A MANUAL FOR RE-ENGINEERING LIVING SHORELINES TO HALT EROSION AND RESTORE COASTAL HABITAT IN HIGH-ENERGY ENVIRONMENTS

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Contents

List of Abbreviations

BESE	Biodegradable EcoSystem Engineering Elements
DHR	Division of Historical Resources
FDEP	Florida Department of Environmental Protection
FWC	Florida Fish and Wildlife Conservation Commission
GAW	Galvanized After Welding
GTM	Guana Tolomato Matanzas
ICW	Intracoastal Waterway
MHWL	Mean High Water Line
NED FDEP	Northeast District of Florida Department of Environmental Protection
NERR	National Estuarine Research Reserve
SJRWMD	St. Johns River Water Management District
USACE	United State Army Corps of Engineers
UF	University of Florida

Why living shorelines?

For centuries, humans have settled on coastlines because of their rich resources and high recreational and aesthetic values. This preference is so pronounced that over one-third of the human population currently lives within a hundred kilometers of the coast (NOAA 2013). This growth of population density along coastlines has created a strong dependence on coastal resources and prominent evidence of human activities in coastal environments.

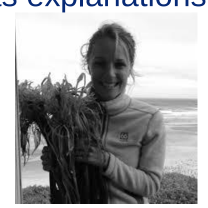
One significant negative effect of coastal development is erosional damage. Coastal erosion is a physical process in which sediment and biological material is removed and re-deposited or lost and exported from the system, resulting in the retreat of the shoreline edge. Natural factors like sediment sources and sinks, geological coastal processes, waves, and tides can contribute to shoreline erosion. However, many anthropogenic factors like dredging, construction, coastal development, and recreational activities (e.g., boating) also act together to alter the hydrodynamic environment within estuaries and accelerate erosional processes (National Research Council 1990).

Both erosional changes of shorelines and the need to protect developing communities have prompted the construction of coastal defense structures such as concrete seawalls, groins, and bulkheads. These structures are designed to act as a barrier and prevent wave energy from impacting the shoreline. However, hardened coastal protection approaches only solve short-term erosional problems and can have several unintended consequences; for example, the erosion of adjacent shorelines or erosion along the toe of the structures (Bozek and Burdick 2005, National Research Council 2007) and the disruption of plant, animal and material flows between the marine and terrestrial environment (Douglass and Pickel 1999, OSTP 2015, Patrick et al. 2014, Seitz et al. 2006). Furthermore, hardened shorelines suppress biodiversity and reduce habitat complexity compared to natural shorelines (Gittman et al. 2016).

Living shorelines are an innovative alternative to hardened armoring that reduces erosional damage and enhances community resiliency. Instead of hardened shoreline structures, living shorelines use plants or other natural elements like oyster reefs to stabilize coastal shorelines. Living shorelines are more resilient to storms than traditional hardened armoring (Smith 2016). Living shorelines are nature-based strategies of shoreline protection that can be utilized when the “do nothing” approach is no longer viable or when a property owner has decided to enhance a hard-armored structure. Examples include replanting mangrove seedlings and marsh grasses along eroded banks, using oyster shell or other substrates to repopulate degraded reefs, and using coir-fiber logs to stabilize shorelines. These natural materials not only dissipate wave energy without scouring and eroding the adjacent shoreline, but also create natural habitat and increase biodiversity and ecosystem functioning (Myszewski 2016).

While there are several advantages to living shorelines, it is important to understand that not all shorelines are the same and protocols will differ with each project. One factor practitioners must consider is maintaining living shorelines along particularly energetic coastlines. Many of the common living shoreline approaches are not suitable for high-energy environments (i.e., areas with high boat traffic). For instance, in high-energy environments, mangrove seedlings and marsh grasses are easily uprooted and bagged oyster shell can become dislodged, leaving the shoreline once again unprotected. Determining how to naturally protect high-energy shorelines remains an outstanding challenge.

To address this issue, a team of researchers and natural resource managers implemented a project, funded through the NOAA National Estuarine Research Reserve System Science Collaborative program, which evaluates the efficacy of a novel living shorelines technique to mitigate coastal habitat erosion along high-energy shorelines. The project team designed a hybrid structure that acts as a double barrier to dissipate boat wake energy along the Atlantic Intracoastal Waterway in Ponte Vedra Beach, Florida. This technique consists of a set of wooden breakwalls placed in front of oyster structures along a dynamic shoreline. The breakwalls act as a first line of defense against boat wakes while the oyster structures serve as substrate to restore oyster reefs that can further dissipate wave energy. Within this manual are the project details, including results from testing the hybrid living shorelines technique as well as explanations of planning, design, installation, maintenance, monitoring, and costs.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Site Selection

This project was conducted along 125 meters of Tolomato River shoreline in the Atlantic Intracoastal Waterway (ICW), Ponte Vedra Beach, Florida, U.S.A., located approximately 8.4 and 21 kilometers north of the St. Augustine Inlet (Figure 1, Appendix A). The six intertidal sites have semidiurnal tides with a range of 1.6 m (NERRS 2017), and are bordered on their landward edge by salt marsh habitat consisting mainly of smooth cordgrass (*Spartina alterniflora*) with isolated black mangrove (*Avicennia germinans*) trees and patches of marsh succulents including saltwort (*Batis maritima*), bushy seaside oxeye (*Borrichia frutescens*), and perennial glasswort (*Sarcocornia perennis*). The sites were selected based on three parameters: 1) the salt marsh edge was showing visible signs of erosion (exposed plant roots, escarped marsh edge profile), 2) the site was dominated by smooth cordgrass (*S. alterniflora*), and 3) the substrate was comprised of a sand/clay mix to standardize initial substrate conditions.

Figure 1: Map of site locations

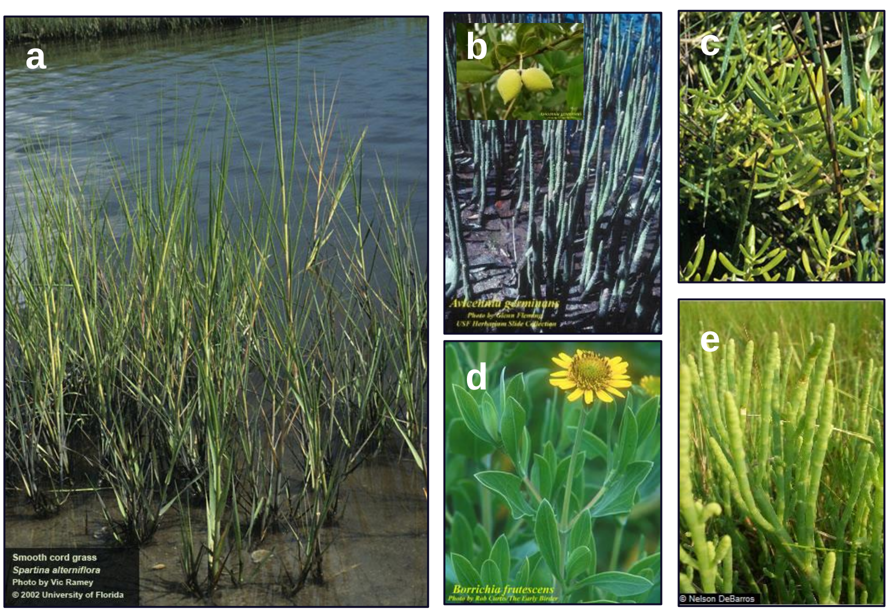

Figure 2: a) Spartina alterniflora (https://plants.ifas.ufl.edu);
b) Avicennia germinans (http://florida.plantatlas.usf.edu);
c) Batis maritima (https://plants.ifas.ufl.edu);
d) Borrichia frutescens (http://florida.plantatlas.usf.edu);
e) Sarcocornia perennis (https://plants.usda.gov)

Historically, extensive Eastern oyster (*Crassostrea virginica*) reefs populated the intertidal margins of this estuary, but due to heavy boat traffic, only dead shell mounds (also called “rakes”) now occur along the ICW channel edge (Figure 3, Appendix B). Live oyster reefs are widespread in tidal creeks and inlets that experience lower levels of boating activity in the area. Oyster larval supply in the area is abundant during the peak reproductive season, which lasts from April through September (Figure 4).

