COMPARATIVE SAMPLING OF NEKTON ASSOCIATED WITH LIVING SHORELINES, NATURAL OYSTER REEFS, AND BARE GROUND IN GEORGIA.

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Introduction

Eastern oysters (*Crassostrea virginica* Gmelin, 1791), found in intertidal estuaries throughout coastal Georgia, are considered ecosystem engineers as their reef-forming nature creates one of the most productive ecosystems in the southeastern United States. Regarded as keystone species, (Jones et al. 1994; Luckenbach et al. 1999; Gutierrez et al., 2003; ASMFC 2007), oysters provide many valuable ecosystem services, including the provision of essential fish habitat (ASMFC 2007), the improvement of water quality and clarity via filtration of phytoplankton and pollutants from the water column(Nelson *et al.* 2004; Porter *et al.* 2004), and shoreline stabilization, making them an ideal species to utilize in the construction of living shorelines in coastal Georgia. Living shorelines are defined by NOAA as a method to help stabilize eroding shorelines that "utilize a variety of structural and organic materials, such as wetland plants, submerged aquatic vegetation, oyster reefs, coir fiber logs, sand fill, and stone" (NOAA 2014).

There is considerable interest by The Nature Conservancy, as well as other agencies in Georgia and the southeast U.S., to identify any difference in species richness and abundance between living shorelines and natural oyster reefs. Previous research in Georgia has found over 60 species of nekton associated with natural oyster reefs and that nekton are similar along the coast, north to south, (Bliss et al. 2010 and 2011) and that nekton found over created oyster reefs does not differ from natural oyster reefs (Bliss and Rinn 2015).

Study Sites

To examine the use of living shorelines by the nektonic and benthic communities, two living shorelines demonstration sites were sampled along with adjacent natural reef controls. The living shorelines were constructed at high eroded sites and utilized bagged oyster shell, native marsh vegetation, and site-specific engineering to restore the natural grading of the tidal creek bank. At Sapelo Island, GA a living shoreline constructed along Post Office Creek (330 linear feet) in 2010 (Figure 1) and a natural reef control along Seine Creek (Figure 2) were selected for monitoring. Post Office Creek is on the west side of Sapelo Island and Seine Creek is on the southwest end of the island (Figure 3) and are 4.1 km apart. The second living shoreline used for sampling was constructed along Mosquito Creek (370 linear feet) at Little St. Simons Island, GA in 2013 (Figure 4). On Little St. Simons Island two natural reef controls were utilized during the study. Initially, a site located on Mosquito Creek upriver of the living shoreline was selected as the natural reef control (Figure 5), but subsequent sampling was not possible due to unusual hydrology that prohibited the site from fulling draining and was therefore abandoned. A second natural reef control site was chosen at the mouth of Mosquito Creek (Figure 6). The living shoreline and natural reef are both located in Mosquito Creek, located on the west side of the island and are sepearted by a distance of 1.1 km (Figure 7).

Figure 1. Living Shoreline site on Sapelo Island, GA. (31°26'3.20"N, 81°16'52.50"W)

Figure 2. Natural reef location on Sapleo Island, GA. (31°23'50.24"N, 81°16'53.46"W)

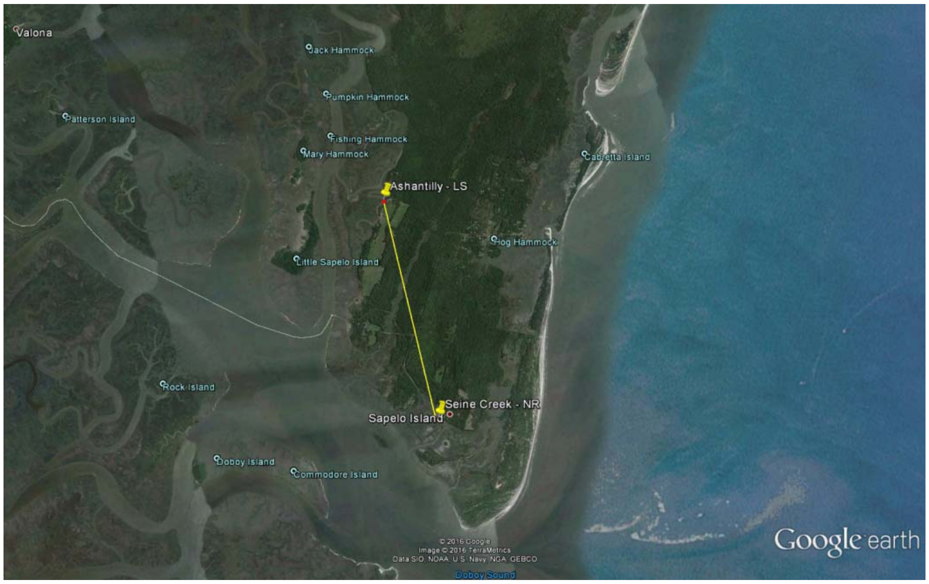

Figure 3. Map of Sapelo Island showing the location and distance between the living shoreline and natural reef location.

