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The Use of Living Shorelines to Mitigate the Effects of Storm Events on Dauphin Island, Alabama, USA

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Abstract.—Gulf of Mexico marshes have been found to support more than 80 species of fish, 60 species of birds, and many reptile, mammal, and invertebrate species (Stout 1984). In addition to the ecological services provided by salt marshes, the 2005 hurricanes in the Gulf of Mexico raised public awareness of the ability of intertidal marshes to reduce personal property damage from storm surges. Since marshes can be destroyed through natural or anthropogenic processes, methods to protect these areas are being developed; one such method is the use of "living shorelines." Living shorelines serve multiple roles by controlling erosion, maintaining natural coastal processes, and sustaining biodiversity through land-use management, soft armoring, or combinations of soft and semihard armoring techniques. Living shorelines provide a viable alternative to common hardened structures such as bulkheads, stone revetments, and seawalls. One type of living shoreline was used at Saw Grass Point Salt Marsh on Dauphin Island, Alabama. Dauphin Island's Fort Gaines Harbor was constructed in the 1950s by removing approximately 3 ha from Saw Grass Point Salt Marsh. The harbor now serves as one of Dauphin Island's two primary access points for recreational and commercial boats to the Gulf of Mexico. Chronic erosion has resulted in the loss of 0.5 ha of the remaining marsh. This saline tidal marsh is of significant ecological importance and is one of only two on Dauphin Island. In 2004, a community-based restoration grant was used to protect and restore the marsh through the use of exposed nearshore precast concrete breakwaters called coastal havens. These structures function as detached breakwaters to minimize the effect of storm surge and boat wake through wave attenuation; they also provide suitable substrate for oyster colonization. These structures were selected over other erosion control technologies, including vertical bulkheads, rock or wooden sills, and headlands. In April 2005, 182 units were installed in two interlocking rows parallel to the east perimeter of the marsh in water approximately 1.3 m deep. Oyster density on the coastal havens, measured 19 months postinstallation, was 205 oysters/m^2. Measurements behind the breakwater indicate some sediment accretion. The project cost was approximately US$335/m to protect 162 m of shoreline. The dual function of these structures has controlled the erosion behind the breakwater and has provided habitat for a wide array of National Oceanic and Atmospheric Administration trust resources, including locally important species such as spotted seatrout (also known as speckled trout) *Cynoscion nebulosus*, blue crabs *Callinectes sapidus* and Gulf stone crabs *Menippe adina*, eastern oyster *Crassostrea virginica*, red drum *Sciaenops ocellatus*, southern flounder *Paralichthys lethostigma*, and various species of commercially important shrimp (brown shrimp *Farfantepenaeus aztecus*, pink shrimp *F. duorarum*, and white shrimp *Litopenaeus setiferus*).

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Introduction

There has been a 50% reduction of our nation's wetlands from historical levels (Dahl 2006). Estuarine wetlands such as salt marshes provide critical refuge, breeding, and nursery habitat for amphibians, birds, fish, invertebrates, mammals, and reptiles (Stout 1984; Burger 1986; Botton and Loveland 1989; Stout 1990; Bozek and Burdick 2005; Roland and Douglass 2005; NRC 2007). Gulf of Mexico marshes have been found to support more than 60 species of birds; 80 species of fish; and many invertebrate, mammal and reptile species (Stout 1984). In addition to the ecological services provided by salt marshes, the 2005 hurricanes in the Gulf of Mexico raised public awareness of the ability of intertidal marshes to reduce personal property damage from storm surges.

Coastal erosion along open and sheltered shorelines is a natural process that is threatening the expanding population within the coastal zone of Alabama and other coastal states. In most undisturbed settings, a strategy of no action allows a naturally occurring landward recession of the shoreline (Hobbs et al. 1981; Hardaway et al. 2002; NRC 2007). However, along developed shorelines, hard structure armoring using seawalls, bulkheads, groins, and revetments are common erosion control technologies. Each of these hard structures has been used with varying degrees of success and all can cause unintended engineering consequences such as vertical erosion, loss of downdrift sediment, and erosion of flanking shores (Douglass and Pickel 1999; Yozzo et al. 2003; Campbell et al. 2005; NRC 2007). Douglass and Pickel (1999) estimated that 30% of the shoreline along Mobile Bay, Alabama was armored, primarily using vertical bulkheads and, to a lesser extent, trash or rubble-mound revetments. Vertical bulkheads tend to increase wave reflection and downrush, leading to scouring around the toe of the bulkhead. The scouring in front of the bulkhead decreases the width of the nearshore environment and increases water depth. Douglass and Pickel projected an increase in the use of these technologies as more homes are built along Mobile Bay's waterfront.

