Coastal Habitats
6. Living Shoreline Creation

DEFINITION

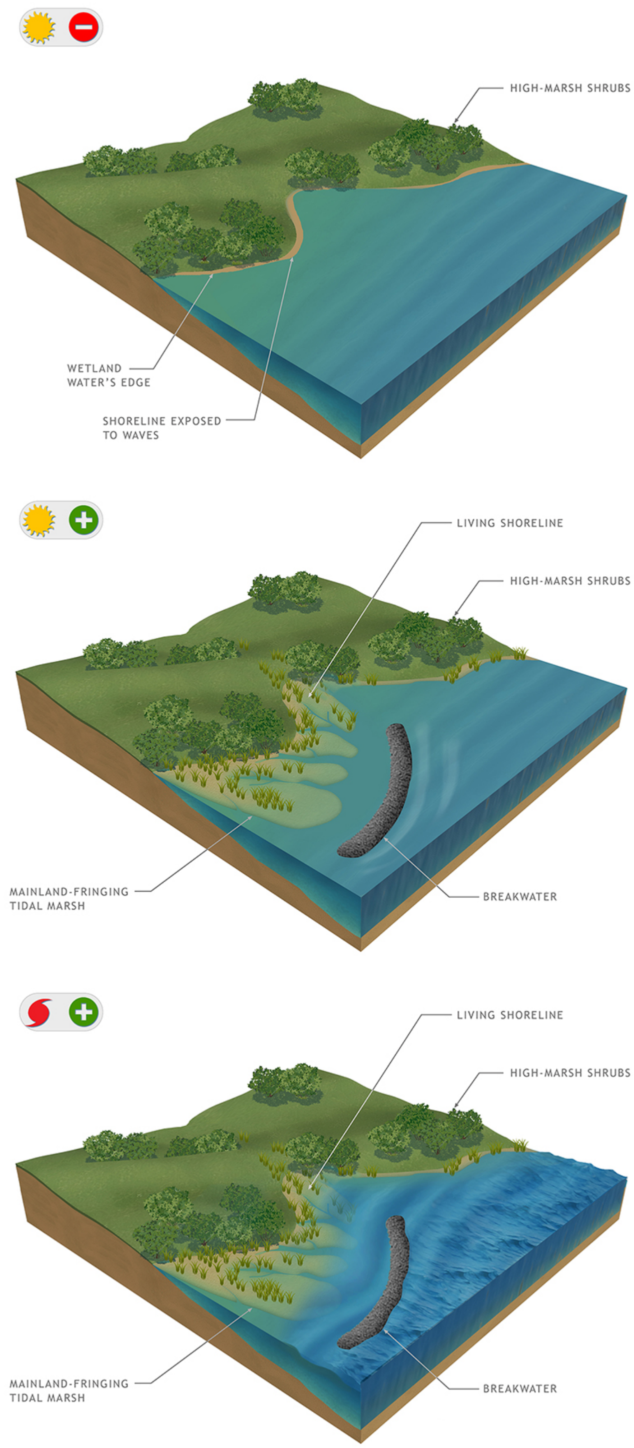
Living shoreline creation refers to the process of planting vegetation along the shoreline and installing structures that help hold the vegetation in place (Olander et al. 2021). Living shorelines help prevent erosion along the shoreline, providing an alternative to traditional gray infrastructure like bulkheads, ripraps, or jetties (Figure 1). These hardened shorelines are on the rise as American coastal regions rapidly urbanize, with one-third of American coastlines expected to be hardened by 2100. Living shorelines are often preferred to gray infrastructure because of their ability to trap sediments from tidal waters, allowing them to gain elevation as sea levels rise (NOAA 2023). Most living shorelines include a breakwater composed of bagged oyster shells, granite, eco-friendly concrete, or reef balls (Olander et al. 2021). Living shoreline creation typically involves planting vegetation, installing organic material, constructing oyster reefs or living breakwaters, and adding sills or other holding structures (NOAA n.d.).