Figure 4. Living Shoreline site on Little St. Simons Island, GA. (31°15'36.75"N, 81°18'8.13"W)

Figure 5. Natural reef #1 location on Little St. Simons Island, GA. (31°14'59.99"N, 81°17'35.76"W)

Figure 6. Natural reef location #2 on Little St. Simons Island, GA. (31°16'2.89"N, 81°18'34.33"W)

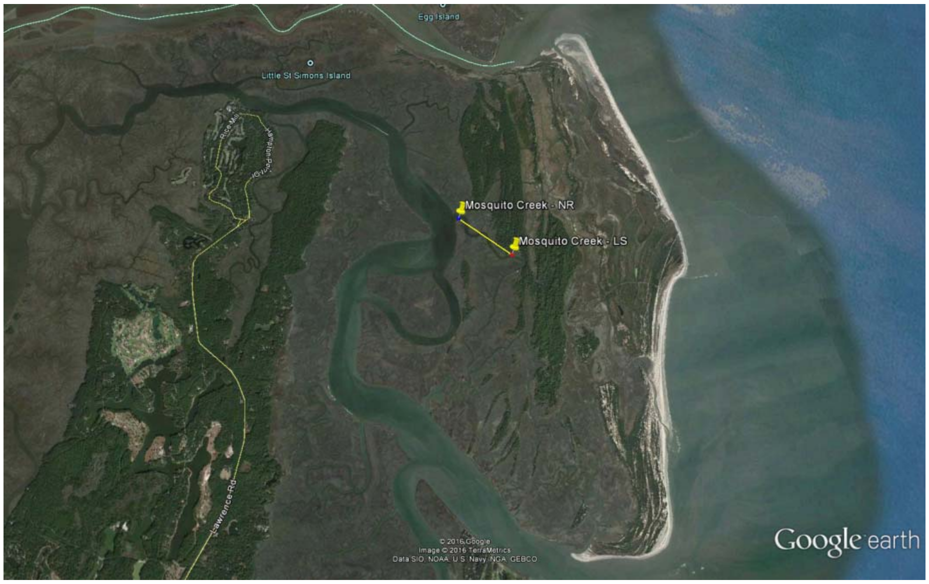

Figure 7. Map of Little St. Simons Island showing the location and distance between the living shoreline and natural reef location

Methods

Nekton

Nekton sampling was performed using a bottomless "lift net" (Wenner et al. 1996) seasonally over living shorelines, natural reefs in 2015 and 2016, and mud flats in 2016 on Sapelo Island and Little St. Simons Island. In 2015, sampling was conducted during the spring, summer and fall of 2015 at Little St. Simons Island, and during the summer and fall of 2015 at Sapelo Island. In 2016, sampling was conducted each season in both locations. Bottomless lift nets are 5 x 3 x 3 meters made of 3.175 mm (1/8 inch) Delta mesh (Memphis Net and Twine) that have a lead line weighted base that was staked with 20 cm stakes in half meter increments around a portion of the living shoreline, natural reef and mud flats. Nets are connected to ten 3.5m pvc poles using 3.175mm (1/8 inch) braided nylon rope. Set up occurs at low tide and raised at high tide the following morning after sunrise. The nets remained raised until the subsequent low tide exposes the substrate completely, at which time the nets were lowered and all trapped organisms are collected (Figures 8 - 9). Sites at each location on LSSI and Sapelo were deployed concurrently, and once sampling was complete the nets and poles were removed to minimize site disturbance. In 2015, sites were sampled once per sample period and in 2016 sites were sampled twice per sample period. All collected organisms were anesthetized in Finquel and placed in 10% seawater buffered formalin for storage. Larger organisms that were alive and could be easily identified were measured on site and released. Collected specimens brought to the UGA Marex lab were identified to lowest taxonomic level possible. Fish and crustaceans were identified, enumerated by species, and length was recorded.

To compare nekton between natural reefs and living shorelines, data from both the Sapelo Island and Little St. Simons Island sites were combined due to low sample size. To examine diversity and eveness the Shannon Index of Diversity was calculated to compare living shorelines, natural reefs, and mud flats. To determine if differences between nekton associated with living shoreline, natural reef, and mud flats in 2016 ANOSIM (analysis of similarity) was calculated using Primer 6. To run ANOSIM abundance was transformed by taking the 4^{th} root and Bray-Curtis Similarity Matrix was calculated in Primer 6 (Clarke and Gorley 2006) for samples in 2015 and 2016. Years were not combined since sampling in 2015 did not occur all seasons and mud flats were not examined. If ANOSIM detects a difference, SIMPER (Similarity/distance percentages) was run post hoc to examine which species contributed most to the difference.

Benthic

To monitor benthic colonization, bags of cured oyster shell (approximately 45 cm long x 25 cm diameter) were used. In 2015, one bag was placed at each site on the living shoreline and natural oyster reefs and allowed to soak for one month each sampling period. In 2016, three replicate bags were placed at each site and soaked for one month. At the end of the one month soak period, bags were collected and placed immediately into a five gallon bucket to catch any loose organisms. The bag was then opened up and shell was rinsed with fresh water over a sieve and shell was removed. All specimens collected were placed in 10% seawater buffered formalin and stored for identification. Specimens collected were identified in the lab to the lowest taxonomic level possible and enumerated.

Oyster Metrics

To estimate density of live and dead oysters, a 0.25 m^2 square quadrat was used at each site. Each site was sampled once at three random locations within the sample area of the natural oyster reef and living shoreline. The locations were selected at random and the number of live and dead oysters was counted. Additionally, the size of 20 randomly selected oysters in each quadrat were measured. A one-way ANOVA (NCSS 9) was used to compare the natural reefs and living shoreline reefs between locations and year.