Figure 3: Oyster shell rake (left) and saltmarsh erosion (right)

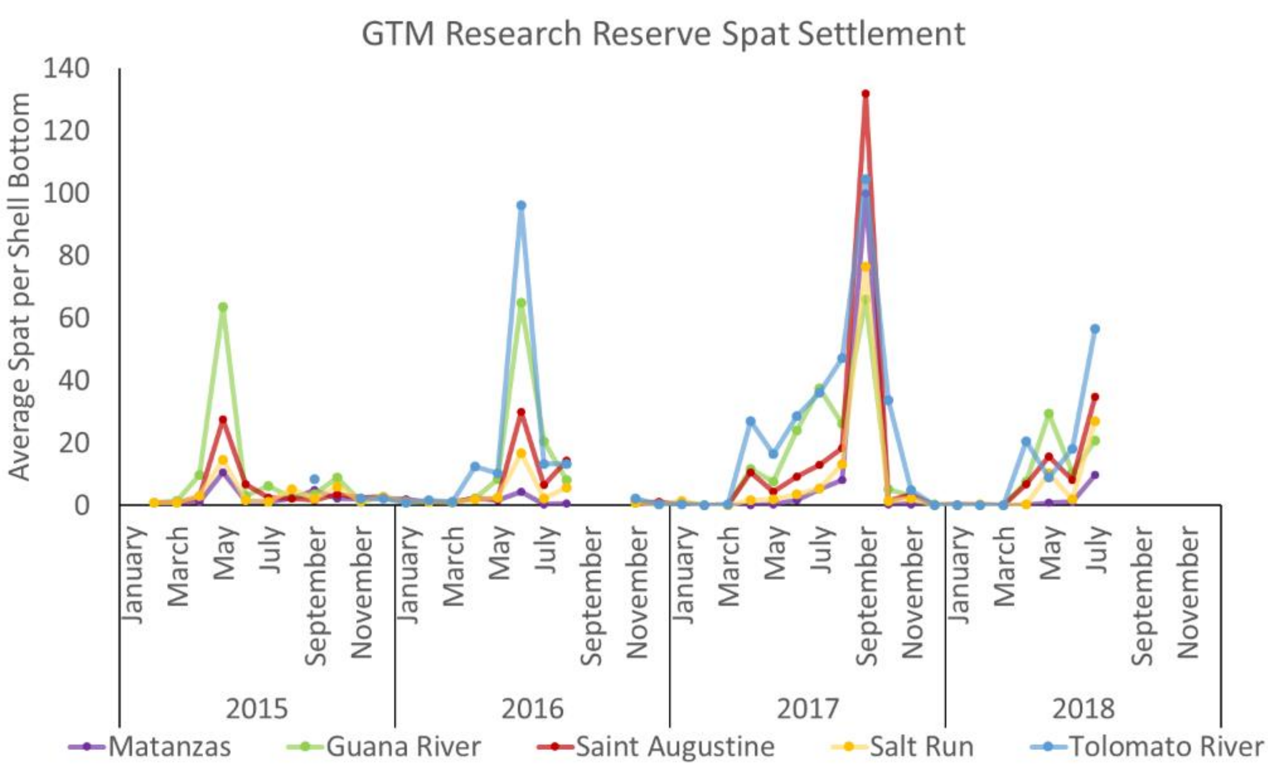

Figure 4: Spat settlement data collected by the GTM Research Reserve. Methodological details available upon request.

Pilot Site

Pilot sites are small-scale preliminary studies to further understand the feasibility, time, cost, impacts, and design of a research project before implementing at a larger scale. In March 2016, a pilot site was installed at site 5. The pilot site served as the "testing" site throughout the entire project and provided guidance for the remaining five sites, including:

- *Shape of oyster gabions* –Large triangular and rectangular cages were used at the pilot site to test stability in high wave energy. These heavy gabions were logistically challenging to transport (Figure 5), so smaller (50 × 20 × 15 cm) rectangular cages were used at remaining sites and deployed by volunteers.
- *Coconut fiber mat* – At the pilot site, tree branches were wrapped in coconut fiber mats that degraded over time (Figure 5), so branches were wrapped with wires at remaining sites.
- *Breakwall structures* –Large PVC pilings were installed at the pilot site for the breakwall frame using jet drilling from a barge (Figure 5). Given the difficultly of installation and permanence of the deep-set PVC, wooden fence posts were used at remaining sites installed with mallets by hand.

Advantages of using the pilot site also included the opportunity to determine how much manpower was needed to install the structures, where ideal access points were by land and by boat, what size branches to use to fill breakwalls, how long each site would take to install, and how to schedule boats, captains, and vehicles.

Figure 5: Transporting large gabions (left); coconut fiber mat (center); installing piling (right)

Permitting

Consult with your local state environmental agency (e.g., Department of Natural Resources, Department of Environmental Protection, Department of Environmental Quality, or Department of Environmental Management) before beginning any living shoreline or shoreline protection projects. Any shoreline work conducted below the Mean High Water Line (MHWL) in the State of Florida requires a permit from a state and/or federal agency: Florida Department of Environmental Protection (FDEP), St. Johns River Water Management District (SJRWMD), and/or U.S. Army Corps of Engineers (USACE).

On April 21, 2015, the project team reached out to the Northeast District FDEP office (NED FDEP) to schedule a pre-application meeting to discuss this project. Pre-application meetings with permitting agencies is strongly recommended for any project. On April 30, 2015, NED FDEP staff, Aquatic Preserve Manager, GTM Research Reserve staff, and Christine Angelini reviewed the sites, discussed the project plans, and took a boat trip to evaluate the sites. NED FDEP made recommendations to increase the spacing between the structures to ensure entrapment of fish and wildlife would not occur during low tide. In addition, NED FDEP recommended that a project summary, updated plans, and location be submitted to FDEP to allow early coordination with Florida Fish and Wildlife Conservation Commission (FWC) to ensure that the project plans would meet all recommended FWC requirements.

On May 6, 2015, the project summary, plans, and locations were submitted to NED FDEP and forwarded to FWC for commenting. On May 22, 2015, FDEP received confirmation from FWC stating that there were no comments or recommendations on the project design and monitoring and that the spacing between the breakwalls and gabions appeared to be appropriate for allowing beneficial hydrodynamic flow and fish and aquatic wildlife passage to prevent entrapment.

On August 4, 2015, the Individual Permit application was received by NED FDEP and forwarded to FWC and the Division of Historical Resources (DHR) for review. During the review period, NED FDEP staff coordinated with the GTM Research Reserve research coordinator on the operation, maintenance, and monitoring of specific conditions to ensure the permittee did not have to submit redundant information to multiple parties. To ensure that these items were covered, NED FDEP required that a management plan for operation, monitoring, maintenance, etc., be developed and approved by the GTM Research Reserve and to be submitted to NED FDEP within one year of issuance of the permit and prior to construction commencement. On August 20, 2015, FWC confirmed that the agency did not have any additional comments concerning the project. On August 21, 2015, DHR provided that the project was not likely to influence historic properties, assuming the applicant made contingency plans in the case of fortuitous finds or unexpected discoveries during ground disturbing activities within the project area. On August 21, 2015, NED FDEP issued the permit, which included the regulatory and sovereign submerged lands authorizations for the project. On December 9, 2015, the maintenance plan was submitted to NED FDEP and approved.

