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ECOLOGICAL AND EDUCATIONAL IMPACTS OF A LIVING SHORELINE ON ST. SIMONS ISLAND, GEORGIA, USA

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Living shorelines encompass a range of nature-based alternatives to traditional coastal armoring structures. In addition to shoreline stabilization and protection, living shorelines are intended to meet conservation goals such as restoring habitat, delivering ecosystem services, and promoting ecological resilience to climate change. While early results have been promising, further monitoring is needed to better understand and evaluate the performance of living shorelines across a range of designs and environmental contexts, thereby informing coastal management. Nature-based shoreline protection is relatively new in Georgia, USA, where in 2015 the state's fourth living shoreline was constructed of oyster shell and native plants on Lawrence Creek at Cannon's Point Preserve, St. Simons Island. To assess ecological impacts of the living shoreline, undergraduate students conducted annual surveys of the oyster reef and marsh-edge plant community, spanning a seven-year period that included five years post-installation. Despite a series of tropical cyclones, the living shoreline successfully enhanced fringing salt marsh habitat occupied by the eastern oyster (*Crassostrea virginica*) and smooth cordgrass (*Sporobolus alterniflorus*), which increased in local density and spatial coverage. These foundation species are known to stabilize tidal creek banks, improve water quality, buffer uplands from storms, and provide nursery, refuge, and foraging sites for nekton. Moreover, the Lawrence Creek living shoreline has fostered experiential learning by students and served as a popular demonstration site for coastal managers, contractors, and property owners, thus raising public awareness and developing regional capacity to support broader utilization of living shorelines as a tool for coastal protection and conservation.

Keywords: coastal management, conservation, course-based undergraduate research, ecological monitoring, oysters, salt marsh, service-learning, shoreline stabilization

INTRODUCTION

Coastal development has intensified pressure to protect estuarine shorelines and adjacent upland infrastructure from erosion, a natural process that is exacerbated by human activities and rising seas. Shorelines have traditionally been stabilized through the use of hard armoring structures such as vertical bulkheads and riprap revetments. As of 2014, an estimated 14% of the contiguous U.S. shoreline was hardened, with shoreline armoring exceeding 50% in many coastal cities (Gittman et al. 2014). Unfortunately, conventional armoring structures can act as ecological barriers between wetlands and uplands and have contributed to the loss and degradation of coastal habitats, biodiversity, and ecosystem services including water filtration and flood control (reviewed by Peterson and Lowe 2009; Bilkovic et al. 2016; Prosser et al. 2018). Furthermore, hardened shorelines are costly to build and maintain, and they are vulnerable to storm damage and sea level rise, spurring coastal managers and property owners to seek more cost-effective and sustainable solutions (Cunniff and Webb 2017; Gittman and Scyphers 2017).

In recent years, “living shorelines” have increasingly been implemented as nature-based alternatives to conventional forms of shoreline armoring. While the specific techniques and materials used by living shorelines vary, in part depending on site characteristics, they generally incorporate natural elements such as planted vegetation and/or oyster reefs, sometimes in conjunction with rock sills or breakwaters (NOAA 2015; Myszewski and Alber 2016; Smith et al. 2020). Living shorelines are primarily intended to stabilize estuarine shorelines and reduce rates of landward erosion, which may be achieved through a combination of wave attenuation, sediment trapping, and storm surge defense (Myszewski and Alber 2016 and references therein). But unlike hardened shorelines, living shorelines are also designed to meet secondary conservation goals: enhancing or restoring coastal habitats, maintaining connectivity at the land-water interface, and providing ecological functions that mimic those of natural fringing salt marshes and oyster reefs (NOAA 2015; Bilkovic et al. 2016). Although most living shoreline projects to date have not been systematically monitored (Bilkovic et al. 2016), a growing number of studies document positive ecological effects across multiple metrics including soil nutrients, plant productivity, benthic invertebrates, and nekton (Davis et al. 2006; Currin et al. 2008; Scyphers et al. 2011; Gittman et al. 2016; Davenport et al. 2018; Isdell et al. 2021). Additional monitoring data are needed to better understand and evaluate the performance of living shorelines across a range of project designs, geographic locations, environmental conditions, and time scales, in turn guiding coastal management and resilience planning (USEPA 2010; CGIES Task Force 2015; Bilkovic et al. 2016; Myszewski and Alber 2016; Prosser et al. 2018; Smith et al. 2020). This is especially true in Georgia, USA, where living shorelines are relatively new and tidal amplitudes exceed those of other South Atlantic and Gulf of Mexico states, presenting unique challenges for coastal protection (GADNR 2023).