Water Quality

Water quality parameters monitored were temperature (°C), dissolved oxygen (mg/L), pH and salinity (ppt) were measured using a Qunata (Hach Company) during net deployment. Measurements were taken at both the surface and at a depth of one meter in the immediate vicinities of the lift nets. During fall sampling a HOBO conductivity logged (model U24) was deployed during set up at each living shoreline and control site and collected water temperature and salinity every 15 minutes. Loggers were retrieved when net was sampled. This allowed for monitoring the water during the night time tidal cycle and the net soak period, and provided information on tidal period.

Figure 8. Picture of bottomless lift nets deployed at high tide over living shoreline site on Little St. Simons Island, GA.

Figure 9. Picture of bottomless lift nets deployed at low tide, prior to sampling, over a living shoreline on Little St. Simons Island, GA.

Results

Nekton

A total of 43 species of nekton were observed and 7,929 specimens were collected from the lift nets over the 2 years. In 2015, 22 species were observed with natural oyster reefs and 18 with living shoreline sites, in 2016, 26 species were collected from natural reefs sites, 19 from mud sites, and 17 over living shorelines. In 2015 abundance was greater on living shorelines than natural reefs with 1,239 and 955 respectively, during 2016 abundance was highest on natural reefs with 3,447 followed by living shoreline with 1,302, and then mud with 986. The most abundant fish was the bay anchovy (*Anchoa mitchilli*) and the most abundant crustacean was grass shrimp (*Palaemontes* sp). The abundance for each species by year and site is listed in Table 1 and the mean total length (mm) is presented in Table 2.

At Little St. Simons Island the greatest number of species observed occurred in fall followed by spring and then summer. Abundance was greatest in summer sampling when the sample was dominated by bay anchovies. The same trend was observed at the natural reef, but unfortunately no sample was collected in the summer sampling due hydrological issues preventing the natural reef from draining. On Sapelo Island, both the number of species observed and abundance was greater on the natural reef than at the living shoreline site. For 2016, living shorelines at both locations had the greatest number of species observed in summer, and mud greatest number of species was in the fall. For natural reefs the greatest number of species was observed in spring, at LSSI, and in fall on Sapelo. The break down of species observed by location, habitat, and year are in Table 3.

In 2015, the Shannon-Wiener index of diversity indicated that both diversity and evenness were greater at natural reefs than living shoreline sites (Table 4). In 2016, natural reefs had the highest diversity and evenness followed by mud flats and living shorelines (Table xx). With locations combined ANOSIM found no difference between natural reefs and living shorelines (Global R= -0.407, p=1.00) in 2015, however in 2016 ANOSIM did detect a difference between natural reef, living shoreline, and mud flats (Global R = 0.098, p=0.014). Pairwise comparison found no difference between natural reef and living shoreline (R=0.019, p=0.221), but did find that natural reefs (R=0.155, p=0.01) and living shorelines (R=0.12, p=0.019) did differ significantly from mud flats. SIMPER results found that grass shrimp (*Palaemonetes* sp.) and bay anchovy were more abundant at natural reefs and living shorelines sites than mud flat and that white shrimp and the darter goby (*Ctenogobius boleosoma*) were more abundant on mud flats. These four species accounted for the majority of the difference between mud flats and natural reefs (Table xxx) and mud flats and living shorelines (Table xxx).

ANOSIM did look for differences between sites at each location a difference was detected (Global R=0.113, p=0.016), pairwise comparisons found that natural reef, living shoreline, and mud flat did not differ from each other on Sapelo, but on LSSI mud did differ significantly from natural reef (R=0.326, p=0.016) and living shoreline (R=0.184, p=0.041).

Table 1. Species and abundance captured in lift nets over living shoreline (LS) and natural oyster reef (NR) and mud (M) sites on Little St. Simons Island and Sapelo Island, GA in 2015 and 2016.

	2015				2016					
	LSSI		Sapelo Island		LSSI			Sapelo Island		
Species	**LS**	**N**	**LS**	**N**	**LS**	**M**	**N**	**LS**	**M**	**N**
Alpheus heterochaelis	0	0	0	1	0	0	0	0	0	0
Anchoa hepsetus	0	0	0	0	0	637	142	37	0	140
Anchoa mitchilli	810	0	8	424	22	11	20	37	14	1885
Bairdiella chrysoura	3	0	0	35	2	2	0	5	13	4
Brevoortia tyrannus	0	0	0	1	0	0	0	0	0	0
Callinectes sapidus	3	18	0	0	2	3	14	0	3	0
Callinectes similis	0	0	0	0	1	3	0	0	2	1
Chaetodipterus faber	0	0	0	0	0	0	8	0	0	0
Chloroscombrus chrysurus	0	0	0	0	0	1	0	0	0	0
Ctenogobius boleosoma	9	0	0	0	2	13	0	0	7	2
Cynoscion nebulosus	0	0	0	0	0	0	0	0	1	0
Cyprinodon variegates	2	0	0	0	0	0	0	0	0	3
Dasyatis sabina	0	1	0	0	0	0	0	0	0	0
Diapterus auratus	0	0	0	0	0	1	0	0	0	0
Diapterus plumieri	1	0	0	2	0	0	0	0	0	0
Elops saurus	1	3	0	0	0	0	0	0	0	0
Eucinostomus argenteus	0	0	0	0	0	2	0	0	0	0
Fundulus heteroclitus	139	121	0	0	5	0	12	5	0	1
Fundulus majalis	2	5	0	0	0	0	0	0	1	144
Gobiosoma bosc	0	0	0	1	1	0	0	0	0	3
Harengula jaguana	0	0	0	23	0	0	0	0	0	0
Hypsoblennius hentzi	0	0	0	0	0	0	2	0	0	0
Lagodon rhomboides	1	0	0	0	0	0	0	0	0	0
Larimus fasciatus	0	0	0	0	0	0	0	0	0	1
Leiostomus xanthurus	0	4	0	0	1	6	0	0	0	0
Litopenaeus setiferus	77	2	8	164	81	58	2	19	20	108
Menidia menidia	16	0	0	12	0	0	1	1	0	78
Mugil cephalus	0	1	0	0	0	0	0	0	0	2
Mugil curema	0	32	0	0	0	0	0	0	0	0
Oligoplites saurus	0	0	0	1	0	0	0	0	0	0
Opsanus tau	2	0	0	0	1	0	0	0	0	1
Orthopristis chrysoptera	0	0	0	0	2	0	1	0	0	1
Palaemonetes sp.	57	53	0	0	339	21	89	735	151	718
Paralichthys dentatus	0	0	0	0	0	0	0	0	2	0
Paralichthys lethostigma	5	0	0	0	0	0	0	0	0	0
Poecilia latipinna	89	14	0	32	1	0	0	0	0	49
Prionotus tribulus	0	0	0	0	0	0	0	0	1	1
Stellifer lanceolatus	0	0	0	0	0	5	0	0	0	7
Symphurus civitatium	0	0	0	1	0	0	0	0	0	0
Symphurus plagiusa	5	4	0	0	2	2	0	0	5	0
Syngnathus fuscus	1	0	0	0	0	0	0	0	0	2
Trichiurus lepturus	0	0	0	0	0	0	0	0	0	1
Trinectes maculates	0	0	0	0	0	1	0	0	0	1

