1)(c) (https://www.scstatehouse.gov/code/t48c039.php).

Rhizome network – A network of roots and stems of a plant.

Salinity – The amount of salt dissolved in a given volume of water.

Sediment accretion – For living shoreline purposes, the deposition of new sediment over time, resulting in a local net gain in substrate elevation.

Sediment fining – Coarser or larger grain (sand) sediment transitioning to finer (mud) or smaller grain sediment.

Sediment scour – Removal of sediment from around the base of objects that obstruct the flow of water.

Shoreline hardening – Shoreline structures that are physically dense and rigid, unnatural, and not nature-based.

Shoreline slope – For living shoreline purposes in this document, the slope, on a line perpendicular to the shoreline, of the substrate surface, provided as either % grade or as a ratio of the “rise” divided by the “run,” for the footprint where a living shoreline or control site is located, and where rise is the vertical change in distance for a given planar horizontal distance.

Shoreline stabilization – Any shoreline installation designed with the goal of preventing erosion or physical degradation of a shoreline. A shoreline is stabilized when it no longer experiences dramatic changes.

Shoreward – Refers to a location that is farther upslope within a living shoreline installation site and farther from the water at low tide.

Sill – A shoreline stabilization structure placed parallel and close to an existing shoreline to reduce wave energy and prevent erosion.

Sink depth – Also called sinkability. Softness of soil or substrate. The distance an object of standard weight, deployed using a standardized method, sinks into the substrate.

Substrate – For living shoreline purposes, the material that composes the bottom or “floor” of the intertidal zone. May also refer to material on which larval oysters can attach.

Waterward – Refers to a location that is farther downslope within a living shoreline installation site and closer to the water at low tide.

8.0 Appendix

Appendix A. Interviews with Private Property Owners

SCDNR conducted a series of semi-structured interviews of private property owners to evaluate their perspectives, values, and needs related to living shorelines. Two groups of homeowners were interviewed: 1) those that currently have living shorelines adjacent to their property; and 2) those that have expressed interest in installing a living shoreline adjacent to their property. The list of interview participants was compiled by project partners based on prior interactions. The interviews were conducted in late 2017 and early 2018. Interviews consisted of 12-16 open-ended questions and included questions about how private property owners use the adjacent shoreline, the aspects of living shorelines that were appealing to them, the process of obtaining or attempting to obtain a living shoreline, what they thought were the most helpful resources, how the shoreline has changed before and after installation, and what resources they currently needed related to living shorelines. A total of 10 interviews were conducted either in person or over the phone, and interview times ranged from fifteen minutes to over an hour. The surveys were analyzed using a grounded theory coding method to uncover major cross-cutting themes. Recorded interviews were coded for sub-themes, which were then grouped under major themes. Each interview was analyzed by two discrete coders to check for intercoder reliability.

Respondents from both groups cited staff from the various agencies involved in living shorelines projects (including SCDNR, SCDHEC OCRM, TNC, and USFWS) as the most useful sources of living shoreline information for private property owners. Even individuals that were unsuccessful at establishing a living shoreline adjacent to their property described the assistance that they obtained from staff as helpful. Respondents often described a lack of online resources available as an issue. In instances where respondents installed a living shoreline adjacent to their property, they were enthusiastic about the assistance and often called out agency representatives by name. This insight highlights the importance of building relationships with stakeholders and the current lack of digital information available to the public. Almost all respondents reported becoming interested in living shorelines after viewing a successful one. One respondent even described how all of his neighbors became interested in pursuing a living shoreline adjacent to their property after seeing the positive impacts of a living shoreline on the marsh adjacent to his property. These results highlight the importance of demonstration projects and their influence on homeowner decision making.

Living shorelines were preferred by respondents from both groups over other shoreline stabilization methods, such as bulkheads or rip rap, due to their aesthetics and co-benefits. These co-benefits included decreased maintenance costs, a feeling of working with nature, marsh protection, increased oyster growth, and fishing opportunities. There was a recurring desire from respondents to protect existing marsh adjacent to their property using natural solutions to prevent future erosion. Many residents reported the importance of maintaining the aesthetic value of the shoreline for their quality of life. Decreased cost associated with installation, maintenance and resilience to storm impacts were also cited by residents from both respondent groups. Multiple respondents also noted improved fishing opportunities as a motivation and benefit of living shorelines; all of these respondents also had recreational docks.

The following are a few quotes from respondents.