To address the living shoreline knowledge gap, the Coastal Green Infrastructure and Ecosystem Services Task Force of the National Science and Technology Council (2015) recommended the adoption of monitoring standards that are scalable, transferable, and require limited resources and technical expertise. These attributes may be achieved through community-based monitoring programs that utilize volunteers to collect data following standardized protocols, with sufficient training and supervision to ensure accuracy (Currin et al. 2008). Here we report the results of a multi-year collaborative effort between the St. Simons Land Trust, Georgia Department of Natural Resources Coastal Resources Division, and students and faculty at the College of Coastal Georgia to monitor and assess a living shoreline on Lawrence Creek at Cannon’s Point Preserve, St. Simons Island, Georgia, USA. This partnership was established to (1) advance scientific understanding of living shorelines in Georgia, (2) facilitate experiential learning by undergraduate students, and (3) serve the conservation missions of community partners (i.e., service-learning; Furco 1996). At the time of its construction in 2015, Lawrence Creek was the fourth living shoreline in the state and the first to be accessible by road, making it an ideal study site for coastal managers, scientists, and students. We hypothesized that by providing hard substrate for oyster recruitment and stabilizing the eroding creek bank, the installation of a living shoreline would promote the establishment of an oyster reef and enhance the fringing salt marsh habitat. In particular, we predicted increases in the spatial coverage and density of two foundation species, the eastern oyster (*Crassostrea virginica*) in the lower intertidal zone and smooth cordgrass (*Sporobolus alterniflorus*; synonym: *Spartina alterniflora*; Peterson et al. 2014; but see Bortolus et al. 2019) along the top of the creek bank. These predictions were based on local site characteristics as well as previous monitoring results from living shoreline projects in Alabama (Scyphers et al. 2011), North Carolina (Currin et al. 2008; Gittman et al. 2016), and Virginia (Isdell et al. 2021).

MATERIALS & METHODS

Site Description and Living Shoreline Construction

The living shoreline was constructed along an approximately 80-m section of Lawrence Creek at the former site of Taylor's Fish Camp, St. Simons Island, Georgia, USA (31.26006, -81.33998; Figure 1). When the property was acquired by the St. Simons Land Trust as part of Cannon's Point Preserve (https://www.sslt.org/protected-properties-2/cannons-point-preserve/), the disturbed creek bank was severely eroding due to wave and tidal action and altered hydrology associated with a sunken dock, which was removed in May 2013. In the project area, Lawrence Creek is a relatively narrow and shallow tidal creek with a mud/sand bottom and a tidal range typically between 1.5-3 m; at low tide the water is approximately 10 m wide and <1 m deep. Before the living shoreline was installed, the steep creek bank consisted largely of bare mud interspersed with smooth cordgrass, marsh wrack, and three small (<3 m wide), isolated patches of oysters that were previously pried off the sunken dock (Figure 2a). Those existing oysters were sacrificed during construction. The shoreline was bordered to the west by a salt marsh fringe consisting of smooth cordgrass, *Borrichia frutescens*, *Distichlis spicata, Salicornia virginica,* and *Sporobolus virginicus*. In the northern-most section, the marsh transitioned abruptly to uplands dominated by non-native turf grasses.

Construction of the living shoreline began in April 2015. First, the eroding creek bank was graded to establish a 1.5:1 slope (H:V) on the lower reach of the bank and a 3:1 slope along the top of the bank. The toe of the graded bank was stabilized with recycled concrete. Next, geotextile fabric was placed on the mud/sand substrate followed by a layer of bagged oyster shell (in 20×76-cm polyvinyl mesh bags) wrapped within a Tensar Triax TX160 geogrid material and secured by timber deadman anchors at the top of the slope. Except for the uppermost section of the shoreline, which was designated for native vegetation, a second layer of bagged oyster shell was placed on the geogrid to provide a laminate surface of exposed cultch material where oyster spat could attach and grow. Oyster bags were manually positioned in rows and anchored using J-hooks spaced every 0.9 m up the slope and every 1.5 m parallel to the creek. The project utilized 8,000 bags of oyster shells, more than 5,000 of which were bagged by volunteers (estimated 637 volunteer hours). The intertidal transition zone bordering the top of the bank (approximately 5-10 m wide) was backfilled with loose native soil excavated from the project site and covered with biodegradable erosion control blankets. A floating dock for launching non-motorized watercrafts was also installed, with a fixed walkway constructed over part of the living shoreline (Figure 1). The lower portion of the living shoreline was completed in August and all construction activities ended by early September 2015. Plugs of smooth cordgrass and *B. frutescens* were planted along the top of the bank and intertidal transition zone between 8 September and 2 October 2015 (Figure 2b). The project was permitted in compliance with the Georgia Coastal Marshlands Protection Act, Georgia Department of Natural Resources, and U.S. Army Corps of Engineers.