Table 2. Species and mean size (total length in mm) captured from lift nets over living shoreline (LS), natural reef (NR), and mud flate (M) habitats on Little St. Simons Island (LSSI) and Sapelo Island (SI), GA in 2015.

	2015		2016		
	LS	**N**	**LS**	**M**	**N**
LSSI					
Anchoa hepsetus				57.07	51.53
Anchoa mitchilli	42.94		57.32	55.73	54.85
Bairdiella chrysoura	113.67		38.00	25.00	
Callinectes sapidus	158.33	157.78	111.00	149.67	150.14
Callinectes similis			21.00	20.67	
Chaetodipterus faber					89.88
Chloroscombrus chrysurus				69.00	
Ctenogobius boleosoma	42.56		51.00	38.08	
Cyprinodon variegates	36.50				
Dasyatis sabina		260.00			
Diapterus auratus				130.00	
Diapterus plumieri	93.00				
Elops saurus	295.00	50.33			
Eucinostomus argenteus				53.00	
Fundulus heteroclitus	43.59	37.74	44.00		46.42
Fundulus majalis	44.00	35.60			
Gobiosoma bosc			37.00		
Hypsoblennius hentzi					59.50
Lagodon rhomboides	188.00				
Leiostomus xanthurus		64.25	122.00	156.50	
Litopenaeus setiferus	64.38	42.50	64.64	68.81	45.50
Menidia menidia	67.00				52.00
Mugil cephalus		131.00			
Mugil curema		49.43			
Opsanus tau	154.00		141.00		
Orthopristis chrysoptera			92.50		51.00
Palaemonetes sp.	24.67	21.00	28.05	27.76	26.52
Paralichthys lethostigma	123.00				
Poecilia latipinna	29.53	32.29	26.00		
Stellifer lanceolatus				35.20	
Symphurus plagiusa	41.80	51.25	41.00	38.50	
Syngnathus fuscus	135.00				
Trinectes maculates				57.00	
Sapelo Island					
Alpheus heterochaelis		23.00			
Anchoa hepsetus			53.00		54.72
Anchoa mitchilli	47.00	50.17	40.68	48.07	47.21
Bairdiella chrysoura		61.31	52.40	40.08	55.75
Brevoortia tyrannus		150.00			
Callinectes sapidus				149.00	
Callinectes similis				52.00	59.00
Ctenogobius boleosoma				44.29	71.50
Cynoscion nebulosus				410.00	
Cyprinodon variegates					23.33
Diapterus plumieri		36.50			
Fundulus heteroclitus			60.20		45.00
Fundulus majalis				26.00	29.80
Gobiosoma bosc		24.00			41.67
Harengula jaguana		40.74			
Larimus fasciatus					47.00
Litopenaeus setiferus	59.38	81.40	86.79	74.45	86.85
Menidia menidia		51.25	38.00		66.52
Mugil cephalus					130.00
Oligoplites saurus		48.00			
Opsanus tau					210.00
Orthopristis chrysoptera					53.00
Palaemonetes sp.			27.10	28.99	26.95
Paralichthys dentatus				53.50	
Poecilia latipinna		24.94			29.16
Prionotus tribulus				56.00	41.00
Stellifer lanceolatus					55.00
Symphurus civitatium		130.00			
Symphurus plagiusa				39.40	
Syngnathus fuscus					195.50
Trichiurus lepturus					206.00
Trinectes maculates					118.00

Table 2. Species and abundance from lift nets on Little St. Simons Island (LSSI) over living shoreline (LS), natural reef (NR), and mud flats (M) sites by season in 2015 and 2016.