Understanding the appropriate permitting process and requirements can often be confusing. To ensure that the appropriate steps are taken, reach out to the local permitting agencies and invite them to the site (local FDEP offices: https://floridadep.gov/sites/default/files/SLERC_contacts_web_map_01-2017_0.pdf). In addition, several states in the southeast region of the United States have permitting guidance documents. In April 2018, the University of Florida IFAS Extension produced a guidance document (TP233), "Streamlining Resiliency: Regulatory Considerations in Permitting Small-Scale Living Shorelines in Florida," (http://edis.ifas.ufl.edu/pdffiles/SG/SG15500.pdf). This document provides guidance for small-scale living shorelines and further details the process of permitting and approval through FDEP and USACE. Other states have similar guidance for living shorelines implementation:

- North Carolina- CAMA Handbook for Coastal Development, April 2014
- Alabama- Mississippi State University Extension Service, Pub. 3120, 2017 and Mobile Bay National Estuary Program, 2014
- Mississippi- Mississippi State University Extension Service, Pub. 3119, 2017
- Bryars, R., et al. 2016 *Living Shorelines: A Technical Guide for Contractors in Alabama and Mississippi*. Prepared for the Gulf of Mexico Alliance, Habitat Resources Priority Issues Team under a grant to the Baldwin County Soil and Water Conservation District.

Signage

The ICW is a heavily trafficked waterbody with visitors from across the world. Informational signage was installed at each site and local boat ramps to inform boaters about the project, and caution buoys were installed at each site to notify boaters of the presence of possibly submerged structures in the area. These 9" can buoys were purchased from Walsh Marine Products (www.walshmarineproducts.com). Informational signage was purchased from Envirosigns. Large signs (26" width x 38" height) were posted at three nearby boat ramps with permission from St. Johns County (Appendix C). Three smaller signs were posted at each site (13" width x 19" height) (Appendix C). The smaller signs were installed on the fence posts and remained at each site, until Hurricane Irma.

Design and Installation

Breakwalls

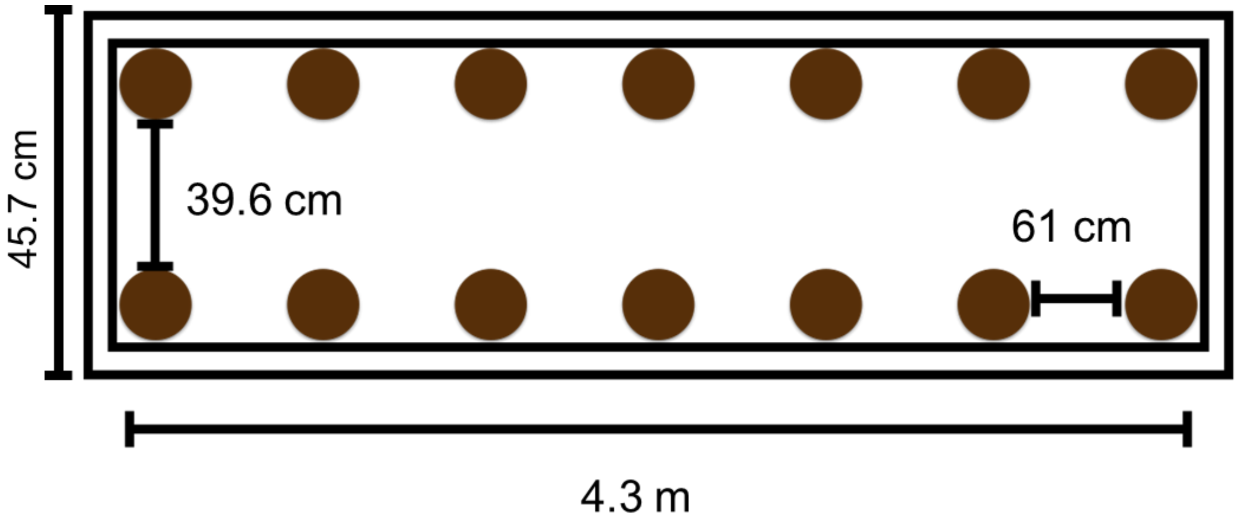

Figure 6: Diagram of a breakwall

Porous breakwalls are living shoreline structures placed parallel to the shoreline edge that are designed to dissipate (rather than refract) wave energy due to their semi-permeable structure. The project breakwalls consisted of fourteen 2-m long wooden fence posts driven into the ground to form a rectangular bin (Figure 6), in which tree branches could be placed to give the wall porosity. The breakwalls built in this project measured 4.3-m long, 0.5-m wide, and 0.5-m high. The breakwalls were deployed in sets of three to protect a stretch of shoreline roughly 15.2-m long, and longer chains of breakwalls may be appropriate for larger scale implementation of this technique. There were two sets of breakwalls of a similar height deployed at each site.

Plastic-coated multipurpose wire and fence post nails held the tree branches within the fence post wall frame. Each breakwall was built by first installing a set of fourteen wooden fence posts arranged in two rows of seven posts (Figure 6). Fence posts were driven at least 0.6-m into the ground using augers and large wooden mallets and positioned into a rectangle, leaving a 61-cm space between adjacent posts (Figure 7). Gas augers can also be used if the sediment is more sandy than muddy. Once the posts were installed, the space inside the wall was filled with tree branches spread evenly across the length of the wall (Figure 7).

It is recommended that the tree branches used to fill the breakwalls measure between 2.1 and 4.2 meters long to ensure that the branches remain inside the fence posts.

Figure 7: Project team installing fence posts using wood mallets

The tree branches used for this project were crepe myrtle (*Lagerstroemia* sp.), but other tree species may be used (Figure 8). Crepe myrtle branches were chosen because it was a locally available, abundant, easily transported, and inexpensive resource. Crepe myrtle branches were also found to resist biofouling better and weigh less than live oak branches. For additional information about the relative vulnerability of crepe myrtle, laurel oak, sweetgum and black mangrove branches to biofouling and shipworms, please see Appendix D.

Figure 8: Bundles of crepe myrtle branches

Tree branches inside the fence posts were stacked to roughly twice the desired height (i.e. 76.2-142 cm high). The tree branches were then compressed by stepping on top of the branches until they were tightly packed within the fence posts (Figure 9). With the branches compressed, a second person began securing the branches in place with the plastic-coasted multipurpose wire (Figure 10). To do this, the multipurpose wire was woven in a zig-zag pattern across the branches along the length of the wall while pulling on the wire to tighten it and secure it with a U-shaped fence nail at every post.

Figure 9: Adding tree branches inside the fence posts and compressing until packed

Figure 10: Compressing tree branches and securing with wire to fence post

Oyster Structures

Four oyster structures were placed on the sediment three meters behind each breakwall with the goal of further dissipating wave energy and promoting the restoration of oyster reefs. For this project, two types of oyster restoration structures were tested: oyster gabions and Biodegradable EcoSystem Engineering Elements (BESE-elements®). These two types alternated behind each breakwall (Figure 11, 12, 14).

Oyster shell material was purchased through the Northeast Florida Aquatic Preserve's Shell Recycling Program. The Shell Recycling Program collects oyster shell from participating local restaurants in the northeast Florida region. The collected shell is quarantined onsite by baking in the sun for a minimum of three months before being utilized in restoration projects (Figure 13).

Oyster gabions (Figure 14) are wire cages filled with recycled oyster shell. These were built using 1”x1” 12.5 gauge GAW wire mesh to form rectangular cages measuring 50 × 20 × 15 cm. The cages were cut to the appropriate length then folded to complete the shape. The sheets were then clamped together using a wire that was folded together. The cages, once assembled, were then filled with recycled oyster shell. Oyster gabions are kept in place by the weight of the oyster shell.