Figure 1. Location of the living shoreline (A) on the Georgia coast, (B) at Cannon's Point Preserve (CPP), St. Simons Island, and (C) on the west bank of Lawerence Creek, where shaded polygons show the areal extent of the restored oyster reef and vegetated salt marsh. Maps A-B were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. The image of the living shoreline site (C) was provided by Georgia Department of Natural Resources.

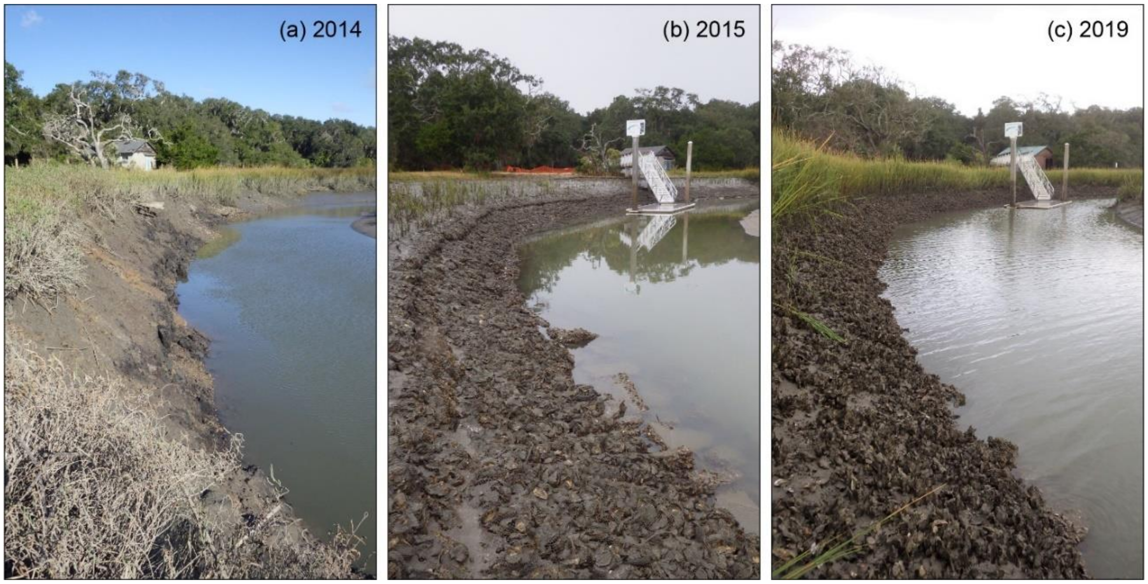

Figure 2. Photographs of the study site in (a) 2014, before the living shoreline was built; showing eroded shoreline; (B) 2015, immediately following construction of the living shoreline, with bagged oyster shell and planted vegetation visible; and (C) 2019, four years post-installation, with dense live oysters and cordgrass.

Monitoring Program

Pre-construction monitoring began in 2014, providing a baseline to assess longitudinal changes in oyster reef and marsh-edge vegetated habitat through 2020, five years after the living shoreline was installed. Due to logistical constraints, we were unable to establish any control or reference sites for comparison. Oyster habitat monitoring followed Baggett et al. (2014). Specific monitoring metrics and procedures are described below. Students were trained and given time to practice methods on-site; senior project personnel then circulated among student groups to supervise data collection.

In October 2014, prior to the start of construction, we used meter tape to measure the spatial dimensions (length, width) of the three existing patches of oysters. Patches were visually modeled as either rectangles or ellipses to estimate the total area of oyster coverage. Nearly two years post-installation (May 2017), high-resolution (37.8 pixels/cm) aerial images of the living shoreline were captured at low tide via a low-altitude drone flight conducted by Georgia Department of Natural Resources. We used the orthorectified (Pix4D) images and ArcGIS (Esri) to estimate the restored oyster reef areal dimensions, distinguishing between project footprint and reef area as defined by Baggett et al. (2014). The project footprint represents the maximum areal extent of the reef, ignoring the possible patchiness of oysters; it was measured by tracing the outer perimeter of the entire zone containing surficial oyster shell substrate. Reef area represents the actual area covered by living and non-living oyster shell within the project footprint, excluding areas covered with sediment; it was measured by summing the areas where the percent coverage of surficial shell substrate was equal to or greater than 25%, delineated using heads-up digitizing. Our pre- and post-installation estimates of reef areal dimensions were not fully consistent due to differences in data collection; reef area was likely overestimated in 2014, when areas of sedimentation within each patch were not excluded.