	2015				2016		
	Spring	Summer	Fall	Winter	Spring	Summer	Fall
LSSI							
LS							
Anchoa mitchilli	0	804	6	22	0	0	0
Bairdiella chrysoura	0	0	3	2	0	0	0
Callinectes sapidus	0	0	3	0	0	1	1
Callinectes similis	0	0	0	0	0	1	0
Ctenogobius boleosoma	0	0	9	0	1	0	1
Cyprinodon variegates	0	1	1	0	0	0	0
Diapterus plumieri	1	0	0	0	0	0	0
Elops saurus	1	0	0	0	0	0	0
Fundulus heteroclitus	0	16	123	0	0	5	0
Fundulus majalis	2	0	0	0	0	0	0
Gobiosoma bosc	0	0	0	0	1	0	0
Lagodon rhomboides	1	0	0	0	0	0	0
Leiostomus xanthurus	0	0	0	0	0	0	1
Litopenaeus setiferus	34	0	43	0	3	75	3
Menidia menidia	0	0	16	0	0	0	0
Opsanus tau	0	2	0	0	0	1	0
Orthopristis chrysoptera	0	0	0	0	1	1	0
Palaemonetes sp.	57	0	0	149	113	32	45
Paralichthys lethostigma	1	0	4	0	0	0	0
Poecilia latipinna	0	0	89	0	0	1	0
Symphurus plagiusa	0	5	0	0	1	1	0
Syngnathus fuscus	0	0	1	0	0	0	0
M							
Anchoa hepsetus	0	0	0	0	0	0	637
Anchoa mitchilli	0	0	0	4	7	0	0
Bairdiella chrysoura	0	0	0	0	2	0	0
Callinectes sapidus	0	0	0	0	1	0	2
Callinectes similis	0	0	0	0	2	1	0
Chloroscombrus chrysurus	0	0	0	0	0	0	1
Ctenogobius boleosoma	0	0	0	5	7	0	1
Diapterus auratus	0	0	0	0	0	0	1
Eucinostomus argenteus	0	0	0	0	0	0	2
Leiostomus xanthurus	0	0	0	0	0	0	6
Litopenaeus setiferus	0	0	0	0	7	12	39
Palaemonetes sp.	0	0	0	19	0	0	2
Stellifer lanceolatus	0	0	0	0	0	0	5
Symphurus plagiusa	0	0	0	0	0	0	2
Trinectes maculates	0	0	0	0	0	0	1
NR							
Anchoa hepsetus	0	0	0	0	0	0	142
Anchoa mitchilli	0	0	0	12	1	7	0
Callinectes sapidus	0	0	18	0	5	7	2
Chaetodipterus faber	0	0	0	0	0	8	0
Dasyatis sabina	0	0	1	0	0	0	0
Elops saurus	3	0	0	0	0	0	0
Fundulus heteroclitus	117	0	4	3	4	5	0
Fundulus majalis	5	0	0	0	0	0	0
Hypsoblennius hentzi	0	0	0	0	2	0	0
Leiostomus xanthurus	4	0	0	0	0	0	0
Litopenaeus setiferus	0	0	2	0	1	0	1
Menidia menidia	0	0	0	0	0	1	0
Mugil cephalus	1	0	0	0	0	0	0
Mugil curema	32	0	0	0	0	0	0
Orthopristis chrysoptera	0	0	0	0	1	0	0
Palaemonetes sp.	53	0	0	40	37	0	12
Poecilia latipinna	14	0	0	0	0	0	0
Symphurus plagiusa	4	0	0	0	0	0	0

Table 3. Species and abundance from lift nets on Sapleo Island over living shoreline (LS), natural reef (NR), and mud flats (M) sites by season in 2015 and 2016.

	2015		2016			
	Summer	Fall	Winter	Spring	Summer	Fall
Sapelo						
LS						
Anchoa hepsetus	0	0	0	0	0	37
Anchoa mitchilli	0	8	4	0	33	0
Bairdiella chrysoura	0	0	0	4	0	1
Fundulus heteroclitus	0	0	0	4	1	0
Litopenaeus setiferus	0	8	0	0	8	11
Menidia menidia	0	0	0	0	1	0
Palaemonetes sp.	0	0	157	571	7	0
M						
Anchoa mitchilli	0	0	10	0	4	0
Bairdiella chrysoura	0	0	12	0	0	1
Callinectes sapidus	0	0	0	0	0	3
Callinectes similis	0	0	1	0	1	0
Ctenogobius boleosoma	0	0	4	2	0	1
Cynoscion nebulosus	0	0	0	0	0	1
Fundulus majalis	0	0	0	0	0	1
Litopenaeus setiferus	0	0	0	4	3	13
Palaemonetes sp.	0	0	113	38	0	0
Paralichthys dentatus	0	0	1	1	0	0
Prionotus tribulus	0	0	0	0	0	1
Symphurus plagiusa	0	0	3	0	0	2
NR						
Alpheus heterochaelis	1	0	0	0	0	0
Anchoa hepsetus	0	0	0	0	0	140
Anchoa mitchilli	306	118	19	24	1842	0
Bairdiella chrysoura	22	13	0	2	2	0
Brevoortia tyrannus	1	0	0	0	0	0
Callinectes similis	0	0	0	1	0	0
Ctenogobius boleosoma	0	0	0	0	0	2
Cyprinodon variegates	0	0	0	0	0	3
Diapterus plumieri	2	0	0	0	0	0
Fundulus heteroclitus	0	0	0	1	0	0
Fundulus majalis	0	0	0	0	0	144
Gobiosoma bosc	1	0	0	3	0	0
Harengula jaguana	23	0	0	0	0	0
Larimus fasciatus	0	0	0	0	0	1
Litopenaeus setiferus	81	83	0	0	15	93
Menidia menidia	12	0	1	0	0	77
Mugil cephalus	0	0	0	1	0	1
Oligoplites saurus	1	0	0	0	0	0
Opsanus tau	0	0	0	1	0	0
Orthopristis chrysoptera	0	0	0	1	0	0
Palaemonetes sp.	0	0	375	336	0	7
Poecilia latipinna	25	7	0	0	0	49
Prionotus tribulus	0	0	0	0	0	1
Stellifer lanceolatus	0	0	0	0	0	7
Symphurus civitatium	0	1	0	0	0	0
Syngnathus fuscus	0	0	0	0	0	2
Trichiurus lepturus	0	0	0	0	0	1
Trinectes maculates	0	0	0	0	0	1