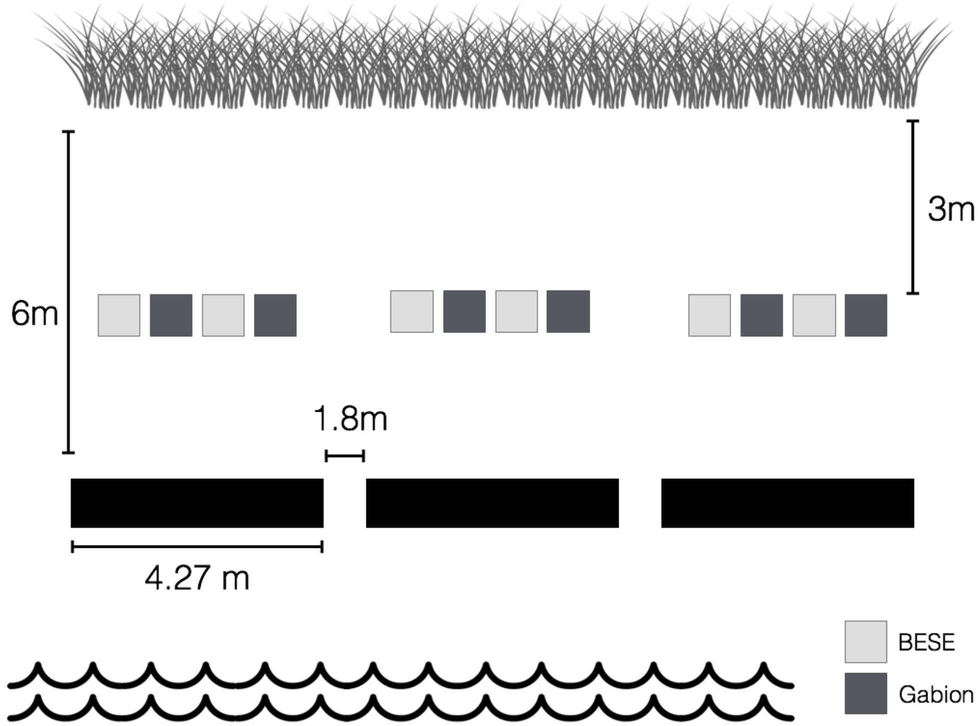

Figure 11: Site diagram of experimental set up relative to the shoreline showing breakwall placement in black and oyster restoration structures in gray.

Figure 12: Oyster structures- BESE are shown in the far left and in the middle; gabions are shown on the far right.

Figure 13: Recycled oyster shell

Figure 14: Oyster gabions

Figure 15: BESE being assembled

BESE-elements® (Figure 15) were developed in the Netherlands and are currently being used for restoration of mussel beds in the Wadden Sea and several experimental projects in Florida. BESE-elements® are structures made of potato starch waste that is molded to form interlocking sheets in a honeycomb pattern. The sheets can be stacked to a desired height. For this project, BESE-elements® structures were assembled to have final dimensions of 89 × 43 × 5 cm and secured using an L-shaped rebar driven into the ground in the middle of the structure.

Care should be taken to install oyster structures after the breakwalls are installed (to protect structures from high wave energy) but just before or during peak oyster recruitment season (to ensure larvae can settle before structures get covered in sediment and algae). In this project, oyster structures were deployed in April 2017. In September 2017, average oyster shell height on gabions was 15 mm and average densities ranged from 4,300 to 22,000/m^2 at the six sites. Breakwall height did not influence oyster settlement patterns. BESE-elements® did not initially recruit oysters. During monitoring in April 2018, oyster shell hash was added to half the BESE-elements® (every other one) at each site. At the time of this manual development, no monitoring had occurred at the BESE-elements® with oyster shell added.

Maintenance

Natural degradation and biofouling, as well as the high-energy environment, will likely damage the structural integrity of the natural materials in this hybrid design. Therefore, periodic maintenance is necessary to extend the life span of the breakwalls and oyster structures.

Breakwalls

Figure 16: Branches missing from the pilot site; likely missing due to wave energy

The most immediate threat to the breakwalls is the dislodgement of tree branches resulting in a loss of wall height (Figure 16). The high-energy conditions of the environment and the loosening of the multipurpose wire around the branches may cause the branches to be washed away. The wall height must be surveyed seasonally and if there is a substantial decrease in height from one monitoring period to the next, additional branches should be added and secured in place.

Biofouling is an additional threat to breakwalls. Barnacles can settle on and shipworms can infest the branches, which can severely compromise their structural integrity. Shipworms are particularly damaging because they burrow and remove wood volume from the branches, making them brittle and prone to breaking. Unfortunately, there is no known treatment that can completely eradicate shipworms (Borges 2014), but it is possible to adjust materials based on shipworms' boring preferences. Shipworms bore more easily into tree species with lower wood density and concentrate their burrowing in branches within the first 20 cm above the sediment (Appendix D). Therefore, a higher density wood would be optimal to prolong the life span of the breakwalls. Special attention should be paid to the bottom 20 cm of the wall because that will be the most vulnerable area to shipworm boring. The posts could also potentially be wrapped with protective coating. This wrapping strategy was not tested in this project. It is also important to consider that shipworms thrive in higher salinities, so periods of drought will result in more shipworm damage and thus increased maintenance.

Oyster Structures

Due to the accumulation of sediment, both oyster gabions and BESE-elements® are prone to partial burial and may need to be repositioned on top of the sediment during the first year to allow for initial oyster recruitment.

The quality of the wire mesh of the oyster gabions may decline with time as metal oxidizes, ideally leaving an established reef in their wake. It is important to periodically examine the wire for signs of deterioration (e.g., rust). If the wire is found to degrade before a mature oyster reef is established, then it may be necessary to use higher gauge wire in the deployment of additional gabions. In this project, 1”x1” mesh, 12.5 gauge galvanized after welded (GAW) mesh was found to hold structures in place while oysters grew around it.

Because of their lightweight structure, BESE-elements® could potentially be dislodged due to the high-energy wave environment. If that occurs, it will be necessary to secure them with additional rebar.

Monitoring

To assess the integrity and efficacy of living shoreline structures, it is recommended that monitoring efforts occur seasonally, once every four months. This section describes a recommended set of shoreline, breakwall, and oyster parameters monitored in this project (Table 1). The monitoring schedule for this project can be found in Appendix E for reference.

Design Component	Evaluation Parameter	Metrics
Shoreline	Lateral movement	Distance from PVC marker (m)
	Structural composition	Ground cover (%)
Breakwalls	Maintenance need: crepe myrtle branch replacement	Wall height (m) Biofouling on fill branches
	Maintenance need: post replacement	Biofouling on posts (% cover)
Oyster Structures	Sediment accretion/ structure sinking	Reef height (m)
	Reef development	Vertical oyster height (mm) Oyster density (#/m^2) Oyster shell height (mm) Percent cover (%) Associated fauna (density)
	Maintenance need	General condition

Table 1. Recommended set of shoreline, breakwall, and oyster structure metrics to monitor throughout the life of a living shoreline project.

Shoreline

Prior to the construction of this project's living shoreline structures, each site's leading edge of the marsh was marked (defined as the point where the cordgrass vegetation terminated) along three 14-m-long segments of shoreline using 15, 2.5-cm-diameter x 0.9-m-long PVC poles that extended 0.5 m above the surface and were spaced 1 m apart. PVC poles were numbered 1 through 15 starting at the northernmost point at each site (Figure 17). These markers were used throughout the project to monitor the shoreline edge pre- and post-construction. Distances were measured from each PVC pole to the most seaward cordgrass stem and patch of peat allowing an evaluation of whether the shoreline was retreating, advancing, or staying the same.