Students conducted annual surveys of oysters and plants each October, at the end of the growing season, from 2014 to 2020. The 2015 survey immediately followed the planting described above, but the lower portion of the shoreline had been installed for several months, allowing for oyster recruitment. Oyster density, oyster size, and vegetated habitat metrics were measured along eight intertidal transects that started at the mean low water mark and extended landward perpendicular to the creek. Transects were spaced at least 10 m apart and at least 5 m from the living shoreline boundaries to avoid edge effects. Transects were not permanently marked, but relocated in the approximate vicinity each year using meter tape.

Oysters were sampled by placing a 0.25-m^2 quadrat extending 0.5 m landward from the mean low water mark (i.e., lower creek bank) of each transect (1 replicate per transect; 8 replicates total). Within each plot, we counted (without removing) the number of live oysters measuring at least 10 mm in height (distance from umbo to distal margin of shell) and used calipers to measure the shell heights of up to 30 randomly selected oysters per plot.

Marsh-edge vegetated habitat was sampled in two ways, utilizing the eight transects described above. First, we placed a 0.25-m^2 quadrat extending 0.5 m seaward from the upper edge of the creek bank (demarcated by change in slope) and counted the number of live smooth cordgrass shoots at ground level. Then, continuing the transects upland through the intertidal marsh fringe, we established two additional 0.25-m^2 plots per transect at 0-0.5 m and 5-5.5 m landward of the bank edge. Within each of these high marsh plots, we identified plants and visually estimated percent cover by species. To control for observer error, two students would independently estimate percent cover and record the average when their estimates were within 10% of one another, or re-estimate together when there was a larger discrepancy. Moreover, each group of 3-4 students typically collected data along only 2-3 transects so that observer effects were minimized once data were pooled across transects. Our monitoring timeline was not impacted by the tropical cyclones described below.

Data Analysis

We tested for changes in oyster and cordgrass density, oyster height, and plant percent cover over time (fixed factor) using one-way ANOVA or, when data were heteroscedastic, Welch's ANOVA, followed by Tukey-Kramer or Games-Howell post-hoc tests, respectively. To improve normality, oyster heights were ln-transformed and plant percent cover data were square-root-transformed. Statistical analyses were performed using IBM SPSS Statistics Version 28.

RESULTS

In 2014, three remnant patches of oysters occurred along the eroding creek bank, constituting a total reef area of approximately 13.5 m^2. By 2017, two years after installation of the living shoreline, the restored oyster reef covered 150.8 m^2 or approximately 84% of the 180-m^2 project footprint (Figures 1-2). Likewise, oyster densities were low in 2014 and 2015, before and immediately after the living shoreline was built, but rose sharply in 2016 and remained relatively stable across subsequent years (Welch's ANOVA: $F'_{6,\ 21.4} = 29.24$, $P < 0.001$; Figure 3). Between 2014 and 2020, mean oyster density increased 21-fold from 41.0 to 864.5 individuals/m^2, suggesting a change in local abundance from approximately 7,380 to 155,610 oysters (roughly estimated as the product of mean density and project footprint, assuming the latter was constant). The oysters that were recruited to the newly constructed living shoreline in 2015 were younger and smaller, on average, than those found in 2014; however, as the reef matured from 2016 to 2020, oyster sizes gradually returned to pre-living-shoreline heights (Welch's ANOVA: $F'_{6,328} = 82.72$, $P < 0.001$; Figure 4).