TECHNICAL APPROACH

Living shoreline creation typically connotes softer or greener shorelines as opposed to gray or hard shorelines (Sutton-Grier et al. 2018). However, many living shoreline projects implement a hybrid of green and gray infrastructure (NOAA n.d.). The following approaches to living shoreline creation encompass both green-gray hybrid strategies and completely green shorelines:

1. **Removing gray coastal barriers:** Before creating a living shoreline, any existing coastal protection structure must be removed. Removing bulkheads, riprap, and revetment must be done in a way that wave energy is dissipated during the removal process. This ensures that workers can safely access the site and the new living shoreline can get established under lower wave energy conditions. Dispersing wave energy generally entails constructing temporary breakwaters that will shield the site during construction (FWC n.d.).
2. **Creating the living shoreline structure:**
    - **Organic materials:** Bio logs, organic fiber mats, and seeded coir logs are some examples of materials used for living shoreline structures. These materials are all biodegradable and mimic natural shoreline ecology, providing habitat for intertidal species that need shelter and helping vegetate the shoreline (Elgin 2022). Furthermore, these materials can serve as living breakwaters which dissipate wave energy as it reaches the shore (NOAA n.d.).
    - **Oyster reefs:** Oyster reefs help protect the coast, stabilizing the seafloor and attenuating waves before they hit the shore. Oyster reef restoration techniques

Figure 6.1 Unprotected shoreline, then shown with a living shoreline under sunny conditions and storm conditions



Note: The living shoreline provides protection from erosion and facilitates marsh growth, leading to additional coastal protection.

Illustration courtesy US Army Corps of Engineers include distributing large amounts of shells with high-pressure hoses, constructing a linear reef to stabilize the shoreline, and bagging oyster shells to jump-start a reef (Figure 2; NOAA 2022).

- **Living breakwaters:** *Living breakwaters* is a broad term that combines many of the other living shoreline creation techniques into a fabricated coastal defense structure. A *breakwater* is a rubble mound structure created in the intertidal region just offshore. Breakwaters are then enhanced with oyster reefs and other organic materials to mimic natural ecology (GOSR 2020).
- **Sills and other holding structures:** A *sill* is a low stone structure that runs parallel to the existing shoreline (VIMS n.d.). Sills help stabilize vegetation in high wave energy environments (NOAA n.d.).
- **Reef balls:** *Reef balls* are small artificial reefs that are meant to mimic natural reef systems (RBF 1999). Reef balls help create living breakwaters and provide enhanced protection to the coast (Olander et al. 2021).
- **Eco-friendly concrete:** *Eco-friendly concrete* is a special type of concrete that is designed specifically for shoreline strengthening and working in tandem with natural barriers. Eco-concrete can help stabilize a living breakwater or serve as a holding structure to support vegetation (Smith et al. 2020).

Figure 6.2 Aerial view of living shoreline construction using oyster castles

Photo courtesy US Fish and Wildlife Service Northeast Region

3. **Revegetation:** Once the structural components of the living shoreline have been installed, revegetation can occur. Revegetation involves planting riparian, marsh and submerged aquatic vegetation, which helps reduce shoreline erosion (NOAA n.d.). On sites where there is low-to-moderate erosion, direct planting can occur. However, in areas where there is severe erosion, one of the following planting techniques should be implemented:

    - **Live staking:** Live staking involves taking cuttings of woody plants and driving them into the shoreline substrate. The cuttings will eventually form roots and begin to grow (NYS DEC n.d.).
    - **Contour wattling:** Working in tandem with live staking, *contour wattling* refers to laying bundles of branches in between the wood stakes and covering them with soil. The branches will stabilize the shoreline and grow (NYS DEC n.d.).
    - **Brush matting:** Similar to contour wattling, brush matting is the process of covering a shoreline with branches to stimulate growth. This simple strategy can reduce wave energy by up to 60% (Herbert et al. 2018).
    - **Vegetated riprap:** This green-gray hybrid approach involves inserting live stakes in between the rocks of riprap. This helps add vegetation to the shoreline without losing the erosion protection provided by the riprap (NYS DEC n.d.).

OPERATIONS AND MAINTENANCE

Living shorelines require regular invasive species and debris removal as well as occasional vegetation replanting or sand fill additions to keep organic materials in place. The estimated cost of maintaining a living shoreline is about $100 per linear foot per year (NOAA 2015).