Figure 17: Photograph showing full experimental setup and monitoring structures. PVC poles on the right mark the initial shoreline position and the spots selected for ecological monitoring.

Ground cover data was collected for each shoreline segment at a subset of five of the PVC poles along each shoreline section. Ground cover measurements were taken from a 0.5 m x 0.5 m quadrat positioned 1) at the PVC marker indicating the shoreline edge (0 m), 2) 1.5 m behind/landward of the marker, and 3) 1.5 m in front/seaward of the marker. Within each quadrat, the percent ground cover of sand, peat, root mat, shell hash, and live oyster on the sediment surface was visually estimated to evaluate whether surficial sediment composition was shifting over time (Figure 17).

Breakwalls

The wooden branches inside the breakwall should be monitored for biofouling and bioerosion by barnacles and shipworms. Wooden branches positioned at greater distances from the sediment (≥30 cm) are more susceptible to biofouling by barnacles, while shipworms more intensively bioerode branches located closer (0-20 cm) to the sediment surface (Appendix D). Breakwalls built from less dense tree species are likely to require more maintenance. Biofouling and bioerosion of this wooden marine infrastructure can be reduced through the strategic use of tree species and treatments that reduce the settlement and growth of these biota.

The project team monitored biofouling on the breakwall posts by haphazardly positioning 10 x 10 cm frame quadrats on the surface of each post, between 10 and 40 cm above the sediment surface, and assessing the percent cover of barnacles and oysters in each. No other biofouling taxa were identified at the sites during this monitoring window. The same method was used to assess biofouling on the branches filling each breakwall; six replicate quadrats were monitored on the landward and seaward sides of each wall.

Oysters

Oyster monitoring methods were designed to collect data on three of the four "universal metrics" proposed by Baggett et al. (2015) for assessing oyster restoration projects. The metrics include reef height, vertical oyster height, and oyster density and size. A fourth universal metric from Baggett et al. (2015), reef area, is not appropriate for this project's experimental substrates because both oyster gabions and BESE have a fixed bottom areal coverage. Additionally, the general condition of the experimental structures and percent cover of oysters on the structures was assessed.

Figure 18: Oyster measuring equipment on three small oyster gabions

Figure 19: Larger oyster gabion set is outlined in red and small, individual oyster gabion is outlined in yellow

Reef Height

The height of the oyster structures from the sediment surface to the top of the structure was measured at all four corners and near the middle of each side of each structure. These measurements were used to quantify burial, the degree of sediment accretion and/or structure sinking.

Vertical Oyster Height

The vertical height of live oysters (projecting above the surface of each structure) was determined by measuring the distance from the structure surface to the outermost shell edge to the nearest millimeter. The five tallest oysters were measured on the top surface of three BESE units and on the top and four sides of three gabions behind each wave break.

Oyster Density and Oyster Size

To monitor oyster density and size in the oyster gabions, three small oyster gabions were randomly selected from each of the two types of wave breaks at each site. One small, individual oyster gabion (Figure 19) was removed from each larger gabion set. The contents were emptied into a fish box and the shell height of live oysters was measured. The shells were then rinsed to remove sediment and debris (Figure 20). All shells in the smaller oyster gabion were counted and 25 of those shells were haphazardly chosen for measurement. All live oysters on the 25 selected shells were counted and measured (shell height to nearest mm) with calipers or ruler. After processing, all shell and live oysters were placed back into the smaller oyster gabion which was returned to the larger gabion from which it was taken. Live oyster density (# oysters/0.1 m^2; and # oysters/0.015 m^3) was determined using the equation below.

Figure 20: Sorting oysters from smaller oyster gabion for size measurements and density calculations

$$\text{\# oysters per } 0.1 \text{ m}^2 \text{ and per } 0.015 \text{ m}^3 = (\text{\# shells in small gabion})\ (\text{total live spat}/25)$$

Size frequency distributions of live oysters were also determined for the measured individuals and assessed by site and wave break type.

The project team planned to monitor oyster density within the BESE-elements®, however the oysters did not grow on the bare BESE-elements®. After a monitoring event, the project team added oyster shell to the BESE-elements® to recruit oyster growth (Figure 21). In the future, to monitor oyster density and size in the BESE-elements®, three BESE-elements® would be randomly selected from each site. A 0.015 m^3 portion with the same dimensions as each smaller gabion (50 cm length × 20 cm width × 15 cm height = 0.1 m^2 surface area) of each of the selected BESE-elements® would be removed and processed as described above for the oyster gabions. After processing, all oysters and BESE-elements® material would be reattached to the larger BESE-elements® from which they were taken using cable ties from the same biodegradable material that the BESE themselves are constructed from.

Figure 21: BESE-elements® with shell material added to recruit oyster growth

Percent Cover

Areal coverage by live oysters, dead oysters, sediment, and other organisms was determined using the point-intercept method. Measurements were made on the top and four sides of each gabion, and only on the top of each BESE. A sampling grid was made from the oyster gabion wire material and was placed on the surface of the oyster gabion (or BESE-elements®). Percent cover was sampled by sliding a flag pin down from the intersections of the wire and identifying the object on the substrate as either “live oyster”, “dead oyster shell”, “sediment”, or “other” (Figure 22). If it was not oyster or sediment (i.e., mud crab) the identification of “other” was defined in the field notes. The total number of observations for each category was recorded, and percent cover calculated using the equation below.

Figure 22: Oysters within the gabions

$$\% \, cover \ = (\# \, of \, \frac{observations}{intersections}) \; x \; 100$$

General Condition

The observed condition of the oyster gabions and BESE-elements® was characterized by visual inspection, with notes and photographs of degradation of wire or materials (rust or deterioration), movement from original position, and sediment buildup and/or subsidence (Figure 23 and 24). Measurements and photos were taken on three randomly selected oyster gabions or BESE-elements® behind each of the two types of wave breaks (tall and short), yielding a total of six assessed experimental substrate units per site.

Figure 23: Measuring vertical distance of sediment (top); green algae growth on BESE-elements (bottom-left); and raccoon tracks landward side of the structures (bottom-right)

Figure 24: Roseate spoonbill utilizing living shorelines for foraging (left); new grasses beginning to grow landward of the oyster structures (right)

Figure 25: Pilot site gabion breakwall with wave energy gauge

Additional Monitoring

This project not only focused on the salt marsh and oyster community, but also the wave/wake climate of the ICW, including bathymetry and hydrodynamic data collection (Figure 25). At three sites, bathymetry data was collected to create three-dimensional plots of the ICW and slopes.

Several hydrodynamic instruments, including Acoustic Doppler Velocimeters and Acoustic Doppler Current Profilers, were deployed to record pressure and flow velocities on the landward and seaward sides of the breakwalls to assess the wake climate and evaluate the wake energy dissipation by the breakwalls. Additional information can be found in Herbert et. al (2018).

Costs

For the breakwall, the main expenses were the wooden fence posts. Because this project had six sites with several individual walls and a pilot site, the project constructed a total of 33 walls, which required 462 fence posts. Other materials purchased were the multi-purpose wire ($9.98) and a box of fence post nails ($11.98). For this project, approximately one 100-ft roll of wire and three large boxes of nails were used per wall, bringing the total for these materials to $341.32. Other equipment costs totaled approximately $489.00. Equipment cost includes the manual augers, wooden mallets, and hammers necessary to build the walls. The total costs for the breakwall construction is $4,663.23 (Table 2).