Management of the negative impacts of erosion involves one or two broad strategies (Hobbs et al. 1981). The first strategy is through institutional controls such as planning, regulations, incentives, or acquisition (Hobbs et al. 1981; NRC 2007). The second strategy is through structural controls that attempt to inhibit or prevent the physical process of erosion of upland property. These techniques include plantings, hardened structures, and trapping or adding sand. Nontraditional ways to protect, stabilize, or restore upland property have been tried in the field with their success depending on their stability during storm events and durability over the economic design life (Yozzo et al. 2003). Within the last 10 years, the term "living shoreline" was coined to help promote interest in alternatives to vertical bulkheads for shoreline protection (NRC 2007). The National Oceanic and Atmospheric Administration (NOAA) defines living shorelines as "a suite of bank stabilization and habitat restoration techniques to reinforce the shoreline, minimize coastal erosion, and maintain coastal processes while protecting, restoring, enhancing, and creating natural habitat" (http://habitat.noaa.gov/restorationtechniques/public). The use of living shoreline strategies serves the dual roles of protecting the shoreline from erosion while providing habitat for a wide array of NOAA trust resources, including locally important species of fish and crustaceans.

The most basic technology used to create living shorelines involves increasing vegetative cover by replanting the eroded shoreline with native plants. To be successful, the source of the erosive forces must be eliminated for plantings to become established. Dredge material, synthetic mats, geotubes, shoreline revetments or riprap, offshore breakwaters, or hybrid structures, such as precast concrete wave attenuators, can be used in combination with native plant landscaping to control shoreline erosion. Proper use of these technologies should be cost effective, maintain ecological services, and control erosion without disrupting coastal transport processes.

In 2004, funding ($100,000) was received from the Gulf of Mexico Foundation's community-based restoration program, the Town of Dauphin Island, and the NOAA Mississippi–Alabama Sea Grant Consortium to abate the chronic erosion occurring in Saw Grass Point Salt Marsh on Dauphin Island, Alabama. The purpose of this paper is to describe the planning process, installation, and short-term results of a living shoreline project using concrete wave attenuators for erosion control and habitat creation.

Methods

Description of Study Area

Mobile Bay has the fourth largest freshwater flow in the continental United States with an average flow rate of 1,800 m^3/s (MBNEP 2002). The mouth of Mobile Bay is bounded by Fort Morgan peninsula on the east and Dauphin Island on the west (Figure 1). Dauphin Island is Alabama's only inhabited barrier island with 1,300 full-time residents and approximately 3,000 seasonal residents. This westward migrating island is 22.5 km long, has a maximum width of 1.6 km, and is 4.7 km from the mainland. The south side of the island consists of a beach and dune system exposed to high-energy waves from the Gulf of Mexico. The narrow western end comprises two-thirds of the island's length and consists of beaches, small areas of marsh, and a remnant dune system. The west end of Dauphin Island is highly susceptible to overwash and breaching during hurricanes. The eastern one-third of the island consists of a functional 4–5-m dune system and maritime forest. The north side of the island consists of backbarrier mashes and brackish ponds (DIBBS 2003).

Saw Grass Point Salt Marsh is the largest marsh on the east end of Dauphin Island (Figure 2). This 14.1-ha saline tidal marsh with its three tidal creeks is of significant ecological importance and has been identified as an area in need of protection (DIBBS 2003). The predominate marsh species are black needlerush Juncus roemerianus and fringing cordgrass *Spartina* sp. communities. Approximately 3 ha from Saw Grass Point Salt Marsh was destroyed in the 1950s when it was dredged to create Fort Gaines Harbor on the east end of the marsh and Pass Drury Channel to the north of the marsh.