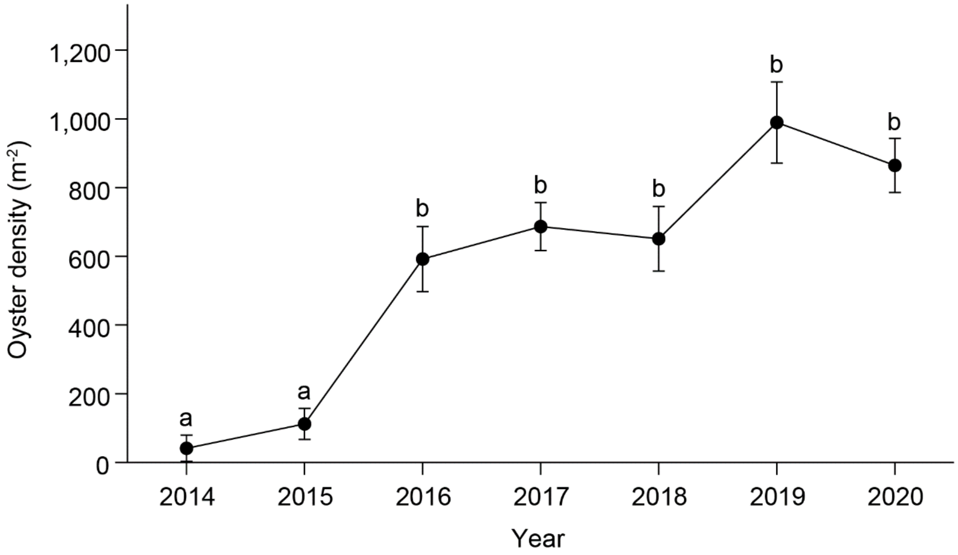

Figure 3. Oyster density (mean ± SE) along the lower bank of Lawrence Creek before and after the living shoreline was installed in 2015. Different letters indicate significant differences between years (Games-Howell post-hoc tests: $P < 0.05$).

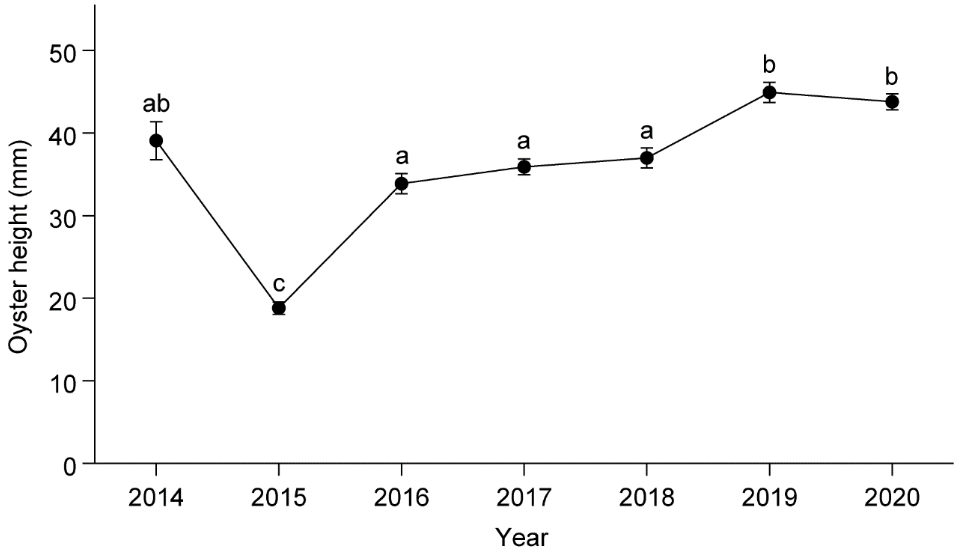

Figure 4. Oyster height (mean ± SE) along the lower bank of Lawrence Creek before and after the living shoreline was installed in 2015. Different letters indicate significant differences between years (Games-Howell post-hoc tests: $P < 0.05$).

The trajectory of smooth cordgrass along the upper zone of the living shoreline followed that of oysters at lower elevations. Cordgrass densities increased in the first year following installation and persisted at high levels through 2020 (ANOVA: $F_{6, 49} = 35.93$, $P < 0.001$; Figure 5). Continuing landward into the marsh fringe bordering Lawrence Creek, construction activity initially reduced the total percent cover of plants, but marsh vegetation recovered in subsequent years, aided by the growth of planted specimens as well as natural recruitment. With the exception of a temporary decline in 2017 (following Hurricane Irma), overall plant cover continued to increase from 2016-2020 (ANOVA: $F_{6, 105} = 13.50$, $P < 0.001$; Figure 6). Although plant species composition remained highly heterogeneous along the length of the shoreline and between sample plots, the percent cover data indicate that *Borrichia frutescens*, *Distichlis spicata*, and *Salicornia virginica* decreased in abundance while *Sporobolus alterniflorus* and *Sporobolus virginicus* increased (Table I).