Species	Group M Av.Abund	Group N Av.Abund
Palaemonetes sp.	0.88	1.54
Anchoa mitchilli	0.51	1.36
Litopenaeus setiferus	1.05	0.65
Ctenogobius boleosoma	0.67	0.07
Anchoa hepsetus	0.47	0.58
Callinectes sapidus	0.26	0.39
Bairdiella chrysoura	0.33	0.25
Fundulus heteroclitus	0	0.33
Callinectes similis	0.26	0.06
Symphurus plagiusa	0.34	0
Fundulus majalis	0.06	0.36
Menidia menidia	0	0.13
Chaetodipterus faber	0	0.11
Gobiosoma bosc	0	0.14
Paralichthys dentatus	0.13	0
Leiostomus xanthurus	0.16	0
Orthopristis chrysoptera	0	0.13
Prionotus tribulus	0.06	0.06
Stellifer lanceolatus	0.09	0.08

Species	Group M Av.Abund	Group LS Av.Abund
Palaemonetes sp.	0.88	2.06
Litopenaeus setiferus	1.05	0.63
Anchoa mitchilli	0.51	0.6
Ctenogobius boleosoma	0.67	0.13
Bairdiella chrysoura	0.33	0.28
Anchoa hepsetus	0.47	0.15
Callinectes similis	0.26	0.06
Symphurus plagiusa	0.34	0.13
Callinectes sapidus	0.26	0.13
Fundulus heteroclitus	0	0.3
Leiostomus xanthurus	0.16	0.06
Paralichthys dentatus	0.13	0

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
LSSIM, LSSIN	0.326	1.6	6435	999	15
LSSIM, LSSILS	0.184	4.1	6435	999	40
LSSIN, LSSILS	0.16	5.8	6435	999	57
SapeloM, SapeloN	0.093	13.7	6435	999	136
SapeloM, SapeloLS	0.052	18.7	6435	999	186
SapeloN, SapeloLS	-0.065	77.7	6435	999	776
LSSIN, SapeloN	0.21	4	6435	999	39

LSSILS, SapeloLS	0.015	34.4	6435	999	343
LSSIM, SapeloM	-0.078	78.2	6435	999	781

Row Labels	LS	NR
LSSI		
Anchoa mitchilli	42.9	0.0
Bairdiella chrysoura	113.7	0.0
Callinectes sapidus	158.3	157.8
Ctenogobius boleosoma	42.6	0.0
Cyprinodon variegatus	36.5	0.0
Dasyatis sabina	0.0	260.0
Diapterus plumieri	93.0	0.0
Elops saurus	295.0	50.3
Fundulus heteroclitus	43.6	37.7
Fundulus majalis	44.0	35.6
Lagodon rhomboides	188.0	0.0
Leithostomus xanthurus	0.0	64.3
Litopenaeus setiferus	64.4	42.5
Mendia mendia	67.0	0.0
Mugil cephalus	0.0	131.0
Mugil curema	0.0	49.4
Opsanus tau	154.0	0.0
Palaemonetes sp	24.7	21.0
Paralichthys lethostigma	123.0	0.0
Poecilia latipinna	29.5	32.3
Symphurus plagiusa	41.8	51.3
Synagathus fuscus	135.0	0.0
SI		
Alpheus heterochaelis	0.0	23.0
Anchoa mitchilli	47.0	50.2
Bairdiella chrysoura	0.0	61.3
Brevoortia tyrannus	0.0	150.0
Diapterus plumieri	0.0	36.5
Gobiosoma bosc	0.0	24.0
Harengula jaguana	0.0	40.7
Litopenaeus setiferus	59.4	81.4
Mendia mendia	0.0	51.3
Oligoplites saurus	0.0	48.0
Poecilia latipinna	0.0	24.9
Symphurus civitatium	0.0	130.0

Table. Results from Shannon-Weiner test of diversity and evenness for living shoreline (LS) and natural reef (NR), pooled among both sites in 2015.

Sample	S	N	d	J'	H'(loge)	1-Lambda'
LS	18	1239	2.387	0.4338	1.254	0.5397
NR	22	955	3.06	0.596	1.842	0.7484

Table. Results from Shannon-Weiner test of diversity and evenness for living shoreline (LS), natural reef (NR), and mud flats (M) pooled among both sites in 2016.

Sample	S	N	d	J'	H'(loge)	1-Lambda'
LS	16	1301	2.092	0.2653	0.7355	0.3099
NR	28	3444	3.315	0.4207	1.402	0.6292
M	20	986	2.756	0.4153	1.244	0.545

Benthic

In 2015, nine species were observed in benthic samples. The most abundant species at Little St. Simons Island was the green porcelain crab (*Petrolishes armatus*) followed by the Atlantic mud crab (*Panopeus herbstii*) at both the natural reef and living shoreline sites. At Sapleo Island, the Atlantic mud crab (*Panopeus herbstii*) was the most abundant at the living shoreline and natural reef site (Table 5). Interestingly, the magnitude of green porcelain crabs was considerably lower at Sapelo at both the living shoreline and natural oyster reef site than at Little St. Simons Island.