Alonzo Landing, located in Fort Gaines

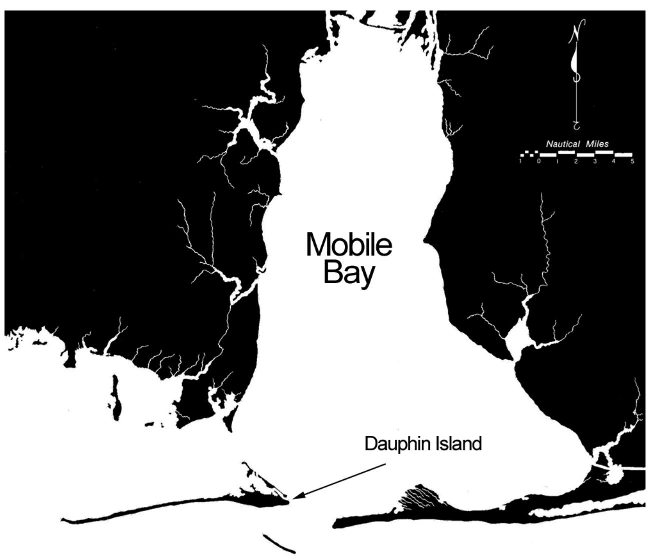

Figure 1. Map of Mobile Bay, Alabama with Dauphin Island identified.

Figure 2. Photograph of the east end of Dauphin Island with Saw Grass Point Salt Marsh identified.

Harbor, serves as one of the island's two primary access points for recreational boats and provides quick access to the Gulf of Mexico. Pilot boats for the Mobile Ship Channel, ExxonMobil crew boats, and the Mobile Bay Ferry dock at Alonzo Landing. The Dauphin Island Sea Laboratory and the U.S. Coast Guard also have docking and mooring facilities within Fort Gaines Harbor. The 30-m-wide Pass Drury Channel separates Saw Grass Point Salt Marsh from Little Dauphin Island. The maintenance depth of the 1.5-m box-cut channel allows private and commercial vessels to navigate to the Dauphin Island Marina or residential docks on the north side of Dauphin Island. Although there is a no-wake zone in Fort Gaines Harbor and Pass Drury Channel, this area of high boat traffic coupled with tropical storms and hurricanes has led to the loss of 0.5 ha of marsh along the north and east edges of the marsh since Fort Gaines Harbor was created in the 1950s (Alabama Department of Conservation and Natural Resources, State Lands Division, personal communication).

Selection of Erosion Control Technology

The construction of coastal erosion control structures is recommended only in locations where barrier island migration is prohibited (Campbell et al. 2005). This is the case at Saw Grass Point Salt Marsh for two primary reasons. First, the main east–west highway running along the south boundary of the marsh and houses abutting the western upland edge of the marsh prevent landward migration of the marsh. Second, naturally occurring sand overwash necessary for long-term sustainability of the marsh has been greatly reduced because of dredging activities in Pass Drury Channel and Fort Gaines Harbor.

A living shoreline technique consisting of hybrid breakwaters and marsh plantings was used to control erosion along Saw Grass Point Salt Marsh. Other erosion control techniques were considered before selecting the precast concrete Coastal Haven wave attenuators manufactured by Coastal Restoration, Inc. in Pensacola, Florida (http://www.coastlinesolution.com). Nearshore low-profile rock or wooden sills have been used in similar conditions by individual homeowners in Dog River, a subwatershed of Mobile Bay. These sills may have provided similar wave attenuation results, with material, transportation, and installation costs approximately equal to the coastal havens. A perceived disadvantage of rock or wooden sills for the Saw Grass Point project was the difficulty in removing or repositioning them if necessary. Additionally, the sills could pose a navigation hazard if they were submerged during mean high tides. Riprap or concrete mat revetments were not chosen because they are designed to prevent the loss of additional shoreline but are not designed to provide the offshore wave attenuation necessary for sediment accretion. Concrete mat revetments are in use along the perimeter of Alonzo Landing near the public boat ramps. However, even in the sheltered area of Fort Gaines Harbor, the mats require regular maintenance due to erosion behind the mats after storm events. Rock headlands, used successfully at two other locations in Mobile Bay, could have been an effective alternative; however, their use would have required greater encroachment into Fort Gaines Harbor and its mandated 1.61-ha turning basin. Removing headlands would also have been more difficult than removing coastal havens if the headlands failed to properly function. Vertical bulkheads made from steel or timber sheetpilings were considered but not selected due to the concerns of scouring in front of the bulkheads leading to an undermining of the structures and negative impacts on ecological services (Douglass and Pickel 1999). Finally, the coastal havens were selected because of initial success in a similar environment in Pensacola Bay, Florida (Florida Sea Grant, personal communication).