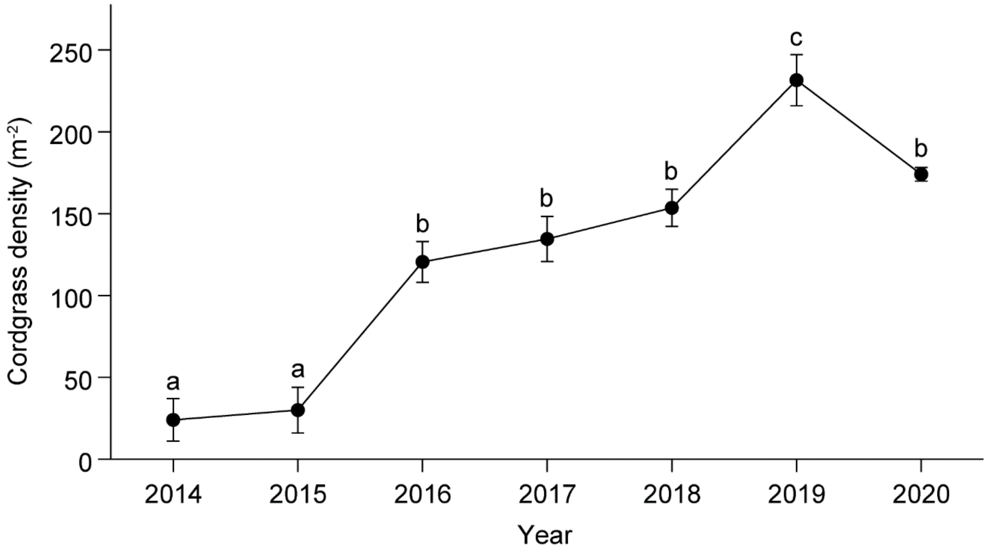

Figure 5. Smooth cordgrass stem density (mean ± SE) along the upper bank of Lawrence Creek before and after the living shoreline was installed in 2015. Different letters indicate significant differences between years (Tukey-Kramer post-hoc tests: $P < 0.05$).

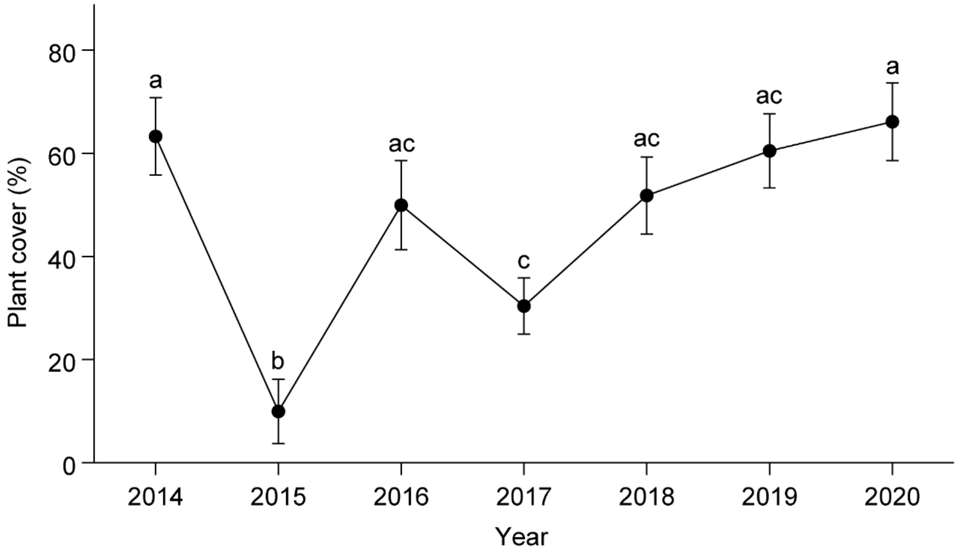

Figure 6. Percent cover (mean ± SE) of all plant species in the marsh fringe bordering Lawrence Creek before and after the living shoreline was installed in 2015. Different letters indicate significant differences between years (Tukey-Kramer post-hoc tests: $P < 0.05$).

Table I. Percent cover of common plant species (≥ 5% cover during any year) in the marsh fringe bordering Lawrence Creek before and after installation of the living shoreline in 2015.