In 2016, 17 species were observed in benthic samples and a total of 2,709 specimens were collected. The green porcelain crab was the most abundant species and accounted for 89.5% of specimens collected and was followed by the Atlantic mud crab that accounted for 7.3%. This trend was observed at natural reef, mud flat, and living shoreline sites on both LSSI and Sapelo and abundance of green porcelain crabs was greatest in the summer and fall.

Table. Species from benthic shell bags on living shoreline (LS) and natural reef (NR) for Little St. Simons Island and Sapelo Island, GA.

Row Labels	Spring	Summer	Fall	Total
LSSI				
LS	**19**	**4**	**63**	**86**
Armases cinereum	2			2
Palamonetes sp.		1		1
Panopeus herbstii	15	1	18	34
Petrolisthes armatus	2	2	45	49
NR	**127**	**1**	**41**	**169**
Geukensia demissa	1			1
Marphysa sanguinea		1		1
Panopeus herbstii	16		6	22
Petrolisthes armatus	110		35	145
Sapelo				
LS		**17**	**23**	**40**
Ampithoe valida			12	12
Menippe mercinaria			2	2
Panopeus herbstii		11	6	17
Petrolisthes armatus		6	3	9
NR		**6**	**7**	**13**
Armases cinereum			1	1
Eurypanopeus depressus			1	1
Marphysa sanguinea			3	3
Panopeus herbstii		4	2	6
Petrolisthes armatus		2		2

Row Labels	Spring	Summer	Fall	Winter	Total
LSSI					
LS	**27**	**83**	**341**	**8**	**459**
Boonea impressa			10		10
Eurypaneus depressis			1		1
Menippe mercenaria			1		1
Nereiphylla fragilis	2		1		3
Nereis succinea			1		1
Panopeus herbsii	13	4	9	7	33
Petrolisthes armatus	11	79	318		408
Tritia obsoleta				1	1
Ura pugilator	1				1
Mud	**12**	**122**	**262**	**41**	**437**
Alpheus heterochaelis				1	1
Nassarius obsoletus	3				3
Nereiphylla fragilis			1		1
Palaemontes sp.			1	1	2
Panopeus herbsii		21	9	13	43
Petrolisthes armatus	9	101	251	22	383
Tritia obsoleta				4	4
NR	**36**	**108**	**380**	**42**	**566**
Boonea impressa			4		4
Brachidontes exustus			1		1
Nereiphylla fragilis	3	1	2		6
Panopeus herbsii	9	14	13	3	39
Petrolisthes armatus	24	93	358	39	514
Sphenia antillensis			2		2
Sapelo					
LS	**17**	**104**	**288**	**21**	**430**
Dipolydora socialis				1	1
Marphysa sanguinea	1				1
Nereiphylla fragilis		2			2
Palaemontes sp.			1	4	5
Panopeus herbsii	5	8	6	8	27
Petrolisthes armatus	11	94	281	8	394
Mud	**11**	**82**	**194**	**8**	**295**
Dipolydora socialis				1	1
Nassarius obsoletus	8				8
Nereiphylla fragilis		1	1		2
Panopeus herbsii	3	5	5	7	20
Petrolisthes armatus		76	188		264
NR	**17**	**160**	**324**	**21**	**522**
Armases cinereum				5	5
Boonea impressa			4		4
Dipolydora socialis				1	1
Nereiphylla fragilis	7		2		9
Nereis succinea		1	1		2
Palaemontes sp.			4		4
Panopeus herbsii	2	9	17	7	35
Petrolisthes armatus	8	150	296	8	462

Oyster Metrics

Live oyster density at natural reefs had means 50.7 and 62.0 live oysters per 0.25 m^2 at Little St. Simons Island and Sapelo Island, respectively. This did not significantly differ (DF=3, F=0.45, p=0.73) from the density of living shoreline reefs which had means of 41.7 and 53.0 live oysters per 0.25 m^2 at Little St. Simons Island and Sapelo Island, respectively. The number of dead oysters per 0.25 m^2 was low at all sites and no difference (DF=3, F=0.25, p=0.86) was detected (Table 6). The only difference observed (DF=3, F=22.4, p<0.001) was that mean size of live oysters. Tukey-Kramer multiple comparison revealed that oysters at the living shoreline site on LSSI are significantly smaller (44.6 mm) than oysters at the natural reef on LSSI (66.8 mm) or oysters found on Sapelo at the living shoreline (71.1 mm) and natural reef (70.2 mm). The smaller size of oysters on the living shoreline on LSSI could be attributed to that it was installed in the spring/summer of 2013 which is 3 years later than when living shoreline on Sapelo was installed in spring 2010. Although limited in scope, this could indicate that it takes oysters recruited to restored sites about five years to resemble oysters (size and density) on natural reefs.

In 2016, mean live oyster density on LSSI was 16.7 and 44.7 and 60.0 and 53.7 on Sapelo Island for natural reefs and living shoreline sites, respectively, and no difference was detected (DF=3, F=1.94, p=0.20). The trend was same for number of dead oysters per 0.25m2 (DF=3, F=0.46, p=0.72) and shell height (DF=3, F=2.09, p=0.10). No oysters were found in any of the quads on mud flats at either location. The mean number of live and dead oysters and shell height can be found in Table xxx.