Each of the coastal havens units has a base length of approximately 2.4 m and a height of approximately 1.7 m. The average volume of individual units is 1.2 m^3 and each weighs 1 metric tons (mt). The units do not require anchoring and, therefore, can be positioned or repositioned as necessary. To release wave pressure buildup (USACE 1985), each unit has three 40 cm/side triangular openings per side and a 27-cm-diameter circular opening at the top of the hollow unit (Figure 3). The cost is approximately $400 per unit.

The design of the coastal havens shares three general similarities with surgebreakers, which are yet another structure that is sometimes used to decrease erosion (USACE

Figure 3. Photograph of coastal havens used at Saw Grass Point Salt Marsh on Dauphin Island, Alabama.

1985). Surgebreakers and coastal havens are made from precast marine concrete, are pyramidal, and have pressure release openings. However, the dimensions and configuration of the pressure release openings are different between the two structures and surgebreakers are deployed side by side in a single row while coastal havens are placed side by side in an offsetting double row.

The nonsegmented placement of the coastal havens in two staggered parallel rows allows them to function as an exposed and detached breakwater to minimize erosion along the eastern shore of the marsh. The coastal havens are designed to decrease the water velocity by reflecting, refracting, and diffracting much of the wave energy vertically and horizontally along, around, and through the pyramids before the waves reach the shore (French 2001; Reeve et al. 2004). Studies conducted by the U.S. Army Corps of Engineers, State of Maryland, and Commonwealth of Virginia (1990) determined that the effects on local wave and sediment transport (functional design) were largely influenced by the ability of the structures surviving a storm environment (structural design). The mass of the coastal haven units and the pressure release opening are important in meeting their structural and functional design of attenuating potentially damaging waves.

Most breakwater designs provide a solid barrier to incoming waves and dissipate wave energy through reflection (French 2001). Detached breakwaters reduce wave energy in the lee of the structures sufficiently to create a zone of sand deposition (Reeve et al. 2004). Accumulation of sediment behind solid nonsegmented breakwaters normally occurs on either end of the breakwater through wave diffraction. The deposition of sediment at the ends of the nearshore breakwater oftentimes leads to the formation of a lagoon if there is little or no longshore sediment transport. The nonsegmented design, two interlocking rows, and the unit openings (sides and top) allow the transmission of lower energy waves to occur evenly on the lee side of the breakwater. Sediment deposition from overtopping and longshore transport should in the short term form a lagoon and eventually create a perched beach, rather than salients, or tombolos, as found in segmented designs.

Preinstallation Sampling and Permitting

Baseline physical analysis and bathymetry were conducted prior to the installation of the breakwaters. The bottom sediment was analyzed to determine the estimated settling rate for the 1-mt units. The sediment analysis revealed that the sand-to-silt ratio would allow an approximate 10% settling rate of the units. A higher estimated settling rate would have required the use of geotextile fabric to control settlement. The bathymetry was obtained to establish the 1.3-m contour on which the coastal havens were installed.

Oyster density was estimated for the water bottom in front of the east edge of the marsh. This was accomplished by randomly sampling 20 sites along a 150-m transect of water ranging in depth from 0.5 to 1.3 m. At each site, a 0.25-m^2 quadrat was placed on the bottom and any oysters within the quadrat were removed and counted. Based on this estimate, there was less than one oyster/m^2. No sea grasses were observed while sampling oyster density.

Required permits were obtained from the U.S. Army Corps of Engineers and the Alabama Department of Environmental Management before installing the breakwater. This aspect of the project was time-consuming and cannot be underemphasized to the restoration practitioner.

Installation of Breakwater

On 5–6 April 2005, 182 units were placed in two rows along 162 m of the eastern perimeter of the marsh (Figure 4). The units were transported approximately 120 km by barge through the Intercoastal Waterway from Pensacola, Florida. A nonsegmented design for breakwater placement was chosen over a segmented design to minimize the likelihood of parabolic bay-shaped salients or tombolos, which commonly form behind a segmented design (Birben et al. 2006). Individual units were arranged in two parallel interlocking rows (centroid location of N 30° 15.145’ W

Figure 4. Aerial photograph of Saw Grass Point Salt Marsh, Pass Drury Channel, Fort Gaines Harbor, and the 182 coastal havens after they were installed. A visible gap between the long and short segments can be seen in front of one of the three tidal creeks within the marsh.