FACTORS INFLUENCING SITE SUITABILITY

- ✓ **Low-to-moderate wave energy:** Vegetation in living shorelines cannot tolerate high wave energy conditions. Areas with low-to-moderate wave energy allow for vegetation to become established and provide ideal conditions for intertidal ecosystems (Zylberman 2016).
- ✓ **Fetch exposure of between 1 and 5 mi:** *Fetch* is the length over water that wind blows without any obstruction. Fetch influences the type of waves that hit the shore, with a higher fetch corresponding to larger waves. Having the appropriate amount of fetch ensures that living shorelines will be able to handle storm surges (Berman and Rudnicky 2008).
- ✓ **Low-to-moderate erosion:** While living shorelines are often installed to remediate erosion, a site with severe erosion is not suitable for a living shoreline. Living shorelines cannot alter external factors influencing erosion, meaning that erosion still may occur even if vegetation is planted. However, if the cause of erosion is determined to be hard armoring, then replacing the hard structure with a living shoreline is likely to reduce erosion (Zylberman 2016).

- ✓ **Near a tidal marsh:** Living shorelines are effective at working in tandem with tidal marshes to control coastal hydrology. Marshes also thrive in similar conditions to living shorelines, making them a proxy for success (Zylberman 2016).
- ✓ **Shallow bathymetry:** A site with a shallow bathymetry is recommended for living shoreline projects because these conditions are conducive to intertidal ecosystems. If there is a steep drop-off in depth near the shoreline, then the wave regime and sediment transport will be significantly altered. A 1 m contour line greater than 30 m from the shoreline is recommended for living shoreline projects (Miller et al. 2015).
- ✗ **Frequently covered by thick ice:** Thick ice can cause significant damage to a living shoreline. As ice becomes frozen to the vegetation, buoyant forces related to the fluctuation in tides can negatively affect the structural integrity of the shoreline (Miller et al. 2015).
- ✗ **Infrastructure, such as buildings or roads, adjacent to the shoreline:** One of the benefits of living shorelines is that they dissipate wave energy over a longer area than hardened shorelines. However, if there is infrastructure directly along the coast, then there will not be enough space to install a properly functioning living shoreline (Carey 2013).
- ✗ **Adjacent to a seawall that will not be removed:** Seawalls disrupt natural sedimentation processes, which result in a lack of sediment downdrift. As a result, areas directly adjacent to a seawall often experience high levels of erosion. If a living shoreline is starved of sediment, then its ability to fight erosion is compromised (Zylberman 2016).
- ✗ **Extreme water depths:** Deep waters near the shoreline encourage boats to go near the living shoreline, potentially damaging the underwater portion. Furthermore, many aquatic plants cannot tolerate deep water (MDE 2013).
- ✗ **Located on a narrow waterway:** Living shorelines take up more space than traditional hard shoreline armoring. A narrow waterway may not have the space to accommodate both the underwater and terrestrial portions of a living shoreline (MDE 2013).

TOOLS, TRAINING, AND RESOURCES FOR PLANNING AND IMPLEMENTATION

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Natural and Structural Methods for Shoreline Stabilization	Document	2015	National Oceanic and Atmospheric Administration (NOAA), US Army Corps of Engineers (USACE)	National	Developed by NOAA, this resource helps users determine the best living shoreline design based on the specific attributes of the site. The guide contains a helpful infographic that displays the spectrum of gray to green shoreline infrastructure.	✓	✓	—	—
Guidance for Considering the Use of Living Shorelines	Guidebook	2015	NOAA	National	Also developed by NOAA, this guidebook outlines the physical, ecological, and policy considerations that influence a living shoreline creation project. Emphasis is given to the site suitability factors for successful projects.	✓	✓	—	—
NOAA's Living Shoreline Projects	Story map	2023	NOAA	National	Containing 199 case studies of successful living shoreline creation projects, this story map documents a variety of restoration strategies from across the country. The map displays the location of each project and gives a short description of the techniques used at that site.	—	—	—	✓
Living Shorelines Training for Marine Contractors	Guidebook	2019	Florida Fish and Wildlife Conservation Commission	Florida but most of the information is more broadly applicable	This guide encompasses the technical aspects of implementing and maintaining living shoreline creation projects. The authors provide in-depth design guidelines and information about the permitting process.	✓	✓	✓	—