	Mean percent cover by year						
Species	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Borrichia frutescens	15.2	0.7	3.6	2.5	4.4	3.8	6.1
Distichlis spicata	5.2	0.0	0.0	0.3	1.3	0.6	2.5
Salicornia virginica	26.8	2.3	11.3	1.0	5.5	4.1	4.9
Sporobolus alterniflorus	6.0	0.4	32.1	21.3	30.5	36.3	35.7
Sporobolus virginicus	9.6	5.6	0.6	4.7	10.2	15.6	16.9
All other species*	0.4	0.9	2.3	0.6	0.0	0.0	0.0

*Other species included *Baccharis halimifolia* and *Iva frutescens* branches and non-native turf grass stolons from plants that did not originate within sample plots. No native marsh plants were extirpated from the project footprint.

DISCUSSION

As alternatives to hard armoring structures, nature-based living shorelines are designed to protect shorelines and their associated biodiversity and ecosystem services (Bilkovic et al. 2016). The conservation benefits of living shorelines are widely assumed but have rarely been documented through ecological monitoring (Davis et al. 2006; Currin et al. 2008; Scyphers et al. 2011; Gittman et al. 2016; Davenport et al. 2018; Isdell et al. 2021). In the high-energy estuarine environment of coastal Georgia, where living shoreline implementation and research lag behind other South Atlantic and Gulf of Mexico states (Smith et al. 2020), monitoring efforts have been sporadic and only preliminary data have been reported in the grey literature (GADNR 2013). Our results indicate that the Lawrence Creek living shoreline at Cannon's Point Preserve, St. Simons Island successfully enhanced salt marsh habitat occupied by the eastern oyster (*Crassostrea* *virginica*) and smooth cordgrass (*Sporobolus alterniflorus*). Local population growth of these foundation species occurred rapidly following construction, and their expanded spatial coverage and high densities were sustained across the five-year post-installation monitoring period. Oysters and cordgrass provide valuable ecosystem services including shoreline stabilization, water filtration, protection of uplands from storms, and provision of nursery, refuge, and foraging sites for nekton such as fish and crustaceans (reviewed by Grobowski and Peterson 2007; Barbier et al. 2011). Although the plant community in the landward marsh fringe was initially disturbed by construction activities, total plant coverage quickly recovered and all native marsh species persisted. Apparent shifts in relative abundance of plant species may indicate broader changes in community structure, but we are cautious not to overgeneralize given the shoreline's heterogeneity and our limited sampling regime. In sum, we conclude that by stabilizing Lawrence Creek and supporting a healthy salt marsh ecosystem, the living shoreline has not only protected upland infrastructure and cultural assets, but has advanced coastal conservation as well.

Our study serendipitously spanned a series of tropical cyclones that tested the durability and resiliency of the living shoreline. On 2 September 2016, Hermine moved northeastward over St. Simons Island as a tropical storm with maximum sustained winds of 35 kt, gusts of 49 kt, and 9.0 cm of rain (NOAA NHC; closest sites reported when local data not available). On 8 October 2016, Matthew moved northward approximately 80 km offshore of the Georgia coast as a category 2 hurricane with sustained winds of 65 kt and gusts of 83 kt at Tybee Island, 15.4 cm of rain at St. Simons Island, and a storm surge of 2.3 m causing an inundation of 1.5 m above Mean Higher High Water (MHHW) at Ft. Pulaski. On 11 September 2017, Irma moved over Florida into Georgia as a tropical storm with sustained winds of 50 kt and gusts of 67 kt at Jekyll Island and a storm surge of 1.7 m causing an inundation of 1.4 m above MHHW at Ft. Pulaski; along the Lawrence Creek living shoreline, the storm surge pushed marsh wrack and debris approximately 48 linear m upland from the mean high tide line. And finally, on 4-5 September 2019, Dorian moved northward offshore of Georgia with sustained winds of 36 kt and gusts of 48 kt at Tybee Island and caused an inundation of 0.9 m above MHHW at Sea Island. Throughout all these tropical cyclones, the living shoreline remained intact and the restored oyster reef and salt marsh persisted. A temporary reduction in marsh-edge plant coverage observed in October 2017 was likely caused by wrack accumulation following Irma's storm surge, but the plant community recovered over the next year. During recent hurricanes in North Carolina, living shoreline designs (marsh plantings with or without sills) consistently outperformed and sustained less damage than bulkheads while maintaining marsh vegetation at higher densities than natural marshes (Gittman et al. 2014; Smith et al. 2018). Thus, living shorelines may be more resilient, and require less maintenance, than traditional hardened shorelines in the face of climate change, which threatens to further accelerate sea-level rise (Nicholls and Cazenave 2010) and increase the frequency of extreme storm events (Grinstead et al. 2013).