088o 04.914'). There was a 10-m gap between two sections of breakwater units near the northern end of the installation to minimize disruptions in flow of a nearby tidal creek. Units were placed approximately 9 m offshore from the centerline of the marsh berm in water approximately 1.3 m deep at mean high water.

Spartina Plantings

Living shoreline techniques often incorporate landscaping with native plantings to provide habitat and stabilize the shore in areas where the wave climate has been sufficiently reduced. In keeping with this living shoreline principle, the Dauphin Island boy scout troop planted 1,200 *Spartina alterniflora* plants in June 2005. Individual bare root plants, spaced on 10-cm centers, were used to replant barren spots of the existing mixed *Spartina* sp. community. In August 2005, Hurricane Katrina dislodged and destroyed all of the plants from this effort. The decision to not replant *S. alterniflora* after the hurricane was made based on the assumption that a properly functioning system would decrease wave energy along the shore sufficiently for plant communities to colonize barren areas within the existing *Spartina* sp. community. To date, however, there has been no measurable expansion of *Spartina* sp. into the barren areas along the fringe of the marsh.

Project Monitoring

The Auburn University Shellfish Laboratory will conduct a long-term monitoring program based on recommendations outlined by Thayer et al. (2003). The goal of the monitoring program is to determine the ability of the coastal havens to provide habitat, stabilize the protected shoreline, and serve as sediment traps. Annual monitoring of the project will be conducted each spring for 10 years. Only key parameters will be sampled over this period to minimize cost. The monitoring plan consists of random sampling of eastern oyster density on individual coastal haven units and along the transect used during the preinstallation sampling, measuring sediment accretion or loss in cm/year at four locations behind the breakwater system, and monitoring the area, percent cover and shoot density of the

Spartina sp. along the foreshore, storm wrack, and berm areas of the marsh fringe.

Results and Discussion

Sediment Accretion

Hurricanes Cindy (July 2005), Dennis (July 2005), and Katrina (August 2005) and Tropical Storm Arlene (June 2005) made landfall within 100 mi of Dauphin Island. These storms occurred after the installation of the coastal havens and before measuring sediment accretion. These storms had sustained winds ranging form 97 to 177 km/h. Sediment accretion measured at five locations at the toe of the leeward side of the breakwater system 19 months after installation of the coastal havens (November 2006) averaged approximately 15 cm based on an estimated 10% settlement rate determined by preinstallation sediment analysis conducted by Coastal Solutions, Inc. There was no shore erosion measured in November 2006 at three 4-m^2 reference sites, which were established when the Boy Scouts planted Spartina. Over the long term, the monitoring program will determine the extent of sediment accretion between the coastal havens and marsh edge. A desired outcome from this project would be the creation of 0.5 ha of marsh. This would be equal to 0.5 ha lost since Fort Gaines Harbor was created in the 1950s, thereby offsetting the impact of the harbor on marsh erosion.

Marsh formation requires abundant sediment supply, low wave energy, and low surface gradient. Once sediment accumulation reaches a critical height, the mud flats are colonized by halophytic plants that aid in trapping sediment when flooding occurs and add organic material to the substrate (Morang et al. 2002). Most marshes along estuarine shorelines are subject to regular or irregular flooding by lunar tides and wind generated tidal fluctuations (North Carolina Coastal Resources Commission 2006). Although the marsh is protected from development through a long-term lease to the Town of Dauphin Island, it is susceptible to the effects of chronic erosion in part caused by the loss of littoral sediment replacement due to maintenance dredging of Fort Gaines Harbor and Pass Drury Channel.