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Shoreline Protection	Website	2023	Michigan Department of Environment, Great Lakes and Energy	Great Lakes region	Discussing the trade-offs between living and hard shorelines is the primary focus of this resource. The website contains best management practices, fact sheets, and a story map illustrating successful projects in the Great Lakes region.	✓	—	—	✓
Living Shorelines Engineering Guidelines	Document	2016	Stevens Institute of Technology	National	This technical document delves into the hydrodynamic, terrestrial, and ecological parameters that impact living shoreline creation projects. Additional topics include regulatory considerations and invasive species management.	✓	✓	✓	—
Living Shorelines and Nature-Based Solutions Guidebook	Guidebook	2022	Commonwealth of the Northern Mariana Islands' Bureau of Environmental and Coastal Quality	Designed for the Northern Mariana Islands but most of the information is more broadly applicable.	Viewing living shorelines through the nature-based solutions paradigm, this guidebook provides techniques to create living shorelines. The guidebook contains additional information about the permitting steps and funding opportunities available.	✓	✓	—	—
A Guide to Living Shorelines in Texas	Guidebook	2020	Texas Coastal Management Program	Texas but most of the information is more broadly applicable.	This resource provides an easy seven-step guide to living shoreline creation projects as well as cost projections, planting guides and permitting considerations. Furthermore, the guide explores hybrid shoreline stabilization methods and recommends techniques based on a property's characteristics.	✓	✓	—	✓

GRAY INFRASTRUCTURE ALTERNATIVES

Living shorelines can be an alternative to gray infrastructure approaches that address coastal erosion and flooding: bulkheads, riprap/revetments, seawalls, groins, and breakwaters. The ability of a living shoreline project to replace or supplement these gray infrastructure approach depends strongly on the project's location and whether it is designed to create the necessary outcomes. Certain environmental conditions may require gray infrastructure rather than a living shoreline. See the gray infrastructure alternative tables in Section 1 for a comparison of living shorelines to these alternatives.

LIKELY BENEFITS AND OUTCOMES

Primary objectives for each strategy are highlighted.

Climate Threat Reduction

- **Reduced flooding:** Living shorelines have been shown to reduce flood risk because of their ability to repel water from developed areas, attenuate wave energy, and reduce erosion once waves reach the shore. Unlike hardened shorelines, living shorelines employ more flexible water management strategies, allowing incoming waves to gradually dissipate over a longer surface area (Moosavi 2017). While gray infrastructure can also mitigate coastal flooding, it is often vulnerable to being breached by large waves and has more expensive maintenance costs (Waryszak et al. 2021).
- **Storm protection**: Living shorelines are more effective at protecting coastal communities from hurricanes than hardened shorelines or natural marshes. This is because living shorelines have higher densities of vegetation than natural marshes or traditional bulkheads, allowing the shoreline to maintain its elevation (Smith et al. 2020).
- **Sea level rise adaptation and resilience:** Living shorelines can gain elevation with sea level rise. However, this depends on numerous factors, including the rate of sediment accretion, management practices and nearby land uses (Mitchell and Bilkovic 2019). Adding biotic components to a living shoreline like oyster shells creates a dynamic structure that can better adapt to rising sea levels (Risinger et al. 2017).

Social and Economic

- **Reduced erosion:** Living shorelines protect coasts from erosion by allowing native plants to stabilize sand and soil with their dense web of roots. Living shorelines promote the accretion of sediments, which provides more substrate to bolster eroding shorelines (Polk and Eulie 2018). Living shorelines also reduce scour, where sediment is removed from the bank of a waterbody, which hardened shorelines like bulkheads exacerbate (Herbert et al. 2018).
- **Property and infrastructure protection:** Despite being low-lying compared to traditional bulkheads, living shorelines are effective at mitigating storm surges. This is because of the greater distance between the ocean and nearby development that living shorelines provide, restoring the natural intertidal exchanges. Vegetation still has a

high wave attenuation capacity even while submerged, preventing water from reaching properties and infrastructure further inland (Polk et al. 2022).

- **Recreational opportunities:** Living shorelines can boost recreation by increasing water quality and local fish stocks, which helps attract recreational fishermen (Olander et al. 2021).
- **Mental health and well-being:** Living shorelines help preserve greenspace for the public to enjoy along the coast, improving mental health and psychological well-being.
- **Jobs:** Contractors will need to be hired to create a living shoreline, aiding the local economy.
- **Resilient fisheries:** Reef balls, living breakwaters, and oyster reefs created during living shoreline projects increase habitat for both finfish and shellfish, sustaining fish populations. This helps increase the total output of the local fishing industry (Olander et al. 2021).
- **Food security:** Some coastal residents rely on healthy fish stocks for their own nutrition, meaning that living shorelines aid local food security (Olander et al. 2021).
- **Cultural values:** Living shorelines can help educate residents about local ecology and provide ideal locations for environmental education.