Material	Amount	Cost per unit	Total cost
Fence posts	462	$4.79	$2,212.98
Multipurpose wire	33 100-ft rolls	$9.98	$329.34
Fence post nails	1 box	$11.98	$11.98
Augers	2	$113.95	$227.90
Wooden mallets	3	$77.03	$231.09
Hammers	3	$9.98	$29.94
Caution buoys	12	$135.00	$1,620.00
Total			$4,663.23

Table 2. Itemized list of the materials and cost needed for the construction of the wooden breakwalls. Note: Prices were determined by reimbursed receipts and all prices are subject to change.

It is important to note that a local landscaper who was pruning crepe myrtles at the time of construction donated the branches for this project. If a local source of branches is not available, this could increase the cost of construction. In terms of labor costs, each wall required at least four people working together and took approximately four to five hours to build.

The oyster gabions required fewer materials, but more time. The oyster shell was donated by the Northeast Florida Aquatic Preserves. This recycled shell was available for purchase at $1/gallon, and is recommended to be used in local projects.

The metal cages used for the oyster gabions were built from 1”x1” 12.5 gauge galvanized after welding wire mesh. Four 100’ rolls were purchased and cut to size. The initial rolls were purchased from Pennsylvania Wire Works, however local vendors (WA Davidson of Jax., Inc.) could be considered to save on freight charges.

Material	Cost per unit	Total cost
1"x1" 12.5 gauge GAW wire mesh	$575.00	$1150.00
Dewalt wire cutters	$14.97	$149.70
Jigs for bending wire mesh	$30.00	$60.00
Rubber mallets	$12.98	$51.92
Galvanized chain link fence hog rings	$1.57	$31.40
Hog ring pliers	$8.99	$89.90
Total		$1532.92

Table 3. Itemized list of the materials and cost needed for the construction of the oyster gabions. Note: all prices are subject to change.

For contact information regarding the BESE, visit the website: https://www.bese-elements.com/.

In addition, given the location of this project's living shoreline sites, a boat and boat captain were necessary for approximately five to six hours each day. Boats and boat captain support charged $250/day. Approximately 81 days were required for the pilot installation, site installations, and monitoring efforts, totaling $20,250 for boat usage and boat captains.

Costs not captured in the construction of these living shorelines include informational signage at sites and boat ramps, Coast Guard-approved buoys, an educational display at the GTM Research Reserve, and outreach through conferences, workgroups, and meetings.

Manpower

Throughout the duration of the project, in addition to the project team, numerous undergraduate and graduate students, GTM Research Reserve staff, and over 130 volunteers provided over 640 hours of support. Volunteers supported this project by building and filling cages with oyster shell, moving materials to the sites, installing the breakwalls at the sites, and even collecting buoys after storm events (Hurricane Irma). Volunteers from Northrup Grumman expedited several volunteer days of gabion construction by taking the metal wire materials to their shop to be cut, bent, and clamped. These volunteer hours do not include the manpower from the SJRWMD and FWC staff.

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Appendices

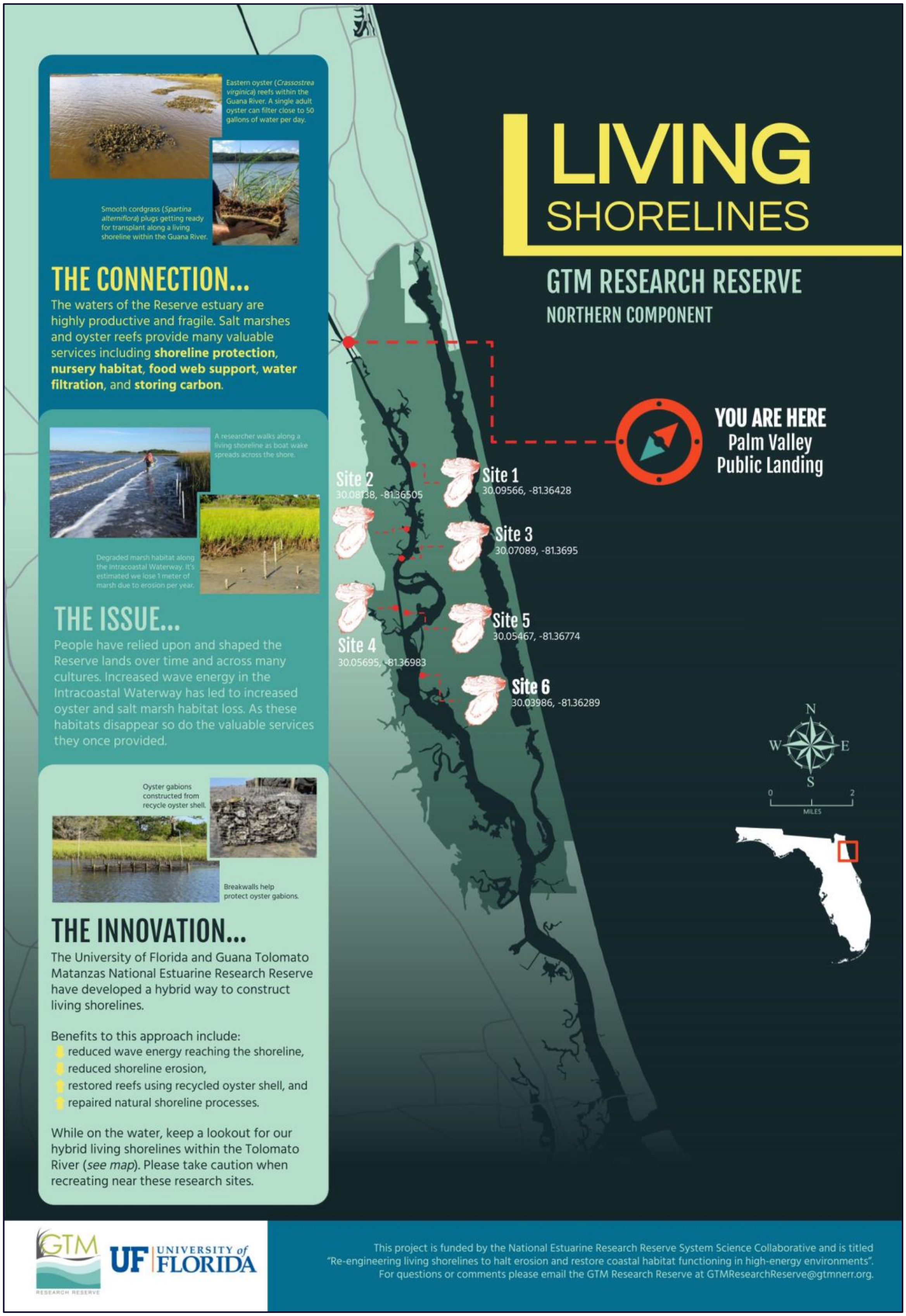
Appendix A: Site Locations

GPS locations of the center of each site:

Site	Latitude	Longitude
Pilot	30.011331°	-81.345214°
Site 1	30.097646°	-81.364781°
Site 2	30.068057°	-81.367993°
Site 3	30.047736°	-81.365311°
Site 4	30.037960°	-81.363216°
Site 5	30.009370°	-81.344639°
Site 6	29.974419°	-81.328151°