Table. Mean number of live and dead oysters per 0.25m^2 and mean length (mm) of live oysters at living shoreline (LS) and natural reefs (NR) at Little St. Simons Island (LSSI) and Sapleo Island SI), GA in 2015.

	Average Live	Average Dead	Average Height
LSSI			
2015			
LS	41.7	5.7	67.0
NR	50.7	4.7	66.8
2016			
LS	44.7	2.0	45.6
M	0.0	0.0	
NR	16.7	3.0	39.7
Sapelo			
2015			
LS	53.0	6.3	71.1
NR	62.0	7.0	70.2
2016			
LS	53.7	2.0	43.7
M	0.0	0.0	
NR	60.0	3.3	50.4

Water Quality

Water quality at the water surface at living shoreline sites and natural reefs sites on Little St. Simons Island and Sapelo Island were similar (Table 7). Water data collected at 1 meter below the water surface was almost identical to surface readings and is not reported. Data from the HOBO sensors indicated that salinity had a range of about 5 ppt during a tidal cycle at LSSI and 2 ppt at SI at each site (Table 8). Water temperature varied by 1.5 to 3.3 °C at sites on LSSI while at SI it only varied by 0.1 to 0.2 °C during a tidal cycle.

In 2016, water temperature at the living shoreline sites and natural reef and mud sites were very similar, we did however notice that salinities in winter and spring were lower at the living shoreline sites on both LSSI and Sapelo Island (Table xxx). Unfortunately, we had probe failure at the LS sites in summer and the natural reef and mud sites in the fall and were not able to see if the trend continued throughout the year.

Table. Water quality data from Quanta sond at living shoreline (LS) and natural reefs (NR) on Little St. Simons Island (LSSI) and Sapelo Island (SI), GA in 2015.

Location	Parameter	Spring		Summer		Fall	
LSSI		NR	LS	NR	LS	NR	LS
	Salinity	37.3	31.5	34.2	35.8	28.4	27.5
	Water Temp	32.8	30.3	28.7	30.1	24.2	24.6
	DO	1.7	2.2	2.2	1.9	3.1	3.8
	pH	8.4	7.8	n/a	n/a	7.8	7.8
SI							
	Salinity					27.2	27.5
	Water Temp					24.8	27.5
	DO					3.7	3.8
	pH					7.6	7.8

Table. Water quality data from HOBO sensors at living shoreline (LS) and natural reefs (NR) for fall only on Little St. Simons Island (LSSI) and Sapelo Island (SI), GA in 2015.

Row Labels	Salinity (ppt)			Mean Water Temp, °C		
	Mean	Min	Max	Mean	Min	Max
LSSI						
Day-High						
LS	20.8	17.1	23.5	23.0	21.3	24.6
NR	23.9	20.0	25.5	22.8	22.4	24.1
Night-High						
LS	21.2	18.1	23.4	23.3	23.0	25.7
NR	23.8	20.6	25.6	22.9	22.6	23.1
Sapelo						
Day-High						
LS	26.9	25.9	27.4	22.3	22.2	22.4
NR	30.3	29.4	31.1	22.2	22.1	22.3
Night-High						
LS	29.6	28.1	31.2	22.7	22.5	23.2
NR	32.6	31.3	33.3	22.3	22.3	22.4

Table. Water quality data from HOBO sensors at living shoreline (LS) and natural reefs, and mud sites (N/Mud) for all seasons on Little St. Simons Island (LSSI) and Sapelo Island (SI), GA in 2016.

Season	**Location**	**Date**	**Mean °C**		**Mean ppt**	
			LS	**N/Mud**	**LS**	**N/Mud**
Winter	LSSI	19-Mar	21.5	20.8	13.1	16.0
		20-Mar	21.1	20.7	13.8	16.4
		21-Mar	19.4	19.6	12.4	15.4
	SI	23-Mar	19.3	19.5	15.4	17.6
		24-Mar	19.4	19.5	15.5	17.7
		25-Mar	19.9	19.7	15.4	17.5
Spring	LSSI	21-May	26.1	26.0	20.5	22.3
		22-May	25.9	25.8	20.2	21.9
	SI	17-May	25.9	25.7	20.0	22.4
		18-May	25.4	24.7	19.5	21.5
Summer	LSSI	15-Aug		31.4		28.8
		16-Aug		30.8		28.9
		17-Aug		30.6		28.8
	SI	19-Aug		32.0		28.9
		20-Aug		31.3		28.7
		21-Aug		30.4		28.5
Fall	LSSI					
		12-Nov	18.2		24.0	
		13-Nov	17.9		23.8	
	SI	14-Nov	17.1		23.3	
		15-Nov	17.0		23.2	
		16-Nov	16.9		23.2	

Discussion

This project illustrates that species associated with living shorelines does seem to mimic that of natural oyster reefs. The presence of structured habitat increases species abundance and diversity in marine systems (Heck and Wetstone 1977; Orth et al. 1984; Hosack et al. 2006) and that complex habitats are typically characterized by dense assemblages of predators and prey (Grabowski and Powers 2004). We found that both natural oyster reefs and living shoreline sites were heavily comprised of bay anchovy (planktivores) and shrimp (detritorves) which are important ecological species and form the base of the food webs (Baird and Ulanowicz 1989; Luo and Musick 1991) and are an important component of the diet of many finfish (Williams 1984; Collette and Klein-MacPhee 2002).

This project was small in scope with a small sample size, but provides information that supports the habitat benefits of living shorelines; however, more robust sampling is needed to fully substantiate these findings.

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