- "….aesthetically, I think it is certainly better than a bulkhead or rip rap"
- "...the beauty of the marsh in front of my house, plus the sustainability of the marsh. I am into the en-

vironment and it's excellent fishing in front of my dock. All of those things made me want to save the marsh, I did not want rip rap on my bluff in ten years and all the marsh to be gone"
- "I think in the long run if you had a big sill of oysters it would clarify the water, there are a lot of positive things to an oyster sill as far as the ecosystem and marsh is concerned."
- "Well I love oyster beds and it's [living shorelines] a natural way to preserve the marsh compared to stone or bulkhead."

Both groups of respondents reported frustration with the current state and federal permitting process, which was described as frustrating, lengthy, complex and financially draining. Specifically, private property owners noted that there was no main point of contact to answer questions and guide one through the process. Multiple private property owners with living shorelines adjacent to their property provided a timeline of events prior to installation. This timeline often spanned multiple years, despite the assistance of agency staff familiar with the process. Respondents from both groups described obtaining a living shoreline permit as financially draining and sometimes cost prohibitive. The requirement for complex engineered drawings and the cost of installation materials, such as oyster shell, were also cited as concerns.

The following are a few quotes from respondents.

- "There was no clear-cut person to talk to, it seemed like I was constantly getting referred to someone else....nobody had a direct answer for me."
- ".. a streamlined application process for private property owners that would involve minimal paperwork, minimal meetings and not need to include an outside engineer preparing expensive plans of the site."

Respondents were asked to identify what types of resources they felt were needed to make the process of obtaining a living shoreline adjacent to their property less frustrating. They expressed a need for an online guidance document with information about living shorelines, permitting, financial assistance, and a shorter, more simplified permit application. Many respondents used the terms "step by step" or "1-2-3" to describe the type of procedural assistance they felt would be beneficial. Private property owners also expressed interest in education for marine contractors and reported that they have had difficulty finding any contractors that were familiar with living shorelines or their installation. Contact lists for both government agency experts and trained living shoreline contractors were requested by a handful of respondents.

The interviews revealed multiple cross-cutting themes and uncovered several opportunities for engagement with private property owners. First, interaction with agency experts knowledgeable about living shorelines and the permitting process was extremely important to stakeholders. As the interest in living shorelines grows, agencies should be prepared to respond with consistent information. Providing training on living shorelines to local municipal staff and environmental organizations may decrease the number of inquiries received by regulatory staff. Providing training to staff from other departments within living shorelines permitting and research agencies may also decrease the likelihood of interested private property owners being passed from person to person and improve their interactions when contacting government agencies for information regarding living shorelines. An online platform for associated materials, including contact lists of experts, may also streamline the process for information sharing.

The second cross-cutting theme was the private property owners interviewed demonstrated "a preference for living shorelines based on aesthetics and co-benefits." It should be noted that this was not an unbiased sample of the general public, but the responses can inform future outreach strategies for living shoreline management agencies in South Carolina. Some waterfront private property owners are motivated to pursue natural marsh stabilization solutions, such as living shorelines, in an effort to protect existing marsh, preserve the current view of the shoreline, enhance fishing opportunities, and decrease future maintenance costs. This study suggests future outreach around living shorelines as an alternative to bulkheads should highlight these potential co-benefits. Additionally, future research aimed at quantifying the co-benefits of living shorelines compared with harder shoreline stabilization methods could provide useful data for outreach and educational programs. The exposure to and knowledge of respondents about living shorelines mainly resulted from viewing successful living shorelines on public properties, revealing the importance of demonstration projects. Installing living shorelines on highly visible properties, in conjunction with educational signage, may provide passive education to waterfront private property owners and lead to increased interest in shoreline restoration projects on private property. Future outreach and training efforts around living shorelines should include in-person site visits as often as possible.

In conclusion, frustration with the lack of a "point-of-contact" and the lengthy, complex permitting process suggests a central source of information needs to be available online. Educational materials included on this website should include: information on the co-benefits of living shorelines, a map showing the location of demonstration sites, a step-by-step guide to the permitting process, including any required forms and a timeline, contact lists of experts, expected maintenance schedules, and links to or sources of potential financial assistance for private property owners. Multiple respondents described an interest in attending a workshop or educational event about living shorelines so that they could obtain information before reaching out to a contractor or incurring expenses. Since both respondent groups reported that contractors had a lack of experience with living shorelines, it may be necessary to develop a marine contractor training program that includes data on site suitability, permitting, preparing plans and drawings, and installation. A mixed approach of passive demonstration sites, online materials, and in-person workshops and trainings should be considered when developing communications strategies for living shorelines.