Ecological

- **Improved water quality:** Living shorelines create a buffer in between anthropogenic terrestrial environments, the source of nutrient and sediment pollution, and the waterbody (Erdle et al. 2006; Askvig et al. 2011). Living shorelines help facilitate denitrification, a process that removes nitrogen from the soil, thus precluding it from entering the water. This reduces nutrient levels in surrounding waterbodies, mitigating one of the major drivers of eutrophication. Along with eutrophication, algae blooms and hypoxic zones decrease when living shorelines are installed (Onorevole et al.2018). Living shorelines also provide habitat for oysters, which filter excess pollutants out of the water (Askvig et al. 2011).
- **Enhanced biodiversity:** Living shorelines have been found to increase biodiversity for both intertidal and marine ecosystems, including higher and more diverse fish populations (Currin 2019). Studies show that fish, crab, and shrimp populations in created living shorelines match those of natural shorelines within three years of construction (Currin et al. 2007).
- **Invasive and nuisance species management:** Hardened shorelines eliminate vital spawning and feeding habitats for native species and better suit the capabilities of invasive species, helping them proliferate (EGLE 2023). Using living shorelines instead of bulkheads or riprap reduces opportunities for invasive species.

BARRIERS AND SOLUTIONS FOR PRACTITIONERS

Common Barriers

Several barriers are common across many of the nature-based solutions strategies; these are described in more detail in Section 1 of the Roadmap. Additional notes about these barriers specific to living shoreline creation are included here.

- **Expense**
- **Capacity**
- **Public opinion:** Many coastal communities have misconceptions about the effectiveness of living shorelines and falsely believe that bulkheads provide a greater degree of protection from coastal flooding. This is largely a result of the ubiquity of hardened shorelines along developed coasts and widespread unfamiliarity with living shorelines (Scyphers et al. 2020).
- **Conflict with other land uses:** While living shorelines increase values of coastal properties, they require that structures be somewhat removed from the coast. Hardened shorelines allow for piers, boardwalks, and residences to be built directly on the water whereas living shorelines are designed to give space in between the water and anthropogenic infrastructure. This protects coastal communities in the long run but limits the economic activity of structures that need to be directly on the water in the short run.
- **Regulation:** Many living shoreline projects will require multiple permits to be approved before construction can begin. At the federal level, the projects will require a permit issued by the USACE. At the state level, permitting requirements differ from state to state, but many states have much narrower parameters than the USACE. At the local level, land use authorities have their own set of criteria needed to approve a project. Navigating the triple-tiered permitting system adds another layer of unpredictability to living shoreline restoration projects (RAE 2014).
- **Lack of effectiveness data**

Economic

- **Cost uncertainty:** Because of the variability of coastal environments, it is difficult to estimate the cost of a living shoreline creation project. While living shorelines typically cost less than bulkheads, the cost uncertainty of living shorelines sometimes causes communities to choose hardened structures instead (RAE 2014).
- **High cost of land:** Living shorelines take up more land than hardened coastal defenses, which can result in nearby structures being removed. This is called *managed realignment* (Neal et al. 2017). Coastal properties are significantly more expensive than analogous inland ones, resulting in a high cost for buyouts (Rinehart and Pompe 1999).

Community

- **Limited shoreline access:** Vegetation on living shorelines cannot endure heavy foot traffic, meaning that many areas must be closed for public recreation. Many states require that areas below the high or low tide line be publicly accessible, termed *public trust shoreline*. While living shorelines may alter some beach access points, they are better at preserving shoreline access in the long term than bulkheads (NOAA 2015).

Ecological

- **Invasive species:** Living shorelines are vulnerable to invasive species, similar to many other intertidal habitats. While living shorelines are more resilient to invasive species than hardened shorelines, control mechanisms may still need to be implemented (Hacker et al. 2001).
- **Trade-offs between existing habitat and created living shorelines:** When a living shoreline is created in an area that was previously undeveloped, some of the previous ecological functions may not be retained. Living shoreline creation may involve converting unvegetated wetlands and shallow subtidal zones into a marsh bounded by a sill. While the living wetland creates a greater diversity of habitats, disruptions to the original habitat will occur (Bilkovic and Mitchell 2013).
- **Limited resilience in hardened environment:** If small living shoreline creation projects are surrounded by hardened shorelines, then the ecological and