Appendix B: Dead intertidal margins along the Tolomato River

Appendix C: Informational Signage

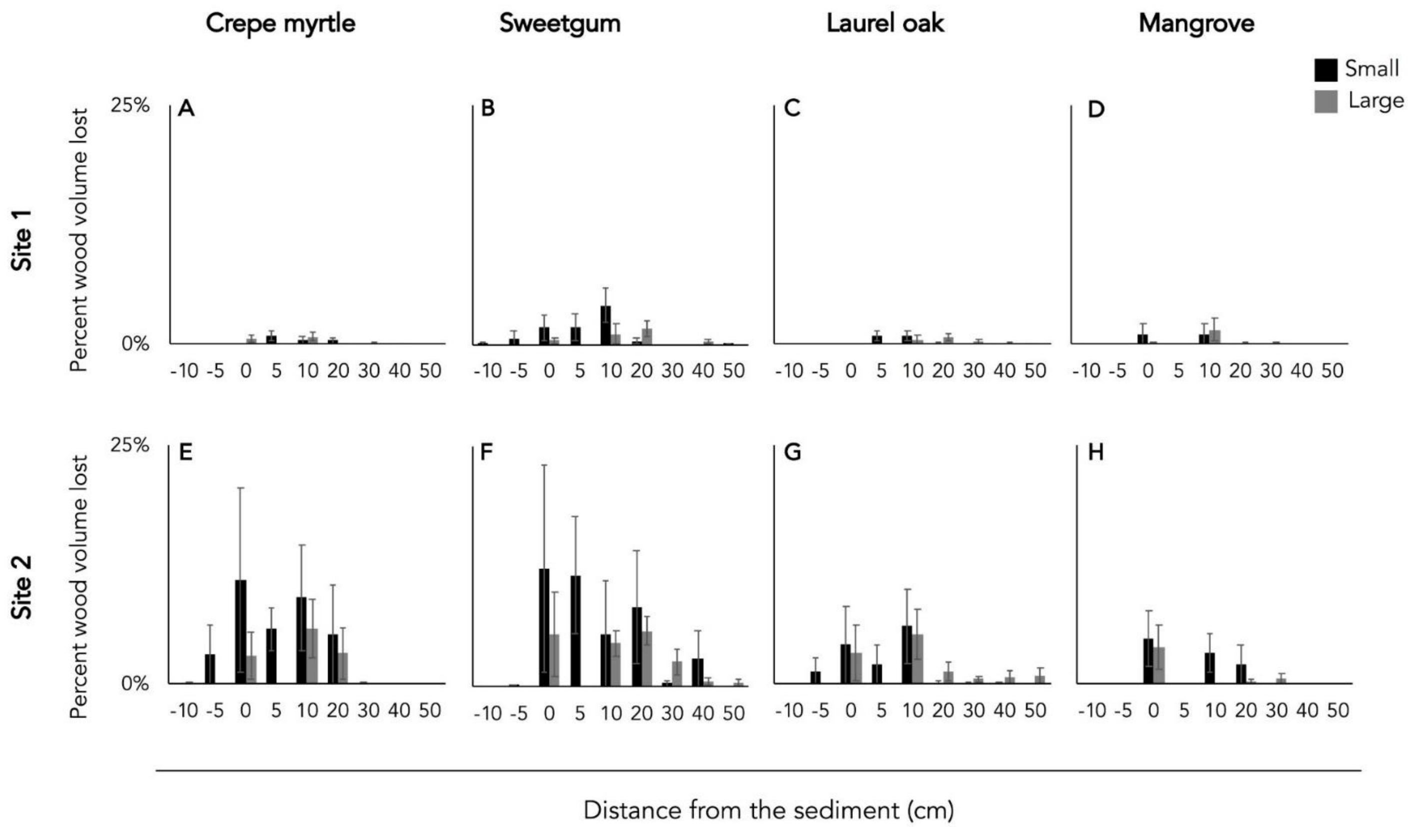



OYSTER
TO-DO LIST
Filter water
Defend shore
Give shelter

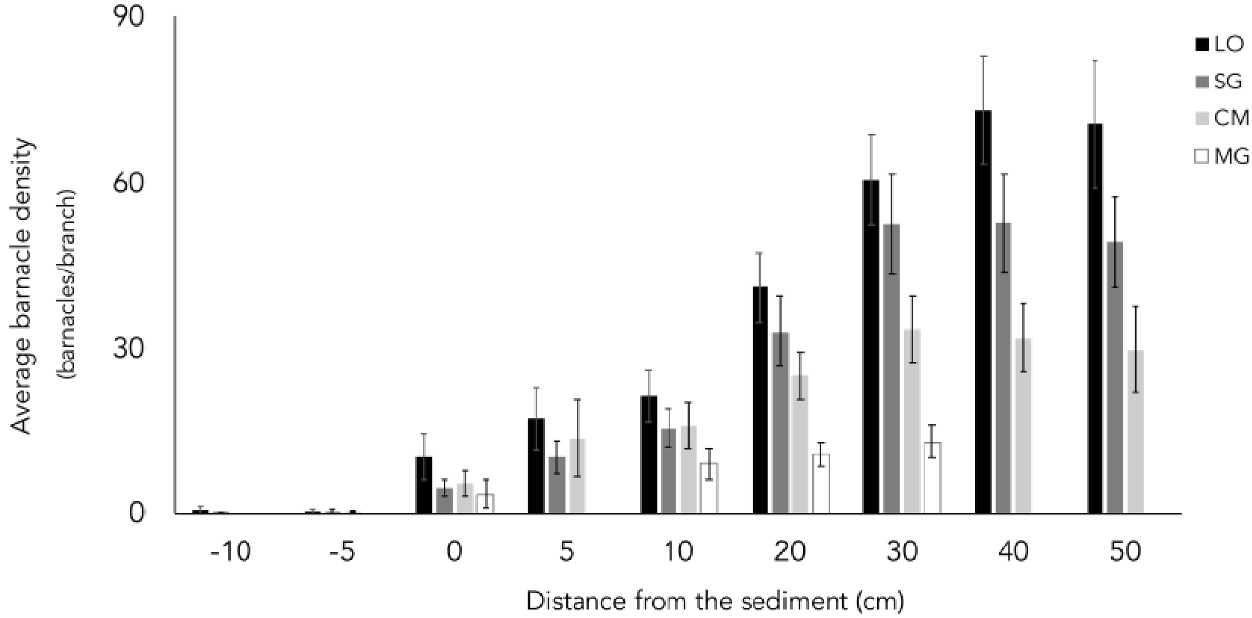

CAUTION
Oysters
working
hard for
the money
UF UNIVERSITY of FLORIDA
GTM

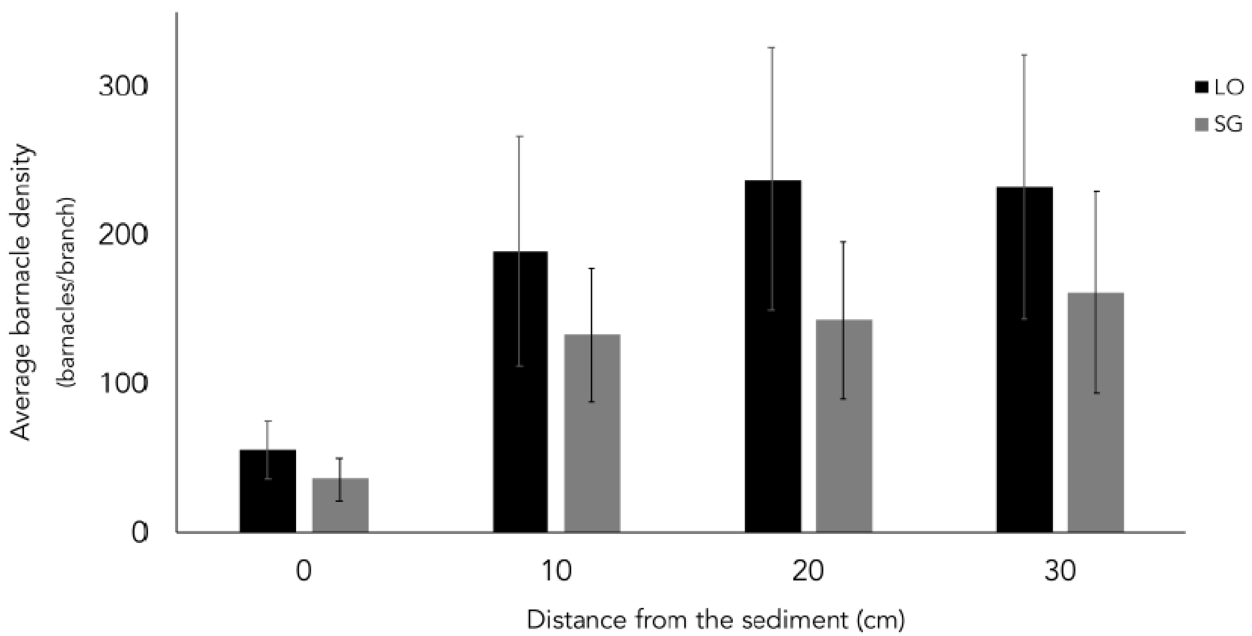
Appendix D: Biofouling Research

Four tree species – laurel oak (*Quercus hemisphaerica*), sweetgum (*Liquidambar styraciflua*), crepe myrtle (*Lagerstroemia spp*.), and black mangrove (*Avicennia germinans*) – were tested to determine the extent of biofouling and bioerosion by barnacles and shipworms. A study by Bersoza and Angelini (unpublished data) found that wood volume lost to shipworms burrows was most concentrated near the sediment surface (0-20 cm) and more prevalent in tree species with lower wood densities (sweetgum and crepe myrtle). Barnacles were most abundant at heights ≥30 cm above the sediment and on laurel oak and sweetgum branches.



Above: Site 1 and Site 2 were located in the Matanzas River Estuary in St. Augustine, Florida. The graph above reflects the wood volume of the four tree species, both small diameter and large diameter branches.





Above: Site 1 and Site 2 were located in the Matanzas River Estuary in St. Augustine, Florida. The graph above reflects the mean (± standard error) number of barnacles for the four branches monitored.

Appendix E: Monitoring Plan

GTM LIVING SHORELINES PROJECT MONITORING								
Category	Parameter	Method	Season	Sites	Sampling Freq.	# Replicates	Stake-based	Comments
Remote Geomorphology	Width of creek/body of water	GIS		All	Once	1/site		
	Creek morphology (straight, curved, winding)	GIS		All	Once	1/site		
	Reef orientation	GIS		All	Once	1/site		
	Long-term erosion rate	GIS: AMBUR		All	Once	1/site		
Hydrological Characteristics	Salinity (min, max, mean): separate parameters for drought, normal, and wet seasons	nearest SWMP or DEP sites	All four seasons separately	All	Once	1/site		
	Tidal range (summer mean)	Closest tidal gauge	Summer	All	Once	1/site		
	Wave/current energy							
Sediment Characteristics	Substrate firmness (in location of future reef)	Cinder block	Spring	All	Once	1/treatment		At existing sites, measure "baseline" firmness 1 meter downslope from reef
	Sediment accretion (1 ft behind reef)	Distance from sediment surface to hole in metal stake	Spring	All	1x/yr	3/treatment	Yes	At existing sites, dig down to base of reef material at the back of the reef to measure amount of accretion
	% silt, % sand, and % organics (1 ft behind reef)	Established laboratory method	Spring	All	1x/yr	3/treatment	Yes	At existing reefs, collect samples in equivalent locations for "follow-up" and in front of reef for "baseline"
Geomorphology	Escarpment height	Measuring tape	Spring	All	1x/yr	3/treatment	Yes	Measure in alignment with behind-reef/marsh edge stake pairs
	Bank width (in gaps between treatments)	Measuring tape: MLW to marsh edge	Spring	All	Once	3/site		Estimate location of MLW when not exactly at low tide; timing-wise, measure as close to actual low tide as possible
	Bank slope (above reef)	Two stakes and measuring tape	Spring	All	1x/yr	3/treatment	Yes	Measure in alignment with behind-reef/marsh edge stake pairs