Although the current results are restricted to a single study site, their broader implications may guide future work on living shorelines in Georgia and other coastal locations with dynamic tidal regimes. First, our findings clearly demonstrate that living shorelines can provide ecological benefits amidst the large tidal amplitudes and severe storms that occur on the Georgia coast. Although local site conditions and engineering methods vary, most living shorelines built in Georgia since the Lawrence Creek project in 2015 have applied similar designs, integrating a layer(s) of bagged oyster shell with planted vegetation. Recently, however, a shortage of shell is prompting experimentation with alternative oyster cultch materials (GADNR 2023). Second, while longer-term and more extensive monitoring is required to fully assess structural and functional responses to living shorelines and their resilience to storms and rising sea levels (Bilkovic et al. 2016; Smith et al. 2020), the rapid growth and expansion of foundation species (oysters and smooth cordgrass) observed at Lawrence Creek suggest that primary habitat enhancement may be detected over a relatively short monitoring period of 2-3 years post-installation, which is sometimes all that is afforded. Systematic monitoring of additional living shoreline sites and designs is needed to verify these tentative conclusions. Ideally, monitoring programs should implement before-after-control-impact (BACI; Baggett et al. 2014) or related designs that permit direct comparisons with control and/or reference sites, which might include natural fringing marshes (e.g., Currin et al. 2008; Gittman et al. 2016; Isdell et al. 2021), conventional armored sites (bulkheads, riprap revetments; e.g., Davis et al. 2006; Gittman et al. 2016; Davenport et al. 2018), and/or non-stabilized eroding shorelines (e.g., Scyphers et al. 2011).

Like many small-scale conservation projects, living shorelines are chronically under-monitored due to limited resources, including labor (Bilkovic et al. 2016). As a form of community science (also known as citizen science or participatory science), community-based monitoring programs can utilize volunteers to help assess living shorelines, with the added social-educational benefit of engaging diverse participants in the scientific process (Sharpe and Conrad 2006; Currin et al. 2008; Silvertown 2009; Sanders and Brandes 2020). Our monitoring program was conducted by undergraduate students at the College of Coastal Georgia, a regional access institution serving populations that are traditionally under-represented in science (i.e., minorities, Pell-eligible, and first-generation college students). To increase the reliability of data collected by students, we provided clear, simple instructions and datasheets, set aside extra time for training and to practice data collection, and maintained close supervision by senior project personnel. The methods were based on established protocols (Currin et al. 2008; GANDR 2013; Baggett et al. 2014) that can be scaled up and transferred to other living shorelines and community scientists, with opportunities to incorporate a wider range of variables such as sediment, elevation, and nekton, depending on project objectives and resource availability (CGIES Task Force 2015).

This study was implemented across seven class sections (>100 students) of BIOL 4020 Conservation Biology as a service-learning project (Furco 1996) and a course-based undergraduate research experience (Waterman and Heemstra 2018), both of which are recognized as high-impact educational practices (Kuh 2008). In contrast with the prevailing model of undergraduate conservation biology courses, which typically lack hands-on activities or rely on computer simulations (Work 2015), the experiential learning approach employed here gave students opportunities to apply their content knowledge and skills toward developing, executing, and assessing an actual conservation project while collaborating with community partners at the St. Simons Land Trust and Georgia Department of Natural Resources. Participants helped develop field methods, collected and analyzed data, interpreted results, generated written reports, presented their findings at College symposia and regional conferences, and reflected on their service-learning experiences. A number of former students (including C.A. and J.F.) are now working in conservation and natural resource management and/or pursuing graduate studies in ecology, marine science, and related fields.

The educational impacts of the Lawrence Creek living shoreline extend far beyond those undergraduate researchers. As one of the first and most accessible living shorelines in Georgia, it serves as a field trip destination for K-12 students from throughout the state (https://www.sslt.org/learn), as well as a study site for graduate students and faculty from research institutions. Cannon's Point Preserve hosts more than 4,000 visitors per year, most of whom see the living shoreline and its interpretive signage. The St. Simons Land Trust and partners also host on-site living shoreline demonstrations and workshops for a range of stakeholders including coastal managers, engineers, marine contractors, and property owners, thus building regional capacity to support the expansion of living shoreline techniques. All this exposure promotes public awareness and acceptance of living shorelines, which along with factors such as scientific understanding, ease of permitting, and competitive costs, will be essential to their growing application as a tool for coastal management and conservation (Scyphers et al. 2015; Gittman and Scyphers 2017).

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