Ecosystem Services

The coastal haven units provided excellent hard substrate on which oysters have established. These created oyster reefs may provide various ecosystem services, including improvement of water quality (Newell and Koch 2004) and creation of a foraging area for fish (U.S. Army Corps of Engineers, State of Maryland, and Commonwealth of Virginia 1990). In November 2006, a random sample of oyster density on individual units was 205 oysters/m^2 (Figure 5) compared to 150 oysters/m^2 on Alabama's most productive oyster reef located approximately 4 km north at Cedar Point (Alabama Department of Conservation and Natural Resources, Marine Resources Division, personal communication). The high oyster density is likely a result of the vertical relief provided by the units and due to the fact that oysters set equally well on the inside surface of the open structures as on the outside surface. Colonization of the units by oysters increases the total volume of the breakwater resulting in additional wave attenuation. Other ecosystem services provided by the breakwater include refuge habitat for aquatic animals and the use of the exposed portions of the breakwaters by colonial seabirds (Yozzo et al. 2003). The foraging and refuge habitats are essential for locally important species such as: spotted seatrout (also known as speckled trout) *Cynoscion nebulosus*, blue crabs *Callinectes sapidus* and Gulf stone crabs *Menippe adina*, eastern oyster *Crassostrea virginica*, red drum *Sciaenops ocellatus*, southern flounder *Paralichthys lethostigma*, and various species of commercially important shrimp (brown shrimp *Farfantepenaeus aztecus*, pink shrimp *F. duorarum*, and white shrimp *Litopenaeus setiferus*.

Design Considerations

Pope (1997) identified 12 questions to be considered before adopting nontraditional technologies for shore protection. There are three general themes in which the 12 ques-

Figure 5. Photograph of coastal havens with oysters visible on the lower one-third of each unit. Mean oyster density in November 2006 was 205 oysters/m^2.

tions could be categorized. The first theme focused on the structural durability and functionality of alternative technologies including susceptibility to storm damage and functional aspects, including unintended negative consequences when compared to traditional approaches. The coastal haven units withstood any negative impacts from Hurricane Katrina, indicating that the unit mass and pressure release openings adequately prevented unit movement during a major hurricane. The sediment stability around the base of the devices was a key consideration in choosing this system over alterative types of hard structures. The second theme focused on the difficulty in removing the alternative structures if they did not perform as expected. Installation of the units was straightforward with the placement of the 182 units requiring the use of a crane over 2 d. In the event that the units fail to meet long-term design expectations, they may be repositioned or removed in a similar manner at a cost estimated to be no more than the total transportation and installation cost of $18,000. This criterion was a determining factor in choosing this system versus the use of a detached rock breakwater because only 182 coastal haven with a total mass of 182 mt would have to be removed versus an equivalent mass of a greater number of smaller rocks needed to create a rock breakwater. Pope's (1997) final theme focused on comparing cost to traditional methods, including the cost to maintain and cost to remove, if necessary. The cost of the 182 units, transportation, and installation was $54,400 with an average cost $335/m to protect 162 m of shoreline. No maintenance has been required and little is expected in the future.

Educational Benefits

The high number of visitors who either wait for the Mobile Bay Ferry or launch boats at Alonzo Landing provides the opportunity to use this project as a passive learning platform. Six interpretative signs were placed on a recently constructed observation pier near the southeast corner of the marsh. From the observation pier, residents and visitors may view a large functional salt marsh, bird watch, and read information describing the ecological importance of salt marshes and oyster reefs to the Mobile Bay ecosystem.

Conclusions

The living shoreline concept applied at Saw Grass Point Salt Marsh appears to be a cost-effective, viable technique for minimizing shoreline erosion and creating estuarine habitat. The primary restoration goal of this project was to stop the erosion along the eastern edge of Saw Grass Point Salt Marsh and eventually restore an additional 0.5 ha of the historical marsh. If the goals are achieved the project cost will be approximately $335/m to protect 162 m of shoreline, assuming no maintenance costs. Protection of the eastern marsh edge from additional erosion using nearshore coastal haven breakwaters has met initial expectations since they were installed in 2005. There has been no erosion along the marsh edge that is protected by the exposed breakwater. Local biodiversity has increased through the conversion of regularly dredged soft bottom found in Fort Gaines Harbor to hard substrate suitable for oyster colonization provided by the coastal havens. An annual monitoring program over an extended period (decadal) will be necessary to determine the long-term effectiveness of this shoreline stabilization project. Monitoring of this and other projects using similar designs is essential to determine design performance, tradeoffs in ecosystem services, and costs over the short and long term, all of which should be taken into consideration by managers and homeowners before widespread application of living shorelines as a shoreline protection system.

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