	Distance from reef to marsh edge	Measuring tape	Spring	All	1x/yr	3/treatment	Yes	Collected as part of bank slope (above reef) measurement; for older SCORE sites without baseline data, check for old imagery for comparison to current measurements
	Bank slope (below reef)	Two stakes and measuring tape	Spring	All	1x/yr	3/treatment	Yes	Measure in alignment with behind-reef/marsh edge stake pairs; down to MLW
	Elevation of sediment (1 ft behind reef)	Trimble R8	Spring	New Only	1x/yr	3/treatment	Yes	

Category	Parameter	Method	Season	Sites	Sampling Freq.	# Replicates	Stake-based	Comments
Treatment Characteristics	Appearance of reef and adjacent shoreline	Fixed photo points (camera atop fixed stakes); 50% sky	Spring	All	1x/yr	7/treatment		During monitoring visits, do first (prior to disturbing site)
	Reef materials: Structural integrity	Yes/No, comments	Spring and Fall	All	2x/yr	1/treatment		
	Reef materials: Remaining in place	Yes/No, comments	Spring and Fall	All	2x/yr	1/treatment		
	Elevations: Reef (highest point); material itself, highest oyster, sediment in front of reef, sediment in back of reef	R8	Baseline & Fall	All	1x/yr	3/treatment	Yes	Transect across reef in alignment with behind-reef/marsh edge stake pairs; capture "sinkage" of reef material over time
	Sinkage of material over time	R8	Baseline & Fall	New Only	1x/yr			
Oyster characteristics	Percent live cover of oysters	0.25 x 0.25m quadrat, take photos directly overhead, estimate based on photos	Fall	All	1x/yr	3/treatment	Yes	need standard location of photo
	Ray's methods							
	Nearest naturally occurring oysters	Laser range finder or measuring tape	Fall	All	1x/yr	1/treatment		
	DACS shellfish management status	GIS	Summer	All	1x/yr	1/site		

Category	Parameter	Method	Season	Sites	Sampling Freq.	# Replicates	Stake-based	Comments
Vegetation Characteristics	Change in position of marsh edge (R8/GeoXT)	Use R8 or GeoXT to trace marsh edge	Spring	New	1x/yr	1/site		
	Area of marsh gain/loss	GIS: Based on marsh edge	Spring	New	1x/yr	1/treatment		
	Marsh gain/loss (photo interpretation)	Based on old and new photo comparison	Fall	Existing only	Once	1/treatment		
	Appearance of vegetation	Fixed photo points	Early Fall	All	1x/yr	5/treatment	Yes	During monitoring visits, do first (prior to disturbing site)
	Presence of Spartina	Yes/No	Early Fall	All	1x/yr	1/treatment		
	Presence of Juncus	Yes/No	Early Fall	All	1x/yr	1/treatment		
	Presence of other marsh plants	Yes/No, comments	Early Fall	All	1x/yr	1/treatment		If yes, record species name(s)
	Density of marsh plants (#/m^2)	# stems / quadrat	Baseline & Early Fall	New Only	1x/yr (2x 1st yr)	3/treatment	Yes	Place marsh stakes 1 foot downslope from marsh edge in line with behind-reef stakes; measure stem density in 1 m^2 quadrat with center downslope edge touching each marsh stake.
	Spartina height	Mean of 5 tallest stems / quadrat	Early Fall	All	1x/yr	3/treatment	Yes	Same quadrat positions as for marsh plant density; for existing sites, do in equivalent positions
Note 1: Each experimental site will consist of 3 treatments, 1 of which will be the "negative control" at one end of the site.								
Note 2: Use walking boards at softer sites to minimize disturbance.								

Notes:









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NIOZ

GTM RESEARCH RESERVE

FLORIDA'S AQUATIC PRESERVES WATERS THAT WORK, PLAY, AND LIVE