EXAMPLE PROJECTS

Name and Link	Location	Leading Organizations	Techniques Used	Size, linear ft	Cost, $	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Fog Point Living Shoreline Project	Glenn Martin National Wildlife Refuge, MD	**US Fish and Wildlife Service (USFWS)**	Living breakwaters, sills	20,950	9 million	1 year	To protect a vulnerable marshland, protective sand and rock structures will be built to rejuvenate an eroding shoreline. This shoreline then was buttressed by submerged aquatic vegetation and clam beds.	Increased storm severity, coastal flooding	Used articulated dump trucks to reach shallow areas that weren't accessible to barges.
Gandys Beach Living Shoreline	Gandys Beach Preserve, NJ	**USFWS,** The Nature Conservancy (TNC), Rutgers University, Stevens Institute of Technology	Living breakwaters, oyster reef restoration	2,750	880,000	2 years	To create a living breakwater, managers installed oyster castles and bags of clam and oyster shells. This also helped restore the oyster reefs along the shoreline.	Increased storm severity	Four years after the restoration was complete, erosion was still occurring along the shoreline. Workers realigned the breakwaters into smaller structures, solving the problem.
Jamaica Bay Living Shoreline Project	Gateway National Recreation Area, NY	**National Park Service,** Fund for the City of New York	Bagged oyster shells, oyster reef restoration, biodegradable coir logs, live staking	2,400	4 million	5 months	The project team added sand to raise the surrounding wetland, revegetated the shoreline, added organic material, and created an oyster reef using bagged oyster shells.	Increased storm severity, coastal flooding	It is important to manage the spectrum of saltwater- to freshwater-tolerant plants, as this project was meant to return a marsh to freshwater state after it turned brackish.

Name and Link	Location	Leading Organizations	Techniques Used	Size, linear ft	Cost, $	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Shinnecock Living Shoreline Restoration Project	Long Island, NY	Shinnecock Indian Nation, **US Geological Survey (USGS),** Cornell University	Oyster reef restoration, revegetation	3,000	3.75 million	1 year	Team members dredged additional sand onto the beach, plant native vegetation, added stones to support the vegetation, and created oyster shells via calcification.	Increased storm severity, sea level rise, coastal flooding	Oyster larvae often need to be induced to attach onto the shells provided.
Weaverling Spit Beach Living Shoreline Project	San Juan Islands, WA	Samish Indian Nation	Installing organic materials, revegetation	1,400	N/A	N/A	To reduce shoreline erosion, workers added driftwood, pebbles, and native vegetation, mimicking a natural shoreline in the Pacific Northwest.	Increased storm severity, coastal flooding	Even heavy driftwood must be anchored into the shoreline to keep it from washing away during severe storms.
Jupiter Inlet Living Shoreline Project	Jupiter Inlet Lighthouse Outstanding Natural Area, FL	**Bureau of Land Management,** Jupiter Inlet District	Living breakwaters, revegetation	550	540,000	4 months	Contractors built a living breakwater that combined green and gray elements and revegetated the shoreline to reduce erosion.	Increased storm severity, coastal flooding, sea level rise	Diversified plantings based on proximity to mean high water levels.
San Francisco Bay Living Shorelines Project	San Rafael, CA	**USGS,** TNC, California State Coastal Conservancy, NOAA	Reef balls, living breakwaters, eco-friendly concrete, oyster reef restoration, eel grass restoration	1,300	2.1 million	2 months	To enhance wave attenuation, workers placed reef balls, eco-friendly concrete, and oyster shells to restore an oyster reef that will also serve as a living breakwater. Eel grass was then transplanted to the surrounding areas.	Coastal flooding	Adequate space between oyster reefs, and eel grass is necessary because of competition for space.

Name and Link	Location	Leading Organizations	Techniques Used	Size, linear ft	Cost, $	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Swift Tract Living Shoreline Restoration	Baldwin County, AL	TNC, Alabama Department of Conservation and Natural Resources, National Fish and Wildlife Foundation, NOAA	Living breakwaters, oyster reef restoration, revegetation	2,100	549,341	1 year	To mitigate shoreline erosion, a gabion and oyster shells were placed offshore to form a living breakwater. The shoreline was also revegetated.	Increased storm severity	Because of the low salinity of the project site, the oyster reef attracted less oysters and more mussels than managers hoped for.

Bolding indicates DOI affiliates.

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